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Bulletin



Contents and Index

Volume 27

1957-1961

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The index was prepared by the Section of Publications and Public Relations and printed by authority of the State of Illinois, IRS Ch. 127, Par. 58.12.

EMENDATIONS

- Page 15, column 1, line 21 of text matter. *For Phyrthaneidae substitute Phryganeidae.*
- Page 18, table 9. *For Hydrochnellae substitute Hydrachnellae.*
- Page 135, column 2, line 4 from bottom. *For Mitchell, substitute Mitchill.*
- Page 215, column 1, line below Apple, James Wilbur. *For Entomologist, 1943-1949 substitute Entomologist, 1942-1949.*
- Page 296, table 4; page 299, table 7; page 319, table 32; page 338, table 39. *For Belastomatidae substitute Belostomatidae.*
- Page 323, column 1, line 7 (boldface head). *For Greater Scaup substitute Common Goldeneye.*
(Corrected in most copies.)
- Page 326, line 16 from bottom. *For Leguminosae substitute Leguminosae.*
- Page 439, column 1, line 21. *For as single hens of male-female pairs substitute as single hens or male-female pairs.*
- Page 448, table 55, line 1. *For five substitute six.*

The following paragraph is from a letter dated December 1, 1959, from W. L. McAtee, for many years with the U. S. Department of Agriculture and the U. S. Fish and Wildlife Service. It may serve as a supplement to Volume 27, Article 2, in that it adds to the list of articles on Stephen Alfred Forbes.

"Two papers of mine relating to Forbes not mentioned in the bibliography are an obituary (*Auk*, July 1930, pp. 453-454), in which I say that he founded the modern science of economic ornithology, and some paragraphs from a chapter 'Economic Ornithology' in *Fifty Years' Progress of American Ornithology 1883-1933* (A.O.U., Lancaster, Pa., 1933, pp. 111-29), elaborating on that appraisalment."

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ILLINOIS NATURAL HISTORY SURVEY
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Ecological Life History
of the Warmouth
(Centrarchidae)

R. WELDON LARIMORE

STATE OF ILLINOIS • WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION • VERA M. BINKS, *Director*
NATURAL HISTORY SURVEY DIVISION • HARLOW B. MILLS, *Chief*

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*Employed on co-operative projects with one of several agencies: Illinois Agricultural Extension Service, Illinois Department of Conservation, United States Army Surgeon General's Office, United States Department of Agriculture, United States Fish and Wildlife Service, United States Public Health Service, and others.

This paper is a contribution from the Section of Aquatic Biology.

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WARMOUTH

Maynard Reece

Ecological Life History of the Warmouth (Centrarchidae)

R. WELDON LARIMORE

OVERPOPULATION among certain warm-water fishes is now commonly recognized as a cause of poor fishing in many lakes and ponds of the United States. More than a decade ago, Bennett (1944:186) suggested that perhaps some sunfish not prone to overpopulation would, with little control by man, produce good fishing over a prolonged period. This suggestion stimulated a search for a species that has a low reproductive potential, a species that does not tend to overcrowd its habitat, and yet has good sporting qualities. The warmouth, *Chaenobryttus gulosus* (Cuvier), appeared to be such a species. The study of its life history and ecology presented here may serve as a basis for an estimate of the potential value of the species as a companion for bass or other game fishes in lakes and ponds of Illinois and neighboring states.

The warmouth is a dark, thick-bodied sunfish (family Centrarchidae) which superficially resembles the somewhat better known rock bass, *Ambloplites rupestris* (Rafinesque). It is readily distinguished from the latter by the presence of three spines in the anal fin; the rock bass has six. A good color and morphometric description of the warmouth is given by Forbes & Richardson (1920:245).

The nomenclature of this robust sunfish was summarized by Jordan, Evermann, & Clark (1930:302-3), in whose check-list *Chaenobryttus gulosus* was the accepted name. Harper (1942:50) pointed out that Bartram in his *Travels*, 1791, had accurately described this species and called it *Cyprinus coronarius*, a name which antedates *Chaenobryttus gulosus* by 38 years. Recently, however, the Committee on Nomenclature of the American Society of Ichthyologists and Herpetologists agreed that, because Bartram was not consistently binomial in the work cited by Harper, the name *Chaenobryttus gulosus* should be re-applied (Bailey 1956:336). Of the 16

or more common names given to the species, warmouth, warmouth bass, and goggle-eye are the most widely known. The American Fisheries Society Committee on Common and Scientific Names of Fishes (1948:16) designates this fish the warmouth, the name used throughout this paper.

The warmouth occurs generally in suitable waters throughout the central and eastern United States and south to the Gulf Coast. Its distribution extends from Kansas and Iowa to the Mississippi River drainage in southern Wisconsin, includes the southern two-thirds of the Lower Peninsula of Michigan, Lake Erie, and the Allegheny River tributaries of Pennsylvania, and embraces the territory southward to Florida and west through the Gulf states to the Rio Grande (Hubbs & Lagler 1947:93). As a result of introductions, it is now found west of the Rocky Mountains. Introductions into California, Washington, and Idaho were made as early as the end of the last century (Smith 1896:441).

In Illinois, the warmouth has a wide, scattered distribution. Approximately a half century ago, Forbes & Richardson (1920:246) found it in glacial lakes of northeastern Illinois and showed that it increased in abundance from north to south; they gave it frequency ratios in their collections for northern, central, and southern sections of the state as 0.44, 0.78, and 1.78, respectively.

Leonard Durham, while employed by the Illinois Department of Conservation in 1950-1955, found a somewhat different pattern of warmouth distribution (unpublished data). In studying representative populations of fish in 426 Illinois ponds and lakes, some of them natural and some artificial impoundments, Durham found little difference in the frequency of occurrence of warmouths in the three zones of the state then recognized by the Depart-

ment of Conservation. In the northern, central, and southern zones, warmouths were taken from 15.4, 17.1, and 15.4 per cent, respectively, of the waters sampled. These figures suggest that the distribution of warmouths in Illinois may have changed since Forbes and Richardson made their collections. The construction of many artificial impoundments requiring the widespread transportation of fishes for stocking purposes probably is responsible for some of the changes that have occurred in the distribution of this species.

Although principally a pond and lake fish, the warmouth occurs in the Rock, Mississippi, and Illinois rivers and is reported as common in small, sluggish streams of the southern part of the state. Its scattered distribution in Illinois coincides with the occurrence of suitable habitat.

ACKNOWLEDGMENTS

The research upon which this paper is based was a project of the Illinois Natural History Survey and was proposed and supervised by Dr. George W. Bennett, who gave guidance and help in all stages of the work.

Much of the material presented here was included in a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Horace H. Rackham School of Graduate Studies of the University of Michigan, 1950. As chairman of my doctoral committee there in the Department of Zoology, Dr. Karl F. Lagler directed my graduate studies, made many suggestions for my research, and helped me revise my thesis manuscript.

The paper published here was edited by Mr. James S. Ayars, the Natural History Survey's Technical Editor. His skill and patience have added considerably to the accuracy and clarity of reasoning, expression, and composition. Mrs. Darlene Ose, while secretary in the Section of Aquatic Biology, read and criticized the manuscript.

Dr. Leonard Durham, while employed by the Illinois Natural History Survey from April, 1947, to August, 1950, assisted in all of the field work and in many of the laboratory preparations; his con-

tinued interest added greatly to the completeness of this study and to the pleasure of conducting it. Mr. W. Leslie Burger, also while employed by the Natural History Survey, helped sort the contents of warmouth stomachs, after which members of the Section of Faunistic Surveys and Insect Identification of the Natural History Survey identified many of the invertebrate food items. Messrs. William J. Harth, James F. Opsahl, and William F. Childers, while with the Department of Conservation, assisted in some of the field work or in the tabulation of data. Other members of the Survey staff and my wife, Glenn E. Larimore, gave willing aid to the work.

I appreciate the permission to refer to unpublished observations by members of the Natural History Survey staff on warmouths in Illinois; observations of special value are those by Dr. Bennett at Ridge Lake, in Coles County, and at the Pollywog Association water area, in Vermilion County, and those by Dr. Donald F. Hansen at Lake Glendale, in Pope County. Credit for these and other unpublished observations is given in the text of this paper.

The Associated Tackle Manufacturers supplied certain equipment necessary for field work and gave financial support for my library studies at the University of Michigan.

The owners of several Illinois ponds in which warmouths were studied aided this investigation through their willing co-operation.

The picture of the warmouth reproduced as the frontispiece was painted by Mr. Maynard Reece and is used here through the courtesy of the Iowa State Conservation Commission.

AREAS OF INTENSIVE STUDY

As part of the investigation reported here, intensive studies of warmouths were conducted in two aquatic habitats, Park Pond and Venard Lake, figs. 1 and 2; these studies were then compared with more general observations on warmouths in other waters.

Both of the aquatic habitats in which the intensive studies were conducted were man-made: a flooded stripmine area and a small artificial lake. The many differ-



Fig. 1.—Southwest section of Park Pond, Vermilion County.



Fig. 2.—Part of Venard Lake (principally the east arm), McLean County.

ences between these two water areas permitted an evaluation of the effects of a considerable range of habitat conditions on warmouth populations.

Park Pond

Park Pond has a history that dates back many years. More than a quarter century ago, in Vermilion County, in east-central Illinois, an abandoned stripmine flooded with waters from the Salt Fork River was

water level was raised by the two small dams, lined the water's edge.

The chemical composition of the water differed from that of many other Illinois lakes, primarily in its high mineral content, table 1. Sulfates were especially high in concentration, but the buffer effect of other substances eliminated the extreme acidity often associated with the sulfur of mine waters.

The fish fauna of Park Pond had been derived from two sources. Many species

Table 1.—Chemical composition (parts per million) of water from Duck Pond, in the Pollywog Association area, Vermilion County, Illinois, and from five recently constructed United States Soil Conservation Service ponds in central Illinois.

POND	IRON		Ca	Mg	Na and K	SO ₄	NO ₃	Cl	METHYL ORANGE ALKALINITY	TOTAL HARDNESS
	Fil-tered	Unfil-tered								
Duck Pond July 15, 1938.....	.....	0.2	74.8	38.2	43.2	236.0	9.0	23.0	152.0	343.5
Duck Pond October 7, 1942....	.....	0.1	58.8	44.6	.....	.....	3.5	33.0	146.0	329.0
Five Soil Conserva- tion Service ponds (average) August- September, 1939...	1.1	2.78	26.9	15.1	11.6	17.2	2.0	2.8	130.8	127.1

leased by a group of sportsmen and conservationists, who, in about 1929, had formed the Waste Land Reclamation Association. In 1932, this area was acquired by a group of sportsmen who had formed the Pollywog Association, an organization that has continued since that time to use the area for hunting and fishing. A few years after the formation of the Pollywog Association, the construction of two small dams raised the water level several feet. A major part of the investigation reported here was based on material from Park Pond, which in 1946 had an area of 18 acres, in the central part of the Pollywog Association area.

When field work for the warmouth study was begun in 1946, the old mining cuts from which coal had been taken in 1889 and 1890 had become filled with water and appeared as irregular lakes connected by many narrow channels, fig. 1. High banks, formed when soil was removed to expose underlying coal beds, had become covered with dense brush and small trees. Older trees, killed when the

of fish had entered on flood waters from the nearby Salt Fork River. Fish of some of these species, as well as others not indigenous to the Salt Fork, had been placed in the pond by the Illinois Department of Conservation. Thirty-six species were recorded from this pond, table 2.

The relative abundance of these species was disclosed by the poisoning of the fish populations in four ponds of the Pollywog Association; each of these ponds was isolated from other waters except during floods. The total area to which poison was applied equaled 9.07 acres and was supporting a fish population which averaged 455.5 pounds per acre. Gizzard shad, carp, and bluegills comprised high percentages of the total weight of all fish collected from these four ponds, table 3. Warmouths represented 1.1, 0.9, 1.5, and 10.4 per cent of the weight in the four areas, or 1.6 per cent of the combined weight of fish from these waters. They made up a greater proportion of the weight of the fish population in these waters of the Pollywog Association than in most other Illinois

Table 2.—List of fishes collected from Park Pond of the Pollywog Association, with information on the relative abundance of each kind.*

SPECIES	RELATIVE ABUNDANCE
Gizzard shad, <i>Dorosoma cepedianum</i> (Le Sueur)	Abundant
Quillback carpsucker, <i>Carpiodes cyprinus</i> (Le Sueur)	Common
White sucker, <i>Catostomus commersoni</i> (Lacépède)	Common
Lake chubsucker, <i>Erimyzon succetta</i> (Lacépède)	Rare
Spotted sucker, <i>Minytrema melanops</i> (Rafinesque)	Common
Silver redhorse, <i>Moxostoma anisurum</i> (Rafinesque)	Rare
Northern redhorse, <i>Moxostoma aureolum</i> (Le Sueur)	Common
Carp, <i>Cyprinus carpio</i> Linnaeus	Abundant
Bluntnose minnow, <i>Pimephales notatus</i> (Rafinesque)	Rare
Fathead minnow, <i>Pimephales promelas</i> Rafinesque	Rare
Golden shiner, <i>Notemigonus crysoleucas</i> (Mitchill)	Common
Channel catfish, <i>Ictalurus punctatus</i> (Rafinesque)	Common
Yellow bullhead, <i>Ictalurus natalis</i> (Le Sueur)	Abundant
Black bullhead, <i>Ictalurus melas</i> (Rafinesque)	Common
Flathead catfish, <i>Pylodictis olivaris</i> (Rafinesque)	Rare
Madtom, <i>Noturus</i> sp.	Rare
Grass pickerel, <i>Esox vermiculatus</i> Le Sueur	Common
American eel, <i>Anguilla rostrata</i> (Le Sueur)	Rare
Banded killifish, <i>Fundulus diaphanus</i> (Le Sueur)	Common
Blackstripe topminnow, <i>Fundulus notatus</i> (Rafinesque)	Abundant
Yellow bass, <i>Roccus mississippiensis</i> (Jordan & Eigenmann)	Common
Yellow perch, <i>Perca flavescens</i> (Mitchill)	Rare
Logperch, <i>Percina caprodes</i> (Rafinesque)	Rare
Johnny darter, <i>Etheostoma nigrum</i> Rafinesque	Rare
Smallmouth bass, <i>Micropterus dolomieu</i> Lacépède	Rare
Spotted bass, <i>Micropterus punctulatus</i> (Rafinesque)	Rare
Largemouth bass, <i>Micropterus salmoides</i> (Lacépède)	Common
Warmouth, <i>Chaenobrytus gulosus</i> (Cuvier)	Common
Green sunfish, <i>Lepomis cyanellus</i> Rafinesque	Common
Pumpkinseed, <i>Lepomis gibbosus</i> (Linnaeus)	Common
Bluegill, <i>Lepomis macrochirus</i> Rafinesque	Abundant
Orangespotted sunfish, <i>Lepomis humilis</i> (Girard)	Common
Longear sunfish, <i>Lepomis megalotis</i> (Rafinesque)	Abundant
White crappie, <i>Pomoxis annularis</i> Rafinesque	Abundant
Black crappie, <i>Pomoxis nigromaculatus</i> (Le Sueur)	Common
Brook silverside, <i>Labidesthes sicculus</i> (Cope)	Common

*The common names used here and elsewhere in this paper follow those of the American Fisheries Society Special Publication Number 1, 1948, or the changes recommended by the Society (Bailey 1952, 1953); most of the scientific names are those given by Bailey 1956.

waters from which fish collections have been taken in recent years.

Venard Lake

Little is known of the early history of Venard Lake, fig. 2, an "old" artificial impoundment 1 mile south of Bloomington, near the junction of state highway 51 and United States highway 66, in McLean County, Illinois. In 1947, the lake had an area of 3.2 acres. Though there was a small spring at the upper end of the lake, most of the water came from surface runoff flowing into the lake from two shallow valleys. Settling basins, built in both of these valleys above the lake, removed much of the silt load carried by surface water;

even so, during a period of several decades, the basin had accumulated much silt. In 1946, the lake was drained, a stunted fish population removed, and the basin allowed to refill with water. In April of 1947, Venard Lake was stocked with the following fishes: 225 yearling largemouth bass between 4 and 8 inches in total length, 15 largemouth bass between 9.6 and 13.7 (average 11.9) inches in total length, and 101 warmouths between 5.1 and 8.1 (average 6.8) inches in total length.

Extremely large broods of both bass and warmouths were spawned in 1947. The fish placed in the lake early in 1947 grew well and supported excellent fishing the following months. Many warmouths of the 1947 year class were caught in spring

Table 3.—Kinds of fish that were collected from four Pollywog Association water areas treated with rotenone and the percentage of the total weight of fish comprised by each kind. The total area of water treated was 9.07 acres and the average standing crop of fish was 455 pounds per acre.*

KIND OF FISH	PER CENT OF TOTAL WEIGHT
Largemouth bass.....	3.5
White crappie.....	3.8
Bluegill.....	14.4
Warmouth.....	1.6
Other fine fish.....	1.0
Catfish.....	0.8
Coarse fish.....	25.5
Gizzard shad.....	49.3
Other forage fish.....	0.1
<i>Total</i>	<i>100.0</i>

*Data from three of the water areas were collected by Dr. George W. Bennett. Data from the fourth, Park Pond, were collected by the author.

fishing of 1949, but very few were taken in the summer of that year. Most of the bass caught in 1949 were of the 1947 year class; many of them were still below the then legal size of 10 inches.

During several weeks in August of 1948, shallow parts of the lake were dredged. This operation killed many of the 1948 brood of warmouths, in particular those trapped in the large weed masses removed from the lake. The bass, on the other hand, were apparently unharmed.

HABITAT CHARACTERISTICS

Collections of the warmouth from many lakes, ponds, and streams of Illinois, and descriptions of the water areas in which this sunfish is found in other parts of its range, indicate that it is usually associated with certain habitat characteristics.

Vegetation and Bottom Materials

Dense weed beds and a soft bottom are two habitat characteristics with which the warmouth is usually associated. Brush and roots attract this sunfish, and in water areas lacking extensive weed beds, as in some of the bottomland lakes of the South, old tree stumps constitute the common hiding places of the warmouth (thus, the name "stump-knocker" is sometimes given

to it). The quiet, almost sulky disposition of the warmouth and the customary association of this fish (particularly young and moderate-sized individuals) with protected hiding places cause members of this species to concentrate in weedy and stump-filled waters.

In the Everglades region of southern Florida, Bangham (1939:263-5) found warmouths second in abundance to gars. The waters were slow moving or still, dark-colored, usually choked with vegetation, and with bottoms composed of soft muck. Of five ponds in the Ocala National Forest in Florida censused by Meehan (1942), all contained warmouths, table 4. The population having the greatest concentration of warmouths was in an old pond (Little Steep Pond) with a thick layer of humus on the bottom and a mat of vegetation covering the entire surface. When Tarzwell (1942) applied poison to three backwater sloughs of Wheeler Reservoir in Alabama, he found warmouths in all populations, although in low percentages by weight; the highest proportion of these fish by weight (1.0 per cent) was associated with a soft silt or mud bottom, table 4.

The greatest proportion of warmouths that Bennett (1943:360) encountered in censusing 22 ponds and lakes of Illinois was in Delta Pond (10.7 per cent warmouths by weight), table 4. As only 2 years had passed since this pond had been stocked with game fish and pan fish, the fish population probably did not reflect the environment of the pond as much as it did the original stocking. Onized Lake, which contained the second greatest proportion of warmouths (6.5 per cent) that Bennett found in a population, was an old pond with heavy marginal vegetation that favored these fish. Warmouths in Onized Lake may have been favored also by extremely heavy and selective fishing that had resulted in the removal of large numbers of fish of other species.

The fish population in four shallow, mud-bottomed backwater areas of the Mississippi River contained low percentages of warmouths (Upper Mississippi River Conservation Committee 1947:25-7 and 1948:23-4). Two of the areas, near Savanna, Illinois, contained respectively 0.3 per cent and 1.0 per cent warmouths by

weight. The two other areas, near Oquawka, Illinois, contained respectively 0.2 per cent and 1.4 per cent warmouths by weight, table 4.

Turbidity

Forbes & Richardson (1920:246) concluded that the waters in which they found the warmouth in their Illinois collections indicated for this fish "a deliberate preference for muddy water over pure." Certainly the warmouth, now as in the time of Forbes and Richardson, is found more frequently and in greater abundance in muddy or turbid waters, usually characteristic of lowland lakes, backwater areas,

and sluggish streams, than in less turbid waters.

However, the occurrence or abundance of the warmouth in turbid waters may not indicate a direct preference of this fish for these waters. Rather, it may show that the warmouth has a greater tolerance of turbid waters and conditions associated with turbidity than have most other sunfishes. This tolerance may give the warmouth certain advantages in a population in which it must compete with many species and may account for its frequently comprising greater proportions of the total fish population in turbid waters than in clear.

Turbidity may affect growth rate of and fishing success for the warmouth. The

Table 4.—Data from fish censuses of 29 water areas containing warmouths: for each area the approximate weight per acre of the standing crop of fish and the percentage of the total weight comprised by warmouths.

BODY OF WATER	SURFACE AREA, ACRES	ESTIMATED WEIGHT OF ALL FISH, POUNDS PER ACRE	WARMOUTHS: PER CENT OF TOTAL WEIGHT	SOURCE OF DATA
Little Steep Pond (Florida)	2.10	105	10.55	Meehan 1942
First Pond (Florida)	7.00	110	0.99	
Big Prairie Lake (Florida)	4.00	61	1.87	
Buck Pond (Florida)	18.00	33	6.61	
Clearwater Lake (Florida)	24.00	22	0.82	
Upper Railroad Pond (Alabama)	6.50	292	0.07	Tarzwel 1942
Powerline Slough (Alabama)	1.10	831	0.07	
Sweetwater Slough (Alabama)	4.40	188	1.00	
Southside Country Club Lake (Illinois)	8.40	719	tr.	Bennett 1943
Homewood Lake (Illinois)	2.83	699	tr.	
Fork Lake (Illinois)	1.38	539	tr.	
Farmer City Golf Course Lake (Illinois)	0.75	455	tr.	
Upper Twin Lake (Illinois)	1.08	392	tr.	
Black Jack Lake (Illinois)	4.00	280	tr.	
Delta Pond (Illinois)	0.80	234	10.7	
Onized Lake (Illinois)	2.14	206	6.5	
Duck Pond, Pollywog Assn. (Illinois)	3.10	673	1.1	
Triangle Pond, Pollywog Assn. (Illinois)	2.50	487	1.5	
Duck Island Farm Lake (Illinois)	4.90	316	tr.	
Sportsmen's Lake (Illinois)	3.70	341	tr.	
Lower Twin Lake (Illinois)	1.36	778	1.0	
Lake Glendale (Illinois)	82.00	86	5.0	Hansen unpub- lished
Park Pond Slough, Pollywog Assn. (Illinois)	0.47	371	10.4	Present study
Mississippi River				Upper Mississippi River Conservation Committee 1947, 1948
Backwaters, Oquawka (Illinois)				
Area 1	1.07	391	0.2	
Area 2	1.76	695	1.4	
Backwaters, Savanna (Illinois)				
Slough 1	2.16	171	0.3	
Slough 2	0.95	423	1.0	
Lamer's Upper Pond (Illinois)	0.25	516	4.7	Elder & Lewis 1955
Lamer's Lower Pond (Illinois)	0.50+	285	3.3	

best fishing for warmouths in experimental areas of central Illinois is in moderately clear water, the poorest fishing in turbid waters. Jenkins, Elkins, & Finnell (1955:42) found the slowest growing Oklahoma warmouth populations in waters known to be continuously turbid.

In a comparison of fish populations in two southern Illinois ponds, one of which was more turbid than the other, Elder & Lewis (1955:394) reported that reproduction and the coefficient of condition of warmouths was better in the less turbid pond, although growth was somewhat better for the warmouths in the more turbid pond. As the two ponds differed in age, size, density of fish population, and fertility, turbidity was not the only factor that might have been responsible for differences in growth.

Depth

Several field observations indicate that small warmouths remain in shallow weed

beds, or other dense cover, for their food and protection, whereas larger warmouths spend more time in deeper water.

In Venard Lake, small warmouths were collected in great numbers from the riprapping along the dam, fig. 3, where they were hiding beneath submerged rocks. Seldom were large warmouths taken from under these rocks; except during the spawning season, most of the fish of larger sizes were taken from deeper water.

Relatively few warmouths of desirable sizes were found in a weed-choked channel of Park Pond, although many large individuals were taken in Park Pond proper.

In Park Pond, winter collecting with an electric shocker turned up large numbers of small warmouths in shallow water close to the banks, although at that time the surface of the pond was covered with thin ice.

Apparently, small warmouths do not leave their protected hiding places in shallow water even during cold weather. This behavior contrasts sharply with that of bluegills. Bluegills, most numerous of the



Fig. 3.—Warmouths, stunned with an electric fish shocker, near the riprapping of the dam at Venard Lake.

kinds of fishes collected along the banks of Park Pond through summer months, were taken there in far fewer numbers after the beginning of cold weather. In the winter, bluegills of all sizes were ordinarily collected in compact schools in deeper water. Large warmouths were likewise in relatively deep water but showed little tendency to group together. The conclusions suggested here are that (1) warmouths of less than 5 inches total length remain in protective cover in shallow water the year around; (2) large individuals spend more time in deep than in shallow water; (3) warmouths exhibit no tendency to group together during the winter months.

Dissolved Oxygen

Observations in the field and laboratory indicate that warmouths may survive in habitats having low concentrations of dissolved oxygen. An example of the tolerance of warmouths for a low oxygen concentration was observed on April 27, 1947, when 23 of 50 fish in an overcrowded aquarium were found dead; of the 50 fish,

about half were warmouths and half were bluegills. Of the 23 fish that were dead, all were bluegills. The few bluegills that were still living were light colored and obviously sick. All warmouths, however, were alive and showed very little or no distress.

Warmouths are among the last species of fish to die when collections of live fish are concentrated in tanks, tubs, or buckets containing water. For example, on November 12, 1949, between 9:30 A.M. and 2:15 P.M., many bluegills and warmouths were taken alive from Park Pond. The morning and afternoon collections were placed in separate fish tanks in a truck. No compressed air was supplied to the water in these tanks, and consequently many fish were dead when the tanks reached the laboratory late in the afternoon. In the tank containing the morning collection, all of the bluegills (about 30) were dead, whereas 40 warmouths in the same container showed only mild signs of distress. Of 50 bluegills collected in the afternoon, only a few remained alive, whereas 24 warmouths collected at the same time and kept in the same tank were in excellent condition.

In order to test the tolerance of warmouths for low concentrations of dissolved oxygen, Leonard Durham and I measured the oxygen consumption of warmouths confined in water containing different amounts of this gas. Dr. C. L. Prosser, Professor of Physiology, University of Illinois, suggested the laboratory procedures for these tests, the results of which supported our observations made in the field.

The Winkler method was used to determine oxygen concentrations of two samples of water, one sample taken at the beginning and one at the end of the test period. The difference between the two samples in cubic centimeters of oxygen per liter of water multiplied by the number of liters of water in the test jar (volume of jar minus volume of water displaced by fish) gave the total amount of oxygen consumed by the fish; the number of cubic centimeters of oxygen used per gram of fish per hour (cc./gm./hr.) was then calculated.

The amount of oxygen used by the test warmouths in water at 20 degrees C. ranged between 0.05 and 0.07 cc./gm./hr.

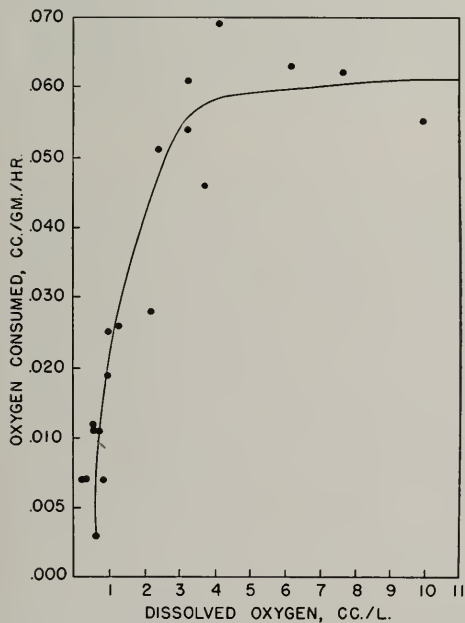


Fig. 4.—Amounts of oxygen consumed (cubic centimeters per gram per hour) by warmouths in water of different oxygen tensions (cubic centimeters per liter) at 20 degrees C.

as long as the available dissolved oxygen in the water exceeded 3 cc. per liter, fig. 4. The consumption of oxygen by the warmouths dropped off abruptly from 0.03 cc./gm./hr. when the dissolved oxygen in the water was 2.5 cc. per liter to less than 0.01 cc./gm./hr. when it was 0.5 cc. per liter. The concentration of dissolved oxygen at which oxygen consumption by the fish declines abruptly is the critical oxygen tension or the oxygen concentration at which the metabolic rate of the fish begins to fall off rapidly. Even though this critical oxygen tension is not lethal immediately it will ultimately be so. For the warmouths in our tests, the critical tension figure was found to be 2.5 cc. per liter (3.6 p.p.m.) at 20 degrees C.

This critical tension figure is close to that determined by Moore (1942:327) after he had studied 13 species of freshwater fishes, including the largemouth bass, the bluegill, the pumpkinseed, and other species which are often associated with the warmouth. Moore stated, "In general, oxygen tensions of less than 3.5 p.p.m. at temperatures of 15-26° C. are fatal within 24 hrs. to most of the species tested."

Although the warmouths in our tests were removed before complete asphyxiation, several specimens had reduced the dissolved oxygen in the water to low concentrations. Only 0.21 cc. of oxygen per liter of water remained at the end of one test on warmouths, 0.24 cc. at the end of another.

Conclusions from the tests described above not only suggest reasons for survival of the warmouth during periods of water conditions that are generally considered unfavorable to fish but also indicate certain of the warmouth's physiological characteristics that are associated with its habitat selection. Turbid waters, organic silt deposits, and dense vegetation, usually regarded as typical features of warmouth habitats, are associated with high oxygen demands and, at times, low concentrations of dissolved oxygen.

Stream Gradient

The abundance of warmouths in flowing waters appears to be related to stream gradient; the occurrence of these fish in-

creases from rare in fast-moving creeks to common in sluggish streams with a low gradient. I have collected warmouths in several central Illinois streams having gradients between 8 and 14 feet per mile, but I have never collected them in large numbers. Nelson (1876:37) mentioned that Professor S. A. Forbes found this species "very common" in the Illinois River and tributaries through central Illinois; and Forbes & Richardson (1920:246) reported it "common" in southern Illinois, "mainly in the smaller streams." The Illinois River has a generally low gradient, and the small streams of southern Illinois in which warmouths are now commonly reported have low gradients.

FOOD HABITS

The food habits of warmouths from Park Pond and Venard Lake were studied through a period of 12 months. The objectives of this study were to determine the kinds and amounts of food consumed and the ways in which food habits of the warmouths were influenced by habitat, season of year, daily feeding periods, size of individual fish, and competing species of fish. Consideration was given to the possible effects of two different computing methods on the interpretation of the data.

Methods of Study

For the food habits study, warmouths were collected from Park Pond and Venard Lake, for the most part at monthly intervals over a period beginning in October, 1948, and ending in September, 1949. Heavy ice prevented collecting from Park Pond in January and from Venard Lake in January and February. Extra collections were taken from Park Pond during the summer months as a means of determining diurnal feeding periods.

No attempt was made to measure the relative abundance of food organisms in the water areas.

A total of 515 warmouth stomachs were collected from Park Pond; of these, 124 were empty and 391 contained food in varying amounts. Of 413 warmouth stomachs taken at Venard Lake, 57 were empty and 356 contained food materials in measurable amounts.

All fish were taken with a rowboat fish shocker (Larimore, Durham, & Bennett 1950), fig. 5. Regurgitation of food by the fish was not caused by the shocker as it was used in this study. While the fish were fresh, their stomachs were removed and

Survey. It was found to be convenient and reliable. When items were measured by both methods, the volume determined by one method agreed closely with the volume determined by the other. The sum of volumes of the different kinds of food in each



Fig. 5.—An electric fish shocker being used from a rowboat to collect warmouths in Park Pond.

placed in cheesecloth bags; the bags were labeled and placed in formalin. Other parts of the digestive tracts were discarded.

In the laboratory, each stomach was first studied as a unit. The contents were removed and their total volume was measured. Then the contents were sorted under a dissecting microscope (magnification 9 to 48 times) into various taxonomic categories, table 5. The number of individual organisms and the volume of each kind of food were determined. Volumetric measurement was made by one of two methods: large, irregular masses of food were measured by water displacement in a calibrated centrifuge tube; small, compact items were measured by comparison with cork blocks of known volumes. This second method was devised by the late R. E. Richardson, for several years employed by the Illinois Natural History

stomach was checked against the total volume recorded for each stomach when the contents were removed.

After data for the sorted food materials had been tabulated, calculations were made that involved (1) the percentage of stomachs in which each kind of food occurred (*frequency of occurrence*), (2) the average number of items of each kind of food in the stomachs containing the food (*average number of items*), (3) the average of the percentages of volume comprised by each of the kinds of food in each of the stomachs examined (*average of volume percentages*), and (4) the percentage of the total volume of all foods represented by each kind of food (*percentage of total volume*). These calculations and similar calculations for largemouth bass used with the warmouths of Venard Lake are summarized in tables 6-12.

Table 5.—Food organisms taken from the stomachs of 391 warmouths from Park Pond, 356 warmouths from Venard Lake, and 99 largemouth bass from Venard Lake; also, for each kind of organism taken from the stomachs, its occurrence rating, based on the number of stomachs in which it was found: abundant (A), common (C), rare (R), or present but with no record of abundance (X).

FOOD ORGANISM	PARK POND	VENARD LAKE	
	Warmouth	Warmouth	Largemouth Bass
Cestoda			
Proteocephalidae.....		R	R
Bryozoa			
<i>Plumatella</i> sp.....	R	R	
Annelida			
Oligochaeta.....		R	
Gastropoda			
Planorbidae			
<i>Gyraulus</i> probably <i>parvus</i> (Say).....	C		
Ancylidae.....			R
Lymnaeidae.....	C		
Physidae			
<i>Physa integra</i> Haldeman.....	C	A	
<i>Physa</i> probably <i>gyrina</i> Say.....	C		
Cladocera			
<i>Simocephalus</i> sp.....	A	A	A
<i>Daphnia</i> sp.....		R	
<i>Chydorus</i> (?) sp.....		R	
<i>Alona</i> (?) sp.....		R	
Copepoda			
<i>Cyclops</i> sp.....	A	A	C
Ostracoda.....	A	C	
Amphipoda			
<i>Hyaella arteca</i> (Saussure).....	A	R	
Isopoda			
<i>Asellus</i> sp.....	C	A	
Decapoda.....	A	A	A
<i>Procambarus blandingii acutus</i> (Girard).....	X	X	X
<i>Orconectes virilis</i> (Hagen).....	X	X	X
<i>Orconectes propinquus propinquus</i> (Girard).....	X		
Araneae			
Lycosidae.....			R
Pisauridae			
<i>Dolomedes triton sexpunctatus</i> Hentz.....	C	C	C
Hydrachnellae			
<i>Limnesia fulgida</i> Koch.....		R	R
<i>Arrenurus</i> sp.....	R		
Collembola			
<i>Podura aquatica</i> Linnaeus.....		R	
Ephemeroptera			
<i>Caenis</i> sp.....	A	A	A
<i>Siphonurus</i> sp.....	C	A	A
<i>Hexagenia limbata</i> (Serville).....	R		
Odonata			
Zygoptera.....	A	A	A
<i>Argia apicalis</i> (Say).....			X
<i>Enallagma basidens</i> Calvert.....			X
<i>E. carunculatum</i> Morse.....			X
<i>E. civile</i> (Hagen).....			X
<i>E. signatum</i> (Hagen).....			X
<i>Ischnura posita</i> (Hagen).....		X	
<i>I. verticalis</i> (Say).....		X	X
<i>Perithemis tenera</i> (Say).....			X
Anisoptera.....	A	A	A
<i>Celithemis</i> sp.....		X	X
<i>Epicordulia princeps</i> (Hagen).....		X	
<i>Erythemis simplicicollis</i> (Say).....		X	
<i>Leucorrhinia</i> sp.....			X
<i>Libellula pulchella</i> Drury.....		X	X
<i>Pachydiplax longipennis</i> (Burmeister).....		X	

Table 5.—Continued.

FOOD ORGANISM	PARK POND	VENARD LAKE	
	Warmouth	Warmouth	Largemouth Bass
<i>Plathemis lydia</i> (Drury).....			X
<i>Sympetrum obtrusum</i> (Hagen).....		X	
<i>Tetragoneuria</i> sp.....		X	
Hemiptera			
Corixidae.....	C	C	C
Notonectidae.....	R	R	C
Nepidae			
<i>Ranatra</i> sp.....	R		
Belostomatidae			
<i>Belostoma</i> sp.....	R		
Veliidae			
<i>Microvelia</i> sp.....	C	C	C
<i>Rhagovelia</i> sp.....	C		R
Gerridae			
<i>Gerris</i> sp.....	C	C	C
Homoptera			
Membracidae.....			R
Neuroptera			
Sisyridae.....		R	
Megaloptera			
Sialidae			
<i>Sialis</i> sp.....	R		
Hymenoptera			
Formicidae.....	R		C
Apidae			
<i>Apis mellifera</i> Linnaeus.....			C
Coleoptera			
Haliplidae			
<i>Haliplus</i> sp.....	R	C	
<i>Peltodytes</i> sp.....	C	A	A
Dytiscidae			
<i>Ilybius</i> sp.....	R		R
<i>Hydroporus</i> sp.....		C	
Hydrophilidae			
<i>Berosus</i> sp.....	C	C	
<i>Tropisternus</i> sp.....	R	C	
Buprestidae.....			R
Chrysomelidae			
<i>Phyllotreta</i> sp.....			R
Elateridae			
<i>Melanotus</i> sp.....	R		
Scarabaeidae			
<i>Ataenius</i> sp.....		R	R
<i>Phyllophaga</i> probably <i>futilis</i>	R		
Trichoptera			
Hydroptilidae.....	A	A	R
<i>Oecetis cinerascens</i> (Hagen).....	X		
<i>Oecetis inconspicua</i> (Walker).....	X		
<i>Oxyethira</i> sp.....		X	X
<i>Orithotrichia</i> sp.....	X		
Phryganeidae.....	A	A	C
Diptera			
Chironomidae.....	A	A	A
Ceratopogonidae.....		A	C
Culicidae			
<i>Chaoborus</i> sp.....	R	A	A
Syrphidae			
<i>Eristalis</i> sp.....	R	R	
Stratiomyidae.....	R	R	
Tabanidae.....	R		
Pisces			
<i>Chaenobryttus gulosus</i> (Cuvier).....	C	C	A
<i>Lepomis m. macrochirus</i> Rafinesque.....	C		
<i>Micropterus salmoides</i> (Lacépède).....		C	C

The reason for calculating the volume of each kind of food by both average of volume percentages and percentage of total volume is that these two calculations give very different expressions of volume. The average of volume percentages is influenced by frequency of occurrence of a kind of food but not by the size of a stomach nor its fullness; thus, it gives the stomach contents of a small fish the same importance as those of a large fish and favors small food items that appear in a high percentage of stomachs. On the other hand, the percentage of total volume emphasizes the importance of large food items and therefore the diet of large fish. Since the percentage of total volume of a food is not affected by frequency of occurrence (the percentage of stomachs in which the food occurs), it does not reflect the food habits of individuals of a population but rather the foods consumed by the population as a whole. A few large items might be important as food to a few large fish but of no value to the smaller members of that population.

Although the above differences have been discussed in other food studies (Bennett, Thompson, & Parr 1940: 18; Martin, Gensch, & Brown 1946; Beck 1952: 398; Reintjes & King 1953: 96), a complete food analysis employing both methods has not been published to illustrate erroneous conceptions inherent in references to volume as a percentage without defining its derivation or meaning.

Principal Foods in Two Habitats

Food items of many kinds were found in the stomachs of warmouths collected from Park Pond and Venard Lake, table 5. Considerable differences exist in the taxonomic levels to which the food items were identified.* A similar situation is found in most food studies of fish and generally is due to difficulties in the exact identification of fragmentary animal remains. In

*Identifications of selected collections were made by the following persons: Dr. H. H. Ross (Trichoptera), Dr. M. W. Sanderson (Coleoptera and miscellaneous groups), Dr. L. J. Stannard, Jr. (Hydrachnellae), Mrs. Leonora K. Gloyd (Odonata), Mr. Robert Snetsinger (Araneae), Dr. T. E. Moore (Hemiptera), and Dr. W. R. Richards (Diptera), all at the time of this study with the Illinois Natural History Survey; Dr. B. D. Burks, with the Division of Insect Identification of the United States Department of Agriculture (Ephemeroptera); Mr. Glenn R. Webb, Ohio, Illinois (Gastropoda); and Dr. H. H. Hobbs, Jr., University of Virginia (Decapoda).

groups such as Odonata, individuals of which were found in large numbers in the warmouth stomachs and which were represented by many species not distinguishable except by a specialist, only selected collections were identified to species. These identifications extended the number of species found in warmouth stomachs but provided no information as to the relative abundance of individual members of these species.

In both frequency of occurrence and volume, the foods of warmouths collected from Park Pond differed from the foods of warmouths collected from Venard Lake, tables 6-11. The six foods that, on the basis of their volume and the percentage of stomachs in which they were found, were judged to be most important for each of the two areas are considered below. Less important food groups that appeared to be significant in the warmouth diet are mentioned as miscellaneous foods.

Park Pond.—Four of the food groups listed among the six most important in Park Pond were included among the six most important in Venard Lake. These were the Decapoda, Ephemeroptera, Zygoptera, and Anisoptera. Trichoptera and Pisces, among the six most important in Park Pond, were comparatively unimportant in Venard Lake.

Decapoda.—Crayfish, which ranked first in bulk as a warmouth food at Park Pond, made up 50 per cent of the total volume consumed by warmouths collected from this pond. Decapods were found in 19 per cent of the stomachs; the average of their volume percentages amounted to 14. Crayfish were important for a few warmouths (generally the larger ones) but of relatively little value to the others.

Ephemeroptera.—Forty-one per cent of the warmouth stomachs from Park Pond contained mayfly nymphs (no adult mayflies were found). These nymphs comprised less than 1 per cent of the total volume, but the average of their volume percentages was 10. Nymphs of three genera were identified: *Caenis* sp. was the only mayfly abundant in the stomachs; *Siphonurus* sp. was uncommon and *Hexagenia limbata* was rare.

Zygoptera.—Damselflies (mostly nymphs) occurred in 34 per cent of the stomachs of Park Pond warmouths. They

made up 2 per cent of the total volume; the average of their volume percentages was 16. Eight species (four genera) were identified; no tabulation was made of the percentage comprised by each species.

Anisoptera.—Dragonflies were less important than damselflies in the stomachs of Park Pond warmouths. Dragonfly nymphs, found in 14 per cent of the stomachs, made up only 2 per cent of the total volume of food; 6 was the average of their volume percentages. Nine genera of dragonflies were identified.

Trichoptera.—Caddisfly larvae occurred in a high percentage (36 per cent) of the warmouth stomachs from Park Pond but amounted to only 3 per cent of the total volume; 13 was the average of their volume percentages. The specimens identified belonged to the families Hydroptilidae and Phryganeidae.

Pisces.—Fishes ranked second to crayfish in total volume of food in the stomachs of Park Pond warmouths. They made up 36 per cent of the total volume and occurred in 18 per cent of the stomachs; 14 was the average of their volume percentages. Small sunfishes were most common, but single individuals of several species other than sunfishes were included.

Miscellaneous.—Among the food items somewhat less important in the diet of Park Pond warmouths than the six listed above were the amphipods. These occurred in 24 per cent of the stomachs from Park Pond but were absent from the Venard Lake collections. Diptera larvae or pupae (mostly chironomids) were identified in 38 per cent of the stomachs of Park Pond warmouths but comprised less than 1 per cent of the total volume of food. Sixteen per cent of the stomachs contained cladocerans.

Venard Lake.—The most striking difference in diet between the warmouths of the two water areas was in the number of fish consumed. Fish were found in less than 2 per cent of the warmouth stomachs from Venard Lake in contrast to 18 per cent of the stomachs from Park Pond.

Isopoda.—Eleven per cent of the total volume of food in the stomachs of warmouths collected from Venard Lake consisted of *Asellus* sp. (a form previously considered *A. communis*), which occurred in 27 per cent of the stomachs examined.

Isopods were found in only about 1 per cent of the warmouth stomachs collected from Park Pond.

Decapoda.—Crayfish occurred in only 10 per cent of the warmouth stomachs collected from Venard Lake and comprised 15 per cent of the total volume of food in these stomachs. They ranked second in percentage of total volume in Venard Lake stomachs, but the percentage was low in comparison to that in Park Pond stomachs (50 per cent of total volume).

Ephemeroptera.—Mayfly nymphs, like crayfish, comprised 15 per cent of the total volume of food in warmouth stomachs from Venard Lake, but they could be considered more important as food because they were found in a larger percentage (43 per cent) of the stomachs. An average of 10 nymphs per stomach was found in the stomachs that contained mayflies. *Caenis* sp. was the mayfly most often found in warmouth stomachs from Venard Lake. *Siphonurus* sp. was found in a larger percentage of stomachs from Venard Lake than from Park Pond.

Zygoptera.—Damselfly nymphs ranked fifth in frequency of occurrence (14 per cent of the stomachs) and fifth in total volume (7 per cent) of food in the warmouth stomachs from Venard Lake.

Anisoptera.—Dragonfly nymphs or emerging adults comprised the greatest volume of food (38 per cent of total volume) in the warmouth stomachs from Venard Lake. They were found in 17 per cent of the stomachs. Nine different species of dragonflies were recognized.

Diptera.—Forty-four per cent of the warmouth stomachs from Venard Lake contained Diptera larvae or pupae. Dipterans comprised only 2 per cent of the total volume; 12 was the average of their volume percentages. Five families of Diptera were represented.

Miscellaneous.—Caddisflies were found in 21 per cent of the stomachs from Venard Lake, a smaller percentage than in the stomachs from Park Pond. Cladocerans occurred in 51 per cent of the stomachs from Venard Lake, ostracods and copepods in smaller percentages of the stomachs. Cestodes, annelids, and collembolans were represented in the stomachs of warmouths from Venard Lake but not in the stomachs of warmouths from Park Pond.

Table 6.—Stomach contents of 64 warmouths collected

FOOD ITEM	STOMACHS FROM 38 FISH OF LESS THAN 5.0 INCHES			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Gastropoda.....	8	2	0.7	0.3
Cladocera.....	11	6	3.6	0.2
Copepoda.....	3	1	tr.	tr.
Amphipoda.....	13	2	3.2	0.3
Isopoda.....	3	1	2.1	0.1
Decapoda.....	0	0	0.0	0.0
Araneae.....	3	1	0.1	0.1
Ephemeroptera.....	32	3	16.9	1.5
Zygoptera.....	32	2	21.3	5.8
Anisoptera.....	21	1	18.6	20.9
Hemiptera.....	5	1	3.0	0.1
Neuroptera.....	3	1	0.1	1.4
Coleoptera larvae.....	3	12	2.6	5.0
Trichoptera.....	16	1	8.0	2.1
Diptera.....	24	1	3.2	0.4
Pisces.....	21	1	15.7	59.8
Filamentous algae.....	5	.....	0.4	1.6
Higher plants.....	5	.....	0.6	0.3
Organic debris.....	0	.....	0.0	0.0

Table 7.—Stomach contents of 79 warmouths

FOOD ITEM	STOMACHS FROM 52 FISH OF LESS THAN 5.0 INCHES			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Bryozoa.....	0	0	0.0	0.0
Gastropoda.....	8	1	0.9	0.5
Cladocera.....	23	3	5.1	0.4
Copepoda.....	13	3	3.4	0.1
Ostracoda.....	4	2	0.5	tr.
Amphipoda.....	37	2	5.6	1.2
Isopoda.....	2	1	0.1	0.1
Decapoda.....	13	1	3.7	2.3
Ephemeroptera.....	56	2	10.7	3.5
Zygoptera.....	52	2	27.3	25.9
Anisoptera.....	8	1	2.4	3.2
Hemiptera.....	2	1	0.1	0.1
Hymenoptera.....	0	0	0.0	0.0
Coleoptera adults.....	0	0	0.0	0.0
Trichoptera.....	40	3	12.0	12.8
Diptera.....	23	5	15.3	6.4
Pisces.....	2	1	1.8	30.6
Filamentous algae.....	6	.....	0.5	0.2
Higher plants.....	8	.....	1.1	0.4
Organic debris.....	23	.....	9.6	12.4

from Park Pond in December, 1948, and January, 1949.

STOMACHS FROM 26 FISH OF 5.0 INCHES OR MORE				STOMACHS FROM ALL 64 FISH			
Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
0	0	0.0	0.0	5	2	0.4	0.1
8	1	tr.	tr.	9	4	2.1	tr.
0	0	0.0	0.0	2	1	tr.	tr.
0	0	0.0	0.0	8	2	1.9	0.1
4	1	tr.	0.1	3	1	1.3	0.1
23	1	16.2	45.0	9	1	6.6	36.6
4	1	0.8	0.4	3	1	0.4	0.3
12	2	4.0	0.1	23	3	11.6	0.4
23	1	15.0	0.3	28	2	18.8	1.3
8	2	3.8	2.0	16	1	12.6	5.5
0	0	0.0	0.0	3	1	1.8	tr.
0	0	0.0	0.0	2	1	0.1	0.3
0	0	0.0	0.0	2	12	1.5	0.9
4	1	0.1	0.4	11	1	4.8	0.7
15	1	3.9	0.1	20	1	3.5	0.1
50	1	46.8	51.3	33	1	28.3	52.9
0	0	0.0	0.0	3	.....	0.2	0.3
15	.....	1.0	0.3	9	.....	0.8	0.3
15	.....	8.5	0.1	6	.....	3.4	0.1

collected from Park Pond in March-May, 1949.

STOMACHS FROM 27 FISH OF 5.0 INCHES OR MORE				STOMACHS FROM ALL 79 FISH			
Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
4	1	3.7	tr.	1	1	1.3	tr.
4	1	3.5	tr.	6	1	1.8	0.1
0	0	0.0	0.0	15	3	3.4	tr.
0	0	0.0	0.0	9	3	2.2	tr.
0	0	0.0	0.0	3	2	0.3	tr.
4	1	0.2	tr.	25	2	3.8	0.1
0	0	0.0	0.0	1	1	tr.	tr.
59	1	43.1	60.9	29	1	17.1	56.2
11	2	0.8	1.1	40	2	7.4	1.3
40	1	8.4	0.8	47	2	20.9	2.9
15	1	4.5	0.8	10	1	3.1	1.0
4	1	tr.	tr.	3	1	0.1	tr.
4	1	3.0	0.2	1	1	1.0	0.1
7	1	0.5	tr.	3	1	0.2	tr.
19	2	3.2	0.3	33	3	9.0	1.3
30	2	1.4	0.2	39	4	10.6	0.7
15	1	11.6	29.7	6	1	5.1	29.7
4	.....	0.6	0.1	5	.....	0.6	0.1
52	.....	6.0	5.1	23	.....	2.8	4.7
26	.....	9.4	0.9	24	.....	9.5	1.8

Table 8.—Stomach contents of 131 warmouths

FOOD ITEM	STOMACHS FROM 98 FISH OF LESS THAN 5.0 INCHES			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Gastropoda.....	14	2	2.1	0.6
Cladocera.....	24	5	4.3	0.3
Copepoda.....	10	5	1.6	0.1
Ostracoda.....	5	4	0.1	tr.
Amphipoda.....	35	3	3.2	1.3
Decapoda.....	16	1	11.4	30.1
Araneae.....	1	1	tr.	0.1
Ephemeroptera.....	58	4	11.6	4.6
Zygoptera.....	47	2	19.5	12.4
Anisoptera.....	17	1	5.1	5.0
Hemiptera.....	6	1	0.5	0.3
Hymenoptera.....	0	0	0.0	0.0
Coleoptera larvae.....	1	1	tr.	tr.
Coleoptera adults.....	4	1	0.1	0.1
Trichoptera.....	52	5	17.3	15.9
Diptera.....	49	3	5.9	3.1
Pisces.....	16	2	9.8	22.4
Filamentous algae.....	4	.....	0.2	0.3
Higher plants.....	11	.....	1.2	1.0
Organic debris.....	17	.....	5.1	2.4

Table 9.—Stomach contents of 117 warmouths collected from

FOOD ITEM	STOMACHS FROM 93 FISH OF LESS THAN 5.0 INCHES			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Gastropoda.....	11	2	2.2	0.4
Cladocera.....	20	17	3.7	0.6
Copepoda.....	15	9	1.7	0.3
Ostracoda.....	3	3	0.1	tr.
Amphipoda.....	35	2	6.8	0.7
Isopoda.....	1	11	1.1	0.6
Decapoda.....	4	1	3.5	20.7
Araneae.....	1	1	0.8	3.9
Hydrochnellae.....	1	1	0.1	tr.
Ephemeroptera.....	49	2	12.9	2.0
Zygoptera.....	24	2	10.9	3.5
Anisoptera.....	15	1	7.2	5.0
Hemiptera.....	7	2	2.7	2.0
Coleoptera larvae.....	1	1	0.1	tr.
Coleoptera adults.....	1	1	0.1	tr.
Trichoptera.....	46	3	18.8	7.5
Diptera.....	55	3	11.3	2.2
Pisces.....	11	1	8.0	48.9
Filamentous algae.....	3	.....	0.5	0.1
Higher plants.....	8	.....	0.9	0.8
Organic debris.....	14	.....	6.3	0.7

collected from Park Pond in June–August, 1949.

STOMACHS FROM 33 FISH OF 5.0 INCHES OR MORE				STOMACHS FROM ALL 131 FISH			
Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
3	1	tr.	tr.	11	2	1.6	0.1
0	0	0.0	0.0	18	5	3.2	0.1
0	0	0.0	0.0	8	5	1.2	tr.
0	0	0.0	0.0	4	4	0.1	tr.
3	1	tr.	tr.	27	3	2.4	0.3
55	1	49.4	73.3	26	1	21.0	64.3
3	1	tr.	tr.	2	1	tr.	tr.
30	1	0.5	0.1	51	3	8.8	1.0
15	1	5.8	0.3	39	2	16.0	2.8
9	1	6.3	2.7	15	1	5.4	3.2
3	1	0.2	tr.	5	1	0.4	0.1
6	1	0.1	tr.	2	1	tr.	tr.
6	1	0.8	tr.	2	1	0.2	tr.
6	1	3.1	0.2	5	1	0.8	0.2
27	1	2.4	1.0	46	4	13.5	4.1
6	4	1.0	tr.	38	3	4.7	0.7
30	1	23.8	21.8	20	2	13.4	21.9
27	.....	1.2	tr.	10	.....	0.5	0.1
24	.....	1.4	0.4	14	.....	1.2	0.5
12	.....	2.2	0.1	16	.....	4.3	0.6

Park Pond in September–November, 1948, and September, 1949.

STOMACHS FROM 24 FISH OF 5.0 INCHES OR MORE				STOMACHS FROM ALL 117 FISH			
Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
4	1	1.2	tr.	9	2	2.0	0.1
0	0	0.0	0.0	16	17	3.0	0.2
0	0	0.0	0.0	12	9	1.3	0.1
0	0	0.0	0.0	3	3	0.1	tr.
8	2	0.4	tr.	30	2	5.5	0.2
0	0	0.0	0.0	1	11	0.8	0.2
29	1	27.4	36.1	9	1	8.4	31.9
12	1	8.3	3.4	3	1	2.4	3.6
0	0	0.0	0.0	1	1	0.1	tr.
4	1	2.8	tr.	40	2	10.8	0.5
12	1	6.4	tr.	21	2	10.0	1.0
8	2	0.4	0.5	14	1	5.8	1.7
8	1	0.1	tr.	9	2	2.2	0.6
0	0	0.0	0.0	1	1	0.1	tr.
8	1	0.6	tr.	3	1	0.2	tr.
25	2	16.5	3.2	42	2	18.3	4.4
12	2	1.1	0.1	46	3	9.2	0.6
33	1	26.4	55.6	15	1	11.8	53.8
0	0	0.0	0.0	3	.....	0.4	tr.
21	.....	5.4	0.5	10	.....	1.8	0.6
12	.....	3.2	0.5	14	.....	5.6	0.5

Seasonal Trends

Each of the various seasons—winter, spring, summer, and fall—designated in the following discussion of seasonal trends in warmouth foods and feeding encompasses 3 months. The seasons are biological rather than astronomical; that is, they are based on similarities in the foods present and utilized by the fish. Winter includes December, January, and February; spring includes March, April, and May; summer includes June, July, and August; fall includes September, October, and November.

The degree to which the stomachs from individual warmouths of Park Pond and Venard Lake were judged to be full was found to be of little value as a measure for determining seasonal trends in feeding activities of the fish or relative amounts of food consumed by them in various seasons of the year. The stomachs from many fish contained one and one-half to two times

as much food as apparently full stomachs from fish of similar sizes.

A better measure of seasonal feeding trends was found to be the average volume of stomach contents of warmouths of several size groups. This measure also proved to have its limitations, most important of which were concerned with differences in rates of digestion and daily feeding periods (discussed under "Daily Changes") that tended to mask the true seasonal trends.

Seasonal trends in average volume of stomach contents (empty stomachs excluded) were apparent in three length groups of warmouths taken from Park Pond. In the warmouths of each of two groups, 3.5–4.9 and 5.0–6.4 inches total length, the average volume increased progressively in the three seasons following winter; the average volume in the fall was two to three times that in the winter. In a group of smaller warmouths (2.0–3.4 inches total length), the average volume of stomach contents was greatest in summer;

Table 10.—Stomach contents of 71 warmouths collected in winter (December, 1948) and 81 warmouths collected in spring (March–May, 1949), all from Venard Lake.

FOOD ITEM	STOMACHS FROM 71 WARMOUTHS COLLECTED IN WINTER				STOMACHS FROM 81 WARMOUTHS COLLECTED IN SPRING			
	Percentage of Stomachs Con- taining Organism	Average Number of Organisms in Stom- achs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Con- taining Organism	Average Number of Organisms in Stom- achs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Bryozoa.....	0	0	0.0	0.0	1	2	tr.	tr.
Annelida.....	0	0	0.0	0.0	1	1	0.4	0.4
Gastropoda.....	3	1	0.7	0.2	0	0	0.0	0.0
Cladocera.....	96	18	28.9	13.4	56	11	9.6	0.8
Copepoda.....	45	7	3.0	1.6	20	3	1.0	tr.
Ostracoda.....	1	1	tr.	tr.	0	0	0.0	0.0
Isopoda.....	45	3	27.8	48.5	57	2	29.1	13.9
Decapoda.....	0	0	0.0	0.0	2	1	1.0	3.3
Hydrachnellae.....	0	0	0.0	0.0	1	1	tr.	tr.
Collembola.....	0	0	0.0	0.0	1	1	tr.	tr.
Ephemeroptera.....	56	3	21.2	12.1	60	24	20.8	20.4
Zygoptera.....	4	1	2.1	3.9	35	3	8.7	8.1
Anisoptera.....	6	1	3.1	15.8	36	3	23.4	47.8
Neuroptera.....	0	0	0.0	0.0	1	1	tr.	tr.
Coleoptera larvae.....	0	0	0.0	0.0	7	1	0.2	0.1
Trichoptera.....	3	1	0.2	0.1	26	5	2.3	2.1
Diptera.....	48	2	12.8	4.4	38	7	1.4	1.3
Filamentous algae.....	1	.....	tr.	0.1	2	.....	tr.	0.1
Higher plants.....	0	0	0.0	0.0	15	.....	0.3	0.2
Organic debris.....	1	.....	tr.	0.1	23	.....	1.7	1.3

Table 11.—Stomach contents of 107 warmouths collected in summer (June–August, 1949) and 97 warmouths collected in autumn (October–November, 1948, and September, 1949), all from Venard Lake.

FOOD ITEM	STOMACHS FROM 107 WARMOUTHS COLLECTED IN SUMMER				STOMACHS FROM 97 WARMOUTHS COLLECTED IN AUTUMN			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
estoda.....	3	1	0.5	1.6	0	0	0.0	0.0
astropoda.....	5	2	2.1	1.5	10	3	3.0	5.6
cladocera.....	32	13	9.3	0.9	37	16	8.6	4.5
amphipoda.....	11	3	0.8	tr.	37	7	7.4	0.3
ostracoda.....	16	5	2.4	0.2	31	24	10.0	0.5
decapoda.....	8	2	1.6	0.4	9	3	5.2	1.1
decapoda.....	24	1	18.0	35.0	8	1	6.8	44.9
phemeroptera.....	33	4	9.7	6.1	31	6	5.9	3.3
dyptera.....	9	1	5.0	3.6	10	3	4.5	4.7
trichoptera.....	10	2	7.2	25.0	16	2	10.1	22.8
hemiptera.....	0	0	0.0	0.0	2	2	0.3	0.2
lymenoptera.....	0	0	0.0	0.0	1	1	tr.	tr.
coleoptera larvae.....	7	2	0.8	1.4	2	2	0.2	0.1
coleoptera adults.....	1	1	tr.	0.1	2	1	0.4	0.4
trichoptera.....	34	4	18.7	8.4	16	3	7.4	3.0
diptera.....	40	2	12.5	1.2	49	7	18.5	4.2
pisces.....	6	1	5.0	12.5	0	0	0.0	0.0
filamentous algae.....	0	0	0.0	0.0	5	.....	0.3	0.4
higher plants.....	9	.....	1.1	0.9	8	.....	0.8	1.0
organic debris.....	10	.....	5.1	1.6	20	.....	10.7	2.9

The trend was downward through the seasons to the lowest figure of the year in spring.

Of some interest is the large number of empty stomachs taken in the winter from the warmouths of Park Pond. Thirty-four per cent of the warmouth stomachs collected there in winter (44 per cent of the stomachs collected in January) contained no food. These high percentages may reflect the influence of partial ice cover and cold water on the feeding activities of warmouths. A large percentage of stomachs empty at a time in which digestion was slow indicated that the fish were going long periods between feedings. A large proportion of stomachs empty in summer was due to rapid digestion and reduced feeding activity after midday.

Tables 6–11 show seasonal changes in kinds of food eaten by warmouths in Park Pond and Venard Lake, as indicated by analysis of stomach contents.

The following discussion and figs. 6 and 7 emphasize the highs and lows of the seasonal trends in foods most commonly found in the warmouth stomachs from the two study areas.

Winter.—In the warmouth collections from Park Pond, fish (Pisces) were found in a larger percentage of stomachs in winter than in any other season, fig. 6. Crayfish (Decapoda), which ranked second to fish in percentage of total volume in winter, were present in only 9 per cent of the winter-collected stomachs examined (all of them from large fish) and did not comprise so large a percentage of the total volume in winter as during the spring and summer. Dipteran and caddisfly (Trichoptera) larvae, cladocerans, and amphipods were found in a smaller percentage of stomachs in winter than in any other season of the year.

In the warmouth collections from Venard Lake in winter, the animal groups

Table 12.—Stomach contents of 99 largemouth bass collected from Venard

FOOD ITEM	STOMACHS FROM 23 LARGEMOUTH BASS COLLECTED DURING MARCH-MAY, 1949			
	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume
Cestoda.....	0	0	0.0	0.0
Gastropoda.....	0	0	0.0	0.0
Cladocera.....	22	70	5.0	1.9
Copepoda.....	0	0	0.0	0.0
Isopoda.....	39	4	22.1	13.3
Decapoda.....	4	2	2.9	1.6
Araneae.....	0	0	0.0	0.0
Hydrachnellae.....	0	0	0.0	0.0
Ephemeroptera.....	83	17	10.3	7.4
Zygoptera.....	57	6	16.6	26.3
Anisoptera.....	61	3	36.9	37.8
Hemiptera.....	9	2	tr.	tr.
Homoptera.....	0	0	0.0	0.0
Hymenoptera.....	0	0	0.0	0.0
Coleoptera larvae.....	0	0	0.0	0.0
Coleoptera adults.....	0	0	0.0	0.0
Trichoptera.....	0	0	0.0	0.0
Diptera.....	39	5	1.0	0.5
Pisces.....	0	0	0.0	0.0
Filamentous algae.....	0	0	0.0	0.0
Higher plants.....	13	.....	0.3	0.2
Organic debris.....	26	.....	5.0	11.0

found in the largest percentages of stomachs were cladocerans, mayfly nymphs, dipteran larvae, copepods, and isopods; each of these groups was in winter at or near its peak for the year in the percentage of stomachs in which it was represented. Fish and crayfish, which in winter led all other food groups in percentage of Park Pond stomachs in which they were found, were not found in any of the Venard Lake stomachs during the winter.

Spring.—In the warmouth collections from both Park Pond and Venard Lake, the nymphs of damselflies were found in a larger percentage of stomachs, and comprised a somewhat larger percentage of total volume of food, in spring than at any other season. Mayfly nymphs were present in a larger percentage of the stomachs from Venard Lake in spring than at any other season; at this season, they were present in a large proportion of the stomachs from Park Pond, also.

In the Park Pond collections, the percentage of stomachs containing fish and the percentage containing dragonfly nymphs

were lower in spring than at any other season. The fragments of so-called higher plants, mostly rootlets or parts of leaves, that were found in 23 per cent of the stomachs probably were taken accidentally with other organisms. About two-thirds of the stomachs that contained plant fragments also contained crayfish.

In the Venard Lake collections, isopods occurred in a larger percentage (57 per cent) of stomachs in spring than at any other season, fig. 7. They did not comprise so large a percentage of total volume in spring as in winter, but their average of volume percentages (29 per cent) was greater and it was greater than that of any other food item taken during the spring. Dragonfly nymphs were present in nearly half of the Venard Lake stomachs collected in spring; the percentage of stomachs containing these nymphs, the average of volume percentages, and percentage of the total volume were much greater during the spring than at any other season. Annelida, Collembola, Neuroptera, and Bryozoa were represented as Venard Lake

Lake during the period beginning October, 1948, and ending September, 1949.

STOMACHS FROM 32 LARGEMOUTH BASS COLLECTED DURING JUNE-AUGUST, 1949				STOMACHS FROM 44 LARGEMOUTH BASS COLLECTED DURING OCTOBER-NOVEMBER, 1948, AND SEPTEMBER, 1949			
Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Percentage of Total Volume	Percentage of Stomachs Containing Organism	Average Number of Organisms in Stomachs Containing Them	Average of Volume Percentages	Per- centage of Total Volume
3	1	0.1	0.1	0	0	0.0	0.0
6	1	tr.	tr.	7	1	0.1	tr.
3	199	3.0	0.4	59	178	23.0	10.1
0	0	0.0	0.0	7	2	tr.	tr.
0	0	0.0	0.0	9	2	0.4	0.1
34	1	18.5	19.8	9	1	9.0	54.0
3	1	tr.	tr.	2	1	tr.	tr.
3	1	tr.	tr.	0	0	0.0	0.0
47	8	2.4	0.9	77	26	24.1	8.7
47	4	17.6	6.3	30	3	5.8	2.1
41	3	15.9	10.6	34	2	15.5	9.8
16	1	tr.	tr.	27	1	6.0	0.8
3	1	tr.	tr.	0	0	0.0	0.0
25	1	3.3	0.7	2	1	tr.	tr.
19	43	4.1	1.9	0	0	0.0	0.0
9	1	tr.	tr.	0	0	0.0	0.0
6	1	0.2	tr.	14	1	2.1	0.3
28	2	1.0	0.1	57	13	6.8	1.4
38	2	30.4	59.1	5	2	4.5	11.4
0	0	0.0	0.0	2	.....	0.2	0.1
6	.....	0.1	tr.	20	.....	0.3	0.4
12	.....	3.3	0.1	14	.....	2.0	0.7

warmouth foods in spring but at no other time.

Summer.—As new broods of young fish became available in summer, a marked increase in the percentage of warmouth stomachs that contained fish was noted in the collections from both Park Pond and Venard Lake.

In the warmouth collections from Park Pond, crayfish occurred in a slightly smaller percentage of stomachs in summer than during the spring but attained a peak in the percentage of total volume of food—64.3 per cent, fig. 6. The percentage of stomachs containing mayfly nymphs and caddisfly larvae increased progressively from winter to summer; these groups were found in proportionately more warmouth stomachs taken during the summer than at any other time of year in Park Pond. The percentage of stomachs in which damselfly nymphs were found was smaller in summer than in spring.

In the warmouth collections from Venard Lake, caddisfly larvae were present in a larger percentage of stomachs in summer

than at any other season. Caddisfly larvae comprised only a relatively small part of the total volume of food, but the average of volume percentages was greater for caddisflies than for any other food utilized in summer. Crayfish also were found in a large percentage of the stomachs collected in summer. Although crayfish made up a smaller percentage of the total volume of food in summer than during the fall months, the percentage of stomachs containing crayfish was three times as great in the summer as in the fall. Fish were found in the stomachs of only those warmouths collected in summer. Mayfly, damselfly, and dragonfly nymphs comprised smaller percentages of the total volume of food and were present in smaller percentages of stomachs in summer than in spring.

Fall.—In the warmouth collections from Park Pond, fish comprised a larger percentage of the total volume of food, and crayfish a smaller percentage of the total volume of food, in fall than in summer; the percentages in the fall were nearly equivalent to those observed during

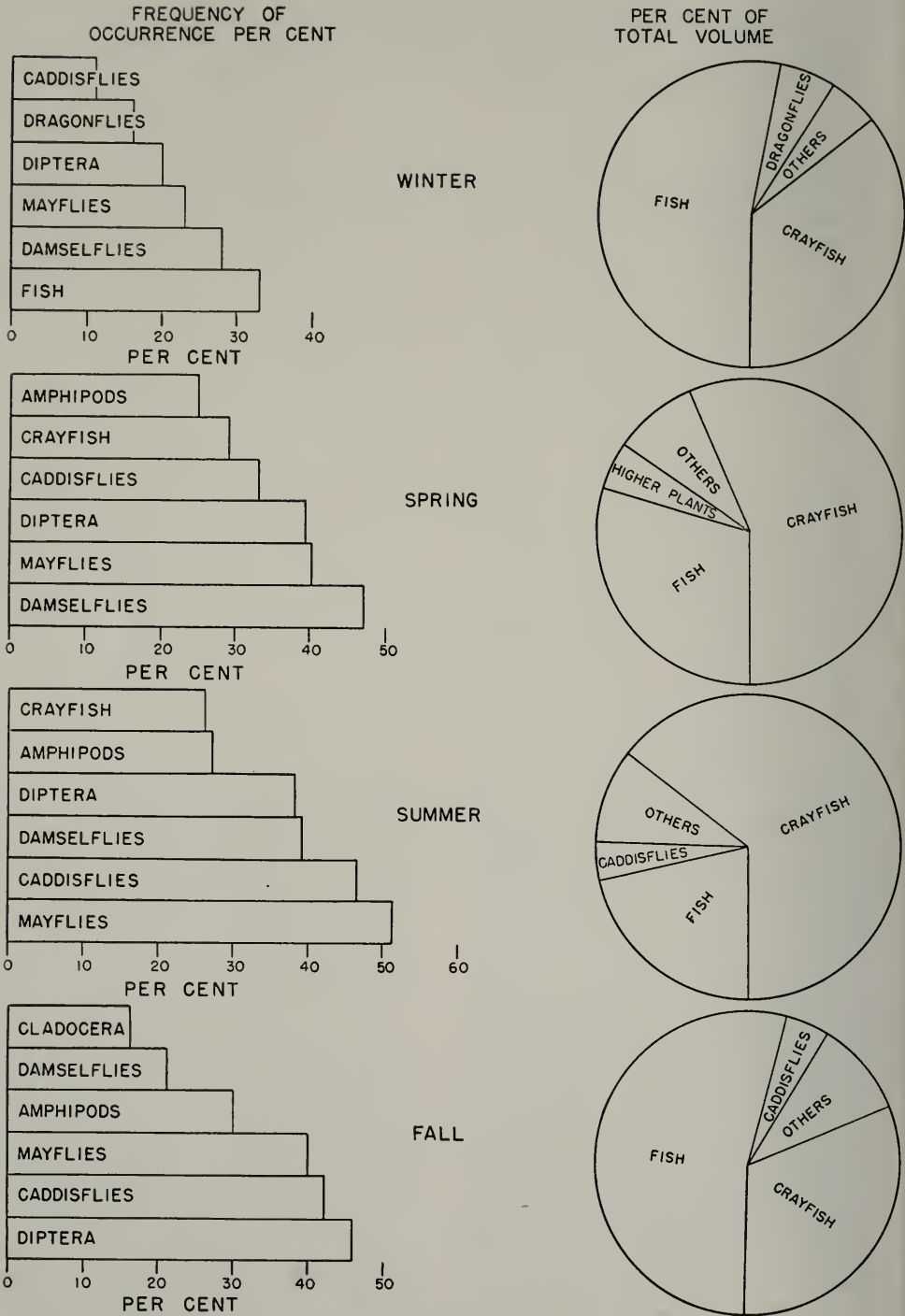


Fig. 6.—For each of the most important foods taken from the stomachs of warmouths collected from Park Pond in each of the four seasons of 1948 and 1949, the percentages of stomachs containing these foods (frequency of occurrence) and the percentage of the total volume of food represented by each of these important foods.

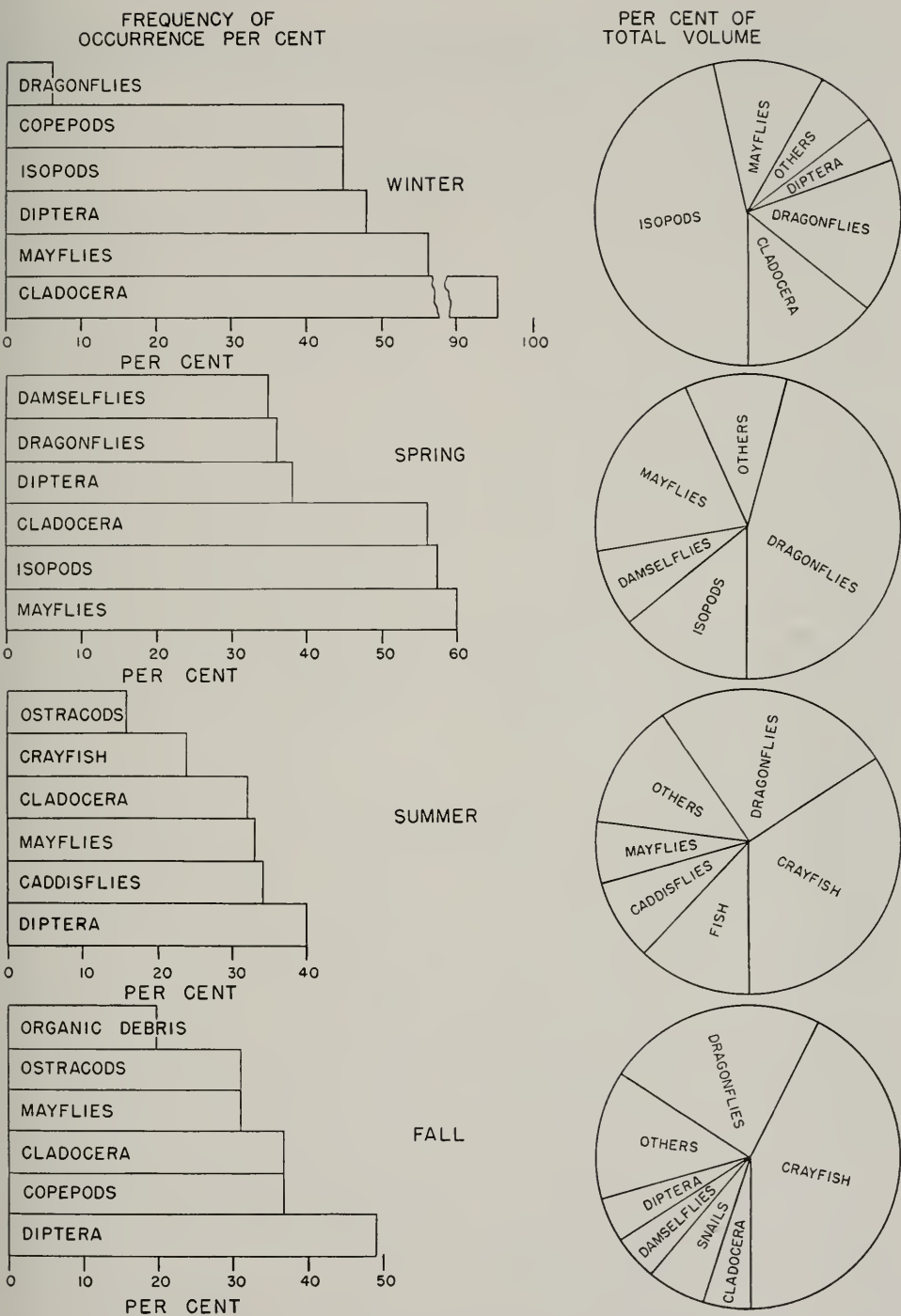


Fig. 7.—For each of the most important foods taken from the stomachs of warmouths collected from Venard Lake in each of the four seasons of 1948 and 1949, the percentage of stomachs containing these foods (frequency of occurrence) and the percentage of the total volume of food represented by each of these important foods.

the winter months, fig. 6. Although fish comprised more than one-half the bulk of food in winter, they were taken from only 15 per cent of the stomachs collected in the autumn. Dipteran larvae (largely chironomids) comprised less than 1 per cent of the total volume of food each season but occurred in a large percentage (33 per cent or more) of stomachs each season—the largest percentage in the fall. In the fall collections, dipteran larvae were present in 46 per cent of the stomachs; the average of volume percentages for these larvae was 9.2. Caddisfly larvae were present in a large proportion of stomachs and ranked first among all food groups in average of volume percentages. Mayfly and damselfly nymphs were found in a smaller proportion of stomachs collected during the fall than during the summer, whereas dragonfly nymphs were present in about the same percentages of stomachs in these two seasons.

In the warmouth collections from Venard Lake, mayfly and damselfly nymphs were present in about the same percentages of stomachs during the summer as during the fall. In November, nymphs of the mayfly, *Siphonurus* sp., showed a sudden pulse of occurrence that extended into December. Caddisfly larvae were present in a smaller percentage of stomachs collected in fall than in the summer months. Throughout the four seasons, dipteran larvae were found in consistently high percentages of stomachs—38 to 49 per cent—the highest percentages in the fall and winter, fig. 7. *Chaoborus* sp., a dipteran larva, was found only occasionally during the spring and summer; but, during the fall months and in December, it was found in large numbers of stomachs. Gastropods (snails) and ostracods were found in higher percentages of Venard Lake warmouth stomachs in the fall than at other seasons.

Daily Changes

During the summer, when water temperatures were high, digestion in the stomachs of fish was rapid, and food remained in these stomachs for only a few hours. At this season, it was possible to determine daily feeding periods of warmouths at Park Pond by comparing the percentages of empty stomachs taken in morning col-

lections with those taken in afternoon collections, table 13. The influence of individual fish size, and of size groups represented by few individuals, was reduced by eliminating from the calculations all warmouths less than 2.0 inches or more than 6.4 inches total length.

Only 4 per cent of the warmouth stomachs collected in the morning were empty, whereas 50 per cent of those collected in the afternoon contained no food.

On July 8 and August 1, 1949, collections were taken soon after sunrise and as late in the evening of the two days as fish could be taken with the shocking apparatus without the use of artificial lights. The daily feeding pattern was quite evident in these collections, table 13. Stomachs removed from fish collected between 6:00 and 7:15 A.M. on July 8 were "relatively full of very dark material"; in contrast, the stomachs collected between 6:15 and 7:45 P.M. "seemed rather empty, the upper intestine completely empty, with only the last three-fourths inch of the lower intestine containing heavy black material representing the early morning feeding."

In stomachs of fish of selected size groups (excluding fish with empty stomachs), total volumes of the food masses averaged consistently lower (by 24 per cent or more) for individuals taken in the afternoon than for those taken in the morning.

Monthly collections of stomachs from Venard Lake in the warm period of the year (1949) indicated for the warmouths of this body of water a daily feeding pattern somewhat similar to that of the warmouths of Park Pond. Of four collections from Venard Lake in the warm months, when the daily feeding pattern might be evident, two were taken in the morning and two in the evening; 13 per cent of the stomachs in the two morning collections and 26 per cent of the stomachs in the two afternoon collections were empty. The differences between morning and afternoon collections were less evident at Venard than at Park Pond, probably because the collections were taken from Venard late in the morning and early in the afternoon.

There was evidence of some feeding activity by warmouths in late afternoon. Although most of the food materials found

Table 13.—Number of warmouths in morning and afternoon collections from Park Pond, June 2–September 2, 1949, and number of those warmouths with empty stomachs. Figures include only those for fish between 2.0 and 6.4 inches total length.

COLLECTION DATE	MORNING		AFTERNOON	
	Number of Fish	Number of Empty Stomachs	Number of Fish	Number of Empty Stomachs
June 2.....			5	1
June 10.....	25	3		
July 5.....			23	8
July 8.....	25	0	18	11
August 1.....	19	1	16	11
August 15.....	16	1		
September 2.....	28	0		
Total number of fish.....	113	5	62	31
Per cent of stomachs empty.....		4		50

in stomachs collected in the afternoon during the summer were well digested, a few were fresh items; most of the materials were nearly digested or else quite fresh, a situation that suggested a resumption of feeding after a period of no feeding. Afternoon feeding during the summer was either very light or it occurred very late in the day, possibly just at dusk when it became too dark for fish to be collected without lights.

Influence of Fish Size

The yolk supply of warmouth larvae observed under laboratory conditions usually was exhausted within 4 days from hatching; without food, the larvae starved to death in 10 or 11 days at 24–25 degrees C. Ordinarily, the postlarvae began feeding at least by the seventh day of life. Stomachs of warmouth larvae collected from outdoor tanks contained a few flagellates and ciliates and many bacteria. One or two of the large protozoans made a rather big meal for an 8-mm. larva. When 14 days old, the warmouth larvae ate considerably larger organisms, feeding even on small mosquito larvae. Both in natural waters and in the laboratory, warmouths 19 mm. long were observed feeding voraciously on postlarval warmouths 5 mm. long.

In a study of differences in food taken by larger fish, the stomach contents of warmouths from Park Pond and Venard Lake were grouped according to sizes of fish from which the stomachs had been taken.

Since it was necessary to present these analyses in compact tables, fish from Park Pond were grouped in two length ranges, tables 6–9, and fish of all lengths from Venard Lake were grouped together, tables 10 and 11. Some of the relationships between lengths of fish and foods taken, such relationships as are obscured in the tables by combining data for fish of various lengths, are given in the following general statements.

Cladocerans, copepods, and ostracods were taken mostly by warmouths less than 3.5 inches in length and were the principal foods of warmouths less than 1.7 inches in length, which only occasionally took small mayfly nymphs or dipteran larvae. Amphipods were an important food for small warmouths at Park Pond but were utilized by very few fish larger than 4.9 inches in length. Snails were eaten mostly by warmouths between 2.5 and 4.9 inches in length.

Crayfish were eaten by more large warmouths than small ones at Park Pond. In contrast, crayfish were eaten by more small warmouths than large ones at Venard Lake, presumably because large numbers of small crayfish were available to the fish there during the summer months.

In both study areas, mayfly nymphs were taken by a larger percentage of small warmouths than of large ones; however, at Park Pond in summer they were taken by 30 per cent of the warmouths over 5.0 inches long. At Venard Lake, where both *Caenis* and *Siphonurus* occurred in large numbers, the nymphs of *Caenis* were taken

mostly by warmouths between 2.0 and 3.4 inches, whereas the nymphs of *Siphonurus*, which were larger, were eaten generally by larger fish, up to 5.2 inches in length.

Caddisfly larvae were eaten by a larger percentage of small warmouths than of large ones; the seasonal trend in consumption was somewhat similar for fish of all sizes. Damselfly and dragonfly nymphs were utilized as food by warmouths of all sizes except those less than 2.0 inches long. Fish were eaten by a greater percentage of large warmouths (over 5.0 inches in length) than of small ones.

The average volume of food found in the stomachs of warmouths of various sizes was not directly proportional to the length or weight of the fish; the larger the warmouth the greater was the volume of food taken in proportion to its size. The stomachs of very small warmouths occasionally contained relatively great amounts of food, but small warmouths feeding on many small items seldom experienced the extreme distention of the stomachs that occurred in many large warmouths when feeding on comparatively large fish or crayfish.

The percentage of stomachs that were empty was smaller among small warmouths than among large ones. The percentages of Park Pond warmouths with empty stomachs were as follows: fish of 1.9 inches or less total length, 3 per cent; fish of 2.0–3.4 inches, 18 per cent; fish of 3.5–4.9 inches, 24 per cent; fish of 5.0–6.4 inches, 32 per cent; and fish of 6.5 inches or larger, 28 per cent. Small warmouths feeding on many small items apparently had a more certain food supply than had large warmouths, which had relatively fewer large organisms on which to feed.

Interspecific Competition

Largemouth bass stomachs were collected from Venard Lake at the same time the warmouth stomachs were obtained. Because only four largemouths were taken during the winter, their food habits for this season were omitted from consideration here. The majority of the bass taken (92 per cent) were between 5.5 and 9.0 inches total length. Of 107 bass stomachs collected, 99 contained food materials, table 12.

Cladocerans were found in surprisingly large numbers in the stomachs of largemouths up to 7.5 inches in length—791 of them in the stomach of one 6.4-inch bass. Of the largemouth stomachs collected in the fall months, cladocerans (almost exclusively *Simocephalus* sp.) were found in 59 per cent. Very few were found in the bass stomachs collected in summer. Cladocerans were found in relatively high percentages of the warmouth stomachs collected from Venard Lake throughout the year; they did not show an increase in utilization by warmouths during the fall months comparable to the increase in utilization by largemouth bass. Cladocerans were found in 32 and 37 per cent of the warmouth stomachs collected, respectively, in the summer and fall and in 96 per cent of the warmouth stomachs collected in December. Copepods were found in very few stomachs of the largemouth bass, and ostracods were found in none. Isopods were found in greater percentages of both largemouth and warmouth stomachs collected in spring than at any other season.

Fish and crayfish together comprised 64 per cent (36 and 28 per cent, respectively) of the total volume of largemouth bass food. The percentages of bass stomachs containing fish or crayfish were low in the spring, high during the summer, and low again in the fall. The seasonal trend was somewhat similar to that for warmouths at Venard Lake. Bass stomachs collected in August contained very few items except fish and crayfish.

That mayfly nymphs and midge (Diptera) larvae were important bass foods at Venard Lake was shown by the consistently large percentage of stomachs in which they occurred. Percentages were larger in spring and fall than in summer. Mayfly nymphs were found in at least as large a percentage of bass stomachs each season as was any other kind of food organism; they were found in a larger percentage of bass than of warmouth stomachs. The fall increase in utilization of mayfly nymphs by bass was not followed by a similar increase by warmouths. Nymphs of *Siphonurus* sp. accounted for the fall increase in consumption of mayfly nymphs by bass; as many as 125 were found in each of several bass stomachs taken during November. Only in the spring collections did the

nymphs of *Caenis* sp. occur in bass stomachs as frequently as those of *Siphonurus*; *Caenis* was consistently the species of mayfly most abundantly taken by warmouths. The variation in utilization of these mayflies may have come from differences in their habitats: *Siphonurus* is generally concentrated in deeper water than is *Caenis* and would be available to largemouths feeding in open areas of the lake. *Caenis* is a shallow-water mayfly and would be taken by warmouths feeding along the banks and in shallow weed beds.

The percentage of bass stomachs that contained damselflies (*Zygoptera*) and/or dragonflies (*Anisoptera*) decreased from spring to fall. A smaller percentage of warmouth than of largemouth stomachs contained nymphs of the Odonata. Largemouth bass stomachs contained more adults and subimagos of damselflies than did warmouth stomachs; in the June collection of bass stomachs, these forms outnumbered the nymphs taken.

Larval and adult beetles (*Coleoptera*), bugs (*Hemiptera*), and bees and ants (*Hymenoptera*) occurred at peak abundance in bass stomachs during the summer, especially in June. The incidence of these insects was much greater in largemouth bass than in warmouths at Venard Lake. Larvae of the aquatic beetle *Peltodytes*

sp. were eaten in large numbers by a few largemouths; in June, 131 of the larvae were found in the stomach of one individual and 115 in the stomach of another.

Certainly the foods and feeding areas of warmouths and largemouth bass overlapped in Venard Lake. However, even though largemouth bass and warmouths fed on the same kinds of organisms, and even though several of these organisms followed similar seasonal patterns of occurrence in the stomachs of the two fishes, the competition was somewhat reduced by differences in feeding habits. Warmouths tended to consume the organisms on the soft bottoms, in shallow waters, and along the banks; largemouths fed more on the surface organisms and free-swimming forms in deeper or more open parts of the lake.

General Conclusions on Food Habits

Considerable differences have been observed in the contents of the stomachs of warmouths taken in small numbers at different seasons or from widely separated localities, table 14.

Forbes (1903:48-9) analyzed the stomach contents of warmouths collected at scattered localities in Illinois and neighboring states and considered the foods uti-

Table 14.—Average of volume percentages for the food of warmouths studied by Forbes (1903), McCormick (1940), and Rice (1941) and for the food of warmouths of approximately the same sizes, and collected at about the same times of year, from Park Pond and Venard Lake.

FOOD ITEM	FORBES (1903)	MCCORMICK (1940)	RICE (1941)	PRESENT STUDY	PRESENT STUDY
	ILLINOIS AUTUMN 6 FISH LENGTH, INCHES 3+	REELFOOT LAKE SUMMER 69 FISH LENGTH, INCHES* 3.3-8.7 (5.4 AVERAGE)	REELFOOT LAKE SUMMER 45 FISH LENGTH, INCHES* 3.3-6.5 (4.8 AVERAGE)	PARK POND SUMMER 59 FISH LENGTH, INCHES 3.4-6.4 (4.7 AVERAGE)	VENARD LAKE SUMMER 27 FISH LENGTH, INCHES 3.4-6.4 (4.3 AVERAGE)
Crayfish.....		46.38	99.5	29.7	27.7
Entomostraca.....		2.90	tr.	0.7	0.7
Mayflies.....	25	2.90	tr.	2.9	5.7
Damselflies.....		1.59		15.7	3.8
Dragonflies.....		10.87		5.2	23.8
Hemiptera.....	18	7.68		0.3	
Diptera larvae.....		10.03	tr.	4.6	3.9
Miscellaneous insects.....	10	5.07		12.2	17.3
Fish.....	47	7.94		20.5	5.9
Miscellaneous items.....		4.64	tr.	8.2	11.2

*Measurements here are equivalents of metric measurements given by author.

lized by fish of different sizes. The small warmouths in his study had eaten large numbers of Entomostraca, as had the small warmouths at Venard Lake and at Park Pond. In his six adult warmouths, table 14, crayfish were not represented, and fish made up a larger percentage of the food (47 per cent) than has been reported in other studies. Forbes related the especially piscivorous habit of this species to the large size of its mouth. Dragonflies were noticeably absent in all the warmouth stomachs he examined.

Data in studies made by McCormick (1940:73) and Rice (1941:26) at Reelfoot Lake, Tennessee, table 14, emphasized the differences in foods utilized by a species in successive years, even at the same location and during the same season of the year. McCormick examined 69 warmouth stomachs which contained food and found that the average of volume percentages of insects was 38.14 per cent. The comparable figure at Park Pond was 40.9 per cent. Crayfish were higher and fish were lower in the average of volume percentages of warmouth food at Reelfoot Lake than at Park Pond. A year after McCormick's study, Rice examined another series of warmouth stomachs from Reelfoot Lake. Of 45 stomachs which contained food, only 1 had food other than crayfish, table 14.

For the periods of time covered by the studies cited in table 14, warmouths at both Venard Lake and Park Pond utilized a greater variety of food items than did warmouths in the other places listed, as is indicated by the percentages of "miscellaneous insects" and "miscellaneous items."

Lewis & English (1949:321) examined the stomachs of 29 warmouths from Red Haw Hill Lake, Iowa. The fish were collected from April through July and ranged from 40 to 177 mm. in total length. In the 17 stomachs that contained food, "food items occurred as follows: 2- to 4-inch fish, 7; crayfish, 4; vegetable debris, 2; unidentified insect larvae, 4; leech, 1; dragon-fly naiad, 1; unidentified insects, 2; and snails, 1." These figures probably refer to the number of stomachs in which each kind of food was found and not to the numbers of individual food items. The conclusion from this study was that "On a volumetric basis, fish and cray-

fish were the most important food items."

In a rather general statement involving five fishes, Black (1945:463) mentioned that the warmouth in Shiner Lake, Indiana, hunts the northern mimic shiner, *Notropis volucellus volucellus* (Cope), to the exclusion of almost all other food. At Park Pond, where many species of minnows were present, small sunfish were more commonly taken by warmouths than were minnows.

Hunt (1953:29) examined 25 small warmouths from the Tamiami Canal west of Miami, Florida. Twelve of these fish, ranging from 1.4 to 3.5 inches in total length, contained food material composed exclusively of animals, including the following organisms: dragonfly, damselfly, and mayfly nymphs; dipteran larvae of various kinds; a few scuds and large ostracods; and a large number of small shrimps, *Palaemonetes paludosa*.

Huish (1947:15-6) examined 17 warmouths from Lake Glendale (southern Illinois) during the summer of 1946. These fish, caught on artificial flies, ranged from 5.0 to 7.5 inches in total length. Of the 14 fish whose stomachs contained food, there were 3 with small fish, 1 with a tadpole, 3 with dragonfly nymphs, and 7 with crayfish.

Fish, crayfish, and immature forms of aquatic insects comprised the important foods for most of the warmouths involved in the present study. Diets of the warmouths in Park Pond were found to differ from the diets of the warmouths in Venard Lake both as to the kinds and to the amounts of certain organisms eaten in various seasons and by fish of different sizes. This study and others, some of which have been cited above, make it seem very unlikely that there is any specific diet or highly restricted food preference for this species. Food items of many kinds are acceptable to the warmouth; this fish may feed upon any of those items that are readily available.

REPRODUCTION

Whether a fish population overcrowds its habitat is determined in part by its rate of reproduction—the development of sex products and the subsequent growth and survival of young fish.

Development of Sex Products

In interpreting the stages of development of sex products in a fish such as the warmouth, which spawns over a period of several months, one must keep in mind that all of the germ cells do not go through the cycle of maturation simultaneously; instead, small groups of these cells mature at intervals and are spawned. This process is accompanied by a continuous recruitment of additional cells from the primordial stock. Thus, in a gonad in spawning condition, in addition to the fully matured sex products, there are other groups of cells representing earlier stages in the maturation process.

Annual Sexual Cycle.—Terms descriptive of the appearance of the fish gonad are useful for designating stages of development associated with seasons, table 15. Some of the terms used here are the same as those used by Bennett, Thompson, & Parr (1940:17).

Partly because the gradual process of growth of germ cells varies among individuals and partly because the developmental process is influenced by climatological conditions, the periods during which the various designated stages may be found overlap and are not exactly the same from year to year for either individual fish or for populations. Overlapping of developmental stages was evident in warmouths

Table 15.—Appearance and significance of each stage in the development of warmouth gonads, related here to the seasonal occurrence of each stage in warmouths from Park Pond, 1948 and 1949.

STAGE OF DEVELOPMENT OF GONADS	APPEARANCE OF GONADS		SIGNIFICANCE OF STAGE IN DEVELOPMENTAL PROCESS	SEASON OF STAGE
	Male	Female		
Latent	Clear pinkish white to colorless; a narrow translucent strand	Light amber, often with small red dots; lobelike in form and somewhat translucent	A quiescent period; gonad containing only primordial germ cells	All year for fish under 3.5 inches; July 1–April 15 for fish over 3.5 inches
Poorly developed	Pinkish white, opaque, becoming ribbon-like	Pinkish orange to light yellow; slightly granular and somewhat enlarged	Initial maturation of sex products	March 1–May 1
Well developed	White, opaque; ribbon-like, with wavy margins	Bright yellow; very granular and fully distended, with opaque eggs	Advanced development of germ cells; heavy yolk accumulation in ova	April 15–June 1
Spawning condition	Appears as in preceding stage but flowing milt when gently pressed	Appears as in preceding stage but flowing eggs when gently pressed	Completed germ cells free in gonad, ready to be discharged	May 15–August 15
Partly spent	White to gray; more nearly flat than in spawning condition	Yellow to orange, with congested blood vessels; less distended than in spawning condition	No germ cells free in gonad, but a considerable stock of well-developed ova and sperm remaining	June 1–August 20
Spent	Muddy white, becoming smaller and less distended	Reddish-orange, flaccid, with congested blood vessels	Remaining matured germ cells resorbed; gonad reorganizing, but effect of spawning still evident	June 15–September 1

collected from Park Pond during the spawning season of 1949. These fish were divided into two size groups established on the basis of differences in maturation: in the first group were "large" warmouths, those of more than 5.4 inches total length; in the second group were "small" warmouths, those between 3.5 and 5.4

2. All the "large" individuals took part in spawning activities, whereas a considerable proportion of the specimens between 3.5 and 5.4 inches remained immature during the entire nesting season.

3. The "small" warmouths recovered more quickly from the effects of spawning than did the "large" ones; all of the

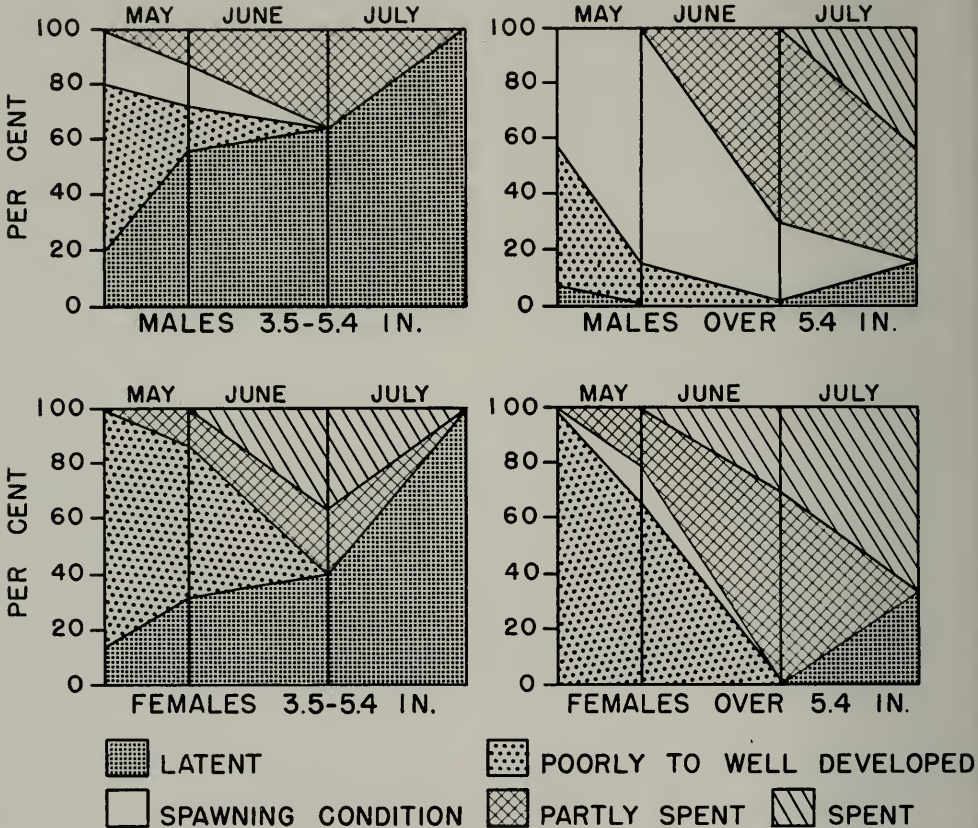


Fig. 8.—Percentage of warmouth males and females (two size groups) in each of five stages of sexual development during May, June, and July. These warmouths were collected from Park Pond, May 13 to August 1, 1949.

inches total length. Warmouths shorter than 3.5 inches were eliminated from this part of the study because they would not mature in the then current season. The following generalizations may be made regarding the season of greatest sexual activity of the warmouth, fig. 8:

1. The "large" warmouths (over 5.4 inches total length) attained spawning condition sooner and spawned over a longer period than did the "small" fish (3.5-5.4 inches total length).

"small" warmouths were in a latent condition by August 1, whereas among the larger fish only 14 per cent of the males and 33 per cent of the females possessed gonads that had become reorganized by that date.

4. The males ripened slightly earlier in the season than did the females and remained sexually active somewhat longer.

In the smaller size group (3.5-5.4 inches total length), a considerable proportion of both males and females had latent

gonads after the first week in May, fig. 8. The continuous rise in percentage of latent gonads found in this size group during the nesting season may have resulted from (1) rapid reorganization of the gonads of early spawners, (2) failure of some small individuals to spawn and prompt return of these individuals to the latent condition, (3) growth of fish during May, June, and July, which resulted in the recruitment of some sexually undeveloped fish into the 3.5–5.4-inch group and the loss of some sexually mature fish from this group to the size group beyond 5.4 inches, and/or (4) inadequacy of collections and their failure to represent true proportions of individuals in the various developmental stages.

Field observations showed that sexually mature females do not have free ova (which can be forced out by gentle pressure on their sides) except immediately before and during the spawning act, whereas sexually mature males may be induced to extrude milt during much of the spawning season. These observations may explain the fact that many more males than females were classed as ripe. The scarcity of small males that were classed as completely spent was due probably to the difficulty of separating partly spent from completely spent individuals in the small sizes.

By expressing the weight of gonads at regular intervals through the year as per cent of body weight, one can follow the increase and diminution in size of the sex glands and fit the observed spawning condition of fish into the annual sexual cycle (James 1946 and others). Statistics on monthly gonad weight–body weight relationships for warmouths in Illinois were based on 222 females and 260 males collected in Park Pond from early October, 1948, to early September, 1949, fig. 9. The fish were divided into three size groups: (1) less than 3.5 inches total length, (2) 3.5–5.4 inches total length, (3) more than 5.4 inches total length. Most of the warmouths of 3.5 inches and longer total length were sexually mature; most below this length were sexually immature.

During the period beginning with September and ending with March, there was no appreciable change in gonad weights among warmouths. Soon after the initial

rise of water temperatures in March, the gonads in warmouths longer than 3.5 inches began to enlarge, and they increased rapidly in weight during April and May. The ratio of gonad weight to body weight increased most rapidly in the large warmouths (over 5.4 inches); males in this group showed their greatest average gonad weight in May and females showed their greatest average gonad weight early in June. The ratio of gonad weight to body weight for both male and female warmouths between 3.5 and 5.4 inches in length averaged highest the first week in June. Soon afterwards, however, the ratio of gonad weight to body weight declined rapidly for females in the two larger size groups. Among males of both groups, there was a drop in weight of testes, but the males remained sexually developed later in the season than did females. The ratio of gonad weight to body weight may be at a minimum immediately following cessation of sexual activity, but it may increase slightly with reorganization of the gonads.

Evidence from the cycle of changes in the ratio of gonad weight to body weight lends support to the conclusion previously drawn that large warmouths mature earlier in the season than do small ones and also remain active reproductively over a longer period. In this series of specimens, initial ripening of the sex products occurred during the second week in May, 1949, fig. 9.

At the time other warmouths were spawning, warmouths under 3.5 inches total length showed no increase in the relative weight of the gonads; in fact, an apparent decrease took place. This decline was probably associated with an improvement in condition (an increase in the body weight) of the smaller fish during May, June, and July. The irregularities that appeared during winter months in gonad weight–body weight relationships of females in the two smallest length groups, fig. 9, were attributed to changes in body weight rather than to changes in gonad weight; these irregularities corresponded to changes in the coefficient of condition, fig. 17.

Increasing length of day and rising temperatures associated with spring are known to stimulate gonad development in fishes.

In 1949, the ratio of average gonad weight to average body weight of Park Pond warmouths began increasing early in March and roughly corresponded to an upswing in mean monthly air temperatures above 40 degrees F. (United States

Weather Bureau 1948-1949, Danville Station). Spawning was actually initiated at water temperatures (12 inches deep) of about 70 degrees F. Low ratios of gonad weight to body weight for the summer months of July and August, 1949, indi-

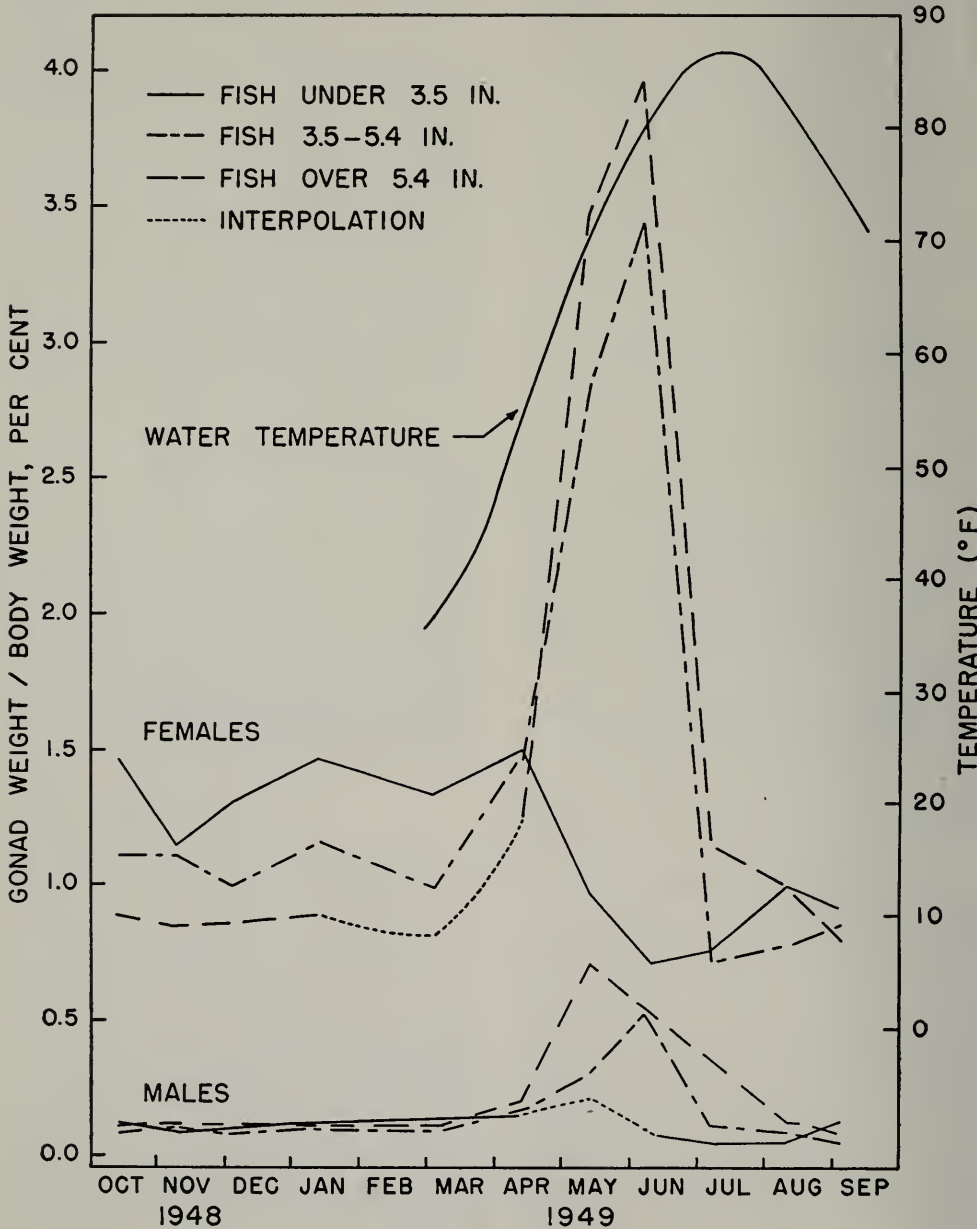


Fig. 9.—Curves illustrating the relationships of gonad weight to body weight (the per cent the gonad weight is of the body weight) for male and female warmouths of three size groups collected from Park Pond, early October, 1948, through early September, 1949, and water temperatures (degrees F.) taken with a mercury thermometer 12 inches below the water surface.

cated that most of the spawning was completed by early July. Information obtained from collections of warmouths made the previous summer suggested that the spawning season in 1949 may have been shorter than in most years.

Fecundity.—Probably one of the more difficult problems in studying the reproduction of a fish is how to estimate the total number of ova developed in a season by an individual female. The problem is especially complex in a fish that, like the warmouth, spawns an indefinite number of times over a rather long period and that contains large numbers of eggs too small to be counted without some magnification. Usually an extended period of sexual activity in fish is associated with a continuous maturation of eggs and sperm, so that sex products may ripen and be discharged at frequent intervals during the spawning season. Thus, at almost any time during the spawning season, in the ovary are several sizes of ova representing various stages of development from primordial germ cells to yolk-laden eggs ready for spawning.

The egg-counting problem presented by the warmouth was not solved by any of the methods previously reported for determining the number of eggs in fish ovaries. The method used—based on the dry weight of the egg mass in an ovary—was developed as an efficient way to estimate the numbers of ova of various sizes. The first step involved measuring several hundred ova and sorting them into seven size groups. A low power binocular microscope ($\times 18$) equipped with an ocular micrometer was used to measure each of the several hundred ova to the nearest 0.05 mm. The seven size groups were as follows: I, 0.15–0.30 mm.; II, 0.35–0.45 mm.; III, 0.50–0.60 mm.; IV, 0.65–0.75 mm.; V, 0.80–0.90 mm.; VI, 0.95–1.05 mm.; and VII, 1.10 mm. and over. Group I included most small ova except the undifferentiated germ cells in the ovigerous lamellae.

All ova diameters were measured as the ova appeared at random on the horizontal scale of the ocular micrometer. Clark (1925:5), in using a similar system of measurement, proved this was a reliable method of measuring eggs that were not spherical. The ova were separated into the

various size groups as they were measured. Twenty ova belonging to each size group were then placed in a platinum crucible of known weight and put in a drying oven at 45 degrees C. After remaining in the drying oven for 48 hours, the eggs, in the crucible, were moved to a desiccator, where they were left until repeated weighings showed no changes in weight. (It is now believed that the use of a desiccator was not necessary.) Each sample was weighed to the nearest 0.01 mg.; through calculations, the tentative average dried weight for ova in each of the various samples was determined. For each size group, five additional samples of 20 eggs each were dried and weighed before a final average dried weight was determined. The average dried weight determined for eggs in each size group was assumed to be the same as the average dried weight for eggs in a similar size group in other ovaries.

Steps in processing each ovary for which a calculation of egg numbers was desired were as follows: (1) The connective tissue sheath surrounding the ovary was removed, and the eggs were teased apart; (2) a random sample of several hundred eggs was taken from the total mass of eggs in the ovary; the eggs in the sample were measured individually and separated into size groups, and the percentage of eggs in each size group was determined; (3) the mass of eggs remaining was washed, placed in a drying oven at 45 degrees C. for 48 hours, moved to a desiccator, and kept there until repeated weighings showed no changes of weight.

Steps in calculating the total number of eggs in an ovary were as follows:

1. The average weight (dry) determined for eggs of each size group was multiplied by the percentage of eggs of the random sample in that size group. The products from the calculations for all the size groups were added and the sum multiplied by 100 to give the calculated dry weight of 100 representative eggs of the sample.

2. The weight of the dried eggs (exclusive of eggs in the random sample) was divided by the calculated dry weight of 100 representative eggs, as determined from the random sample, and the resulting quotient was multiplied by 100; to this product was added the number of eggs

in the random sample. The sum of these numbers was the calculated total number of eggs in the ovary.

The calculated number of eggs in each size group in the ovary was determined by multiplying the calculated total number of eggs in the ovary by the percentage of the random sample represented by the size group.

A modification of the dry-weight method described above, and one that did not require the initial work of determining the average dried weight of eggs of each size group was as follows: After the eggs were teased apart and the connective tissue removed, (1) eggs in a random sample were counted (and measured if there was interest in size groupings), dried, and weighed, (2) the eggs remaining were dried and weighed, and (3) the total number of eggs was then calculated on the basis of the total dried weight of all eggs in the ovary including those in the random sample. This method was similar to that used by Katz & Erickson (1950:176) for estimating fecundity of herrings, in which only one size group of eggs was involved.

When the numbers of ova in only a few ovaries are to be calculated, this modified dry-weight procedure is faster than the method first described. However, once the average dried weight of ova of each size group has been determined, the first method requires less work and is faster because the sample ova that are measured, sorted, and counted do not have to be dried and weighed.

Ovaries for which estimates of numbers of eggs were made—38 ovaries from Park Pond and 10 from Venard Lake—had been divided into four groups: those taken from Park Pond warmouths in (1) January and March, (2) April, May, and June, (3) July and August, and (4) those taken from Venard Lake warmouths, May 25, 1949. In these ovaries, there was a positive correlation between estimated numbers of eggs in individual fish and total length of fish. Coefficient of correlation values ranged from 0.64 to 0.98.

Seasonal variations in the number of eggs in warmouth ovaries were considerable. There was a marked increase in number of eggs per ovary from late winter to the peak of the spawning period, fig. 10.

Immediately after the peak of spawning activities, the number of eggs per ovary was considerably reduced. At that time, the correlation between number of eggs and size of fish was lowest; this low correlation was due to the depleted condition of the ovaries, some of them being partly spent, some entirely spent, and others partly recovered. Females showing recovery from spawning contained more eggs than did the spent fish. During the fall and winter months, the number of eggs per ovary increased gradually; the final and greatest increases took place in the spring when groups of small eggs were adding yolk and undergoing final maturation.

Fish of comparable sizes in different bodies of water did not produce comparable numbers of eggs. For example, a Venard Lake female, 5.3 inches in length, contained 40,400 eggs, whereas a female of this length from Park Pond contained only 12,500 eggs, table 16. This large difference may be explained in part by differences in environmental stresses upon these warmouth populations resulting from (1) a rapidly expanding population in Venard Lake in 1947 and 1948 in contrast to an older and more stable population in Park Pond, (2) a greater concentration of fish in Park Pond than in Venard Lake, and (3) a higher incidence of parasitic infestation in the more concentrated population of fish.

Venard Lake was stocked in the spring of 1947, and the fish population expanded rapidly during the 1947 and 1948 growing seasons. Although the population probably had attained its maximum size by the time ovaries were collected for egg counts in 1949, the rapid expansion of the population in the preceding two seasons may have been at least partly responsible for the fact that the number of ova per female warmouth was greater for fish collected from Venard Lake than for those from Park Pond.

Park Pond had a higher population density of fish other than warmouths than had Venard Lake, which had only warmouths and largemouth bass. Where many fish are concentrated within a limited volume of water, there may be severe competition for food and space among members of this population. The smaller number of eggs per warmouth in Park Pond may have been

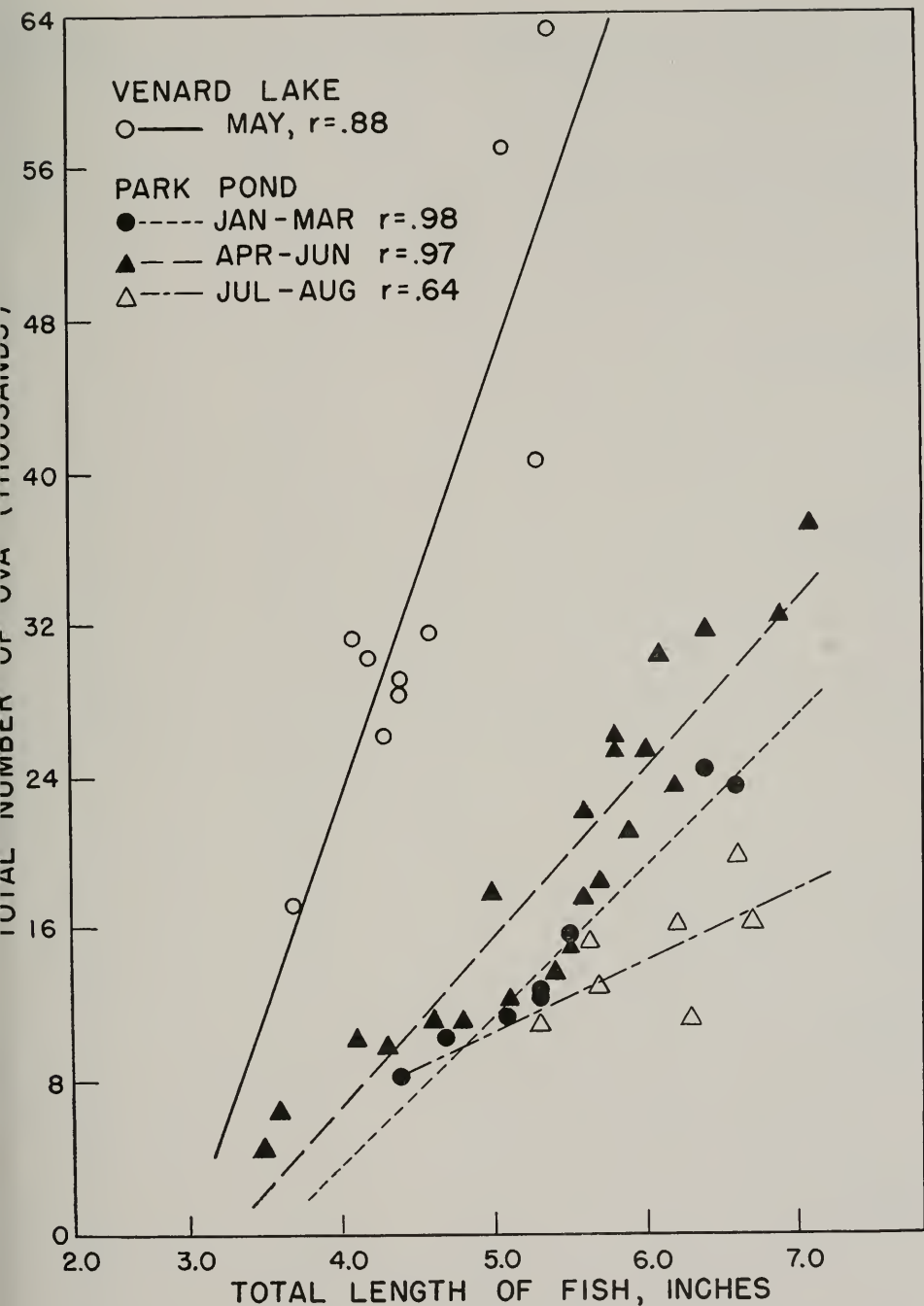


Fig. 10.—Estimated number of ova from warmouths of various total lengths in collections from Park Pond (January–March, April–June, and July–August) and Venard Lake (May), 1949. Scattergram, regression line, and coefficient of correlation (r) are given for each collection group. Elevations of the regression lines indicate seasonal changes in numbers of ova in three groups of Park Pond warmouths and also indicate that females from Venard Lake produced more ova than did females of similar sizes from Park Pond. Each graphic symbol represents one female from which the number of ova was estimated.

associated with interspecific competition among several species rather than intraspecific competition among warmouths.

Of the warmouths for which ova counts were made, the females from Venard Lake

were in much better body condition (average of coefficient of condition 82.2) than were Park Pond females of similar sizes taken at about the same time (average of coefficient of condition 73.8). This differ-

Table 16.—Estimated numbers of ova in 38 warmouths from Park Pond and 10 from Venard Lake, 1949, arranged according to seasons and in order of increasing total length of fish.

PLACE AND TIME	LENGTH OF FISH, INCHES	WEIGHT OF FISH, POUNDS	DATE OF COLLECTION	ESTIMATED NUMBERS OF OVA
Park Pond, January-March	4.4	0.06	March 2	8,100
	4.7	0.07	March 2	10,200
	5.1	0.09	March 2	11,200
	5.3	0.11	March 2	12,300
	5.3	0.11	March 2	12,500
	5.5	0.13	January 8	15,600
	6.4	0.21	January 8	24,300
	6.6	0.24	January 8	23,400
Park Pond, April-June	3.5	0.03	May 23	4,500
	3.6	0.03	April 9	6,200
	4.1	0.05	May 13	10,200
	4.3	0.05	April 9	9,800
	4.6	0.06	May 14	11,200
	4.8	0.09	May 13	11,200
	5.0	0.09	April 7	17,700
	5.1	0.10	May 13	11,600
	5.1	0.10	May 14	12,000
	5.4	0.12	May 13	13,900
	5.5	0.13	May 13	15,500
	5.6	0.12	June 10	17,900
	5.6	0.14	April 9	22,200
	5.7	0.15	June 10	18,300
	5.8	0.15	June 10	26,000
	5.8	0.15	May 13	25,600
	5.9	0.16	May 13	21,200
	6.0	0.18	May 14	25,500
6.1	0.18	May 13	30,400	
6.2	0.17	May 14	23,700	
6.4	0.20	June 3	31,900	
6.9	0.28	May 14	32,700	
7.1	0.29	June 10	37,500	
Park Pond, July-August	5.3	0.12	August 1	11,000
	5.6	0.14	August 15	15,100
	5.7	0.15	July 5	13,100*
	6.2	0.20	July 8	16,200
	6.3	0.16	July 5	11,300**
	6.6	0.24	August 15	19,800
	6.7	0.24	August 1	16,100
Venard Lake, May	3.7	0.04	May 25	17,200
	4.1	0.06	May 25	31,400
	4.2	0.06	May 25	30,200
	4.3	0.06	May 25	26,000
	4.4	0.07	May 25	28,200
	4.4	0.07	May 25	29,000
	4.6	0.08	May 25	31,600
	5.1	0.11	May 25	57,000
	5.3	0.12	May 25	40,400
	5.4	0.14	May 25	63,200

*Two plerocercoids of *Protocephalus*.

**Four plerocercoids of *Protocephalus*.

ence in body condition indicated that the Venard Lake females had a greater amount of reserve energy, which was available for the production of eggs.

Functions of the gonads of warmouths may be disturbed by internal parasites. Two ovaries in the series examined were parasitized by plerocercoid tapeworms and contained fewer ova than expected, table 6. However, in both Park Pond and Venard Lake there was such a high correlation between egg production and length of fish, regardless of differences in parasitic infestations, that it does not seem possible that parasites greatly influenced egg production in these populations.

Fecundity in warmouths may be reduced by lack of suitable nesting space, by overcrowding of the population, unfavorable weather conditions, or other circumstances which limit spawning opportunities and result in large numbers of mature eggs being retained and resorbed in the ovaries. Examination of ovaries from warmouths taken from Park Pond during the middle and last of June, 1949, revealed that only small percentages of mature eggs were present in these fish and that some of these eggs were being resorbed, indicating that not all the ova produced were actually discharged. It was found that the spawning period for warmouths was generally shorter in this water area than in other water areas under observation in Illinois.

Seasonal Development of Ova.—Development of warmouth ova through the seasons was observed in the fish collected from Park Pond, figs. 11 and 12. The development was followed by assigning the ova collected at various times to the size groups defined on page 35. The seasonal occurrence of eggs in these size groups was as follows:

1. From January to early April, ovaries contained only the smallest eggs (size group I, 0.15–0.30 mm. diameter).

2. During the second week in April, the ova began to increase in size; some ova were in group II.

3. By the middle of May, in some fish two-thirds of the eggs were of the smallest size, or size group I, and small numbers of eggs were in size groups II, III, IV, and V. In other fish only one-third of the eggs were in size group I, and group VI, as well as groups II, III, IV, and V, was

represented. In still other fish, there were relatively more eggs in groups V and VI than in groups II, III, and IV.

4. Toward the end of May, all of the size groups of ova were well represented, and some of the eggs appeared to be ripe.

5. By the end of the first 2 weeks of June, the ovaries of all the mature fish had discharged most of the largest eggs. Some of the fish appeared to be preparing for a final spawn; about one-fourth of their eggs were in size group V and only low percentages in groups II, III, and IV. Other fish appeared to have completed spawning, and their ovaries appeared to have begun reorganizing, as small eggs again comprised three-fourths of the ova present.

6. On completion of spawning in July or early August, ovaries contained many pulpy eggs that were undergoing rapid resorption; the only other eggs present were those of group I. The ovigerous lamellae were poorly organized, showing no recovery from the production and crowding of large volumes of mature eggs.

7. By mid-August, ovaries were fully reorganized; the well-arranged ovigerous lamellae contained many small ova which comprised a part of the egg-stock for the next season.

Prespawning Activities

Nest building and spawning activities of the centrarchids probably have been studied more thoroughly than the spawning behavior of any other family of fishes (Breder 1936 and others). Although the reproductive behavior of the warmouth is much like that of other sunfishes, it may differ in the location and construction of nests, recognition of sex, courtship, care of eggs and larvae, and spawning schedule.

Location and Construction of Nests.—Warmouths appear to exercise selection in their choice of nesting sites. Both available bottom materials and cover influence this selection. In Venard Lake, where nesting was easily observed, the following types of bottom were available: loose silt, silt containing sticks and leaves, rubble, rubble covered with a thin layer of silt, sand with loose silt, and clean sand. No nests were found on clean sand (such as is often selected by bluegills and pumpkinseeds), and the only nests seen on loose

silt were closely associated with tree roots or mats of submerged plants. Even though the Venard Lake warmouths used each of the bottom types (except sand) as nesting sites, they showed some preference for rubble lightly covered with silt and detritus.

The warmouths at Venard Lake were not so consistent in nesting on a particular kind of bottom as they were in selecting a spot near a stump, root, rock, clump of

vegetation, or some similar object. This habitual preference for a location adjacent to a stationary object may account for the lack of nests on the clean sand bottom in Venard Lake. Nests were never found on an area of bottom completely exposed, such as the bluegill usually selects. In laboratory aquariums, the locations most often used by warmouths for nesting were near the vertical drain pipes.

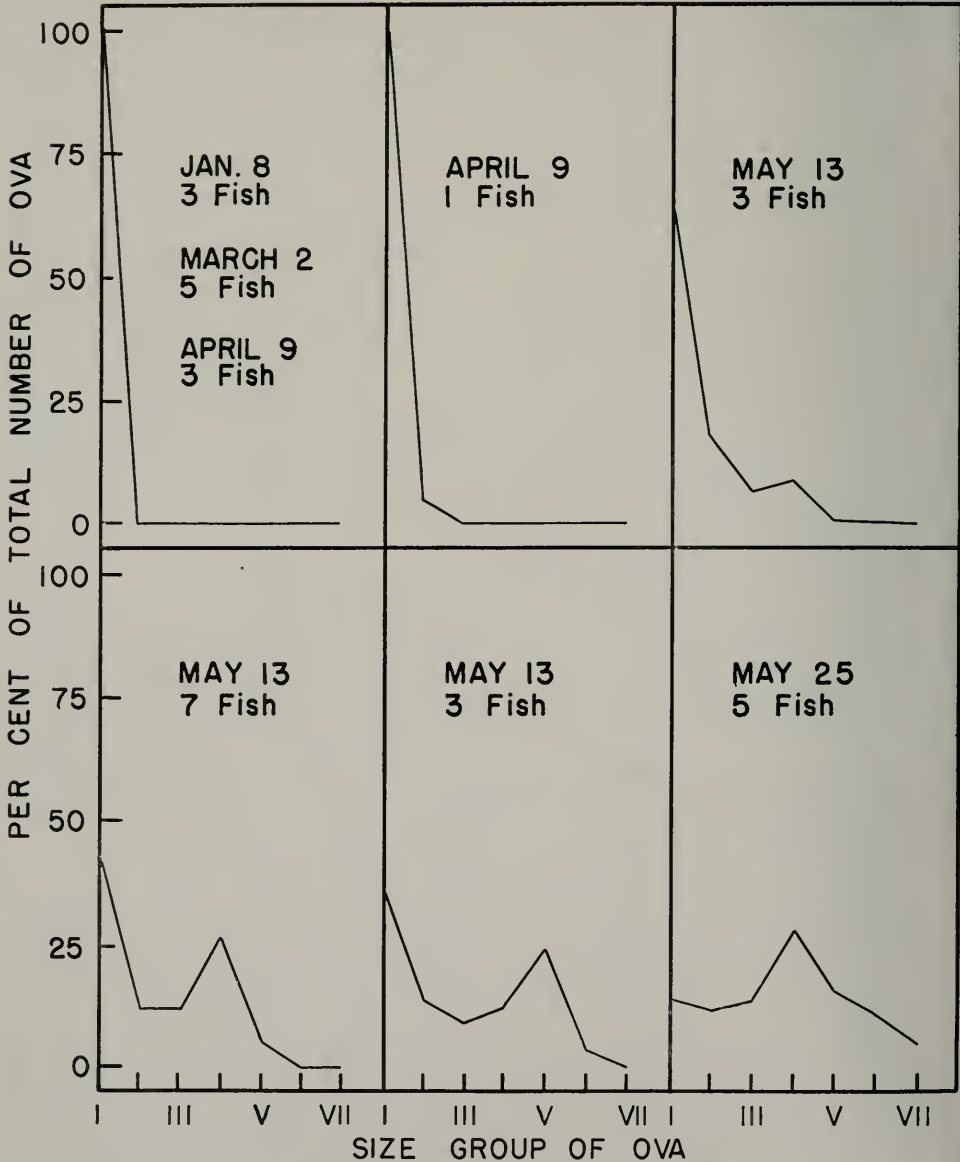


Fig. 11.—Percentage of total number of ova in each size group of ova found in warmouths collected from Park Pond and Venard Lake, January 8 to May 25, 1949.

In Park Pond, warmouths nested among weed masses, stumps, roots, and brush; they nested in areas where the water was less than 4 feet deep and were most frequently seen where the shale and rubble spread out at the ends of the old spoil banks or had filled in the back portions of the flooded strip channels. They were not seen nesting where the banks were steep and sloped off quickly into deep water.

Warmouths build nests within a wide range of water depths, and consequently nest locations vary in their distances from shore. Earlier observers of warmouths recorded a variety of water depths selected: 6 to 10 inches (Richardson 1913:412); mostly 2 to 10 inches (Carr 1940:109); 3 feet (Hubbs 1919:144); 2 or 3 feet (Toole 1946:33). In Venard Lake, the depths of water over warmouth nests that

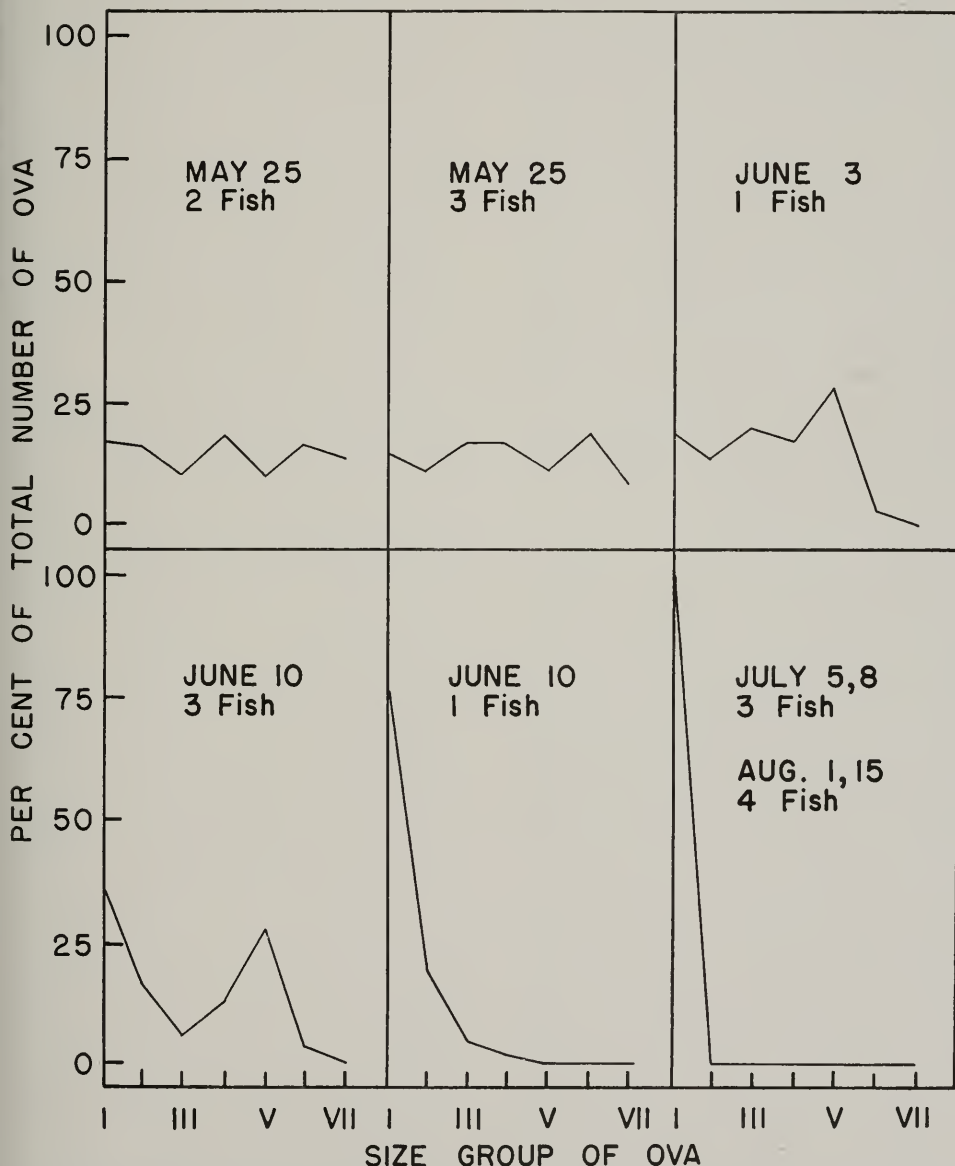


Fig. 12.—Percentage of total number of ova in each size group of ova found in warmouths collected from Park Pond and Venard Lake, May 25 to August 15, 1949.

were found ranged from 6 to 60 inches. Most of the nests were covered with 2 to 2.5 feet of water; nests in deeper water were more difficult to locate and may have been more common than counts showed. The limited areas of shallow water or the high transparency of the water in Venard Lake might account for the comparatively great depths at which nests were found in this body of water.

Reports of some observers indicate that the warmouth is gregarious in its nesting habits, forming colonies of nests (Richardson 1913:412; Carr 1940:110). It seems probable, however, that colony formation is a result of restricted nesting habitat. Observations of Carr (1940:109) in Florida and of the author in Illinois support the assumption that the reason warmouth nests are sometimes found close to each other is that the fish are tolerant of each other rather than gregarious in their habits. The warmouth colony studied by Carr was formed on what may have been the only bottom of suitable depth not covered with ooze. In Venard Lake, in May and June, 1947, nests were scattered in shallow water along the shore line with no indication of colonization. Three nests within a linear distance of 4 yards were the only ones that were found very close together.

Nest construction by warmouths in laboratory aquariums was observed many times in the course of the study reported here. As in other sunfishes, the male excavates the nest. Violent sweeping motions of the tail clear the loose debris away from the selected spot and produce a shallow, irregular concavity. The male begins each sweeping movement by approaching the nesting spot with his nose low and close to the bottom. As he enters the nest site, he turns abruptly upward, giving three or four violent sweeps with his tail while balancing in an almost vertical position and checking his forward motion with his pectoral fins. The loose material in the nest area is stirred up, and much of it settles outside the spot being cleared. The size and neatness of the nest depend to some extent on the amount of time the male spends in its construction. Many nests in natural waters are rather shapeless oval depressions of 4 by 8 inches from which loose silt has been cleared. The male may con-

tinue to improve the nest if a female is not immediately available for spawning. One warmouth male nesting in an aquarium worked on his nest until it was a beautifully symmetrical depression 18 inches in diameter and 5 inches deep. Though most warmouth males under natural conditions spend no more than a few hours in clearing small nesting spots, the male in the aquarium spent a week working on his nest while waiting for the female that was present to become ripe.

A mature female warmouth isolated in an aquarium during the breeding season constructed a shallow nest; her attachment to the nest was much weaker than that characteristic for a male.

Preliminary Courtship.—The preliminary courtship phase of warmouth nesting was observed by the author only in laboratory aquariums. Normally it appeared as an aggressive threat to other males, serving to drive them away, and as a persuasive gesture to females in spawning condition.

During the first week in May, 1947, three unripe warmouths were placed in each of four aquariums previously filled with water and supplied with a layer of sand and gravel. By the second day, some of these fish had selected favorite corners and were accepting food. Two of the three fish in each tank soon began constructing nests and making advances at the third fish. On the basis of behavior, only the nest-building warmouths appeared to be males; the third fish in each of the tanks showed no interest in nesting and apparently was being courted by the aggressive males. Courtship in each tank progressed to the act of driving the nonnest-building warmouth into the nest depression and going through motions of spawning. Vivid spawning colors (discussed in the following section) were displayed by only the aggressive males; no color changes were shown by the fish that were being courted. After these courtship activities had continued for several days, the fish were examined. Several had become ripe since being put in the aquariums and were flowing milt. Dissection of the nonaggressive, nonnest-building fish revealed that they, too, were males, although not in advanced stages of development, as were the aggressive males.

These initial observations of spawning suggest that (1) warmouth males begin construction of the nests in the absence of females and well before their testes are ripe; (2) sex recognition among warmouths is based on behavior and response to courting; and (3) in a small group of warmouths, during the breeding season some individuals assume dominance over less aggressive fish.

When a female that is not yet ready to spawn is placed in a tank with a nesting male, she is charged, nipped, and driven to the surface. She remains quiet and retiring, ignoring as much as possible the male's advances. Being unable to escape the male in an aquarium, she may finally be killed by his continued aggression. Under natural conditions, the female does not become exposed to the unavoidable advances of the nesting male before she is ready to spawn.

Spawning

In the warmouth, the mating act, which includes the deposition and fertilization of eggs, requires the simultaneous ripening of sex products and synchronization of behavioral attitudes in a male and female. Many environmental conditions, as well as the state of maturity of the fish, affect the spawning process.

Size and Age at Sexual Maturity.

—The attainment of sexual maturity in fishes is influenced by both age and size. In the warmouth, size seems to be more important than age in determining when a fish attains maturity. However, there is considerable variation among warmouths in the size (and age) at which maturity is reached. As might be expected, this variation is greater between fish of different populations than among fish within a single population.

Sexual maturity is attained by warmouths when the fish are between 3 and 4 inches in length. In Venard Lake, both males and females matured at 1 year of age and at lengths between 3.1 and 3.4 inches. In Park Pond, warmouths did not mature until they were 2 years old and at least 3.5 inches in length. Thus, at the time the fish became sexually mature in Park Pond, they were somewhat larger than the sexually mature 1-year-old fish in

Venard Lake. Hile (1941:319) found for the rock bass that rapid growth appears to be correlated with an early attainment of sexual maturity.

Nesting Season.—The observed nesting season for the warmouth in central Illinois begins during the second week in May, reaches its peak early in June, starts to decline after the first of July, but often extends well into August. The length of the nesting season differs among different populations of warmouths in different lakes and probably varies considerably from year to year. The length of the season varies also with the size of the fish; large warmouths spawn over a longer period than do small ones, fig. 8.

Although the exact length of the spawning season is difficult to determine for an individual fish, studies of gonads have shown that a fish may spawn several times during a summer. In Texas, Toole (1946:33) reported, "One pair of these fish was observed to spawn three different times during one year from April to October." At the Natural History Survey laboratory, two females that spawned early in June, 1948, were examined 2 weeks later and were found to have well-developed ova. These fish were not spent after the one spawning period and would undoubtedly have produced more ripe eggs during the same season. Warmouths that were collected in July, 1948, and that presumably had spawned at least once, were placed in a small pond on the following August 10; they produced a good brood of young in the pond that season.

Deposition and Fertilization of Eggs.—Only when a female is ready to lay her eggs will she allow a male to guide her to the nest for spawning. In getting the female to the nest, the male assumes a very aggressive attitude, approaching her with his opercles widely spread and his mouth open. The body of such a courting male becomes bright yellow in color and his eyes become blood red. The adjustment to these colors is very rapid, requiring only 5 to 10 seconds. If the female is ready to spawn, she is easily directed toward the nest, and spawning soon follows.

The number of females contributing to the complement of eggs in a nest may depend upon how many females are ripe and available to the male. It is probably not

uncommon for more than one female to spawn in a single nest, as has been observed for other centrarchids. That such polygamy seldom occurs after the male assumes close guardianship of the eggs is indicated by the fact that freshly laid eggs are not commonly found in nests containing eggs in advanced stages of development. In a laboratory aquarium, however, a male guarding yolk-sac fry brought a female to the nest and proceeded with spawning activities.

One female observed in a large aquarium in which two males had nests only 10 inches apart alternated between the two nests during a continuous spawning sequence. During an hour of spawning activity, the female spawned with both males. When she was in one nest, the male in the other nest showed no concern for her; he would inspect the newly deposited eggs, stir the nest with his tail, and wait for the female to again approach his nest. The female spawned almost continuously for 40 minutes and for another 20 minutes at brief intervals and less vigorously. When spawning was finished, the female was temporarily removed from the

aquarium; gentle pressure on the sides of this female did not cause the discharge of any eggs.

On entering the nest site, both male and female begin to circle, the female being nearer the center of the nest, slightly on her side and somewhat beneath the male, fig. 13. As they circle inside the nest, the female works her jaws three or four times and suddenly jerks her body violently, giving the male a sharp thump on the side. Each time the female jerks, she extrudes about 20 eggs. The thump she gives the male probably stimulates a discharge of sperm, although no milt was ever seen coming from the genital pore. After circling the nest several times, the female interrupts the activities and leaves the nest site. The male usually follows her a short distance but returns quickly to the nest to assume guardianship. At this point in the spawning activity, males often have been observed to fan the nest with sweeping motions of the tail in a manner similar to that exhibited when nest building.

Spawning activities like those observed in aquariums were carefully watched in Venard Lake. In nature, when a female



Fig. 13.—Warmouths spawning in an aquarium. The light-colored fish is the male; the darker fish below and slightly on her side is the female.

is ready to spawn, she makes her appearance near a nest and accepts the advances of the male. After a few spawning turns inside the nest, she retires, usually to a clump of weeds several yards away. The male remains over the nest for a few minutes before again making advances toward the female. This procedure is repeated until the female has discharged her ripe eggs. With spawning completed, the female swims away, and the male settles down quietly to protect and fan the eggs.

History of Embryos and Larvae

When the warmouth starts its life and development, it is confronted by greater stresses of physical and biological factors than it will face at any other time during its life. Temperature changes or temperature extremes, disease and predation, and dependence on the constant protection of a parent fish, which may at the same time be exposed to many dangers, result in high losses in the period of early development of the warmouth.

Development of Embryos.—Four groups of warmouth eggs, 10 in each group, were artificially inseminated in order to observe the gross development of the embryos and the exact length of the incubation period. The following account includes the time sequence of certain easily discerned stages of development at temperatures between 25.0 and 26.4 degrees C. Within this temperature range, the average developmental period of the 40 eggs was 34 hours and 30 minutes and the interval between hatching of the first egg and hatching of the last was 2 hours and 40 minutes.

When eggs and sperm were mixed in a petri dish and then immediately flooded with water, a high percentage of the eggs became fertilized. The inseminated eggs measured 0.95 to 1.03 mm. in their greatest diameters during their first and second minutes in water. These measurements are slightly below those of the largest ova taken from preserved ovaries. Differences in size measurements between preserved and live ova may have been due to differences in shapes: irregular shapes of the ova preserved intact in the ovaries and almost spherical forms of the live ova in water. Each of the live eggs, translucent and light

amber in color, contained a single, dark amber oil droplet 0.35 mm. in diameter.

Within 3 minutes after an egg was impregnated by a sperm cell, a thin perivitelline space could be seen between the outer membrane (chorion) and the egg cell proper. Thirty minutes later, a blastodisc was evident as a slightly raised cap, giving the egg a somewhat oval appearance. The first division of the blastodisc occurred 43 minutes after impregnation. Each blastomere then measured 0.4 mm. across. The second, third, and fourth divisions took place at 60, 75, and 90 minutes, respectively. The resulting group of blastomeres appeared whitish, the yolk was very pale yellow, and the oil droplet remained dark amber in color.

After 2 hours and 15 minutes, the blastomeres formed an oval-shaped mass at one end of the yolk. The segmentation cavity was formed beneath this mass, and at 2 hours and 30 minutes the blastoderm began growing down over the yolk mass.

The blastoderm had grown over two-thirds of the yolk mass within about 11 hours after impregnation, and a thickened band of cells at the margin of the blastoderm had appeared as the germ ring. About an hour later (12 hours and 15 minutes after impregnation), the blastoderm covered all but a small plug of yolk, which contained the oil droplet. The first differentiation among the dividing cells was visible in the live egg after 14 hours and 15 minutes. A groove extended around the egg from a patch of opaque cells near where the yolk plug and oil droplet entered the blastoderm. This groove, formed by the neural plate and neural folds, became quite distinct during the following hour (15 hours and 10 minutes after impregnation).

After 16 hours and 30 minutes, the primordial form of the embryo was defined. The ensuing process of organ formation, however, could not be discerned. Movement of the embryo was first observed 25 hours after impregnation.

The first egg hatched 33 hours and 20 minutes after impregnation. All eggs had hatched by the end of the following 2 hours and 40 minutes (36 hours after impregnation). Fry emerging from the eggs early during the hatching period were smaller (2.30–2.60 mm. in total length)



Fig. 14.—Warmouths from hatching through postlarval stage: *A*, prolarva, 3.4 mm., soon after hatching; *B*, prolarva, 4.6 mm., 48 hours old; *C*, postlarva, 5.3 mm., 4 days old; *D*, postlarva, 7.6 mm.; *E*, postlarva, 8.8 mm.; *F*, postlarva, 12.0 mm.

than those emerging later (2.65–2.85 mm. in total length). The oil droplet in the newly hatched fish was the same size (0.35 mm. in diameter) and color as it was in the newly fertilized egg. The greatest depth of the fry was 0.80 mm. across the yolk sac.

It is interesting to note here that warmouth eggs fertilized with sperm from a green sunfish showed no difference in rate of development from the rate described above. There was a high percentage of survival of both embryos and fry of the warmouth and green sunfish cross.

Development and Growth of Larvae.—Specimens for a study of growth of larvae were collected from a nest in a laboratory aquarium. The eggs were laid during the morning of June 24, 1947. Daily collections were made until the postlarvae left the nest. Then the free-swimming larvae were transferred to an outdoor tank, where observation and sampling were continued. The specimens, preserved in alcohol, served as materials for the following descriptions of developmental stages. Observations indicated that total length of a larva is a better indicator of the stage of its development than is actual age, which was known for each specimen. Measurements made with an ocular micrometer to the nearest 0.01 mm. were used in the description of body form. In general, descriptions follow the procedure used by Fish (1932); terms for growth stages are those suggested by Hubbs (1943:260).

Prolarva, 3.4 mm., soon after hatching, fig. 14A: Total length 3.4 mm.; length to anus 1.7 mm.; length of yolk sac 1.0 mm. Large oval yolk mass containing one oil droplet 0.3 mm. in diameter. Head deflected sharply downward in front of yolk sac, making the midbrain the most forward part of the body and the forebrain lying directly beneath it. Head from front of forebrain to end of hindbrain 0.65 mm. Optic capsule faint, 0.23 mm. in diameter. Notochord straight. Myomeres incomplete anteriorly, numbering about 8 in front of anus and 17 behind anus. Embryonic marginal fin fold complete except for faint break where intestine penetrates fin to outside. Fin extending forward on back to point 1.0 mm. from front of body. No visible ray development nor pigmentation.

Prolarva, 4.6 mm., 48 hours old, fig. 14B: Total length 4.6 mm.; length to

vent 2.0 mm.; length of head 0.63 mm.; greatest depth of body in front of vent 0.70 mm.; greatest depth of body behind vent (excluding fin fold) 0.35 mm. Forebrain still somewhat deflected, with globular cerebellum extending high above anterior part of medulla. Eyes well pigmented, each 0.35 mm. in diameter; optic fissure still quite apparent. Mouth indistinct. Fin fold extending forward on back to point 1.2 mm. from front of body, entire except for break at anus. Very weak indications of fin rays below and above end of straight notochord, giving effect of diphycercal tail. Pectoral lobes present. Myomeres indistinct forward, about 10 to anus, 19 caudad from anus. Branchial elements forming.

Postlarva, 5.3 mm., 4 days old, fig. 14C: Total length 5.3 mm.; length to anus 2.2 mm.; greatest depth of body anterior to anus 0.6 mm.; greatest depth of body posterior to anus 0.35 mm.; diameter of eye 0.41 mm.; length of head 0.90 mm. Cranial flexures almost straightened, but cerebellum high and bulblike. Optic cavity distinct. Fin fold beginning on back 1.5 mm. from front of body, becoming slightly narrow on caudal peduncle but wide again at tail. Faint indication of rays forming in areas of the anal and soft dorsal fins. Distinct fin rays on either side at end of the straight notochord. Kidney apparent through body wall. Pectoral fin lobes well developed but with no rays. Myomeres 10 anterior to anus, 19 posterior to anus. Branchial arches well formed and with developing gills. Mouth gape extending obliquely forward from point below middle of eye. Dark row of spots on either side of ventral fin fold; two large chromatophores between bases of pectoral fins.

Postlarva, 7.6 mm., fig. 14D: Total length 7.6 mm.; length to anus 3.4 mm.; length of head 1.5 mm.; diameter of eye 0.55 mm.; greatest depth of body anterior to anus 1.15 mm.; greatest depth of body posterior to anus 0.65 mm. Myomeres 11 before anus, 19 behind anus. Fin fold still complete except for break at anus; high at soft dorsal fin region, quite low above and below caudal peduncle. End of notochord bent upward at 40-degree angle, giving appearance of heterocercal tail. Caudal fin rays well developed on lower side of notochord, with middle rays longest. Rays weak but distinct in unformed anal fin;

rays very weak in soft dorsal. Rays visible in pectoral fins. Mouth only moderately oblique. Pigmentation much more developed. Row of spots along ventral fin fold spreading as stellate chromatophores over ventral surface of body. Series of dark dashes indicating lateral line. Heavy chromatophore lying above anus. Some color apparent at base of caudal fin rays. Six stellate chromatophores between bases of pectoral fins and a row of five chromatophores on each side across branchiostegals. Distinct, dark chromatophores scattered over top of head.

Postlarva, 8.8 mm., fig. 14E: Total length 8.8 mm.; length to anus 3.9 mm.; length of head 2.0 mm.; length of snout 0.4 mm.; diameter of eye 0.75 mm.; depth of caudal peduncle 0.65 mm. Caudal peduncle long and narrow. Notochord with upturned end but tail appearing essentially homocercal. Fin fold present immediately anterior to anus. Anal and soft dorsal fins separate from caudal fin but each broad at base, due to some remaining parts of the embryonic marginal fin fold. Rays distinct in all fins present. Pelvic fins not developed. Otic region large and clear. Anus protruding from ventral line of body. Lateral line chromatophores quite distinct. Ventral spots larger, with more chromatophores scattered over head region.

Postlarva, 12.0 mm., fig. 14F: Total length 12.0 mm.; length to anus 5.4 mm.; length of head 2.8 mm.; diameter of eye 1.0 mm.; length of snout 0.7 mm.; greatest depth of body 2.45 mm.; length of caudal peduncle 2.4 mm.; depth of caudal peduncle 1.15 mm. Fin fold remaining only as short keel in front of anus. Pelvic fins present but weak and with indistinct rays. Spinous dorsal developed only as a row of short stubs. Distribution of pigment about the same as in 8.8 mm. stage, except spots appearing more distinct. More dark chromatophores around mouth; a vertical row present at base of caudal rays.

Juvenile, 15.7 mm. (not photographed). Body form essentially like that of adult fish. Total length 15.7 mm.; length to anus 7.0 mm.; length of head 4.35 mm.; diameter of eye 1.4 mm.; length of snout 0.85 mm.; greatest depth of body (at about anterior insertion of spinous dorsal) 3.7 mm.; length of caudal peduncle 2.9 mm., depth 1.5 mm. Anus protruding only

slightly from abdomen. No trace of embryonic marginal fin fold. Pelvic and spinous dorsal fins well formed. Pigmentation much heavier than in earlier stages. More color apparent over head and caudal peduncle. Belly rather free of pigment. Many large chromatophores scattered over back. Heavy row of spots forming circle behind eye and distributed over top of head. Chromatophores noticeable on soft dorsal, anal, and caudal fins.

Behavior of Larvae.—Activities of the warmouth larvae during their early life in the nest were limited to a few feeble movements. There was definite sequence, however, in the behavioral development of these small fish. The following description of behavior was based on laboratory observations in aquariums with water of 24–25 degrees C. (75–77 degrees F.).

Immediately upon hatching, the delicate prolarvae dropped down onto the sand and silt between coarse gravel particles of the nest. As the heavy yolk sac restricted movement, the prolarvae were difficult to see in the nest. When the prolarvae were between 36 and 48 hours old, fig. 14B, they began making feeble jumps an inch or so above the bottom of the nest. Most of these prolarvae were between gravel particles in the nest, but a few could be seen resting on the flat surfaces of the largest particles.

Although the yolk supply was about exhausted by the fourth day, the young fish still limited their movements to poorly directed jumps above the nest. They did not begin active swimming until the end of the fifth day, when they appeared as in fig. 14D. At this time, they swam about the nest in rather compact groups. Their movements were well controlled, and they showed remarkable ability to avoid a dip net. In the aquariums, these small fish had no food supply and starved in 10 or 11 days after hatching, but in outdoor tanks they began feeding at least by the seventh day after hatching.

School formation among postlarval warmouths in natural habitats was not so obvious as in postlarvae of certain other sunfishes, for the warmouths remained either among dense submerged vegetation or else in small pockets of open water closely surrounded by plants. The individual shown in fig. 14F was taken from a

school near the nest in which it had hatched. The schools gradually dissolved as individuals began independent searches for food. No juvenile warmouths were observed in large groups.

Factors Affecting Survival.—Rate of survival of warmouth eggs and young is influenced greatly by many physical and biological factors. Incubating eggs are readily affected by adverse weather conditions. Sudden drops in water temperatures promote the rapid growth of fungi infecting the eggs; often, entire nests of eggs are destroyed early in the spawning season as a result of low temperatures and fungi. For example, many warmouth nests in Venard Lake contained eggs during the last week in May, 1947, but, after several days of cold weather, the eggs in every nest observed were covered with fungi. Although heavy rains and high turbidity were not seen to affect nesting of adults or survival of fry, rapidly falling water levels might disturb nesting:

In several Illinois lakes, minnows and sunfishes were observed destroying eggs and larvae in unprotected warmouth nests. In laboratory aquariums, warmouths were seen to rob poorly guarded nests; they charged in to snap up eggs or larvae.

Postlarval and juvenile warmouths which have left the nest are eaten in great numbers by larger fish. Venard Lake supported a heavy spawn of both largemouth bass and warmouths in the summer of 1947. On June 30 of that year, bass 1.75 inches long were voraciously feeding upon warmouths 0.75 inch long, which had been eating large numbers of postlarval warmouths. In the laboratory, a 0.75-inch warmouth ate 11 postlarvae (4 days old) in 5 minutes; another ate 12 in the same length of time.

Survival of small warmouths is closely related to the density and composition of the fish population, the time of year, and the character of the habitat in which they are produced. Fry hatched late in the spawning season are in a population with a larger number of potential predators (fish only slightly larger than themselves) than are the fry produced earlier. However, because the density of aquatic vegetation increases during June and July, survival in the late summer broods is frequently higher than in early broods.

GROWTH

Whether one is studying a single species of fish or the entire fish population of a body of water, it may become necessary to consider the growth of individuals in the one or more species involved. An analysis of growth is not always the objective of such a study, nor is determination of the morphological relationships which must be known before an analysis of growth can be made. The ultimate value of a growth study may come from its use in determining the factors that govern or influence growth of fish under particular conditions.

Relative Growth

Various parts of a fish's body grow at differential rather than uniform rates. The differential rates are not necessarily the same even for closely related species in the same habitat, nor for fish of the same species in different habitats. Consequently, when making a growth analysis of a selected species in a given habitat, one must determine several morphological relationships, namely, those of body growth to scale growth, body growth to growth of tail fin, and growth in length to growth in weight. Lewis & English (1949) and Hennemuth (1955) have plotted some of these relationships for two populations of Iowa warmouths, and Jenkins, Elkin, & Finnell (1955) for several populations of Oklahoma warmouths.

Relation of Body Growth to Scale Growth.—A regression line to show the relationship between length of anterior radii of scales and length of body was constructed from measurements of 1,068 warmouths from Venard Lake and Park Pond, fig. 15. Data were obtained from collections made approximately monthly beginning in June, 1948, and ending in November, 1949. Regression lines constructed for warmouths from Venard Lake and for those from Park Pond proved to be so similar that data from the two lakes were combined.

Key or representative scales were taken from the side of each of the fish near a point where the tip of the pectoral fin laid backward touched the third row of scales below the lateral line. Fish were separated into total length classes at 0.5-inch

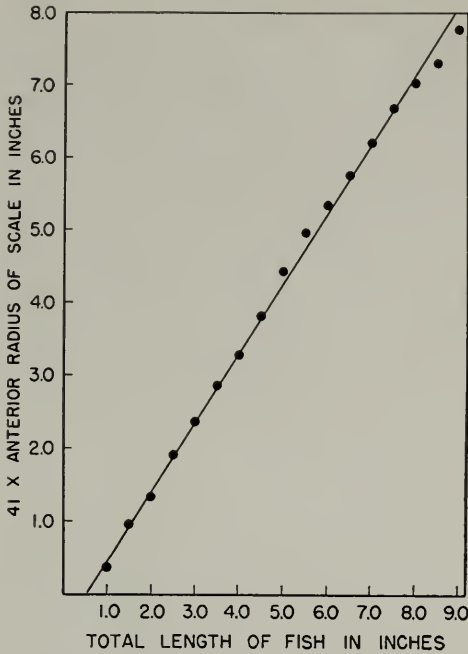


Fig. 15.—Regression line expressing the relationship between total length of fish and radius of scale for 1,068 warmouths collected from Park Pond and Venard Lake, early June, 1948, through middle November, 1949. The dots show the anterior radius of scale $\times 41$ for fish of various total lengths (one-half-inch intervals).

intervals, and the average of the total lengths for the fish in each of these classes was determined. Scales of these fish were placed in a scale-reading machine that magnified 41 times, and images of the anterior radii of the scales were measured and averaged for the fish in each length class. Average total lengths of fish and corresponding average anterior radii of selected scales were used in developing

the regression line shown in fig. 15 and the following equation:

$$L = 0.5278 + 1.048 S$$

where L = total length of fish in inches
and $S = 41 \times$ anterior radius of scale in inches

Relation of Body Growth to Tail Growth.—Growth of the body of a fish in relation to growth of its tail, or caudal fin, may be ascertained by comparing the standard length of the fish with its total length. As defined by Hubbs & Lagler (1947:13), total length includes the caudal fin, whereas standard length does not.

The relationship between growth of body to growth of tail was calculated from measurements of 264 warmouths taken from Park Pond, summer, 1948, and November, 1949, and Venard Lake, October, 1949. As the average body length of the warmouths increased, the average tail length became relatively less, table 17. In fish less than 4.0 inches total length, the average total length was 1.259 times the average standard length; in fish of 4.0 to 6.9 inches, the average total length was 1.240 times the average standard length; and, in fish longer than 6.9 inches, the average total length was 1.211 times the average standard length.

Relation of Growth in Length to Growth in Weight.—The relationship between growth in length and growth in weight was calculated from data on 866 warmouths collected from Park Pond between early June, 1948, and early November, 1949. Size groups were established at 0.1-inch intervals. Average weights were determined for each group within the size range beginning with 3.3 and ending with 8.2 inches total length. The length-weight relationship for each of

Table 17.—Factors derived from measurements of warmouths from Venard Lake, October, 1949, and Park Pond, summer, 1948, and November, 1949, for converting standard length (S.L.) to total length (T.L.), and the reverse, with the same and with different units of measurement.

TOTAL LENGTH, INCHES	NUMBER OF FISH	CONVERSION FACTORS			
		T.L. to S.L. (Same Units)	S.L. to T.L. (Same Units)	S.L. (Mm.) to T.L. (Inches)	T.L. (Inches) to S.L. (Mm.)
Under 4.0	130	0.795	1.259	0.0495	20.18
4.0-6.9	93	0.806	1.240	0.0488	20.48
Over 6.9	41	0.826	1.211	0.0477	20.98
Combined	264	0.809	1.240	0.0487	20.52

the specimens (866) was expressed by the equation:

$$\log W = -4.49867 + 3.04902 \log L$$

where W = weight in grams
and L = standard length in millimeters

Length-weight relationships were calculated for the especially heavy and especially light warmouths in the Park Pond population. For warmouths heavier than average, the equation was as follows:

$$\log W = -4.36191 + 3.01387 \log L$$

For those lighter than average, the equation was as follows:

$$\log W = -4.35603 + 2.95352 \log L$$

From these equations, it may be seen that fish either heavier in relation to length, or lighter in relation to length, than the average bore a systematic relationship of length to weight roughly paralleling that of the average. Such divergence from the average as was discernible was found particularly among the fish of greater lengths and weights, fig. 16.

Coefficient of Condition

The coefficient of condition (C), based on total length in inches and weight in pounds, was computed for the 866 Park Pond warmouths used in the analysis of length-weight relationships. Fish smaller than 3.3 inches total length were not considered because individuals were weighed only to the nearest 0.01 pound, and greater weighing preciseness would have been necessary if smaller fish had been used; warmouths of more than 8.2 inches total length were not used because few were available.

Condition (C) increased progressively with increased size of fish. The average C (weighted to compensate for differences in numbers of individuals in groups) for each of several size groups, 3.3–4.2, 4.3–5.2, 5.3–6.2, 6.3–7.2, and 7.3–8.2 inches total length, was 72.6, 74.8, 78.6, 80.9, and 82.6, respectively. Warmouths within the size range 3.3–4.2 inches total length showed a wide seasonal variation in condition (C). This variation among small warmouths may have been caused by their dependence upon food items that fluctuated widely in abundance from month to month, such as cladocerans and certain insects and their larvae. Larger warmouths,

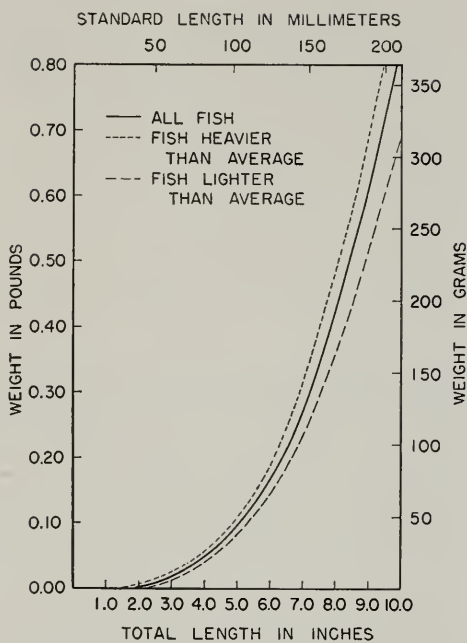


Fig. 16.—Curves illustrating the relationship between length and weight of warmouths collected from Park Pond, early June, 1948, through middle November, 1949.

feeding more upon crayfish and fish, varied less in body condition from one season to the next than did small warmouths.

The condition (C) of warmouths for each of three size groups, 4.3–5.2, 5.3–6.2, 6.3–7.2 inches total length, was similar in seasonal fluctuations. A sudden, severe drop in condition occurred in September, 1948; a low level in condition lasted through October, and was followed by a rapid recovery by mid-November. Condition declined gradually during the winter and spring, but then began an increase that continued through May and June. Condition remained relatively high and constant throughout the summer of 1949 and then declined during the fall months. Fig. 17 suggests that for the warmouths of Park Pond a definite cycle of condition associated with seasons could not be established.

Since food habits were studied for these warmouths collected from early October, 1948, to early November, 1949, it was possible to associate the foods eaten with the seasonal variations in condition of the fish. The low level of condition in the winter (1948–49) was coincident with a comparatively low consumption of crayfish, dip-

teran larvae, amphipods, and mayfly nymphs and with a comparatively high consumption of fish and dragonfly nymphs, fig. 6. During the spring of 1949, when

the warmouths used in the present study are as follows:

1. There was a regular increase in the number of annuli accompanying an in-

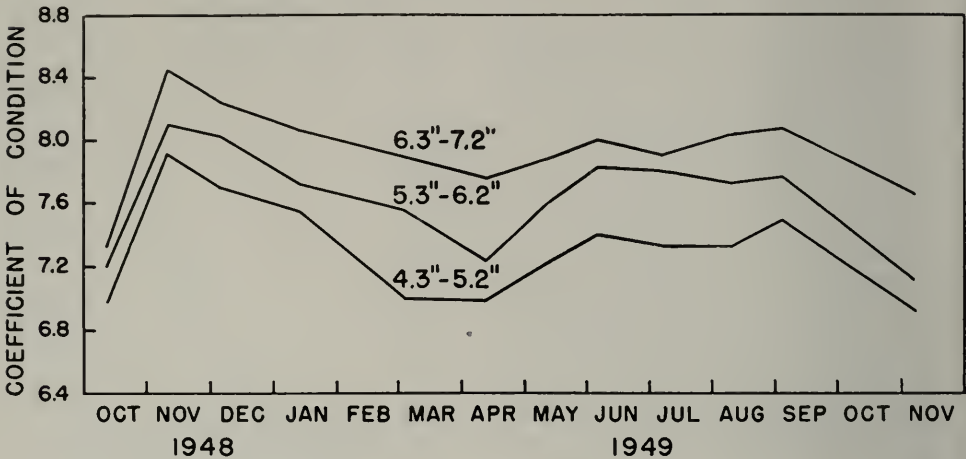


Fig. 17.—Coefficient of condition of 392 warmouths of three size groups (6.3–7.2 inches, 5.3–6.2 inches, 4.3–5.2 inches) collected from Park Pond, early October, 1948, through early November, 1949. Warmouths collected and weighed in the summer of 1948 were so few in number that data on them were not included in the graph.

the warmouths were eating high percentages of crayfish (volume) and damselfly nymphs (frequency), the condition of these fish was steadily improving. The relatively good condition of warmouths during the summer of 1949 was associated with the extensive use of mayfly nymphs, caddisfly larvae, and crayfish.

There were no consistent differences in condition between male and female warmouths in Park Pond.

Scale Method of Calculating Growth

The method of calculating warmouth growth from fish lengths and scale measurements is a composite of methods developed by several authors but generally follows the procedures suggested by Hile (1941).

Validity of the Annulus as a Year-Mark.—Age and growth studies made from the scales of warmouths in Venard Lake and Park Pond indicate that the annulus is a reliable year-mark in this species. Hile (1941:201–4) outlined the most important features of a valid annulus. Four points used to test the validity of the scale method of age determination for

crease in size of fish, and fish assigned to any single age group were within a certain length range, table 18.

2. Lengths calculated from scale measurements agreed reasonably well with actual lengths of fish of corresponding ages, tables 18 and 21.

3. Calculated lengths were similar for the same age groups of fish collected in different years and consistent for different age groups of fish collected in the same or different years. Because the calculated lengths were very similar for warmouths in the 1948 and 1949 Park Pond collections, data for these two collections were

Table 18.—Averages of total lengths of warmouths of various ages collected from Park Pond, June, 1949.

YEAR OF LIFE	NUMBER OF FISH	AVERAGE TOTAL LENGTH, INCHES	RANGE OF TOTAL LENGTH
2.....	17	2.31	1.9–2.8
3.....	35	3.53	2.8–4.6
4.....	90	5.20	3.6–7.1
5.....	114	6.62	5.4–8.2
6.....	31	7.66	6.0–8.7

combined and are not shown separately; however, consistency in calculated lengths of fish of the same and of different age groups is shown in tables 21 and 26.

4. There was similarity among warmouths of different year classes with respect to growth rates in certain calendar years, tables 23 and 24.

Characteristics of the Annulus.—

The true annulus on the warmouth scale appears as a result of resumption of growth of body and scales after the cessa-

tion of growth during winter months. True annuli or year-marks usually show several rather definite characteristics, fig. 18. Across the anterior field of the scale the annulus appears as a break in the arrangement of circuli; it is bordered on the inside by closely spaced, incomplete circuli and on the outside by complete, widely spaced circuli. The radii in the anterior field are slightly distorted in the region of the annulus. On the lateral fields of the scale, the annulus and newly formed circuli

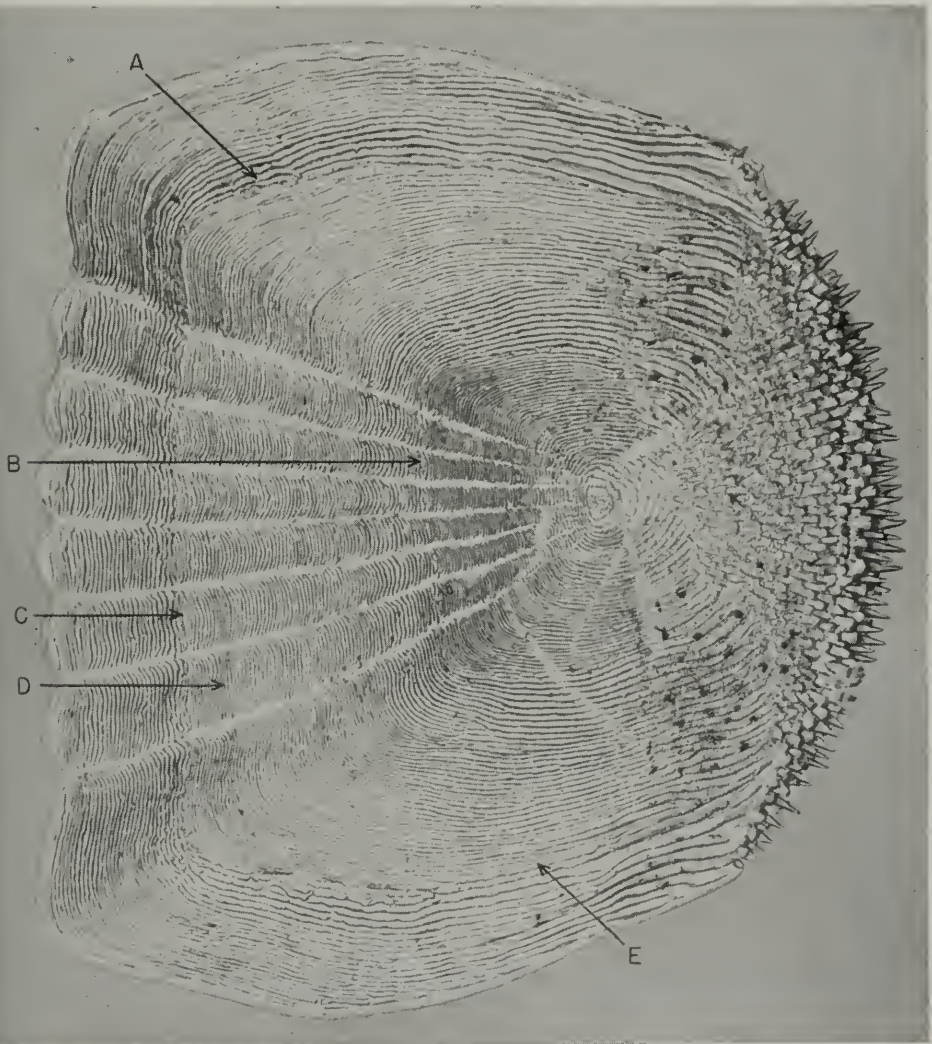


Fig. 18.—Warmouth scale: *A*, wide spacing of circuli especially evident following resumption of growth in spring; *B*, first annulus; *C*, second annulus; *D*, crowding of circuli during period of slow growth resulting from habitat disturbance; *E*, new circuli cutting across ends of circuli laid down in previous season.

"cut over" the circuli laid down near the end of the previous season. The annulus extends only part way across the posterior field of the scale. Slight differences in spacing of circuli and in the lengths of ctenii (small surface spines on scale) may aid in recognizing the location of the year-mark in the posterior field.

The first annulus formed on the warmouth scale does not show as much "cutting over" in the lateral fields as do later annuli, nor are the differences in spacing of circuli so apparent in the first as in later annuli. The differences which may exist in length and distribution of ctenii are most useful in recognizing the first annulus. Annuli formed later are generally more difficult to recognize with certainty, mainly because they are closer together than those earlier marks laid down when the fish was increasing rapidly in length.

Time of Annulus Completion.—

In 1949, the time of annulus completion in warmouths at Park Pond was determined from 129 specimens collected between April 7 and May 20. Sixty-eight per cent of the warmouths collected May 13 and 14 had laid down the year's annuli on their scales, so that the average time of annulus completion appeared to be about the first week of May, table 19, at which time the water temperature 1 foot below the surface of the water was about 70 degrees F., fig. 9. Small fish usually lay down the year-mark earlier in the spring than do the larger ones, because the former begin to grow at an earlier date. Fifteen per cent of 39 fish collected from Park Pond on April 7 and 9 showed new annuli on their scales; all but one of these fish were less than 4 inches total length.

As annulus formation is associated with the resumption of growth of the fish in spring, the annuli on the scales of fish may not be completed at the same time each year, and the time may vary from one population to another. Warmouths in Venard Lake showed a period of annulus formation in 1949 that differed from the period shown by the warmouths in Park Pond. In the fish collected from Park Pond, some year-marks appeared before April 7, but only 68 per cent of the fish in the May 13-14 collections had completed annulus formation; the period in which annuli were being completed covered more

than 6 weeks. In Venard Lake, on the other hand, none of the specimens collected on April 5 had formed an annulus; in the collection of May 12, about 5 weeks later, 30 of 31 fish (nearly 97 per cent) had completed annulus formation.

Ecological conditions in Venard Lake, where warmouths were confined to a small area having only minor fluctuations in

Table 19.—Percentages of warmouths with and without new annuli, Park Pond collections, 1949.

DATE OF COLLECTION	NUMBER OF FISH	PERCENTAGE LACKING NEW ANNULI	PERCENTAGE WITH NEW ANNULI
April 7-9.	39	85	15
May 13-14.	38	32	68
May 16.	40	20	80
May 20.	12	8	92

depth, probably were more nearly uniform than in Park Pond, where warmouths were found in shallow sloughs, deep channels, and open waters. It seems reasonable to believe that a population inhabiting a pond with a wide variety of physical conditions might show annulus formation over a longer period than a population exposed to more nearly uniform physical conditions. Furthermore, in Park Pond, fish of many other species were competing with warmouths for the natural foods available in early spring.

False Annuli.—Some scales of warmouths show false annuli, or marks which are not true year-marks but merely indications of physiological disturbances during growing seasons. False marks were found on the scales of many fish from Park Pond. Most of them could be recognized with confidence. They did not appear uniformly throughout a population or regularly at definite times of year.

False marks were formed on the scales of a large part of the warmouth population of Venard Lake during August of 1948. These marks could be distinguished, particularly in the 1947 year class, on the scales of fish collected in succeeding years. Since monthly collections allowed the false annuli to be originally dated and to be recognized by their location in relation to

true annuli on the scales in later collections, these marks gave little trouble in age determinations. The formation of the marks coincided with a 4-week period of shoreline dredging with a dragline. Such a severe disturbance of the habitat must have reduced the food supply or its availability and caused a temporary stoppage of growth that produced the false marks.

Growth in Park Pond

Park Pond, an 18-acre lake in a flooded stripmine area, in 1948 and 1949 supported an old (60 years at least), rather large fish population of about 36 species native to the region. Most of these species had been introduced into the lake from the Salt Fork in times of flood, page 4.

Collection and Preparation of Materials.—In the period beginning June 7, 1948, and ending November 12, 1949, 1,420 warmouths were collected from Park Pond. Hoop nets, fig. 19, were used in collecting 367 warmouths; of these fish, 298 were collected between early June and mid-September, 1948, and 69 between

June 27 and July 5, 1949. An electric shocker rigged for operation from a rowboat (Larimore, Durham, & Bennett 1950) was used to collect specimens for growth analyses and food studies. A total of 788 fish were taken by this method in collections made at monthly intervals from early October, 1948, to early November, 1949, except that no collections were made in February and October, 1949. Even though Park Pond supported the largest naturally established warmouth population that had then been examined in Illinois, warmouths were never taken there in great numbers; a good day's take might consist of 2 dozen warmouths from the usual set of six hoop nets or 50 warmouths from the operation of the electric shocker. Large specimens predominated in the hoop net catches; fish of all sizes were present in collections made by shocking. On August 22, 1949, rotenone was applied to a shallow, isolated, 0.47-acre slough in Park Pond, and a census was made of the fish population. Scales for growth studies were taken from 265 of the 504 warmouths collected from this area.



Fig. 19.—Collecting fish with a hoop net in Park Pond.

Ages were determined for 1,328 of the 1,420 warmouths collected (265 from the shallow, isolated slough and 1,063 from other parts of Park Pond). Scales from 84 fish were regenerated and unreadable; scales of 8 other specimens were so difficult to read that ages could not be determined with certainty. Fish from the slough that was treated with rotenone were considered separately because they showed growth rates significantly different from those taken in the other collections. Impressions of the warmouth scales were made on cellulose acetate slides, and the images of these impressions were projected for study at a magnification of 41 diameters. Measurements along the median, anterior radius of a magnified scale image were marked on a manila paper strip, and the strip was used for calculating past growth on a nomograph, as described by Carlander & Smith (1944). Calculated lengths, based on a straight-line relation between scale length and body length, were corrected for an intercept of 0.53 inch in body length (fig. 15 and equation on page 50).

The following sections, "Growth Differences Between Sexes," "History of Successive Year Classes," "Fluctuations in Annual Growth," and "Seasonal Growth," refer to Park Pond warmouths other than those from the slough.

Growth Differences Between Sexes.—Sex was determined by dissection or by visible discharge of sex products for

600 specimens in year classes 1944 through 1948. Calculated lengths of males and females of each of the year classes were averaged and compared, table 20. Fish in both the 1943 and 1949 year classes were represented by so few specimens for which sex was determined that they were omitted from the calculations.

Very consistent, although rather small, differences existed between the growth rates of males and females. Males were larger than females at the end of each year of life in the five year classes considered. The greatest differences occurred in the 1944 year class, but the small number of specimens (only seven females) made this growth comparison less reliable than that for other year classes. The next oldest brood, the 1945 year class, was represented by 187 specimens. Males in this group averaged only a little longer than females. Schoffman (1940:32) observed that the lengths and weights of male and female warmouths of the same ages in Reelfoot Lake, Tennessee, were either the same or only slightly different.

Since the actual differences in lengths of male and female warmouths were rather small in those year classes represented by substantial numbers of specimens, data for the two sexes were not separated in the growth analyses discussed in the following paragraphs.

History of Successive Year Classes.—All the specimens were assigned to year

Table 20.—Average calculated total lengths in inches for male and female warmouths, representing five year classes, collected from Park Pond, October, 1948, through November, 1949.

YEAR CLASS	SEX	NUMBER OF FISH	AVERAGE CALCULATED TOTAL LENGTH IN INCHES AT END OF INDICATED YEAR OF LIFE				
			1	2	3	4	5
1944.	Male	15	1.64	3.51	5.39	6.68	7.32
	Female	7	1.46	3.01	4.72	5.73	6.35
1945.	Male	102	1.73	3.49	4.89	5.88	
	Female	85	1.62	3.34	4.68	5.85	
1946.	Male	84	1.56	2.85	4.21		
	Female	85	1.56	2.81	4.11		
1947.	Male	79	1.58	2.99			
	Female	71	1.48	2.61			
1948.	Male	33	1.62				
	Female	39	1.61				

Table 21.—Average calculated total lengths in inches for 1,063 warmouths, representing nine year classes, collected from Park Pond, June, 1948, through November, 1949.

YEAR CLASS	NUMBER OF FISH	AVERAGE CALCULATED TOTAL LENGTH IN INCHES AT END OF INDICATED YEAR OF LIFE*							
		1	2	3	4	5	6	7	8
1940.....	1	1.61	3.08	4.20	5.50	6.33	6.93	7.94	8.61
1941.....	6	1.58	2.86	4.39	5.75	6.89	7.91	8.58	8.54
1942.....	10	1.47	2.89	4.54	5.98	7.37	8.04	8.43	
1943.....	46	1.59	3.25	5.28	7.00	7.69	8.76		
1944.....	122	1.62	3.77	5.73	6.75	7.10			
1945.....	362	1.75	3.80	4.86	5.99				
1946.....	239	1.59	2.90	4.26					
1947.....	187	1.53	2.83						
1948.....	90	1.63							
<i>Weighted averages</i>		1.64	3.38	4.91	6.40	7.44	8.02	8.47	8.56

*Average for last year in each year class based on fish in which annulus for current year was present.

classes on the basis of number of true annuli on their scales. The length of each fish at the end of each year of life was calculated from its scale measurements. The calculated lengths for each year of life were then averaged for fish of each year class. In the length calculations for 1948 growth of fish collected in 1949, only those fish taken after annulus formation in May could be used. The calculated lengths for 1,063 warmouths, table 21, suggested the following conclusions:

1. Average calculated lengths for fish of the 1943, 1944, and 1945 year classes were greater in most years of life than the weighted averages for the fish of all year

classes (averages were weighted to compensate for differences in numbers of fish in the various groups); fish of both the 1944 and 1945 year classes showed less than the average length for the last complete growing season (1948) prior to capture.

2. Average calculated lengths for fish of the 1946 and 1947 year classes were less in most years of life than the weighted averages for the fish of all year classes.

3. Average calculated lengths exhibited no large growth rate differences for the same years of life among warmouths caught at different ages—no phenomenon of apparent change in growth rates as described by Lee (1912:9). (However,

Table 22.—Average calculated total lengths in inches for each year of life of 1,063 warmouths collected from Park Pond, June, 1948–November, 1949, with equivalent standard lengths in millimeters and weights in pounds and grams. Calculated annual increments in lengths and weights are based on these averages.

YEAR OF LIFE	TOTAL LENGTH, INCHES	STANDARD LENGTH, INCHES	WEIGHT, POUNDS	WEIGHT, GRAMS	ANNUAL CALCULATED INCREMENT OF TOTAL LENGTH, INCHES	ANNUAL CALCULATED INCREMENT OF WEIGHT, POUNDS
1.....	1.64	33	0.004	1.8	1.64	0.004
2.....	3.38	68	0.026	11.8	1.74	0.022
3.....	4.91	101	0.088	39.9	1.53	0.062
4.....	6.40	131	0.200	90.7	1.49	0.112
5.....	7.44	153	0.337	152.9	1.04	0.137
6.....	8.02	168	0.432	196.0	0.58	0.095
7.....	8.47	178	0.510	231.3	0.45	0.078
8.....	8.56	180	0.527	239.0	0.09	0.017

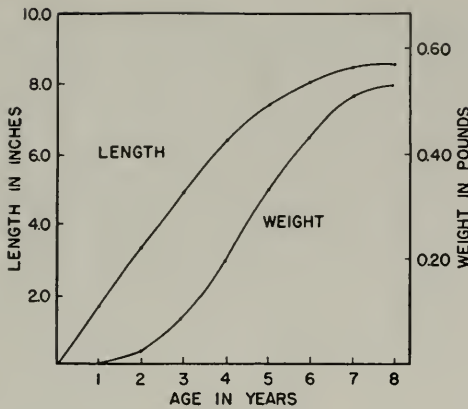


Fig. 20.—Averages of calculated total lengths and calculated weights at end of each year of life for 1,063 warmouths of various ages from Park Pond, early June, 1948, through middle November, 1949.

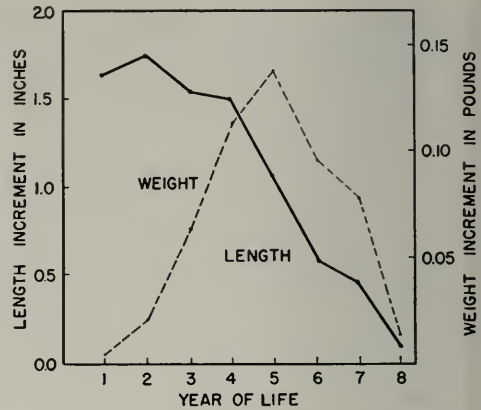


Fig. 21.—Averages of annual increments of calculated total lengths and calculated weights in each year of life for 1,063 warmouths from Park Pond, early June, 1948, through middle November, 1949.

Lee's phenomenon was evident in Venard Lake warmouths, figs. 23 and 24.)

Annual length increments based on calculated lengths were determined for each year of life of the 1,063 warmouths, table 22. These length increments were greatest for the second year of life and decreased thereafter; they declined rapidly after the fourth year and were very slight in the eighth year of life.

The pattern of weight increase was different from that of length increase. Average calculated weights in pounds, corresponding to average calculated lengths in inches (length-weight prediction equation, page 51), furnish evidence that in the warmouths studied the rate of weight increase was slow during the first 2 years,

reached a peak the fifth year, and declined rapidly in the following years, table 22. Fig. 20 shows the average lengths and weights; fig. 21 shows the increments of length and weight for each year of life.

Fluctuations in Annual Growth.—

There were calendar years of good and of poor growth for all year classes of warmouths at Park Pond. These years of good and of poor growth were evident even though warmouths in certain year classes were of consistently larger or smaller sizes than the average for all warmouths.

Using the average annual length increment for all warmouths in each year of life as a base, tables 21 and 22, one can calculate the percentage of the expected increment attained by each year class for

Table 23.—Average percentage of expected annual length increment attained in each year of life in eight separate year classes of 1,062 warmouths collected from Park Pond, June, 1948–November, 1949.

YEAR CLASS	NUMBER OF FISH	AVERAGE PERCENTAGE OF EXPECTED ANNUAL LENGTH INCREMENT ATTAINED IN INDICATED YEAR OF LIFE						
		1	2	3	4	5	6	7
1941.....	6	96	74	100	91	110	176	149
1942.....	10	90	82	108	97	134	116	
1943.....	46	97	95	133	115	66		
1944.....	122	99	124	128	68	34		
1945.....	362	107	118	69	76			
1946.....	239	97	75	88				
1947.....	187	93	75					
1948.....	90	99						

each year of life and for each calendar year, table 23. Percentages of expected growth during selected calendar years may be read from table 23 in diagonal rows from lower left to upper right. The percentages of expected growth in each calendar year, when averaged, show clearly the fluctuations in annual growth, table 24.

Actual length increments exceeded the expected increments in only 1945 and 1946, table 24. Poor growth in 1942 and 1943 may have been due to heavy floods, which caused the water to remain muddy for 6 or 7 weeks during the early summer of each of these years.

The exceptionally good growth of warmouths during 1945 and 1946 may have resulted from an artificial thinning of the fish population. On June 26, 1945, May 15, 1946, and July 29, 1946, Dr. George W. Bennett and other members of the Illinois Natural History Survey staff sprayed most of the shallow waters of Park Pond with rotenone to reduce the numbers of small fish in the population. Although no estimate could be made of the percentage of the total fish population killed by these partial poisoning operations, the great number of small fish destroyed may well have allowed a substantial increase in growth rates of the surviving fish.

Seasonal Growth.—Growth patterns of the 1946, 1947, and 1948 year classes of warmouths in Park Pond during the summer of 1949 are shown in fig. 22. The length increment for each fish was calculated from scales. The growth increment on each scale used was measured on the

Table 24.—Average percentages of expected annual length increment attained in each calendar year by warmouths collected from Park Pond, June, 1948–November, 1949; year classes combined.

CALEN- DAR YEAR	NUMBER OF FISH	AVERAGE PERCENTAGE OF EXPECTED ANNUAL LENGTH INCREMENT ATTAINED IN EACH YEAR OF LIFE
1941.....	6	96
1942.....	16	82
1943.....	62	93
1944.....	194	98
1945....	546	114
1946....	785	128
1947.....	972	91
1948....	526	74

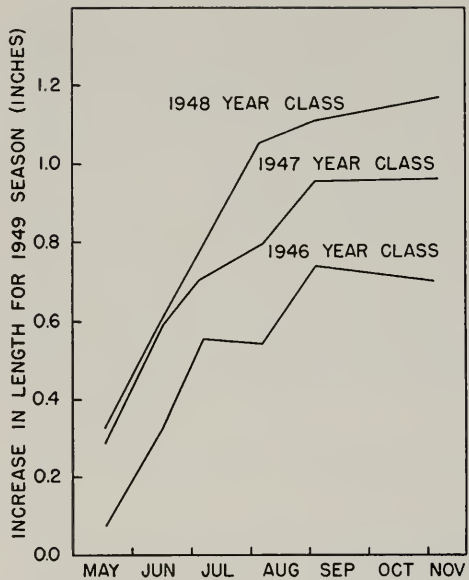


Fig. 22.—Averages of length increases of warmouths of the 1946, 1947, and 1948 year classes in Park Pond during the 1949 growing season. The growth increment for each warmouth was calculated from scale growth outside of the last annulus.

median anterior radius from the outermost annulus to the margin of the scale. Average monthly length increments were calculated from scale collections made each month except October in a period that began in May and extended into November. When more than one collection was made in a single month, the collections were combined and an average date was used. In this particular analysis, year classes other than those of 1946–1948 could not be used because they were not represented by sufficient numbers of warmouths to give validity to the calculations.

Growth was rapid for the three year classes in May and June, and this good growth continued through July for the 1948 year class, fig. 22. Growth rates decreased in July for the 1946 and 1947 year classes and improved considerably in August. Little or no growth was evident in the three year classes after August. Certain general differences were discernible between the fish of these year classes. The oldest fish (1946 year class) showed a mid-summer slump in growth and had completed their seasonal growth by September, whereas the youngest fish (1948 year class)

grew rapidly through July and showed some growth in each of the months through October. The growth pattern for the 1947 year class was intermediate between the patterns for the 1946 and 1948 year classes.

Seasonal growth rates of three year classes of warmouths in Venard Lake are shown in figs. 23 and 24.

Measurements of warmouths from Park Pond, fig. 22, from Venard Lake, figs. 23

long. Most of these warmouths were less than 3.5 inches in length.

Age determinations for 265 of the 504 warmouths revealed a growth rate considerably less than was found in other areas of Park Pond, table 25. Of the 265 specimens aged, very good growth was found in 23 large fish belonging to the 1944 and 1945 year classes. These fish did not seem to be representative of the population of

Table 25.—Average of calculated lengths of 265 warmouths from which scale samples were taken, after being collected from Park Pond Slough, shown with similar calculated lengths of warmouths from other parts of Park Pond.

GROUP OF FISH	YEAR CLASS	NUMBER OF FISH	CALCULATED TOTAL LENGTH AT END OF INDICATED YEAR OF LIFE					AVERAGE TOTAL LENGTH AT CAPTURE
			1	2	3	4	5	
Fast-growing warmouths from slough	1944	2	1.74	4.07	5.38	6.65	7.11	7.35
	1945	21	1.91	3.83	5.14	5.87		6.15
Slow-growing warmouths from slough	1945	10	1.56	2.90	4.00	4.86		5.27
	1946	74	1.54	2.85	3.97			4.59
	1947	93	1.46	2.54				3.34
	1948	52	1.48					2.50
	1949	13						1.65
Slow-growing warmouths from slough, average		242	1.50	2.64	3.64	4.62		
Warmouths from other Park Pond areas, average	Combined year classes	1,063	1.64	3.38	4.91	6.40		

and 24, and from certain Oklahoma waters (Jenkins, Elkin, & Finnell 1955:42) indicated an apparent decrease in the average lengths of the fish of some age groups in July or August. This apparent decrease may have been due to changes in habits or distribution of the warmouths from the early part to the middle part of the summer, changes which might have affected the efficiency or selectivity of the collecting method, with a result that a proportionally smaller number of large members in each age group was taken.

Growth in Localized Population.

—In the isolated, 0.47-acre Park Pond slough to which rotenone was applied in 1949, warmouths comprised 10.4 per cent of the weight of the fish population. Although this weight represented 504 individuals, only 18 were more than 6 inches

the slough. Their history of rapid growth suggested they had only recently moved into this area.

All of the smaller specimens in this slough showed consistently poorer growth than warmouths from other areas of Park Pond. A study of the fish population of the slough indicated that (1) isolated populations of warmouths existed within the total warmouth population of Park Pond; (2) individuals of these isolated populations, most of them in dense weed beds, grew slowly; and (3) individuals of these populations appeared to remain in the same locations throughout their life spans.

Compensatory Growth.—Three hundred thirteen warmouths from Park Pond were separated into three size groups based on calculated lengths of fish at the end of the first year of life, table 26. The average

length increment for each year of life was then calculated for each size group as a means of determining the growth rate—whether fast, intermediate, or slow.

Of the 313 warmouths considered, 94 had been collected with hoop nets during the summer of 1948; these 94 were fish of the 1944 year class and were faster-growing individuals than the specimens (219) that had been taken from the slough. Warmouths taken from the slough had been collected after being poisoned with rotenone; they belonged to the 1946, 1947, and 1948 year classes, table 26.

For the fish taken in hoop nets, the difference in average calculated lengths between the largest and smallest size groups was 0.55 inch for the first year of life, 0.74 inch for the second, 0.55 inch for the third, and 0.42 inch for the fourth. The decline in differences between these two size groups in the third and fourth years of life may indicate compensatory growth among

individuals of the smallest group in these years. However, the compensatory growth that occurred was slight and it did not overcome the length advantage held by the fish that grew most rapidly during the first year of life.

In the slow-growing population from the slough, the maximum differences in length between the two extreme size groups of the various year classes declined little or not at all after the second year. In the 1946 year class, after an increase in length difference at the end of the second year, the differences were about the same at the end of the third and fourth growing seasons, table 26.

A study of compensatory growth in these four year classes of warmouths from Park Pond suggested the following conclusions:

1. Warmouths that were largest at the end of the first year of life increased this length advantage in the second year of life.

Table 26.—Compensatory growth, in inches, in four year classes of warmouths collected from Park Pond. Fish in the 1944 year class were collected in hoop nets from several parts of Park Pond in the summer of 1948; those in 1946–1948 year classes were taken from a slough to which poison was applied on August 22, 1949.

YEAR CLASS AND PLACE OF COLLECTION	GROUP OF FISH, BASED ON CALCULATED TOTAL LENGTH IN INCHES AT END OF FIRST YEAR OF LIFE	NUMBER OF FISH	CALCULATED AVERAGE TOTAL LENGTH AT END OF INDICATED YEAR OF LIFE				CALCULATED AVERAGE LENGTH INCREMENT IN INDICATED YEAR OF LIFE			
			1	2	3	4	1	2	3	4
1944 (Entire pond)	Below 1.45	22	1.33	3.53	5.68	6.70	1.33	2.20	2.15	1.02
	1.45–1.70	42	1.58	3.80	5.74	6.76	1.58	2.22	1.94	1.02
	Over 1.70	30	1.88	4.27	6.23	7.12	1.88	2.39	1.96	0.89
	Maximum difference		0.55	0.74	0.55	0.42	.....	.....	.....	.....
1946 (Slough)	Below 1.3	13	1.20	2.49	3.61	4.25 ^a	1.20	1.29	1.12	0.64*
	1.3–1.6	33	1.43	2.63	3.74	4.35*	1.43	1.20	1.11	0.61*
	Over 1.6	28	1.84	3.28	4.41	5.04 ^a	1.84	1.44	1.13	0.63*
	Maximum difference		0.64	0.79	0.80	0.79	.....	.....	.....	.....
1947 (Slough)	Below 1.3	19	1.22	2.24	3.11*	.....	1.22	1.02	0.87 ^a	.....
	1.3–1.6	55	1.41	2.47	3.27*	.....	1.41	1.06	0.80*	.....
	Over 1.6	19	1.81	3.03	3.79*	.....	1.81	1.22	0.76 ^a	.....
	Maximum difference		0.59	0.79	0.68	.....	.....	.....	.....	.....
1948 (Slough)	Below 1.3	14	1.24	2.24*	.....	.....	1.24	1.00*	.....	.....
	1.3–1.6	24	1.41	2.42*	.....	.....	1.41	1.01*	.....	.....
	Over 1.6	14	1.82	2.89*	.....	.....	1.82	1.07*	.....	.....
	Maximum difference		0.58	0.65	.....	.....	.....	.....	.....	.....

^aEmpirical length representing growth to August 22, 1949.

2. Warmouths that were smallest at the end of the first year of life showed no compensatory growth in the second year but showed a slight compensatory growth in the third year.

3. Although warmouths that grew fast the first year of life underwent a decline in annual length increment after the second growing season, they retained their length advantage over warmouths that grew slowly the first year.

4. Warmouths that grew slowly the first year of life showed more compensatory growth in later years if they were members of fast-growing populations than if they were members of slow-growing populations.

These conclusions are in fair agreement with those from similar studies done on several other sunfishes. Hubbs & Cooper (1935:678) found no compensatory growth during the second year of life in the longear sunfish, pumpkinseed, or bluegill, or in bluegill \times pumpkinseed hybrids. Their data did not include growth rates beyond the second year. For the rock bass, Hile (1941:332) stated: "First-year advantage in size may be retained over 1 or 2 additional years, but more probably it will be increased in the second and/or third year of life. Compensatory growth occurs in the later years."

Sizes and Longevity.—A 9.6-inch male was the largest warmouth collected from Park Pond. This fish weighed 1.0 pound and was 6 years of age. The majority of the large fish were males. Although the males grew slightly faster than the females, table 20, it did not necessarily follow that the males reached greater maximum sizes than did the females. The occurrence of more large males than large females in the collections may have indicated only that the former were more readily taken than were the latter—a logical hypothesis in view of the differences in behavior during the nesting season. The sedentary nest-guarding habits of the males would have made them very vulnerable to collection by shocking.

Schoffman (1940:36) mentioned spawning habits to explain the greater percentage of females than males in the groups of large warmouths he collected from Reelfoot Lake, Tennessee. As his collections were taken with traps operated during the

breeding season, nest-guarding males were not caught so readily as females. The largest warmouth handled by Schoffman (1940:34) was a 9.29-inch female.

Growth in Venard Lake

In 1948 and 1949, warmouths in Venard Lake, an artificial lake of 3.2 acres, were associated with only one other species, the largemouth bass. Both species had been introduced in April, 1947, page 5.

The 1,102 Venard Lake fish used in this study were from collections made with an electric shocker each month (except January and February) in a period beginning September, 1948, and ending October, 1949. Methods used for scale preparation and age determination were similar to those described for the collections from Park Pond.

Since Venard was a recently stocked lake, it contained only a small number of year classes of warmouths: 1947, 1948, and 1949. A comparison of growth rates was made between warmouths of the first, fast-growing year class (1947) and those of the two following year classes (1948 and 1949). The following points seem apparent, figs. 23 and 24:

1. Both actual and calculated lengths of warmouths of the first year class to be spawned in the lake (1947) averaged more at the end of the first year and of each succeeding year of life than did those of later year classes.

2. The actual length range for members of the first year class was greater than that for members of each succeeding year class.

3. The average calculated lengths of warmouths of 1947 and 1948 year classes collected in successive months of 1949 showed a decline.

4. The average annual growth of warmouths in Venard Lake was very similar to that of warmouths in their first 3 years of life in Park Pond, table 27, in spite of large ecological differences in the two habitats.

Growth in Other Water Areas

The rate of growth of warmouths may be influenced by various environmental factors or combinations of them. This fact is

illustrated by the differences observed in the growth rates of warmouths taken from 12 Illinois water areas, table 27.

The most rapid growth recorded in Illinois warmouths was in Enright Pond in McLean County in which some members of the first brood produced in the lake attained 6 inches in total length during their first 13 months. Thinning the total fish

population by intensive angling resulted in an increase in the growth rate of warmouths in Onized Lake, a 2-acre body of water in central Illinois (Bennett 1945: 396-7).

Exceptionally rapid growth of warmouths usually accompanies the expansion of fish populations in new reservoirs. During the first 6 years after impoundment of

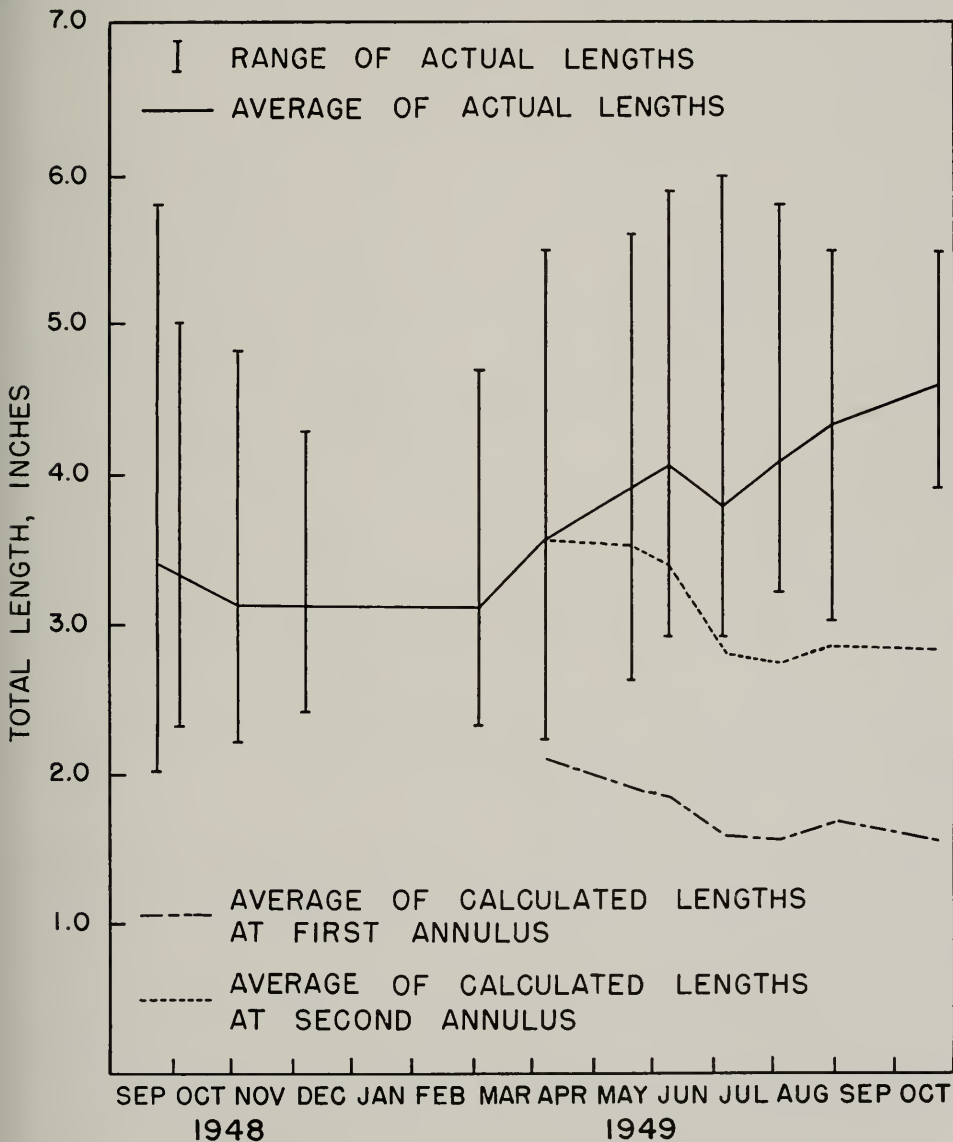


Fig. 23.—Averages of actual total lengths and averages of calculated total lengths at time of formation of first annulus and at time of formation of second annulus for warmouths of the 1947 year class taken in 12 collections from Venard Lake, late September, 1948, through middle October, 1949; also range of actual total lengths in each collection.

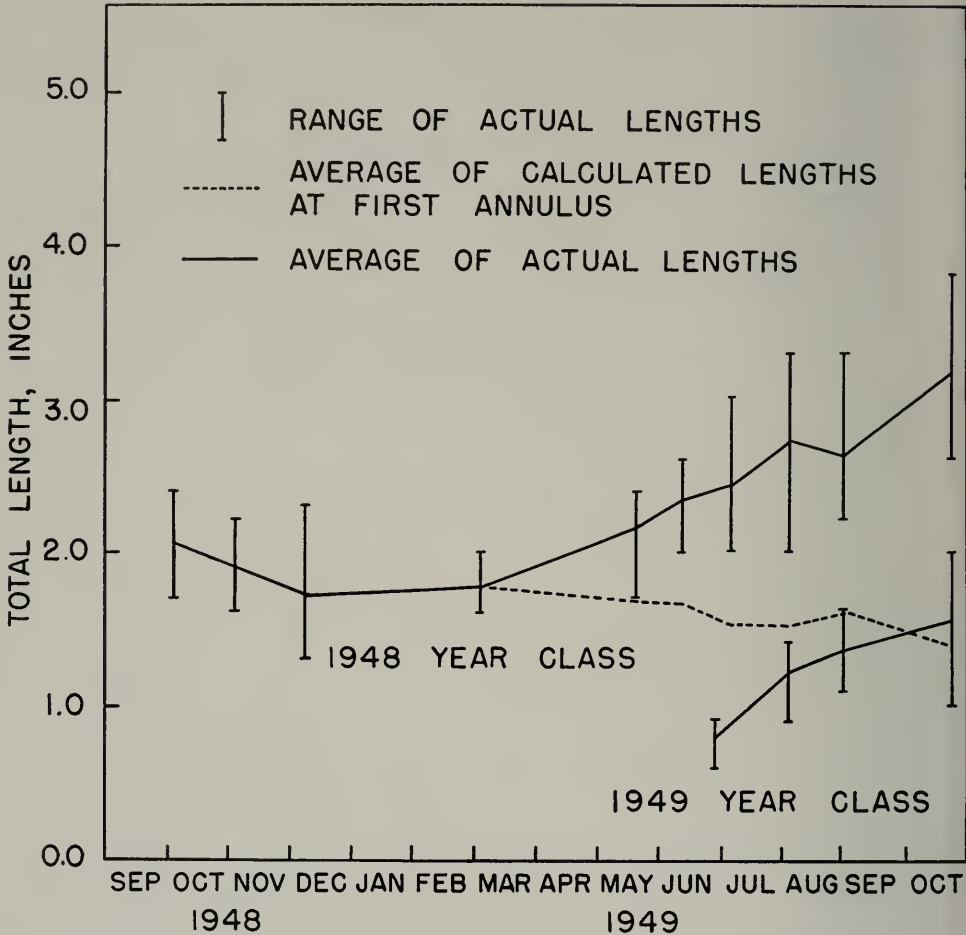


Fig. 24.—Averages of actual total lengths and averages of calculated total lengths at time of formation of first annulus for warmouths of the 1948 year class taken in 10 collections from Venard Lake, early October, 1948, through middle October, 1949; averages of actual total lengths of warmouths of the 1949 year class taken in 4 collections, late June through late October, 1949; also range of actual total lengths in each collection.

Lake Glendale, an 82-acre lake in Pope County, Illinois, warmouths showed a growth rate that was exceptionally fast for the species (Dr. Donald F. Hansen of the Illinois Natural History Survey, unpublished studies of Lake Glendale). Another example of improved growth rate in a new impoundment is given by Hall & Jenkins (1953:34); they found that, in Tenkiller Reservoir in Oklahoma, the growth rate of warmouths was rapid during the first year of impoundment. Jenkins (1953:79) found that in Grand Lake, Oklahoma, the growth rate of warmouths gradually declined during the years of impoundment.

Data from several studies of warmouth

growth in other states are summarized by Carlander (1950:191-2; 1953:370-1). An inspection of these data and those given in table 27 reveals a wide range of differences in warmouth growth rates.

PARASITISM

No attempt will be made here to survey all published records concerning parasites of the warmouth. Reference should be made, however, to several important studies involving autopsies of comparatively large numbers of warmouths. Holl (1932:99-100) examined 90 warmouths from North Carolina and discovered an in-

teresting seasonal fluctuation in relative numbers of parasites and in percentages of fish infested. In a study of centrarchids from southern Florida, Bangham (1939: 265) examined 143 warmouths and found all of them infested with parasites of one

the genus *Physa*, any one of several species of fish, and the great blue heron, *Ardes herodias* L. As little age immunity has been demonstrated in intermediate hosts of most flukes, the numbers of metacercariae of this strigeid probably continue

Table 27.—Growth rates of warmouths in 13 water areas in Illinois.

WATER AREA	COUNTY	YEAR OF COLLECTION	NUMBER OF FISH	CALCULATED TOTAL LENGTH AT END OF INDICATED YEAR OF LIFE						
				1	2	3	4	5	6	7
Park Pond.....	Vermilion	1948-49	1,063	1.6	3.4	4.9	6.4	7.4	8.0	8.5
Park Pond Slough..	Vermilion	1949	242	1.5	2.6	3.6	4.6			
Venard Lake.....	McLean	1948-49	334	1.7	3.2	4.6				
Onized Lake*.....	Madison	1941	101	1.4	4.0	6.1				
Lake Glendale.....	Pope	1945-46	108	2.1	4.6	6.2				
Mississippi River†...		1944	26	1.8	4.8	6.2	7.1			
Lake Chautauqua...	Macon	1947	30	1.4	2.7	4.5	5.9	6.8		
40-and-8 Lake.....	Henry	1954	22	1.5	2.9	4.2	6.0	7.0		
Staunton Lake.....	Macoupin	1953	18	1.7	3.1	4.5	5.6			
Mount Clare Lake..	Macoupin	1953	16	1.3	2.8	4.6	5.7			
McKenzie Lake.....	Montgomery	1952	12	1.3	2.4	3.5	4.4	5.0	5.4	
Weldon Springs.....	De Witt	1952	28	1.7	3.5	5.7				
Fairmount Quarries.	Vermilion	1953	100	1.7	3.0	4.6	5.6			

*From Bennett 1945:397.

†From Upper Mississippi River Conservation Committee 1946:20.

or more species. The fish populations from which these specimens were taken contained relatively high concentrations of warmouths. Venard (1941:15) found that of 45 warmouths examined from Reelfoot Lake, Tennessee, all were parasitized. Bangham & Venard (1942:33) listed 22 species of parasites from 58 specimens examined from Reelfoot Lake; all of the specimens were infested with parasites.

A comprehensive investigation of warmouth parasites was not made in this study. The following brief discussions are of the general relationships between the hosts and four common parasites of warmouths from Venard Lake and Park Pond.*

The strigeid fluke, *Posthodiplostomum minimum* (MacCallum), was the most abundant parasite of the warmouths in Park Pond. Its hosts include a snail of

to increase in the host warmouth until the fish dies. Extremely heavy infestations of metacercariae were found commonly in Park Pond warmouths over 5 inches in length, but seldom in smaller ones.

The bass tapeworm, *Proteocephalus ambloplites* (Leidy), was present in all warmouths examined from Park Pond. As a plerocercoid larva, it occurred in most of the internal organs, especially in the liver, gonads, and mesenteries. Since the warmouths acquired these parasites by eating copepods containing the proceroids, the rate at which the fish acquired the parasites declined as the fish changed their food preferences from Entomostraca to larger items. Therefore, unlike *Posthodiplostomum*, plerocercoids did not occur in relatively greater numbers among the large warmouths than among the small ones at Park Pond.

An interesting nematode, *Camallanus oxycephalus* Ward & Magath, lives in the lower intestine of the warmouth. Blood-red worms of this species were so numerous in some warmouths from Park Pond that they often formed tangled masses in the lumens of the guts. Frequently *Camal-*

*Dr. L. J. Thomas, University of Illinois, checked the identification of the cestode and trematode parasites and suggested possible relationships between these parasitic worms and the fish population. The late Dr. H. J. Van Cleave, University of Illinois, identified the acanthocephalan; Professor R. V. Bangham, College of Wooster, identified the nematode; and Professor M. C. Meyer, University of Maine, identified the leech.

lanus worms were seen hanging as a red tuft from the anus of a fish taken from the water. *Camallanus* attaches to the inner intestinal wall. The warmouth serves as the final host, and infestation may take place at any time.

The only parasite which infested noticeable numbers of warmouths from Venard Lake was a leech, *Illinobdella moorei* Meyer. During the autumn and winter of 1948, leeches of this species were present in such large numbers that they appeared as compact fringes on the fins of the warmouths. The caudal fins of the fish were severely damaged, frequently suffering extensive destruction of the rays. Although the infestation was still heavy during the spring of 1949, only relatively few of the leeches were seen during the following summer months.

An examination of 25 ovaries from warmouths taken from Park Pond on November 12, 1949, revealed the following: (1) 14 ovaries contained one or more parasites; (2) ovaries of all sexually mature females were parasitized; (3) 24 plerocercoids of *Proteocephalus ambloplites* occurred in 12 ovaries, as many as 4 in 1 ovary; (4) 27 metacercariae of *Posthodiplostomum minimum* occurred in 10 ovaries, 12 in 1 ovary; and (5) 4 sexually undeveloped adult acanthocephalans, *Lep-torhynchoides thecatus* (Linton), were found in 4 ovaries (1 in each ovary). In spite of these parasites, no sterile fish were found and no primary damage to the ovaries was evident.

Warmouths were collected in sufficient numbers from Venard Lake and Park Pond to permit tentative conclusions to be drawn relative to the influence of parasites on the general physical condition of these fish. Warmouths from Venard Lake had fewer internal parasites and a consistently higher coefficient of condition (C) than had warmouths of similar sizes taken from Park Pond. At the same time, among the heavily infested warmouths of Park Pond, no positive relationship could be shown between a fish's coefficient of condition and the number of parasites present. Therefore, it is believed that the difference in condition of warmouths from the two lakes was more directly a result of difference in densities of the total fish populations than of parasitism.

Even though no harmful effects of parasites on the condition (C) of warmouths in Venard Lake or Park Pond could be demonstrated, possibilities of some other harmful effects must be recognized. Female warmouths from Park Pond produced much smaller numbers of eggs than did Venard Lake females, table 16, which were less heavily infested.

BEHAVIOR

Observations on the behavior of the warmouth are scattered through many sections of this publication. For example, the aggressive behavior of the nesting male is described (page 43) under "Spawning" in the section on reproduction. It seems desirable to bring together here certain aspects of observed behavior of the warmouth, although to do so will mean some repetition.

General Activity and Disposition

The warmouth has a quiet disposition; it moves around relatively little and displays no showy activity except during the nesting season. It seeks the cover of weed masses, stumps, or rocky banks (pages 6 and 8), and avoids intense light.

Reproductive Behavior

Tinbergen (1953:23) describes synchronization, persuasion, orientation, and reproductive isolation as functions of mating behavior in animals. These functions, along with defense of the nest area, the spawning act, and parental care, are considered here as reproductive behavior in the warmouth.

Defense of the Nest Area.—The nesting warmouth male displays an aggressive threat toward other fish that approach his nest area (page 42). He assumes a belligerent attitude by swimming toward the intruder with his mouth open and his opercles spread; at the same time, his eyes become red and his body becomes light yellow in color. As the nesting male nears the intruder, he usually turns abruptly to one side or upward and, with vigorous movements of his tail fin, forces small pulses of water toward the intruder. He may also nip the intruder. The entire

threat attitude associated with defense of the nest area is similar to the persuasive behavior employed by the nesting male in courting a female (page 43).

Synchronization.—The spawning period for warmouths extends over several months (page 43). Male warmouths become ready to spawn earlier and remain capable of spawning later in the season than do females. Thus, a ripening female generally encounters many males ready to spawn. More precise synchronization for the actual discharge of sex products is brought about by the preliminary courtship and persuasive gestures of the male and finally by the thump given the male as the female extrudes a group of eggs (page 44).

Orientation.—The special orientation for mating in warmouths consists simply of the male having an established nest, the female with ripening eggs wandering into the vicinity of the nest, and the male initiating the persuasive actions. A signal—such as sound, odor, or color display, used by many animals to attract a mate from considerable distances—is not known to be given by the male warmouth. However, the female probably receives some internal physiological stimulus to wander as her eggs ripen and they become free for discharge.

Persuasion.—The male warmouth's threat attitude, described above, serves to initiate the action for persuading the female to spawn. A female that is not ready to spawn responds to the threat as any other intruder would and is driven from the nesting area (page 43). On the other hand, a female that is ready to spawn quietly submits to the aggressive male. The threat, in which the male spreads his opercles and shows some display of color, is followed by attempts to guide the female to the nest depression. With only mild resistance and casual reluctance, the ripe female accepts more and more of the male's actions and soon enters the nest to remain with him for periods of time that become increasingly longer until spawning actually takes place.

The Spawning Act.—The series of signals and responses described above culminates when the male and female come together to deposit their sex products simultaneously. Although the aggressive at-

titude of the male makes it seem that he is controlling the spawning activities, the female enters the nest only when she is ready, she gives the final signal (thumping the male's side) for extrusion of eggs and milt, and she leaves the nest depression for short intervals between egg laying. The spawning signals and responses follow a definite sequence; it is interesting to recall that a female warmouth in a laboratory spawned alternately during one continuous spawning sequence with two male warmouths (page 44). After having been brought to a spawning attitude by one male, the female then responded to either of the two nesting males.

Reproductive Isolation.—Hybrids are produced between the warmouth and a great number of the species of *Lepomis*, and yet such hybrids seldom occur in large numbers in natural populations. What forms the reproductive isolation that prevents greater hybridization was not determined in this study. There is little spatial separation of the various sunfishes. The warmouth is usually found living and even nesting with several species with which it could genetically hybridize, and yet few hybrid individuals are formed. In the absence of any other observable isolating barrier, the isolation appears to result from a lack of the specific signals and responses necessary to bring a warmouth to successful spawning with an individual of another species. In the laboratory, male warmouths have courted green sunfish and bluegill females but have not succeeded in spawning with them and seldom are able to guide them to the nest depressions. Apparently, the series of specific signals and responses is not followed through to successful spawning.

Parental Care.—After the warmouth fry leave the nest area, they receive no parental care. In ponds and lakes, the fry scatter into dense weed masses (page 48), and thus it becomes impossible for the male parent to keep the young together for close care. Protection afforded by the dense weed masses eliminates most of the needs for parental care. The male warmouth seems to lack the drive to care for his free-swimming young; even in a laboratory aquarium without vegetation in which the young may hide, he shows little interest in his fry after they leave the nest.

Group Behavior

The warmouth is not a gregarious fish, even though large numbers of individuals may be concentrated in a comparatively small area. The following observations concern the social relations among warmouths.

Aggregations.—There is no school formation among warmouths except that immediately associated with the nest (page 48). Aggregations form around desirable cover, such as the riprapping along a dam (page 8), but little social structure can be detected in such groups. Even during the winter, when many fishes form groups, warmouths show no tendency to gather together except in response to choice habitats. The nesting colonies that have been reported (page 42) are probably due to restricted nesting habitat rather than to a gregarious nature of the species.

Hierarchy.—To what extent an order of dominance occurs in a natural warmouth population has not been observed. Attempts at observations on dominance are hampered by the difficulty of identifying individual fish in a natural setting; also, the order of dominance becomes complicated by nesting behavior, mating aggression, feeding activities, and local movements.

A hierarchy is quickly established among warmouths in a restricted group, such as that in an aquarium. The aggressiveness of a fish, as for food or space, and the dominance of the fish relative to other members of the group, determine its position in the hierarchy. The smaller the group, the more stable and definite the order of dominance appears. In groups of more than three or four, the order may change frequently. Nesting studies in the laboratory revealed that a male in spawning condition tends to assume dominance over one not so sexually advanced (page 42). The attitude of aggression which initiates the breeding behavior temporarily affects any existing hierarchy.

Witt (1949:34) discovered a definite hierarchy among five warmouths in an aquarium. He found no correlation between the order of dominance and the errors the fish made in learning to distinguish a worm on a hook from a worm that is free.

Feeding Behavior

Warmouths have a simple pattern of taking food. When a food item is sighted, the fish turns toward it, judges its acceptability as food, and then may move in quickly to snap it up. An unacceptable food item may hold the warmouth's attention for several minutes. Seldom is a motionless object picked up by a warmouth.

Suction created as the warmouth quickly opens its wide mouth aids in the capture of food. This suction causes a loud noise when the fish gulps an item of food from the water's surface and may be responsible for taking a considerable amount of detritus with the food.

Learning

Witt (1949:27) found that warmouths could learn to distinguish a worm on a hook from a free worm. As isolated individuals, warmouths learned about as quickly as did bluegills and more quickly than did largemouth bass, but in groups the warmouths made more errors than did either largemouths or bluegills. Individuals of all three species exhibited a fair degree of learning, making the majority of their errors in the first two of the seven trial periods. After being penalized for making an error, the warmouth was not so cautious as the bluegill in its approach to a hooked worm.

Warmouths do not seem so cautious in taking fishing lures or so quick in recognizing artificial situations as most other sunfishes. In ponds and in laboratory aquariums, warmouths were seen to strike repeatedly at artificial lures without, apparently, becoming suspicious that the lures were unnatural. In an aquarium, a resting warmouth, molested by a succession of lures dangled before its face, apparently was so undisturbed by the experience that it turned to snap at a lure more attractive to it than the others. On several days at Ridge Lake, Coles County, Illinois, a fisherman repeatedly hooked and released what appeared to be the same large warmouth by dangling a worm in front of an old piece of tile. This warmouth may have learned, but, if so, its memory did not last from one fishing trip to the next.

The warmouth's gullibility toward baits

may be a desirable trait for a warm-water sport fish.

ECONOMIC RELATIONS

Warmouths attain their greatest importance as food and sport fish in the lower Mississippi River valley and states bordering the Gulf of Mexico. There they are commonly taken with live bait by cane-pole fishermen. In the midwestern and eastern states, warmouths usually are not taken in large numbers but are caught on a wide variety of baits and lures. Because of their gamyness and plumpness, they are attractive to most anglers.

The Warmouth as a Food Fish

The warmouth is now of little commercial value, partly because in most states its sale is illegal; where it can be legally sold, the warmouth is not an important food fish in comparison to the larger species now being marketed.

In North Carolina during the early part of this century the warmouth was taken in gill nets and other nets and sold throughout the year (Smith 1907:235). At Reelfoot Lake, Tennessee, in 1937, it was one of the seven sunfishes that as a group comprised approximately 10 per cent of the weight of the commercial catch (Kuhne 1939*b*:58).

Most people consider the warmouth an excellent table fish. At times, however, this fish may have a "muddy" flavor, which is generally blamed on its association with silt bottoms and muddy waters, but which is caused at least partly by the food organisms comprising its diet. Warmouths taken off silt-covered bottoms of Park Pond usually had an excellent flavor; they were intermediate between the bluegill and the largemouth bass in both flavor and texture of flesh.

The Warmouth as a Sport Fish

An early angling critic, Henshall (1903:59), was very enthusiastic about the warmouth; he wrote, "For its size, it is the gamest member of the family except the black-bass." In a discussion following a paper by Lovejoy (1903:120), Henshall pointed out that this sunfish takes a fly

well, responds to almost any kind of bait, and is an excellent table fish. Evermann & Clark (1920:393), Baker (1937:44), Curtis (1949:266), and others have praised the fighting qualities of the warmouth or have termed it "an excellent small game fish."

The value of the warmouth as a sport fish is enhanced by the wide variety of natural and artificial lures that are effective in catching it. Through most of its range, the warmouth is taken more commonly on natural baits (earthworms, minnows, grasshoppers, crickets, or grubs) than on artificial baits.

The yield to the warmouth fisherman, using either natural or artificial lure, is often restricted by the difficulty of working the lure in close enough to weed masses, brush, and other dense cover to present it properly to the fish without getting the hook snagged. This difficulty increases during the summer as aquatic vegetation grows rank. Floating lures, such as poppers, are effective during the summer, because they can be dropped in pockets of open water among water weeds—where the warmouths may be hiding, feeding or nesting—and then be lifted out without becoming entangled. Worm fishing with a long pole offers similar advantages in fishing for warmouths around dense vegetation and heavy brush.

Most Illinois fishermen believe that warmouths may be taken in greater numbers during the spring and early summer than at other seasons. At the Pollywog Association property and at the flooded limestone quarries (Fairmount Quarries) near Fairmount, Vermilion County, good catches of warmouths are usually made in May and June but seldom later in the summer—at least not on the artificial lures that are relatively effective during the earlier months. Most of the warmouths caught at Ridge Lake (Dr. George W. Bennett, unpublished creel records from Ridge Lake, Coles County, Illinois) have been taken during the first month of the summer fishing season. Although the catch of warmouths at Lake Glendale (Dr. Donald F. Hansen, unpublished creel records from Lake Glendale, Pope County, Illinois) was distributed rather evenly in the period May through August in 1945, the catch of warmouths in 1946 was much

higher in April and May than during the summer months. No warmouths were taken at Lake Glendale during September in either year. These records form an interesting contrast with the records of Ricker (1945:330) for Muskellunge Lake, Indiana, where a striking increase in the catch of warmouths occurred during September.

Censuses of sport fishing reported by Ricker (1945) for three Indiana lakes show that warmouths were taken regularly by anglers but not in abundance. Lewis & English (1949:317) recorded only four warmouths taken during 6,513 man-hours of fishing in Red Haw Hill Reservoir, Iowa, even though warmouths were fairly common in the lake. They suggested that the low catch was due to the difficulties of angling among the dense marginal vegetation of this lake. Kuhne (1939a:51) calculated a take of warmouths at Reelfoot Lake, Tennessee, that amounted to 1.02 per cent by weight of the anglers' catch for 1937. The combined catches of resident and non-resident fishermen amounted to only 0.02 warmouth per hour (Kuhne 1939a:48). In a creel census for the period March 1 through September 30, 1952 (Cobb 1953:21), warmouths comprised 2.05 per cent of the weight of all fish taken by sport fishermen at Reelfoot Lake.

Creel records for Illinois lakes show that the warmouth usually is not abundant in the anglers' catches.

In Onized Lake, Illinois, Bennett (1945:380-3) reported only 105 warmouths caught during 7,526.9 hours of fishing in a period beginning in 1938 and ending in 1941. This catch represented about 0.01 warmouth per hour. Even though this species comprised 18 per cent of the total number of fish (6 per cent by weight) in the final census of 1941, it made up only 2.6 per cent by numbers (2.9 per cent by weight) of all fish caught in the period of study. Since only a few warmouths were caught during a period when the other sport fish were being severely cropped in this 2-acre lake, one might have expected warmouths to replace the other fish of desirable sizes removed by angling. However, only 13 warmouths of 6 inches or more in length were recorded in the final census.

At Horseshoe Lake, Alexander County, in southern Illinois, 2 per cent of the fishermen's catch during the summer of 1956 was composed of warmouths (Bruce Muench, 1956, report to the Illinois Department of Conservation and Southern Illinois University).

At Venard Lake, 20 of the 101 warmouths planted in this lake early in 1947 were caught by anglers later in the same year. This take represented about 20 per cent of the number of warmouths planted but only 14 per cent of the total catch. About 52 per cent of the 240 largemouth bass that had been planted with the warmouths were taken by anglers in 1947.

In 1946 at Lake Glendale, in southern Illinois, the percentage of warmouths in the anglers' creel was not far below the percentage of warmouths in the total fish population. Warmouths were first caught in Lake Glendale the third summer after impoundment of the lake in 1940 and they increased in the anglers' catches during each of three summers following their first appearance (Dr. Donald F. Hansen, unpublished creel records from Lake Glendale, Pope County, Illinois). In the last year of the 3-year sequence, warmouths comprised 4.5 per cent of the total number of fish taken. When the lake was drained and the fish population censused, warmouths made up 6 per cent of the total number of fish and 5 per cent of the total weight; 57 per cent of the warmouths were over 6 inches in total length.

Several central Illinois ponds that, as part of the life history study reported here, had been stocked with warmouths produced hook-and-line yields that were low in proportion to the populations of these fish. The exploitation rate from angling was proportionally lower than for most other centrarchids inhabiting these waters. Fly and plug fishermen caught relatively few warmouths; most large catches of warmouths from these stocked ponds were taken on live baits.

Warmouth populations in the creeks and rivers in most parts of Illinois contribute very little to the creels of anglers. However, anglers who fish a few of the streams of southern Illinois report the common occurrence of warmouths in their creels. The warmouth is probably not abundant

enough in the Mississippi River from Caruthersville, Missouri, to Dubuque, Iowa, to be considered of much importance in the sport fishery (Barnickol & Starrett 1951: 319).

The Warmouth as a Laboratory Fish

The warmouth is a desirable fish for laboratory experimentation. It is relatively easy to transport from the field and to keep alive in the laboratory. It is large enough to be easily handled and yet small enough to be accommodated in most aquariums. It has a quiet disposition, quickly becomes adapted to laboratory conditions, and readily feeds on a wide variety of foods.

In the laboratory, the warmouth will nest and spawn, apparently undisturbed by the presence of an observer. The wide variety of foods acceptable to it simplifies the task of keeping this fish for long periods in the laboratory. Such characteristics as its tolerance for low concentrations of dissolved oxygen, its rapid color responses to excitement, and its unusual individual and group behavior present interesting problems for study. The warmouth has been used in Natural History Survey laboratories in studies of food conversion, learning, group behavior, and marking techniques, as well as in studies reported in the present paper.

The Warmouth in Artificially Established Populations

Several combinations of species have been used by fisheries biologists in seeking to establish fish populations that will produce and maintain good sport fishing in lakes and ponds. In some waters, the largemouth bass and bluegill have seemed to be suitable companion species (Swingle & Smith 1941:271). In many Illinois lakes, however, this combination has not proved satisfactory, as bluegills have tended to overpopulate the water (Bennett 1944:186).

Lovejoy (1903:116-7) considered the warmouth one of the three best species to be used in stocking small ponds in the south. He wrote, "It grows to much larger size than the bream, thick and fleshy, with large mouth, and is to some extent

cannibalistic, but not enough so to make it objectionable. It will eat a few of its own young, but not enough to miss them—just enough to make the balance grow well."

The stocking of inland waters with warmouths for sport fishing was begun before the turn of the century. Records indicate that the distribution of warmouths by state and federal agencies has been sporadic and probably never on a large scale. For example, an Oklahoma state agency distributed 36,300 fingerlings in the calendar year 1935, and the United States Bureau of Fisheries distributed 53,160 fingerlings in the fiscal year ending June 30, 1936 (Earle 1937:16, 23). In the 12-month period beginning September 1, 1946, a Texas state agency distributed 134,345 warmouth fingerlings, and in 1947 the United States Fish and Wildlife Service distributed 20,348 warmouth fingerlings and 20 warmouths at least 6 inches in length (Tunison, Mullin, & Meehean 1949:55, 58). The Fish and Wildlife Service distributed 64,040 warmouth fingerlings in 1949 and 710 in 1950 (Duncan & Meehean 1953:5-6); 4,600 warmouth fingerlings and 610 warmouths at least 6 inches long in 1951 and none in 1952 (Duncan & Meehean 1954:4-5).

In Alabama, Swingle (1950:49-73) stocked 10 of 34 experimental ponds with warmouths in combination with largemouth bass, bluegills, and other fishes. Seven of the 10 ponds containing warmouths produced populations that were considered balanced and 3 produced populations that were considered unbalanced. Warmouths comprised less than 6 per cent of the total weight of fish in all but 1 of the 10 ponds, a pond with a population judged to be unbalanced; in this pond warmouths made up 11.3 per cent of the weight. Bluegills far outnumbered the warmouths in each population.

The relatively low proportions of warmouths encountered (usually less than 10 per cent by weight, table 4) indicate that these fish have no tendency to become dominant at the expense of other kinds of fishes. However, even these low proportions may represent overcrowding for the warmouths themselves, as indicated by slow growth and the occurrence of a high percentage of small individuals reported in

several censuses. Growth studies in Illinois indicate that as low a proportion of warmouths as 10.4 per cent by weight, found in Park Pond Slough (a weed-choked channel in Park Pond) may represent overcrowding for these fish. Growth of warmouths in this channel was considerably slower than was that of warmouths in Onized Lake, just preceding 1941, when warmouths made up 6.5 per cent of the total weight of the fish population (Bennett 1945:382, 397), and slower than that of warmouths in Lake Glendale just preceding 1946, when warmouths made up 5.0 per cent of the total weight (unpublished information from Dr. Donald F. Hansen of the Illinois Natural History Survey). In Onized Lake, the fish population had been thinned by excessive fishing, and in Lake Glendale the population had been expanding during the 6 years following impoundment of the water.

Experimental Species Combinations.—As part of a series of management experiments by the author, 17 ponds in central Illinois were stocked with warmouths in various combinations that included largemouth bass, smallmouth bass, several pan fishes, and minnows. Because these experiments have not yet been completed and because they are not an integral part of the life history study reported here, the stocking combinations are listed below with consideration given principally to the early development of the populations and such factors as directly relate to the life history of the warmouth.

Warmouths (Adults); Largemouth Bass (Fingerlings and Yearlings).—This combination of species and sizes was first tested in 3-acre Enright Pond over a period of 15 months. Sixteen adult warmouths, 4 yearling largemouths, and 60 fingerling largemouths per acre were released in May, 1947. Warmouths spawned the first summer, and both species produced broods of young the second summer. Growth of all fish was rapid; some of the first-brood warmouths attained lengths as great as 6 inches in a little more than a year. There was a desirable distribution of numbers in size groups of both species.

Warmouths (Fingerlings and Adults); Largemouth Bass (Fingerlings and

Adults).—Both species were introduced in numbers and sizes simulating a "pyramid of numbers." This combination was tried in Enright Pond after termination of the experiment described above; the population was established during the early fall months of 1948 with 90 fish of each species per acre. Moderate-sized broods of both species were produced the next summer, and in each of the seven following summers the population was studied. The striking difference between what occurred in this warmouth-largemouth population and what usually occurs in a bluegill-largemouth population was that in the Enright Pond population the bass successfully produced a brood each year and fish of the companion species (warmouths in Enright) never produced such large numbers of young that they dominated the population. In 187 hours of recorded fishing during the sixth summer (there were fewer records for other years), 98 largemouths and 16 warmouths were caught at a rate that averaged 0.6 fish per hour. The number and sizes of fish of each species in this population were more nearly constant from year to year than in populations started with fish of one size.

Warmouths (Adults); Largemouth Bass (Yearlings and Adults).—Venard Lake was stocked in 1947 with 32 adult warmouths and 70 yearling and 5 adult largemouths per acre. The growth and competition for food in this population have been discussed previously in this paper. The bass gained an early dominance over the warmouths; by the end of the third growing season, the lake was becoming overcrowded with bass.

Warmouths (Adults); Largemouth Bass (Adults).—Fifteen adult warmouths and 22 adult largemouths per acre were released in Reece Pond in May, 1949. This 2.5-acre pond was characterized by a large proportion of shallow water and dense masses of aquatic vegetation (*Potamogeton foliosus*). Both species of fish spawned the first summer and they produced broods in each of the 7 succeeding years. The extensive vegetation permitted the survival of more young fish than could grow well in this pond.

Warmouths (Adults); Largemouth Bass (Adults) Added 1 Year Later.—In April and May, 1948, approximately 20

adult warmouths were released in a 1-acre pool above Venard Lake. They produced a large brood in the summer of 1948. The following spring about 20 adult largemouths were added to the pool. A small brood of bass was spawned, and the young grew well; by the end of the summer they were feeding on small warmouths. This combination and sequence of setting up the population allowed the warmouths to become well established, may have limited

of sport fishes—was investigated in three populations containing warmouths and largemouths.

Three adult warmouths and 30 fingerling largemouths per acre were released in June, 1952, in Parkhill Pond, a 3-acre pond which contained a large established population of the bullhead minnow, *Pimephales vigilax* (Baird & Girard). When the study was terminated at the end of about a year, which included parts of



Fig. 25.—Central part of Kearney Pond, McLean County, stocked with warmouths and largemouth bass.

the size of the first bass spawn, and provided small forage fish for the bass.

Warmouths (Established Population); Largemouth Bass (Adults).—In June, 1951, Kearney Pond (2.5 acres), fig. 25, containing a small population of warmouths, principally yearlings, was stocked with 5 adult largemouths per acre. In the following October, 20 more adult bass per acre were added, along with 40 fingerling and adult warmouths per acre. The warmouths produced a moderate-sized brood in 1951. In 1952, the largemouths produced a large brood, the warmouths a relatively small one. This relative spawning success of the two species was maintained in each of the 3 following years, or until the study was terminated.

Warmouths (Adults); Largemouth Bass (Fingerlings); Minnows.—The influence of minnows—both as a forage item and as a predator on the eggs and fry

two breeding seasons, there was an abundance of minnows, the bass and warmouths had grown exceptionally fast, and the warmouths had produced broods the first and second summers. The largemouths, which were 10 to 12 inches in total length early in the second season, did not produce a brood. Since the warmouths spawned successfully even though an abundant minnow population was present, it seems likely that the largemouths would have produced a brood the next year.

In July, 1948, Lutz Pond contained a large population of several species of minnows, the most abundant of which was the bullhead minnow. This 1.5-acre pond was then stocked with 20 adult warmouths and 60 fingerling largemouths per acre. Warmouths spawned the first summer (1948) and produced a large brood; these young fish grew rapidly. The warmouths produced another brood (1949) before the

2-year-old largemouths spawned in 1950. The minnow population declined rapidly during the third summer.

Kearney Pond (2.5 acres) contained minnows (species unidentified) and darters, *Etheostoma nigrum* Rafinesque, when it was stocked in June, 1949, with 10 adult warmouths and 46 fingerling largemouths per acre. The warmouths, minnows, and darters reproduced well in the first summer. Growth of the sport fishes was good. The numbers of minnows and darters declined during the summer.

In Parkhill Pond and Lutz Pond, two broods of warmouths were produced before the first spawn of bass. In all three ponds, the abundance of small forage fish provided food for the warmouths and largemouths, which grew rapidly; largemouths provided some fishing the second summer; and a bass brood of moderate size was spawned the third summer in the presence of two broods of warmouths.

Warmouths (Fingerlings and Adults); Minnows.—In August, 1948, 34 fingerling and 14 adult warmouths per acre were introduced into Longworth Pond (2 acres), which contained a large population of fathead minnows, *Pimephales promelas* Rafinesque. The warmouths spawned successfully during the remainder of the 1948 season and again the following summer. The broods in both years were small; evidently the minnows had a depressive effect on the warmouth population.

Warmouths (Adults); an Established Sunfish Population.—Three experiments were conducted to see if a small number of warmouths could successfully reproduce and survive in an established population consisting of several species of sunfishes.

Seven large adult warmouths were planted in a one-half-acre pond, Green Gravel Pit, which at the time (June, 1947) contained a population of bluegills, redear sunfish, green sunfish, and largemouth bass. Only one warmouth (original stock) was recovered when poison was applied to the pond in August, 1948. The warmouths had failed to establish a brood during the two intervening spawning seasons.

In November, 1949, Taylor Pond (2 acres) was stocked with 69 adult warmouths per acre. A few weeks before, it had been stocked with 100 bluegill fin-

gerlings, 100 largemouth fingerlings, and 15 largemouth adults per acre; a few adult green sunfish, longear sunfish, and bluegills also were added. The population was killed during the second spawning season (June, 1951); two adults, each a half pound in weight, were the only warmouths recovered from a rather large sunfish population (337 pounds per acre).

Twenty-three adult warmouths were released in June, 1952, in a 3-acre pond, McCarty, which contained a new but large population of bluegills and largemouth bass. No young warmouths (definitely identified) were taken from this pond during the following 4 years.

Warmouths (Adults); Redear Sunfish (Adults); Smallmouth Bass (Adults and Fingerlings).—This combination of species was tested in two ponds.

In July, 1951, 2-acre Taylor Pond (mentioned in connection with another experiment) was stocked with 21 adult warmouths per acre. These fish produced a small brood in the same summer. In the following fall and spring, 10 fingerling and 7 adult smallmouth bass and 17 adult redears per acre were added. A small brood of smallmouths, a moderate-sized brood of warmouths, and a relatively large brood of redears were produced in the summer of 1952.

Observations the next 2 years revealed the following: The smallmouths produced a very small brood in 1953 and no brood in 1954. Growth of the original stock of bass was good, but growth of both the 1952 and 1953 year classes was very poor. The warmouths and redears reproduced successfully each year and at first grew at satisfactory rates; however, by the spring of 1955 there were relatively few over 6.5 inches in length.

Sparks Pond (3 acres), fig. 26, was stocked with 22 adult smallmouth bass in November, 1949. The following spring the smallmouths spawned very successfully. In June, 25 adult warmouths and 34 adult redear sunfish were added to the population of this pond. Both of these species reproduced, although the brood of warmouths was quite small in numbers.

During the following 7 years, these observations were made: Smallmouth bass of the first brood (1950) did not grow well after the first summer. The bass spawned



Fig. 26.—South side of Sparks Pond, Woodford County, stocked with warmouths, redear sunfish, and smallmouth bass.

each year, but the fingerlings disappeared before attaining 1.5 inches in length. The only successful brood of bass after the first was that produced in 1954, which came after the redear sunfish population had been reduced in numbers by poison applied to part of the pond, a tremendous number of small sunfish had been lost over the spillway during a severe flood, and bass of the 1950 brood had become less numerous. Growth in this 1954 brood of bass was poor.

The redear sunfish spawned very successfully each year. The original stock and the first brood grew very well. Broods produced later showed much slower growth. After the fourth year, there were very few redears over 6 inches in length, although redears of smaller sizes were numerous.

The warmouth population was slow to develop. Warmouths spawned successfully each year, but the broods produced were small. However, by the fourth year warmouths were numerous and had become large enough to be attractive to anglers.

Warmouths; Largemouths; Bluegills (Adults of One Sex).—Four experiments were set up in attempts to produce warmouth \times bluegill hybrids.

Kearney Pond (mentioned in connection with other experiments) contained a 4-year-old warmouth-largemouth popula-

tion when 8 adult female bluegills per acre were added, July, 1955, in an effort to produce hybrids with the warmouths. No hybrids were found in the two spawning seasons after the bluegills were added.

Dunmire Pond (4.5 acres), fig. 27, was stocked in May, 1950, with 16 adult warmouths, 19 adult male bluegills, and 100 fingerling largemouth bass per acre. In July, 1955, 10 more adult male bluegills per acre were added. The warmouths and largemouths grew well, spawned successfully each year, and produced good fishing. The male bluegills grew exceptionally large (1.2 pounds), but no hybrids were observed in the first 6 years after the pond was stocked.

A shallow 3-acre pond on the University of Illinois Golf Course near Savoy was stocked with 45 adult warmouths, 185 adult female bluegills, and 907 largemouth bass fingerlings. These fish were placed in the pond in two groups, one group in each of the summers of 1949 and 1950. In the third summer following the original stocking, a large brood of bluegills was produced; one or more male bluegills must have been accidentally introduced in 1950. No warmouth \times bluegill hybrids were collected from this pond.

During the summers of 1949 and 1950, 19 adult warmouths and 59 adult male bluegills were released in Green Gravel

Pit, mentioned in connection with another experiment. Broods of warmouths were produced in each of these two summers and the two following summers that the study was continued. The male bluegills built nests, but no warmouth×bluegill

minnow population and grow well when they become large enough to utilize the minnows as food.

Largemouth bass in a pond with warmouths apparently grow faster and produce better fishing than do smallmouth



Fig. 27.—North arm of Dumire Pond, Woodford County, stocked with warmouths, largemouth bass, and male bluegills.

hybrids were collected. This half-acre pond, in which a substantial warmouth population had been developed, should have offered a desirable situation for hybrid production.

General Conclusions About Species Combinations.—Several general conclusions may be drawn from the preliminary observations on these experimental populations. Usually when sexually mature warmouths are released in a pond before the middle of August, they will produce a brood the same summer. In established warmouth populations, a high proportion of each new brood is spawned so late in the season that the fish are too small in their second summer of life to reproduce then. Small numbers of warmouths when introduced into a pond overcrowded with other sunfish seem unable to establish a population. Warmouths reproduce successfully in the presence of a large

bass in a pond with warmouths. There is little difference in growth rates between warmouths that develop in a pond with largemouths and those that develop in a pond with smallmouths. Warmouths will not establish a large enough population to support angling and materially reduce the survival of young bass unless adult warmouths are introduced a year before adult bass are added, or unless fingerling bass, instead of adults, are introduced with the adult warmouths.

There is no assurance that hybrids will be produced when bluegills of only one sex are introduced into a warmouth population.

SUMMARY

1. The ecological life history of the warmouth, *Chaenobryttus gulosus* (Cuvier), was studied intensively in two habi-

tats of central Illinois: Venard Lake, a 3.2-acre artificial impoundment stocked only with warmouths and largemouth bass, and Park Pond, an 18-acre flooded strip-mine area containing a fish population of 36 species. The intensive investigations in these two areas were supplemented by observations in other habitats and by published records on warmouth habitats and populations.

2. Field observations and published records indicated that the warmouth is usually associated with habitats characterized by soft bottoms and dense stands of aquatic vegetation.

3. In the water areas under observation, small and medium-sized (less than 5 inches total length) warmouths remained in protected areas of shallow water throughout the year, whereas larger individuals spent more time in deep, open waters.

4. Laboratory experiments supported field observations demonstrating that warmouths are able to survive in water having very low concentrations of dissolved oxygen. The critical oxygen tension observed was 2.5 cc. per liter at 20 degrees C. Tolerance for low oxygen concentrations allows the warmouth to survive and grow in a wide range of habitats and to survive during periods of water conditions that are generally considered unfavorable to fish.

5. The food habits of warmouths from Park Pond and Venard Lake were studied through a 12-month period. In volume and frequency of occurrence, the various food items identified in warmouth stomachs showed little similarity in the two areas, although crayfish and nymphs of mayflies, dragonflies, and damselflies were abundantly utilized at both places. During the summer months, feeding activity was at a peak early in the morning; it practically ceased in the afternoon.

6. Postlarval warmouths observed in the laboratory fed first on protozoa and bacteria. There was a general increase in size of food items taken by warmouths of Park Pond and Venard Lake as the fish increased in size; the percentage of stomachs that were empty was higher among large fish than among smaller ones.

7. In Venard Lake, warmouths and largemouth bass consumed about the same

kinds of foods, but differences in their feeding habits may have prevented extensive competition between these species.

8. Seasonal changes in appearance and weight of gonads indicated that the warmouths collected from Park Pond and Venard Lake attained sexual maturity when between 3.1 and 3.5 inches total length and that fast-growing fish matured earlier in life than did slow-growing ones. Warmouths over 5.4 inches total length attained spawning condition earlier in the nesting season, and spawned over a longer period, than did fish of smaller sizes. Males matured slightly earlier in the season than did females. In central Illinois, the spawning season for warmouths generally extends from mid-May through mid-August.

9. An estimation was made of the total number of eggs in ovaries of warmouths of different sizes, from different water areas, and taken at different times of year. Total egg counts ranged from 4,500 to 63,200 per ovary. Females from Park Pond consistently produced fewer eggs than did those from Venard Lake.

10. A month before the beginning of the spawning season, groups of developing eggs began moving away from the primordial egg-stock in sexually mature warmouth females. There was a gradual withdrawal of eggs from the egg-stock throughout the spawning season. Ova in advanced maturation were resorbed if not spawned before the cessation of nesting.

11. In all instances of warmouth nesting observed in the field, the male constructed the nest, usually near some projecting object and on a bottom of loose rubble containing some silt and detritus. No colony formation was observed.

12. Sex recognition among warmouths observed in the laboratory was based apparently on behavior and response to courting. Males displayed temporary color changes during courtship and spawning. There was evidence that many males and females spawned two or more times during a summer; in some instances, more than one female contributed to the complement of eggs in a nest.

13. In the laboratory, incubation of eggs lasted about 34.5 hours at temperatures between 25.0 and 26.4 degrees C. Immediately after hatching, the prolarvae dropped to the bottom of the nest. The

yolk supply was exhausted in 4 days, and the larvae attempted feeble, poorly directed jumps. By the fifth day, they swam actively. They began feeding by the seventh day; considerable pigmentation had developed and the caudal fin appeared homocercal. The 15.7-mm. young were essentially like an adult in body form.

14. The mathematical relationship (in inches) between the anterior radius of a warmouth scale magnified 41 times (S) and the total length of the fish (L) was expressed by the equation:

$$L=0.5278+1.048 S$$

15. In the populations studied, as the body length of the warmouth increased, the tail became relatively shorter; different mathematical relationships between standard length and total length were found for fish of various sizes.

16. The relationship of standard length in millimeters (L) to weight in grams (W) was expressed for 866 Park Pond warmouths by the equation:

$$\log W=-4.49867+3.04902 \log L$$

17. The coefficient of condition (C) for 866 warmouths from Park Pond showed no consistent seasonal cycle. Seasonal variations in condition were greater in warmouths between 3.3 and 4.2 inches than in larger fish. Coefficient of condition increased progressively with increase in size of fish.

18. The annulus was found to be a reliable year-mark in the warmouth. Warmouths in Park Pond completed the 1949 annulus between April 7 and May 20. Warmouths in Venard Lake completed the 1949 annulus over a shorter period than did those in Park Pond, where ecological conditions in the habitat varied greatly. Dredging of the shore of Venard Lake during August, 1948, is believed to have caused the formation of a false annulus.

19. Females from Park Pond were consistently smaller than males of the same ages. The difference was small, however.

20. Age was determined for 1,063 warmouths from Park Pond; it was found that fish of certain year classes had consistently grown more rapidly than others. Growth for all year classes was better in certain years than in others.

21. The 1946, 1947, and 1948 year classes in Park Pond showed different growth patterns for the summer of 1949.

The fish in each year class grew rapidly during May and June. Although growth continued through the summer for the younger fish, it declined rapidly after June for the 1946 year class. The 1947 year class showed a growth pattern intermediate between the earlier and later year classes. Growth rates were different for warmouths in different parts of Park Pond.

22. A comparison of length increments for the first and for later years of life showed that warmouths in Park Pond with the greatest length increment for the first year added to this length advantage the second growing season. Fish that grew slowly the first year showed a slight growth compensation during the third year, although they did not overcome the length advantage held by the larger fish.

23. Three year classes, represented by 1,102 warmouths, were studied in Venard Lake. Fish of the first year class spawned in the lake grew faster than did those of succeeding year classes. The length range in a single year class was greater during the first summer than in succeeding years. The average growth in length for warmouths in their first 3 years in Venard Lake was similar to that for warmouths of comparable ages in Park Pond.

24. Warmouths in Park Pond were heavily infested with *Posthodiplostomum minimum*, *Proteocephalus ambloplites*, and *Camallanus oxycephalus*. Except for an infestation of the leech, *Illinobdella moorei*, warmouths in Venard Lake were relatively free of parasites. No direct harmful effect of parasites was established.

25. Laboratory and field observations showed that the warmouth has a quiet disposition. In its reproductive and group behavior, it is similar to other centrarchids, but it displays certain behavioral characteristics peculiar to the species.

26. Reports and field observations demonstrated that the warmouth is caught on a wide variety of baits and lures, and that warmouth fishing is best during the spring and early summer months. The warmouth has been praised by sport fishermen for its fighting qualities. It is a useful fish for laboratory experimentation.

27. That warmouths have no tendency to become dominant at the expense of other kinds of fishes was indicated by the rela-

tively low proportions of warmouths reported in fish populations of Illinois and other states. In 17 ponds in central Illinois stocked with 11 different fish combinations that included warmouths with other spe-

cies—largemouth bass, smallmouth bass, and several pan fishes—warmouths tended to establish small broods each year without seriously restricting the reproduction or growth of companion species.

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- Volume 26, Article 1.—The Mayflies, or Ephemeroptera, of Illinois. By B. D. Burks. May, 1953. 216 pp., frontis., 395 figs., bibliog. \$1.25.
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ILLINOIS NATURAL HISTORY SURVEY

Bulletin

Printed by Authority of
the State of Illinois



A Century of Biological Research

HARLOW B. MILLS

GEORGE C. DECKER

HERBERT H. ROSS

J. CEDRIC CARTER

GEORGE W. BENNETT

THOMAS G. SCOTT

JAMES S. AYARS

RUTH R. WARRICK

BESSIE B. EAST

A CENTURY OF BIOLOGICAL RESEARCH IN ILLINOIS — 1950

STATE OF ILLINOIS • WILLIAM G. STRATTON, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION • VERA M. BINKS, *Director*

NATURAL HISTORY SURVEY DIVISION • HARLOW B. MILLS, *Chief*

NATURAL
HISTORY SURVEY



ILLINOIS NATURAL HISTORY SURVEY
Bulletin

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Urbana Illinois

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FOREWORD

THE record of one hundred years of the scientific progress of the Illinois State Natural History Survey inspires us to reflect on its origin and brilliant achievements. We pay the highest tribute to those early educators and scientists who had vision beyond the exigencies of the moment.

And we express the highest commendation to the present Chief, Dr. Harlow B. Mills, and all of his staff for their contributions to the well-being and pleasure of our citizens. The important results of their research extend well beyond the borders of Illinois.

In contemplating the future, we are confident that this group of dedicated men and

women will meet the increasing demands for assistance in the problems of the production of the necessities of life, that they will continue their research on the development and protection of our natural resources. In the future we may be dependent for our very existence on scientists such as these. We know they will meet the challenge.

Illinois is justly proud of the century of progress of one of its own agencies.

Congratulations!

VERA M. BINKS, *Director*
Department of Registration
and Education



The original building of the Illinois State Normal University, Normal, Illinois, spring, 1880. In this building the Illinois Natural History Society was founded and its museum was housed. Here the Illinois State Laboratory of Natural History had its headquarters from its founding in 1877 until late in 1884, and here the fourth State Entomologist was located for approximately 2 years.

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Aerial view, from the south, showing the Natural Resources Building on the University of Illinois in Urbana-Champaign. The central part of the building was completed in 1940, the two wings in 1950. The main offices and laboratories of the Illinois Natural History Survey occupy most of the west half of the building. The experimental greenhouse and its service building are shown in the left foreground.

From 1858 to 1958

HARLOW B. MILLS

THE mid-point of the nineteenth century in the United States was marked by ferment, by excitement, by great ideas. River traffic was at a peak; railroads had been built and were being extended. New areas were becoming more easily accessible to settlers. The point of departure to the exciting and mysterious Far West was on the Mississippi River, and two things happened just before 1850 which focused attention on that vast and largely unexplored area—the movement of the Mormons from Nauvoo, Illinois, on the banks of the Mississippi, to the Great Salt Lake, and the discovery of gold at Sutter's Mill in California.

The United States tried its muscles in the Mexican War in its first international conflict since its last test with England, and it ended Mexican dominance in California with the assistance of the Bear Flag Revolution.

Politically the young country was going through the series of events which ultimately led to the Civil War. On August 27, 1858, the most important of the Lincoln-Douglas debates, according to the estimate of some historians, took place at Freeport, Illinois. This debate is said to have won for Judge Douglas the Senatorship in his contest with Lincoln, but at the same time it lost the Presidency for the Judge in a later contest with the same adversary.

At the debate, there was a boy of fourteen who wormed his way to the front of the crowd and gained some renown by vocally taking issue with Douglas at one point in this historically climactic discussion. The youngster was considerably chagrined by reproof from those around him, but perhaps he was caught by the character of that meeting, for it is reported by George W. Smith (1927: 410) that

There was much confusion—some real disorder. . . . It appears from the reports that orators, reception committees, invited guests, and newspaper reporters all engaged in a

hand-to-hand conflict for seats and in some cases for standing room.

This boy who had the courage to challenge Judge Douglas was Stephen Alfred Forbes, later to be the person most responsible for the development of the Illinois State Natural History Survey, the centennial of which this number of the *Bulletin* commemorates.

Not only was this point in history one of swift movement and of critical importance in the politics and development of the country; it also brought science into clearer focus. Many scientific societies were organized. Darwin's *Origin of Species* appeared in 1859. Scientists were just beginning to play with the idea that their field was not a mental toy, that it could be put to practical use; and some scientists were announcing that they were interested in the practical application and popularization of their knowledge, much to the distress of most of their colleagues.

As an illustration, there is a rather long apology which Walsh (1868b:9) felt constrained to include in his *First Annual Report of the Acting State Entomologist*. Apparently this comment was written for the eyes of Walsh's scientific confreres; in part it says:

In a Memoir intended for publication in the Proceedings of some grave Scientific Society, it would, of course, be highly indecorous to break the dreary monotony of scientific hair-splitting by a single remark, which had the slightest tendency towards exciting that convulsive movement of the midriff, which the vulgar herd of mankind call "laughter." . . . Four hundred years ago Martin Luther said, that "he could see no reason why the Devil should run away with all the good tunes." I can see no reason, in the year 1867, why the pestilent yellow-covered literature of the day should monopolize all the wit and humor. If there is one thing which I have at heart more than another, it is to popularize Science—to bring her down from the awkward high stilts on which she is ordinarily paraded before the world—to show how sweet and attractive she is when the frozen crust, in which she is usually enveloped, is thawed away by the warm breath of Nature—. . . If I merely succeed in enticing away a single young woman from her

mawkish novelettes and romances into the flowery paths of Entomology, or if I can only induce a single young man, instead of haunting saloons and lounging away his time at street-corners, to devote his leisure to studying the wonderful works of the Creator, as exemplified in these tiny miracles of perfection which the people of the United States call "bugs," I shall think that I have not written altogether in vain.

The growth of the population of Illinois resulted in the bringing together, within the state's boundaries, of people with common interests in natural history. This field of knowledge had not gone unnoticed in this general geographical area, but the investigators here were individuals and worked pretty much alone. Just across the Wabash River to the east, Thomas Say had earlier done research on insects and other animal groups. Across the Ohio River to the south, John James Audubon had studied birds.

NATURAL HISTORY SOCIETY

Because by mid-century people interested in natural history had become more numerous in the state, Cyrus Thomas of Carbondale was able to propose to the December, 1857, meeting of the State Teachers' Association in Decatur that a Natural History Society of Illinois be formed (Bateman 1858*a*). The next year, on June 30, 1858, the Society was organized at Bloomington in the office of the Illinois State Normal University (Bateman 1858*b*:258-9). It was given official sanction and notice when it was chartered by an act of the state legislature approved February 22, 1861 (Illinois General Assembly 1861:551-2).

Immediately after its organization the new Society began the development of a museum and the collection of scientific literature.

Among its active members mentioned by Forbes (1907*c*:893-4) were C. D. Wilber, who later became a consulting mining engineer; Dr. J. A. Sewall, who later became President of the University of Colorado at Boulder; Major J. W. Powell, who was to gain renown as an explorer in the West; Dr. George W. Vasey, for many years botanist with the United States Department of Agricul-

ture; A. H. Worthen, head of the first Illinois State Geological Survey; Cyrus Thomas, Benjamin D. Walsh, M. S. Bebb, Dr. Oliver Everett, James Shaw, Dr. Henry M. Bannister, Dr. J. W. Velie, Professor J. B. Turner, Dr. Edmund Andrews, Dr. Frederick Brendel, and Newton Bateman. The above list indicates a great breadth of interest and no lack of intelligence on the part of the original members of the Society.

The first officers of the Society included a General Agent, among whose duties were the collection and exchange of specimens (Bateman 1858*b*:258). C. D. Wilber was named to this office. The Society's original constitution (Bateman 1858*b*:258) and the revised constitution of 1859 (Francis 1859*b*:662-3) provided that all specimens should be deposited in the Museum of the State Normal University.

The constitution as revised on June 20, 1859 (Francis 1859*b*:662-3), dropped the General Agent, gave most of his duties to a newly created Superintendent, and added a Curator, whose duties were to receive and arrange specimens. Cyrus Thomas, who was elected Curator, lived in Jackson County, many miles from the Museum, and the elected Superintendent, Wilber, who taught geology at the State Normal University, according to Marshall (1956) acted as unofficial curator.

At the 1860 meeting, R. H. Holder of Bloomington was named both Curator and Treasurer (Wilber 1861*a*:538).

The state charter of 1861 gave the Society authority to establish its own Museum at the State Normal University (Illinois General Assembly 1861:551), and officers of the Society set December 25, 1861, as the date on which the Museum was to be "dedicated, with appropriate exercises, as a FREE OFFERING TO THE CITIZENS AND SCHOOLS of Illinois" (Wilber 1861*c*:675).

Forbes (1907*c*:893) listed Sewall, Powell, Vasey, and himself as curators of the Society's Museum, Vasey serving only nominally as Powell's deputy. Powell was named Curator by the State Board of Education on March 26, 1867. His appointment was ratified and consented to on the same day by the Directors of the Natural History Society (Bateman 1867:

8). Forbes was appointed to the same office on June 26, 1872, the day Powell's resignation was offered and accepted (Bateman 1872:6).

Because the Natural History Society was composed principally of people who were prosecuting natural history investigations as sidelines to other activities, and because it was not a strong cohesive agent, it finally reached the point where it could no longer sustain itself. Forbes (1907c: 898) said of the times, "It should be remembered, in this connection, that this was a time when college men, as a rule, worked like dray-horses and were paid like oxen, . . ."

The Society turned to the state for aid, and by an act approved February 28, 1867, \$2,500, to be paid annually to the State Board of Education, was appropriated by the General Assembly for the salary of a curator and "for the necessary expenses of improving and enhancing the value" of the Museum (Illinois General Assembly 1867:21). Major Powell was the first curator to receive state aid. The state appropriations, according to Forbes (1907c:895), "were largely drawn upon to outfit and maintain the Powell expeditions to the far west." As a condition upon receiving further state aid, as provided by legislative act approved April 14, 1871, the Society had to turn its Museum over to the state (Illinois General Assembly 1872:152). On June 22, 1871, the Society agreed to the transfer and when, on June 28, 1871, the Board of Education accepted the transfer, the Museum officially became state property (Bateman 1871:9; Forbes 1877:324-5).

On December 15, 1875, the State Board of Education passed the following resolution (Etter 1876:17):

Resolved, That we regard the Museum as a State institution, devoted to the prosecution of a natural history survey of the State, to the encouragement and aid of original research, and to the diffusion of scientific knowledge and habits of thought among the people.

Forbes, who in 1872 had been appointed by the State Board of Education as Curator of the Museum, remained in that capacity until July 1, 1877, when by legislative act approved May 25, 1877, a State Historical Library and Natural History Museum were established at Springfield,

and the Illinois Museum of Natural History at Normal was "converted into a State Laboratory of Natural History" (Illinois General Assembly 1877:14-6).

STATE LABORATORY OF NATURAL HISTORY

The act that established the State Laboratory of Natural History relieved Forbes of the necessity of developing museum exhibits and allowed him to turn more of his attention to research. Shortly after the establishment of the Laboratory, Forbes' title was changed from Curator to Director (Etter 1877:25).

Forbes had not been occupying his time completely in the preparation of museum material while he was Curator of the Illinois Museum of Natural History. He had taught classes in zoology at Illinois State Normal University and he had started a series of bulletins reporting on research and investigation. The first number of the series is dated December, 1876, and carries the title, *Bulletin of the Illinois Museum of Natural History*. From the appearance of No. 2 of the first volume, in June, 1878, until the beginning of Volume 13, in 1918, the title was the *Bulletin of the State Laboratory of Natural History*, and from that time to the present it has been the *Bulletin of the Illinois State Natural History Survey* or *Illinois Natural History Survey Bulletin*. The volumes have been numbered serially from December, 1876, to the present time.

The work of the Laboratory and its young Director attracted the attention of the new Illinois Industrial University at Urbana. Not only had Forbes been publishing actively, but in 1882 the duties of State Entomologist had fallen on his capable shoulders. Shortly afterward the University made an offer of employment to the Director of the Laboratory and State Entomologist. Forbes faced the choice of declining the offer, of abandoning the Laboratory, which had been established at the Illinois State Normal University by legislative act, or of moving the Laboratory with him.

Apparently at his suggestion, the matter was taken up with the State Board of Education by the Trustees of the Illinois Industrial University, and an agreement

was made that the law be changed to allow for the move. In a report addressed to the Regent and dated December 12, 1884, Forbes made known his needs at the University (Burrill 1887a:10). He stated:

As you are doubtless aware, I have for some time held the position of Director of the State Laboratory of Natural History, located in the Normal University building at Normal, and, indeed, still remain in nominal charge of that establishment, having received from the State Board of Education a leave of absence, without pay, from January 1 to June 30, 1885, in order to enable me to enter upon my duties in the University here. If I believed that my acceptance of a chair in this University necessarily involved an interruption or serious modification of the work which I have organized as Director of the State Laboratory of Natural History, I should keenly regret it; and, indeed, I did not express my acceptance of that position until I had arranged a plan of readjustment which I thought adequate to prevent such a contingency.

Later in the same meeting, Trustee Alexander McLean offered the following resolutions (Burrill 1887a:18):

Resolved, That the Trustees of the Illinois Industrial University have heard with great satisfaction the suggestion that the State Laboratory of Natural History may be united with the University under their charge.

Resolved, That in case such a union shall be accomplished they will, to the extent of the means intrusted to them, aid in carrying forward the valuable work of the laboratory, by assigning to it suitable apartments in the building of the University, and by providing such conveniences as the nature of the work may require, to the end that it may enjoy a commodious and perpetual home within, and the generous coöperation of, an institution founded and maintained for the promotion of scientific research and the dissemination of practical knowledge.

Forbes officially took over his duties at Urbana on January 1, 1885 (Forbes 1886b:lx).

In the following March the Regent, Dr. Selim H. Peabody, had the following comment (Burrill 1887a:19-20):

The unsuccessful effort of three years ago to secure for the University the presence and aid of Prof. S. A. Forbes for the organization of the instruction of Zoölogy was renewed last year, and has been crowned with better fortune. Since the opening of the new year the Zoölogical laboratory has become an active agency in this department of physical science, and its success is well assured. A new interest has been aroused in this science.

The office of the State Entomologist has found a home, it is to be hoped permanent, where it naturally belongs. The governing board of the Normal University has unanimously resolved that the State Laboratory of Natural History should find its proper abode here at the State University, and has consented that the property peculiar to the work of that [laboratory] may be transferred hither. This change requires only legislative action before it can legally go, as it has practically gone into effect, and there appears to be little doubt that such action will be taken during the present session.

The legislature approved the action, and everything was legal.

On July 1, 1885, the appointment of Forbes as Professor of Zoology and Entomology at the University of Illinois (previously Illinois Industrial University) at an annual salary of \$1,160 was approved by the Board of Trustees, which also appointed Forbes Director of the State Laboratory of Natural History and authorized him to receive laboratory property transferred by the State Board of Education (Burrill 1887a:50). It is interesting to note the size of the Laboratory staff at that time. On September 8, 1885, the Trustees approved the following appointments (Burrill 1887a:55-6):

Entomological Assistants

Thomas F. Hunt \$40 a month

Clarence M. Weed \$40 a month

Botanical Assistant

Charles F. Hart \$45 a month

Amanuensis

Miss Mary J. Snyder \$45 a month

Services relating to botanical survey

Prof. T. J. Burrill \$300 for the year

F. S. Earle \$83 1/3 a month

Such other miscellaneous assistants as might be required and within the funds available

The State Laboratory of Natural History continued under that name until 1917.

STATE ENTOMOLOGIST

The rapid settlement of Illinois during the middle of the nineteenth century brought in a great number of agriculturists. The country was new, and the breaking down of the original vegetation for the establishment of fields in which crops were grown brought about great losses from insects. These losses, while

seen and experienced, were not well understood. Official entomology was born during this period. The agriculturists felt the need of assistance and cried out to the government for it.

At the end of the Civil War, the President of the young Illinois State Horticultural Society, John P. Reynolds, spoke vigorously on the subject at the December 19, 1865, meeting of the Society at Normal. In his retiring address, Reynolds (1866:8) said:

And, first, the appointment of a STATE ENTOMOLOGIST. The time has been in this State when it required some moral courage for any one to advocate the appointment and compensation from the treasury of an officer to look after the bugs, but I venture the opinion that there is no subject in which you, as amateur or professional horticulturists, have a more direct, immediate or larger pecuniary interest, than in Entomology— . . . No one who has given the subject any attention will question the truth of the statement that the people of Illinois are to-day many

millions of dollars poorer by reason of noxious insects; nor the additional statement that a very large proportion of this loss might have been averted by the labors of a competent Entomologist with a little means at his disposal.

In 1866 the Horticultural Society, meeting at Champaign, passed the following resolution (Deyo 1867:58):

Resolved, That we most urgently pray the honorable legislature of our great state to appoint a State Entomologist, that Agriculturists and Horticulturists may not quite despair of ever overcoming the giant insectiferous [*sic*] difficulties in the way of success in their professions. As one eminently qualified, and the highest in his profession in the whole west, we most hopefully mention the name of Benjamin D. Walsh, of Rock Island.

The Horticultural Society was not alone in this movement. At a meeting of the executive committee of the Illinois State Agricultural Society on January 3, 1866, G. W. Minier offered the following



University Hall on the University of Illinois campus. This building, completed in 1874 and razed in 1938, was headquarters for the Illinois State Laboratory of Natural History and the Office of State Entomologist for a few years after they were moved from Normal to Urbana.

specific and forthright resolution (Reynolds 1868:18):

Resolved, That whenever a sum of fifteen hundred dollars (\$1,500) shall have been obtained, by legislative action or otherwise, for an annual salary, this Board will then appoint a competent scientific man as State Entomologist.

Resolved, That Mr. B. D. Walsh be and he is hereby appointed State Entomologist, subject to the preceding resolution.

The legislature listened to these pleas and in 1867 passed a law which authorized the Governor, with the consent of the Senate, to appoint a state entomologist. The work of this officer was considerably handicapped. While he was voted a salary, he was given no work fund, and the first

three persons to hold the position maintained their offices in their homes or in offices devoted to other purposes. The job was a difficult one, and Forbes (1915: 7-8) once rather facetiously wrote:

He [Walsh] performed as well as he could his various duties of private, captain, colonel, adjutant, and major-general of this new force—and in two years he was dead. He had two successors enlisted for the war on precisely the same terms, the first of whom, Dr. Wm. Le Baron, of Geneva, Illinois, maintained for five years the unequal contest, when he also died; and the second, Dr. Cyrus Thomas, of Carbondale, abandoned the field in despair after seven years of diligent service, going then to Washington for work in another department of science, where he lived to the good old age of eighty-five. I have sometimes wondered if his long survival was



Benjamin Dann Walsh, State Entomologist, 1867-1869.

not largely due to his fortunate escape from an untenable situation.

Forbes set out to disprove this contention, and carried the duties, however with more help than his predecessors had, from 1882 to 1917, a span of 35 years.

Let us now look at the four men who carried the title and responsibility of Illinois State Entomologist.

Benjamin Dann Walsh

Although the resolutions passed by the State Horticultural Society and the State Agricultural Society in 1866 mentioned specifically Benjamin D. Walsh as a potential State Entomologist, Walsh did not obtain this title without some complications. An act providing for this officer was passed by the legislature and was approved on March 9, 1867 (Illinois General Assembly 1867:35-6). No appointment was made at that time. However, a special session was called on June 11 of the same year, and at that time the name of Walsh was presented for the Senate's approval. The session was called for specific purposes, of which the approval of an appointee as State Entomologist was not a part. Therefore, the Senate decided that constitutionally it could not act on this matter.

Walsh acted as State Entomologist, without legal status, and with an assignment of \$500 by the Horticultural Society, until the legislature passed an act "for the relief of the state entomologist," March 25, 1869 (Illinois General Assembly 1869:53-4). This act legalized what Walsh had been doing for nearly 2 years. It is interesting to note that Walsh's first annual report was made to the Horticultural Society and not to the Governor, and was signed by Walsh (1868*b*:3) as Acting State Entomologist.

Walsh was a most interesting person. He was born in Frome, Worcestershire, England, September 21, 1808 (Weiss 1936:234). He was well educated, and, about 1830, received a Master of Arts degree from Trinity College, Cambridge, where he was a classmate of Charles Darwin. He was married in England, and in 1838 he came to America. His wife had relatives in Henry County, Illinois, and he purchased a 300-acre farm in that part of the state. He operated the farm until

1851, when he moved to Rock Island and entered the lumber business.

He was not a politician, but in 1858, when he suspected that the city was being cheated by the city council, he placed his name in contention for alderman. His purpose was to get at the city's books. This action did not endear him to some elements of the city, and his life was threatened. Undaunted, he went ahead with a successful campaign, exposed the frauds, and resigned.

Although he had made a small collection of insects in England, he publicly had shown no deep interest in entomology until January, 1860, when he lectured for 2 hours to the State Horticultural Society. Thereafter he contributed regularly to the *Prairie Farmer* and other agricultural journals. Further, in the proceedings of scholarly societies, he published several excellent scientific papers on insects. He collaborated with E. T. Cresson, A. R. Grote, and J. W. McAllister in the publication of a monthly called the *Practical Entomologist*, which lasted for only 2 years, until September, 1867. In September of the following year, Walsh and C. V. Riley started the *American Entomologist*.

On November 12, 1869, as Walsh was walking down a railroad track, busily engrossed in reading a letter, a train approached. When he saw the train, he was too late to clear himself completely, and his left foot was badly injured. The foot was amputated, and to console his wife he said, "Why, don't you see what an advantage a cork foot will be to me when I am hunting bugs in the woods: I can make an excellent pin-cushion of it, and if perchance I lose the cork from one of my bottles, I shall simply have to cut another one out of my foot" (Riley 1869-70:65).

He published an article exonerating the engineer from all blame in the accident.

He appeared to be recovering well from the accident when suddenly he began to decline, apparently from some internal injury. He passed away on the 18th of November, 1869.

William Le Baron

In 1870 Governor John M. Palmer requested William Le Baron to take over the position left vacant by the unfortunate

death of Walsh. This request was quite unexpected, for entomology was only an active side interest of this competent physician.

Things which are half-said in history pique the imagination. We find that Dr. Goding (1885:123), in a biographical sketch of Le Baron, had the following to say:

In 1870 two candidates appeared for the office of Illinois State Entomologist made vacant by the untimely death of the lamented Walsh—Dr. Henry Shimer of Mt. Carroll and Mr. Emery of the *Prairie Farmer*, both of whom were well qualified for the position. For reasons that cannot be given at this time, Gov. Palmer refused to appoint either, but

named *Dr. Le Baron* for the place, taking him entirely by surprise.

Le Baron was a native of North Andover, Massachusetts, where he was born October 17, 1814. He came from a line of New England professional people; his father was a medical doctor and his maternal grandfather was Dr. Thomas Kittredge, a well known and highly respected surgeon of his day.

Le Baron's calling was decided at an early point in his life. After studying medicine under an uncle, Dr. Joseph Kittredge, he practiced for several years in his home town. Later he completed his medical studies and was graduated from the



William Le Baron, State Entomologist, 1870-1875.

Harvard Medical College. In 1844 he moved to Geneva, Illinois, where he continued a successful career as a physician.

As a child he was greatly interested in nature, moving from ornithology to botany to entomology. In 1850, after 6 years in Illinois, he published his first article, a

way. He died on October 14, 1876. The excellence of his four reports is a measure of the high ability that Le Baron possessed.

Cyrus Thomas

The third State Entomologist did not attend college (Goding 1889:106). The



Cyrus Thomas, State Entomologist, 1875-1882.

treatise on the chinch bug, in the *Prairie Farmer*. This study was so exhaustive that Asa Fitch, the New York State Entomologist, republished it in his Second Report. In 1865 Le Baron was made the entomological editor of *Prairie Farmer*.

In the position of State Entomologist he labored diligently until his health gave

competence Cyrus Thomas attained was the result of his own personal labors. He was a versatile and practical person. He was born in Tennessee, July 27, 1825, and his mother had hoped that he would become a physician. In 1849 he moved to Jackson County, Illinois, where he studied law and taught school. In 1851 he

was admitted to the bar and was elected county clerk. About 1864 he dropped law and entered the ministry.

For some time, Thomas had considered entering the field of science and, as evidence of his practicalness, in 1856 he deliberately began the study of entomology as being a field which was inexpensive and in which there was an abundance of material close at hand upon which he could work. He became an authority on the Orthoptera. He wrote many articles on entomology, some of which he contributed to farm journals.

From 1869 to 1874 he was associated with the federally sponsored Hayden Geological Survey, paying special attention to the entomology and agricultural resources of the West. During this period he published many reports of entomological significance.

In 1874 Thomas was elected to the Professorship of Natural Sciences at Southern Illinois Normal University, whereupon he severed his relationship with the federal survey. The next year, 1875, he was appointed by Governor Richard J. Oglesby to take the place of Dr. Le Baron as State Entomologist. Six reports were published by Thomas and his collaborators.

On March 3, 1877, the United States Entomological Commission was authorized by Congress. Thomas found time, along with his regular work, to become a member of this Commission. Other members of the Commission were C. V. Riley and A. S. Packard, Jr. Thomas was not collaborating with amateurs when he joined these two men on the Commission. Both were giants in the profession—names that still command respect. Riley was State Entomologist for Missouri, as well as a member of the Commission, and the real originator of entomological research in the federal government. Packard was a scholarly gentleman, a member of the National Academy of Sciences and other learned groups, and an author of note in his field.

Thomas was a man of real capability, holding, as he did simultaneously, a professorship at Southern Illinois Normal University, the State Entomologist's responsibility, and membership on the historic federal Entomological Commission.

Thomas was interested in many things, and in July, 1882, he resigned his various Illinois positions and accepted employment in the Smithsonian Institution's Bureau of Ethnology, leaving a brilliant and uncompleted career in entomology. He was to gain further laurels in archeology and to become an authority on the Mayan language.

About some things he was adamant. He published a review of Darwin's works from an orthodox view, which so impressed the officials of Gettysburg College that they hastened to award him an honorary Ph.D. degree.

Thomas lived to be 85 years old, passing away on June 27, 1910.

He bears a peculiar relationship to the Natural History Survey, for he is credited with having first proposed an Illinois Natural History Society in 1857, and he was a State Entomologist.

Thomas was a man of multiple aptitudes, as the above sketch indicates. He moved his intellect in many fields: school teacher, lawyer, county official, minister, entomologist, explorer, college professor, and archeologist.

Stephen Alfred Forbes

No one has molded the character of the Natural History Survey so much as Dr. Forbes, a man of irrepressible intellect and insatiable curiosity, and the fourth and last Illinois State Entomologist.

Forbes was born of pioneer parentage on May 29, 1844, in Stephenson County, Illinois. He was one of a large family. His father died when he was 10, and a brother assumed the responsibility for an invalid mother, Stephen, and a younger sister. Stephen attended district school until he was 14, and his brother carried on his education for 2 more years. For a short time in 1860 he attended Beloit Academy. He had an innate interest in language, and on his own he learned to read French, Spanish, and Italian.

When the Civil War broke out in 1861, Forbes was 17. He joined Company B, 7th Illinois Cavalry, in September of that year. He rapidly advanced from orderly to sergeant to lieutenant to captain, reaching the last rank when he was 20. In 1862 he was captured while carrying dispatches near Corinth, Mississippi, and



Stephen Alfred Forbes in the 1880's, while State Entomologist and Director of the State Laboratory of Natural History at Normal.

was in Confederate prisons for 4 months. During this period of enforced idleness he studied Greek from books he managed to buy at Mobile. He participated in 22 military engagements, and, other than suffering from scurvy and malaria while in prison, he emerged from the war unscathed.

At the end of hostilities he entered Rush Medical College in Chicago. Because of lack of funds and certain psychological difficulties revolving around surgery without anesthesia, he never finished the course. After leaving Rush, he taught school and, on the side, studied

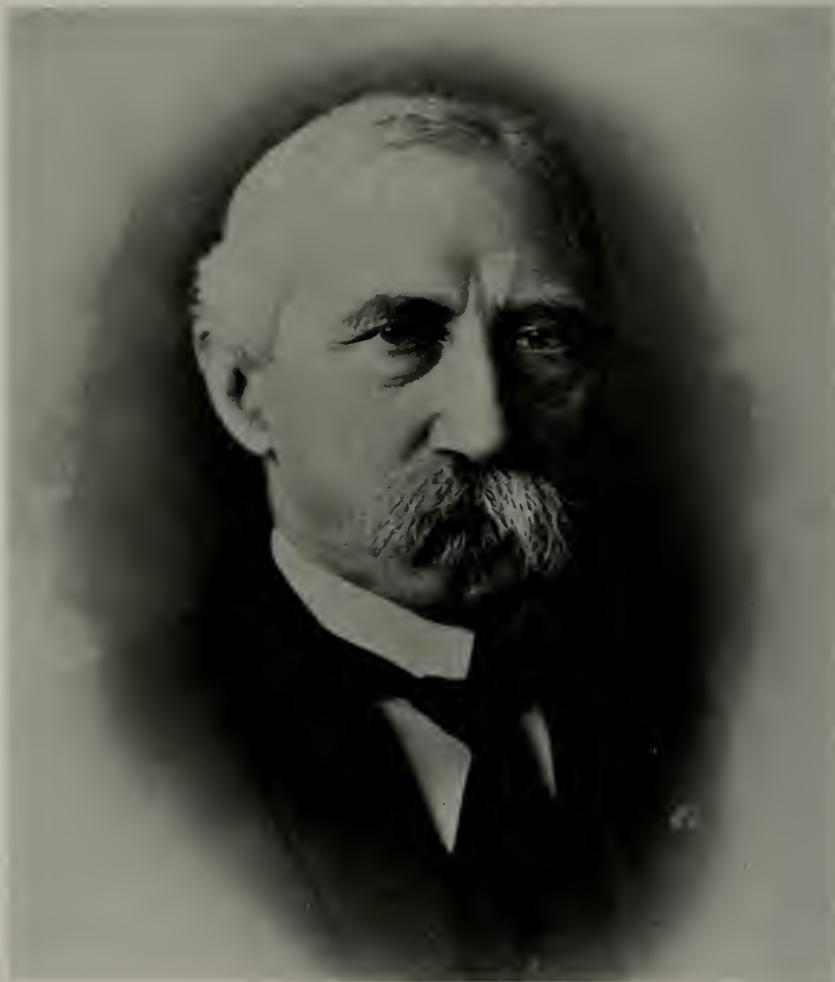
natural history. His first publications appeared in 1870, and these led to his appointment in 1872 as Curator of the Museum established by the State Natural History Society at Normal. He held this position until 1877, when he was appointed to head the State Laboratory of Natural History, the child of the Museum.

After the resignation of Thomas as State Entomologist in 1882, Governor Shelby M. Cullom appointed Forbes to that position. In 1884 Indiana University awarded Forbes the Ph.D. degree "by thesis and examination." He did not have a bachelor's degree. In 1885 he moved to

the University of Illinois, where he was Professor of Zoology and Entomology, Director of the State Laboratory of Natural History, and State Entomologist. He was Professor of Zoology for 25

he directed the first forest surveys of Illinois. These represent only a few of his innumerable interests.

He was a member of many learned societies and the recipient of many honors.



Stephen Alfred Forbes in about 1915, shortly before being named Chief of the Illinois Natural History Survey at Urbana.

years, Professor of Entomology for 13 years, and Dean of the College of Science for 16 years.

He was especially interested in the interactions of organisms and has been called "the father of ecology." His interests covered all of biology. He investigated or directed investigations of the food of fishes and birds, the fishes of the state, and the biology of the Illinois River, and

Beyond this, he was active in his church, helped organize the first golf club at the University, was a member of a hiking club, and late in life delighted in driving an automobile. On his eightieth birthday he was arrested for speeding, an incident which gave him some pleasure.

When the State Laboratory of Natural History and the State Entomologist's Office were united in 1917 to form the Nat-

ural History Survey, Forbes became the first Chief of the new organization. He held this position until his death, March 13, 1930, when almost 86 years of age.

The four sketches above cannot do justice to the entomological pioneers who are their subjects, but they will give some indication of the high quality of the men. All were competent individuals with

the State Laboratory *Bulletin* by University staff members.

The State Entomologist's responsibilities changed as time went on, and the agency became responsible for the administration of some laws, as well as for research (Forbes 1909:64-5). With the discovery of the San Jose scale in Illinois in 1896, there was concern over the pos-



The Natural History Building on the University of Illinois campus. About 1894 headquarters and laboratories of the Illinois State Laboratory of Natural History and of the State Entomologist were moved into this building. From July 1, 1917, until the middle of 1940 it housed the main offices and most of the laboratories of the Illinois Natural History Survey.

high standards, even though they came from widely different backgrounds and possessed widely different trainings.

(Among the sources of biographical material on Forbes are Anon. 1930, E. B. Forbes 1930, Ward 1930, Howard 1932, Van Cleave 1930, 1947, and Marshall 1956.)

Reorganization

Forbes administered the State Laboratory of Natural History and the State Entomologist's Office as a unit, interchanging personnel and materials. Further, he made these agencies available to the University of Illinois in many ways, and considerable publishing was done in

sible spread of other pests into the state. In 1899 legislation was passed giving the State Entomologist large powers in inspection, certification, and quarantine. Other duties were added in 1907.

According to Forbes (1909:55, 66), in 1909 the staffs of the two agencies consisted of the following:

State Laboratory of Natural History

- 1 Director
- 1 Entomologist
- 2 Zoological Assistants
- 1 Artist
- 1 Secretary

Special assistants from time to time

State Entomologist's Office

- 1 State Entomologist

- 10 Assistants
- 1 Draftsman
- 1 Chief Inspector
- 4 Temporary Inspectors
- 1 Foreman
- 12 Laborers

Forbes' interest was primarily in research and not in administering laws.

During the reorganization of state government under Governor Frank O. Lowden's administration, the chance came to make changes which would bring Forbes' interests into clearer focus. The State Laboratory of Natural History and the research activities of the State Entomolo-

gist were brought together in 1917 under a new name, the Natural History Survey. This Survey was placed in the Department of Registration and Education along with the two other scientific surveys, Geological and Water. The administration of quarantine laws and the like was transferred to the State Department of Agriculture.

NATURAL HISTORY SURVEY

We have followed the meanderings of organization from the Illinois Natural History Society of 1858 through the So-



Theodore Henry Frison, Acting Chief, 1930-1931, Chief, 1931-1945, Illinois Natural History Survey.

ciety's Museum to the Illinois State Laboratory of Natural History. We have also discussed the development of the State Entomologist's Office from 1867 and have seen this office united with the State Laboratory in their research duties to form the State Natural History Survey in 1917.

A new type of administrative responsibility was set up in the Civil Administrative Code of 1917, which has remained essentially unchanged to the present time. The Code (Illinois General Assembly 1917:34) stated that:

Unless otherwise provided by law, the functions and duties formerly exercised by the State entomologist, the State laboratory of natural history, the State water survey and the State geological survey and vested by this Act in the department of registration and education, shall continue to be exercised at the University of Illinois in buildings and places provided by the trustees thereof.

Within the Department of Registration and Education was established a Board of Natural Resources and Conservation; this Board is the responsible agent for the activities of the Natural History, Geological, and Water Surveys. The charge (Illinois General Assembly 1917:34) under which this group has worked through the years has been to

1. Consider and decide all matters pertaining to natural history, geology, water and water resources, forestry, and allied research, investigational and scientific work;
2. Select and appoint, without reference to the State civil service law, members of the scientific staff, prosecuting such research, investigational and scientific work;
3. Co-operate with the University of Illinois in the use of scientific staff and equipment;
4. Co-operate with the various departments in research, investigational and scientific work useful in the prosecution of the work in any department.

The Board consists of the Director of the Department of Registration and Education, who is chairman, the President of the University of Illinois or his representative, the President of Southern Illinois University or his representative, all of whom are *ex officio* members, and, in addition, experts in the fields of geology, biology, chemistry, forestry, and engineering who must have had a minimum of 10 years of experience in their professions. Expert members are appointed by the

Governor and they have traditionally held long appointments. The biological scientists who have given or are giving of their time in this important state activity were or are William Trelease, John M. Coulter, Henry Cowles, Ezra J. Kraus, Carl G. Hartman, Lewis H. Tiffany, and Alfred E. Emerson.

The present Board consists of Director Vera M. Binks, Dean William L. Everitt (the representative of President David D. Henry of the University of Illinois), President Delyte W. Morris of Southern Illinois University, Dr. Walter H. Newhouse, Dr. Roger Adams, Mr. Robert H. Anderson, Dr. Lewis H. Tiffany, and Dr. Alfred E. Emerson.

The Board meets quarterly, receives reports from the Chiefs, counsels with them on their research programs, appoints their scientists, and examines and approves their budgets.

To return now to 1917: When the reorganization took place, Forbes, who was Director of the State Laboratory of Natural History and State Entomologist, was retained as Chief of the Natural History Survey. He remained as Chief until his death in 1930, and was extremely alert mentally until 9 days before his death.

Not long after the turn of the century, Dr. J. W. Folsom of the University of Illinois Department of Entomology was walking down a street in Urbana when he discovered a youngster who was engrossed in observing a colony of ants. Folsom engaged the boy in conversation and was impressed with his interest and knowledge. Thus began a close and personal relationship between Dr. Folsom and young Theodore Henry Frison.

Frison was born in Champaign, Illinois, on January 17, 1895, and was educated in the schools of that city. Through Dr. Folsom he became acquainted with Dr. Forbes, and these two scientists allowed the boy to attend University courses prior to high school graduation (Campbell 1946). Frison was in the army for a short time in 1918, after which he returned to the University, which awarded him all of his degrees. After short professional appointments in Wisconsin and New Jersey, and upon receiving his Ph.D. degree, he joined the staff of the Natural

History Survey as Systematic Entomologist. This was in 1923. Upon Forbes' death in 1930, Frison was made Acting Chief, and on July 1, 1931, he was appointed Chief.

Frison was an indefatigable worker, becoming a specialist in bumble bees,

concluded that it would be essential that they attempt to obtain funds for a separate building. In this attempt they were successful. The University assigned an area for the building, and in 1940 the two Surveys began the move into a new Natural Resources Building, built for



Leo Roy Tehon, Acting Chief, Illinois Natural History Survey, 1945-1947.

aphids, and stoneflies. His tenure as Chief was marked by growth in staff and facilities. In the 1930's the growth of his organization was such that it was difficult to find space for the personnel in the rooms which the University could devote to use of the Natural History Survey. Dr. Frison and Dr. M. M. Leighton, Chief of the Illinois Geological Survey, conferred on the problems of space and

their occupancy. The building, and subsequent wings which were completed in 1950, were given to the University and added to that organization's inventory. For the first time, the Natural History Survey had a home which it could really call its own.

Frison had wide interests, and immediately upon becoming Chief he began the development of wildlife research. This

field, as a separate discipline, was new. He was instrumental in organizing the Midwest Wildlife Conference, the initial meeting of which was held in Urbana in 1935. Also he was a charter member of the Wildlife Society.

The staff of the Natural History Survey increased from 16 in 1930 to 38 at the beginning of World War II.

In intellect and aggressive enthusiasm, Frison was a worthy successor of Forbes. He made many contributions to knowledge. He was a member of many learned societies and was given positions of responsibility in them. Beyond that, he was a golf and tennis player, a fine violinist, and had a great interest in art, history, and current affairs.

It was a loss to the Natural History Survey, and to science, when he passed away December 9, 1945, after 15 profitable years as Chief.

On December 10, 1945, Dr. Leo R. Tehon was appointed Acting Chief, a position which he held until February 28, 1947. Tehon was a meticulous scholar. He was not only a fine plant pathologist and mycologist, but also a good linguist and musician (Carter 1955, Ayars 1956).

On March 1, 1947, Dr. Harlow B. Mills, the present incumbent, took over the duties of Chief.

THE FUTURE

Throughout its century of existence, this organization has attempted to meet the needs of the economy of Illinois with an eye to the state's future requirements. The Board has appointed scientists with broad views and excellent training, men who were not satisfied with the present but who had a strong interest in the future. A half century ago Forbes (1907c:892) wrote, "I shall be governed by the reflection that we are to-day looking forward and not back—that we are preparing for the future and not studying the past— . . ." The same fresh view should govern us at the end of 100 years. The problems in nature are ever changing, or, rather, our needs from and approach to nature are ever changing. There are new demands and new approaches. New research techniques require re-evaluation of what has been done. In agricul-

ture there are new crops and new methods of raising them. New plant diseases appear. New insect pests invade the state. New demands are made for recreation. New advances in pure scientific knowledge must be made. All of these demands and approaches require the attention of the research specialist. All are inextricably bound up in the future. A scientist who looks only to the past is professionally dead.

Perhaps the greatest challenge of the future lies in the indisputable fact that human populations in the world—and that includes Illinois—are increasing. The demands which these people make on their environment are increasing more rapidly than are the people themselves! For most of our food and living room we are dependent on that surface which marks the boundary between the earth and the atmosphere, on that surface upon which the sun's rays strike. We are dependent on it for our food and for our relaxation. More people mean greater food demand and greater need for removing ourselves periodically from the intricacies of a complex civilization. More people mean a reduction in space for both of these necessities. This is the dilemma of the future. As the years roll by and the population statistics pile up, our dependence for existence on our living resources constantly becomes greater, and our dependence on the research scientist in fields of interest to the Natural History Survey becomes a complete necessity.

Now, in 1958, we are concerned about the great strides made by the physical sciences. These advances have great potential for good and tremendous potential for human destruction. International scientific competition has raised its head. If the deleterious side of this physical science development is kept in check, we can be sure that the need for sustaining humanity, both physically and spiritually, will be colossal in the years ahead.

We hear in 1958 of "crash programs" to develop in the shortest possible time certain phases of physical science application. When the collective human population of the United States has to tighten its collective belt just one small notch, we will hear of a "crash program" the like of which has not as yet even been



Harlow Burgess Mills, Chief, Illinois Natural History Survey, 1947 to date.

conceived. And when that time comes, the Natural History Survey will be called on for even greater activity.

In closing this discussion, it would be well to call attention to a House Joint Resolution introduced in the Seventieth General Assembly of the State of Illinois by Representatives Ora Dillavou, Charles Clabaugh, and Leo Pfeffer (Illinois House of Representatives 1957). The Resolution reads as follows:

WHEREAS, On June 30, 1858, a group of far-sighted citizens of this State met at Bloomington and organized the Illinois State Natural History Society which was incorpo-

rated in 1861 by an Act of the legislature; and

WHEREAS, In 1877 the name of the society was changed to the State Laboratory of Natural History, and in 1885 the laboratory was moved to Urbana where it was placed under the direction of the Board of Trustees of the University of Illinois; and

WHEREAS, The State Laboratory of Natural History and the research activities of the State Entomologist's office were united in 1917 to form the State Natural History Survey Division of the Department of Registration and Education; and

WHEREAS, The Natural History Survey has rendered outstanding service in the field of natural history, especially in regard to the control of noxious insects, the control of

diseases attacking floricultural and ornamental plants, the development of forestry in Illinois, the management of fishes in ponds and streams, the foods and movement of waterfowl in this State, the problems of upland game species, and the periodic report of species which are especially endangered, such as the prairie chicken and wood duck; and

WHEREAS, The following world recognized scientists and scholars have been associated with the wonderful work of the Natural History Survey: Stephen A. Forbes, Robert E. Richardson, David S. Jordan, Frank C. Baker, Charles A. Kofoid, Robert Ridgway, Benjamin D. Walsh, Wesley P. Flint, Victor E. Shelford, Theodore H. Frison, and Leo R. Tehon; and

WHEREAS, Since 1858 the Natural History Survey has received wide recognition for its contributions to society, has gained the respect of scientists throughout the world, has brought considerable prestige to this State,

and, above all, has contributed immeasurably to the welfare of all the people of this State; and

WHEREAS, The 100th anniversary of the Natural History Survey will be celebrated in 1958; therefore, be it

Resolved, By the House of Representatives of the Seventieth General Assembly of the State of Illinois, the Senate concurring herin, that this General Assembly, on behalf of all the people of this State, extend heartiest congratulations and sincere appreciation to the staff, members and employees of the State Natural History Survey Division, on the occasion of their 100th anniversary, for the outstanding contributions they have made toward the growth and development of this State; that we extend to them a wish for continued success and progress in the future, and that a suitable copy of this preamble and resolution be forwarded to the chief of the State Natural History Survey Division, Mr. Harlow B. Mills.

Economic Entomology

GEORGE C. DECKER

WHEN settlers moved into the Illinois country, established homesites, and began to till the virgin soil, they found that hundreds of species of insects native to the area readily transferred their affections from wild plants to cultivated crops, at times in hordes sufficient to destroy the crops completely. It was inevitable that the Illinois settlers, like the eastern colonists, had brought certain pests along with them. The hitch-hiking pests included the codling moth in apple barrels, the hessian fly in straw used as packing material, bedbugs in bedding, and lice on the bodies of the settlers. As if these were not enough, other migrants, such as the Colorado potato beetle, the imported cabbage butterfly, the cotton leafworm, the San Jose scale, the Norway rat, and the fleas thereon, invaded the area. They were followed in later years by such notorious insect pests as the oriental fruit moth, the European corn borer, the sweet clover weevil, the Mexican bean beetle, and the Japanese beetle.

The early Illinois settlers were a hardy, self-sufficient, and determined lot, generally not rich but for the most part thrifty and aggressive. They took pride in the fact that they were skilled in the agricultural arts of their day. At the same time, they admitted that the problem of coping with the many insect pests that damaged their crops, annoyed their livestock, and invaded their homes was beyond their comprehension. They sought the aid of neighbors, school teachers, doctors, and local amateur naturalists, who in turn sought the counsel and advice of Fitch, Harris, and other entomologists located in the far-off New England and Atlantic coastal states. When these sources of information proved inadequate, the settlers appealed to the state legislature to appropriate funds and to appoint a state entomologist to study what appeared to be the most perplexing of all their problems. On February 27, 1867, the Illinois Gen-

eral Assembly created the office of State Entomologist.

EARLY HISTORY

Pleasant surprises await the curious who attempt to assay the extent and usefulness of man's knowledge of insects, their habits, and control measures in the 1850's and 1860's. It is gratifying to note that local, self-trained entomologists such as Walsh, Le Baron, Thomas, Shimer, and Riley had collected and identified hundreds of species and that they possessed a remarkable knowledge of the life cycle and ecology of perhaps three-fourths of the economic species ordinarily included in any current list of noxious insects in the Midwest. Le Baron (1871:5-6) summarized the situation as he saw it at that time:

The history of many of our noxious insects, and especially the most notorious of them, has been pretty thoroughly traced, not only by the entomologists expressly employed by several of the States for this purpose, but also by many other active gleaners in this field. Still, any one who enters upon the study of this extensive subject, soon finds work enough upon his hands. It cannot be said that the history of any insect is perfectly and absolutely known, and it is a notorious fact that some of the insects which have been longest known and studied, such as the Plum Curculio and the Apple Worm, are the very ones which are causing the most damage to the horticulturist at the present day; and if we take into account the multitude of insects which are preying upon our shade and ornamental trees and shrubs, which, in the estimation of many, are scarcely inferior in value to the fruit bearing trees, we may safely conclude that the prospect is very remote when the work of the practical entomologist will cease or materially diminish. And the force of this view is greatly enhanced by the [occurrence], every year, to a greater or less extent, of new species of noxious insects, or rather of insects which, having existed here or elsewhere in moderate numbers, from time immemorial, have suddenly sprung into destructive profusion in consequence of an abundant supply of congenial food, or the absence of their natural enemies, or other conditions favorable to life, some of which are known, and some of which are obscure or in-

scrutable. The Colorado Potato-beetle, the Currant Saw-fly, the Asparagus-beetle, and the *Bruchus granarius*; to which we might add the Pear-caterpillar (*Callimorpha lecontei*), and the Lesser Apple-leaf folder (*Tortrix malivoreana*), treated of in the following report, were all unknown here as noxious insects until within the last few years. It is true that some noxious insects, on the other hand, have greatly diminished, and some, which have been the sorest scourges of the orchardist, such for example, as the notorious Bark-louse of the apple tree, seem to be in the process of extinction.

Walsh and the others acquired much of their knowledge through their own observations and experience, but obviously they were familiar with most of the world literature on the subject. Furthermore, it seems reasonably certain that then, as now, much unpublished knowledge on the subject was transmitted from individual to individual through correspondence and conversation, some of it even as tradition. We know that pioneer naturalists obtained considerable information from the Indians. For example, the English explorer, Jonathan Carver (1778:493-4) wrote of his travels among the American Indians in 1766:

I must not omit that the LOCUST [grasshopper] is a septennial insect, as they are only seen, a small number of stragglers excepted, every seven years, when they infest these parts and the interior colonies in large swarms, and do a great deal of mischief.

One may be more than a little surprised to discover that several local amateur naturalists—doctors, lawyers, college professors, orchardists, and agriculturalists, never referred to as or considered to be entomologists—knew many of the common insects by name and possessed a knowledge of their biology and habits adequate to permit these men to engage in lengthy and intelligent discussions on the subject at meetings of agricultural and horticultural societies. For example, Dr. E. G. Mygatt (1855), a physician, wrote an essay, "Bark Louse of the Apple Tree," for the first *Transactions* of the Illinois State Agricultural Society, 1853-54, and J. B. Turner (1859), a professor of Latin and Greek, presented a paper, "Microscopic Insects," at the first meeting of the Illinois Natural History Society in 1858. It is interesting to note that at this time two men, Le Baron (1855)

and Thomas (1859a), each one later appointed to the office of State Entomologist, were presenting papers on Illinois birds and other topics in the field of natural history.

In the light of these pleasant surprises, one is amazed to realize that the combined knowledge of all the experts was almost nil when it came to questions of practical control measures that could be employed to eliminate these pests or even to reduce materially the annual losses attributable to them. It is possible that the paucity of practical information can best be understood if we recall that for many years it was believed well-nigh sacrilegious for a scientist to consider the practical application of his accumulated knowledge; as the distinguished Professor Louis Agassiz (1863:24) once said, "the man of science who follows his studies into their practical application is false to his calling."

Local and national repudiation of this philosophy contributed to the industrial and agrarian crusades that resulted in creation of state entomologists' offices and land grant colleges. Touching upon the new philosophy of science and education in addressing the founders of the Illinois Natural History Society at their first meeting in 1858, Turner (1859:647) said:

In respect, also, to those grosser forms of vegetable and animal life, it seems to me that our research should in future aim more directly at practical utility than in the past.

We are quite too content with mere description of forms and names, sometimes, without pushing our inquiries into the causes, relations and uses, and evils of things. . . .

We need not simply to christen all these things—not simply to name the beasts, but also to rule over them, as did our great father Adam; and, also, all other forms of matter. And we cannot do this till we know minutely their history, habits and relations to other things and beings.

The grand end to be aimed at, in reference to most forms of fungi and parasites of all sorts, is their prevention or destruction. But a vast amount of minute antecedent knowledge is needed before we can hope to say, "thus far and no farther," even to one single race or tribe, much more to the vast myriad of races and tribes.

Benjamin Walsh, the first State Entomologist of Illinois, was in full accord with the views of Turner. In addressing

a meeting at Cobden, Illinois, in November, 1867, he said:

I do not regret to say that I belong to the modern school of science, and think it no degradation, so far as my specialty is concerned, to bring science to the aid of practical men in the related departments of human industry. And I need not tell you, for you know, that insects pick your pockets, and that to fight them successfully it is necessary to know their habits and how to distinguish friends from foes (Walsh 1868a:143).

Cyrus Thomas subscribed to the new philosophy several years before he became State Entomologist.

And the study of natural history is a useful study, having many direct practical advantages. Agriculture is the pedestal on which the stately fortunes of bankers and merchant kings are reared, and as the pedestal contracts or expands, so rises or falls the lofty column (Thomas 1859a:667).

Therefore, we say, that natural history should be studied for the practical use made of the knowledge obtained. And, if it be a study so desirable and so useful, the question arises, *Should not the study be generally introduced into our schools and colleges?*

I answer, most emphatically, yes! There is no other branch of physics, nor any branch of metaphysics so important and so necessary to be studied in the school room as natural history. And I am glad to see that quite a number of institutions have ventured to cross the Rubicon; yet others are halting at the brink, fearful of the result (Thomas 1859a:668).

Thus, the first and third State Entomologists publicly expressed their views. They took office dedicated to the task of assisting the residents of the state of Illinois to find practical solutions for their numerous and complex entomological problems. Their successors followed the same course.

PRACTICAL PROBLEMS AND PROGRESS

Change is eternal in the insect world; thus, it appears that the need for continued study of insects will never end. This situation may be confusing to laymen, but entomologists and others who have closely studied nature realize that insects are dynamic creatures subject to constant change in characteristics. Because of their great mutability, insects have survived in an ever-changing world for millions of years and are still capable of

making the necessary adjustments to many of the important changes in their environment. Most of the important ecological changes in an area or community are accompanied by changes in the insect fauna; some species drop out and others move in.

Every agricultural practice adopted or discarded by man induces a significant environmental change or modification which will favorably or unfavorably affect insects and, for that matter, all other living organisms in the area involved. Changes in crop rotations, fertilization practices, pruning, or drainage will prove favorable for some species and unfavorable for others.

At the time the Office of State Entomologist was established in Illinois, fruit and vegetable crops could not be economically produced and marketed in the state without reasonably effective insect control. Since the high per acre value of such crops seemed to warrant expenditures for insect control, Illinois producers of these crops demanded and received a large share of the Entomologist's time. As the nature and magnitude of insect losses in other agricultural and nonagricultural areas became more apparent and better understood, pressures from a multitude of other sources necessitated a realignment and much greater diversification of entomological research.

Space will not permit enumeration and full discussion of all the insect problems that have arisen to plague Illinois farmers in the past century and it will not allow a detailed review of the thousands of printed pages that have been used to record the findings of research conducted during this period. Therefore, in the brief resumé that follows we confine our attention to a few specific examples.

Fruit Insects

In 1868 an editor of *The American Entomologist*, probably Walsh, summarized the fruit insect situation as follows:

It is notorious among fruit growers, that the Curculio has now almost entirely vetoed the cultivation of the plum; and of late years this pernicious little Snout-beetle has extended its ravages to the peach, and even to the apple and pear, to say nothing of those rarer and

choicer fruits, the nectarine and the apricot. The strawberry and the grape vine are infested by a host of insects, some of them known for many years back to science, others described and illustrated for the first time by the editors of this paper in various publications; while there are still others the natural history of which has never yet been published to the world, and which will be figured and described by the editors in the progress of this work. What with the Bark-louse in the North, the Apple-root Plant-louse in the South and the Apple-worm everywhere, the apple crop in North America is gradually becoming almost as uncertain and precarious as the plum crop (Walsh & Riley 1868a:1).

To show that the testimony of an entomologist was not biased and that the conditions described above were more or less general, we may note a comment made by the eminent journalist Horace Greeley (1870:301):

If I were to estimate the average loss per annum of the farmers of this country from insects at \$100,000,000, I should doubtless be far below the mark. The loss of fruit alone by the devastations of insects, within a radius of fifty miles from this city, must amount in value to millions. . . . We must fight our paltry adversaries more efficiently, or allow them to drive us wholly from the field.

The first white settlers in Illinois observed that the native fruits—plums, grapes, haws, and berries—were subject to attack by a variety of insects. More than three-fourths of the species recognized as fruit pests today were recognized and mentioned in agricultural or horticultural reports and farm journals prior to 1870. The plum curculio, for example, was to be found in every plum thicket and, when improved varieties of plums were introduced, the curculio took to them like ducks to water. In discussing plum culture at a fruit growers' meeting in 1852, a Mr. Brewster reported that for 4 years the curculio had destroyed his plum crop. Then followed a general discussion of proposed control measures, such as jarring, banding, paving, and using lime, soap suds, and chamber lye. The following year a similar report provoked a repetition of the members' favorite control measures, but by then two gentlemen had the answer: Just fence the plum orchard and turn in chickens (J. A. Kennicott 1855:296, 314-5).

The idea of using chickens for control of curculio paralleled a suggestion made

by a Mr. Harkness at a horticultural meeting in 1853:

Some twelve years since, a neighbor of his enclosed a wild plum thicket, as a yard for swine; trees bore full crops every year; never troubled by curculio, whilst other thickets about had fruit nearly all destroyed by them. Four years since the hogs were turned out, and the ground appropriated to other uses; the first year after, the fruit was mostly destroyed by curculio (J. A. Kennicott 1855:314).

Gradually certain members of the curculio tribe developed a liking for related stone fruits and even apples. In his first and only report as State Entomologist, Walsh (1868b:64) noted:

Although the Curculio now infests the cultivated species of Plum (*Prunus domestica*, Linnaeus,) to fully as great an extent as our common wild species (*Prunus americana*,) yet it is only at a comparatively recent date that it attacked our cultivated Plums, and since that epoch it has been growing every year worse and worse, and making onslaughts upon other fruits, such as the Peach, the Cherry, and even the Apple.

For 20 to 30 years the use of Hull's curculio catcher or similar devices to jar curculios out of infested trees, so that the insects could be destroyed, and the use of hogs and chickens confined to the orchards to consume infested fruits as they fell were the two principal, and perhaps the only meritorious, control measures. One should note, however, that farm journals carried glowing advertisements for numerous concoctions, which were almost worthless or which did more harm than good.

The successful use of insecticides for the control of the plum curculio on peach and other stone fruits did not materialize until lead arsenate came into the picture in the late 1890's, because the more soluble arsenic compounds—white arsenic, Paris green, and London purple—then available proved too phytotoxic for use on such delicate foliage as that of peach, plum, and cherry. With the aid of improved insecticide formulations, spray schedules, and equipment developed through years of continued research, Illinois orchardists were able to hold their own with the curculio until a crisis developed during World War II. Then as labor and other overhead costs increased and lead arsenate became less effective,

many peach growers, after a few years in the red, pulled up their trees and abandoned production. A hope that DDT would control plum curculio faded quickly, but BHC became available just in time to save the peach-growing industry. BHC was short-lived as an insecticide for plum curculio control; it was replaced by more effective and less objectionable materials such as chlordane, dieldrin, and parathion. However, it was BHC that saved the day for a number of orchardists. Orchards that could have been bought for a song, and a poor one at that, in the fall of 1946 and spring of 1947 were not for sale in 1948.

After a century of research by the Natural History Survey and its parent organizations, we find the plum curculio is, for the moment at least, very well under control. Surveys conducted in 32 commercial peach orchards for the past 5 years showed that at harvest time less than 1 per cent of the fruit was infested or damaged by this weevil.

Other insects of the peach that have required research attention include the oriental fruit moth, a group of sucking insects responsible for an injury known as catfacing, the peach tree borers, and at least three species of scale insects. Fortunately these, too, are successfully controlled by currently available measures. Even so, peach growers insist that the entomologist will have to find more economical control measures, or the high cost of producing peaches will put the growers out of business.

The codling moth (mentioned by Walsh as the "Apple-worm"), unquestionably the No. 1 apple insect in Illinois, apparently arrived in eastern United States from Europe about 1800 and made its first appearance in Illinois about 1850. In 1869, while checking his theory that this insect had been a hitch-hiker in apple barrels, Walsh reportedly found about 200 cocoons in a single barrel. The codling moth wasted no time in becoming adapted to its new environment. In the early transactions of the horticultural and agricultural societies and in pioneer farm journals, there are numerous references to the ravages of this insect. For example, in the first issue of *The American Entomologist* in September, 1868, we read:

Jotham Bradbury, residing near Quincy, Ill., has an old apple orchard, which many years ago used invariably to produce nothing but wormy and gnarly fruit. A few years ago he plowed up this orchard and seeded it to clover, by way of hog pasture. As soon as the clover had got a sufficient start, he turned in a gang of hogs, and has allowed them the range of his orchard ever since. Two years after the land was plowed the apple trees produced a good crop of fair, smooth fruit, and have continued to bear well ever since (Walsh & Riley 1868b:4-5).

In the same article, further extolling the value of hogs, we read:

But the plum curculio and its allies are not the only insects that we can successfully attack through the instrumentality of the hog; neither is stone fruit the only crop that can be protected in this manner. For the last fifteen years or so, pip fruit, namely, apples, pears, and quinces, have been annually more or less deteriorated by the apple worm or larva of the codling moth boring into their cores, and filling their flesh with its loathsome excrement (Walsh & Riley 1868b:3).

In addressing the Southern Illinois Fruit Growers Association in 1867, President Parker Earle (1868:137) said:

The curculio and the tree borers have been discussed at length in our former meetings, but the codling moth—which threatens us even greater damage than the curculio—has received little attention. There is some hope that great promptness and energy may save us from the terrible devastation which this moth has wrought in all the older States, and in the older fruit-growing neighborhoods of Illinois. Its damage to the apple crop of the country each passing year should be reckoned at millions of dollars. From all sections we have the same sad story of "the apples dropping prematurely"—"the apples mostly wormy"—"the apple crop used up," by the codling worm.

In many districts of the East where apples were once abundant they now entirely fail, because of the worms, and they not only threaten the destruction of the apple crop of the country, the whole country, but pears seem equally exposed. In many sections of the West nine-tenths of the pears are reported spoiled by the codling moth.

The comments of Earle and other early horticultural leaders clearly establish the codling moth as the outstanding pest of apples in Illinois in the third quarter of the nineteenth century. From 1850 to 1870 the pasturing of hogs in the orchards and the use of straw or cloth bands around the tree trunks to trap larvae for later destruction were about the only control measures of established merit. Even

these measures were only partially effective, and a large percentage of the apples harvested showed insect damage. In fact, the situation was so bad that the fruit judges at county fairs protested the admission of fruit damaged by codling moth, and eventually a rule was passed that the unmistakable evidence of codling moth damage or the presence of San Jose scale disqualified a fruit for competition. Insecticides did not come into the picture until after the value of Paris green had been established for the control of the Colorado potato beetle and a number of other pests.

In his third report as State Entomologist, Le Baron (1873:172) recommended only cultural practices for control of the codling moth:

PRACTICAL TREATMENT.

This may be reduced to the four following heads:

- 1st. Destroying the insects in their winter quarters.
- 2d. Picking the wormy apples from the trees.
- 3d. Gathering the wormy apples from the ground, or letting swine and sheep have the range of the orchard.
- 4th. Entrapping the worms in bands and other contrivances.

To which may be added the help to be derived from their natural enemies.

In his previous report, Le Baron (1872:116) had mentioned the use of Paris green to control cankerworms on apple, and this may in part have led to the subsequent work by Forbes and others for control of codling moth on apple.

We find but few references to trials with Paris green on crops in 1867 and the following decade. In 1880, however, with repeated warnings that suitable precautions must be observed, large-scale testing of Paris green and its companion, London purple, got under way. After 2 years (1885-1886) of experimentation, Forbes (1889:15) concluded:

The experiments above described seem to me to prove that at least seventy per cent of the loss commonly suffered by the fruit grower from the ravages of the codling moth or apple worm may be prevented at a nominal expense, or, practically, in the long run, at no expense at all, by thoroughly applying Paris green in a spray with water, once or twice in early spring, as soon as the fruit is fairly set, and not so late as the time when the growing apple turns downward on the stem.

He presented data showing that, in 1885, 68 per cent of the unsprayed apples were wormy, whereas only 21 per cent of the sprayed apples were wormy, and, in 1886, 40 per cent of the unsprayed apples were wormy and 12 per cent of the sprayed fruit. When lead arsenate became available about 1895, entomologists began experimenting with it, and for the next 30 to 40 years practically all codling moth research centered around attempts to improve formulations and spray schedules involving the use of this chemical. Between 1915 and 1918, in seven separate studies, Illinois entomologists found that in unsprayed blocks fruit ranged from 9 to 84 per cent wormy and averaged 45 per cent wormy, whereas in the blocks sprayed with improved lead arsenate formulations the fruit ranged from 1 to 20 per cent wormy and averaged 4.4 per cent wormy.

With what appeared to be a satisfactory control measure working reasonably well year after year, entomologists and fruit growers alike became more or less complacent, only to be shocked by a double-barrelled attack. The codling moth began to show evidences of resistance to arsenical sprays, and, as dosage rates and numbers of applications were increased, the United States Food and Drug Administration began to bear down on lead and arsenic tolerances. The next three decades might be characterized as a period of mad scramble for cover. Attempts were made to find (1) ways to remove spray residues, (2) suitable substitute materials, (3) ways to synergize insecticidal action without increasing residues, and (4) better sanitation and other non-chemical procedures. Research did well to hold its own, during this critical period, until DDT came into the picture at the close of World War II. The success of DDT in controlling the codling moth was spectacular, and within 2 years the growers' clamor for more work on codling moth control faded.

A review of research data and the results of harvest surveys made the past 3 years show that now 33 to 94 per cent of the fruit in unsprayed apple orchards is wormy, approximately the same percentages as in the 1860's, 1880's, and the second decade of the present century. In

contrast, we find that in sprayed orchards 0.03 to 7.6 per cent, or an average of 2.2 per cent, of the fruit is wormy. Thus, we find that, in spite of adversities and reverses, continued research has developed control measures that have enabled apple growers to reduce the percentage of

a dozen important scale insects alone. One scale insect of great importance is the San Jose scale, which was introduced into California from China about 1880 and into Illinois about 1895. For a time this scale threatened to wipe out the Illinois commercial fruit industry. Parasites,



Spraying equipment designed and used about 1897 by the State Entomologist and his assistants for experiments on control of San Jose scale. "The principal apparatus used is a large and complicated machine sprayer consisting of a one-horse power gasoline engine, a three-cylinder force pump, and a large double galvanized-iron tank with a powerful gasoline heater beneath for making the solution of whale-oil soap" (Forbes 1900:14). The sprayer was mounted on a two-horse baggage wagon.

worm-damaged apples from possibly 60 to 100 per cent in 1867 to 21 per cent in 1885, 4.4 per cent in 1915, and 2.2 per cent in 1957.

If it appears that entomologists have devoted too much attention to this one insect, let us recall that codling moth research has been the traditional guinea pig for the study of many insect control procedures, and that the measures developed for the control of the codling moth for the most part have given satisfactory control of a considerable number of other pests of apples.

A list of the insects attacking fruit crops in Illinois would no doubt include 100 or more species. There are at least

predators, and diseases have played an important role in holding this insect at bay, but for over 50 years orchardists have found it necessary to apply a dormant spray or some other special treatment to bring this insect under control. As late as 1950, Illinois apple growers seemed to agree that if the use of sprays was to be forbidden San Jose scale would eliminate commercial orchards within 5 years. This insect, perhaps more than any other, has been responsible for the development of a strong plant inspection and quarantine system in Illinois, and, for that matter, in other states as well. Here we have an insect that can barely survive on wild or neglected trees but that thrives on young,

vigorously growing orchard trees—an excellent example of how man creates, or at least aggravates, his own insect problems. The more man prunes and fertilizes, the more certain he is to develop a serious San Jose scale problem.

Truck Crop Pests

An article, probably by Walsh, published in 1869 makes it clear that at an early date a host of insects were recognized as important pests of a wide variety of vegetable crops:

There is scarcely a vegetable raised in our gardens that is not preyed upon by one or more grubs, caterpillars, or maggots, so that, when we eat it, we have positively no security that we are not mingling animal with vegetable food. Two distinct kinds of maggots, producing two distinct species of two-winged Fly, burrow in the bulb of the onion. Scabby potatoes are inhabited by a more elongated maggot, producing a very different kind of two-winged Fly, and also by several minute species of Mites. Turnips, beets, carrots and parsnips are each attacked by peculiar larvae. And as to the multifarious varieties of the cabbage, not only are they often grievously infested by the Cabbage Plant-louse—a species which has been introduced from Europe into this country—but also by an imported caterpillar producing a small moth, and by several indigenous caterpillars producing much larger moths, some of which caterpillars, when full-grown, are over one inch long (Walsh & Riley 1869:114).

Why the article failed to include the corn earworm, the squash vine borer, the cucumber beetles, and the melon louse is hard to say, for they were numbered among the best known pests at the time. One is amazed that the Colorado potato beetle was not mentioned, because this species was the most spectacular insect pest of vegetable crops in Illinois in the latter half of the 1860's. Presumably, prior to 1850 the Colorado potato beetle was unknown except as an interesting species found only in the foothills of the Rocky Mountains, where it fed on a wild potato somewhat resembling the common horse nettle. When the pioneers planted Irish potato and egg plant in Nebraska and Colorado, the beetle found these closely related plants to its liking, increased its numbers many fold, and took off for the East, flying from one settler's potato patch to another's. Here again we have an example of how man may create

his own insect control problems. The introduction of a crop highly attractive to a native insect invites this insect to transfer its affections to the newly introduced crop. The potato beetle transferred its affections from its native host to the introduced potato. It seems quite probable that the potato beetle's many natural enemies did not travel eastward but continued searching for it in its old haunts. With an abundance of lush, nutritious potato vines and a temporary release from its natural control agencies, the Colorado potato beetle, in the vernacular of today, "went to town" until a new system of checks and balances could be established.

The eastward movement of the potato beetle was first noted in eastern Colorado in 1859. It did not appear in Illinois until 1864. Damaging populations of this beetle were reported in several Illinois counties in 1865. Some of the tales of wholesale potato destruction related in the local press and the *Prairie Farmer* were downright pathetic:

"Let every man and woman in the country or in town, who has a potato patch, try experiments for the destruction of these pests and report progress. Something must be done to stop the destruction of the vines by these insatiate creatures or we may as well quit trying to raise potatoes" (*Cedar Valley, Iowa, Times*, quoted by Riley 1866:432).

I know of several cases near Rock Island, Illinois, where the owners of potato-patches, after persevering in a course of hand-picking for fully a month, finally gave up in despair, because as fast as they killed off their own bugs, a fresh supply from their neighbors' potato-patches kept flying in upon them (Walsh 1866:14).

All accounts seem to agree that neither lime, nor ashes, nor any available external application is of the least use in checking the depredations of this insect. The *Prairie Farmer* says that "Mr. Jones found, after many experiments, that neither hot lime, lime-water, brine, tobacco-water, wine (?) nor sulphur had any effect on them; that turpentine, benzine and kerosene would kill them when copiously applied, but also killed the potatoes," and that "coal-oil mixed with water is ineffectual." . . . Although there is some contradictory evidence, yet the general result of all the testimony is, that neither domestic fowls, nor ducks, nor turkeys will eat them, at all events to any very extensive amount (Walsh 1866:14).

Hand picking, or the manual collection and destruction of the beetles, their larvae, and their eggs, was about the only really effective control measure. During

the next several decades, it was said of many a farm boy who had risen to a prominent position, "He made his first dime collecting potato bugs on his grandfather's farm"—not his father's farm, for there, in accord with the tradition of the

The value of predators and parasites was not overlooked, and at times different kinds of poultry, particularly turkeys, were noted as effective control agents. Hellebore, London purple, and calcium arsenate were later added to the list of



Spraying equipment developed in recent years by entomologists of the Illinois Natural History Survey for the control of the corn earworm and the European corn borer on sweet corn and field corn.

day, he performed the task without compensation as a member of the family.

Many potato growers experimented with Paris green applied in several ways, and by 1870 dusting plants with a mixture of Paris green and flour or lime was quite generally accepted as the most effective remedy available. However, there were many growers who were fearful of the poisonous properties of the arsenical compounds and they continued to place their trust in hand picking. Some growers went so far as to design rather elaborate mechanical devices which they mounted on skids and dragged up and down the rows to beat the beetles from the plants and collect them in pans, trays, or boxes, where the beetles could be destroyed.

insecticides recommended for control of the Colorado potato beetle. As the potato leafhopper, aphids, blight, and other pests attracted increased attention, a variety of insecticide and fungicide combinations came into common use. Research produced minor improvements in formulations and methods of application that enhanced the effectiveness or economy of control measures, but there was no substantial or basic change in control procedures or practices until the advent of DDT in 1946. While potato growers and entomologists alike had been inclined to feel that the control measures in use in the early 1940's left little to be desired, they apparently overlooked or grossly underestimated the damage inflicted by the insects, for within 2 years after

DDT came into general use the per-acre potato yields practically doubled.

Numerous early reports indicate that the pioneer cabbage grower had to contend with about the same insects that plague the cabbage grower of today, but the pioneer had no arsenal of effective insecticides. Lime, lye, and ash mixtures advocated by some growers were of little use except in those cases where the plants were so heavily coated with one of the mixtures that physical contact between the insect and the plant was practically impossible. The scalding water drench proposed by some persons was at times of value, but was very apt to damage the plants. The arsenicals were used sparingly and on small plants only; they could not be safely employed on more mature cabbages. Thus, for many years the sound, unblemished head of cabbage was a rarity, and there was always danger of consuming protein with the slaw. In fact, it is very doubtful if any kraut made in those days could have passed present day Food and Drug Administration inspections for insect fragments. There are those who contend that the prevalence of scurvy in the armies of the North and the South during the Civil War was in no small measure due to the fact that farmers could not produce adequate quantities of cabbage and related cole crops.

Although some nicotine and pyrethrin products had been known for many years, they did not come into practical use until about 1910. Derris, cubé, and other rotenone preparations made their appearance in the 1920's. When properly applied, these insecticides were quite effective, but they possessed very limited residual properties and were relatively expensive. Their acceptance by cabbage growers was not enthusiastic, and entomologists were under constant pressure to improve formulations by the use of synergists or stabilizing agents. Then came DDT and the organic phosphate insecticides, and it looked for a time as if the cabbage growers' insect problems were effectively solved. But the insects once again demonstrated their mutability, and soon cabbage worms were resistant to DDT. Today the entomologist is worse off than he was in the early 1940's, because the cabbage growers, having once

experienced the fine performance and economy of DDT in the early 1950's, are unwilling to settle for anything less efficient. The currently recommended spray schedule, which calls for using endrin until cabbage heads begin to form and finishing with occasional applications of phosdrin or parathion, is a highly effective treatment, but the growers remember equally satisfactory results with the less complicated use of DDT.

Sweet corn growers in Illinois, like the cabbage growers, must cope with an insect problem that requires both a thorough knowledge of the seasonal activities of the pest and a rather meticulous control treatment. The corn earworm is a native American pest that has long contested man's right to the sweet corn produced in Illinois. Unlike the cabbage worm, this insect has continued to defy man's best efforts to control it. Several reasonably effective control measures have been developed, but none has been fully accepted by Illinois sweet corn growers. The corn earworm control measure currently recommended involves precise but not unreasonable methods of application and accurate timing of treatments. Some Illinois sweet corn growers have been unable or unwilling to apply the requisite control measures. When infestations of the corn earworm are light, mediocre control practices prove adequate, but, when infestations are heavy, more meticulous practices are essential. In parts of Florida and Texas, where sweet corn growers cannot afford to gamble on having light infestations, many growers produce 97 to 99 per cent clean ears of corn by carefully following the control measures recommended by entomologists.

Cereal and Forage Crop Pests

Insect depredations were by no means confined to the fruit and vegetable crops produced by the early settlers in Illinois. Wheat, corn, and even the native prairie grasses were subject to attacks that at times amounted to almost total crop destruction. In an article in the first issue of *The American Entomologist*, a writer, presumably Walsh, observed:

Few persons are aware of the enormous amount of wealth annually abstracted from the pockets of the cultivators of the soil by those

insignificant little creatures, which in popular parlance are called "bugs," but which the scientific world chooses to denominate "insects." Scarcely a year elapses in which the wheat crop of several States of the Union is not more or less completely ruined by the Chinch-bug, the Hessian Fly, the Wheat Midge, or the Joint Worm. . . . The White Grub attacks indiscriminately the timothy in the meadows, the corn in the plowed field, the young fruit trees in the nursery, and the strawberry beds in the garden; always lurking insidiously under ground, and only making its presence known to the impoverished agriculturist by the losses which it has already inflicted upon him. . . . at periodic intervals the Army-worm marches over their fields like a destroying pestilence; while in Kansas, Nebraska, and Minnesota, and the more westerly parts of Missouri and Iowa, the Hateful Grasshopper, in particular seasons, swoops down with the western breeze in devouring swarms from the Rocky Mountains, and, like its close ally, the Locust of Scripture and of Modern Europe, devours every green thing from off the face of the earth (Walsh & Riley 1868a:1).

Certainly Walsh was in a position to know the armyworm problem, because in 1861, 6 years before the creation of the State Entomologist's Office, the Rock Island and Chicago and the Illinois Central railroads granted him, as a member of the Illinois Natural History Society, passes that permitted him to spend several weeks studying a major armyworm outbreak that developed in central and southern Illinois. That fall, in typical Walsh style, he wrote:

. . . I always hate to give *nothing* for *something*, and having been obliged by the railroad companies, I endeavored, to the extent of my poor abilities, to return the obligation, by seeking a remedy for a little pest, that has this year destroyed one-fourth part of the tame hay grown within the limits of the State (Walsh 1861:350).

This was the introduction to an extremely interesting and informative 15-page report on the ecology of the armyworm and its natural enemies which he appended to an essay prepared for delivery at the annual meeting of the Illinois Agricultural Society. Walsh reported:

When they [armyworms] leave the meadows in which they originate, they travel on—sometimes as far as half a mile—until they meet with wheat, rye, oats, corn, sorghum, or Hungarian grass (Walsh 1861:351).

Many instances are on record of the great difficulty with which they have been kept out

of houses which happened to lie in their path (Walsh 1861:352).

From the *Prairie Farmer* of July 4, 1861, Walsh (1861:351) quoted the words of "an accurate observer" who described an infestation of armyworms: "As to their number, they have been seen moving from one field to another, THREE TIERS DEEP. A ditch has been filled with them to the depth of THREE INCHES IN HALF AN HOUR."

Walsh was fortunate in being able to acquire, through contacts with a number of pioneer settlers, valuable notes on historic armyworm outbreaks of the past. Some of these notes seem worthy of repetition as an example of the fund of unpublished entomological history and knowledge that has passed from one generation to another:

As we might expect from the laws governing the development of insect life, the armyworms make their appearance in noticeable numbers in different years in different parts of the State. I have no doubt that they exist in small numbers in every part of the State from year to year; for although they have never appeared till 1861 in the neighborhood of Rock Island, in such numbers as to attract attention, yet I myself captured a single specimen of the army-worm moth in Rock Island county, in each of three years, '58, '59 and '60. At Okaw they are recorded to have appeared in 1850; in the south part of Vermilion county, in 1835; and Mr. Joseph Bragshaw, of Perry county, says that they visited that county in '25, '26, '34, '39, '41 and '42. Colonel Dougherty, of Jonesboro, in Union county, one of the oldest and most respected citizens of Southern Illinois, informed me that about 1818 or '20 they were far more numerous there than in 1861, and that in 1861 there would not be a single cock of hay put up in his neighborhood save one meadow which was part clover and part timothy, and which I can myself testify was badly "patchy," there not being more than an eighth part of it which would turn out a good swarth of clover, the timothy being "nil" throughout. In 1838 again, according to the Colonel, there were but few of them. In 1842 they were about as in 1861; and in 1856 they occurred only in small numbers (Walsh 1861:353).

It certainly is an encouraging sign of the progress of entomological discovery in this State, that a noxious insect of primary importance should have been, for the first time, traced through all its transformations in the year 1861 by no less than four citizens of Illinois to my certain knowledge—I refer to Mr. Cyrus Thomas of Murphysboro, Mr. Emery of the Prairie Farmer, Col. Dougherty of Jonesboro, and last and least myself (Walsh 1861:356).

While many of the observations made by Walsh and the other gentlemen mentioned were sound and are still valid, one observation was in error and resulted in a recommendation which, although it had the desired effect, was based upon a false premise. Walsh (1861:349) advised, "Burn your tame grass meadows over annually, in the dead of the year, and get your neighbors to do the same, and you will never more be troubled with the army worm." Walsh thought that the armyworm passes the winter in the egg stage, but such is not the case, and therefore burning, as he recommended, did not destroy the eggs. We now know that when the moths appear in the early spring they fly at night; in the daytime, they hide in rank grass, preferably a dense mat of old, dead grass in a vigorous meadow. There, in April and May, they lay their eggs. Thus, while winter burning did not destroy eggs, it had a profound effect on the number of worms developing in burned-over fields and often, if not usually, prevented serious infestations from developing.

The recommendation for burning persisted for several years, and by 1880 it was supplemented by a recommendation for the use of dusty trench barriers to trap worms on the march. Spraying strips with Paris green was proposed by some, but was generally considered both dangerous and impractical.

The use of poison bait (a mixture of bran and Paris green) for the control of armyworms, cutworms, and grasshoppers came into use about 1885, and with minor modifications remained the principal and most practical control measure available until the advent of the modern chlorinated hydrocarbon insecticides. Since 1951, growers have been generally successful in controlling armyworms by spraying with such materials as toxaphene, dieldrin, and endrin. Furthermore, with the insect outlook and warning service bulletins available weekly during crop seasons from the Natural History Survey, Illinois farmers are now able to control armyworms effectively when the worms are one-fourth to one-half grown. Applied control measures save the small grain and the meadow grasses as well as protect adjacent crops from migrations.

The chinch bug, another infamous pest, has been well known to Illinois farmers since 1820. This species, like the armyworm and many others, is not a serious pest every year, but tends to be sporadic, perhaps somewhat cyclic, in its appearance. Weather, of course, is a factor that influences the chinch bug population.

One is indeed surprised to learn that the farmers of 1860 were just about as much aware of this pest as are the farmers of 1958. In 1861 Thomas (1865:466-7) observed:

Although we cannot predict with certainty one season the action of insect enemies for the next, yet we often can from the character of the season itself, know that certain species are likely to be upon us in increased numbers.

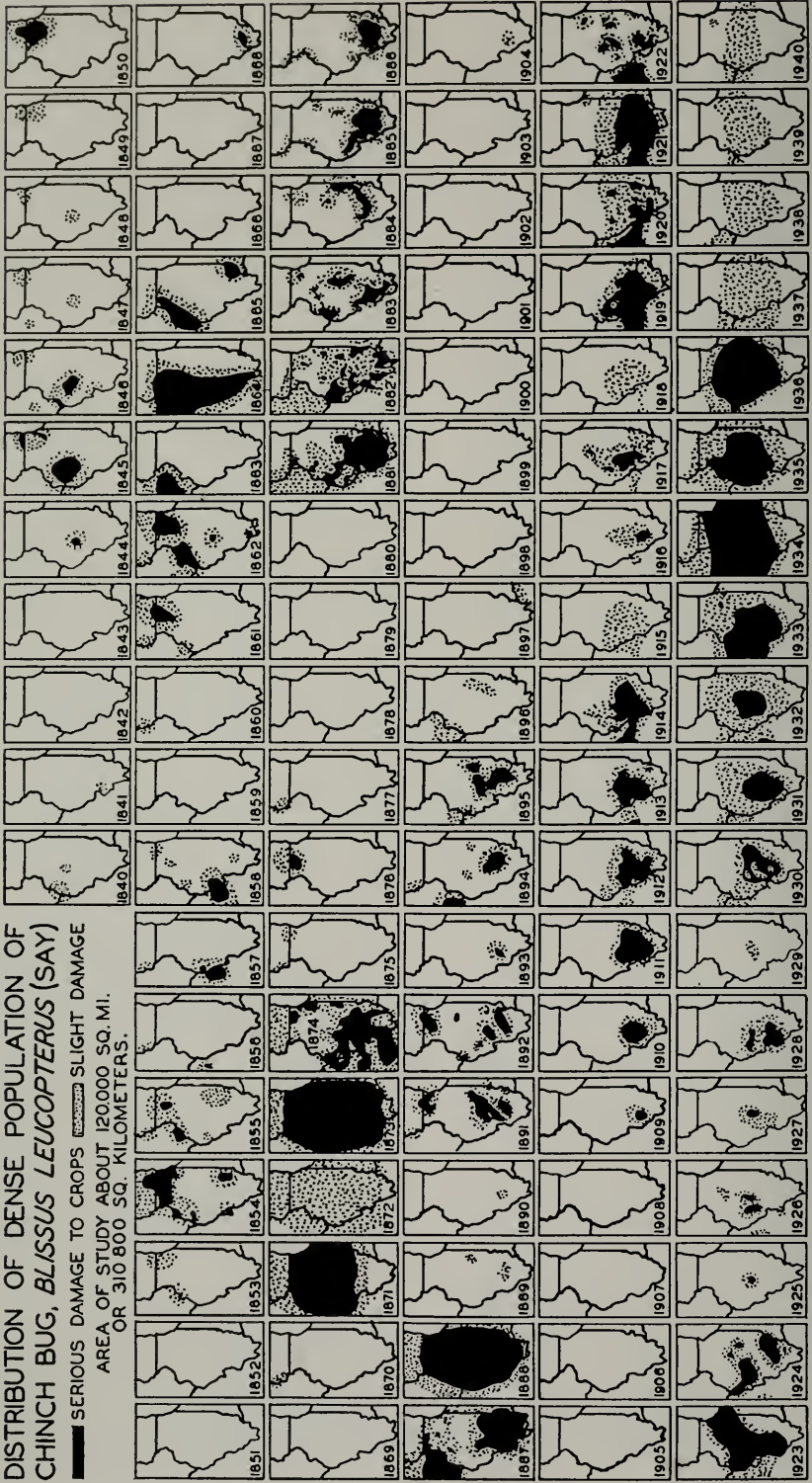
This was the case the present season in regard to the appearance of the "Army-worm." The cold, cloudy spring hanging so long before opening into summer weather, caused the exclamation from several of our older citizens, "I wouldn't be surprised if we had the Army-worm this season." Although this was rather guessing, yet there evidently pervaded the minds of the elder settlers a semi-conscious feeling of dread in regard to this insect, which most assuredly originated from the similarity in this spring to the previous seasons when it had appeared. And when the long dry weather we sometimes have in June and July has parched the vegetation, we may expect the grass-hoppers to multiply rapidly, and by their attacks on the plants already struggling for life, to soon effect a far greater injury than the same attack made on vigorous plants would have done.

Later, Thomas (1880:242) observed, "The high temperature of 1854, '71 and '74, together with the diminished rainfall, furnish the key to the cause of the great development of the Chinch-bug during these years."

One could cite hundreds of quotations, from the *Prairie Farmer* and other early farm papers, concerning damage by the chinch bug and other field crop pests that would put the potato beetle reports to shame. But let the words of Walsh and of Thomas suffice. Walsh wrote as follows:

It is only two years since the entire wheat crop of the State was so damaged by the chinch bug that a great deal of it was not cut at all, and a great deal that was cut barely paid for the harvesting. Scarcely a year elapses but what more or less damage is done to it by this insect, and by the Hessian fly and the wheat midge. A large breadth of winter wheat, which is commonly supposed to be "winter-

DISTRIBUTION OF DENSE POPULATION OF CHINCH BUG, *BLISSUS LEUCOPTERUS* (SAY)
 ■ SERIOUS DAMAGE TO CROPS [stippled] SLIGHT DAMAGE
 AREA OF STUDY ABOUT 120000 SQ. MI.
 OR 310 800 SQ. KILOMETERS.



Maps of Illinois and parts of adjoining states on which are shown areas of serious damage, slight damage, and no damage by chinch bugs in 101 years, 1840-1940. Records kept by the Illinois Natural History Survey and its parent organizations make possible the study of population trends in such groups as insects, fishes, birds, and mammals.

killed," is in reality killed by the Hessian fly; and there may be, and probably are, many other insects which depredate upon this crop, but whose habits have not yet fallen under the notice of entomologists (Walsh 1861:335).

Taking the average of years, we may safely assume that a fifth part of the wheat crop—or, which is the same thing, a quantity equal to one-fourth of what we actually do harvest—is destroyed by insects. Even at the low price, therefore, of 75 cents per bushel, we have *over four and a half million dollars' worth* of wheat annually destroyed by "little vermin which it is not worth our while to notice." But this is not all. Other crops are damaged by other insects, though not generally to so ruinous an extent; so that we cannot put the whole annual damage done by insects to the State of Illinois at less than TWENTY MILLION DOLLARS (Walsh 1861:336).

And Thomas (1865:457) wrote: "So much has already been written in the papers of this State concerning the Chinch-bug (*Macropus leucopterus*, Fitch,) that I shall pass it by in this paper without further notice."

Shelford & Flint (1943) made a thorough study of the history of the chinch bug in Illinois. The figure on page 116 is presented to illustrate the type of historic records that have been made and preserved by the Natural History Survey. The data on which the figure is based cover the century beginning in 1840. Records for subsequent years have, of course, been kept. Similar data have been collected for several other important pests.

In the 1860's and '70's, many measures were proposed for control of the chinch bug: abandon wheat and barley or corn; burn fencerows and all wild grass areas to destroy hibernating bugs; plant border crops to retard migrations; fertilize crops to get dense stands unattractive to the insects; and construct barrier lines of lime, salt, and carbolic acid solutions. The measure most widely used was the dusty furrow. Each year saw some new version of the furrow proposed, such as pouring tar oil, road oil, or creosote into the furrow to form a barrier; covering the furrow with straw and setting it afire to destroy the bugs; digging post-hole traps in the furrow and later spraying the trapped bugs with kerosene and burning them. There was no great change until the paper fence barrier, proposed in 1934, was widely adopted, but even this barrier

was not without precedent; over 50 years earlier the use of tar-covered boards set on edge and placed end to end had been proposed. The later control measures, like the early ones, were scheduled to be used around harvest time. About 1945, the paper fence barrier was practically replaced by the dinitro dust barrier, and in another 10 years this was replaced by diel-drin, sprayed on strips of ground along the margins of small grain fields where these fields adjoined fields of corn or later maturing grain. The more aggressive followers of research progress were spraying entire fields of heavily infested wheat as soon as chinch bug eggs began to hatch so as to protect the wheat crop itself from serious damage and to eliminate the necessity of establishing a barrier of any type 2 or 3 weeks later.

In the past century, progress has been made in controlling many other insect pests that attack cereal and forage crops. Among the most important of these pests are the grasshoppers, the cutworms, the white grubs, and the hessian fly. Instead of attempting to summarize in detail, we note here some of the general trends in this area of insect control.

Before extensive agricultural development of the state, a large part of Illinois consisted of broad expanses of prairie grass, much of which was replaced by timothy and other tame grass or cereal crops planted by farmers. Insects preferring these crops became notorious pests, but as the acreage of grasses was reduced as a result of increased legume production, certain insects began to decline in importance. These included the white grubs, the billbugs, the armyworms, the sod webworms, and the corn root aphid. The burrowing webworm and the cutworm *Luperina stipata* have all but disappeared; not a single specimen of either has been received by us for identification in the last 20 years. As the rail fence was replaced by the wire fence, and roadsides and ditch banks were graded or otherwise cleaned up, the amount of giant ragweed and elderberry available to insects was greatly reduced, so that the common stalk borer became less important and the old spindlegirdler was practically exterminated. Likewise, as the pot holes and low spots were drained, wireworm damage in

those areas declined steadily. Conversely, in certain dry, sandy areas which were brought under irrigation wireworm damage increased.

As legume production increased, the insect pests of legumes tended to increase. Notable examples are the clover leaf weevil, clover root borer, pea aphid, bean leaf beetle, sweet clover weevil, green cloverworm, and spotted alfalfa aphid.

Two attempts to initiate and promote the commercial production of sunflowers in Illinois were doomed to failure largely because of the overwhelming insect problems encountered when many species from the native sunflowers swarmed onto the cultivated varieties. In contrast, we find that in extreme southern Illinois cotton production survives in a rather unfavorable climate, and under other adverse conditions, largely because important cotton insects are absent and planters are spared the cost of extensive insect control measures.

Pests of Forest and Shade Trees and Ornamental Plants

Effective control measures are now available for most of the insect pests of trees and ornamental plants; yet man seems to have little success in combating these insects. It is not that these insects are new or relatively unknown, for the majority of these pests were recognized and well known prior to 1850. The bark lice (scale insects), round-headed borers, flat-headed borers, bark beetles, bagworm, walnut caterpillars, cankerworms, and the 17-year locusts are frequently mentioned in the Illinois entomological writings of a century or more ago. Chemical control measures were not available at that time, but some of the proposed measures were partially effective and more or less practical. Mechanical barriers and sticky bands were used to control the cankerworms, sometimes successfully and sometimes not. It now appears that improper timing and failure to recognize the difference between the spring and the fall cankerworms accounted for most of the variation in control. Hand picking was often mentioned and, according to reports, if done diligently it was effective in controlling the bagworm, the walnut caterpillars, and the tent caterpillars.

Hand grubbing, with a wire or knife, was considered an effective means of controlling several species of borers. Several types of soapy washes were proposed for the control of aphids and scale insects, but perhaps the most positive, wisest, and most ingenious of all recommendations was that proposed by Dr. Mygatt (1855: 516) in his essay on the bark louse: "Whether you choose a seedling or graft, by all means **TRANSPLANT A CLEAN TREE**, if you have to occupy hours and even days in examining and clearing your trees from *every scale*."

As insecticides and means of applying them were being developed for use on various agricultural crops, it was natural that most of them would be tested to determine their potential usefulness in controlling insects attacking trees. The value of Paris green in controlling the cankerworms was established at a very early date. By 1910 lead arsenate, first developed in 1891 for use against the gypsy moth, was being recommended for a variety of leaf-eating insects, and by 1925 high-powered sprayers, dusters, and even airplanes had been developed and were quite generally available for use in treating both shade and forest trees. Nevertheless, progress was slow; apparently the weather and tree protection have something in common—everybody talks about them, but nobody does anything about them.

The average citizen who professes an interest in and a love for trees is sometimes like the kibitzer who, at an active poker table, talks a good game, but, for reasons best known to himself, fails to put his money on the line. In the past 2 years in many Illinois communities, beautiful landscape plantings, such as juniper, valued at hundreds of dollars were rendered unsightly and in many cases were killed outright by the bagworm; a dollar's worth of malathion, or the old faithful, lead arsenate, and 30 minutes' time could have prevented any damage. In some communities there has been a wholesale loss of elm, oak, and birch trees of inestimable value and irreplaceable in less than 3 decades; little evidence was available that control measures were even considered.

This seeming indifference in some communities is partially offset by the genuine

interest of a number of ardent tree lovers and conservationists in other communities. Some of these tree lovers, however, clamor for more research without making full use of the control measures already available. Scientists have spent many years in developing fairly efficient and practical control measures for 90 per cent of the insect pests affecting shade trees and ornamental plants, yet we find that these measures either are ignored or are employed in less than 1 per cent of the cases in which they might be useful. It seems doubtful whether administrators will feel justified in diverting any considerable portion of their funds to similar projects until there is evidence that the control measures already recommended are being put to better use. A recently published circular (English 1958) will bring interested people up to date on control of insects attacking ornamentals and shade plants.

Insects Attacking Man and Animals

Entomology has made its most profound and spectacular advances of the past 100 years in combating those insects that are pests to man and animals. There seem to be two good reasons why this is so. In the first place, we have learned considerably more of the habits and relative importance of these pests than was known in 1858, and, in the second place, as the medical implications of these pests became apparent, state and federal public health agencies, men in many branches of science, and the general public gave wholehearted support to large research and action programs.

Early Illinois entomologists had collected and identified many species of ticks, mites, mosquitoes, and flies, and it did not require the services of a scientist to advise farmers that large numbers of these species were sources of annoyance to their livestock, their families, and themselves. A couple of very casual comments adequately attest to the ferociousness of these pests: "There are prairies in Central Illinois, as I am credibly informed by numerous witnesses, across which it is impossible to ride or drive a horse in the heat of a summer's day on account of the *Tabanus*" (Walsh quoted in Cresson *et al.* 1865:18). The genus *Simulium* in-

cludes "the Buffalo-fly of Illinois and the West, which I have observed killing poultry in great numbers, and which is known to torment horses and other animals to death, when very numerous" (Barnard 1880:191).

While these reports may sound far-fetched and exaggerated, the latter is supported by a more recent experience. In 10 days of April, 1945, black flies killed 125 head of horses and mules and untold numbers of poultry in Franklin and Williamson counties, Illinois.

Possible relationships between these insects and several of the most dreaded diseases known to occur in the state were unknown in 1858 and for the most part were unsuspected. For example, no one thought of connecting the common house fly with the spread of cholera that took the lives of one-tenth of the population of several western Illinois communities in the 1830's or with the outbreaks of typhoid fever and dysentery that were so common during and immediately after the Civil War.

It seems ironic that B. D. Walsh, the first State Entomologist, was driven from his farm near Cambridge by a malaria epidemic and that he never suspected the mosquitoes that increased with the damming of the river as being responsible for the epidemic. All we know of this incident is contained in two sentences of Walsh's obituary by C. V. Riley (1869-70:67).

Finally, a colony of Swedes settled in his neighborhood, and, by damming up the water at Bishop Hill, produced so much miasma in the vicinity, that very much sickness prevailed there. His own health in time became impaired, and at the suggestion of M. B. Osborn, of Rock Island, he removed to that city in 1851, and entered into the lumber business.

Indeed, there is every reason to believe that neither Walsh nor any of his contemporaries even suspected the relationship between mosquitoes and malaria. In his zeal to protect all beneficial insects and to maintain the balance of nature, Walsh was inclined to regard house flies, horse flies, and mosquitoes as possibly more beneficial than destructive. In 1865 he was quoted as saying:

The scheme of the Creation is perfect and Nature is never at fault. It is only when Nature's

system is but half understood, that we heedlessly complain of its imperfections. We blame the house-flies for annoying us, and fail to see that in the larva state they have cleared away impurities around our dwellings, which might otherwise have bred cholera and typhus fever. We excrete the blood-thirsty mosquito, and forget that in the larva state she has purified the water, which would otherwise, by its malarial effluvia, have generated agues and fevers. In all probability, when we rail at the *Tabanus* that torment our horses in the summer, we are railing at insects which, in the larva state, have added millions of dollars to the national wealth, by preying upon those most [insidious] and unmanageable of all the insect-foes of the farmer—subterraneous, root-feeding larvae (Walsh quoted in Cresson *et al.* 1865: 18).

An editor of *The Practical Entomologist*, in commenting on Walsh's paper, cautioned his readers:

Before you undertake to kill off the larvae of the Horse-flies and the Mosquitoes, you had best make yourself quite sure that they are really your enemies, and not, as Mr. Walsh maintains, some of your very best friends (Cresson *et al.* 1865:18).

Flies and mosquitoes passed practically unmentioned until about 1880 when, because of the insects' annoyance and nuisance characteristics, a few workers began to investigate suppressive measures. Window screens and the use of smoke came into the picture first, followed by oil sprays, crude repellents, and several fly traps. If we exclude the modern insecticides developed since 1940, most of the control measures that are recommended today for the control of flies and mosquitoes had been developed by 1900. By the combined use of drainage, good sanitation practices, screening, and the known insecticides such as lime, borax, oils, arsenicals, and pyrethrins, public health agencies made remarkable progress in reducing the incidence of insect-borne diseases, but it was not until DDT and the more recent synthetic organic insecticides became available that it was possible to reduce fly and mosquito numbers to the near vanishing point and to eradicate almost all insect-borne diseases of man.

Shortly before the outbreak of World War I, the country embarked on an all-out "Swat-the-Fly" campaign that carried over into the dairy industry. This campaign stimulated interest in the development of sprays for use on livestock, as

well as space sprays for use in and around buildings.

Unfortunately, many of the formulations used prior to the late 1930's were only partially effective in controlling flies, and in many cases the injury they inflicted on cows exceeded the benefits derived. It was difficult, if not impossible, to establish clearly the fact that flies did affect milk production and that good fly control would pay dividends in the form of higher milk production. In the last 10 years, with the new insecticides such as DDT, methoxychlor, and several effective organo-phosphates, and with some repellents far more effective and much more persistent than anything available prior to 1940, it has been possible to demonstrate that good control of flies, whether they be tabanids, stable flies, or horn flies, will result in an increase of milk production of as much as 10 to 25 per cent. The exact gains depend upon the intensity of the fly population, the species involved, and the duration of the attack. Significant findings in this field have been reported in a number of scientific articles (Bruce & Decker 1951, 1957, 1958; Bruce 1952, 1953).

BIOLOGICAL CONTROL

Man discovered at a very early date that not all insects are bad, that some are definitely his allies, some are indifferent or neutral, and some are in the category of Dr. Jekyll—Mr. Hyde—half good and half bad. Walsh, Le Baron, Thomas, and other early entomologists in their writings repeatedly referred to the necessity of distinguishing between man's foes and friends in the insect world, and emphasized, as did their successors, the importance and potentialities of parasites and predators in the natural control of insects.

In December, 1854, William Le Baron, who 16 years later became the second State Entomologist of Illinois, wrote:

Birds benefit the agriculturist by destroying countless myriads of noxious insects, whilst they injure him by consuming a part of those products which he would fain reserve for his own exclusive benefit. But it is the universal testimony of those who have investigated the matter, that the evil compared with the good which they accomplish is extremely trivial. Probably every reader of ornithology will call

to mind, in this connection, the computation of Mr. Wilson the ornithologist, the result of which was, that the single species of Red-winged Blackbird, which is usually considered one of the greatest pests of the farmer, consumes in one season, in the United States, sixteen thousand and two hundred million of noxious insects (Le Baron 1855:559-60).

In an essay on insects, prepared in 1861 at the invitation of the Illinois Agricultural Society, Cyrus Thomas (1865:462, 464) made several pertinent comments on insect control measures, the balance of nature, and the biological control of insects:

When we have obtained a complete knowledge of the laws of nature, and shall have attained to perfection in agricultural pursuits, then most assuredly our reliance for a check upon these insect enemies will be upon the parasites a kind Providence has provided for our benefit. And the reason for so doing will be that then we will work in accordance with the laws of nature which are adapted to our best method of living and acting. Then if this theory be true, the nearer we can approach such a condition, individually or collectively, the better it will be for us.

Let the birds go unmolested, or even go so far as to entice them to abide near you. Learn to distinguish insect enemies from insect friends, and when you find the hiding places of the latter, as far as possible, protect them from injury. When you find a swarm of "Lady-bugs" huddling around the root of a tree in the winter, throw a few dry leaves over them that the birds may not see them. When you see the eggs of the Syrphus fly lying singly among those of the Aphis, do not molest it, for the young larvae will surely destroy that nest. And when the bright banded flies hover like bees around you, during the hot days of summer, while resting beneath the shade, brush them lightly away, and remember they are your friends. And when you see the eggs of the Lace-winged fly (*Hemerobius*) mounted on their long stalks on the leaves of your plants, let them alone, the voracious larvae they produce will soon destroy the most numerous colony of plant lice.

Benjamin Walsh (1861:339-40, 341) likewise had something to say about the balance of nature and the value of parasites and predators:

Now it is universally the case, that whenever man, by his artificial arrangements, violates great natural laws, unless by some artificial means he can restore the overturned balance, he pays the penalty affixed to his offense. The voluptuary may overload his stomach, but, unless he has recourse to his dinner pill, he pays the penalty of an indigestion. So with the farmer and the horticulturist. Until they can

restore the natural equilibrium which has been disarranged by their artificial processes, they pay the penalty in the damage inflicted on them by plant-feeding insects. They must assist nature, whenever, for necessary purposes, they have thwarted and controlled her, if they wish to appease her wrath.

If these views be correct, it would seem to follow, as a necessary consequence, that one of the most effectual means of controlling noxious insects is to be found in the artificial propagation of such cannibal species as are naturally designed to prey on them.

Although, so far as I am aware, cannibal insects have never yet been bred for utilitarian purposes, yet it is by no means an uncommon practice to collect such as are found at large in the woods and fields, and apply them to subdue some particular insect that is annoying us.

The foregoing quotations portray not only the profound interest in biological control that these early entomologists possessed but also the breadth and depth of the general knowledge of the day.

Forbes, who followed Thomas as State Entomologist, was likewise interested in parasites and predators. The fact is impressive that, in studying the biology and ecology of insect pests, these men invariably made extensive notes on the parasites and predators encountered. While others before him had made notes of entomophagous fungi and other evidences of disease, Forbes was the first to examine the possibilities of control of insects by their diseases. In fact, he is regarded by many as the father of insect pathology in the United States. His work on the chinch bug fungus and the work by Dr. F. H. Snow of Kansas are outstanding classics of early research in this field.

Forbes did not limit his interest and research in insect pathology to chinch bug diseases. He noted, and in many cases studied in great detail, the diseases found in numerous lepidopterous larvae, aphids, white grubs, grasshoppers, and several other insects. In the late 1880's he was strongly advocating more thorough studies on the possible advantageous uses of contagious insect diseases, and his Eighth Report (Nineteenth Illinois Report), published in 1895, contained a monograph of nearly 150 pages on chinch bug diseases. In general, the success of attempts to propagate insect diseases and to disseminate them as a means of controlling noxious insects in Illinois has not been as

spectacular as sponsors and interested observers had hoped. These projects have been greatly underestimated by the public; control of insects by their diseases has a value that should not be ignored.

If nothing more, these studies demonstrate the important role that insect diseases play in the natural control of many important pest species. They also shed light on the epizootiology of these diseases, which may prove to have even further value. Unfortunately, in practically all cases these projects were initiated on the premise that an epidemic would be initiated that could and would completely eliminate the pest species in a matter of days or weeks. When extermination of the offending pest was not immediately forthcoming, public sentiment turned from hope to disgust and ridicule, and researchers were forced to abandon their studies for lack of financial support. It is doubtful whether there is a single case in which an honest appraisal of the long-range or even the immediate value of disease inoculation or dissemination, or a combination of both, has been made. In recent years we have belatedly come to realize that insect pathogens have not been adequately explored nor their potential value determined. We and others are renewing our efforts in this basic field of research.

The performance of a protozoan disease of the European corn borer, a disease which, like the parasites of the hessian fly, apparently accompanied the host when it migrated to North America, seems worthy of mention. In Illinois the disease was first observed in the north central part of the state in 1945, 6 or 7 years after the borer made its first appearance in Kankakee County. The disease was artificially introduced into all sections of the state by colonizing disease-infected borers in many widely scattered counties. It is now prevalent in all parts of the state and has for several years been an important, if not the most important, factor in holding corn borer populations to relatively low levels, where they can be successfully controlled by other means at a greatly reduced cost.

In a co-operative effort, the Illinois Natural History Survey, United States Department of Agriculture, and Illinois

Conservation Department introduced a virus disease obtained from Canada to combat a serious outbreak of a pine sawfly, *Neodiprion sertifer*, that in 1952 was raging out of control in the Henderson State Forest. The virus took hold in a spectacular fashion, and sawflies died by the thousands. Whether the virus can be given full credit or not remains to be determined. In any case, the sawfly has not been reported as doing serious damage in that area since 1953.

The value of parasites imported from abroad to help control accidentally introduced species has also been underestimated. Here, as in an effort to control an insect pest by disease, the public seems to expect the immediate annihilation of the pest species or it regards the effort as a complete failure. To demonstrate that a species need not be annihilated to be prevented from causing appreciable damage, let us look at the record. The hessian fly and the wheat midge were both introduced in colonial days as immigrants from Europe. Fortunately, several of their European parasites came along with them in the same lots of straw, but, as usually happens, each pest reproduced and spread faster than its parasites. In due time the parasites overtook their hosts, and, for over a century, they have been important factors in preventing these pests from eliminating wheat production from the list of agricultural enterprises in Illinois.

When the oriental fruit moth appeared in Illinois in 1927, the Illinois Natural History Survey, in co-operation with the United States Department of Agriculture, obtained, for release in Illinois, oriental fruit moth parasites (principally *Macrocentrus ancylivorus*) reared in New Jersey. These were colonized at several points in the infested southern Illinois counties. At first the results of the experiment did not appear promising, but consistent recoveries were made in 1934, and eight surveys made since then have shown that parasitism by this species ranged from 17.3 to 53.2 per cent and averaged 36.5 per cent. While the parasite has not eliminated its host, it has held the population to a level where peaches can be adequately protected with a minimum use of insecticides. The average

percentage of the fruit infested since the establishment of the parasite is less than one-tenth what it was before colonization of the parasite was initiated.

Shortly after the European corn borer made its appearance in the Midwest, attempts to introduce several of its parasites into the infested area (1926-1930) were relatively, if not wholly, unsuccessful. Later attempts, in which the Illinois Natural History Survey and the United States Department of Agriculture co-operated (1944-1950), were more successful, and a Tachinid fly, *Lydella stabulans griseascens*, became firmly established in all sections of the state. Surveys made annually for the past 10 years have shown that, for the state as a whole, 15 to 40 per cent of the overwintering corn borers are parasitized and destroyed by this fly. In many instances parasitism in some of the northern Illinois counties has run as high as 80 to 85 per cent. While this parasitic fly has not eliminated the corn borer, it plays a very important role in holding this pest in check.

VALUE OF INSECT CONTROL

Man's progress in applied entomology is partly obscured by the ever-changing circumstances and conditions of insect control. Quantitative data on the exact magnitude of insect damage are generally unavailable, and only the more or less catastrophic insect outbreaks are adequately recorded in the literature. There are few specific points of reference with which we can compare the present with the past. Our memories are often faulty. We recall that Grandfather had a home orchard and how much we enjoyed the fruit; only after prolonged meditation do we also recall that only 1 apple in 10 was fit for storage in the fall, and that even in preparing a pie from the stored apples Grandmother had to cut out numerous areas damaged by codling moth.

Despite the paucity of precise quantitative data, entomologists have developed practical control measures for a long list of once serious pests. Orchardists are now able to produce fruit crops 90 to 99 per cent free of insect damage instead of crops only 10 to 50 per cent free of insect damage, as they were 100 years ago

or as they are now in abandoned or unsprayed orchards. The Colorado potato beetle, which came close to eliminating Irish potato production just about 100

Table 1.—Number of acres treated with insecticides and estimated profit from treatment for a few important insect pests of cereal and forage crops in Illinois, 1953-1957.

YEAR	NUMBER OF PEST SPECIES CONSIDERED*	NUMBER OF ACRES TREATED	ESTIMATED PROFIT FROM TREATMENT
1953	10	770,625	\$ 8,596,995
1954	7	1,095,165	7,130,258
1955	9	1,532,859	13,983,855
1956	10	1,405,624	7,097,630
1957	11	934,224	2,696,960
<i>Average</i>	9	1,147,699	\$ 7,901,140

*Insects considered in these surveys: spittlebug, leafhopper, spotted alfalfa aphid, sweet clover weevil, pea aphid, soil insects, chinch bug, cutworms, grasshoppers, European corn borer, and fall armyworm.

years ago, is no longer regarded as a serious pest. The grasshoppers, the armyworms, and the chinch bug, which less than a century ago caused many Midwestern pioneers to give up in despair and to abandon their farms, can now be controlled with comparative ease. The principal insect vectors of important human diseases have been brought under control to such a degree that the once dreaded diseases—malaria, typhoid fever, dysentery, cholera, and bubonic plague—are little more than an unhappy memory. Reasonably effective measures for the control of important household pests such as the bedbug, cockroaches, stored-grain pests, clothes moths, and carpet beetles have brought peace of mind to the housewife and have contributed much to increase the comfort of the home. Measures developed for the control of insects attacking livestock—ticks, tabanids, stable flies, lice, and screwworms—have contributed much to the livestock industry. The successes mentioned above were attained despite the drastic rise in level of acceptance imposed by the public, the United States Food and Drug Administration, and market grades and standards. Under present regulations, the diseased and damaged condition of fruits, vegetables, grain, and other agricultural products that were accepted at the turn of the century would eliminate them from moving in interstate

commerce or even from being sold on the local market.

Though it is not possible to establish monetary values for each of the accomplishments just mentioned, the almost \$8,000,000 average annual profit, table 1, resulting from the use of insecticides on cereal and forage crops in Illinois illustrates the benefits of entomological research.

There are those who will say that agriculture cannot afford the cost of insect control or that the farmer dare not add such charges to his overhead cost. Such assertions are economically unsound. The overhead charges associated with the planting, cultivating, and harvesting of each acre of crops are fixed. If a farmer can increase yields sufficiently to provide a cash return of two, four, eight, or more times the cost of insecticide treatment, the extra harvest is produced much more cheaply than the rest of the crop and thereby increases net profits and effects a reduction of operating costs.

Insect control—or the lack thereof—may have an indirect bearing on economic and sociological considerations in addition to those related to crop savings or crop losses. By increasing per-acre yields, maximum utilization of insect control measures might enable upwards of a million acres of Illinois farm land to be retired from cultivation and put to new uses. Some reactionaries will argue that increased yields would mean overproduction and lower prices; this argument has been applied to almost every new technological development.

For years we have been attaining production goals by mining the soil—by wringing from it the fertility that must be replaced if future generations are to have their share. Economically and morally, we are obligated to produce maximum yields as efficiently as possible on a minimum number of acres. The surplus land should be removed from annual cultivation and its fertility maintained or improved with soil building practices employed until such time as an expanding population requires further production. Even if Illinois could afford to squander its land resources and its manpower, the support of research for effective insect control would still be a foresighted invest-

ment. When men of wisdom, interested in the nation's future, combine forces in building a sound agricultural program, insect control will rank high in the list of technological musts.

EMPHASIS FOR THE FUTURE

Throughout the past century in Illinois, the extent and variety of insect control problems, which were often of an emergency nature, dictated that entomology be strictly applied and be aimed at immediate, practical goals. Perhaps the pressure for immediate, practical results reached its peak in the mid-1940's, when a number of new and apparently highly effective insecticides became available for study and use. Everyone wanted to know at once what these insecticides were good for, how they should be used, and what hazards might be involved in their use. Now this pressure is subsiding; the Illinois farmer is in possession of reasonably practical control measures for most of his important insect pests. Economic entomology in Illinois is now in a position to seek information on the basic problems of insect control.

This statement does not mean that all the insect problems of Illinois are solved; we should not be surprised that new problems will arise as new insect species are introduced and as species already here modify their habits or adjust their responses and behavior to an ever-changing environment. However, we have apparently reached a turning point that will require a revision of our responsibilities and will materially alter our objectives and procedures.

With reasonably effective control methods available for most pests, and with the majority of our basic crops in surplus production, emphasis on the temporary solution of immediate problems and on increased production must logically be shifted to the development of more basic studies ultimately leading to new methods of insect control. A review of the history of chinch bug, armyworm, codling moth, and potato beetle control makes it apparent that progress came in steps spaced 10 or 20 or more years apart. In entomology, as in other branches of science, real progress is made through the

development of some new fact, some biological or chemical law or principle referred to as a "break-through," discovered by scientists pursuing basic research.

Practically all entomologists agree that Nature is more efficient than man in controlling insects; there is an urgent need for a return to the basic study of insect biology and ecology and for expanded work in the promising field of biological control. With a more thorough knowledge of the environmental factors that favor insect reproduction and survival and of those factors detrimental to these processes, man might conceivably control some pests by diminishing the favorable factors, enhancing the unfavorable factors, or pursuing both courses. This type of basic research is expensive, and progress comes slowly, but successful projects based on the accumulated results of such research pay handsome dividends.

While more intensive studies in insect genetics, ecology, and biology may play increasingly important roles in the development of new insect control procedures, man will for many years find it necessary to rely on chemical weapons—insecticides—to fight many of his insect pests. As more and more toxic insecticides are developed, it becomes increasingly important that they be thoroughly tested for safety before they are placed in general use. The evaluation of insecticide residues, their degradation products, and possible adverse effects on man and other animals, is currently time consuming and expensive. We must undertake considerable basic research to discover and to develop basic principles or natural laws that will simplify insecticide evaluation and reduce the cost of pursuing such routine studies.

Come what may, man must never become complacent with his temporary successes nor assume that the insects have given up or will give up their struggle for supremacy. We must be ever mindful of the theses of L. O. Howard (1933) that insects are better equipped to occupy the earth than are humans; insects have been on earth for 40,000,000 years, while the human race is only 400,000 years old. As Forbes (1915:2) soberly asserted:

The struggle between man and insects began long before the dawn of civilization, has continued without cessation to the present time,

and will continue, no doubt, as long as the human race endures. It is due to the fact that both men and certain insect species constantly want the same things at the same time. Its intensity is owing to the vital importance to both of the things they struggle for, and its long continuance is due to the fact that the contestants are so equally matched. We commonly think of ourselves as the lords and conquerors of nature, but insects had thoroughly mastered the world and taken full possession of it long before man began the attempt. They had, consequently, all the advantage of a possession of the field when the contest began, and they have disputed every step of our invasion of their original domain so persistently and so successfully that we can even yet scarcely flatter ourselves that we have gained any very important advantage over them.

There seems to be little question that insects will continue to demand tribute of enormous proportions which will have to be paid in terms of damage, pain, and suffering caused by the insects, or in expenditures for insect control. Man may, through judicious expenditures for research and practical insect control measures, reduce or minimize the tribute to be paid, but he can never eliminate it entirely. In this connection, it should again be noted that entomology is not static. Insects, as highly versatile living organisms, are constantly changing to meet each change in the environment, whether it be biological, physical, or chemical. If we are to hold our own in this continuing battle, research must be carried on undiminished, and, if we are to make progress, research must be expanded.

At the moment, entomology and related biological sciences appear to be losing ground. State and federal appropriations have not kept pace with rising costs. Basic research is currently financed largely by grants from the principal endowed foundations. If it were not for funds made available by chemical and other large industrial companies, applied research in entomology would have been greatly handicapped and curtailed in the last decade.

Today, faced with the fact that another nation was the first to launch a man-made earth satellite, America is subjecting her own research facilities and educational system to critical review. At the moment, the physical sciences are in the limelight and apparently stand to profit from increased emphasis. That the

natural sciences can safely be relegated to a secondary or back-seat position is open to question. Almost 100 years ago, B. D. Walsh, deploring American neglect of the natural sciences, observed: "They manage these things better in Europe. In Russia and other continental states, Entomology in its rudiments is made a portion of common school education" (Anon. 1860:12).

There is every reason to believe that current entomological research in other countries is in no way inferior to our

own. If the biological sciences, including entomology, are neglected in a revitalized educational program, America may find herself again out-distanced by other countries—by men who are trained in a science-oriented system that is balanced to include all areas of scientific endeavor. If one step forward in the physical sciences causes us to slide two steps backward in the biological sciences, all our efforts spent to initiate a sound program for the advancement of science—all science—will have proved useless.

Faunistic Surveys

HERBERT H. ROSS

IN their beginnings and early development, investigations of the fauna of the Midwest differed in several respects from similar endeavors in other parts of the world. The Midwest was explored and collected intensively considerably later than the eastern American seaboard, so that the advances in the knowledge of the North American fauna made in the eastern United States were available as an aid to moderately rapid advances when faunal studies were begun in the Midwest. In the eastern United States and also in Europe, systematic investigations were begun in response to man's inherent curiosity concerning the kinds of life in his surroundings and were developed to a considerable state of advancement chiefly under this stimulus. In the Midwest, the first serious systematic efforts were undoubtedly begun in answer to pure curiosity, but almost immediately after their inception, especially in Illinois, these studies were picked up and swept along by the tremendous demand for identification caused by the agricultural and scientific developments of the latter half of the nineteenth century.

EARLY BACKGROUND

The sudden formation of natural history societies in the Midwest during the 1850's— at Louisville in 1851, Grand Rapids in 1854, Milwaukee in 1855, and Chicago in 1856—gives an impression in retrospect that before that decade there were no naturalists in the area. This was far from the case, for a few enthusiastic naturalists were active in various localities through the Midwestern region even before these dates.

Among the Midwestern naturalists were the famous zoologists Thomas Say, C. A. Le Sueur, and G. Troost, living and working on the banks of the Wabash River at New Harmony, Indiana, in the 1820's and 1830's, and C. S. Rafinesque at Louisville, Kentucky, in the 1810's

and 1820's. Many other persons collected material for these men or sent specimens for identification to taxonomists in the eastern United States or Europe.

The early faunistic workers of the 1840's and the 1850's in Illinois included such men as Cyrus Thomas, John A. and Robert Kennicott, J. B. Turner, and Benjamin D. Walsh, all of them self-taught naturalists. These and other enthusiasts made accurate observations on the fauna, built up collections of various animal groups, and kept in touch with their confreres in the eastern states. The Illinois entomologists published articles, some of them in the *Prairie Farmer*, and absorbed the ideas of such great early entomologists as T. W. Harris of Massachusetts and Asa Fitch of New York.

In Illinois the State Agricultural Society, formed in 1853, was an important agent in bringing together Illinois zoologists, entomologists, and botanists into an organized natural history society. The progressive officers of the Agricultural Society were conscious from the first of the destructive nature of insects and were sufficiently versed in biological concepts to realize that applied biology requires a full knowledge of all forms of natural life. To encourage acquisition of this knowledge, the Agricultural Society offered prizes at its state fairs for collections in natural history fields. In 1854 Wm. J. Shaw of Tazewell County won first prize for the "Best suite of the animal kingdom, including insects and animals injurious to the farmer" (J. A. Kennicott 1855:122). In 1855 Robert Kennicott won two prizes, one for the "Greatest and best collection of named insects," the other for a zoological collection; in 1856 he won seven firsts—for a collection in each of the following classes: shells, named insects, zoology, botany, stuffed birds, reptiles, and fishes (J. A. Kennicott 1857:90, 142).

In the State Agricultural Society's first *Transactions*, three lists of animals for Illinois were published, one on southern

Illinois birds by Henry Pratten (1855), one on the Mollusca of southern Illinois by H. A. Ulffers (1855), and another (solicited by the Society's secretary) on the animals of Cook County by Robert Kennicott (1855). It is interesting that in this last article Kennicott recorded "buffalo" and elk for Cook County and noted that the "wild pigeon" (passenger pigeon) was "very abundant" and the magpie "not uncommon in winter."

For a few years after the first corporate form of the Illinois Natural History Survey had come into being as the Illinois Natural History Society, the Agricultural Society published the proceedings of the infant organization.

In Illinois the faunistic worker of 1858 had few of the work aids which we enjoy today. The only Midwestern institutional reference collection was that at Northwestern University, built up by Robert Kennicott and considered outstanding in its day, although small and limited in group representation compared with collections now available.

Most zoologists accumulated their own private collections, identifying their specimens with the aid of the few books available and through consultation with other naturalists. Few libraries existed in the area. The reference shelves of the best zoologists contained comprehensive treatments covering the eastern North American fauna for most of the vertebrates and the Mollusca. For the insects Say's volumes were available, but for many orders his treatment was fragmentary. For most insect groups and many other invertebrates, extremely helpful world synopses had just been written by European authors, and some of them contained separate keys for the North American species. Aside from these basic references, there existed a number of journals carrying short papers, some of them published by the scientific societies of the Atlantic seaboard states, where such societies had been organized a century before their Midwestern counterparts.

This period, the 1850's, was a stirring one scientifically. Europe had just witnessed the successive development of comparative anatomy and physiology, the cell theory, embryology, histology, and the theory of evolution. These basic concepts

did not immediately influence faunistic work in North America but they did so later to a greater and greater degree. In North America prior to the 1850's, the great bulk of the invertebrate material, including insects, had been sent to European specialists for description. Following the pioneer examples of Frederick Melsheimer and Thomas Say with insects and mollusks, American zoologists were beginning to describe more and more species of the native American fauna. In the invertebrate groups they had virtually a virgin field, for in 1858 great numbers of species were still unknown, and workable synopses were available for only a small proportion of the native American fauna.

CHANGING HABITATS

Originally Illinois was chiefly a combination of forested hilly country and flat mesic prairies of a marshy nature. Interspersed with these main types were sand areas, bogs, river and stream habitats, and other local areas of diverse kinds. The rapid rise in the population of Illinois in the mid-nineteenth century initiated in the native vegetation drastic changes which have progressed steadily to the present time; these changes have had a marked effect on the distribution and composition of the animal life of the state.

By 1858, towns or farms or logged-over areas had broken up large tracts of forest. Plowing had made great inroads into the prairies. Large area drainage operations in the marsh country had started about 1850, had gained great momentum by 1880, and by 1900 had turned the great bulk of the marshland into farms. The resultant changing ecology is a background feature important to keep in mind when viewing the faunistic developments outlined in this chapter.

PERIODS OF FAUNISTIC ACTIVITIES

The faunistic activities of the Illinois Natural History Survey and its predecessors may be divided into three fairly distinct periods, the initial, chiefly voluntary, period of roughly 1858-1869, the

expansion period of roughly 1871-1922, and the specialized faunistic survey period of roughly 1923 to date.

Initial Period, 1858-1869

The Illinois Natural History Society, when formed in 1858, had as its primary objectives the exploration of the biota of Illinois and the establishment of a scientific library. Encouragement of animal studies was patently aimed at systematics; yet even in the inaugural presidential address by J. B. Turner there is more than an overtone of putting systematics to work. In the words of Turner (1859: 647),

A true philosophy, as it seems to me, would never let us rest content till we had truly and fully learned not the bare name and form, but the final cause and use, the good and evil, the full relation of each thing, object and being, to all other beings, and especially to man—to all his interests, enterprises, arts, uses and developments, physical, mental and moral.

At the anniversary meeting in 1860 at Bloomington, certain objectives of the Society were expressed differently but in equally broad terms (Anon. 1860:3):

It is the aim of the Society . . . to establish a Museum of Natural History, at the State Normal University, comprising every species of plants, birds, shells, fishes, insects, quadrupeds, minerals and fossils, found in Illinois, together with such collections from various parts of the world as will assist our youth in gaining a knowledge of the general studies of nature.

The Natural History Society did in fact found a museum at Normal, Illinois, which served as a rallying point for zoologists of the area. The Society's papers and proceedings continued to be published by the Agricultural Society, which further continued its active encouragement of faunistic work by awarding prizes for exhibited collections at the state fair.

At about this time several Illinois naturalists began publishing accounts of the zoology of the state. C. D. Wilber (1861*b*) described a fossil mastodon, Thomas (1861*a*, 1861*b*) wrote lists of mammals and of some insects, R. H. Holder (1861*a*, 1861*b*) wrote about birds, and Walsh (1861-1868) published a remarkably fine series of papers before his

death in 1869. Although a skeleton network of railroads crisscrossed the state, most of the collecting was local, because it had to be done as a hobby appended to the naturalist's business or other occupation; hence, the papers were based chiefly on material from a few localities.

Collections exhibited at the state fairs give another informative light on faunistic activities of that time. At the 1859 fair three entries were exhibited, one a red deer, another a collection of stuffed birds, and the third a collection of insects. In 1860 seven entries (Reynolds 1861:190-1) and in 1861 eight entries (Reynolds 1865:137) were exhibited in zoology. There were no more exhibits in zoology until 1864; in that year the winners were chiefly the Illinois Natural History Society and Illinois Wesleyan University at Bloomington (Reynolds 1865:310). Apparently these two groups enjoyed some rivalry at that time in the development of natural history.

An idea of the high merit of these exhibits can be gained from the 1861 Awarding Committee's remarks (Reynolds 1865:149) on the insect exhibits:

In Entomology, a collection exhibited by T. G. Floyd, of Macomb, entitled the exhibitor to the "commendation" of the Society. In this department, Dr. Charles A. Helmuth, of Chicago, made a fine exhibition. His collection of Beetles is very valuable and attracted much attention. He has over 1100 species collected in Illinois, besides many fine species from other States and foreign countries. We think him entitled to "very high commendation," especially for specimens exhibited belonging to the order of Coleoptera. But by far the best collection exhibited was presented by B. D. Walsh, Esq., of Rock Island. It is hardly possible to speak in too high terms of this extensive collection of the insects of Illinois. So far as Illinois insects are concerned, it outnumbered in the order of Coleoptera, the collection of Dr. Helmuth, and is very full in all the other orders. It could only have been collected and arranged by an exercise of industry, [perseverance] and skill, and by an application of scientific knowledge, reflecting great honor upon the collector and entitling him to high rank among the Naturalists of the State and of the country. The Committee do not hesitate to pronounce his the "best collection illustrating the Entomology of Illinois," and unanimously award to him the premium of the Society.

In spite of the achievements in faunistic activities shown by both publications

and exhibits, the Natural History Society itself faltered because it could not make ends meet on private subscriptions alone and by the end of the 1860's was a mere shell of an organization.

Expansion Period, 1871-1922

The establishment of the State Entomologist's Office in 1867 and the incorporation of the Illinois Natural History Society into the State Board of Education in 1871 brought together as official state organizations two agencies investigating natural science and marked the beginning of continuing state support for faunistic programs.

The appointment of Walsh as first State Entomologist had little effect on this movement because Walsh confined his official writings almost entirely to nontaxonomic subjects. His successor, William Le Baron, introduced serious taxonomic contributions into the reports of the State Entomologist in 1871.

In his first report as State Entomologist, Le Baron described a new species of moth attacking apple, in his second described four more new species of insects of economic importance, and in his third gave an outline of and key to the orders of Illinois insects (Le Baron 1871: 20-3; 1872:117-24, 138-9, 140, 157-8; 1873:25). Here he called particular attention to the great need for identification aids in the pursuit of economic entomology. Le Baron's was the first of much faunistic work which continued as an integral part of the development of economic entomology in Illinois. At almost the same time (1871), the educators and scientists of the state, alarmed at the continued decline of their Natural History Society, induced the legislature to take over and assign the Society's museum and library to the State Board of Education in exchange for state appropriations (Illinois General Assembly 1872: 151-2) for the Society's continued growth. Thus, the need for state aid in the development of faunistics arose from two different directions.

Both Le Baron and Thomas as State Entomologists published many fine taxonomic insect studies in their reports. Under the auspices of the Illinois Museum of Natural History, naturalists in the state

published faunistic papers on a wide range of Illinois groups, including Crustacea, fish, birds, reptiles, and insects.

The period 1858-1878 witnessed the first concerted awakening of American naturalists to the taxonomic opportunities in the invertebrates, especially in the insects. Specialists in many states published comprehensive treatises on orders or families of insects of North America. For these animals, this was truly the age of North American discovery.

In 1877 the Museum of the Natural History Society, by that time known as the Illinois Museum of Natural History, was separated into two institutions: the Natural History Museum, designed as a public exhibition museum, in Springfield, and the State Laboratory of Natural History, at Normal (Illinois General Assembly 1877:14-6). The duties of the State Laboratory, presumably as set forth by Stephen A. Forbes, its Director, stressed ecological approaches to the animal life of the state and in this policy reflected thoughts expressed by Turner 20 years before. The primary intent of the systematic program described was "to monograph those groups which have not been thoroughly studied elsewhere" (Forbes 1882a:9).

In 1882 Forbes became State Entomologist, as well as Director of the State Laboratory. Following the establishment of both of these offices at Urbana in 1885, the faunistic program received great impetus. Reading between the lines of the original reports of the Director, it seems safe to surmise that by this time the ecological studies already attempted had highlighted the pressing need for the accurate identification of the animal species encountered in these studies. In the revised list of duties of the State Laboratory we find the directive, "he [the Director] shall present for publication, from time to time, a series of systematic reports covering the entire field of the zoölogy . . . of Illinois" (Illinois General Assembly 1885:23). In its *Bulletin*, the Laboratory had previously published many papers by nonstaff members, but from this time on a larger and larger proportion of these papers was the product of staff members of the State Laboratory or of the State Entomologist's Office.

The main faunistic activities of these staff members concerned aquatic organisms and insects associated with the development of ecology and economic entomology. Forbes repeatedly mentions that the most important tools of the biologist are

roads traversed the state and these were the only means of rapid travel. Collecting was done intensively around a few headquarters, especially Urbana, Carbondale, and Havana. On the Illinois River and other waterways, boats were available



Field party of the Illinois State Laboratory of Natural History at one of several collecting stations near Havana, 1894. This station was on the east shore of Thompson's Lake, which has since been drained. In the picture are, left to right, Frank Smith and Henry E. Summers, zoologists, Charles A. Hart, entomologist, and Miles Newberry, fisherman and boatman.

a reference collection for the identification of specimens and a scientific library. All staff members collected specimens as part of their duties, and every effort was made to obtain material from different parts of the state and from areas of interest in adjacent states. By 1894 the collections were of sufficient magnitude to be placed under the charge of a curator, C. A. Hart. In 1903 Hart became Systematic Entomologist and Curator of the insect collections, and R. E. Richardson was brought in to take charge of the fish collections. In 1915 J. R. Malloch was appointed to assist Hart with the insects.

Collecting conditions from 1870 to well into the 1900's were greatly different from those of today. A few rail-

roads traversed the state and these were the only means of rapid travel. Collecting was done intensively around a few headquarters, especially Urbana, Carbondale, and Havana. On the Illinois River and other waterways, boats were available

for travel up and down the rivers. Local travel was done by horse-drawn vehicles. As late as 1900 Forbes (1901:3, 5-6) wrote of the Laboratory:

Its field operations have been conducted mainly from the Illinois Biological Station [at Havana and Meredosia] as a center, . . .

Besides this local work on the fishes of the State, two extensive wagon trips have been provided for, one made in the fall of 1899, and the other in progress at this date [September, 1900]. . . .

A considerable number of collections have also been made by high school principals and science teachers and sent to the Laboratory in aid of this survey.

Hart and his assistants traveled to various points by train and in each town set up headquarters in a local hotel or rooming house, hired a buggy, and made

day trips into the surrounding territory. In this way, over the years a remarkably fine collection of insects was built up from almost every part of the state. The establishment of the field laboratory at Havana formed a basis for many seasons of intensive insect collecting in the rich waters of that area and on the extremely interesting sand areas which line the east bank of the Illinois River through several counties.

At the present time such restrictions on movement might seem a terrible handicap, but one must remember that in those days the land was not so intensively cultivated as it is at present. Within a very short distance of almost any town, tracts of virgin forest, prairie, marsh, or other undisturbed habitats could be reached with little effort. Many of the old virgin landscapes which were the type localities of Illinois species are now either flooded by artificial lakes, under cultivation, or covered by urban developments. Most of the marshes, which were once commonplace, have been drained. Because of the abundance and accessibility of varied habitats, the early collections were both large and diversified. The very nature of the substation headquarters method encouraged the collection of all species of insects in a given locality, rather than specialization on any one group. Human labor was relatively cheap; hence, preparators and collectors could be hired and trained at a nominal cost.

As a result, the State Laboratory insect collections (which constituted also the insect collections servicing the State Entomologist's Office) became the finest which had ever been assembled for any one state, and early in the twentieth century the collections of fishes and certain other groups were equally fine. This faunistic program reached a peak about 1910 and continued into the next decade.

In 1917, when the State Entomologist's Office and the State Laboratory were combined to form the present Illinois State Natural History Survey, the reorganization did not effect any changes in the internal structure of the faunistic staff. Immediately afterward, however, the faunistic program began to dwindle. Many of the well-trained personnel accepted positions in universities and other

scientific centers which were growing rapidly. World War I drew away much of the younger help. Richardson concentrated on ecology. Hart, the work horse of the entomological collections, died in 1918, and in 1919 C. P. Alexander was appointed Systematic Entomologist. Alexander and Malloch worked chiefly on stream surveys. The studies of Alexander resulted in a report on the Vermilion River (Alexander 1925). After the resignations of Malloch, in 1921, and Alexander, in 1922, there were no faunistic taxonomists left on the Natural History Survey staff. No comprehensive faunistic projects had been in operation for several years, and these resignations left the Survey without even curators.

Specialization Period, 1923 to Present

The appointment of Theodore H. Frison as Systematic Entomologist in 1923 marked the beginning of a resurgence in the faunistic activities of the Natural History Survey. Until several years later this move was felt primarily in the insects, but eventually it spread to the other animal groups. Frison's first endeavors were to collate the insect collections, but his chief thoughts were aimed at methods for revitalizing the old charge to publish a series of systematic reports covering the entire field of the zoology of Illinois (Illinois General Assembly 1885:23). Forbes was as anxious as Frison to see this program begin. By this time several factors had changed the faunistic outlook considerably from that of the beginning of the century. Good roads reached almost every hamlet in the state, and the automobile had supplanted the train and buggy as a ready means of travel. The ease of reaching all points of the state made up in large measure for the increasing destruction of large tracts of native habitats and the necessity of seeking primeval collecting spots in remote and widely separated localities.

Taxonomically the picture had changed to an equal extent, at least for insects. In 1900 it was generally considered that except in groups like aphids and ectoparasites, species could be readily identified by external characters through use of, at most, a hand lens. Variation had

been little recognized as a factor in and a difficulty of identification. A reference series of a few specimens was considered thoroughly adequate for each species. Although the value of series of specimens was becoming recognized at the beginning of the twentieth century, the true necessity for larger population samples was not fully recognized in insect groups until about the 1920's. By this time, in group after group of insects and indeed of other invertebrates, many of the older species units were each being divided into several species separated only by microscopic characters, which were often minute in character and difficult to see. So detailed was the knowledge required to identify many of these groups that it was no longer possible for one person to cover reliably the tremendous number of groups which Hart had done so successfully according to the standards of his day.

Influenced by these changes, a faunistic program was evolved centering around intensive studies of individual groups. The program called for each staff member to study some special group, collect material throughout the state at different seasons and in different habitats, identify the material, and write up a report of the group for Illinois. It was hoped that the services of specialists at other institutions could be obtained during the summer months to work with Natural History Survey personnel on Illinois reports. In the original plan, the thought was that these reports could be restricted quite closely to Illinois material and to Illinois species. This plan did in fact prove satisfactory for the aphids and Orthoptera, which were relatively well known for the country as a whole. When, however, projects were started for groups which were poorly known for the continent, it was found essential to extend the scope of the reports to cover roughly the mid-central states, as Forbes had implied as a general policy as early as 1900.

It was recognized early in this program that many insect groups of little importance economically were nevertheless of great importance ecologically. An attempt was therefore made to develop a program which would alternate the treatment of groups having principally

economic importance with those having principally ecological importance.

Within the bounds of a primarily systematic treatment, it was hoped that basic information could be obtained on *the place of the species in nature*. Collecting programs therefore stressed discovering the microhabitats, hosts, seasonal appearance, or other ecological attributes of the different species.

An aim of great importance which developed for these reports concerned their usability from the viewpoint of the beginning student. Many keys made by specialists contained language too technical to be readily understood by non-specialists. Frison was acutely aware of this fact and insisted that all keys in the faunistic bulletins be couched in language as simple as possible and that, wherever helpful to an understanding of characters or specialized terms, illustrations should accompany the keys.

Frison's plan for faunistic reports was not put into operation until 1928, when F. C. Hottes was employed during the summer as a special appointee to work on the aphids of Illinois. The appointment of Hottes was the first of several of its kind. In 1931, when Frison became Chief, Herbert H. Ross became Systematic Entomologist. In 1935 the insect systematic program became the Insect Survey Section of the Natural History Survey.

The identification of economic insects, always a duty of the Systematic Entomologist, became an important feature of the Section. The Section was called on also for the identification of certain other invertebrates important in agriculture or public health, especially mites, ticks, aquatic Crustacea, and earthworms. In these activities, changing taxonomic concepts and the introduction of economic insects and mites new to the state continually increased the difficulties of accurate identification and the need for obtaining additional specialists for the staff.

In 1947 the faunistic program was expanded to cover all animal groups, with the idea of extending to groups other than the insects the faunal survey aims which had been developed for insects. The Insect Survey Section was renamed the Section of Faunistic Surveys and Insect Identification, and it became the

custodian of all the Survey's taxonomic collections of animal groups.

Over the years several artists have contributed greatly to the utility and appearance of the Survey's faunistic publications—Lydia M. Hart, H. K. Knab, C. O. Mohr, Kathryn M. Sommerman, and Elizabeth Maxwell. Miss Hart and Dr. Mohr, especially, have graced Natural History Survey publications with a multitude of remarkably fine total views of insects.

RESEARCH COLLECTIONS

The great value of research and reference collections to programs in natural history was stressed in the founding articles of the Illinois Natural History Society and has been evident ever since in all phases of applied ecology. The Natural History Survey has therefore stressed the assembling and maintenance of adequate research collections of animal groups as a corollary to its faunistic activities.

The general aims in augmenting the collections have varied over the years, but in recent decades have approached closely the policy expressed at the 1860 anniversary meeting of the Natural History Society and have emphasized first the species found in Illinois and then species or additional material from other regions which contribute to analyzing or interpreting the Illinois fauna.

Taxonomists in other institutions have aided the Illinois Natural History Survey greatly by identifying Survey material in their respective specialties. This aid has not only resulted in keeping the Survey collection up-to-date but has afforded needed reference material in many genera or families.

Vertebrates

During the early periods of Survey history, Forbes and his assistants built up and maintained a large collection of Illinois fishes, but kept only a small reference collection of other groups. Much of the fish collection is intact at present, but the older material of other vertebrate groups has become dissipated. In recent decades emphasis has been placed on building up collections of amphibians and

reptiles, especially variational series from Illinois and surrounding states; on starting reference collections of birds and mammals; and, more recently, on assembling fish collections designed to be a basis for a re-study of Illinois fishes.

Invertebrates Other Than Insects

In early records of the Survey, there is no indication of the extent of invertebrate collections other than that given by incidental mention in a few small published papers. The largest of these collections comprised the molluscs; the aquatic species were obtained chiefly from river surveys and the extensive series of land species from the collecting of Frank C. Baker and Thural Dale Foster. Early collections of other groups were made, at least of phalangids, crustaceans, and certain protozoans, but only scattered vials or slides of these materials are extant at the present. Since 1930, special Illinois collecting has been initiated for a few groups, and in the pseudoscorpions and ticks excellent Illinois series have been assembled.

Insects

From the late 1870's to the present, the insect collections grew steadily. The first official collection was Walsh's private collection purchased by the State for Le Baron in 1870. Le Baron picked out duplicates for a reference collection in his office and then sent the main Walsh collection to the Chicago Academy of Sciences for safekeeping. There it was destroyed in the Chicago fire of 1871. Ironically, some of the material Le Baron selected from the Walsh collection may have persisted and be represented in the present Natural History Survey collection. Since the extant Le Baron specimens lack locality data, however, it is impossible to determine their original source. A collection of aphids made by Thomas was preserved, also.

The insect collection which Forbes began in the State Laboratory was quite small while he was at Normal. As soon as he became established in Urbana in 1885, he started to place great emphasis on building it up. About 5 years later Forbes (1890:3) gave the following account of the collection:

The entomological collection has been greatly enlarged, especially in Diptera, and a large number of determinations in all orders have been made. The named collection is now contained in 160 double boxes, and numbers about 5,000 species, each being represented, as a rule, by four selected specimens. The pinned and determined duplicate insects on hand—largely in process of distribution to public schools—amount to 42,600 specimens. The alcoholic insects, including large numbers of larvae, are contained in about 10,200 bottles and vials.

Although we have no later estimates of the size of this insect collection, it is obvious from material now in the collection that by 1910 Hart was keeping much larger series of each species.

In addition to material gathered by the staff, in the Natural History Survey collection are several collections of note that have been given to or acquired by the Survey. Notable items include the W. A. Nason collection (insects of Algonquin, Illinois), the C. W. Stromberg collection (insects of northwestern Illinois), the Andreas Bolter collection (all orders of insects), the Emil Beer Lepidoptera collection, the Charles Robertson collection (insects on flowers), the L. J. Milne caddisfly collection, the C. L. Metcalf flower fly collection, the W. P. Hayes weevil collection, the A. D. MacGillivray sawfly collection, the P. N. Musgrave water beetle collection, and the K. F. Auden beetle collection. Amateur entomologists, such as Murray O. Glenn of Henry and Alex K. Wyatt of Chicago, have made numerous valuable additions to the collection.

Because of special taxonomic interests on the part of staff members, the collection is unusually comprehensive in certain groups of insects. To this category belong the stoneflies, mayflies, and caddisflies; the aphids, mirids, and leafhoppers; the leaf beetles, rove beetles, and June beetles; the sawflies and bees; the thrips and psocids; the springtails; and a few groups of the true flies. In many orders the collection contains a great deal of material of the immature stages, which have been emphasized in our reports. The large collections of rove beetles, sawflies, and ectoparasitic groups are associated with plans for future projects.

Since 1925 primary types at the Natural History Survey have been segregated

for reference and protection. In 1927 these represented about 1,000 species; the number now stands at about 2,500 species. At present the total insect collection contains roughly 2,000,000 specimens, including over 50,000 slide mounts, representing about 40,000 species and housed in 2,700 insect drawers and 100,000 vials.

FAUNISTIC REPORTS

The preparation and publication of reports on the animals of Illinois, a responsibility repeated several times in mandates to the Natural History Survey and its predecessors, was begun with the first publications of the Illinois Natural History Society and has been continued to the present. Many of the first reports were mere lists, often local in nature, and have needed revision or complete retreatment.

In addition to the chiefly systematic accounts outlined below, ecological and economic studies over the years have contained a wealth of records and descriptions of a large number of species. This is true especially of surveys of the sand areas, prairie and forest areas, and extensive bottom fauna and shore studies of the large rivers.

Vertebrates

Faunistic reports have been published on all the vertebrate groups occurring in Illinois. Certain of the older reports are now out-of-date because of our greatly increased knowledge of the fauna.

Fishes.—The work on Illinois fishes may truly be considered the first sustained faunistic project carried on by personnel of the Natural History Survey or its parent organizations. The project was begun with Forbes' first connection with the Illinois Natural History Society and continued as a cohesive systematic study until 1909.

At the time of birth of the Illinois Natural History Society, approximately three-quarters of the Illinois fishes had been described and named by such distinguished early ichthyologists as Rafinesque, Le Sueur, Girard, Agassiz, Mitchell, and Kirtland. Half a dozen of these species were first discovered in Illinois waters. During the next three or four decades,

when Illinois waters were being studied intensively by Forbes and his colleagues, most of the remaining Illinois fishes were described by such famous zoologists as Jordan, Cope, Gilbert, Nelson, and Forbes himself.

A regional list treating the fishes of the Chicago area was prepared by Robert Kennicott (1855), and comprehensive catalogs of the fishes of the entire state appeared in the first volume of the *Bulletin* (Nelson 1876; Jordan 1878). Several years later Forbes (1884) prepared a third catalog of Illinois fishes, and early in the present century Thomas Large (1903) published a fourth list.

Some time in the 1870's Forbes seems to have developed the idea of producing a well-illustrated and detailed account of the Illinois fishes which would be useful for all the Mississippi River states. Year after year, wagon parties were sent to explore and collect in different streams of the state until finally records were available for virtually every river and rill in Illinois. Along the Illinois River large collections were made year after year. Some extensive collecting parties visited localities in neighboring states. The amount of human endeavor that went into this project is monumental and represents the steadfast patience and toil of 30 years. The final report, *The Fishes of Illinois* and its *Atlas*, by Forbes & Richardson (1908), summarized all this information and featured a remarkable set of color plates prepared by Lydia Hart.

Since the appearance of the Forbes & Richardson report, two other contributions have been made by the Natural History Survey to Illinois fish taxonomy. D. H. Thompson & F. D. Hunt (1930) published a report on the fishes of Champaign County, and D. J. O'Donnell (1935) published an annotated list of Illinois fishes.

Birds.—Before 1858 there was an abundance of illustrative and synoptic references to North American birds by Wilson, Nuttall, Audubon, and others, and there were local lists of Illinois birds by Robert Kennicott (1855) and H. Pratten (1855). Later, R. H. Holder (1861a) published a list of Illinois birds and a short taxidermy manual in the *Transactions* of the Illinois Natural His-

tory Society. In 1881 Robert Ridgway published a revised catalog and, a few years later, two large reports, the two volumes of *The Ornithology of Illinois* (Ridgway 1881, 1889, 1895). The first volume was destroyed by fire in the state printer's office and had to be completely reprinted before it was issued. These two volumes were among the pioneers in the use of structural characters in keying the birds of an area. Ridgway, a native of Illinois, was not an employee of the state but wrote these volumes because of his intense interest in Illinois birds.

In later years Forbes, A. O. Gross, and Frank Smith made many observations on Illinois birds, but these studies were primarily of an ecological nature.

Amphibians and Reptiles.—Survey studies concerned with these animals did not start until the 1880's. In the first volume of the *Bulletin*, N. S. Davis, Jr., & F. L. Rice (1883) published a catalog of amphibians and reptiles found east of the Mississippi River. H. Garman (1890) also studied these groups. No synoptic collections were kept of the early material. In the 1930's Francis Lueth and Willard Stanley accumulated records and assembled several hundred specimens. In the early 1940's the Natural History Survey focused attention on these groups through the co-operation of H. K. Gloyd of the Chicago Academy of Sciences, C. H. Pope of the Chicago Natural History Museum, and H. M. Smith of the University of Illinois. In 1947 P. W. Smith initiated an intensive study of these animals, making collections in all parts of the state and plotting the variation and distribution of each species. In 1957 this project culminated in a comprehensive report on the amphibians and reptiles of Illinois; the report is now awaiting publication.

Mammals.—The Natural History Survey and its parent agencies have published only a small number of reports on Illinois mammals. The first, by Cyrus Thomas (1861b), was published by the Natural History Society. Early in the present century, F. E. Wood (1910a) published on the mammals of Champaign County. In the 1930's C. O. Mohr became interested in the mammal fauna of Illinois and gathered a great deal of in-

formation on distribution and habits. After Mohr left the Natural History Survey in 1947, the work on mammals was taken up by D. F. Hoffmeister of the University of Illinois, and the resulting fieldbook appeared shortly after Mohr had rejoined the Survey staff (Hoffmeister & Mohr 1957).

Invertebrates Other Than Insects

Most of the invertebrate studies made during the early history of the Survey concerned chiefly aquatic organisms which were important in limnological investigations. The first paper by Forbes (1876) in the *Bulletin* was a list of the Illinois Crustacea; this was followed by a paper on Crustacea by L. M. Underwood (1886). A. Hempel (1896, 1899) described a few rotifers and protozoans from the Illinois River, and C. A. Kofoid (1898, 1899) described a few plankton organisms of Illinois. R. W. Sharpe (1897), F. W. Schacht (1897, 1898), and Ernest Forbes (1897) made additional contributions to a knowledge of the Crustacea. C. M. Weed (1890) did considerable work on the phalangids of Illinois and published a partial catalog of the group.

Several other invertebrate studies published in the *Bulletin* were almost entirely the work of nonstaff members, some of whom worked actively in co-operation with the Survey. J. P. Moore (1901) treated the Illinois leeches; Frank Smith (1895-1928) published many papers on earthworms; H. J. Van Cleave (1919) studied Illinois River Acanthocephala; Henry E. Ewing (1909) studied the orobatid mites; and F. C. Baker (1906) published a catalog of the Illinois Mollusca.

Ecological work on the rivers amassed collections of the various plankton groups, but only those portions noted above were ever analyzed taxonomically. Much of the material was discarded after being recorded, and much was lost by desiccation. Except for the collections of Mollusca, by 1947 only a small amount of the early invertebrate collections remained.

About 1930 a survey of the land snails of Illinois was organized under the leadership of F. C. Baker. The field work

was done primarily by T. D. Foster. Foster used a motorcycle on collecting trips and shared with S. C. Chandler the distinction of being one of the few members of the Survey's motorcycle brigade. For 2 years he conducted a whirlwind search over the entire state for land snails and brought together a remarkable number of records. The material was identified by Baker, who prepared a report that appeared as a fieldbook of the Illinois land snails (Baker 1939). The book was beautifully illustrated by C. O. Mohr.

Berlese collecting, instituted about 1933 primarily for exploring the insects in duff, netted not only insects but large numbers of terrestrial invertebrates, mainly arachnoids. About 1940 C. C. Hoff of the University of New Mexico became interested in co-operating in a study of pseudoscorpions of Illinois. He found that many species collected in these Berlese samples were new and represented a Midwestern faunal element which had remained unseen because other pseudoscorpion specialists lived in either the East or the West. Hoff's report on the Illinois fauna was published by the Natural History Survey (Hoff 1949).

Insects

Considering not only the economic importance of insects but also the exceedingly large number of species expected in the state (approximately 20,000), it is not surprising that the Natural History Survey's most extensive faunistic contributions have been made in this group. Many of the studies have resulted in descriptions of new species, life history notes, and distribution records contained in short papers; many others have resulted in comprehensive accounts of various groups found in Illinois.

Orthoptera.—Thomas was early a keen student of the Orthoptera and in the first of the *Transactions* of the Natural History Society published a list of this order for Illinois (Thomas 1859*b*). His interest continued and he published a second, enlarged list in the first volume of the *Bulletin* (Thomas 1876). In the early 1900's, Hart and A. G. Vestal made large and extremely interesting collections of this order in the Illinois sand areas, in which an appreciable number of western

species occur. In 1932 Morgan Hebard of the Academy of Natural Sciences of Philadelphia offered to prepare an account of the Dermaptera and Orthoptera of Illinois. For this project staff members made additional collections in areas of the state not previously covered for the group. The report appeared 2 years later (Hebard 1934).

Aphids.—This group was one of the first emphasized in studies by the Natural History Survey's parent organizations. Thomas, one of the leading early investigators in the taxonomy of this group, published a synopsis of one of the tribes and described many new forms from Illinois (Thomas 1878). About the same time Nettie Middleton (1878) described another species, and several years later C. M. Weed (1891) published the results of his studies on the life histories of a number of species. Little more was done with this group until J. J. Davis started

further taxonomic investigation of the aphids about 1908. In the *Bulletin*, Davis (1913) published a commentary on the Cyrus Thomas collection and in addition 20 papers on aphid taxonomy in various entomological journals. Most of this work he did while an assistant in the State Entomologist's Office.

In 1928 Frison and F. C. Hottes, the latter now at Grand Junction, Colorado, took up a study of Illinois aphids. This was the first study to be based on a combination of intensive collecting for one group and opportunities for rapid travel to all parts of the state. Field investigations were made during the summers of 1928–1930. Each year collecting parties started in the southern part of Illinois and worked north and then reversed the pattern so that each locality was collected at different seasons. A complete set of slide mounting equipment was taken into the field, and temporary headquarters were



An Illinois Natural History Survey entomologist making field notes relating to insects he has collected. The association of insects with their host plants is an important phase of the work of Survey entomologists.

set up in hotels at various towns. Each party consisted of three persons. Usually all three collected during the first half-day spent in each locality; after that one person stayed in the headquarters hotel and mounted aphids while the other two continued collecting. Lists of potential hosts, with especially interesting ones indicated, were used as a tick sheet in each locality. About a hundred species, 36 of them new to science, were added to the state list. The report on this project was published in the *Bulletin* (Hottes & Frison 1931).

Odonata.—Nymphs of this order were frequently encountered in limnological work, and H. Garman and Hart reared many of them during the 1880's and 1890's. This work set the stage for the first report on Illinois dragonflies, an article by J. G. Needham & Hart (1903). Later Philip Garman did much work on the group and wrote an excellent account of the damselfly suborder Zygoptera in Illinois (P. Garman 1917).

Pentatomoidea.—This group includes the stink bugs, a group of sucking insects for which Hart had a special interest. He assembled a remarkably fine collection of the Illinois species and had virtually completed an account of the state fauna at the time of his death. The manuscript was completed by J. R. Malloch and was published in the *Bulletin* (Hart 1919). This report was especially useful because it included not only keys to the Illinois species but also keys to the Nearctic genera.

Diptera.—The first serious work on the flies done for the Natural History Survey or a parent organization was by J. R. Malloch. Although interested in Diptera in general, Malloch specialized in the Chironomidae or midges, of great importance in the economy of Illinois waters. He reared a large number of these insects and was one of the first workers to delve into the minute characters of the male genitalia and the larval mouthparts as an aid in species discrimination and identification. His rearings were done chiefly in the vicinity of Havana and Urbana, with a great deal of help from Hart, who also collected adult material from various parts of Illinois and surrounding states. The report by Malloch (1915) on the midges was outstand-

ing among faunistic works. Not only did it give equal emphasis to the adults and larvae, a most unusual feature for the time, but it benefited from two remarkable faculties of Malloch's. One was Malloch's ability to spot new characters (dipterists agree that Malloch was a genius at this not only in the midges but in every group in which he worked). The other was his ability to prepare unusually clear keys, which made his publications quite out of the ordinary in their usefulness to other workers.

The breadth of Malloch's interest in Diptera was expressed when he published in the *Bulletin* a classification of the order based primarily on larval and pupal characters (Malloch 1917). This study was one of the first in which recognition was given to the value of characters of the immature stages in determining the relationships of families within a large insect order. Certainly it is a classic and contains cogent ideas of fly classification which even at this date have not been fully incorporated into accepted classifications of the order.

The next intensive Natural History Survey work on Diptera was a study commenced by H. H. Ross about 1938 on the Illinois mosquitoes. Because of restrictions on travel and lack of availability of personnel during World War II, field work and rearing progressed at a relatively slow rate. The report on these insects was published in the *Bulletin* (Ross 1947).

Plecoptera.—Although the Plecoptera or stoneflies are an abundant component of many aquatic communities, no state-wide taxonomic work on the Illinois species was done until Frison became interested in them in 1927. Previously Walsh (1863, 1864a) had observed and recorded many of the species occurring in the vicinity of Rock Island. Frison and another entomologist, R. D. Glasgow, loved to hike and picnic, especially in the hilly country along the Salt Fork River south of Oakwood, Illinois. On fall excursions to this locality they noticed that, in some of the very small streams, the smallest of the stonefly nymphs kept increasing in size as winter approached. This observation excited Frison's curiosity and from it arose an abiding interest

in and love of stoneflies which continued through the rest of his life. Frison followed the development of these little stoneflies, which proved to be the small group called winter stoneflies. He discovered that little was known concerning the fauna of the Midwest and began a study of the group for Illinois. The first report on stoneflies treated a few small families comprising the winter stoneflies (Frison 1929).

The collecting and rearing of species of the other families in the order were begun. Rearing these insects proved to be difficult because the laboratory water available at Urbana did not sustain the stoneflies. Copper cages on a raft placed in a stream were eventually devised to overcome this difficulty, but the losses of these expensive cages by vandalism finally proved so great that the practice was discontinued. A considerable number of species were reared from emerging nymphs caught at the water's edge. By one means or another, all the Illinois species were finally reared. Six years after publication of the winter stonefly report, a report covering all the Illinois Plecoptera appeared (Frison 1935).

Frison found sets of nymphal characters which appeared to have great promise for indicating natural groupings of the species and genera, indications such as Malloch had previously found when exploring characters of the larvae and pupae of Diptera. The studies of stonefly nymphs set the stage for what might be called the modern classification of the order and stimulated emphasis on the study of immature stages in subsequent Survey projects on several other orders of insects.

These insects proved so fascinating that Frison's studies did not long stop at the boundaries of Illinois. Through material obtained on vacation trips and at other opportunities, the stonefly collection was enlarged to cover all of North America. With large series available from diverse areas of the continent, it became apparent that many of the old species were in reality species complexes, and as a result many of the Illinois populations had to be described as new. The results of these latter developments in the stoneflies were published in the *Bulletin* (Frison 1937,

1942a) and as shorter papers in various entomological journals.

Megaloptera.—These, the alderflies and dobsonflies, were collected during the aquatic work on stoneflies and caddisflies; some specimens were received from fishermen who had encountered them along streams and had sent them in for identification. Attempts to identify these Megaloptera by means of then current literature proved unsatisfactory. In the alderfly genus *Sialis*, characters noticed in the male genitalia seemed to provide an excellent means for positive determination of the species and an analysis of these characters led to a re-evaluation of the species in the genus, many of which proved to be new. About half a dozen species were found in the material from Illinois and surrounding states. As part of an effort to learn something of the entire distribution pattern of the Illinois species, the study was extended to cover the fauna of the whole continent. The report on this study was published in the *Natural History Survey Bulletin* (Ross 1937).

Miridae.—As the aphid project was coming to a close, H. H. Knight of Iowa State College agreed to work summers with the Illinois Natural History Survey and prepare a report on the Miridae or plant bugs of Illinois. Knight was on the Survey payroll for three summers. Previously Hart had assembled and identified an excellent collection of this group for the state, but since Hart's time Knight had shown that characters of the genitalia indicated a much larger fauna than earlier workers had suspected on the basis of the external characters they used.

The mirid field trip pattern followed that of the aphids, with the trips around the state scattered through the different seasons. Again host collecting was emphasized, and field headquarters were set up locally in hotels. The general plan was to collect until about 3 o'clock in the afternoon, and then pin up the day's catch. With the Miridae, this was thought desirable because of the fragile nature of certain diagnostic characters, especially pubescence, which might be brushed off if the specimens were relaxed and pinned later. Many thousands of specimens were collected each year, and

again a large number of species, including about 20 new ones, were added to the state list. Members of the staff served as "guinea pigs" to try out the keys, to point out spots difficult for the uninitiated, and to suggest improvements. Mohr did his usual excellent job in providing many total views of various species. The report resulting from this project was published in the *Bulletin* (Knight 1941).

Ephemeroptera.—The mayflies were early recognized as being one of the most important components of the fresh-water biota of Illinois, but, except for early local studies by Walsh (1863, 1864*b*), little was done concerning their systematics in this state until about 1925. At that time collections were sent to J. W. McDunnough at Ottawa, Canada, who identified a considerable amount of material. Collecting and rearing of species in the order were only sporadic until about 1937, when B. D. Burks, assigned to the project, began an intensive field program.

Certain genera of the mayflies proved difficult to rear because the subimagos seldom survived in cages, and in some species the nymphs did not molt to the subimaginal stage in still water. For these genera Burks worked out a neat contrivance. He placed fully mature nymphs (which emerge at night) in a pan of water containing a large stone, placed the pan on the floor of a car at nightfall, and had the car driven over a gravel road. The wave action produced in the pan by the rough ride broke the surface film enough so that the nymphs could emerge. As the driver guided the car along the road, Burks sat in the back seat and periodically examined the pan with a flashlight; he captured each subimago as it emerged, put it in a vial for emergence to imago, and associated the cast skin with it.

The extremely short period of adult emergence of many species frequently necessitated camping out along a stream and keeping an around-the-clock vigil for emergence. During one summer a rearing station was established at a fish hatchery along Nippersink Creek, in the extreme northeastern part of the state, which is especially rich in mayfly species. A flash flood inundated the rearing rooms and nearly swept away the summer's material. The material was res-

cued as the vials were beginning to float out of the window in the shoulder-deep water.

At first, Burks had difficulty obtaining good series of imagoes, although the subimagos could be collected in quantity at lights. Burks found that he could catch great quantities of these subimagos in paper bags, turn them loose in his hotel room, and have them emerge in fine shape, so that any desired number of imagoes could be secured.

When Burks left the Natural History Survey in 1949, he had completed the mayfly report, which was published in the *Bulletin* (Burks 1953).

Cicadellidae.—About 70 years ago, C. W. Woodworth (1887) published a short treatment of this family, comprising the leafhoppers, and later Hart and Malloch made extensive collections of these insects, some of which were identified and recorded by W. L. McAtee of the United States Biological Survey (McAtee 1924, 1926). Malloch himself (1921) wrote a short paper on the group.

In 1934 D. M. DeLong of Ohio State University agreed to tackle the job of working up a more extensive treatment of the leafhoppers of Illinois. A few years prior to 1934, DeLong had begun an investigation of the male genitalia in the leafhoppers and found that, as in a number of other groups, many of the species previously identified on the basis of external characters were in reality clusters of species which could be separated primarily on the basis of genitalic structures. Both in North America and elsewhere the discovery of these characters had set off a tremendous burst of activity by leafhopper workers to explore these structures. It was in the midst of this burst of effort that the Illinois project was launched. DeLong and other staff members spent almost all of the next three summers crisscrossing Illinois and collecting leafhoppers in the various habitats of the state. During rainy weeks and also during the winter back in Columbus, Ohio, DeLong identified these collections and continued his revisional studies. Various members of the staff made special collections as indicated by new taxonomic discoveries.

By 1945 it was apparent that a report embracing all the leafhoppers under one cover was impractical, and DeLong prepared the manuscript for about half of the fauna, which included all the subfamilies except the Cicadellinae. This report was published in the *Bulletin* (DeLong 1948).

At this time, R. H. Beamer of the University of Kansas had drawn attention to the tremendous number of Midwestern species contained in the genus *Erythroneura*, the largest genus of the untreated subfamily Cicadellinae. Mrs. D. J. Knull had identified a large part of the Natural History Survey material in this genus. Most of the several hundred species were known only from hibernation collections, and it was felt that, before proceeding with the manuscript on this subfamily, the host relationships and other ecological information should be ascertained for these species. As a result the project was realigned and a new host-collecting program for the entire subfamily was delegated to the faunistic staff of the Survey. The large number of host associations already established have proved of interest in contributing ideas concerning evolutionary problems in insects having moderately rigid host associations.

Trichoptera.—A study of the caddisflies was prompted by the importance of this group in the economy of Illinois freshwater habitats. The project was planned originally as a joint one with Dean Cornelius Betten of Cornell University, who had in manuscript at the time the first comprehensive and useful New World faunistic study of the group; his study dealt with the fauna of New York. Betten in America and A. B. Martinov in Russia had pioneered in the technique of clearing the male genitalia of Trichoptera in KOH in order to get a more exact knowledge of these diagnostic structures. Betten spent 6 weeks on the Illinois Natural History Survey staff in the summer of 1931, his time being spent partly on collecting trips around the state and partly in identifying the caddisfly material in the Survey collection. In 1932 press of other duties caused Dean Betten to retire from the project, which was then assigned to Ross.

Much of the caddisfly collecting was done as an adjunct to stonefly, mayfly, midrid, and leafhopper collecting, but special trips were made to springs and certain rivers, such as the Kankakee, which supported unusual species. As the taxonomic analysis of the material progressed, it became evident that the Illinois fauna differed in remarkable fashion from that of the only other state for which it was well known, New York. As a result, it was necessary to practically revise the entire North American fauna before the Illinois groups could be satisfactorily segregated to species. This was true especially in the family Hydropsychidae and the so-called microcaddisflies, the Hydropsychidae. As with the other aquatic groups, an effort was made to rear the species and associate larvae and pupae. Some of this work was done with rearing cages, but the greater part was accomplished by associating mature pupae with their corresponding larval parts in the cocoon or case. The report of the Illinois fauna of this order, including keys to the adults and immature stages, was published by the Natural History Survey (Ross 1944).

After this report appeared, some activity relating to the Trichoptera was continued, primarily centered around attempts to reconstruct the origin of groups and the dispersal patterns which led to the formation of the present Illinois fauna. As genera and families from other parts of the world were studied, it was possible to get a better understanding of the classification and evolution of the order. It is reminiscent of Malloch's and Frison's work in the Diptera and Plecoptera that the immature stages were found to hold the principal key to deducing the evolution of the group. These studies made possible the publication of the book *Evolution and Classification of the Mountain Caddisflies* (Ross 1956).

Coleoptera.—The beetles have frequently been the subject of intensive study by the Natural History Survey staff. Early in the history of the organization, extensive rearing was done, and volumes of important information on this work are scattered through the State Entomologist's reports. The first extensive Illinois publication on the order was by Le Baron (1874) who, in his fourth report as

State Entomologist, published an outline of the Coleoptera of Illinois, with keys to genera and notes on many species.

The next serious study of the order concerned the genus *Phyllophaga*, the June beetles. The larvae of these beetles were extremely serious pests, and before 1890 Forbes and his assistants set about making systematic collections of the genus throughout the state. Forbes (1891) published a survey of the Illinois June beetles; the publication included keys to the species written by Hart. R. D. Glasgow (1916) reviewed this material and published a synopsis of the synonymy and the description of a new species. Shortly after, J. J. Davis made a detailed study of the ecology of *Phyllophaga* and also became interested in their taxonomy. The study resulted in one fine paper on the natural enemies of June beetles and in another describing new forms. These two papers appeared in the *Bulletin* (Davis 1919, 1920). Glasgow continued his interest in the genus, but subsequently published only one or two small papers on the subject.

In 1944 another beetle project was inaugurated, this one on the leaf-feeding beetles, or Chrysomelidae, with M. W. Sanderson as the investigator. The beginning of the leaf beetle investigation was based on a need for supplying correct names for various species of economic importance to Illinois crops. Early attempts at identification disclosed that much of the older literature on the family was unreliable, and diagnosis of species often was uncertain. Not only were there deficiencies in the literature; few attempts had been made in North America to relate larval and adult morphology for generic or species diagnosis. The project for Illinois was organized along the lines of earlier faunistic studies. Collections were made throughout the state, with special emphasis on securing host-adult-larval associations. At present a report embracing two-thirds of the subfamilies and including about a half of the Illinois species is nearing completion, and a large proportion of the field work for other subfamilies is in an advanced stage.

Thysanoptera.—Survey activity relating to this order of little insects, the thrips, had its beginning about 50 years

ago; J. D. Hood (1908) published a paper describing a group of species from Illinois. Late in the 1930's, when Berlese sampling was started in the Survey, interest in this group was again aroused because of the large number of specimens and variety of species which appeared in the collections from moss and leaf mold.

In 1947 L. J. Stannard planned a comprehensive faunistic study of the order for Illinois. Many difficulties were encountered, including the inaccessibility of critical types, difficulties in finding satisfactory mounting media, and difficulties in interpreting existing keys and descriptions. The genera were especially poorly defined and inconsistently used, and before satisfactory names could be established for the Illinois species it was necessary to embark on major studies in the general classification of the group. The results of one of these studies, investigating the generic categories in the suborder Tubulifera, were published by the University of Illinois (Stannard 1957). As a consequence of all these factors the Illinois study of this group has come close to a treatment of the thrips for half the continent. Intensive collecting in all conceivable situations and at different seasons has brought to light large numbers of new state records. A report on these insects for Illinois is in an advanced state of preparation.

Lepidoptera.—As mentioned earlier, in his first report Le Baron (1871) described a new species of moth. Since that time a great deal has been written, especially in the State Entomologist's reports, on the moths of Illinois. Most of this material, however, is in the form of small contributions on the descriptions of species, their larvae, or their habits. However, Thomas (1881), with the assistance of Nettie Middleton and John Marten, published a synopsis of lepidopterous larvae for Illinois. This report included a similar synopsis by D. W. Coquillett (1881). Later, Forbes and his assistants prepared keys to certain economic species, and W. P. Flint & Malloch (1920) published in the Natural History Survey *Bulletin* a paper on the European corn borer and related species.

In 1955 R. B. Selander began a faunistic project designed to cover many of

the families of small moths or microlepidoptera, which were poorly known in Illinois. The Blastobasidae were chosen as the first family for study because the genitalic structures of the Nearctic species had never been investigated. Selander, now with the University of Illinois, assembled large quantities of Illinois material and unearthed a diagnostic set of characters in the genitalia. Work on this project is continuing.

Hymenoptera.—Aside from rearing and describing a few parasites and sawflies, the Natural History Survey staff has done only one serious piece of work on the Illinois Hymenoptera fauna. This was a study by Malloch (1918) on the genus *Tiphia*.

Collembola.—Although among the most abundant insects numerically, the Collembola or springtails were not stressed until 1928, when large collections were made in various parts of the state and sent to J. W. Folsom, U. S. Department of Agriculture, for identification. When Folsom died, the project reverted to simply a collecting program. Subsequently, Berlese sampling added large quantities of these insects to our series. The project was revitalized when H. B. Mills joined the Natural History Survey in 1947; since that time steady progress has been made on a study of this group for Illinois.

RETROSPECT AND PROSPECT

In following the objectives set forth in the original organization of the Illinois Natural History Survey, the faunistic program performs three principal functions pertaining to the animals of Illinois—assembling and maintaining research and reference collections, preparing re-

ports on the various animal groups, and identifying economic species. At times the program has emphasized one function more than another, but over the years steady progress has been made in all three departments.

Today the taxonomic methods by which these functions are achieved are far more complex and time-consuming than they were when the program was started. If transplanted to today, the faunistic worker of 1858 would doubtless be astonished at changes in the species concept, in taxonomic techniques, in microscopic and other equipment, and at the great increase in recognized invertebrate species and genera.

As these complications have developed, it has become clear that there is no easy short cut in making an adequate survey of an animal group for Illinois. Each report represents a great deal of collecting and study over a period of years.

Members of other sections of the Natural History Survey have aided the faunistic program immeasurably by rearing and collecting material, identifying host or indicator plants, editing reports, and assisting with library problems. Taxonomists in other institutions have been of great aid not only by publishing papers of inestimable use in studies of Illinois species, but also by assisting in many other ways with specific problems.

It is a tribute to the founding fathers of the Illinois Natural History Society that certain of their general principles were and still are remarkably good guides for a faunistic program. The importance of combining systematics and ecology and of having a broad geographic scope for reference collections becomes more apparent as new discoveries help unravel the complex faunal relationships of Illinois species.

Applied Botany and Plant Pathology

J. CEDRIC CARTER

WHEN the Illinois Natural History Society was organized in 1858 to promote the advancement of science in the state, botany was a major field of interest of several of its founders.

The earliest reported botanical research in Illinois was the study of flora in southern Illinois by André Michaux (Sargent 1889), a distinguished botanist of France. In 1795 Michaux traveled from the Ohio River up the Wabash River to Vincennes, Indiana. He crossed Illinois to Kaskaskia, August 23–30, to Prairie du Rocher, September 5–6, and returned to Kaskaskia, September 8–9. On October 2, he started toward the Ohio River and arrived at Fort Massac on October 8. Later he returned to Kaskaskia, Fort Chartres, and Prairie du Rocher and started on his return from southern Illinois on December 14.

Following Michaux and during the first half of the nineteenth century, many physicians and amateur botanists studied and reported on the flora of Illinois. Dr. Lewis C. Beck (1826*a*, 1826*b*, 1828), in publishing his contributions to the botany of both Illinois and Missouri, listed 65 plants in the prairies near St. Louis and 14 in barrens. Also, he reported on his studies of plants along the Illinois River bluffs near St. Louis. A catalog of plants collected in Illinois by Charles A. Geyer was published with critical remarks by Dr. George Engelmann (1843) of St. Louis, Missouri. Dr. C. W. Short (1845) of Louisville, Kentucky, reported on his observations and collections of the flora of prairies of Illinois as a result of his extensive travels in several sections of the state. Dr. S. B. Mead (1846) prepared a catalog of plants growing in Illinois, most of them growing near Augusta in Hancock County; this work was published in the *Prairie Farmer*. Dr. Mead mentioned the habitats of the plants he included in his catalog. Also, he listed the uses of the plants, including those used by dyers and coopers, those used for hedges, chair bottoms, hay, ornamentals,

edible fruits, common tea, and medicine, those known to be poisonous, and those known to be troublesome weeds. The year before the Illinois Natural History Society was founded, I. A. Lapham (1857*a*) published a catalog of the plants of Illinois; his catalog included lists contributed by Mead and Engelmann. In preparing the catalog, Lapham examined the extensive collections of plants made by Robert Kennicott, Emile Claussen, and others.

Mead's list, as mentioned above, comprised plants principally in the vicinity of Augusta in Hancock County. Engelmann's list comprised plants in southern Illinois, especially in the vicinity across the Mississippi River from St. Louis, Missouri. Dr. Mead, Lapham (1857*a*:494) wrote, "has probably devoted more time and labor to the examination of Illinois plants than any other botanist, and his collections now form part of most of the principal herbaria of the world."

Lapham emphasized that catalogs of plants were useful to farmers, physicians, horticulturists, botanists, cabinet makers, wheelwrights, and other workers in wood because these catalogs listed plants of interest to each group; his catalog listed 1,104 species representing 111 orders of plants. From a geographical point of view, Lapham divided Illinois into three districts: (1) the heavily timbered tracts, mainly in the southern portion of the state, and the "groves" or detached bodies of timber surrounded by prairies, in the middle and northern portions of the state; (2) the open prairie tracts of 1 to 20 miles in diameter and destitute of trees; (3) the tracts of "barrens," intermediate between the prairie tracts and the timbered tracts. The barrens appeared to be in transition from open prairies to densely timbered tracts. They were sparsely covered with several species of oak trees and with dense undergrowth of shrubs and annuals.

Treatises on plant material, published in the Illinois State Agricultural Society

Transactions for 1856–1857, indicated the rapidly increasing interest in applied botany. These treatises, presented by O. Ordway (1857) of Lawn Ridge, H. L. Brush (1857) of Ottawa, Samuel Edwards (1857) of La Moille, J. P. Eames (1857), Dr. Frederick Brendel (1857) of Peoria, and I. A. Lapham (1857*b*) of Milwaukee, Wisconsin, dealt with several phases of research, including culture and cultivation. The types of plants studied were evergreens, flowers, grasses, grain fruits, and vines.

At La Moille, Edwards started planting evergreens in 1845 and, by 1857, had planted more than 125,000 plants obtained from forests of Minnesota, Wisconsin, Michigan, Indiana, Ohio, New York, and upper Canada and also some obtained from eastern and European nurseries—in all, more than 25 species of evergreen plants. He was most favorably impressed with the growth of Norway and black spruces, Austrian, Scotch, and white pines, and balsam fir. Siberian and American arbor vitae and red cedar, he found, were excellent for screening. Other species he mentioned that succeeded well in this climate and soil were Irish, Swedish, and savin junipers, red spruce, and a variety of pine from Tennessee. Hemlock was subject to winter injury; Douglas spruce, cedar of Lebanon, deodar cedar, silver fir, English and Irish yews, Himalayan and Araucarian pines, and Chinese arbor vitae did not survive the winters. In 1857 Dr. Cyrus Thomas, with the help of S. Burtley, started studying the flora of the Murphysboro region of southern Illinois (Thomas 1857).

EARLY ACTIVITIES

Among the persons interested in botany who were active in organizing the Illinois Natural History Society were M. S. Bebb, Dr. Frederick Brendel, E. Hall, Robert Kennicott, Dr. S. B. Mead, Dr. Cyrus Thomas, and Dr. George Vasey. Much of the information obtained by them on the flora of Illinois was published in the Illinois Natural History Society *Transactions*. When the original purpose in organizing the Natural History Society was set forth as the advance-

ment of science, botany was mentioned along with entomology and geology. In succeeding years special interests developed in the field of botany, as indicated by the published works of Brendel, Bebb, Vasey, Thomas, Edwards, G. W. Minier, Henry W. Bannister, and H. H. Babcock from 1859 to 1887, most or all of whom were members of the Natural History Society. Brendel was a prolific worker and was the author of numerous articles published over a period of nearly 30 years (Brendel 1859*a*, 1859*b*, 1859*c*, 1859*d*, 1860, 1861, 1870, 1876, 1887). These articles included information on the flora of Peoria and other areas of the state. Brendel was interested in shrubs and forest trees, especially the oaks. Also, he wrote on rare plants in the state and on a peculiar growth of the water lily. It is significant that an article by him, "The Tree in Winter," was one of the first articles published in the *Bulletin* of the Illinois State Museum of Natural History.

Bebb (1859) published a list of 44 species of plants occurring in the northern counties of the state; his list was an addition to the catalog by Lapham (1857*a*). Vasey's interest in different phases of botany is indicated by his papers (Vasey 1859, 1861, 1870*a*, 1870*b*). Among these papers were studies on flora, including mosses of the state and maritime plants of the Great Lakes and interior regions; also, descriptions of two plants new to Illinois.

When Thomas (1861*c*) proposed a plan for a natural history survey of Illinois, he suggested that this survey include a systematic cataloging of the flora and fauna of the state and that the data be published so that the same work would not need to be repeated by others. Bannister (1868) described prairie and forest plants of Cook County, and Babcock (1872) described the flora of the Chicago area. John Wolf and Elihu Hall prepared a list of mosses, liverworts, and lichens of the state. This list, which was published in the *Bulletin* of the Illinois State Laboratory of Natural History, contained 115 genera and 386 species (Wolf & Hall 1878). Wolf was on the staff of the State Laboratory of Natural History in 1880.

By 1865 concern was voiced that trees of the state were being used so rapidly for lumber that cultivation and planting of trees should be promoted. Minier (1865, 1868) published two articles on the cultivation of forest trees. In his second article Minier (1868:279) stated: "Tree planting in Illinois is no longer for ornament merely. It has become a necessity. . . . If, then, the *coming* generations are to be supplied with timber, the *present* must plant it for them." Edwards (1868) recommended planting trees but pointed out that black locust trees that had been planted 25 years earlier had been seriously damaged by borers.

Specific interest in some specialized groups of plant life in Illinois became evident shortly after 1870, as indicated by the works of Thomas J. Burrill on plant diseases caused by fungi and bacteria. Burrill, on the staff of the Illinois Industrial University, the University of Illinois, and the Illinois State Laboratory of Natural History, was a close associate of Stephen A. Forbes for 27 years. He reported on fungus diseases in the 1870's, especially on fungi which cause diseases of vegetable and fruit crops (Burrill 1874, 1876, 1877). Later he reported that the widespread blight of pear trees was caused by a bacterium (Burrill 1881). This, the first report that bacteria cause plant diseases, opened up a new field of research. Burrill continued to publish articles on fungi and bacteria that cause plant diseases and in 1885 he published a 115-page article, in the *Bulletin* of the Illinois State Laboratory of Natural History, on the parasitic fungi of Illinois (Burrill 1885).

Following 1885 botanical research expanded in scope to include all types of native and naturalized plants in the state. The work of Burrill while on the staff of the Illinois State Laboratory of Natural History from 1885 to 1892 indicates the expanding development of botanical interest in forest trees and diseases of crop plants. Burrill prepared papers not only on fungal and bacterial diseases of crop plants but also on forest, roadside, and street trees, biology of silage, and extermination of the Canada thistle (Burrill 1886, 1887*b*, 1887*c*, 1888, 1889*a*, 1889*b*, 1890). Among others em-

ployed as botanists on the staff of the State Laboratory of Natural History were Rachel M. Fell, Arthur B. Seymour, Benjamin M. Duggar, and Arthur G. Vestal.

A well-illustrated, 142-page article on edible and poisonous mushrooms in Illinois, prepared by Walter B. McDougall (1917), was published in the *Bulletin* of the Illinois State Laboratory of Natural History. This article contains many plates illustrating the mushrooms described and is exceedingly useful in differentiating between poisonous and edible mushrooms.

Studies on plankton were carried on by C. A. Kofoid from 1895 to 1900 and by Samuel Eddy from 1925 to 1929. Kofoid's extensive work on the plankton of the Illinois River was published in the *Bulletin* of the Illinois State Laboratory of Natural History (Kofoid 1903, 1908). Eddy's work dealt with plankton of Lake Michigan, the Sangamon River, and some sinkhole ponds in southern Illinois; this work was reported in the *Bulletin* of the Illinois Natural History Survey (Eddy 1927, 1931, 1932).

Interest in the ecology of vegetation and plant associations of sand prairies in Illinois is indicated by the papers of C. A. Hart and H. A. Gleason (Hart & Gleason 1907; Gleason 1910), F. C. Gates (1912), and Vestal (1913) published in the *Bulletin*. Information was obtained not only on the general plant associations but also on the physical environment, the blow-out formations, the blow-sand complex, the blackjack oak associations, and some adaptations of the plants to the environment.

Although Minier (1865, 1868) and Edwards (1868) were concerned about the rapid destruction of trees in the 1860's, it was not until 1911 that a policy on forest management was recommended by R. C. Hall and O. D. Ingall. In an article on forest conditions in Illinois, published in the *Bulletin* (Hall & Ingall 1911), they recommended (1) adoption of an adequate state fire-protection system, (2) inauguration of an education campaign for scientific and practical forest management, and (3) further investigation of the forest problems involved and development and extension of wood lots

in the state. Also, they proposed a forest law for the state. Later, Forbes and Robert B. Miller (Forbes 1919_a, 1919_b; Forbes & Miller 1920) pointed out that the forests of Illinois were being rapidly destroyed and that only very few of the remaining forests were being properly handled. Miller (1923) made the first extensive report on a survey of the forests of Illinois; the report was published in the *Bulletin* of the Illinois Natural History Survey. The survey covered land classification; history and types of forests and important trees in the forests; uses of forest trees in milling and logging operations, wood-using industries and veneer industries; production of charcoal, ties, and mine timbers; and adverse effects of fires, erosion, and grazing on forested areas.

The second extensive report on a forest survey of Illinois was made by Herman H. Chapman and Miller and published in the *Bulletin* (Chapman & Miller 1924). In this report the economic value of the forests and the forests as a crop were emphasized. The uses made of forest trees were discussed, and a policy of proper management of the forests to prevent the continued decimation of timber was outlined.

C. J. Telford (1923), a Natural History Survey forester, reported on height and growth studies on certain bottomland tree species in southern Illinois. He found that naturally stocked plantings of sycamore, cottonwood, pin oak, and maple produced better growth than did plantings of most other species in the bottomlands.

Telford (1926) reported on the third forest survey of Illinois. In this report, which included descriptions of the forests in the state and data on growth of individual trees and yields of different types of trees, he reviewed the proposed forest policies given in the two previous forest surveys of the state and urgently recommended setting up an educational program to promote the development of farm wood lots, the protection of the then present forests, and the reforestation of much of the waste land, estimated to total 1,577,663 acres.

These reports on forests of Illinois stimulated interest in the preservation and

expansion of the forest resources of the state. A forestry program was carried on and expanded by the extension foresters who succeeded Telford and who were employed jointly by the Natural History Survey and the Department of Forestry of the University of Illinois. They were L. E. Sawyer, J. E. Davis, and L. B. Culver. Since 1954 the Natural History Survey has not participated in this forestry program.

By 1900 special emphasis was being directed toward control of plant diseases in Illinois. This trend was emphasized by some of Burrill's papers, such as that on spraying for the control of bitter rot (Burrill 1903). As interest in this field continued to increase, it became evident that a systematic study of plants and plant diseases in Illinois should be inaugurated. In 1921 a botanical section was established within the framework of the Natural History Survey by the appointment of Leo R. Tehon as the first botanist.

Under the direction of Tehon as botanist in charge of the Section of Botany from 1921 to 1935 and as botanist and head of the Section of Applied Botany and Plant Pathology from 1935 until his untimely death in 1954, botanical research expanded to include work not only in the field of general botany but especially in the fields of mycology, plant pathology, and taxonomy. The number of technically trained scientists on the staff was increased from 1 in 1921 to 10 in 1954.

Tehon's broad background and training and his mastery of the various fields of research carried on in the botanical section are indicated, in part, by his many and varied publications. Tehon described many new genera and species of fungi, most of them in a series of six articles under the title "Notes on the Parasitic Fungi of Illinois" (Tehon 1924, 1933, 1937_b; Tehon & Daniels 1925, 1927; Tehon & Stout 1929). Also he wrote "A Monographic Rearrangement of *Lophodermium*" and "New Species and Taxonomic Changes in the Hypodermataceae" (Tehon 1935, 1939_d). He described diseases affecting economic crops, including those of fruits, vegetables, grain and forage crops, and diseases of ornamen-

tal plants, especially trees (Tehon 1925, 1939*b*, 1939*c*, 1943; Tehon & Stout 1928; Tehon & Jacks 1933; Tehon & Boewe 1939; Tehon & Harris 1941). He was especially interested in developing methods and principles for interpreting the phenology of crop pests (Tehon 1928).

Tehon's botanical interests are indicated by such publications as *The Native and Naturalized Trees of Illinois* (with Robert B. Miller), *Rout the Weeds, Pleasure With Plants, Fieldbook of Native Illinois Shrubs, The Drug Plants of Illinois*, and (with collaborators) *Illinois Plants Poisonous to Livestock* (Miller & Tehon 1929; Tehon 1937*a*, 1939*a*, 1942, 1951*a*; Tehon, Morrill, & Graham 1946). He was a linguist and translated Giovanni Targioni Tozzetti's *Alimurgia*, part V, 1767, an Italian article of 156 pages on diseases of wheat and other cereals; the translation was published in English as *Phytopathological Classics* No. 9 (Tehon 1952*a*).

RECENT ACTIVITIES

The early work in the Section of Botany consisted not only of a survey of the plant diseases in the state but the development and co-ordination of research in botany, with special emphasis on plant diseases and the establishment of a herbarium, which included a plant disease collection and a native plant collection. In an annual report Forbes (1923:386) described the work of the botanical section as follows:

Beginning in July, 1921, active work has been done throughout the State on the fungus parasites of the crop plants, many of which are highly destructive and difficult to control. It was the principal first object of this inquiry to make accessible existing knowledge of the plant diseases of the State and of their distribution in Illinois and their destructiveness, and to ascertain whether known methods of protection against them are generally used, this to be followed by measures intended to make crop growers acquainted with the most important preventable diseases and the losses due to them and with established means for their prevention and control.

To aid in the work of the Section of Botany the co-operation of 135 unpaid field observers was obtained to watch for plant diseases and to report any unusual outbreaks of diseases occurring at any

time. The information obtained included the crops attacked by each disease, the stage of growth of the crop when attacked, the damage caused, the first date of appearance of disease, the amount of damage to the crop, the control measures used, and the prevalence and destructiveness of each disease.

As the work of the Section of Botany continued to expand, greater emphasis was placed on the application of research information for the control of plant diseases, and in 1935 the name of the section was changed to Section of Applied Botany and Plant Pathology. At this time the activities of the section were divided into four main groups, namely, (1) Plant Disease Survey, (2) Botanical Survey, (3) Shade and Forest Tree Pathology, and (4) Floricultural Pathology. The first full-time staff member to conduct research on floricultural pathology was not appointed until 1939.

Plant Disease Survey

The plant disease survey, started by Tehon in 1921, included a survey of the diseases of all crop plants of Illinois, with special emphasis on field crops and fruit crops. Among the persons who have assisted in the plant disease survey since its beginning are Charles O. Peake, Charles L. Porter, O. A. Plunkett, Harry W. Anderson, Paul A. Young, Gilbert L. Stout, and G. H. Boewe. Constantine J. Alexopoulos and Leo Campbell collected numerous plants around peach orchards in southern Illinois counties as part of a study of possible hosts of the peach yellows virus.

Field Crop Diseases.—After the establishment of the Section of Botany in July of 1921, flag smut of wheat was the first major disease studied. This disease, discovered in Illinois in 1919, was causing serious losses of wheat in the East St. Louis area. The limits of the disease in the state were determined, and effective control measures, including a quarantine, were enforced. By following rigid quarantine regulations, which required burning all straw and treating all grain sold for seed, and by introducing varieties of wheat resistant to the disease, it was possible to eliminate flag smut. The effectiveness of this control program

prevented the disease from spreading over the whole soft wheat area.

Other activities of the Section during the 1920's included warning cotton growers in southern Illinois of the diseases to be encountered, discovering and destroying the only known instance of alfalfa infestation by the stem nematode, and collecting data on the prevalence and destructiveness of stinking smut of wheat. By 1923 it had been determined that 165 diseases affecting 44 different crops were present in the state. In that year the estimated reduction in yield of Illinois wheat caused by five diseases (leaf rust, stem rust, stinking smut, loose smut, and scab) was 7,712,800 bushels, valued at \$11,837,000.

In most years of the past decade the estimated annual losses from diseases of

Illinois wheat have been 5,500,000 to 7,150,000 bushels. The greatest loss in a single year, 7,150,000 bushels, valued at \$15,158,000, occurred in 1950. In 1953, a year of minimum loss, the estimated reduction in yield was only 368,800 bushels, valued at \$586,400.

The estimated annual losses resulting from diseases of corn usually are greater than the losses resulting from diseases of wheat. In the past decade the lowest estimated reduction in corn yield, 54,250,000 bushels, valued at \$82,450,000, occurred in 1952 and the highest estimated reduction in yield, 168,100,000 bushels, valued at \$198,358,000, occurred in 1949. The average annual estimated reduction in yield of corn in Illinois during the past decade was 90,626,100 bushels, valued at \$112,139,072.



Homemade mixer used about 25 years ago by plant pathologists of the Illinois Natural History Survey to demonstrate effectiveness of chemical treatments in control of seed-borne diseases of small grains.

The plant disease survey not only indicates the annual losses caused by plant diseases but reveals diseases new in the state and the sudden and widespread damage caused by any disease that has caused only minor damage in preceding years. Downy mildew of alfalfa appeared generally in the state and was abundant in the extreme north in 1924. This disease had not been seen in Illinois previous to that year. A new leaf spot of cowpea was discovered in Clinton County in 1927. In an article by Stout (1930), 16 new fungi found on corn in Illinois were described. Downy mildew of soybean, first reported in Illinois in 1929, caused considerable damage in 1935, when it was found in 12 counties. Brown stem rot of soybean, first recognized in the state in 1944, suddenly became widespread and destructive in 1948. This outbreak of the disease followed a fortnight of low temperatures, which ended on August 10. Septoria leaf spot of broom corn was discovered in Illinois in 1949 and was very destructive in several fields west of Galton in Douglas County.

Diseases recorded for the first time in Illinois in recent years include ergot on timothy, bacterial blister spot on apple, charcoal rot on pepper, and downy mildew on wheat in 1952; basal glume rot on barley, anthracnose on sweet clover, and rosette on cherry in 1954; *Ascochyta* leaf spot on rhubarb and bacterial leaf spot on mulberry in 1955; powdery mildew on apple, ergot on oats, *Helminthosporium* leaf spot on red top, and *Gloeosporium* leaf spot on currant in 1956; and *Phytophthora* root rot on alfalfa, *Phytophthora* stem rot on lily, *Cercospora* leaf spot on *Deutzia*, *Abelia*, ornamental gooseberry, and wafer ash, downy mildew on cucumber, squash, and watermelon, rust on apricot, anthracnose on iris, powdery mildew on pecan and fragrant sumac, *Badhamia* slime mold on timothy, *Herptobasidium* scorch on bush honeysuckle, and *Phyllachora* tar spot on lespedeza in 1957.

In the plant disease survey, not only are the various kinds of crops examined but many plants in many fields of the same crop are examined each summer. For instance, in 1949, data on prevalence and severity of wheat diseases were ob-

tained by examination of plants in 42 wheat fields that totaled 1,033 acres and that were located in 38 widely scattered counties of the state.

Another phase of the plant disease survey is that of forecasting the anticipated occurrence and seriousness of plant diseases. This forecasting has been notably effective for Stewart's disease of corn. The bacterium that causes Stewart's disease overwinters chiefly in the body of the adult corn flea beetle (*Chaetocnema pulicaria*). The mortality rate of the flea beetle is affected by weather conditions during hibernation.

Although forecasting the early season or wilt stage of Stewart's disease had previously been worked out by others, forecasting the late season or the leaf blight stage was worked out by G. H. Boewe. Making use of data accumulated in the 5-year period 1944-1948, Boewe found that a winter temperature index rather accurately forecast the late season development of Stewart's disease. The index for any growing season was based on the sum of the mean temperatures of the previous winter months of December, January, and February. While early season epidemics do not develop unless the index is 90 or above, light to moderate late season epidemics develop when the indexes are between 80 and 85, and moderate to heavy late season epidemics when the indexes are above 85. No disease or only a trace of disease develops when the indexes are below 80. Forecasting of the severity of disease each year has been quite accurate.

The appearance and spread of new diseases on crops in Illinois often are recorded first as a result of the annual survey made for plant diseases. Aid to farmers in combating these diseases is made through warnings and through publications such as *Diseases of Small Grain Crops in Illinois* (Boewe 1939).

Fruit Diseases.—Of the many diseases that affected fruit trees in the state each year during the early years of the plant disease survey, the most common and destructive were scab, shothole, brown rot, and leaf curl of peach; fire-blight, frog-eye, and blotch of apple; fire-blight, leaf blight, and leaf spot of pear; and shothole and leaf spot of cherry.

In early August of 1927 Professor M. J. Dorsey of the University of Illinois found, in a large orchard near Centralia, the first authentic case of peach yellows in Illinois. By 1929 the disease had spread to 37 trees scattered in 11 orchards located in Jefferson, Marion, Pike, and Pulaski counties. In recent years peach yellows has not been observed in Illinois. Diseases which are destructive to the peach crop and which have appeared annually in recent years are scab, brown rot, shothole, and peach leaf curl.

During the early years of the plant disease survey, nailhead canker was a serious disease of apple trees. However, this disease disappeared from the orchards of the state when growers eliminated those varieties susceptible to the disease. The major destructive diseases of apples which have continued to appear annually are scab, fireblight, frog-eye, and blotch. Mildew has increased in destructiveness in recent years because the sulfur fungicides which controlled the disease in the early years have been replaced by new types of fungicides; these new materials more effectively control the other diseases of apples. Cedar apple rust, which was prevalent and destructive for many years, is controlled satisfactorily at present by some of the recently developed fungicides, ferbam plus sulfur on the deciduous hosts, Elgetol and acti-dione on the evergreen hosts.

Many pear orchards in the state have been severely damaged or destroyed by fireblight. At present there is hope that this disease can be effectively controlled by some of the new antibiotic sprays. Other diseases destructive annually to pear trees are leaf blight and leaf spot.

The disease most destructive to cherry trees in the state is shothole. Yellowing, necrosis, and premature leaf drop, caused by this disease, gradually reduce the vigor of affected trees and, eventually, the quality and quantity of cherries produced.

Diseases that may appear annually on other fruit crops are bacterial spot and black knot of plum; black rot, downy mildew, and powdery mildew of grape; crown gall and rust of blackberry; angular leaf spot of currant; leaf spot, leaf scorch, and yellows of strawberry; anthracnose of raspberry, currant, and goose-

berry; and Septoria leaf spot of blackberry and raspberry. Although many of these diseases are not destructive each year, they cause serious losses in some years.

Vegetable Diseases.—Although vegetable crops are affected by many diseases, only a few of the diseases cause serious losses annually. The most common and destructive diseases in Illinois are bacterial blight, halo blight, and mosaic of bean; yellows of cabbage; *Ascochyta* leaf spot, *Fusarium* wilt, and powdery mildew of pea; *Fusarium* wilt, mosaic, and bacterial leaf spot of pepper; early blight, *Fusarium* wilt, black leg, and scab of potato; and early blight, *Fusarium* wilt, and *Verticillium* wilt of tomato.

Botanical Collections

The first of the present botanical collections of the Natural History Survey was started in a small way in 1921. At that time the collection of plant disease fungi of the Natural History Survey was separated from the collection of the University of Illinois. The vascular plants collected with State Laboratory funds and with Natural History Survey funds previous to 1921 were left in the herbarium of the University of Illinois.

Plant Disease Collection.—The earliest reported specimens in the plant disease collection of the Natural History Survey are several hundred specimens collected, 1918–1921, by H. W. Anderson of the University of Illinois. Collection, identification, and preservation of such specimens were expanded rapidly during the four summers of 1921 through 1924, when special emphasis was placed on obtaining information on the plant disease situation of the state. To conduct this plant disease survey, one to four men were employed full-time each summer to collect specimens of diseased plants in each county of the state. This activity resulted in adding over 18,000 plant disease specimens to the collection. Among these specimens were five plant diseases new to the state and 18 species of plant parasites new to science.

In 1924 this collection contained type specimens which represented three genera and 73 species of plant-inhabiting fungi

first known for their occurrence in Illinois. Although some specimens have been added to the plant disease survey collection by all botany staff members since 1924, most of the specimens have been added by Boewe, the plant pathologist now responsible for the plant disease survey. Specimens of special interest sent to the laboratory for diagnosis of disease are added to the collection.

Gilbert L. Stout was the first plant pathologist to devote full time to plant disease survey work. He was succeeded by Boewe in 1930. In this work diseased plant material is carefully examined to determine the specific disease involved. Many specimens are collected not only as characteristic examples of the disease but for further study in the laboratory to determine the organism causing the disease. Specimens of diseases new to the United States, Illinois, or a county of the state are preserved in the plant disease collection.

As of April, 1958, the plant disease collection contained 32,624 specimens. Although this collection contains mostly fungi that cause plant diseases, it also contains specimens affected by disease-causing bacteria, viruses, and noninfectious agents. Information on new diseases has been published in *Mycologia*, *Phytopathology*, and the *Plant Disease Reporter*.

Vascular Plant Collection.—The collection of vascular plants in Illinois by Natural History Survey staff members was begun in 1927 with the establishment of a project on the accumulation of plants of the state. By 1931 three additional projects had been added: maintenance of a herbarium containing representative plants of Illinois, maintenance of a bibliography of Illinois plant records, and maintenance of a card record of the occurrence of plants in Illinois.

The first systematic collection of Illinois vascular plants for the Natural History Survey was made by James Schopf, who collected 1,676 specimens during the summer of 1931. In September of 1931 Dr. Herman S. Pepoon joined the Survey staff. Pepoon, with the assistance of E. G. Barrett, collected 1,300 specimens. After Pepoon left the Survey in 1933 the accumulation of Illinois plants was added to the duties of the plant pathologists.

Much of the collecting was done by Boewe in conjunction with his work on the plant disease survey. In October of 1946 R. A. Evers joined the staff and was assigned the botanical survey work. His work is devoted almost exclusively to a study of the flora and vegetation of the state. Since 1946 he has collected plant specimens annually in each of the 102 counties of the state.

Previous to 1947 the number of specimens in the vascular plant collection was increased by gifts of specimens from R. A. Dobbs of Geneseo, R. A. Evers then of Quincy, and G. D. Fuller of the Illinois State Museum. Also, the herbarium of Charles Robertson of Carlinville was acquired. Since 1947, plant specimens, as gifts or exchanges, have been received from Franklin Buser (graduate student), James Long of Amboy, Dr. V. H. Chase of Peoria, Dr. Sidney Glassman of the University of Illinois staff at Navy Pier, Chicago, Dr. John Voigt of Southern Illinois University, Dr. John Thieret of the Chicago Museum of Natural History, and others.

Thirteen species of plants have been added to the known flora of Illinois by Natural History Survey staff members since 1947. They are *Daucus pusillus*, *Medicago arabica*, *Setaria faberii*, *Specularia biflora*, *Rudbeckia missouriensis*, *Heliotropium tenellum*, *Eriochloa villosa*, *Dicliptera brachiata*, *Cyperus lancastriensis*, *Haplopappus ciliatus*, *Verbascum virgatum*, *Helianthus angustifolius*, and *Jussiaea leptocarpa*.

Publications resulting from the collection of vascular plants of Illinois include a 339-page bulletin on native and naturalized trees of the state (Miller & Tehon 1929), two fieldbooks, one on wild flowers (Anon. 1936) and one on native shrubs (Tehon 1942), and articles on genera and species of Illinois plants, including several new to the state (Evers 1949, 1950, 1951, 1956; Evers & Thieret 1957).

Identification and preservation of vascular plants in the Natural History Survey herbarium were under way to a limited extent by 1927. In succeeding years students have been employed to mount specimens for the herbarium. In 1936 Richard A. Schneider was em-

ployed to identify the accumulated collection of plant specimens. Although collection, identification, and preservation of vascular plant specimens were curtailed during World War II, the herbarium contained 13,749 specimens in May of 1943 and 17,339 specimens in October of 1946. The abundant collection of plant material in succeeding years has increased the number of vascular plant specimens in the herbarium to 70,600, and approximately 8,000 additional specimens are on hand to be added to the herbarium. Under present conditions three student assistants are employed to prepare the plant material for placing in the herbarium. A card index is maintained of all plant specimens.

The bibliography of Illinois plants, started previous to 1931, is not up-to-date because of lack of funds and lack of assistants to examine the literature.

In co-operation with L. E. Yeager, R. E. Yeatter, A. S. Hawkins, and D. H. Thompson, fellow staff members doing wildlife or fisheries research, botanists made a census of waterfowl food plants of the Chautauqua Drainage District, carried on a survey of Illinois plants useful to wildlife as food or cover, and conducted experiments on propagation of plants useful to wildlife as food or cover. A collection of 848 samples of seeds was developed for identification of seeds ingested by waterfowl.

Activities pertaining to the botany of Illinois include preparation of manuscripts designed for publications, mainly of an educational or popular type. These publications are on such subjects as noxious weeds, directions for the study and identification of plants, drug plants (Tehon 1937*a*, 1939*a*, 1951*a*), plants poisonous to livestock (Tehon, Morrill, & Graham 1946), and vegetation of hill prairies in the state (Evers 1955).

The publication on the vegetation of hill prairies is a report on an extensive ecological study of 61 prairies on the brow slopes of bluffs of the Mississippi River from East Dubuque to southern Illinois, the Illinois River from the big bend near Hennepin to Grafton, and the Rock and Sangamon rivers. This type of publication by the Natural History Survey is a continuation of those published

earlier by the State Laboratory of Natural History.

Shade and Forest Tree Pathology

The earliest reported conspicuous dying of trees in Illinois was among the elms in Normal-Bloomington and Champaign in the period 1883–1886 (Forbes 1912*a*). The next reported conspicuous dying among elms occurred from 1907 through 1911, when many trees succumbed in southern Illinois. During this period conspicuous losses of elms were reported in Cairo, Carbondale, Centralia, Clayton, Du Quoin, Edwardsville, Fairfield, Galatia, McLeansboro, Mount Vernon, Quincy, Robinson, Sumner, and Vandalia. These 14 towns are located in 13 counties of western and southern Illinois. Although the cause of the dying of elms during these two periods was not determined, it was suggested that some disease might be involved. Dying of feeder roots, wilting of foliage, and dying of terminal twigs was followed by death of the trees. Many of the affected elms in southern and western Illinois were heavily infested with the elm borer, *Saperda tridentata*, and the red elm bark weevil, *Magdalis armicollis*, called by Forbes the reddish elm snout-beetle.

Elm Diseases.—A few years after the establishment of the Section of Botany in 1921, reports and inquiries were received about a widespread wilting of elms growing in commercial nurseries and in decorative plantings, most of them in northern Illinois. Some special examinations made of these trees by Dr. Christine Buisman of Holland, an expert on elm diseases, revealed that the malady was not Dutch elm disease. Research on the cause and control of this wilting was started in 1930. Until May, 1934, the work was carried on by graduate students—H. A. Harris, Leo Campbell, J. A. Trumbower, and A. S. Peirce. In May of 1934 J. C. Carter joined the staff as a full-time plant pathologist to study diseases of trees. Although intensive study of the elm wilt problem was continued for several years, other elm diseases and diseases of other species of trees were studied as they became evident. From 1934 to 1950 research on tree diseases was carried on by Carter. With the expan-

sion of the tree disease research program in 1950, additional plant pathologists were added to the staff. The recent research program has been carried on by four plant pathologists, Richard J. Campana, Walter Hartstirn, Eugene B. Himelick, and Dan Neely.

In the studies on the cause and control of the wilting of elms, it was found that several fungi were involved. Although the first report on this work (Harris 1932) indicated that several fungi were capable of causing the wilting, later studies showed that most wilting was caused by the *Dothiorella* wilt fungus and it was most serious in plantings of trees that were weakened by overcrowding and by repeated annual defoliations from heavy infestations of the spring cankerworm. Spraying with copper and sulfur fungicides was not effective in noticeably reducing or preventing wilting. This spraying included dormant and foliar applications, in some years as many as one dormant and seven foliar sprays. Although research failed to find a control for this type of wilting of elms, it showed that applications of either sulfur or copper fungicide in June and early July gave excellent control of the black leaf spot disease (Trumbower 1934). Control of this disease in commercial nursery plantings of elms increased the annual growth; sprayed trees made as much growth in 4 years as unsprayed trees made in 5 years (Carter 1939).

A conspicuous and widespread dying of elms which became evident in Danville and Peoria in the late 1930's appeared in other areas in succeeding years. It now is widespread and destructive throughout the southern two-thirds of the state. North of Peoria, Bloomington, Champaign, Urbana, and Danville, it occurs in only a few isolated places. The northernmost isolated infection is in Rockford. This disease, called phloem necrosis and described as a virus disease in 1942 (Swingle 1942), has killed thousands of elms in Illinois and is one of the two major diseases that continues to kill thousands of elms annually. In Champaign and Urbana phloem necrosis killed 2,460 trees in a period of 14 years; this number represents over 16 per cent of the total elm population in the two cities. Mount

Pulaski, with an elm population of approximately 600 trees in 1940, had all but 19 elms killed by the disease by September of 1948.

During the late 1930's and early 1940's, in investigations of the wilting and dying of elms, several fungi capable of producing cankers were studied. Canker diseases usually were confined to a few trees in a planting of elms but were found in plantings in widely scattered locations in the state. The cankers caused by species of *Cytosporina*, *Phoma*, and *Coniothyrium* were prevalent only on American elm. The canker caused by *Tubercularia ulmi* affected the Asiatic species of elm, *Ulmus pumila* and *U. parvifolia*.

A serious and widespread wilting of elms in Hinsdale was brought to the attention of the Natural History Survey by Village Forester W. E. Rose in 1939. Intensive research on these elms resulted in the discovery of a bacterial disease called wetwood (Carter 1945). Wetwood is a chronic disease that affects most elms but usually does not result in the death of affected trees. *Ulmus pumila* is especially susceptible to wetwood. Research on this disease is described in a 42-page article under the title "Wetwood of Elms" (Carter 1945). The National Arborist Association awarded a citation to the author in "recognition of his excellent work" reported in the article. This work the Association "considered the outstanding research during 1945 on shade tree preservation."

Dutch elm disease is the most destructive disease of elms in Illinois. Although this disease was first discovered in the United States at Cleveland and Cincinnati, Ohio, in 1930, it was not until 1950 that the first diseased elm was found in Illinois. Only one tree affected with Dutch elm disease was found in 1950, 11 were found in 1951, 24 in 1952, and over 500 in 1953. The numbers of counties in which the disease has been found each year were 1 in 1950, 4 in 1951, 9 in 1952, 15 in 1953, 55 in 1954, 74 in 1955, 86 in 1956, 94 in 1957, and 99 in 1958. The rapid destruction of elms by the disease is illustrated by the numbers of trees affected each year in Champaign and Urbana. Only one affected tree was found in



Plant pathologists of the Illinois Natural History Survey culturing sample of American elm suspected of being affected by the Dutch elm disease. Modern laboratory equipment enables the plant pathologists to substantiate field diagnoses.

Urbana in 1951. The numbers of affected trees in succeeding years in Champaign and Urbana were 11 in 1952, 164 in 1953, 694 in 1954, 1,805 in 1955, 1,836 in 1956, and 2,116 in 1957. These 6,627 diseased elms represent over 44 per cent of the elm population of Champaign and Urbana when the disease was first found there.

The Natural History Survey has had one full-time plant pathologist conducting research on elm diseases, including Dutch elm disease, since July, 1951: Ralph W. Ames in 1951 and 1952 and Richard J. Campana in 1952 and later.

Oak Diseases.—Numerous inquiries about diseases of oak during the 1930's led to a special investigation which culminated in the publishing of a preliminary report (Carter 1941). Although a dozen

fungi were associated with the development of canker and dieback diseases of oak in the field, only one fungus, *Dothiorella quercina*, caused canker and dieback under controlled experimental conditions. The other organisms appeared to produce canker and dieback only on trees previously weakened by adverse growing conditions.

Oak wilt, the most destructive and widespread disease of oak trees in the United States, was not found in Illinois until 1942, when a few affected trees were discovered in Ingersoll Park at Rockford in Winnebago County. In following years the disease was found in other counties; by 1958 it was killing trees in 70 of the 102 counties of the state.

Extensive research on the disease was started in 1950 with a grant of money

from the Forest Preserve District of Cook County, Illinois. A graduate student at the University of Illinois, E. A. Curl, was employed on a half-time basis. A second grant of money was received from the Forest Preserve District in 1951. Also in 1951, funds were obtained from the National Oak Wilt Research Committee of Memphis, Tennessee, composed of 10 hardwood industries, and from state appropriations for research on the diseases of trees. These funds made it possible to add three plant pathologists in 1951 to conduct full-time research on the oak wilt disease. The men employed were Bert M. Zuckerman, George J. Stessel, and Paul F. Hoffman. Additional funds were obtained from the National Oak Wilt Research Committee in 1952, 1953, and 1954. Funds appropriated by the state have continued to be a part of the Natural History Survey's regular budget. These funds have made it possible to employ additional plant pathologists to do research on oak wilt and other tree diseases. In 1953 four men full-time and two men half-time were conducting research on oak wilt. At present, with only state funds to support the research on oak wilt, three full-time regular staff members are continuing research on this disease. The men who have helped to carry on this program include E. A. Curl (1950-1954), Bert M. Zuckerman, George J. Stessel (1951-1952), Paul F. Hoffman, Eugene B. Himelick (1952-1954), Richard D. Schein (1952-1953), Norman C. Schenck (1952-1953), Irving R. Schneider, Harry Krueger (1954-1955), Arthur W. Engelhard, James D. Bilbruck (1955-1958), John M. Ferris, R. Dan Neely, and Walter Hartstirn. Persons whose names are followed by dates were employed on research funds granted to the Natural History Survey by the Forest Preserve District of Cook County, Illinois, or by the National Oak Wilt Research Committee. The dates indicate the periods of employment. Himelick was employed on research funds granted by the National Oak Wilt Research Committee (1952-1954) before he was employed by the Survey.

As a result of this extensive research program on oak wilt, many papers were published. The phases of research covered

in these papers include laboratory studies on the morphology and physiology of the fungus (Zuckerman & Curl 1953) and isolation of the fungus from species of oak on which it had not been previously reported (Carter & Wysong 1951); greenhouse studies on host range (Hoffman 1953) and experimental transmission of the fungus by insects, mites, and squirrels (Himelick, Curl, & Zuckerman 1954; Himelick & Curl 1955, 1958); greenhouse studies on infection by and spread of C¹⁴-labeled fungus in inoculated oaks (Zuckerman & Hoffman 1953; Hoffman & Zuckerman 1954); and field studies on distribution and spread of oak wilt in Illinois (Carter 1952), availability of oak wilt inoculum in the state (Curl 1953, 1955a, 1955b; Himelick, Schein, & Curl 1953), characteristic growth of the fungus under natural conditions (Curl, Stessel, & Zuckerman 1952), discovery of the perfect stage of the fungus in nature (Curl, Stessel, & Zuckerman 1953; Stessel & Zuckerman 1953), and effect of the fungus on oak fence posts (Walters, Zuckerman, & Meek 1955).

Other Diseases of Trees.—Although oak wilt, elm phloem necrosis, and Dutch elm disease are the most destructive tree diseases in the state, other diseases of trees and of shrubs have been sufficiently destructive to require the attention of plant pathologists of the Natural History Survey. A wilt disease that affects many species of trees in Illinois is Verticillium wilt. It is known to affect 27 species of plants, including 7 varieties of woody ornamentals representing 19 genera. Of the 27 species of woody hosts of this disease, 12 were first reported in Illinois: black locust, catalpa, Chinese, English, and slippery elms, goldenrain tree, linden, magnolia, multiflora rose, tupelo, wayfaring tree, and yellow-wood. Maple, elm, and catalpa are frequently affected by this disease.

Canker diseases found in Illinois affect different species of trees, including crab apple, hawthorn, juniper, maple, mountain ash, pine, poplar, redbud, spruce, sycamore, and willow. Rust diseases are widespread and destructive in some years. They include cedar apple rust, cedar-hawthorn rust, cedar-quince rust, pine needle rust, and poplar leaf rust.

Foliage diseases which cause especial damage during cool, moist springs affect many species of trees. The most destructive foliage diseases are anthracnose of ash, maple, oak, and sycamore; blotch of buckeye and horsechestnut; and leaf spot of elm, hawthorn, maple, oak, and walnut.

Some trees decline and die each year because of unfavorable growing conditions that include physiological disorders, adverse weather conditions, and mechanical injuries. These conditions, as well as disease organisms, have received the attention of Natural History Survey plant pathologists.

Research on the control of foliage diseases includes testing of numerous fungicides each year. In some years as many as 18 species of trees have been treated with fungicides and as many as 12 different fungicides have been tested on one or more species. An example of an effective control measure resulting from these tests is the use of organic mercury fungicides to control anthracnose of sycamore.

Chemotherapy.—One phase of Natural History Survey research on the control of tree diseases relates to the effectiveness of various chemicals in preventing fungi from infecting trees or from causing disease symptoms after they have infected the trees. The early studies were confined mainly to oak wilt; the present studies include diseases of several species of trees and especially oak wilt, Dutch elm disease, and *Verticillium* wilt of elm, maple, and other trees. Of the hundreds of chemical compounds tested, a few systemic fungicides and antibiotic materials appear to be effective in preventing disease development. To obtain more information on what happens when these materials are introduced into trees, plant pathologists are studying the physiology of trees as well as the physiology of the fungi. The staff members who have carried on this program are Paul F. Hoffman, Eugene B. Himelick, Irving R. Schneider, John M. Ferris, and Walter Hartstirn.

Floricultural Pathology

Little research by the Natural History Survey was done in floricultural pathology before 1939. In response to numerous requests for help in dealing with disease

problems in floricultural crops, a program of research was initiated, and Don B. Creager was appointed to the staff in September of 1939. This program, carried on by Creager for 5 years and continued by J. L. Forsberg, included work on diseases of greenhouse crops and field- and garden-grown floricultural plants. Much attention was given to bulbous ornamental plants, which were being propagated extensively in Illinois for shipment to other states.

The early work was concerned with (1) obtaining as much information as possible about diseases important to Illinois growers, (2) conducting research on diseases for which vital information on cause and control was lacking, and (3) rendering every possible aid to growers in the recognition and control of diseases in their crops. As the work progressed more attention was given to developing disease control measures that would be more effective than those that were being used.

Crops which have received attention during the course of this work are amaryllis, aster, azalea, begonia, calla, carnation, chrysanthemum, gardenia, geranium, gerbera, gladiolus, hollyhock, hydrangea, iris, ivy, lily, orchid, peony, peperomia, periwinkle, petunia, poinsettia, rose, African violet, snapdragon, stevia, stock, sweet pea, tuberose, tulip, violet, and zinnia. Of these crops, gladiolus, rose, and carnation are grown in greatest quantity, and, since all three crops are subject to a number of destructive diseases, more work has been done on them than on the other crops.

Because of the serious losses due to diseases of gladiolus in the large commercial gladiolus growing area in Kankakee County, much research work has been directed toward developing effective control measures for these diseases. Prior to 1940, gladiolus corms generally were not treated for disease control, but in recent years nearly all commercial gladiolus planting stocks in all parts of the United States have been treated with a fungicide before being planted. This practice has developed largely as a result of the success of experimental treatments by Illinois Natural History Survey pathologists. If these or other equally effective treat-

ments had not been worked out, the gladiolus industry in Illinois would have succumbed.

Among other noteworthy accomplishments achieved by Natural History Survey pathologists in the field of floricultural pathology are the following: control of peony measles with an Elgetol ground spray (Creager 1941c, 1943a); control of black mold of rose grafts by chemical treatments (Creager 1941b); control of calla rots by chemical treatments (Creager 1943b); establishment of viruses as the causes of peperomia ringspot (Creager 1941a), carnation mosaic and streak (Creager 1943c, 1944, Forsberg 1947), and coleus mosaic (Creager 1945); clarification of the *Fusarium* disease complex in gladiolus (Forsberg 1955a); discovery of the vascular phase of the *Curvularia* disease of gladiolus (Forsberg 1957); discovery of scab on violets in Illinois (Forsberg & Boewe 1945); control of *Thielavia* root rot of sweet peas (Creager 1942); control of bacterial scab of gladiolus by use of soil insecticides (Forsberg 1955b).

The value of an insecticide in the control of bacterial scab of gladiolus became apparent in 1953 when gladiolus corms were treated with a seed protectant which contained an insecticide in addition to a fungicide. This treatment resulted in the production of corms free of bacterial scab and free of injury caused by white grubs. Results of this treatment supported observations that white grubs are instrumental in spreading bacterial scab. Succeding tests showed that 25 per cent aldrin granules applied to the soil at the rate of 4 or 8 grams per 10 feet of row prevented white grub injury and bacterial scab.

Identification and Extension

During each growing season the Section of Applied Botany and Plant Pathology receives for examination and diagnosis several thousand samples of trees, shrubs, and other plants suspected by Illinois residents of being diseased. Diagnosis results and treatment recommendations are sent as soon as possible to the persons sending the samples.

Most of the samples received are from elms suspected of being affected with

Dutch elm disease. To handle the laboratory diagnoses requires the full-time help during the summer months of four additional persons: one mycologist, two laboratory technicians, and one stenographer. It is anticipated that the demand occasioned by Dutch elm disease for service from Natural History Survey personnel will continue indefinitely.

To supply the demand from hundreds of communities and individuals throughout the state for information on identification, control, and other aspects of Dutch elm disease has occupied a major portion of the time of one plant pathologist. Educational material on Dutch elm disease has been prepared for distribution; this has included mimeographed leaflets on control and other phases of the disease, a series of news releases, kodachrome transparencies, black and white photographs, specimens, exhibits, maps, tables, and graphs. Technical advice and information were furnished the Illinois State Chamber of Commerce for two state-wide conferences on Dutch elm disease, one in 1955 and one in 1956. These conferences provided specific and detailed information on the nature and control of the disease. Outstanding authorities on Dutch elm disease in the United States were on the programs. Additional activities have included aid in field identification of the disease, aid in local surveys, training and instruction in collecting specimens, setting up laboratories for final diagnosis of the disease, and making laboratory diagnosis of each of several thousand specimens received each year.

Each year, activities of an educational or extension nature by staff members of the Section of Applied Botany and Plant Pathology include talks on plants and vegetation of Illinois, and on diseases of trees, shrubs, and floricultural crops. Examinations are made of numerous plantings of ornamental and economic crops in various parts of the state. Numerous pasture lands are examined in co-operation with members of the University of Illinois College of Veterinary Medicine for plants poisonous to livestock. Many plants examined in the field or received through the mail are identified for farmers, homeowners, and other interested persons.

PAST AND PRESENT

Early botanical research in Illinois was concerned mainly with field surveys of plants native to the state and with the distribution of these plants in the state. Although botanical research in the state is still concerned with native plants, it is concerned also with the cause and control of diseases affecting ornamental plants—trees, shrubs, and floricultural crops—and losses caused by diseases of economic crops, including cereal, fruit, forage, pasture, and vegetable crops.

Much of the early work with plants was done by amateur botanists who had very little formal training in botany. Some of these men were physicians who were interested in plants that had medicinal values. These early botanists were individuals, engaged in various professions or businesses, who were keenly interested in nature, especially in the plant life around them. They usually studied plants in local areas, as their modes of travel were by foot, by horseback, or by carriage. Their equipment and reference works were meager. Their efforts were directed mainly toward the collection and identification of plants.

Many of these early botanists were members of the Natural History Society. Some of them became professional botanists and were employed by the State Laboratory of Natural History.

Inheritors of some of the traditions of these early botanists are the present members of the Section of Applied Botany and Plant Pathology of the Natural History Survey. Unlike the early botanists, these men have received specialized botanical training in leading colleges and universities of the United States. Their fields of specialization include botany, taxonomy, plant pathology, plant physiology, mycology, and biochemistry.

They are provided with specialized equipment including high-powered compound and phase microscopes, high-speed centrifuges, pH meters, fluorescent lamps, spectrophotometer, and Geiger counter, and with excellent library facilities including numerous books on specialized subjects in botany and related fields. They are able to study plants in all parts of the state, as they can rapidly travel

great distances by automobile, train, airplane, or helicopter. They study the taxonomy of plants, as the early botanists did, and in addition the pathology, physiology, mycology, and biochemistry of plants, including fungi, and especially the fungi that cause diseases of plants.

UNSOLVED PROBLEMS

The partially solved problems receiving major attention of the Section of Applied Botany and Plant Pathology at the present include the control of gladiolus corm rots, oak wilt, elm phloem necrosis, and Dutch elm disease. Although these diseases have been investigated for several years, continued research is needed to develop more effective treatments for their control. Other unsolved problems include the abnormal growth, wilt, decline, or death of trees, floricultural crops, and shrubs used for ornamental, shade, or forest purposes. Some specific unsolved problems are a virus disease complex of gladiolus, a general decline of ash, elm, and oak in localized areas of the state; a rapid decline and death of red pine in localized plantings in northern Illinois; wilt, occasionally followed by death, of ash, catalpa, fragrant sumac, Japanese quince, and hard maple; a needle blighting of white pine; diseases of hackberry, Norway spruce, and white pine, with symptoms suggesting virus diseases; and wetwood of elm.

Although a research program on the control of diseases of fruit, grain, and vegetable crops is conducted by the Agricultural Experiment Station at the University of Illinois, some of the unsolved or partially solved problems are mentioned here. Because of the continued appearance of new physiologic races of rust on small grains, it is essential to develop new varieties of grains resistant to these races. Also needed are varieties of small grains resistant to scab and loose smut. Another disease of small grains that needs further study is the virus disease known as yellow dwarf.

Corn is affected by stalkrots caused by several fungi; varieties of corn are needed that are resistant to the stalkrot caused by each fungus. Other problems include more effective control for bacterial spot

of pepper and for diseases caused by soil-borne microorganisms including bacteria, fungi, and nematodes.

If the future can be measured in terms of experience in the past, new diseases and other types of new plant disorders will appear each year to require additional attention of the research personnel of the Section of Applied Botany and Plant Pathology.

FUTURE POSSIBILITIES

Future possibilities in the botanical survey include further collections of native and naturalized vascular plants to increase the knowledge of the habitats and the range of these species in the state. As plants migrate, slowly under natural conditions but swiftly with the help of man, it is necessary to be on the alert for new additions to the state flora and to give warning if any introductions are of an obnoxious character. The final aim of a floristic study is to produce a manual of the flora of Illinois which will give not only good descriptions of the species but also a discussion of the variations of the species within the state and a discussion of their distribution in Illinois.

Collections of the nonvascular plants—algae, fungi, and bryophytes—should be expanded. Although a small collection of bryophytes—mosses and liverworts—is housed in the herbarium, much collecting remains to be done before the present bryophyte flora and its distribution in the state can be known. A nucleus of a phycological collection has been made and should be increased. Only a few of the nonpathogenic fungi are represented in the Natural History Survey collections. Collections of slime molds, lichens, and fleshy fungi—mushrooms and bracket fungi—should be started, as these plants are a part of the flora of Illinois and thus a part of the natural resources of the state.

Vegetational studies should be continued. Although many of the original prairie types of Illinois have been destroyed and only remnants remain, these remnants should be described so that future citizens of Illinois will have some botanical knowledge of the prairie types. Hill prairie studies should be continued to solve

some of the problems of succession in this type of prairie and to learn how such prairie recovers from heavy grazing. Additional study should be made of the vegetation of the sand areas of the state. An ecological study of the forests in Illinois should be made. The ultimate aim of these studies is to produce a manual of the plant geography of Illinois.

Not only should the various vegetations of Illinois be described; remnants of them should be preserved. This is true especially of the prairie types. As we do not know what lies in the future for land use in the locations of the present hill prairies, now one of the least disturbed prairie types in Illinois, several of these beautiful grasslands should be set aside as natural areas by the state or federal government and should be so administered that picnic parties, hunters, or others cannot disturb them but that interested persons may view and study them. Although only very small remnants of the flatland and bottomland types of prairie remain, several such remnants should be set aside and allowed to expand so that future generations may have a general idea of the nature of these types of prairie which gave the name "the prairie state" to Illinois. Examples of sand prairies should be preserved. Some of these prairies which come under state control should be left as prairies instead of being converted into pine plantations. Abandoned railroad trackways in sand prairie regions should be permitted to develop as a type of the sand prairie. Other vegetations also should be preserved. The bogs in northeastern Illinois, in Lake County, are valuable from the botanist's point of view. The few remaining, sizable tamarack bogs could be easily set aside for the study of bog plants and animals and of succession in the bogs.

Future research on plant diseases will continue the advancement of present research, and new fields of research will open up. Some of the types of research that appear promising in the control of plant diseases include the use of chemotherapeutants, antibiotics, and soil fungicides. Further research is needed on insecticides and their indirect role in the control of plant diseases. One instance of this is illustrated in the control of bac-

terial scab of gladiolus by use of aldrin to prevent white grub injury to the corms. Chemical compounds obtained from mineral deposits in the state hold promise for the control of some plant diseases (Schenk & Carter 1954). Research on these compounds through the co-operation of the Geochemical and Coal sections of the Illinois Geological Survey and the Wright Air Development Center of the United States Air Force has been fruitful in the development of fluorine compounds with fungicidal properties against certain disease-producing fungi. Research along these lines resulted in publication of six articles on the fungistatic capacities of aromatic fluorine compounds in relation to cloth-rotting fungi (Tehon 1951*b*, 1952*b*, 1954; Tehon & Wolcyrz 1952*a*, 1952*b*; Finger, Reed, & Tehon 1955).

Research on the physiology of plants and on organisms that produce plant diseases will aid materially in the development of more effective controls for these diseases. One objective of this research is to develop a more realistic approach to the control of diseases through obtaining information on the movement of raw materials, elaborated foods, and chemical

compounds introduced into woody plants. The addition of a plant physiologist to our staff would materially increase research in this field.

In our study of several thousand specimens of diseased ornamental plants each year, many unknown fungi are obtained. These fungi need to be identified and those that are found affecting new hosts or that have not been found previously in the state should be added to our mycological collection. To adequately handle this work, to make monographic studies of economically important fungi, and to attack new mycological problems as they appear, a mycologist with special interest in economic fungi would greatly facilitate our research.

As we contemplate the future possibilities for research by the Section of Applied Botany and Plant Pathology, it is evident that there are unlimited opportunities not only to continue the research now in progress but to expand into new fields of research. This statement applies to the botanical survey, the study of vegetation, the study of diseases of ornamental plants, and the study of the various kinds of fungi that occur in the state.

Aquatic Biology

GEORGE W. BENNETT

THE research in aquatic biology that was so much a part of the endeavors of the staff of the Illinois State Laboratory of Natural History and later the Illinois Natural History Survey was initiated by Stephen A. Forbes. From the very beginning of his active period in Illinois, Forbes showed great interest in fishes and he began collecting specimens for species records, distributional records, and food habits studies. He wrote articles on Illinois Crustacea and food of Illinois fishes for the first volume of the *Bulletin* of the Illinois State Laboratory of Natural History (Forbes 1876, 1878*a*, 1880*b*, 1880*c*, 1883*b*, 1883*c*). In the period 1876–1888 he collected 1,221 fish of 87 species, 63 genera, and 25 families; these he used to study their diagnostic characteristics, their distribution in the state, and their food habits. Forbes' interest in aquatic biology was broad, and he himself worked on or arranged for others to work on crustaceans, leeches, protozoans, rotifers, and aquatic insects, as well as fishes native to Illinois.

BEGINNING OF AQUATIC ECOLOGY

Many of the early publications of the Illinois State Laboratory of Natural History dealt with the taxonomy and distribution of aquatic animals new to science, or additions to the known distribution of named animals. Forbes was familiar with these subjects and also with the ecology of aquatic organisms at least as early as 1887. In that year his "The Lake as a Microcosm" was first published in the *Bulletin* of the Peoria Scientific Association; later it was republished in volume 15 of the *Bulletin* of the Illinois State Laboratory. In this short but epoch-marking paper, Forbes (1925) described a lake or pond as an environment in which the animals and plants were largely isolated from the surrounding terrestrial animals and plants but were very much interrelated and interdependent

among themselves; each organism was producing more new individuals than the environment could support, so that many of them served as food for other types of animals, and competition was very keen. Forbes had observed the biological phenomena associated with fluctuating water levels—with floods following excessive precipitation and low waters following droughts—and described them as follows:

Whenever the waters of the river remain for a long time far beyond their banks, the breeding grounds of fishes and other animals are immensely extended, and their food supplies increased to a corresponding degree (Forbes 1925:538).

As the waters retire, the lakes are again defined; the teeming life which they contain is restricted within daily narrower bounds, and a fearful slaughter follows; the lower and more defenceless animals are penned up more and more closely with their predaceous enemies, and these thrive for a time to an extraordinary degree (Forbes 1925:539).

Forbes recognized that periods of biological expansion and contraction were normal and, without the introduction of abnormal forces, would tend to hold "each species within the limits of a uniform average number, year after year." Every organism had its enemies that seemed to be balanced against its reproductive potential and, although every species had to "fight its way inch by inch from the egg to maturity," yet no species was exterminated.

Apparently the Illinois State Fish Commissioners, assigned the duties of protecting the fisheries resources of the state during this period, either had not read Forbes' "The Lake as a Microcosm" or did not understand it, because their main activity for the 20 years following 1890 was the rescuing of fishes from the land-locked, drying backwaters of the Illinois and Mississippi rivers and the returning of these fishes to the open waters.

Perhaps the Commissioners should not be condemned severely, because their beliefs and activities were in no way dif-

ferent from those of similar bodies in other states throughout the country. They were in tune with the times. In the report of the Commissioners to the Governor of Illinois for the period October 1, 1890, to September 30, 1892 (Bartlett 1893:3), is to be found the following statement:

The number of fish left to die in the shallow waters has been beyond computation, and has seemed to be greater than ever before, from the fact that the attention of the people generally has been called to them and the terrible waste ensuing. . . .

We have been severely criticised because so many fish are allowed to perish, but when the fact is considered that the Mississippi river has a meandering frontage of 450 miles in this State, with bottoms varying in width from a few hundred yards to several miles, and the Illinois and other rivers adding perhaps as much more, it can readily be seen that, if the work were carried on to a successful completion, it would require hundreds of men and thousands of dollars of expense; in other words, it would be simply impracticable.

Fish rescue operations were done with seines dragged through shallow waters by crews of men. The fish were separated from the mud and vegetation and carried by boat to open water, or in tubs to tanks on wagons when overland transportation was necessary. The operations were carried on in summer and early fall when both the water and the air were very warm. Today fisheries biologists are well aware of the fact that, even if the fish had been released "alive" in open water, their chance of survival was very low. Few fishes are able to survive even a short exposure to a lukewarm, mud-and-water suspension, such as is created when a seine is dragged through shallow backwaters in August. This statement applies particularly to the game and fine fishes.

We now suspect that the phenomenon of fluctuating water levels, which created a fish rescue problem along the Illinois and Mississippi rivers for the Illinois State Fish Commissioners, may have been highly favorable to the well-being of the population of fishes, particularly largemouth bass, northern pike, walleyes, crappies, and other pan fishes. A combination of natural predation (largely by fish-eating birds) and water level fluctuations prevented excessive competition

among the coexisting species and allowed for excellent survival of game fish. The report of the Fish Commissioners (Bartlett 1893:4) for the 2-year period ending September 30, 1892, contains the following statement:

In the Quincy Bay [of the Mississippi River], this season, the number of black bass has been unprecedented, and a fair estimate of the number taken with hook and line would place it in the hundreds of thousands. Most of them were too small to use on the table, yet were as voracious as larger ones and fell an easy prey to the angler, whether he of the rod and reel or the small boy with a willow switch and a tow line, all caught bass. One man, who called himself a sportsman, boasted of having caught 800 of them in one day with hook and line, all too small to eat, but he carried them away and threw them on the ash heap. From my office window I saw 225 taken by two little boys in one day, all of them wasted.

The production of a dominant brood of bass (undoubtedly largemouth) such as this might be expected to follow a period of very low water in the late summer and fall and a period of moderately high water during the bass spawning season the following June.

The theory of the benefits of fluctuating water levels is further substantiated by a published record of the catch of four commercial fishing firms operating in the Illinois River near Havana between July 1 and December 1 (5 months) in 1895 (Roe & Schmidt 1897). Their catch was 358,843 pounds, mostly of carp and buffalo, which made up 85.7 per cent of the total. An unusual part of the catch was the proportion of "bass" (undoubtedly largemouth), 7,852 pounds, and walleye and "pike" (northern), each 200 pounds. The last two species are seldom taken in the Illinois River today. The catch of bass (7,852 pounds) was larger than the catch of crappies (7,405 pounds). Crappies are easily caught in hoop and fyke nets or seines; bass do not enter hoop and fyke nets readily and when surrounded with a seine they show considerable aptitude for jumping over. Inasmuch as more pounds of bass than of crappies were caught, probably many more pounds of bass were available.

Today, with water levels of bottomland lakes in the Havana region much more stabilized, it would be an impossi-

ble task to catch 7,000 pounds of bass with commercial fishing gear. This important game species is very much less abundant now than it was when the river was free to spread over its wide flood plain.

FIRST FIELD LABORATORY

Forbes was much interested in the Illinois River and in 1894 he established a biological station on its shores (Forbes 1895a:39) "for the continuous investigation of the aquatic life of the Illinois river and its dependent waters, near Havana."

That Forbes (1895a:46-7) had great breadth of vision in biological research is shown by his description of the objectives of the laboratory:

The general objects of our Station are to provide additional facilities and resources for the natural history survey of the State, now being carried on, under legislative authorization, by the State Laboratory of Natural History; to contribute largely to a thoroughgoing scientific knowledge of the whole system of life existing in the waters of this State, with a view to economic as well as educational applications, and especially with reference to the improvement of fish culture and to the prevention of a progressive pollution of our streams and lakes; to occupy a rich and promising field of original biological investigation hitherto largely overlooked or neglected, not only in America, but throughout the world; and to increase the resources of the zoological and botanical departments of the University by providing means and facilities for special lines of both graduate and undergraduate work and study for those taking major courses in these departments.

The Station differs from most of the small number of similar stations thus far established in this country from the fact that its main object is investigation instead of instruction, the latter being a secondary, and at present an incidental object only. It has for its field the entire system of life in the Illinois river and connected lakes and other adjacent waters, and it is my intention to extend the work as rapidly as possible to the Mississippi river system, thus making a beginning on a comprehensive and very thoroughgoing work in the general field of the aquatic life of the Mississippi Valley, in all its relations, scientific and economic.

The special subject which I have fixed upon as the point of direction towards which all our studies shall tend is the effect on the aquatic plant and animal life of a region produced by the periodical overflow and gradual recession of the waters of great rivers, phenomena of which the Illinois and Mississippi rivers afford excellent and strongly marked examples.

Forbes (1895a:47) believed that the natural sciences should be studied out of doors and that colleges and universities of his day were not doing well by their students in botany and zoology when they confined them to laboratory studies:

Not many years ago, biological instruction in American colleges was mostly derived from books. Of late, it has been largely obtained from laboratories instead, but several years' experience of the output of the zoological college laboratory has convinced me that the mere book-worm is hardly narrower and more mechanical than the mere laboratory grub. Both have suffered, and almost equally, from a lack of opportunity to study nature alive. One knows about as much as the other of the real aspect of living nature and of the ways in which living things limit and determine each others' activities and characters, or in which all are determined by the inorganic environment.

It is possible that Forbes' feeling on this point of training may have influenced the University of Illinois to require field courses at a biological station before granting a graduate degree in zoology.

Havana was selected as the location for the Illinois Biological Station because of its several advantages: Forbes liked the bluffs along the eastern shore of the Illinois River because at their bases they furnished a clean, hard sand beach suitable to work from and ideal for camping. Moreover, along these bluffs was an abundance of pure, cold spring water.

The laboratory consisted of "three well-placed rooms" in the town itself and a "cabin boat" on the Illinois River.

The office and laboratory rooms were supplied with running water and electric light, and liberally provided with the usual equipment of a biological laboratory, consisting of compound and dissecting microscopes (Reichert and Zeiss), microtomes, biological reagents to the number of one hundred bottles, water and [paraffin] baths, laboratory glassware, tanks for alcohol, a coal stove, a kerosene stove, laboratory tables for five assistants, and a working library of about one hundred and twenty volumes (Forbes 1895a:48).

The cabin boat was stationed on Quiver Lake north of Havana, about 2.5 miles from town. The boat contained a well-furnished kitchen and sleeping quarters for four men. Most of the rest of the space was taken up by equipment, including limnological apparatus, seines, collecting nets, microscopes, and a small library.

The original staff of the station, in 1894, consisted of Frank Smith, who was directly in charge and whose principal interest was aquatic worms; Charles A. Hart, entomologist and curator of collections for the State Laboratory; Adolph Hempel, who worked on protozoans and rotifers; and Mrs. Dora Smith, who served as microtechnician and was in charge of the rooms in Havana. Miles Newberry, who lived in Havana, had charge of the cabin boat and acted as a general field assistant. Others who were present at some time during the first year of operation were Ernest Forbes, for 6 weeks of general collecting, Professor Thomas J. Burrill, a Mr. Clinton, a Mr. Yeakel, and a Miss Ayers, all of the University of Illinois Botany Department, who were collecting aquatic plants; a Professor Palmer, who was making chemical analyses of the water; Assistant Professor Henry E. Summers of the University Physiology Department, who photographed the region; and the staff artist, Miss Lydia M. Hart. Professor Forbes exercised general supervision over the station work, planning and following its operation.

FISHES AND PLANKTON

Within a year or so aquatic investigations were stepped up through increased use of the laboratory and cabin boat at Havana. At the beginning of this century Frank Smith (1901:567) stated in *Science* that the ichthyological survey of Illinois had received much attention during the previous 2 years and that a comprehensive report was soon to be published. He also stated that Dr. C. A. Kofoid had been studying the plankton of the Illinois River for the previous 5 years. This short statement in *Science* announced the progress being made on two of the important contemporary contributions to aquatic biology, namely Forbes & Richardson's *The Fishes of Illinois* (1908) and Kofoid's studies on the plankton of the Illinois River.

Shortly after, in an essay dealing with "statistical ecology," Forbes (1907a) presented a method for showing relationships between individual species of fishes and preferences of certain kinds of fishes

with respect to features of the physical environment. The validity of this method depended upon the numbers of collections that were available for study. Where sufficiently large numbers of collections could be mustered, Forbes compared observed relationships with expected relationships and obtained a *coefficient of association* by dividing the former by the latter. A hypothetical example is given below:

Given species *A* and species *B* inhabiting waters in the same general land area: In 1,000 collections, species *A* occurred 159 times and species *B* 85 times. Thus, the probability that they would occur together in any single collection was $159/1,000 \times 85/1,000$ or 13,515 times in a million or 13.5 times in 1,000, and the probable number of these double occurrences in the 1,000 collections was $13.5/1,000 \times 1,000/1$ or 13.5 times. However, in the 1,000 collections, species *A* and species *B* were found together in 40; thus, the coefficient of association for species *A* and *B* was $40/13.5$ or 2.96: they were found together about three times as often as was to be expected.

This same type of reasoning was applied to show relationships between individual species and the physical environment: stream, lake, pond, marsh; size of water area and water movement; bottom of mud, sand, gravel, or rock. These coefficients of association are found frequently in Forbes & Richardson's *The Fishes of Illinois*. Unfortunately about half the collections referred to in this publication were made without notes on water current and bottom materials, so that this method of showing association could be applied only to stream, lake, pond, or marsh, or to sectional distribution in the state. Thus, when Forbes & Richardson (1908:195) stated that the frequency ratios for a fish were "3.19 for the smaller rivers, 2.06 for creeks, and .58 for the largest streams," they meant that these fish exceeded expectancy in "smaller rivers" and "creeks" by about 3 and 2 times, respectively, and were considerably below expectancy in "the largest streams." A coefficient of association of 1 indicated correspondence with expectancy; a coefficient below 1 indicated a negative relationship.

This method of showing ecological relationships between species and ranges, species and local habitats, or between species themselves, allowed the use of numbers to show the degree of the relationship or lack of it. Its shortcoming was that it made no distinction between collections containing one fish of a species under consideration and those containing several hundreds or thousands.

THE FISHES OF ILLINOIS

The first edition of *The Fishes of Illinois* was published by the State of Illinois in 1908; a second edition was published in 1920. Collections and observations for this work had been started in 1876 by Forbes and had been expanded through the help of many assistants working at rather irregular intervals until 1903. Field work on fishes became nearly continuous for a few years after establishment of the Illinois Biological Station at Havana in 1894. Special recognition was given to Wallace Craig, who collected during the winter and spring seasons of 1898 and 1899, to H. A. Surface, who collected during 1899, and to Thomas Large, who made extensive wagon trips, the most important of them in 1899, to collect fishes from streams in many parts of the state. Recognition was given also to unnamed high school teachers who collected fishes under specific instructions.

Collections of fishes studied by Forbes and Richardson were taken from many sources: catches made by collecting parties with seines of various size and mesh (including minnow seines and bag seines), trammel nets, set nets (both fyke and hoop); catches made by commercial fishermen; and selections from fishes on display in fish markets. More than 200,000 specimens representing 150 species were collected from more than 450 locations in the state.

The Fishes of Illinois was published in two parts, one of which was an atlas. The larger or first part contained a section on "The Topography and Hydrography of Illinois" written by Professor Charles W. Rolfe, at that time head of the Geology Department of the University, a section entitled "On the General and Interior Distribution of Illinois

Fishes," a section on "The Fisheries of Illinois," and one on the individual species of fishes found in the state. This last section made up by far the largest number of pages and included keys for the identification of fishes and a glossary of technical terms. For each species of fish were given the scientific name, common name or names, synonymy of scientific names (where such existed), and a detailed description of the fish. The description was followed by a statement of the fish's distribution within and without the state, a statement on average and maximum lengths and weights, and information on habitat preferences, food preferences, and other phases of biology. For most species, information was given on how the fish might be caught and its value (if any) as food. Many species were illustrated by black and white photographs or by colored plates painted by Mrs. Lydia M. (Hart) Green and Miss Charlotte M. Pinkerton. These colored plates were so fine that for nearly a half century none published elsewhere was their equal.

The second part, the atlas, contained maps of the 10 stream systems of the state. These maps showed the glacial geology of Illinois, localities from which collections were made, and interior distribution of 98 of the most important fishes.

As a state publication on fresh-water fishes, *The Fishes of Illinois* remained unique for a period of more than 40 years.

ILLINOIS RIVER PLANKTON

Kofoid's studies of the plankton of the Illinois River appeared as five articles in volumes 5, 6, and 8 of the *Bulletin* of the State Laboratory of Natural History. Altogether Kofoid published nearly 1,000 printed pages on the plankton of the Illinois River.

From 1895 to 1900 Kofoid was superintendent of the biological station at Havana. In 1900 he went to the University of California at Berkeley. At the time he left Illinois for California and a new position, he had published only three short papers on plankton, one dealing with methods and apparatus, one with a



Two members of the staff of the Illinois State Laboratory of Natural History making observations on the breeding habits of fish near Havana, 1910 or 1911. The box at the stern of the boat was used by observers in watching the movements of fish and in searching for fish nests and fry.

new species, and one with a new genus of plankton (Kofoid 1897, 1898, 1899). Two longer papers on plankton (Kofoid 1903, 1908), one on quantitative investigations and the other on constituent organisms and their seasonal distribution, he wrote in California. Kofoid remained on the staff at Berkeley until his retirement in 1936.

BOTTOM FAUNA

R. E. Richardson's classic studies of the bottom fauna of the Illinois River covered a period that coincided with severe changes in the biology of the river (Forbes & Richardson 1913, 1919; Richardson 1921, 1925*a*, 1925*b*, 1928). Before 1900 the Illinois was a reasonably clean river receiving very limited organic pollution from a small number of towns along its banks. By 1900 Chicago had become an important trading center and was growing rapidly. In order to get rid of the sewage and the organic waste from

a number of meat packing plants of Chicago, a diversion channel was opened between Lake Michigan and the Des Plaines River, one of the headwater streams which united with the Kankakee to form the Illinois. Forbes and Richardson had collected bottom fauna in the Illinois prior to 1900, and Richardson had continued to do so after the diversion of Lake Michigan water had begun. At first the organic pollutants created a nuisance only in the upper part of the river, at Morris, Marseilles, and Starved Rock. Richardson studied the bottom fauna throughout the length of the upper part of the river in 1909, 1910, and 1911 and found that the river was nearly normal at Chillicothe and Hennepin. Above these towns it became progressively more polluted.

During the period 1900-1908 the organic pollutants acted as fertilizer, and the annual fish yield of the lower part of the Illinois increased from 11.5 million to 24 million pounds. Gradually, after

1908, organic waste from Chicago increased until the volume approached the capacity of the river to oxidize it. Diversion was increased, and the fish yield dropped; a peak diversion occurred in 1927 with a flow of 10,245 cubic feet per second (Mulvihill & Cornish 1930:57). The period of maximum pollution occurred between 1915 and 1920. From his studies of bottom fauna during this time, Richardson calculated a reduction in the total weight of bottom organisms in the reach from Chillicothe to La Grange of 34.5 million pounds, representing a potential loss of 7 million pounds of fish. By 1921 the fish yield of the river had hit an all-time low of 4 million pounds, partly from pollution and partly from extensive bottomland lake drainage. After 1922 there was some reduction of the raw sewage going into the Illinois River, and from 1924 to 1930 the yield of commercial fish varied around 10 million pounds per year.

Between 1913 and 1928, Richardson (with some assistance from Forbes on two of the early papers) published six articles in the *Bulletin* series. Because of the opportune timing of his studies in relation to the pollution of the Illinois, Richardson was able to set up a classification of seven degrees of pollution based on the presence of certain groups of aquatic organisms. These groups were often better indicators of the degree of pollution than were oxygen analyses, because the animal associations were sensitive to small increases in pollution, or to fluctuations in pollution that might be missed unless oxygen analyses were made continuously.

NEW LINES OF RESEARCH

During the second decade of the twentieth century, biologists became interested in measuring the effects of physical and chemical changes in the aquatic environment upon fish, and in the responses of the fish to these changes. From 1914 to 1925, members of the staff working in aquatic biology published papers on the suitability of bodies of water for fishes; the poisoning of fishes by illuminating gas wastes; the reaction of fishes to carbon dioxide and carbon monoxide; a collecting bottle for quantitative determination of

dissolved gases; methods of measuring the dangers of pollution to fisheries; and observations on the oxygen requirements of fishes in the Illinois River. These publications were the work of Victor E. Shelford (1917, 1918a, 1918b), Morris M. Wells (1918), Edwin B. Powers (1918), and David H. Thompson (1925). They represent a new approach to fisheries studies, e.g., the use of laboratory studies to explain and expand the knowledge of the relationships of fishes and other aquatic organisms to their environments.

In the early 1920's aquatic investigations were continued on the Illinois River, where the Natural History Survey maintained a houseboat laboratory and attending boats and equipment. At this time studies were begun on the lakes of north-eastern Illinois, studies that included the taking of quantitative plankton and bottom samples and collections of fishes and higher aquatic plants. In 1923, an investigation was begun also on the Rock River (Forbes 1928).

Surveys on the Illinois River, made in co-operation with the Illinois Water Survey in 1923 and 1924, showed that the normal life of the river had been destroyed by pollution as far down as Peoria Lake.

By 1927 the staff had published in the *Bulletin* 20 articles, comprising 1,856 printed pages, on Illinois River biology. These articles apparently had had a profound effect on aquatic biologists in many parts of the United States; other states were engaged in making their own lake and stream surveys, for the most part not so comprehensive as those of the Illinois River, but adequate to give some information on physical and chemical conditions and rough measurements of the fish food resources, plus inventories of the kinds and relative abundance of fishes present.

At this time (1927) the Natural History Survey had expanded its own stream survey program to include, besides the Rock River, the Hennepin Canal, the Sangamon and Kaskaskia rivers, and the streams of Champaign County (Forbes 1928). The Rock River investigation was operated from 1923 to 1927 with David H. Thompson in charge of field collecting and R. E. Richardson in charge

of the analysis of data at Urbana. Thompson and three or four other men, working steadily each year through spring, summer, and fall, collected and shipped to Urbana about 90,000 fishes of 90 species, 2,400 fish stomachs, 15,000 river mussels belonging to 40 species, 820 collections of small invertebrates, and 500 collections of plankton and algae.

Samuel Eddy (1927, 1931, 1932) worked on the plankton of Lake Michigan and the Sangamon River and on plankton collections from some sinkhole ponds in southern Illinois.

EARLY MANAGEMENT ATTEMPTS

Many of the early activities in the management of aquatic resources of the United States were based on premises which later research proved to be inaccurate or erroneous. These included such measures as stocking and the protection of fish from human exploitation through restrictions in the form of fishing seasons, length limits, and creel limits. Toward the end of the last century, James Nevin (1898:18), speaking before the American Fisheries Society, made the following statement:

Personally I have been on the various spawning grounds of the whole chain of Great Lakes from the Gulf of St. Lawrence to Lake Superior during the spawning seasons; and I have many times watched the salmon trout, white fish and wall-eyed pike spawn in their natural way; and I am convinced that only a very small percentage of the eggs so deposited are fertilized.

This statement represented the attitude of the hatchery supervisors and most administrative personnel connected with federal and state agencies dealing with fisheries resources. As the spawning grounds of most fishes of the Great Lakes remain relatively unexplored even today, it is doubtful if Nevin was very familiar with them.

Ideas having no scientific basis often become widely accepted. For example, almost everyone has heard that one should wet his hands before handling a fish if he wants it to remain alive after release. Apparently this idea originated with G. H. Thomson, Superintendent of the Estes Park Fish Hatchery, Colorado.

Thomson had cards printed with the title, "A Plea for the Fish." The cards stated:

When removing an undersized trout from your hook, always moisten your hands before grasping the fish; otherwise the dry hand will remove the slime from the back of the trout, when it is only a question of time until fungus sets in and the fish will die.

Thomson distributed these cards to residents of all states and of many foreign countries. In 1912 he reported that at the September 21-24, 1908, meeting of the American Fisheries Society in Washington, D. C., the Society "recommended that the various state commissions educate the people by every means in their power to follow the directions given about wetting the hands" (Thomson 1913:171). He reported also that his program was endorsed by 28 fish and game commissioners throughout the United States. His idea was so widely disseminated that almost everyone has heard of it; yet there is no evidence that any attempt was made to test it through scientific experimentation.

In spite of continued emphasis on artificial propagation, new techniques were gradually discovered and put into use by researchers in the fisheries field, and these laid the foundation for modern thought in management. Borodin (1924) and Barney (1924) called attention to the value of using growth rings on scales and otoliths for determining the age of fishes; Wiebe (1929) proposed the use of fertilizers to increase plankton production; Surber (1931) discussed the use of sodium arsenite in the control of aquatic vegetation; Burr (1931) used electrical equipment to stun fish; Markus (1932) investigated the relationship between water temperatures and food digestion in largemouth bass; through tagging and recovery, Thompson (1933a) studied migrations of stream fishes. These and other findings laid the groundwork for modern attack on the problems of fish management.

MODERN MANAGEMENT

The modern concept and use of the term "fish management" first appeared about 30 years ago. It was suggested

(if not named) by E. A. Birge in writing about fish and their food. Birge (1929:194) stated:

Good fishing for sport calls for the continued presence in a lake of a relatively few large individuals of the desired species, which are to be caught singly. They must be larger than the average adult. They are not caught primarily for food but for sport and as a basis for stories. A dozen half-pound bass are by no means an equivalent to one three-pounder from this point of view. But these large individuals are few in number: they are old and have come to full size very slowly. It is easy to catch them and very hard to replace them in the presence of the vigorous competition for food that goes on in a lake. *And as yet little thought and less study have been given to the needs of this specific form of conservation of fish resources.* (Italics mine.)

This statement implies a concept of management for sport fishing.

When Carl L. Hubbs described the organization of the Institute for Fisheries Research (Hubbs 1930), fisheries researchers in Michigan were working on a state-wide creel census, lake and stream surveys, stream improvement, nursery waters, fish migration, predators of fish, fish diseases, and fish growth.

At about the same time, fisheries research at the Illinois Natural History Survey (Wickliff 1933) included studies of fish migration through tagging of fish, ages and growth rates of important fishes, general quantitative determinations of plankton and bottom organisms, a comparison of fish population densities by means of standardized fishing methods, and the determination of the fish population of a lake by capture, fin marking, and recapture of adult fish.

The point at which fish management emerged as a more or less discrete discipline is not easily established. If fish management is assumed to be the art of producing sustained annual crops of wild fish for recreational use (modified from Leopold 1933), agreement as to the time management began is difficult to reach.

Modern management could hardly have made a beginning until biologists had discovered enough basic information about fishes to be able to discredit the unfounded but strongly held theories relative to the values of stocking, closed seasons, length limits, and creel limits. This basic information came from many

sources and was available before 1940. In Ohio, Langlois (1937) was convinced that the closed season was worthless for increasing the numbers of bass. In Michigan, Eschmeyer (1938) had poisoned the entire fish populations of several small lakes in which the fishing was poor and had discovered an "overabundance of fish" instead of a scarcity. Also in Michigan, Carbine (1939) had investigated the spawning and hatching of nest-building centrarchids in Deep Lake and had discovered that many more young were produced than the lake could support. In Illinois, David H. Thompson had followed dominant broods of crappies in Lake Senachwine for 4 years (1933-1936) and had come to the conclusion that, while sizes and numbers of fish varied, the total weight of the population remained fairly constant. Also in Illinois, Thompson & Bennett (1939c) had demonstrated relationships between length of food chains and poundages of fish supported by ponds. In Alabama, Swingle & Smith (1939) had demonstrated the capacity of fish populations to expand or contract in relation to the capacity of the habitat to support them.

These researches on the dynamics of fish populations formed the bases for modern fish management. Yet old ideas were difficult to uproot. Clarence R. Lucas (1939) of the U. S. Bureau of Fisheries published a paper titled "Game Fish Management," in which he listed what he termed the "operative" techniques of fish management: (1) regulation—closed seasons, bag limits; (2) fish culture—rearing of game fishes for stocking; (3) distribution—transportation and liberation of hatchery-reared fish; (4) stream and lake improvement; and (5) predator control—the removal of predatory fishes or of fishes that otherwise interfere with the production of the game fish crop. This paper reflected exactly the old conception of operation, but under a new name.

Thompson's ideas on fish management were summarized in his contribution to *A Symposium on Hydrobiology*. In a section titled "The Fish Production of Inland Streams and Lakes" Thompson (1941) stated that production and yield were synonymous—both represented the

crop that was harvested. The total amount of fish in a lake or stream at any given time was the standing crop; when the standing crop reached "saturation" it represented the carrying capacity of the lake or stream. Thompson believed that the food resources and the carrying capacity of a body of water remained fairly constant but that the number of fish could vary widely. He reasoned that, if the weight of fish remained constant, then the removal of some fish would furnish more food per individual for those remaining, and the growth rate would increase; if more fish were planted, less food would be available per individual, and the growth rate would decrease. To further this thesis, he was able to demonstrate from his own laboratory experiments that at a water temperature of 70 degrees F. a 10-inch bass required as food an amount of minnows equal to three-fourths of 1 per cent of its body weight per day in order to maintain a constant weight; and that, at an optimum feeding rate, 2.5 pounds of minnows were required to produce 1 pound of bass.

Complete censuses of nine Illinois lakes subject to floods and indiscriminate stocking showed that, although 46 different species were present, only 10 species of fish comprised more than 1 per cent each of the total weight of all fish. The rough fish listed were redmouth buffalo, mongrel buffalo, and carp; forage fish were gizzard shad and golden shiner; catfish included only the black bullhead; the pan or fine fish were bluegill, white crappie, and black crappie; and the only game fish was the largemouth bass. These species must be considered as showing superior adjustment to the pond habitat in Illinois.

Thompson had observed cycles in fish that were the result of interspecific and intraspecific competition. The "fine" fish in Lake Senachwine (Illinois) amounted to about 50 to 55 pounds per acre, regardless of the number of fish or the area of the lake. In some years there were 10 times as many fish as in other years, and the individual fish averaged one-tenth the weight of the individual fish of other years. Large broods of crappies were produced at intervals of about 4 years, and during interim seasons they controlled the

survival of their own young and the young of other species.

Thompson attempted to construct a theoretical maximum cropping rate for any water area as a percentage of its carrying capacity. He believed that the cropping rate was related to latitude (length of growing season). He estimated annual cropping rates for Vilas County and Madison, Wisconsin; Urbana and Cairo, Illinois; Memphis, Tennessee; Jackson, Mississippi; and New Orleans, Louisiana. He assumed that in northern Wisconsin about 21 per cent of the carrying capacity could be replaced each year; in New Orleans the replacement could be as much as 118 per cent; other locations fell between these extremes.

Thompson also presented the idea that fish predators were probably beneficial, although he gave no data to back this assumption.

THE LAST TWENTY YEARS

With the death of Robert E. Richardson in 1935, the aquatic biology staff of the Illinois Natural History Survey was reduced to Thompson and one full-time field assistant; however, several graduate students were working under Thompson's direction. At that time, Thompson was interested in beginning some pond management investigations. As a result of a policy of expansion for the Section of Aquatic Biology, I was employed on January 1, 1938, to work with Thompson on ponds. To gather experience in a new censusing technique that involved poisoning fish with rotenone, a technique developed by R. W. Eschmeyer in Michigan, Thompson and I made a trip to Ann Arbor, where Eschmeyer was censusing several small Michigan lakes. We helped in one of the censusing operations and were served some of the poisoned fish at the home of Dr. Carl L. Hubbs.

Returning to Illinois, we (with the help of Donald F. Hansen) began censusing ponds, one of the first of which was Homewood Lake, a 2.8-acre pond on the property of the Homewood Fishing Club on the outskirts of Decatur, Illinois. From the standpoint of public relations, the operation was a huge success. The pond contained mostly carp, buffalo, giz-

zard shad, and stunted bluegills; all day, local sportsmen slipped through the underbrush to spy on the "fish killers," but, seeing few, or no, dead useful hook-and-line fish, they stayed to help us collect the outsized carp and buffalo.

Through the able assistance of Sam A. Parr, at that time Investigator for the Department of Conservation for Macon County, we were able to census 22 artificial lakes and ponds in central and southern Illinois. One of these ponds was Fork Lake, owned by Paul S. Smith (formerly Chief Inspector with the Department of Conservation), who gave us carte blanche use of the pond. These censuses, and the studies of the fish populations that replaced those poisoned in these ponds, led to the publication of three reports on lake management (Thompson & Bennett 1939*a*, 1939*b*, and Bennett, Thompson, & Parr 1940) and two articles of the *Bulletin*, "Management of Small Artificial Lakes" (Bennett 1943) and "The Bass-Bluegill Combination in a Small Artificial Lake" (Bennett 1948).

Censuses of the ponds, most of which were poor fishing waters, brought out the fact that overpopulation and stunting and/or large numbers of fish of undesirable species, rather than a lack of fish, were the causes of poor fishing. In fact, one of the poorest ponds for fishing was found to contain 1,145 pounds of fish per acre. At Fork Lake ("The Bass-Bluegill Combination in a Small Artificial Lake"), we attempted to crop heavily the largemouth bass and bluegills in this 1.4-acre pond; we used six fyke nets of 1-inch-mesh, set with leads to completely block off the pond into sections. When these nets were fished for 10 days each month from March to November of each year for 3 years, we discovered that we could not crop the bass because they refused to enter the nets, and the constant cropping of bluegills contributed to the well-being of both species. This discovery led to the belief that anglers had nothing to fear from commercial fishing operations.

In July of 1938 Hansen was given charge of the scale collections for studying age and growth of fishes and the task of investigating the fish populations of water supply reservoirs where fishing was an important secondary function to water

supply. At that time he was operating fyke nets at Lake Decatur and in other waters in order to gather material for a life history study of the white crappie (Hansen 1951).

In the late 1930's and the early 1940's federal agencies were engaged in construction projects under various work programs. The Natural History Survey was to benefit from these programs through the construction of a laboratory located on the Chautauqua National Wildlife Refuge, near Havana, and a laboratory and artificial lake in Fox Ridge State Park, near Charleston. The Havana laboratory, completed in early 1940, became the headquarters for waterfowl and fishery research on the Illinois and Mississippi rivers. The laboratory and lake in Fox Ridge State Park were completed in 1941 and became a center for studies on largemouth bass management.

About the same time the U. S. Forest Service constructed two lakes in the Shawnee National Forest in the southern part of Illinois. These were Pounds Hollow Lake, near Gibsonia, and Lake Glendale, near Dixon Springs; the latter has been used by the Natural History Survey as a study area since it was first stocked in 1940. Lake Glendale is located in a region of low soil fertility and is fairly typical of impoundments in forested lands. Hansen has found that the lake produces excessive populations of both bass and bluegills, and that fishing may be improved at intervals by the removal of part of the population of both of these species.

In 1942 Thompson and Hansen made a fish survey of the Illinois River from Channahon to the river mouth at Grafton. About 34,000 fish were studied, most of which were caught in hoop or fyke nets. Many of the carp in the upper part of the river (particularly at all stations above Henry) showed the knothhead abnormality which was an indication of gross pollution. At Channahon 94.8 per cent of the catch was composed of "rough" fish, most of them carp or goldfish. In contrast, at the Creve Coeur station below Peoria, 88.4 per cent of the fish taken were "fine" fish (most of them white crappies or black crappies) and only 6.0 per cent were "rough" fish.

In December, 1943, conservation representatives from the states of Illinois, Iowa, Missouri, Minnesota, and Wisconsin, from the United States Fish and Wildlife Service, and from other interested agencies met at Dubuque, Iowa, and formed the Upper Mississippi River Conservation Committee (Smith 1949). This group was organized for the purpose of sponsoring studies of the fishery and wildlife resources of the Mississippi River from Caruthersville, Missouri, to Hastings, Minnesota. The studies were designed to serve as a basis for making scientifically sound recommendations for the management of these resources (Barnickol & Starrett 1951:267).

Field operations in the Missouri-Illinois section were begun in March, 1944, with the Conservation Commission of Missouri, the Illinois Department of Conservation, and the Illinois Natural History Survey participating. A crew consisting of four men, working from the Natural History Survey's laboratory boat *Anax*, operated test nets and other types of fishing gear at 19 stations between Caruthersville, Missouri, and Warsaw, Illinois. Two years later, in 1946, field operations were resumed in the Iowa-Illinois part of the river with the Iowa Conservation Commission and the two Illinois agencies co-operating. The survey in 1944 was begun with Thompson in charge of the laboratory boat and Paul G. Barnickol as the chief fisheries investigator for Missouri. Thompson resigned from the Natural History Survey to go with the Forest Preserve District of Cook County, and in May, 1945, Barnickol was employed to replace him. Barnickol was in charge of the crew that covered the upper part of the river from Burlington to Dubuque in 1946. In May, 1948, Barnickol was recalled to Missouri to become Head of Fisheries Research for the Conservation Commission. At that time data from 2 years of field work on the Mississippi River were only partly analyzed.

On July 1, 1948, William C. Starrett began employment by the Natural History Survey for the difficult task of working over Mississippi River fishery data collected by others. In this he had the co-operation of Barnickol; their combined efforts resulted in publication of two articles of the Natural History Survey *Bulletin*: "Commercial and Sport Fishes of the Mississippi River Between Caruth-

ersville, Missouri, and Dubuque, Iowa" (Barnickol & Starrett 1951) and "Efficiency and Selectivity of Commercial Fishing Devices Used on the Mississippi River" (Starrett & Barnickol 1955). The first of these articles listed the fishes caught in the Mississippi River, their distribution, size range, growth rates, and other information on their biology. A total of 26,037 fish weighing 28,294 pounds were taken in 1944 and 1946. The second article presented a statistical study of the efficiency and selectivity of various types of gear used in the Mississippi River survey. The study was made for the purpose of furnishing information to those assigned the task of managing the river's commercial fishery. It included a consideration of seines, trammel nets, basket traps, wing nets, hoop nets, trap nets, and trot lines, the kinds of fish most commonly captured or trapped, the sizes of fish taken with various mesh sizes, and the comparative efficiency of several types of gear.

One of the interesting findings to come out of the Mississippi River survey was the collection of post-larval paddlefish, *Polyodon spathula* (Wal.), by Thompson and Barnickol. While minnow seining off a sand bar in the Mississippi near Cape Girardeau, Missouri, on May 29, 1944, the Thompson and Barnickol party took four paddlefish ranging in length from 17 to 26 mm. Other than the collection of seven paddlefish larvae (17-20 mm.) taken by Thompson in 1933 (Thompson 1933*b*); these are the only young paddlefish of less than 35 mm. in length known to have been collected.

These post-larval paddlefish and other paddlefish material were studied by R. Weldon Larimore (1949, 1950), who described the changes in the cranial nerves of the paddlefish accompanying development of the rostrum and gametogenesis of *Polyodon* and its relationship to practical regulation of the paddlefish fishery.

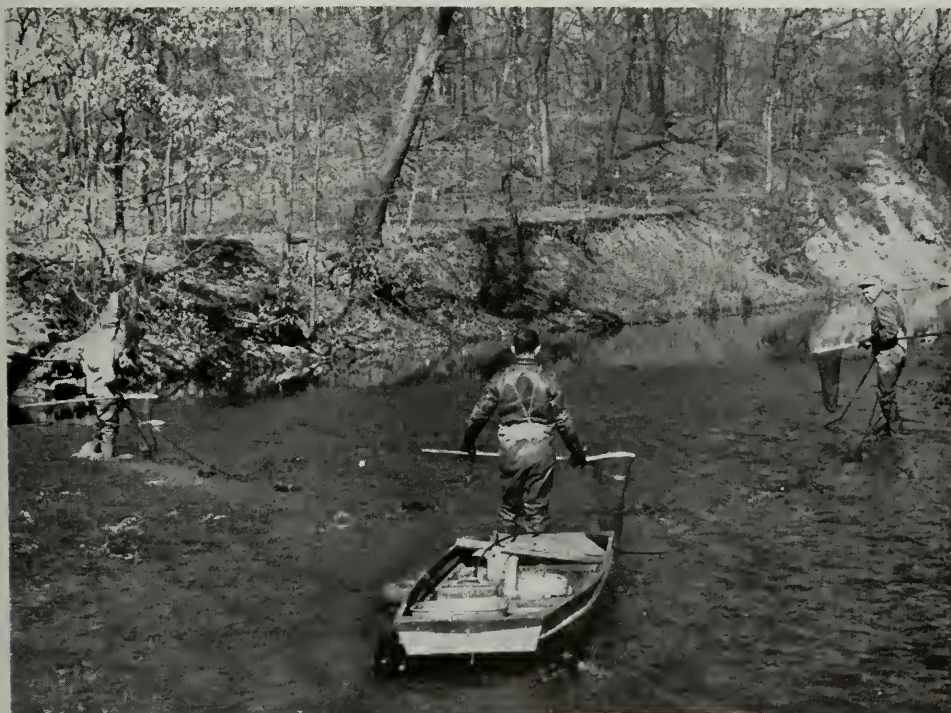
In 1948 Larimore was made a permanent member of the Aquatic Biology staff. He had already nearly completed a study on the life history and ecology of the warmouth, *Chaenobryttus gulosus* (Cuvier), a fish that was being considered as a possible companion species for largemouth bass in ponds. This study of

the warmouth was later published as an article of the Natural History Survey *Bulletin* (Larimore 1957).

During the summer of 1950 Larimore, with the help of Leonard Durham and others, began an intensive investigation of the fishes in Jordan Creek, a small spring-fed, upland stream in Vermilion County. This project marked the beginning of upland stream investigations as a continuous program of the Section of Aquatic Biology. Through the use of the electric seine and other special equipment developed for stream work, it has been possible to make both intensive and extensive studies on the ecology of stream fishes in the central Illinois region (Larimore, Pickering, & Durham 1952). The smallmouth bass, *Micropterus dolomieu* Lacépède, was found to be the most important anglers' fish in these streams. The fry of this bass were particularly vulnerable to floods on streams when the floods were accompanied by sudden changes in water temperatures. The adult

bass showed well-developed homing instincts as did some other species (Larimore 1952). Tests of the value of planting 6- to 8-inch smallmouths in a stream already containing a population of smallmouth bass demonstrated that it was possible to build up numbers of these fish only temporarily. Minnows removed from a stream with an electric seine were replaced by other minnows through migration and reproduction within a period of a few months (Larimore 1955). Apparently streams are quickly repopulated even when fish are killed by drought conditions, heavy winter ice, or temporary severe pollution.

In studies of ponds and lakes, by 1945 evidence had accumulated to substantiate the idea that a lack of fish predators was an important problem to be faced in the management of these waters. Obviously, fishing was no substitute for natural predation, and much of the task of the fish manager was that of functioning as a predator of small fishes (Bennett 1947).



Fisheries technicians of the Illinois Natural History Survey using fish shocker for sampling the population of a stream. The shocker is a recent development that has been used successfully in both streams and lakes.

Studies on the effects of fish predators were begun with the placing of six short-nosed gars in a 1-acre pond containing bass and bluegills; in this pond, bluegills were constantly in a state of overpopulation. Because the short-nosed gars were unable to reproduce in the pond, their numbers were easily controlled. From this experiment, Durham (1955) expanded the investigations of fish predation to include about a dozen additional ponds containing populations of stunted fish. Using gars and cormorants as predators, he was able to show improvement in growth and size of fish and an improvement in the survival rate of naturally produced bass.

Ten years of recording catches of fishermen at Ridge Lake (Bennett 1954a) gave a yield figure of more than 11,000 largemouth bass following an original stocking of 435; the fact that, in the last 6 years of the 10, 155,000 bluegills had been removed following an original stocking of 129 of these fish indicated that the bluegills were not only more prolific but showed a higher survival rate than the bass. The annual hook-and-line yield of bass varied between 10.9 and 30 pounds per acre, although the lake was not considered a highly fertile one. During this time the standing crop of bass varied between 30 and 50 pounds per acre. The success of a bass spawn (and survival) was negatively correlated with the numbers of yearling fish present in the lake, particularly yearling bluegills. Young bass surviving to post schooling fry stage had about 1 chance in 35 of living to reach a size of 7 to 10 inches; natural mortality remained relatively high until the fish reached an average weight of 0.75 pound; then it dropped to less than 5 per cent per year until fish reached ages of 7 to 8 years, when the natural death rate again became high. With the system followed at Ridge Lake of culling the fish population at intervals of 2 years, the average length of bass at the end of the first growing season was 7.5 inches, at the end of the second growing season 10.8 inches, and at the end of the third 13.0 inches. The single most important finding at Ridge Lake was that a large new year class of bass could be produced at any spawning season by reducing the

numbers of small bluegills in the lake prior to the spawning period. This reduction could come about through artificial culling of the fish population, or, as was later discovered, through concentrating the fish during the fall months preceding the bass spawning season by releasing a large proportion of the water from the lake and then allowing the lake to refill over winter. Studies of the effects of these water releases, or draw-downs, were begun in 1951 (Bennett 1954b) and they are still in progress.

Swingle & Smith (1942), working on fishes in Alabama ponds, built their management practices around a program of pond fertilization; they recommended fertilization for ponds in other parts of the country. In order to test the usefulness of fertilization as a pond management technique in Illinois, Donald F. Hansen began a testing program in ponds located on the University of Illinois Experimental Farm near Dixon Springs in southern Illinois, where soils are as poor as any within the state. After 7 years of fertilizing three ponds at various rates with complete fertilizers and using three other similar but unfertilized ponds for controls, Hansen concluded that the improvement in fishing did not justify the cost of the fertilizer, if fish were cropped by hook-and-line. The unfertilized or control ponds furnished better bass fishing than the fertilized ponds. Bluegills could be caught at a more rapid rate in the fertilized ponds, and the fish averaged larger in size. In terms of extra fish flesh produced by the fertilizer, the improved fishing cost about \$1.00 per pound of fish.

Tests on various combinations of fishes in ponds have been going on for many years (Bennett 1952). The combinations used include largemouth bass-bluegill; largemouth bass-bluegill-warmouth-black bullhead; largemouth bass-bluegill-warmouth-channel catfish; largemouth bass-golden shiner; largemouth bass-redear; largemouth bass-warmouth; largemouth bass-short-nosed gar; largemouth bass-bluegill-short-nosed gar; smallmouth bass alone; and largemouth bass alone. No combination appeared to be ideal, although several combinations proved to be as productive of good fishing as the highly ad-

vertised largemouth bass-bluegill combination.

Redear sunfish, *Lepomis microlophus* (Gunther), were not reported from Illinois prior to 1945. In that year Dr. C. L. Schloemer, then located at Denton, Texas, sent a small number of adult redears to the Natural History Survey at Urbana. These fish were placed in several ponds near Urbana, but none apparently survived the winter of 1945-46. In the spring of 1946 Dr. William E. Ricker, then located at Bloomington, Indiana, furnished 30 large adult redears from central Indiana. These fish were planted in several locations; 12 were placed in a stripmine pond, near Danville, that contained largemouth bass. The redears in the stripmine pond multiplied very successfully and were the source for introductions into many lakes and ponds scattered through central and southern Illinois. Redears are now present in tributaries of the Illinois River (particularly the Sangamon) and in the Wabash drainage along the eastern border of the state, as well as in the Big Muddy system of southern Illinois. As far as is known, all of these fish originated from the 12 fish released in the pond near Danville.

In 1949 Starrett was placed in charge of the Natural History Survey laboratory at Havana, where he began a study of Lake Chautauqua, a shallow flood plain lake of some 3,000 acres belonging to the U. S. Fish and Wildlife Service and used principally as a waterfowl refuge. This lake was fairly typical of other areas in the Illinois valley that had been leveed to keep out the river, pumped dry so that they could be used for farming, and later flooded. We wondered about comparative over-all values of these areas for recreation (duck hunting and sport fishing), fish production (commercial fishes), fur production (native furbearers), and timber production (wood pulp), as contrasted with values of these areas for corn production that required government help in the construction and maintenance of levees, pumping costs and equipment, and support of corn prices. In spite of the fact that recreational values are often intangible, it soon became evident that the value of this area for fishing and recreational

activities by people in the nearby industrial towns of Pekin and Peoria were much greater than the value of the corn the lake bottom would produce if the lake were drained (Starrett & McNeil 1952). In addition to studies in recreational values, Starrett has made intensive studies of the fish and bottom fauna of Chautauqua and similar lakes, and the physical, chemical, and biological factors which influence them. Through the assistance of biologists from the Illinois Department of Conservation he has collected annual commercial fishing statistics on all of the large Illinois rivers and information on native lamprey distribution.

In many of our operations during the past 20 years we have had the co-operation of the Illinois Department of Conservation: in pond management studies, stream investigations, surveys of the fishes of large rivers, and statistical studies on yields of commercial fishes. Sometimes this assistance has been in the form of funds for construction works or for physical equipment, sometimes for half-time or full-time assistants; occasionally personnel of the Department have participated in operations requiring many men for a short period of time. This co-operation has not been based on written agreement; rather, it has come about through an understanding of mutual needs and interests by certain personnel of the Department, particularly Sam A. Parr, formerly Investigator, Inspector, and Superintendent of Fisheries, now Administrative Assistant to the Director of Conservation; and William J. Harth, recently made Superintendent of Fisheries. We are grateful for this assistance and co-operation.

DIRECTION OF FUTURE STUDIES

In looking toward the future we find that some lines of research are taking shape now and others are still in the planning stages.

One program that was begun in the spring of 1958 centers on a study of such basic concepts of fish management as carrying capacity and standing crop, as well as the effects of cropping and

stocking on populations of fishes. This work is centered at the Fin 'n' Feather Club near Dundee.

At the Eighteenth North American Wildlife Conference held in Washington, D. C., in 1953, Max McGraw, President of the North American Wildlife Foundation, suggested the development of a fisheries research unit at the Fin 'n' Feather Club. It was agreed that the McGraw Foundation (with the assistance of the Illinois Department of Conservation) would develop a research unit of at least 15 1-acre ponds and provide space for laboratory and offices in the Fin 'n' Feather Lodge. When this would be accomplished, the laboratory and pond unit would be assigned to the North American Wildlife Foundation, which in turn would assign the use of the facility to the Illinois Natural History Survey and the Illinois Department of Conservation for fisheries research. Some progress had been made in physical plant construction by 1956, and on February 1 of that year David Homer Buck was employed by the Natural History Survey to give immediate supervision to the project. Soon after, Maurice A. Whitacre, biologist with the Department of Conservation, was assigned to this program to work with Dr. Buck. At the beginning of the 1958 season 11 ponds were ready for use. Eight other ponds are in various stages of construction, and as these are completed they will be stocked and added to the units in operation.

A second program, already begun, has to do with studies of the biochemistry of fishes. A chemical laboratory was developed in conjunction with the aquarium laboratories in the Natural Resources Building at Urbana, and Robert C. Hiltibran was employed on May 1, 1957, to begin biochemical investigations. Hiltibran was forced to pioneer in this field because little research had been done on fish biochemistry. He has begun by studying the "normal" enzyme systems of the bluegill, *Lepomis macrochirus* Rafinesque. Once the "normal" enzyme systems are known, Hiltibran will measure the action of various chemicals on these

systems: waste products from commercial chemical processes and substances applied to aquatic areas for the control of noxious animals and plants. From these studies he may be able to suggest methods of reducing the toxicity of these chemicals to fishes and other aquatic organisms.

Prior to 1934 Wilbur M. Luce (now Professor of Zoology, University of Illinois) and David H. Thompson developed a method for stripping and fertilizing sunfish eggs, which they used to produce hybrids between species of these centrarchids. Luce raised many of these sunfish to maturity, and Thompson recognized that two of the hybrids were similar to fish pictured by Forbes & Richardson (1908) as being valid species. Recently we have revived the technique of artificial insemination of sunfish eggs in order to explore the possibility of developing hybrids for use in fish management. In 1957 William F. Childers produced viable fry from all possible combinations of crosses of bluegills, redears, green sunfish, and warmouths. Some of these combinations appear to be superior to parent types.

It is probable that within the next few decades great advances will be made in the management of fish populations for sport and commercial uses. Research basic to this management may lead to the discovery of ecological factors which control the expansion of populations of important sport species, such factors as have already been found for the largemouth and smallmouth basses. Adjustments of these factors may be, to some extent, applicable to most natural waters, but they probably will be more practical in artificial waters and in controllable natural waters. It seems reasonable to assume that progress will be made in environment control until waters can be made to produce crops of selected plants and animals much as terrestrial habitats can be made to produce wheat, rice, swine, and cattle. The development of water management may not only give ways to control the kinds and numbers of fishes but also to control the individual steps in the food chains of fishes.

Wildlife Research

THOMAS G. SCOTT

WILDLIFE was high on the scale of human values during the period of discovery and initial settlement in Illinois. When the Illinois Natural History Society was founded in 1858, most Illinoisans were self-reliant farmers who measured values in terms of the length of fences constructed, the acreage of cleared forest land, the acreage of land under cultivation, and the extent of drainage programs, roadways, and railroads. The Illinois Central Railroad line from Chicago to the junction of the Ohio and Mississippi rivers had been completed only 2 years earlier. Representative of the period are the reflections of Benjamin F. Johnson, chairman of a committee for the examination of farms and nurseries for the Illinois State Agricultural Society. In reporting on improvements in "northern Illinois" following inspections in 1859 by the committee, Johnson (1861:84) undoubtedly impressed members of the Society when he stated that

the progress of improvement in this portion of Illinois is little less than wonderful. Ten years ago much of the country was wild, open prairie; now there is scarcely a rood of uninclosed land, except portions of the timber along the rivers and streams.

Today one cannot help but ponder why there weren't a few rebels hardy enough to stand against the surge of progress and insist that Illinois, the settlers' "prairie state," set aside a prairie park or primitive forest for future generations.

The loss of primitive areas and much of what went with them was accepted as inevitable. Even Dr. Stephen A. Forbes (1912*b*:40), a giant among the naturalists of the time, pointed out that the reduction and elimination of wildlife through settlement of Illinois by white man

has evidently been a perfectly natural and inevitable one—as much so as the flow of the tide in the wake of the revolving moon—and immensely advantageous, also, from every point of view except that of the inadequate, incompetent and ill-adapted population which it [settlement] has reduced or suppressed.

Dr. Theodore H. Frison (1938:19), who knew and understood Forbes as well as anyone, quoted the above statement as representative of the philosophy of 1912.

DEVELOPMENT

Wildlife research, as it is recognized today, first became evident in the annals of the Natural History Survey in the late 1870's when Forbes initiated his investigation of the food of birds. O. B. Galusha (1881:238) provided insight into the conception of this research when, following Forbes' presentation of a paper on the food of meadowlarks at the January, 1881, meeting of the Horticultural Society of Northern Illinois, he observed

that when a few of us, six years ago, met in the Normal University, as a committee of the State Horticultural Society, to inaugurate the enterprise, I had serious fears that the work was too great for accomplishment.

These studies accompanied and probably assisted in the accomplishment of the reorganization which converted the Illinois Museum of Natural History into a State Laboratory of Natural History on July 1, 1877. The reorganization was accompanied by a new conception of purpose, relieving the members of the staff of the preparation of museum displays and allowing them to concentrate on research. Although I have been unable to uncover direct evidence of it, I feel certain that the change was manipulated by Forbes and members of the Illinois State Horticultural Society. Of legislative action approved May 29, 1879, to become effective July 1, 1879, Forbes (1880*f*:1) generously reported:

We were also directed to investigate the large and intricate subject of the food of birds, in the interests of agriculture and horticulture, \$200 per annum being voted for the expenses of this work.

Forbes' research on the food of birds was to become one of the outstanding contributions to avian biology. This research

provides us with further insight into the motivations of the man who guided the program of the Natural History Survey and its parent organizations for many years (1872-1930). I have come to believe that wildlife research made such an auspicious start in the Survey program not only because of Forbes' professional qualifications but also because of his intense desire to contribute to knowledge relating to human economy and welfare. W. L. McAtee (1917:249) believed that F. E. L. Beal and Forbes were "the founders of the scientific method of studying the economic value of birds." *Birds in Their Relations to Man* (Weed & Dearborn 1903) is inscribed "To Stephen Alfred Forbes . . . whose classic studies of the economic relations of birds will long remain the model for later students."

In an early report Forbes (1882a:1) advised:

The work of the State Laboratory of Natural History . . . is essentially that of a zoological and botanical survey of the State, conducted with principal reference to economic questions, and to the interests of public education.

Although economic consideration constituted a principal responsibility, such a responsibility is adequately met only when men are willing to meet it and are capable of meeting it. If the desire had not been there, it seems likely that Forbes and his associates would have been content to occupy themselves with the systematics and descriptive records of the native flora and fauna, and wildlife research would have had to find its beginning at a much later date. I marvel at the courage of Forbes' convictions when I consider the statement of Robert Ridgway (1901:1), a close associate of Forbes, on a prevailing attitude of the day:

There are two essentially different kinds of ornithology: *systematic* or *scientific*, and *popular*. The former deals with the structure and classification of birds, their synonymies and technical descriptions. The latter treats of their habits, songs, nesting, and other facts pertaining to their life-histories. . . . Popular ornithology is the more entertaining, with its savor of the wildwood, green fields, the riverside and seashore, bird songs, and the many fascinating things connected with out-of-door Nature. But systematic ornithology, being a component part of biology—the science of life—is the more instructive and therefore more important.

It is unfortunate that Forbes' responsibilities were such that he could not have devoted more time to wildlife research, for he seems to have possessed an understanding of wildlife biology which was much in advance of his time. In a single early paper (Forbes 1880a), a number of observations were made which, by their earliness, seem prophetic of views which are credited to relatively recent times. Current beliefs on predation may be seen in "*the annihilation of all the established 'enemies' of a species would, as a rule, have no effect to increase its final average numbers*" (Forbes 1880a:11).

Forbes (1880a:8) recognized a need for an understanding of animal populations long before they received serious study. Of this he wrote:

Our problem is, therefore, to determine how these innumerable small oscillations, due to imperfect adjustment, are usually kept within bounds—to discover the forces and laws which tend to prevent either inordinate increase or decrease of any species, and also those by which widely oscillating species are brought into subjection and reduced to a condition of prosperous uniformity.

It is apparent that this view implies population management in the modern sense. Further implications of management may be seen in the following statement by Forbes (1880a:4):

It is also plain that if man understands clearly the disorders which arise in the system of Nature as a result of the rapid progressive changes in his own condition and activities, and understands also the processes of Nature which tend to lessen and remove these disorders, he may, by his own intelligent interference, often avoid or greatly mitigate the evils of his situation, as well as hasten their remedy and removal.

Forbes (1880a:9) seems to have been well on the way toward an understanding of density dependent factors as used by today's students of animal populations, as well as modern views on predation, when he wrote: "The fact of survival is therefore usually sufficient evidence of a fairly complete adjustment of the rate of reproduction to the drains upon the species." That his understanding of the effect of density dependent factors on animal populations was astonishingly well advanced is evident in his (Forbes 1882b:122) reasoning that excessive populations are, "in one way or another, self-

limiting." Earlier he (Forbes 1880a:5) had written that "as a general rule, the rate of reproduction is in inverse ratio to the grade of individual development and activity; . . ." The "grade of individual development and activity" refers to the degree of evolutionary progress from a primitive form. Forbes (1880a:11) seems to have been grasping at the role of density independent factors in population control when he observed that the "real and final limits of a species are the *inorganic* features of its environment,—soil, climate, seasonal peculiarities, and the like."

What is today recognized as wildlife research continued to develop under Forbes' guidance in the form of bird censuses. The results of these censuses are classics in American ornithology. They constituted the first extensive, quantitative investigations of bird numbers, or of any wildlife population for that matter, and introduced a census technique.

Despite Forbes' modern views, there is little evidence that he promoted wildlife management to any great extent. The thinking of Forbes (1912b:40) with respect to game management, despite earlier, more promising views, seems to have been limited to the encouragement of restrictive laws, as evidenced by the following: "Our resident game birds would all have been gone long ago if it had not been for the restraints of law put upon the activities of the hunter . . ." Forbes (1912b:46) made a plea for the Illinois Academy of Science to support by resolution the "Anthony bill" (Migratory Bird Act of 1913), then under consideration in the House of Representatives. It should be remembered that legal protection was virtually the only management concept of the times.

ORGANIZATION

Game research in the modern sense began to receive recognition in the Natural History Survey's program in the early 1930's. Probably stimulation was received from the federal government's emphasis on conservation of natural resources, an emphasis that accompanied the search for work during that period of national economic emergency, and from

the influence of Herbert L. Stoddard (1931) and Aldo Leopold (1931, 1933). By that time, progressive leaders in the field realized that restrictive regulations and game farms were not meeting wildlife management needs. Also, it had become apparent that game populations could be managed wisely only when management practices were based on a fund of pertinent and precise knowledge. Frison, who became Acting Chief of the Illinois Natural History Survey upon Forbes' death on March 13, 1930, and then Chief on July 1, 1931, was among these leaders. An enthusiastic hunter, Frison had a consuming interest in game management. Wildlife research was recognized in the organizational structure of the Natural History Survey for the first time when Frison (1938:31) established a Section of Game Research and Management on July 1, 1934. Dr. Ralph E. Yeatter, one of the nation's first game specialists, was employed in this section.

Frison initiated formation of the now well-established Midwest Wildlife Conference, and the first meeting was held in Urbana on December 5, 6, and 7, 1935. This meeting, known as the North Central States Fish and Game Conference, was the first regional conference of wildlife technicians in the United States. Frison (1938:27) described the conference as

essentially a fish and game clinic at which scientists from all the north-central states, without being dominated by administrators or the political type of conservationists, freely discussed wildlife management practices in an effort to winnow out the chaff from the wheat, to coordinate such researches and to orientate scientific studies of wildlife resources in such a way that demonstrable sound management practices would result.

By 1936 Frison (1938:31) had concluded that experimental wildlife areas were needed for the purpose of testing management theories under practical conditions, a need which has still not been adequately met. A Section of Wildlife Experimental Areas was listed on the staff page of the *Bulletin* from March, 1938, to September, 1945. On June 1, 1938, a special program dealing with forest problems in game management was undertaken by Dr. Lee E. Yeager, who had joined the staff in the Section of Forestry,

Following passage of the Federal Aid in Wildlife Restoration Act in 1937, Frison undertook to arrange a co-operative wildlife research program with the Illinois Department of Conservation and the United States Bureau of Biological Survey (now the U. S. Bureau of Sport Fisheries and Wildlife). The first co-operative project, "Illinois Fur Animal Resources Survey," with Louis G. Brown as leader, was approved on May 23, 1939 (Frison 1940:8-9). In 1940 a Cooperative Wildlife Restoration Program, embracing interagency co-operation in Federal Aid, was listed on the staff page on the section level. Of this program Frison (1940:8) recorded: "General program planning and supervision of projects dealing with wildlife research have been assigned to the Chief and various other members of the scientific staff of the Illinois Natural History Survey." In evidence of its success this co-operative arrangement has survived through the years, and in 1956 the Conservation Advisory Board (Mann 1956:6) included, in a statement of policies, provisions for the development of an adequate game research program "through cooperation with and support of the Illinois Natural History Survey Division."

Thus, by 1940 Frison had stimulated and obtained support for a wildlife research program which involved the primary activity of four sections within the Natural History Survey's organizational structure. This compartment of the work was believed by those who knew Frison to have grown out of his extreme interest in wildlife resources and his desire to give each facet of study his personal direction.

There was little change in the wildlife research program while Dr. Leo R. Teton served as Acting Chief, December 10, 1945, through February 28, 1947, following Frison's death on December 9, 1945.

Dr. Harlow B. Mills, who became Chief on March 1, 1947, proved to have the same consuming interest in wildlife research which had marked Frison's leadership. In August, 1947, the Cooperative Wildlife Restoration Program was more properly designated Cooperative Wildlife Research, and a Section of Migratory Waterfowl was added to the organiza-

tion. The latter section had been discontinued by June, 1948.

Dr. Thomas G. Scott was appointed the Head of the Section of Game Research and Management on January 1, 1950. He was the first person to bear this title. Soon after that date, arrangements were made for formal co-operation in wildlife research between the Natural History Survey and Southern Illinois University, where Dr. Willard D. Klimstra was guiding the program in wildlife research and education. That part of the Survey's organizational structure, Cooperative Wildlife Research, which embraced the Federal Aid research, was dropped, and the personnel and administrative responsibilities of this program were transferred to the Section of Game Research and Management in March, 1950. On September 1, 1954, the Section of Forestry was abolished, and all of its wildlife activities and personnel transferred to the Section of Game Research and Management. Thus, by 1954 all wildlife research had been assigned to one section. The name of the section was more appropriately designated the Section of Wildlife Research on May 1, 1956. The area of research assigned to the section was similar to that of its predecessors: the biology of warm-blooded vertebrates except that associated with taxonomy and classification. In 1956 the extensive activities of the section were divided and were assigned to branches to provide for more effective supervision. The new branches were Nongame Birds, Upland Game Birds, Migratory Game Birds, Mammals, Co-operative Wildlife Research, and Environmental Research.

As the first century of the Illinois Natural History Survey ends, interest in wildlife resources of Illinois and other parts of the United States is greater than ever before. The number of people engaged in the wildlife management profession is at an all-time high and promises to go higher. Frison's North Central States Fish and Game Conference has so grown in attendance and extent of interest that its facilities no longer seem to meet the needs seen at the outset. As a consequence, there is a tendency for specialists to draw apart in committees or "councils." Some of those who look

into the future to a greatly increased human population and a more intensive land-use program seem to be returning to Forbes' "let's face the inevitable" philosophy of 1912. They seem willing to stand by while part of our wildlife heritage, the prairie chicken, for example, goes down the drain. Foreign game birds are being feverishly investigated and released with the hope of finding species which will supplement populations of native game birds being reduced by a changing habitat. In anticipation of the time when shootable wild game populations will no longer meet the demand, there are the programs for pen-rearing game birds to be released under the gun. The rooting out of osage orange hedges throughout the state is symbolic of the cancerous-like growth in activities designed to bring increasing amounts of land into agricultural, residential, or industrial use. Public realization of the vital importance of habitat in the management of a wildlife resource is showing growth; however, the area of desirable wildlife habitat, especially that for upland species, is continuing to shrink. Thus, the most perplexing problem of the wildlife manager in Illinois today is that of developing and protecting suitable habitat.

RESEARCH CONTRIBUTIONS

A review of outstanding contributions made to wildlife biology and conservation by employees of the Illinois Natural History Survey and its parent organizations will aid understanding of work in these fields during the first 100 years. A few publications by non-Survey personnel are cited to provide perspective or to recognize Survey publications by workers who were not employed by the Survey.

Birds

Contributions on the biology and conservation of birds may be conveniently grouped into three classes: those for non-game, those for upland game, and those for migratory game birds.

Nongame Birds.—Of the meadowlark, Forbes (1881*b*:234-5) wrote:

He is first cousin to the Indian, the prairie-wolf and the badger, but with a better knack

than they at adapting himself to the new life of civilization. He is a perfect reflection of his most constant surroundings—with a bosom of prairie butter-cups, a back like the dead grass of autumn, and a song that harmonizes well with the whistling of prairie winds.

This colorful description reveals something of Forbes' deep feeling for birds. Sentiment, however, is not evident in his systematic and painstakingly conservative evaluations of the place of birds in an economic scheme of things.

Forbes' research on the food of birds constituted a milestone in ornithological history. "No part of the recent work of the Laboratory has excited a wider interest than that relating to the food of birds" (Forbes 1880*f*:7). This work established Forbes among contemporary ornithologists as the ranking authority on the insect food of birds. Dr. Elliott Coues (1883:105) believed him to be "Our best authority upon the insect food of birds . . ." Drs. Clarence M. Weed and Ned Dearborn (1903:19-20) considered Forbes' publications on the food of birds to be "classic papers" and "the basis for the modern development of economic ornithology."

The findings of Forbes' studies of the food of birds appeared in a number of papers. The most substantial contributions, however, were brought together in two papers (Forbes 1880*d*, 1883*a*). The first dealt with the food of certain birds in the families Mimidae and Turdidae. The second reported observations on the regulative action of birds feeding on an excessively high population of cankerworms and vine leaf chafers. The latter paper, "The Regulative Action of Birds Upon Insect Oscillations," was approved by Indiana University in fulfillment of Forbes' thesis requirements for the Ph.D. degree granted in 1884 (letter of May 2, 1952, from E. Lingle Craig, Reference Librarian, Indiana University, to Marguerite Simmons, Librarian, Illinois Natural History Survey). Of lesser importance were notes on the food of the meadowlark (Forbes 1881*b*), the English sparrow (Forbes 1881*c*), and the kinglets (Forbes 1883*d*).

The scope of these investigations may be seen in the following report (Forbes 1882*a*:5-6):

The collection designed to illustrate the food of birds has been more than doubled in the last two years, and now numbers over six thousand stomachs, representing about two hundred species. Eight hundred and eighty of these have now been exhaustively studied,...

Unfortunately, the analyses were apparently discontinued at this point, for there were no more publications on the food of birds, and the annual reports of the State Laboratory of Natural History indicate that nothing further on this subject was done.

Forbes' evaluations of his findings on the food of birds indicated awareness of the need for giving special consideration to the high mobility of birds, food preferences, density effects, ability to diversify diet, and the importance of seasons, geographic location, and specific ecological circumstances. Forbes (1880*e*:122-3) described what appears to have been a new method of evaluating proportions of food in the stomachs and crops of birds, a technique which is used yet today. He (Forbes 1881*a*:107) also showed himself to be aware of the importance of sample size and made crude tests for significance by comparing the results of analyses of small samples with those of larger samples to determine whether there were important departures in the pattern of the diet.

Because Forbes believed that the numbers and kinds of birds in specific habitat categories needed to be known before their economic importance could be evaluated, he encouraged studies based on systematic censuses, which were carried out in 1906, 1907, 1908, and 1909. These studies are classics in American ornithology and introduce a new censusing technique for birds. I believe them to be the first extensive statistical analyses of bird populations in this country. Although the results of these surveys are presented in six papers, two of them contain most of the data (Forbes & Gross 1922, 1923). Unfortunately, a final paper in which it was hoped to present all of the findings for each species was never published. Plans for this paper are described (Forbes & Gross 1923:397) as follows:

It has been our general plan to work at first with broad strokes of the full brush, refining upon our neutral background by degrees and ending, as we hope to do in a paper follow-

ing the present one, with the final details for each species taken up separately and followed all over the state and around the year.

Forbes' experience with plankton surveys guided him in the development of the census technique devised specifically for the bird surveys (Forbes & Gross 1921:1). Forbes believed that two men walking abreast could identify and count all of the birds flushed by them or crossing their track on a strip 150 feet wide in relatively open country but 60 feet wide in heavier cover, such as orchards, open woods, and patches of close shrubbery. This census technique was pictured (Forbes & Gross 1921:1) as a

huge net a hundred and fifty feet wide, drawn in straight lines across every kind of crop or other surface vegetation, by which all the birds found there should be caught and held until they had been identified and counted.

Results were obtained by application of this census technique during the summers of 1907 and 1909 (Forbes & Gross 1922:189, 199); the census indicated an average of 852 birds per square mile for the state as a whole. The numbers of birds per square mile showed a striking increase of 54 per cent from the 1907 figure to that of 1909. Orchards were found to have the greatest numbers of birds per square mile, 3,943; yards and gardens were a close second with 3,418. The statewide number of birds per square mile in winter was estimated from data collected in 1906 and 1907 to have been 520 (Forbes & Gross 1923:398).

Dr. Frank Smith (1930) prepared a thorough and useful paper dealing with a chronology of the spring migration of 221 species of birds through Urbana from 1903 through 1922. The objective of the study was to determine whether there was a correlation between migration flights of spring migrants and certain kinds of weather. Smith (1930:112) concluded:

A careful study of the weather maps during the time when records were being made revealed that the greatest migratory activity in spring occurred at times when the weather maps showed an area of low barometric pressure approaching from the west, with the south winds and rising temperatures which normally accompany such movements.

The monograph by Dr. Alfred O. Gross (1921) on the dickcissel must be

classified as one of the outstanding early studies of its kind. I was especially impressed by his statistical evaluation of the abundance of the bird in relationship to

habitat categories. He found that hayfields constituted preferred habitat; within this classification, clover and alfalfa were preferred to other kinds of hayfields



Ornithologists in winter equipment ready to set out on a collecting expedition for the Illinois State Laboratory of Natural History, about 1906. At the right is Alfred O. Gross, and with him is Howard A. Ray.

available at the time. Perhaps it is also appropriate to mention the paper by W. E. Loucks (1894) on the prothonotary warbler. While the paper is unfortunately more subjective than objective, it constitutes a colorful record of the findings of a talented observer.

The participation of the Natural History Survey staff in the effort to obtain legal protection for all hawks and owls in Illinois merits attention. At the urging of Dr. David H. Thompson, Director Ralph Bradford of the Illinois Department of Conservation sought and obtained legislation, effective July 1, 1929, to protect all hawks and owls except the great horned owl, the goshawk, sharp-shinned hawk, Cooper's hawk, duck hawk, and pigeon hawk.

Members of the Natural History Survey staff continued to advocate protection of hawks and owls, and, effective July 1, 1941, protection was obtained for all but the great horned owl. This condition prevailed until July 1, 1947, when, for some unexplained reason, the Cooper's and sharp-shinned hawks were removed from the protected list. In 1956 and 1957 a new effort, spearheaded by Elton Fawks, representing the Illinois Audubon Society, was made to obtain protection for all hawks and owls. I presented a paper at the annual meeting of the Natural Resources Council of Illinois on October 20, 1956; this paper has been credited with having much to do with winning the support of the Council and member clubs for the needed legislation (Fawks 1957:1). I read a second paper at the annual meeting of the Illinois Audubon Society in Rockford on May 18, 1957, at the time the bill was before the legislature (Bayless 1957:3), and I made an appeal for further support in the official publication of the Illinois Federation of Sportsmen's Clubs (Scott 1957). Dr. Richard R. Graber assisted this effort by analyzing data on hawk and owl numbers reported in the Christmas counts of the Illinois Audubon Society for the past 50 years and by demonstrating that some species had declined in numbers and that there was no evidence of need for measures designed to reduce hawk and owl populations. The bill proposed for the protection of hawks and owls, House Bill No.

1063, included protection also for the crow, blue jay, cowbird, and grackle by the time it had passed the General Assembly, June 27, 1957, and was signed into law by Governor William G. Stratton, July 8, 1957 (Illinois General Assembly 1957:1937-8). The bill provided for amending Section 21 of the Game Code to define all hawks and owls as protected species but, as a consequence of an oversight, Section 36 of the Code was not amended to include the Cooper's hawk, the sharp-shinned hawk, and the great horned owl among the hawks and owls which were unlawful to have in possession at any time.

The Prairie Chicken.—If the Illinois farmer of the 1860's had taken time from his backbreaking work to sit down and figure out the cause of the enormous populations of prairie chickens which he alternately cursed and blessed, perhaps he would have seen that he had just completed a gigantic habitat development project for upland game birds. He had extended the range of the chicken by clearing the timberland, and he had provided thousands of food patches by establishing grainfields.

From these high populations, the prairie chickens declined in numbers with the gradual increase in grain farming and the accompanying reduction of grassland. The hunting season on prairie chickens was closed in 1903 and was not opened again until 1911. The relaxation of hunting regulations at this time undoubtedly followed an increase in the population, probably associated with "The Indiana 'Comeback' of 1912" (Leopold 1931:172). Contemporary data for Illinois had apparently not been called to Leopold's attention because Forbes (1912b:47-8), reported that

prairie-hens—thanks to our protective laws—are now to be seen in at least seventy-four counties, so abundantly in some that farmers are beginning to protest against their further increase because of the amount of grain which they devour.

The records on which this statement is based remain in the files of the Illinois Natural History Survey. Re-examination of them brings out the conservativeness of Forbes, for they indicate that the reporting observers had found a few prairie

chickens in all of Illinois' 102 counties except 10 (Yeatter 1957:8). Despite an exaggerated confidence in protective regulations, Forbes (1912b:48) recognized the basic environmental factor which was limiting the prairie chicken population because he advised that:

The very country in which it was formerly most numerous—that is, the open prairie—is now least favorable to it because of the agricultural operations, which disturb and destroy it during its breeding season.

When it again became evident that the prairie chicken population was endangered, Director Bradford of the Department of Conservation, at the urging of Dr. Thompson of the Natural History Survey, obtained legislation, effective July 1, 1933, to prohibit the taking of the prairie chicken at any time. No open season on this bird has been permitted since that date.

It seems fitting that, with the upsurge of interest in wildlife conservation in the 1930's, one of the first comprehensive studies of a game species to be undertaken in Illinois was concerned with the prairie chicken. The valuable monograph (Yeatter 1943) resulting from this study includes data on early distribution, range, life history, populations, mortality causes, food habits, and management. I believe that this publication was the first to direct attention to the importance of grass-seed farming in the management of prairie chickens. Yeatter (1943:409) advised that areas harboring a few prairie chickens

might be converted into good chicken range by leasing, and converting to refuges for a term of years, 25 per cent of the total land in the form of 20-acre, 40-acre or larger tracts of the poorer farm soil throughout each township.

In a later publication Yeatter (1957:8) revised his recommendation on grassland refuges to a minimum of 40 acres in each square mile of farm land.

When unusually large numbers of young prairie chickens were found dead on a study area in Jasper County in 1935 and 1936, an investigation of parasites as a possible cause of these deaths was undertaken (Leigh 1940:186). Tapeworms were found in 10 of 14 partly grown birds and in not one of 14 adults which were

collected in Jasper and Richland counties in the summers of 1936 and 1937.

Because cestodes of a previously undescribed species of *Railletina* occurred in 10 [actually 9] of 14 young birds and in 4 cases were so numerous or so large as to occlude the lumen of the greater part of the small intestine, they should not be overlooked as a factor in prairie chicken mortality (Leigh 1940:188-9).

Shelford & Yeatter (1955) interpreted year-to-year population fluctuations of male prairie chickens during a period of 18 years on the study area near Hunt in Jasper County, Illinois, in relation to weather and climate. Field observations indicated that the period of the late stages of development of the reproductive cells during April, the period of egg-hatching in June, and the period when young prairie chickens were 4 to 8 weeks old were critical times in the reproductive cycle of prairie chickens. Many trials in which various weather records were used showed that the population level tended to respond to only two weather combinations: (1) rainfall and sunshine in April and (2) rainfall and temperature in June. Reproduction was most successful in seasons when April rainfall averaged 2-5 inches and when 48-64 per cent of the possible hours of sunshine were experienced. As the amounts of rainfall and sunshine varied from these optimum limits, reproductive success became progressively lower.

Thus, the prairie chicken in Illinois has passed from the enormous populations of Civil War times to small, scattered colonies, in only 24 counties in 1957 (Yeatter 1957). It seems evident that the prairie chicken will soon become something of the past in Illinois unless a positive program of management such as that being proposed at the present time saves them.

The Bobwhite Quail.—To the upland bird hunter of Illinois, events which established the present boundaries of Illinois proved inadvertently provident, for they led to the inclusion of excellent quail range over the southern one-third of the state as well as what was to become fairly good pheasant range in the northern one-third.

Illinois has the distinction of being the locale of the first systematic and extensive

census of quail populations. These censuses were carried out during the period 1906-1909 by a strip-census technique (Forbes & Gross 1921, 1922, 1923). The increase in the density of quail populations from north to south in Illinois was just as clearly marked in the findings of Forbes and Gross as it is today. Censuses during the summers of 1907 and 1909 revealed quail populations of 21 birds on 7,966.5 acres or 1 bird per 379.4 acres in northern Illinois, 53 birds on 5,823.9 acres or 1 bird per 109.9 acres in central Illinois, and 241 birds on 5,527.2 acres or 1 bird per 22.9 acres in southern Illinois (Forbes & Gross 1922:191, 197).

A similar distribution of quail population densities was evident in the winter counts made during the period November 23, 1906, through February 21, 1907, when 180 quail were counted on 1,422.4 acres or 1 bird per 7.9 acres in southern Illinois and 54 on 4,956.0 acres or 1 bird per 91.8 acres in central and northern Illinois combined (Forbes & Gross 1923: 398, 400). The data for the counts made during the summers of 1907 and 1909 indicated an increase in quail populations for the state as a whole; 91 quail were counted on 7,693.6 acres, 1 bird per 84.5 acres, in 1907 and 224 birds on 11,624.1 acres, 1 bird per 51.9 acres, in 1909 (Forbes & Gross 1922:191).

The densities of quail populations were recorded by general habitat category. In a special study, August 19 to September 15, 1908, in which orchards in the vicinity of Centralia and Olney received special attention, 774.5 acres of orchard and 594.5 acres in other habitat categories were censused; 356 quail, 1 per 2.2 acres, were counted in the orchards and 32, 1 per 18.6 acres, outside the orchard area (Forbes & Gross 1921:5, 7). The importance of undisturbed grassland to the management of quail was suggested by Forbes & Gross (1921:3) in their consideration of reasons for the high densities of quail in orchards when they concluded: "Evidently it is not the trees that attract it, but the cover afforded by an undisturbed growth of grass and weeds between the rows."

Following these early censuses, there was a pause in the attention given quail by Natural History Survey researchers.

The species did not become the subject of further study until the hunting season of 1936, when 141 quail were collected in an investigation of helminth parasites by Leigh (1940:186, 190), who concluded "that the quail of Illinois are not so heavily infested with the diversity of helminth parasites as are the quail of the southeastern states." In the summer of 1938 a brief investigation of quail productivity in Calhoun County was carried out by Bellrose (1940:10), who pointed out the importance of undisturbed grassland and concluded that the possibilities for providing suitable nesting sites were greatest in apple orchards.

In 1948 and 1949 the hatchability of the eggs of the bobwhite was compared with that of the eggs of pheasants after experimental exposure to temperatures of 62, 73, 78, 83, and 88 degrees F. for a period of 7 days to simulate preincubation exposure (Yeatter 1950:529). Yeatter (1950:530) concluded that "No significant reduction of hatchability of the bobwhite eggs by high temperatures was evident."

Bobwhite quail were investigated from 1948 to 1954 on the Crab Orchard National Wildlife Refuge, in Williamson County, to determine what types of cover importantly influenced the abundance of quail (W. R. Hanson & R. J. Miller unpublished MS). Quail abundance was significantly correlated with the amount of "edge" between cultivated fields and brushy pastures. Twenty-five linear miles of multiflora rose hedges, planted on an area of about 5.5 square miles, failed to increase the numbers of quail.

A most important step was made in the direction of a thoroughgoing investigation of the biology of the bobwhite quail in Illinois by the signing, on October 3, 1950, of a memorandum of understanding providing for co-operation between the Natural History Survey and Southern Illinois University. The observations and impressions (Scott & Klimstra 1954) obtained during a trip to quail management areas in southeastern United States for the purpose of co-ordinating this co-operative program of research in Illinois with work elsewhere are believed noteworthy and cover the following subjects: hunting, management of habitat, and populations.

The co-operative research has involved nearly all phases of quail biology and an experimental habitat management program. Among the important contributions are two studies, one on the diet of quail (E. J. Larimer unpublished MS) and the other on quail populations on an unmanaged area. The second study has emphasized once again the great importance of undisturbed grassland to quail productivity and provided evidence of the amount and distribution of undisturbed grassland required to insure high quail productivity. The quail investigations have received outside financial assistance from Max McGraw, A. E. Staley, the North American Wildlife Foundation, and the United Electric Coal Company; the coal company also has made available extensive landholdings for experiments with habitat management.

The Ring-Necked Pheasant.—Although the attempt to establish pheasants in Illinois had gotten under way in the 1890's, this state's biological researchers were apparently unimpressed with it as a subject for investigation. In a discussion of the animal resources of the state, Forbes (1912b:48) advised that he had not had time to appraise efforts to improve "the composition of our fauna by the introduction of exotic species." Little or no attention was given pheasants until Leigh (1940:190) made his limited survey of the parasites of pheasants collected during the hunting season in 1936. During the summer of 1938 Bellrose (1940) made nesting studies and population estimates of pheasants in the southern part of Calhoun County, which is outside the recognized range of pheasants in Illinois. His observations (Bellrose 1940:9) appeared to indicate that this population had been maintained by repeated releases.

Intensive investigations of the ring-necked pheasant did not get under way until April 1, 1946, when the Illinois Department of Conservation, the U. S. Fish and Wildlife Service (now the U. S. Bureau of Sport Fisheries and Wildlife), and the Illinois Natural History Survey entered into a co-operative project with Federal Aid funds. Dr. William B. Robertson (1958) described the results of this co-operative research from inception to December 31, 1951, together with an

account of the early history of pheasants in Illinois and an analysis of the factors limiting the pheasant range.

His report constitutes the first comprehensive account of pheasant research in Illinois. It is a valuable historical record of early introductions of pheasants and the development of hunting regulations. Curves based on an annual average of over 300 dates of the hatching of eggs in nests were constructed and analyzed for effects of photoperiod, weather, and farming operations. Observations made on the breeding behavior of marked birds released in Kendall County are believed to be especially enlightening. Of particular note to students of populations and behavior was the observation that adult hens tended to become associated in the harems earlier than did juvenile hens. One of the earliest attempts to eliminate bias from evaluation of the worth of artificial stocking is reported upon in the paper. Robertson (1958:129) concluded "that 35 to 50 per cent of the cock pheasants in summer releases in Illinois were bagged in the succeeding hunting season. The recovery rate for spring-released adult cocks, estimated by similar methods, was only 6.1 per cent." In Livingston County a release of 1,000 adult hens in September of 1948 resulted in a survival of about 50 per cent to May, 1949; released hens made up one-third of the hens on the area at the latter date. It was found that about 33 per cent of the broods seen the following summer were accompanied by released adult hens. In Kendall County the effect of a release of 500 adult hens in August and 1,000 juvenile hens in November and December of 1949 was evident when it was seen that 25 per cent of the broods in 1950 were accompanied by released hens.

There has been much speculation as to the reason pheasants have failed to become established in southern United States. During brood studies beginning in 1937, Yeatter (1950:529) observed that the hatchability of pheasant eggs frequently declined in late spring in east-central Illinois, which is on the southern edge of the pheasant range. This observation suggested that high environmental temperatures at the time of egg-laying constituted a critical limiting factor. In 1948

and 1949 Yeatter (1950:529) compared the effect of temperature on paired lots of pheasant and quail eggs during a 7-day preincubation period and stated "that the hatchability of pheasant eggs was reduced by heat exposures, the reduction increasing with the higher temperatures." It was concluded that this vulnerability of pheasant eggs to high air temperatures constituted an important barrier to the southern distribution of pheasants, and it was suggested that pheasants in the southern Pacific Coast and Rocky Mountain regions might be more tolerant of higher temperatures. Recent experiments by Yeatter lend strong support for this surmise (Yeatter unpublished MS).

At the present time, the Illinois Department of Conservation, the Illinois Natural History Survey, and the U. S. Bureau of Sport Fisheries and Wildlife are co-operating in a comprehensive and intensive investigation of the ring-necked pheasant. This research is being carried on by Dr. William R. Hanson, Dr. Frederick Greeley, Jack A. Ellis, and Ronald F. Labisky and involves study of range-limiting factors, the biology of pheasants within the established range, and experiments with the establishment of self-maintaining populations outside the existing range.

The Canada Goose.—Canada geese wintering on the islands and bars in the Mississippi River from Chester, Illinois, southward to Cairo must have found the fight for survival during the early part of the twentieth century severe indeed. The conservationists who, with the objective of providing for pole-and-line fishing, arranged for the purchase of Horseshoe Lake, an ancient oxbow of the Mississippi River in Alexander County, by the Illinois Department of Conservation in 1927 were unaware of the part they would play in protecting this goose population and setting the stage for its future growth. About 1,900 Canada geese wintered at Horseshoe Lake, now famous as the Horseshoe Lake Game Refuge, during the first year. During the winter of 1957-58, about 225,000 Canada geese wintered in southern Illinois; these geese constitute a resource which has been estimated to contribute about \$1,500,000 annually to the economy of southern Illinois.

The refuge was soon surrounded by commercial shooting clubs, and a problem which attracted national interest was created. Leopold (1931:206) wrote: "The question of whether public refuges should be surrounded by public shooting grounds is frequently debated. Horseshoe Lake in Alexander County, Illinois, is a good place to study the question." Nevertheless, it was not until 1939, when about 40,000 (the same number estimated to have been killed in southern Illinois in 1957) geese were wintering at the refuge, that the annual kill and the need for knowledge on which to base intelligent control became alarming enough to attract researchers.

In 1940 Arthur S. Hawkins initiated the Illinois Natural History Survey's long-time research program on Canada geese (Hanson & Smith 1950:70), and in 1941 geese were banded in the area for the first time by Hawkins and John M. Anderson. The initial effort was necessarily directed toward the development of efficient trapping and handling methods (Hanson 1949a), and colored bands were tested on geese (Balham & Elder 1953) for the first time.

The massing of so large a portion of the Canada geese of the flyway at Horseshoe Lake created a unique opportunity for population research. Practical methods for aging geese were worked out for the first time (Elder 1946; Hanson 1949b, 1953a), and these methods, which were used for measuring the composition of the population, formed the basis for all subsequent investigations. Elder's (1946:94-8) analysis of the weight of Canada geese by sex and age constituted the first analysis of its kind for geese. Hanson (1949b) developed techniques for placing Canada geese in three age categories (juvenile, yearling, and adult), thus making possible a considerable advancement in the understanding of population mechanics in these birds.

A definitive investigation of the biology of the Canada goose constitutes the long-range objective of the research on this species. Early findings were reported in a 144-page article (Hanson & Smith 1950). In this article the four flyway populations of Canada geese breeding in the general area of Hudson Bay were

revealed for the first time. The breeding range, migration routes, wintering grounds, and populations were discussed for each flyway population. Later, the South Atlantic Flyway population was treated in greater detail (Hanson & Griffith 1952). Observations on the relation of hunting losses to the age structure of the population wintering at the Horseshoe Lake Game Refuge proved especially useful. The heavy kills of immature geese in the first half of the 1940's not only altered the age composition of the flock but reduced the average longevity of these geese as shown by life survival indices, the first constructed for a species of waterfowl (Hanson & Smith 1950: 172-88). A recent 3-year study of the kills of Canada geese by the natives of the Hudson-James Bay region has established the location and size of these hunting losses with exactness (Hanson & Currie 1957).

The Canada geese on the Horseshoe Lake Game Refuge provide a unique opportunity for study of behavior. The adult males of the largest families usually dominate males leading smaller families, and the social rank of the adult female is determined by that of her mate (Hanson 1953b). The conception "that the small goose flock is usually a family and that larger flocks are frequently multiples of families rather than mere aggregations of individuals . . ." also became apparent in observations made at the Horseshoe Lake Game Refuge (Elder & Elder 1949:139).

Diseases and parasites of Canada geese have been investigated in anticipation of epizootics among geese crowding into winter refuges. Blood protozoa (Levine & Hanson 1953) and microfilaria (Hanson, Levine, & Kantor 1956; Hanson 1956) have been surveyed. The prevalence of helminths in relation to age and the incidence of *Leucocytozoon* infection in immature geese are currently under study. Dr. Norman D. Levine (1953) made a valuable review of the literature on coccidia in the avian orders Galliformes, Anseriformes, and Charadriiformes. Coccidial infection was initially investigated in the flock at the Horseshoe Lake Game Refuge by Levine (1952), and the coccidia of North American wild

geese and swans were subsequently considered by Hanson, Levine, & Ivens (1957). Host specificity of some species of coccidia was shown, and certain coccidia seemed restricted to one flyway population. Thus, coccidia appeared to offer promise as biological tracers for confirming the distribution of flyway populations indicated earlier by band recoveries (Hanson & Smith 1950:74-9).

Ducks.—The early settler found multitudes of ducks in Illinois, not only along major streams, but also on the prairie sloughs. The vast numbers of ducks migrating through the bottomlands of the Illinois River valley made this valley a famous shooting ground as far back as the 1880's. Indeed, in 1886, a group of businessmen from the Peoria area founded the Duck Island Preserve, probably the first hunting club in the state.

Prior to 1900 the Illinois River and its connecting waters were in a near pristine condition. Sloughs and lakes contained an abundance of aquatic vegetation (Kofoid 1903), which provided food for ducks; other food was furnished by pecan nuts and pin oak acorns which became available when high water flooded the low-lying, timbered bottoms. In January of 1900 the Chicago Sanitary and Ship Canal was opened, greatly increasing earlier diversion of water from Lake Michigan (Mulvihill & Cornish 1930:53). This increased diversion resulted in water levels which were high enough to destroy extensive tracts of bottomland timber, including most of the pecans and pin oaks, in the Illinois River valley.

During the early 1900's not only were the tracts of mast-producing trees, so important as sources of food for mallards, lost to the ducks, but drainage destroyed many other important feeding grounds. Between 1900 and 1922, almost 200,000 of 400,000 acres in the flood plain of the Illinois River valley were leveed and drained (Mulvihill & Cornish 1930). The number of ducks in the lower flood plain area and shooting success declined when the mast-producing trees were lost. Then the practice of feeding waterfowl was begun at some duck hunting clubs in the early 1900's, was prohibited by state

law from 1909 to 1911, became a widespread practice in the 1920's, and was prohibited by federal regulation in 1935 (Bellrose 1944:333).

Finally, in recognition of the importance of waterfowl problems in Illinois, the Natural History Survey employed Arthur S. Hawkins and Frank C. Bellrose to initiate a waterfowl research program in 1938. Up to that time, the study

of baiting and live decoys on waterfowl and "estimated that 6,000,000 bushels of corn were fed by Illinois clubs during the 1933 season" (Bellrose 1944:365).

About 1938 initial attention was given to the wood duck, and in 1939 the first successful nesting box of rough-cut lumber was developed for this waterfowl species (Bellrose 1953a). By experimenta-



Wildlife technicians preparing to fluoroscope a mallard drake at the Illinois Natural History Survey field laboratory near Havana. The fluoroscope has facilitated studies involving crippling by hunters and lead poisoning.

of waterfowl had received little attention in Illinois. In 1922, at duck hunting clubs near the mouth of the Sangamon River, Dr. Frederick C. Lincoln (1924) of the U. S. Bureau of Biological Survey (now the U. S. Bureau of Sport Fisheries and Wildlife) made the first large-scale bandings of ducks in North America. Francis M. Uhler of the same agency examined the food contents of duck gizzards collected at the Duck Island Preserve in 1933 (Uhler unpublished report). Also, Uhler investigated the ef-

fect of baiting and live decoys on waterfowl and "estimated that 6,000,000 bushels of corn were fed by Illinois clubs during the 1933 season" (Bellrose 1944:365). About 1938 initial attention was given to the wood duck, and in 1939 the first successful nesting box of rough-cut lumber was developed for this waterfowl species (Bellrose 1953a). By experimenta-

Because diversion of Lake Michigan water, drainage, and sediment decreased the duck foods in the Illinois River valley, several of the early investigations

dealt with duck food plants. A study of the ecology of aquatic and marsh plants revealed the relationships of fluctuating water levels and turbidity to plant growth (Bellrose 1941). As a result of this study, two techniques for production of duck foods were recommended: (1) dewatering certain areas to encourage growth of moist-soil plants on exposed mud flats and (2) stabilizing water levels at depths of 2 to 3 feet to promote growth of aquatic plants.

A study of the relative value of various plants as duck foods (Bellrose & Anderson 1943:432-3) showed that moist-soil plants, such as rice cut-grass, millets, smartweeds, and nutgrasses, were much more valuable as duck foods than such aquatic and marsh plants as the pondweeds, coontail, duck potato, and bur-reed. This study is believed to be the first in which the food habits of waterfowl were related to food availability. Later, a study by Low & Bellrose (1944:21) revealed that, among 28 waterfowl food plants, 6 of the 7 heaviest seed producers were emergent or moist-soil plants. Harry G. Anderson (unpublished MS) made a little known but substantial contribution to knowledge of the diet of ducks in Illinois when he analyzed and reported upon the contents of 4,977 gizzards of ducks, representing 17 species, taken during the hunting seasons in 1938, 1939, and 1940.

In a sense, Illinois is at the bottleneck of the Mississippi Flyway, the flyway with the largest population of ducks in North America. The resulting constriction of duck populations streaming into Illinois has provided a remarkably fine opportunity for study of flyway populations. A comprehensive investigation of sex and age among ducks, covering 1939 through 1954, has been completed (Bellrose, Hawkins, Low, & Scott unpublished MS). From 1938 through 1958, periodic censuses have been taken of waterfowl populations in the Illinois River valley during fall, winter, and spring. In 1946 the census route was expanded to include the Mississippi River valley between Rock Island and Alton. These censuses have provided information on the effect of weather, water levels, food, and refuges upon waterfowl populations.

A 5-year investigation of duck populations and kill by hunters revealed that "altering the length of the season is one of the most expedient ways to regulate the duck kill" (Bellrose 1944:371). The most desirable dates for waterfowl hunting seasons of various lengths in Illinois were determined (Bellrose 1944:371):

For a 30-day season, November 1-30; for a 45-day season, October 22-December 5; for a 60-day season, October 10-December 8; for a 70-day season, October 1-December 9; for an 80-day season, September 26-December 14; for a 100-day season, September 20-December 28.

A study of flyway refuges in Illinois (Bellrose 1954:169) led to the conclusion that they were of value both to waterfowl and to hunters. Flyway refuges permitted waterfowl to rest along the flyway during the hunting season and placed more food within their reach, thereby conserving food resources on the wintering grounds. Waterfowl concentrating on the refuges fed in fields and marshes within their daily cruising range. Thus, the refuges provided for holding local concentrations of ducks which could be shot when they flew out to feed.

One of the most impressive duck flights in a decade swept through Illinois on November 2, 1955 (Bellrose 1957). It was determined that most of the birds in the flight left Canada on November 1 and moved so rapidly that some reached the Gulf of Mexico by the morning of November 3. This mass migration of waterfowl was evaluated by Bellrose (1957:24) as follows:

Low pressure areas in Canada resulted in a southward flow of a mass of Continental Arctic air. The low temperatures resulting from Continental Arctic air triggered the flight from the Great Plains of Canada and the United States.

Over 75,000 ducks, largely mallards, have been banded by Natural History Survey investigators at four widely separated localities in the state. Recoveries from some of the bandings were used in calculating the annual mortality of the mallard, black duck, and blue-winged teal (Bellrose & Chase 1950). Of the three species, the mallard proved to have the lowest mortality rate, and this "amounted to 55 out of 100 birds the

first year, or year of banding, 20 the second year, 11 the third year, and 6 the fourth year" (Bellrose & Chase 1950: 25). The banding data have also been used to delineate the migration routes of ducks passing through Illinois.

As part of an effort to evaluate losses from crippling by hunters, several thousand ducks were trapped and fluoroscoped for shot pellets and broken bones. Among apparently healthy mallards, 36.4 per cent of the adult drakes, 18.0 per cent of the juvenile drakes, and 21.4 per cent of the hens were carrying one or more shot pellets imbedded in flesh or internal organs (Bellrose 1953*b*:344). "Of the ducks . . . knocked down by hunters, as reported from various sections of the United States, 22.5 per cent were not retrieved" (Bellrose 1953*b*:357).

A spectacular die-off of mallard ducks near Grafton in January, 1947, prompted a joint investigation by the Natural History Survey and the United States Fish and Wildlife Service [now U. S. Bureau of Sport Fisheries and Wildlife]. A still greater die-off in the same area a year later attracted the attention of officials of the Western Cartridge Company of East Alton. As an outgrowth of the situation, a co-operative investigation of lead poisoning in waterfowl was begun in July, 1948, by the Illinois Natural History Survey, the Western Cartridge Company, which is a Division of the Olin Industries, Inc. [now Olin Mathieson Chemical Corporation], and the University of Illinois (Jordan & Bellrose 1951:3-4).

Although Lubaloy shot and several lead alloys were tested as substitutes for commercial lead shot, none showed promise in alleviating lead poisoning in waterfowl (Jordan & Bellrose 1950:167-8). It was estimated by Bellrose (1959) that each year approximately 4 per cent of the mallards of the Mississippi Flyway die from lead poisoning and that an additional 1 per cent are afflicted with lead poisoning but are bagged by hunters. Although several other species of ducks ingested larger numbers of shot per bird than did the mallard, the mallard suffered the highest rate of loss. Mortality from lead poisoning proved to be greater among ducks of the Mississippi Flyway than among those of other flyways. The use of iron shot as a substitute for lead shot was suggested as a possible means of contending with the lead poisoning problem

in the event drastic measures should become necessary.

The means by which ducks find their way from their breeding to wintering grounds has been under investigation. Juvenile blue-winged teals were captured in migration in Illinois and held in captivity until all the other blue-winged teals had migrated south of the United States (Bellrose 1958*a*). They were then banded and released. From recoveries of bands it was found that these juveniles, though unfamiliar with the route, flew southward along lines of flight similar to those of adults. Experiments with wild mallards demonstrated an ability to orient by celestial means (Bellrose 1958*b*). The initial flight of mallards released in unfamiliar areas was northward on clear days or nights and in apparently random directions when skies were cloudy and sun and stars were obscured.

The Mourning Dove.—The mourning dove became the subject of an intensive research effort in the autumn of 1948 when it was seen that data were needed for an objective evaluation of claims that doves were being shot to extinction by hunters in Illinois. The kill of doves in 1946 and 1947 was estimated from hunter reports to have been 200,000 in each year and about 300,000 in 1949 (Hanson & Kossack 1950:31). It was later determined that the kill was fairly evenly distributed over the state (Marquardt & Scott 1952).

A program of dove banding, particularly of nestlings, was undertaken to determine points of origin of populations. Banding by amateur co-operators was encouraged (Kossack 1955), and a technique employing elastic adhesive tape to secure bands on small nestlings was developed (Kossack 1952). These aspects of the program were later adopted on a country-wide scale by the U. S. Bureau of Sport Fisheries and Wildlife.

A portable candler was constructed for aging dove eggs in the field (Hanson 1954). Photographic and descriptive guides for aging incubated eggs and nestlings were prepared (Hanson & Kossack 1957*a*). The predominance of unisexual broods in mourning doves was found in early studies (Kossack & Hanson 1953). This subject is being treated

in greater detail in a report, now in preparation, on sex ratios in doves.

The effort to appraise mortality among mourning doves included study of their parasites and diseases (Kossack & Hanson 1954; Levine 1954; Hanson, Levine, Kossack, Kantor, & Stannard 1957). The paper by Hanson *et al.* describes the ectoparasites of doves and the arthropod fauna of their nests and summarizes the results of a 7-year study of the incidence of blood parasites in relation to ages of the doves and to regions of the state.

The relation of age and the stages of wing molt to body weight, body fat, and migration habits was studied (Hanson & Kossack 1957*b*). In contrast to interpretations of fat deposition in passerines, the analysis of data on fat deposition in mourning doves showed no consistent relationship to migratory habits, but instead proved to be related to the energy demands of the molt, regional farming practices, soil fertility, and food habits. Doves that had fed almost exclusively on corn in good soil areas had formed relatively heavy amounts of fat; most of those taken on poor, sandy soil where they fed largely on seeds of wild plants had formed little or no fat.

After 10 years of study there is still no evidence that dove populations in Illinois are controlled by hunting. Population declines which have taken place are generally traceable to habitat destruction, disease, and adverse weather.

Mammals

To the wildlife historian the apparent lack of interest in mammals by early researchers of the Natural History Survey and its predecessors constitutes something of an enigma. Almost half a century slipped away before Forbes, upon receiving a letter from C. A. Rowe of Jacksonville in April of 1907 reporting the destruction of seed corn by moles and enclosing the stomach contents of a mole containing about 65 per cent corn, was stimulated to authorize research on a problem in economic mammalogy (West 1910:14). The resulting studies (Wood 1910*b*; West 1910) provided the first evidence that moles included corn, or any substantial amount of plant food, for that matter, in their diet.

Fur-Bearing Mammals.—Forbes (1912*b*) included fur-bearing mammals among the animal resources of Illinois, but a program of consequence did not get under way until the 1930's, when evaluations of fur resources were undertaken.

Neither technical nor popular interest was great enough to focus further attention of the state's research agencies on furbearers until, in 1930, David H. Thompson, E. C. Driver, and D. I. Rasmussen of the Illinois Natural History Survey staff borrowed trappers' reports . . . from the Illinois State Department of Conservation, to which law provided that each licensed trapper report his catch monthly during the trapping season (Mohr 1943*a*:505).

Brown & Yeager (1943:437) stated that some of the figures derived by Driver and Rasmussen were published in the *Blue Book of the State of Illinois* (Frison 1931, 1933).

Following a limited survey of helminth parasites in fur-bearing animals collected during the hunting seasons of 1935–36 and 1936–37, Leigh (1940:191) stated that "A study of the literature offers little information on pathogenicity of the parasites found in the hosts studied." This shortcoming in our knowledge continues to prevail.

The desire to obtain a reasonably reliable evaluation of the fur resource in Illinois eventually resulted in two impressive reports (Brown & Yeager 1943; Mohr 1943*a*). Brown & Yeager (1943) based their evaluation on an intensive oral survey covering the 1938–39 and 1939–40 trapping seasons, and Mohr (1943*a*) made an analysis of fur-taker reports beginning with the 1929–30 trapping season and ending with that of 1939–40, excepting the 1931–32, 1932–33, and 1933–34 seasons. The results obtained by the two methods were relatively similar. The average value of the annual fur catch was estimated to have been a little over \$1,000,000, about 80 per cent of which represented returns for muskrats and minks. To aid in investigation of fur-bearing animals, Yeager (1941*a*) assembled a bibliography of over 2,600 references on North American fur animals.

Some valuable contributions on the relationship of muskrat populations to

fluctuating water levels in bottomland lakes flanking the Illinois River have been made by Natural History Survey researchers. Bellrose & Brown (1941:207) observed that the numbers of muskrat houses

were nearly six times as many in lakes with a stable, as in those with a semistable, water level and there were twice as many lodges per acre in lakes with a semistable, as in those with a fluctuating, water level.

Stable water levels favored the growth of those species of aquatic plants most desirable for muskrats. Later, following an investigation of the response of muskrat populations to flood and low water levels in these bottomland lakes, Bellrose & Low (1943:187) concluded:

While muskrats may be harassed and decimated within a short time during flood conditions, those living under low water conditions may escape without serious loss in summer but may be seriously affected during cold, winter weather.

In 1940-41 and 1943-44 Bellrose (1950) developed a new technique for evaluating the food preferences of muskrats by comparing the proportions of plant foods taken from "feeding" lodges in mid-winter with the proportions of plants known to have been within the feeding range of the muskrats. Cattail was rated the most preferred food. The capacity of vegetative types to support muskrat populations was determined by recording the density of muskrat lodges in each vegetation type. River bulrush and cattail had the greatest population values.

Advantage was taken of two unusually fine opportunities for measuring the response of raccoons to a food windfall of ducks (Yeager & Rennels 1943) and geese (Yeager & Elder 1945) made available as hunters' crippling losses at the Pere Marquette Wildlife Experimental Area immediately above the confluence of the Illinois and Mississippi rivers and at the Horseshoe Lake Game Refuge in Alexander County. At the Horseshoe Lake Game Refuge, where crippling losses were alarmingly high, bird remains, chiefly those of Canada geese, occurred in 20.7 per cent of the raccoon droppings collected a day after the hunting season opened and in 87.9 per cent of the droppings collected 3 weeks after the close of

the season (Yeager & Elder 1945:49-51). In 1939 and 1940, on the Pere Marquette Wildlife Experimental Area, duck remains did not occur in raccoon droppings collected before the opening of the waterfowl season, but after opening of the season "remains of mallard, pintail, and wood duck were 89 per cent of the bird material in 1939, and 76 per cent in 1940" (Yeager & Rennels 1943:59). These findings indicate that crippled waterfowl may not constitute a complete loss, inasmuch as furbearers utilize them as food. The biology of the raccoon is currently under intensive study by Glen C. Sanderson.

A survey of the population and distribution of beavers in Illinois was conducted under a co-operative Federal Aid project from April 1, 1947, through June 30, 1951. It was found (Pietsch 1957: 193-6) that beavers were "last reported" in Illinois in 1912, were reintroduced in 1929, were estimated to number 3,565 in 45 counties in 1950, and were reported from 55 counties in 1954.

The red fox was made the subject of a thorough evaluation (Scott 1955) because the values of this colorful mammal were believed to have been regularly underrated. This evaluation was based on personal experience extending over 20 years and a number of intensive investigations (Scott 1943, 1947; Scott & Klimstra 1955) especially relating to the red fox as a predator. As a result of this evaluation, Scott (1955:14) recommended:

1. The encouragement of an increased use of red foxes for sport hunting, . . .
2. The education of those who hope for increased small game populations through fox extermination campaigns to the more concrete and lasting results that may be expected from habitat improvement programs. . . .
3. The elimination of bounty payments on red foxes.
4. The enactment and enforcement of more effective antirabies laws, especially as applied to the compulsory vaccination and quarantine of domestic dogs, and prompt reduction by organized trapping of red fox populations in which rabies epizootics occur.
5. The increased attention by game managers to the proper management of the red fox resource in general, including assistance with the cropping of surplus animals in areas where adequate cropping has not been accomplished by hunters.

Game Mammals.—The cottontail rabbit tops the list of game mammals in Illinois in a number of respects. In a survey of license-stub kill cards for the 1950–51 hunting season, Marquardt & Scott (1952:4) found that rabbits provided twice as many sportsmen with game in the bag as did any other game species and numbered more than twice as many as any other kind of game animal reported. Rabbits constitute the chief game animal of the state largely because they are widely distributed and because they possess the reproductive potential to maintain themselves despite high mortality, including that from severe hunting pressure.

Proving that there is some bad with the good, however, is the fact that tularemia, a disease which is transmissible to man, occurs in rabbits. "In the period 1926–1949, Illinois had more than 3,000 reported cases of human tularemia, about twice as many as any of the other states" (Yeatter & Thompson 1952:351). Yeatter & Thompson (1952:379) reported that "The human tularemia rate in any year in Illinois seems to be determined both by temperatures about the time of the opening of the rabbit season and by the abundance of rabbits." They concluded that the incidence of human tularemia in Illinois could be reduced by delaying the opening of the rabbit hunting season until about December 1. As a result of these findings, the opening of the hunting season in Illinois was postponed until November 26 in 1955. In recent years methods of treating tularemia in humans have been greatly simplified by the use of antibiotics. It seems certain, however, that most hunters will prefer not to depend upon antibiotics—that they will enjoy their rabbit hunting far more knowing that by hunting within a season which opens after the onset of sharp freezing weather they and their families are exposed to the hazard of tularemia only to a minimum extent.

Yeatter & Thompson (1952:378) recommended, as a refinement to their studies, further study of ticks, other tularemia vectors, and the biology of the rabbit. Ecke (1955:294–6) recorded a complete description of the courtship and mating of cottontails. Also, Ecke (1955:305) found evidence which suggested

"that some component of green vegetation, possibly Vitamin E, is responsible for stimulating the pituitary glands of rabbits into the secretion of somatic nutritives, and consequently, determining the breeding conditions of the animals."

Dr. Rexford D. Lord (1958:274) has recently constructed life tables which indicate that as many as 24 to 27 per cent of the rabbits available to hunters in autumn may be the young of rabbits born in the spring of the same year.

Ecke & Yeatter (1956:212–3) attributed the death of a rabbit, estimated to have been about 13 days of age, to coccidiosis and suggested further study of coccidiosis as a cause of mortality among rabbits. Detailed studies of ectoparasites of rabbits have been carried on since 1952 by Dr. Lewis J. Stannard, Lysle R. Pietsch, Dr. Carl O. Mohr, and Dr. Lord.

The realization that tradition for a summer hunting season on squirrels in Illinois was not biologically sound touched off a thorough investigation (Brown & Yeager 1945) of fox squirrels and gray squirrels in 1940. The chief objection to a summer hunting season was that it resulted in the killing of pregnant and lactating females. Brown & Yeager (1945:526) estimated that summer hunting resulted in a wasteful loss of 31.8 unborn and suckling squirrels for each 100 squirrels bagged. Because the tradition for summer hunting was strong and because squirrel hunting was good in some parts of the state despite early hunting seasons in the past, Brown & Yeager (1945:526–8) believed it unwise to enact a season beginning so late that it would prevent all losses resulting from the killing of pregnant and lactating females and they observed: "Such a season could hardly begin earlier than October 1, and it would certainly be opposed by a large number of hunters." A compromise season of September 15 to November 15 in central and northern Illinois and September 1 to October 31 in southern Illinois was recommended. This recommendation has not been accepted by Illinois hunters.

The report by Pietsch (1954) on deer populations in Illinois will be of especial value to the future wildlife historian,

Pietsch reported upon the early history of the deer in Illinois, recent populations, and management. Hunting was suggested as a means of control, and the deer season, after being closed for 56 years, was opened in 1957 for hunting with bows and shotguns.

Miscellaneous Contributions to Mammalogy.—Mohr (1943*b*, 1947*a*) appraised population data for small mammals in North America. He calculated the weight of specific populations within the area occupied and concluded that population densities within groups of mammals having similar feeding habits were limited by the size of the mammal concerned. Also, Mohr (1947*b*) recorded miscellaneous data on populations of certain mammals in Illinois for future reference.

On December 1, 1956, a grant-in-aid was made by the National Institutes of Health of the U. S. Public Health Service to initiate a 3-year study of epizootiology of rabies in wild mammals. This investigation is aimed at identification of the key hosts to rabies in Illinois and those factors that make them key hosts.

WILDLIFE MANAGEMENT

“Applied programs in the field of biological science are seldom, if ever, developed without the aid of years of patient, so-called unapplied, researches” (Frison 1942*b*:5). Frison believed that sufficient basic knowledge had been accumulated to support applied management programs of an exploratory nature, and, with characteristic vigor, he encouraged work of this kind in the late 1930's. Later, he insisted that these programs be evaluated for monetary return, wildlife yield, and other benefits.

Two of these early programs concerned management of upland wildlife in central and northern Illinois. One of the first attempts to develop wildlife habitat on intensively cultivated land took place on the Urbana Township Wildlife Area, which was believed “typical of the best Illinois cornbelt farmland” (Hesselschwerdt 1942:31). Habitat development was begun on this area in 1937, and in 1939 the project came under the Federal Aid program. Development fea-

tures included fencerow plantings, installation of den boxes, block planting, and protection of strips along drainage ditches. Usage of the den boxes was evaluated. Fox squirrels appeared to extend their range and to increase in numbers as a result of the provision of den boxes (Hesselschwerdt 1942:33–4, 36). Usable den boxes are no longer present on the area, and resident fox squirrels are uncommon. As the fencerow plantings matured, cottontail rabbits and songbirds increased in numbers (Wandell 1948:262–3), but populations of pheasants and quail have shown no appreciable increase. Minks and muskrats trapped along an ungrazed section of a drainage ditch in 1944–45 provided an estimated per-acre income of \$62.78, more than 10 times that produced by the same ditch where it was heavily grazed (Yeager 1945:85).

On October 1, 1939, a Federal Aid project to determine the availability of land for wildlife habitat on the intensively cultivated farm land of the Illinois dark prairie was initiated (Spooner & Yeager 1942). Land for refuges and cover development was found to be available, without purchase, in small scattered tracts, and obtainable through long-term easements. Spooner & Yeager (1942:54) concluded that “Although the project shows promise of wide application on the Illinois prairie, there are yet many problems which must be further analyzed before its entire success is proved.”

Natural History Survey staff members have participated in various other programs closely related to management of upland wildlife. The Survey sponsored the initial acquisition in 1940, by the Department of Conservation, of a tract of sand prairie and wet land in Lee County, the Green River Area, as a management area for prairie chickens, waterfowl, and other animals. It is believed that this tract of land has played an important part in maintaining the only sizable flock of prairie chickens surviving in northern Illinois. However, unless the area is managed with primary consideration for the original objectives, it may well go down in history as the place where native prairie chickens met their end in northern Illinois. Frank C. Bellrose proposed the purchase of the Rice

Lake Wildlife Area by the state in 1942, and the area, now the best duck area in the state, was purchased by the Illinois Department of Conservation in 1943.

In 1955 a Federal Aid research project was initiated by Southern Illinois University, the Illinois Department of Conservation, and the Illinois Natural History Survey to determine the economic values and benefit to wildlife of wide-row culture of corn in southern Illinois. Potential benefits, to the farmer, of wide-row culture and interplanting with cover crops included conservation of soil, increase of fertility, elimination of the low-paying oat crop in rotations, saving of labor, and yields of corn comparable to those from conventional cultural methods (Vohs 1957).

The extent of use of wide-row cornfields by wildlife varied with the attractiveness of the interseeding. However, comparable observations on the numbers of wildlife in wide-row fields and standard interval fields revealed ratios of 5 to 1 for bobwhite quail, 12 to 1 for mourning doves, and 6 to 1 for cottontail rabbits. Wide-row corn is considered to have great potential for wildlife management especially, because it provides for an increase in wildlife values in thousands of acres of corn.

Evaluations of wildlife populations and possibilities for their management were made on marginal lands. Analyses were made of possibilities for management of coal-stripped land for the benefit of upland game and furbearers (Yeager 1941*b*, 1942), management of agricultural drainage systems for production of furbearers (Yeager 1943), and yields of fur from animals produced on different types of land (Yeager 1945). Another project concerned the use of hunting dogs in sport and conservation (Yeatter 1948).

Levee and drainage districts have reduced the flood plain along the Illinois River by almost half, about 200,000 acres. In view of the resulting loss of recreational opportunities and the increased danger from floods, Bellrose (1945) made a survey of the relative values of drained and undrained bottomlands. Later, Bellrose & Rollings (1949) calculated the annual per-acre value, to the public and to owners, of bottomland

lakes of the Illinois River valley. They concluded that bottomland lakes in the Illinois River valley had an annual per-acre value to the public, 1944-1947, of \$26.35, made up as follows: duck hunting \$12.18, angling \$2.40, commercial fishing \$9.65, and fur trapping \$2.12; they estimated that privately owned lakes were capable of producing an average yearly gross return to owners of \$18.57 per acre (Bellrose & Rollings 1949:23).

Following an investigation of the effects of flooding on mammals in and around a bottomland lake in the Illinois River valley, Yeager & Anderson (1944:178) concluded that "The effect of flooding on mammals ranged from heavy mortality in the case of woodchucks to apparently little basic change in the behavior of minks." For various kinds of fur-bearing and game mammals, Yeager (1949) recorded the changes in abundance caused by permanent flooding of wooded bottomland over an 8-year period, 1939-1946. The site was a tract of 600 acres in the junction of the Mississippi and Illinois rivers; the area was flooded in 1938 by closing of the gates of the then new Alton dam.

THE FUTURE

Because the wildlife resource and the environment essential to its existence have economic and recreational values beyond general public appreciation and because knowledge on which to base intelligent management of this resource is in the best interest of the people of Illinois, I believe that we must plan for the future of wildlife research in Illinois as a part of our evaluation of the past.

Forbes (1907*c*:892) expressed this view when he wrote

that we are . . . practically interested in what has come and gone only as it may help us to bring a new thing into being in a way to secure its permanent continuance and its normal growth.

In the past the wildlife research program of the Illinois Natural History Survey has been heavily weighted toward investigations of migratory game birds. These investigations have been extremely valuable and must be continued in the

future; however, increasing attention must be given to other wild species, including nongame species. Nongame species must be studied not only because they represent economic and esthetic values but also because some of them, such as mice, are especially useful in basic research. Responsibility for research on certain species cannot be side-stepped on the ground that effective study of these species is being carried on in other states, for Illinois has problems characteristic of its own land-use pattern and it bears a responsibility to other states inasmuch as enlightenment on particular problems is often best obtained through comparison of range-wide differences.

While it is true that great progress has been made in wildlife research, and the number of unknowns has been reduced, this increased knowledge has expanded our awareness of unknowns. Many research techniques have been developed, but, in most instances, the degree of their reliability has not been adequately determined, and refinement is desirable. Although the research has been increasingly objective, it must be admitted that there is need for improvement. The expanding field of wildlife research requires specialization, but it also requires integration and synthesis.

This post-mortem of wildlife research impresses me with the fact that the quality of a contribution is influenced not only by the capabilities of the individual researcher but also by the length of time devoted to concentrated effort on particular problems. If real progress is to be realized in the future, the sustained and concentrated effort of top-flight researchers must be insured. Illinois will stand among the leaders in wildlife research only so long as the means with which to attract and hold qualified personnel for extended periods is provided. Provisions must be made for long-range research, with monographic-type publication being an objective. And, finally, we must guard against becoming desk- and laboratory-bound theorists and interpreters. It is essential that contact be maintained with living organisms in their natural surroundings.

Much of our research effort has moved in the direction of life history, ecology,

and populations. And much of it must continue to move in this direction. However, means for improvement must be constantly sought out. In life history studies, we must be increasingly objective. In ecology, we must be mindful of the need for land-use practices which are compatible with the best interests of both landowners and wildlife, especially in view of the increasing use of marginal land and agricultural chemicals. In the area of population mechanics, we must not only measure population trends and population composition; we must also seek and evaluate with greater refinement those factors which influence population trends and make-up.

In the future more attention must be given to fields of study only lightly touched upon in the past. Animal behavior, a vital and challenging field, must be explored particularly, for what an animal does is more important to the wildlife manager than what it is. Mobility, especially migration, must be examined more critically. Nutrition, qualitative as well as quantitative, must be investigated, and techniques for evaluating "condition" in wildlife must be explored. Anatomy, embryology, genetics, physiology, and biochemistry must, of necessity, play a larger part in the evaluations of the future.

We must guard against the neglect or shunning of certain research by avoiding a "that's been done before" philosophy. It may well have been done before, but we must be careful to evaluate the thoroughness with which it was done. We must examine it for weaknesses and for its value as a basis for new working hypotheses.

The wildlife research of the Natural History Survey has been instrumental in bringing about desirable changes in established policies and practices and in the establishment of new policies and practices which affect wildlife. We must provide adequate bases for the policy making of the future. To these ends we must move in the direction of prompt publication, and we must make certain that useful publicity is given especially to those findings which indicate that support of, or changes in, practices or administrative policies are desirable.

Our thinking must be projected far into the future in an effort to visualize those areas where knowledge will be most needed. Anticipating the future is admittedly fraught with pitfalls. It seems certain, however, that human populations will continue to increase in Illinois. This increase will be attended by more intensive use of land and water, more extensive transportation and communication systems, more extensive residential and industrial areas, more exhaustive use of fuels and metals, greater use of atomic energy, more automation, and more leisure time.

From the wildlife manager's point of view, this condition forewarns of an increasingly severe competition between wildlife and basic human needs. When it is considered that wildlife must be produced primarily on lands utilized for other purposes, the problems of the future for wildlife become obvious. The increasing demand for human food will make it essential that harvest methods be refined to reduce waste, that more heavily yielding crops be developed, that more marginal land be brought into use, and that more agricultural chemicals be applied. This promises not only to reduce wildlife populations but to force them below minimum survival levels, unless effective provisions, such as wide-row corn may prove to be, are constantly sought out by wildlife managers. The need for refuges to insure the survival of rare species will increase. The relative importance of those wild animals which compete with humans for food by eating or contaminating it will be magnified. Intensive use of water could create a

pollution problem such as would virtually deny aquatic life outside protected areas, unless pollution control, including provision for disposal of radioactive waste, keeps pace with increased water utilization.

The provision of a means for satisfying the psychological needs of a human population with more leisure time and relatively less elbow room comprises a formidable challenge. If the human population is to maintain some semblance of sanity, services such as those offered by wildlife biology must be given equal recognition with those of the physical sciences. Perhaps the average family of the future will tend to satisfy more of its needs for pleasure in the out-of-doors and for escape from the pressures of civilization in its own backyard. Hence, the wildlife manager should contrive to know more about the management of the home landscape for wildlife. It seems certain that an increasing amount of hunting will take place on regulated shooting areas, that is, unless hunting proves to be good in outer space.

The wildlife manager's problems of the past, considerable as they have been, seem as child's play compared with those looming in the future. The wildlife manager is going to need determination, courage, ability, compensation, and means such as never before. Perhaps we can ease some of his problems by the effective planning of current research to provide a sound basis for the essential decisions of the future. Indeed, wildlife management as a profession may well depend on the soundness of today's plans for the future.

Publications and Public Relations

JAMES S. AYARS

MANY of the men whose names were written large in the early annals of the Illinois Natural History Survey had been educated in the classical tradition. Most of the physicians, educators, and others whose formal schooling included college had undergone the discipline of Latin and Greek studies.

Jonathan Baldwin Turner, elected first president of the Illinois Natural History Society in 1858 (Bateman 1858*b*:258), was a graduate of Yale College and for many years Professor of Belles Lettres, Latin, and Greek at Illinois College, Jacksonville (Carriell 1911:12, 46).

Charles E. Hovey, first secretary of the Society (Bateman 1858*b*:258) and first head of the Illinois State Normal University, was a graduate of Dartmouth College (Marshall 1956:28). Joseph Addison Sewall, early curator, had studied at both Yale and Harvard and was a graduate of Harvard Medical College (Marshall 1956:78).

Benjamin Dann Walsh, first State Entomologist, was a graduate of Trinity College of Cambridge University in England (Weiss 1936:234). William Le Baron, second State Entomologist, was, like Sewall, a graduate of Harvard Medical College (Goding 1885:122).

Although Stephen Alfred Forbes, fourth State Entomologist, first and only Director of the State Laboratory of Natural History, and first Chief of the Natural History Survey, had comparatively little formal education as a youth, he had subjected himself to the discipline of language study. At home he had studied French and Spanish, and in Confederate prisons during the Civil War he had spent some of his "abundant leisure" in studying Greek from books he managed to buy at Mobile (Howard 1932:6).

The early leaders in Illinois science, most of them classicists before they were scientists, had developed respect for the meaning and sound of words, and had acquired a skill in word usage that carried into their scientific writings.

Trained in the classics though most of these leaders were, many were nevertheless aware that classical education had limitations. They saw that in Illinois, in the middle of the nineteenth century, education must be brought out of ivied halls to the furrow and the work bench.

In the Illinois College classroom Turner was a teacher of Latin and Greek. Out of the classroom, he was a leader in the movement for industrial education, the education of the farmer and the mechanic.

Turner asked (Carriell 1911:76):

But where are the universities, the apparatus, the professors, and the literature specifically adapted to any one of the industrial classes? . . . society has become, long since, wise enough to know that its *teachers* need to be educated; but it has not yet become wise enough to know that its *workers* need education just as much.

Socrates, Cincinnatus, Washington, Franklin, and other worthies, Turner argued, derived their education "from their connection with the practical pursuits of life" (Carriell 1911:117):

What we want from schools is to teach men . . . to derive their mental and moral strength from their own pursuits, whatever they are, and to gather from other sources as much more as they find time to achieve. We wish to teach them to read books, only that they may the better read and understand the great volume of nature ever open before them.

Can, then, no schools and no literature, suited to the peculiar wants of the industrial classes, be created by the application of science to their pursuits?

Walsh (1868*b*:9) emphasized that his annual report as Acting State Entomologist was "intended chiefly for the use of common folks."

Writing as Editor of the only volume of *Transactions* published by the Natural History Society itself, C. D. Wilber (1861*d*:3-4) epitomized the educational movement of the time, a movement that might be termed a revolt of the classicists against the classical tradition:

It has been the aim of the Editor, to present only such articles and papers as are immediately useful and interesting to the citizens and

schools of Illinois, with a hope that a zeal for the pursuits and studies of Natural History may spring up among our people, like the seeds of the sower, in the parable, falling upon good soil, and yielding, "some sixty and some an hundred fold."

In order to render the greatest good to all, the subjects have generally been treated in a popular rather than a technical style. It has been said, that he who places a valuable truth or fact within the reach of the million, is doing more for humanity than he who discovers it. And, indeed, if scientific men, or libraries and museums, cannot contribute to the elevation of the masses who are less privileged, their usefulness is questionable.

The ideas reflected in Turner's questions and answers and in Wilber's comments culminated in the Morrill Act of 1862, in land grant colleges, and, specifically, in the Illinois Industrial University at Urbana. Both cause and effect of the movement for general education was the increasing thirst that Illinois people in the middle of the nineteenth century had for knowledge, the growing conviction that information should be widely disseminated. The movement led to the formation of, and was abetted by, the Illinois State Horticultural Society, the Illinois State Agricultural Society, and the Illinois Natural History Society.

The Natural History Society was not an accident nor an isolated segment of history. It was part of a contagious movement sweeping the prairies. As seen by Wilber (1861*d*:7):

The demand for this movement seemed to proceed from a want of accurate knowledge in nearly all departments of Natural History in the State; and also, from a desire that all facts and discoveries in a field so vast as Illinois, should be made immediately subservient to the great ends of popular education.

EARLY PUBLICATIONS

The Illinois scientist in mid-nineteenth century looking for means of disseminating knowledge had few publication outlets. Among the small number of scientific journals published before 1860 were *The American Journal of Science*, founded in 1818, the *Entomologist of London*, in 1840, and the *Boston Journal of Natural History*, in 1834. The first *Transactions* of the Illinois State Agricultural Society were published in 1855; the first *Transactions* published by the Illinois

State Horticultural Society itself were dated 1863. The first *Proceedings* of the Entomological Society of Philadelphia were published in 1861. The *American Naturalist* was not founded until 1867, the *Botanical Gazette* not until 1875.

The *Prairie Farmer* had been established at Chicago in 1841, and to this periodical, frankly slanted toward the interests of practical farmers, Illinois scientists of mid-century turned for publication of their technical papers. The publication by *Prairie Farmer* of many of these papers, some significant enough to attract the attention of eminent scientists in other parts of the country, is indication of the extent to which the classicists and the industrialists had become wedded.

That publication of scientific papers was an important aim of the founders of the Illinois Natural History Society is evident from written records of the organization. The object of the Society, as outlined by Cyrus Thomas in his letter read before Illinois teachers meeting in Decatur, December 29, 1857 (Bateman 1858*a*:12),

shall be the investigation and study of the Flora, Fauna, Geology, and Mineralogy of Illinois, and the illustration of the same by gathering specimens, exchanging the same, and by publishing such meritorious works thereon as the authors may present, . . .

At the last session of its second meeting, held on June 20 and 21, 1859, at Bloomington, the Society (Francis 1859*b*:664) resolved that "the Executive Committee be required to procure the publication of the papers and proceedings of the Society in some paper generally circulated through the State." The Executive Committee in turn resolved that, "in accordance with the resolution of the Society, we select THE PRAIRIE FARMER as its medium for publishing the papers and proceedings of the Society."

Another outlet for papers written by members of the Natural History Society was provided by the Illinois State Agricultural Society. In its own published *Transactions* the Agricultural Society included the *Transactions* of the first three meetings of the Natural History Society and several papers contributed by members (Francis 1859*a*, 1859*b*, Wilber 1861*a*).

In 1861 the Natural History Society itself published what it termed the "Second Edition" of Volume I, Series I, of its *Transactions* (Wilber 1861*d*). Most of the material in this volume had been printed previously by the Agricultural Society in its *Transactions* for 1857-1858 (Wilber 1861*a*). Wilber's Preface to the volume published by the Natural History Society was dated October 30, 1861 (Wilber 1861*d*:4). The Civil War had begun 6 months before.

In 1867, after the War was over and men again had time to consider civilian science, the state legislature in a single session made an appropriation to the Illinois Natural History Society, provided for a State Entomologist, and authorized establishment of the Illinois Industrial University (Illinois General Assembly 1867).

The legislative act that provided for a State Entomologist required him to prepare "a report of his researches and discoveries in entomology for publication by the state, annually" (Illinois General Assembly 1867:36).

The act of 1867 in which state appropriations were first made to the Illinois Natural History Society and the act of 10 years later establishing the Illinois State Laboratory of Natural History made no mention of publications (Illinois General Assembly 1867:21-2; 1877:14-6). In 1879, however, the state legislature appropriated to the State Laboratory for "publication of bulletins, the sum of two hundred and fifty dollars per annum" (Illinois General Assembly 1879:42).

An act approved June 27, 1885, a few months after Forbes had moved to Urbana, was specific about publication. It stipulated that the Director of the State Laboratory "shall present for publication, from time to time, a series of systematic reports covering the entire field of the zoölogy and the cryptogamic botany of Illinois." The act appropriated "for the publication of bulletins, the sum of three hundred dollars per annum, and for the preparation and publication of the second volume of the report upon the zoölogy of the State, the sum of fifteen hundred dollars per annum" (Illinois General Assembly 1885:23-4).

The following year, Forbes staged an intellectual sit-down strike over a proposed publication. Insufficient funds and conflicting legalities would not permit him to include what he considered suitable illustrations in the State Entomologist's report he had prepared for publication in 1886.

Forbes (1886*a*:3) explained the situation in the preface to a group of articles that he and members of his staff had written and that he had submitted to the State Board of Agriculture for publication in its *Transactions*:

A recent opinion of the Attorney General makes it doubtful whether the State Entomologist of Illinois has the right, under the laws referring to that office (to some extent inconsistent and conflicting), to prepare any other than a biennial report; and a change in practice of the State Board of Contracts leaves no doubt whatever that a report published this year could not be illustrated. As an elaborate monograph of insects injurious to Indian corn was intended as the principal part of my entomological report for 1885, and as this article certainly should not be published without a large number of excellent figures, I have decided, under existing circumstances, not only to withhold this paper, but also to refrain from presenting any formal report for 1885, leaving it to the State Legislature to provide for the proper illustration of the reports hereafter, and to remove the present inconsistencies of the law. Unwilling, however, that the work of the office of the past year should be without representation in the *Transactions* of the State Board of Agriculture, with which the entomological report has been annually published for the last ten years, I have submitted to the Board, at the request of its Secretary, C. F. Mills, Esq., the following miscellaneous essays on economic entomology, summarizing the results of such part of our operations as may well be published without cuts.

At its next session the Illinois General Assembly (1887:72) appropriated to the State Laboratory of Natural History \$300 for publication of Laboratory bulletins and \$500 for "the illustration of the biennial report of the State Entomologist."

In these days of high cost of printing, engraving, and other services, such sums as \$300 and \$500 seem insignificant. In 1887, however, they bulked large enough to help confirm in the public mind the importance of publication and illustration in scientific research.

In a biennial report issued about 3 years after assuming his duties in Urbana,

Forbes (1888:7) described in detail the publications that were being issued under his direction:

Our regular publications run in four series, two from the Laboratory and two from the Office of the State Entomologist,—the former comprising the State zoological report and the bulletins of the State Laboratory of Natural History, and the latter the biennial entomological report and the bulletins of the entomological office.

During the past two years we have finished the printing of the first volume on the zoology of the State,—containing five hundred and twenty pages of text and forty-six plates,—devoted to the ornithology of Illinois as far as the water birds. This is a reprint of the volume, the first edition having been entirely destroyed in the burning of the office of the State Printer last February.

PUBLICATIONS SERIES

The words "Volume I, Series I," at the top of the title page of the only *Transactions* published by the Illinois Natural History Society under its own name are evidence that the members looked forward hopefully to continued publication. The date at the bottom of the page, 1861, and a glance at American history give testimony to the role the Civil War played in the Society's annals. In 1861 Charles Hovey, first secretary of the Society and head of Illinois State Normal University, marched off to war as Colonel of the Schoolmaster's Regiment, taking with him most of the men of the student body and some of the faculty (Marshall 1956:75-6). No one knows how many potential scientists died at Fort Donelson and in other engagements, or how much brain power from Illinois centers of learning was siphoned from the science of peace into the science of war.

Two years after the Civil War was over, biological science in Illinois resumed its march, but the Natural History Society limped badly. It never recovered from the effects of the conflict. However, in voting an appropriation to the Natural History Society and establishing the State Entomologist's Office and the Illinois Industrial University, the Illinois General Assembly (1867) gave substantial evidence that the people of the state wanted to continue the educational movement that founders of the Society had helped to start.

Walsh's first and only report as State Entomologist was followed by the reports of his successors: 4 by William Le Baron, 6 by Cyrus Thomas, and 18 by Forbes. Le Baron (1871) named *his* first report *the* first report of the State Entomologist. The reports were discontinued when the State Entomologist's Office was merged with the Illinois State Laboratory of Natural History in 1917.

In 1876, about 4 years after his appointment as Curator of the Illinois Museum of Natural History, Forbes issued the first number of a technical series that has come down through the years as the *Bulletin*. It has been known successively as the *Bulletin* of the Illinois Museum of Natural History, 1876; *Bulletin* of the State Laboratory of Natural History, 1877 to the end of June, 1917; *Bulletin* of the Illinois State Natural History Survey, July, 1917, to early 1932; and Illinois Natural History Survey *Bulletin*, late 1932 to the present. Throughout its existence the *Bulletin* has reported the results of mature, original research. Most of the articles have been slanted toward technical workers in the biological sciences.

Of wider interest are numbers of the circular series. The emphasis in this series is on "how-to-do"—for example, how to control diseases or insect pests of shade trees. Directions in the circulars are based on the best available information and usually only to a limited extent on original research by the writers. The language of the circular series is less technical than that of the *Bulletin*.

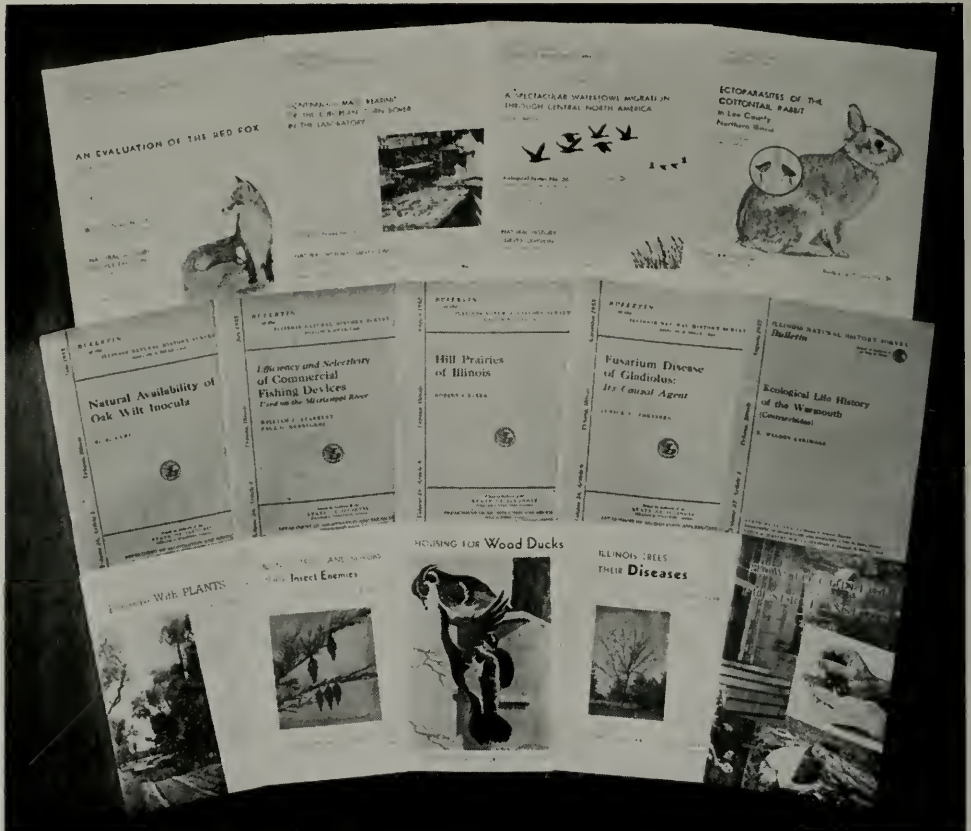
The complete history of the circulars is not known. "We have also issued several entomological circulars not of any series," Forbes (1888:7) wrote 70 years ago. The modern circular series dates from 1918 and a 6-page unnumbered publication titled "The More Important Insecticides and Repellents," by W. P. Flint. Between 1918 and 1930, 13 other circulars (3 unnumbered and 10 numbered) were issued by the economic entomologists, 4 by the foresters, and 1 by the botanist on the staff. Each circular was issued as a product of the section represented by its author. In 1934 the circular series was reorganized and the early circulars were numbered or renumbered.

The last circular published, *Illinois Trees and Shrubs: Their Insect Enemies*, is numbered 47. Some of the circulars have been reprinted more than once, one of them, that on insect collecting, five times.

Diverse in several ways are the articles published in the Biological Notes series,

tions of typewritten copy. The most recent article of the Biological Notes is No. 39.

The fourth of the series of publications now issued by the Illinois Natural History Survey is the manual. Each number is concerned with a single group of the



A few of the circulars, articles of the *Bulletin*, and biological notes issued recently by the Illinois Natural History Survey.

the first of which was issued in December, 1933, in mimeographed form. Some of the articles stand as progress reports of extensive projects, later to be subjects of articles in the *Bulletin*. Some are final reports covering small projects. Some are technical. Some emphasize "how-to-do" and in content and language are similar to the circulars. They are on various subjects and of various lengths. Early articles in this series were mimeographed and they contained no illustrations. Recent articles have contained illustrations and they have been planographed reproduc-

state flora or fauna, and each is designed for use by young as well as mature naturalists. The first of the manuals was *Fieldbook of Illinois Wild Flowers*. It was issued in 1936, is now out of print, and is being revised. Three other manuals have been published, one on land snails, one on native shrubs, and one on mammals.

Preceding the manual series in time, and somewhat similar in character, were the now discontinued final reports, two on birds and one on fishes (Ridgway 1889, 1895; Forbes & Richardson 1908).

Other discontinued series were the Executive Reports of the State Laboratory of Natural History, 1878-1916, and of the State Entomologist, 1900-1915. Most of these reports were published as pamphlets and were published also in University of Illinois reports or in *Transactions* of the State Horticultural Society.

Annual reports made by the Natural History Survey to the Illinois State Department of Registration and Education were begun in 1918 and have been continued to the present. These reports have been published by the Division or by other administrative units of the state government. Biennial reports have for many years been included in the Blue Book of the State of Illinois.

A considerable number of important contributions by Illinois Natural History Survey staff members have been published in the bulletin and circular series of the Illinois Agricultural Experiment Station.

Many staff-written articles covering results of research have been published in technical journals. In a biennial report published 70 years ago, Forbes (1888:8) listed about a dozen articles "written at the Laboratory, but published elsewhere." In each of the past few years, approximately 80 articles written by staff members of the Illinois Natural History Survey have appeared in publications other than those issued by the Survey.

EDITORIAL PERSONNEL

That some editing was done on the first papers published by the Illinois Natural History Society is evident from a sentence in the Secretary's Report published with the *Transactions* for 1860 (Wilber 1861*d*:8): "The following papers were prepared—most of them—for the last meeting of the Society, and have since been revised for publication in this report." The Preface indicates that Wilber (1861*d*:3-4) was the Editor.

For many years Forbes himself did considerable editing of the papers issued by the agencies he headed. Until 1926 his principal editorial assistants were Charles A. Hart and Miss Mary Jane Snyder. "Mr. C. A. Hart, my efficient secretary," Forbes (1882*a*:8) wrote in an early report, "is responsible for the cor-

respondence, for the preparation of papers for the press, the correction of proofs, and other clerical service." To the "efficient secretary" was soon assigned the "labeling, determination, and arrangement of the insect collections" of the State Laboratory (Forbes 1887:2). By 1896 he was listed as Systematic Entomologist and Curator of Collections (Forbes 1896:2).

Miss Snyder joined the staff of the State Laboratory of Natural History in 1883 and retired from the staff of the Natural History Survey in 1925. She died in 1938 at the age of 93 years. She was listed successively as amanuensis, stenographer, secretary, and editor and proofreader. Apparently, as Hart's entomological activities increased, his editorial duties were taken over by Miss Snyder.

A scientist who knew Miss Snyder well characterized her recently as "an excellent editor." He added, "overcritical in a way." Good editors, like good scientists, are apt to be "overcritical in a way."

Tradition reports that Forbes was not easily satisfied either with his own or his assistants' papers, that he was meticulous about detail.

H. H. Chapman, Yale University staff member who worked on forestry problems for the Natural History Survey during the summers of 1922 and 1923, stated recently that Forbes was accustomed "to revising the reports of his subordinates, cutting them down to about one-fourth of their original bulk" (letter of July 10, 1958, from H. H. Chapman to C. W. Walters).

Successor to Miss Snyder in 1926 was H. Carl Oesterling, who for 2 years, before he was appointed full-time Editor of the Natural History Survey, was employed jointly by the Illinois Geological Survey, Illinois Water Survey, and Natural History Survey. Oesterling had previously taught at the University of Illinois.

After Oesterling went to the University of Illinois Press in 1931, Carroll B. Chouinard was appointed to replace him. Following Chouinard's appointment, the editorial office was called the Section of Publications. Chouinard resigned in 1937 to go to Pennsylvania State College, and James S. Ayars was appointed Editor. In 1947 the title of Editor was changed to

Technical Editor. In 1948 the Section of Publications was renamed the Section of Publications and Public Relations.

Until Mrs. Blanche Penrod Young was appointed Assistant Technical Editor in September, 1948, the editorial staff had consisted of the Editor and temporary or part-time assistants. In 1958 Mrs. Diana Root Braverman was appointed as a second Assistant Technical Editor.

For many years photographs for illustrating publications have been taken by members of the technical staff. More than 60 years ago, Forbes (1894:36) mentioned in a biennial report "a dark room for photography" among the rooms available to the State Laboratory of Natural History.

Robert E. Hesselschwerdt was the first person on the staff whose title included the word *photographer*. He was appointed Assistant Technical Photographer in 1946 and assigned to the Section of Publications. Upon his resignation in 1948, he was replaced by Charles L. Scott, who is now picture editor of the *Milwaukee Journal*.

William E. Clark, the present staff photographer, was appointed in April, 1951.

PUBLIC RELATIONS

Long before public relations in name were added to Illinois Natural History Survey activities, public relations in fact were being practiced with consummate skill. Forbes had a natural flair for public speaking and for writing. He was popular as a speaker before scientific, agricultural, and educational groups. His articles on insects and other subjects were welcomed by editors. In a biennial report Forbes (1888:8) mentioned "a considerable number of articles written for the agricultural papers in response to inquiries from their editors."

His well-organized, stimulating, even exciting reports of accomplishments by, or plans for, the agencies he represented were included as important parts of larger reports by university presidents or other administrators.

In recent years public relations media have included principally news releases (to press, radio, and television), educa-

tional motion pictures, photographs, and magazine feature articles. Many public contacts have been made each year by the Chief and members of the staff in addressing groups of persons interested in biological sciences and related subjects.

EDITORIAL POLICY

The scientific articles published by the founding fathers of the Illinois Natural History Survey and by Forbes and his contemporaries set standards of excellence that have served as a tradition and a challenge to subsequent members of the staff. Through the years, exactness of research and quality of the published reports based on research have been given precedence over quantity of research and speed of publication. Most of the organization's reports that stand as landmarks in biological literature were several years in the making. Extreme examples are some of the reports on the extensive bird studies made in 1905-1909; the last of the reports on these studies was not published until 1923 (Forbes 1907*b*, 1908, 1913; Forbes & Gross 1921, 1922, 1923).

Even 70 or more years ago, when printing and engraving processes were less efficient than now, Forbes laid great stress on adequate illustrations. His policy with respect to adequate illustrations has been continued, and with improvement in printing and engraving processes have come changes in illustration practices that have added to the convenience of readers. Instead of grouping illustrations at the end of an article, as Forbes was sometimes forced to do, recent editors have been able to place each illustration close to its principal text reference.

In the writing and editing of reports designed for publication is still felt the influence of the founding fathers, the classicists who sought to broaden the base of education. Respect for words is combined with respect for persons, the potential readers.

Editorial problems have not been so simple in the past half century as when Wilber (1861*d*:3) wrote that "the subjects have generally been treated in a popular rather than a technical style." The wide range of subject matter and the diversity of interests of the various reader

groups served by the Natural History Survey have made necessary a diversity of style and even of format. Each report to be published is written and edited for a particular reader group in the hope that to this group the report will be "immediately useful and interesting."

The joint aim of the writer, or writers, and the editorial staff is to make each published paper an orderly, logical presen-

tation of the results of a particular segment of research; to include all pertinent data and to exclude all inconsequential or extraneous matter; to achieve accuracy in original data and in quoted and paraphrased material; to state only such conclusions as can be justified by data presented; to make all statements so clear that they can be easily understood and cannot readily be misunderstood.

Library

RUTH R. WARRICK

WHEN Cyrus Thomas proposed a Natural History Society of Illinois in 1857, his plan provided for the development of a library. In the letter outlining his plan, we find this statement: "That such works as can be collected by gift, which will be useful in the investigation of Natural History and relate thereto, be gathered by the members to form a library" (Bateman 1858a:12).

While the Natural History Society was in the process of organization, Dr. E. R. Roe of Bloomington reported for the Committee on Library (Wilber 1861d:12): "That it shall contain all available works on the Natural Sciences, Home and Foreign Surveys, Manuals, Works of Reference in the several departments, Miscellaneous Works, not strictly scientific, Maps and Charts, etc."

THE LIBRARY AT NORMAL

When the Society received its charter from the state legislature in 1861, a library was provided for in Section 3 (Wilber 1861d:15):

Said natural history society shall also provide for a library of scientific works, reports of home and foreign surveys, manuals, maps, charts, etc., etc., such as may be useful in determining the fauna and flora of Illinois, and said library shall be kept in the museum of said society at the State Normal University.

This library, while it was still at Illinois State Normal University, Normal, was transferred to the Illinois State Laboratory of Natural History when the Laboratory was created in 1877.

The library served not only the members of the Natural History Society and the State Laboratory; it was used by naturalists located in other parts of the state. In the report for 1879-1880 (Forbes 1880f:9-20), a classified list of more than 300 titles of the principal works added during that period was included. This list was for the "benefit of the students of natural science throughout the State" and included works on mammals, birds,

reptiles, fishes, insects, plants, and miscellaneous biological subjects.

THE LIBRARY AT URBANA

In 1885, when Forbes accepted the position of Professor of Zoology and Entomology at Illinois Industrial University (soon to become the University of Illinois), he made the request that the property of the State Laboratory of Natural History be transferred to this University (Burrill 1887a:10-1). "The essentials of my original work and of the State natural history survey can be transferred from the Normal building to the basement of the University without detriment to any part of the work of the Normal School, . . ." The property transferred included the library (Burrill 1887a:101).

A special project of the State Laboratory of Natural History in 1893 was an exhibit of the zoology of Illinois at the Columbian Exposition, held in Chicago. This exhibit included a section of the library, "the books selected being mainly entomological, and including serial publications, periodicals, monographs, reference books, pamphlets, etc., to the number of about five hundred volumes" (Forbes 1894:7).

When the biological station was established near Havana in 1894, the libraries of the University and of the Laboratory supplied a working library of about 120 volumes (Forbes 1894:3, 19).

The floating laboratory, launched in April, 1896, had a cabin that at one end housed an office and library, 11 feet, 6 inches by 16 feet. A 24-page illustrated pamphlet describing the biological station contained the information that to summer students doing research "access will be given to the biological library of the Station. Books will also be loaned, as needed, from the library of the State Laboratory of Natural History and from that of the University of Illinois" (Forbes 1896:16, 26-7).

The library remained in the possession of the State Laboratory of Natural History and its successor, the State Natural History Survey, until 1928, when it was turned over to the University of Illinois Library (Cunningham 1928:275-6). This transfer was made with the following stipulations:

1. That each article now belonging to the library of the Natural History Survey or added to it hereafter shall bear a distinctive mark;
2. That such additions shall be made to it, from time to time, as are necessary to the work of the Natural History Survey as certified by the Chief thereof and approved by the President of the University; and
3. That the scientific staff of the Natural History Survey shall have at all times a prior right to the use of books, pamphlets, and papers of the aforesaid library, their use by members of the faculty and by the students of the University being second to this claim.

When the Natural History Building was completed, the library moved to the rooms assigned to it (Forbes 1894:35-6).

Since my last report to you the State Laboratory has removed to the rooms assigned to it in the new Natural History Hall of the University of Illinois, five on the first floor and two in the basement. These rooms are a Director's office, 21 ft.x19 ft., a library room 22x32, . . .

Provision was again made for a separate library when the Natural Resources Building was planned. Plans for transferring the book collection from the Natural History Building to the Natural Resources Building were being considered as early as July, 1939. A letter dated July 26, 1939, from Dr. P. L. Windsor, Director of University Libraries, to Dr. T. H. Frison, Chief of the Natural History Survey, contained this statement:

I am beginning to think of the preparations that will have to be made when the State Survey building is completed and you take over with you, such parts of the Natural History Library as you think are necessary for your current work.

After much planning and working out of policies, an agreement between the Natural History Survey and the University was reached. This agreement was outlined in a letter dated January 22, 1941, from Dr. Carl M. White, then Director of University Libraries, to Dr. Frison, as follows:

(1) The University is to catalog all books, journals, etc., including arrears and recataloging.

(2) The University is to provide in the regular library budget a fund for the purchase of books for the Natural History Survey (at present \$400).

(3) The University is to manage the Natural History Survey Library the same as other departmental libraries, including provision of service to the Natural History Survey from other libraries on the campus. The professional staff of the Survey is to receive service from the various libraries on the campus on the same basis as the faculty of the University.

(4) The University is to allow the Natural History Survey "preferred use" of the material in the Natural History Survey Library as "preferred use" is defined in your letter to me of December 16.

(5) The University is to provide, besides general supervision, the sum of \$700 in 1940-41 for staff in the Natural History Survey Library.

It is to provide \$1500 for each year of the biennium 1941-43.

(6) The Natural History Survey is to provide housing for such books as need to be housed in the Natural Resources Building.

(7) The Survey is to relieve the University September 1, 1943, of the responsibility for providing staff for library service.

The Natural History Survey Library, opened as a separate unit in September, 1940 (Lill 1942:1), was located on the fourth floor of the Natural Resources Building, and remained in that location until the west wing of the Natural Resources Building was completed. In February, 1952 (Simmons 1952:1), the library was moved to its permanent location on the first floor at the south end of the west wing.

LIBRARY COLLECTIONS

In a paper, "Natural History in Schools," which was read before the Illinois State Teachers' Association in 1860, A. M. Gow of Dixon gave a brief history of the Illinois Natural History Society and stated that its library at that time contained 300 volumes (Gow 1861:96).

Professor Forbes in his 1881-1882 report stated that additions to the library since his last report had been 360 volumes and 200 pamphlets, many of them "rare and costly works—the foundation stones of zoölogical and botanical literature" (Forbes 1882a:7). He wrote that

"particular attention has been paid to cataloguing, and this has been kept fully abreast of the additions. A card catalogue of authors is now absolutely complete to date, and a subject catalogue is well under way."

In 1885, when the State Laboratory of Natural History was transferred from Illinois State Normal University to the University of Illinois at Urbana, the library had a collection of 1,207 bound volumes and 3,856 pamphlets and periodicals (Burrill 1887a:101). The library additions in 1899-1900 were 648 volumes and 764 pamphlets (Forbes 1901:11). Professor Forbes in 1909 stated that the library then had nearly 7,000 books and something over 17,000 pamphlets (Forbes 1909:55-6).

The library at present contains over 19,000 volumes and approximately 5,000 pamphlets, the greater part being periodicals and other serials. The field of entomology is represented most strongly in the collection, but other subjects, such as

zoology, botany, wildlife, and conservation, are emphasized.

For many years, the library has added to its collection by exchanging the publications of the State Laboratory of Natural History and the Natural History Survey with other institutions. The policy toward exchanges was expressed by Mr. Tow (1861:96) nearly 100 years ago: "The library of the Society will embrace everything that can be procured by gift, purchase or exchange, upon Natural History in particular, and Science in general."

As the number of publications of the State Laboratory increased, the library was able to establish a larger number of exchanges, especially with European societies and institutions (Forbes 1901:10).

We are now receiving in exchange for our State Laboratory Bulletin one hundred and eighty-one periodical scientific publications, of which fifty-nine are American, twenty-eight are British or British-colonial, twenty-six are German, sixteen French, twelve Italian, and the remaining forty are Russian, Swedish, Norwegian, Danish, Dutch, Hun-



Part of the Illinois Natural History Survey library in the Natural Resources Building. This library is noted especially for its large collection of bound volumes of periodicals in the biological sciences.

garian, Portugese, Egyptian, South American, and Japanese.

At the present time the library has an exchange arrangement with approximately 500 scientific institutions and societies, a large number of which are foreign.

LIBRARY PERSONNEL

Provision for the care of the library has been made from the beginning of the Natural History Society to the present time. The person in charge of the library has always had the title *librarian* and has been a member of the staff, first of the Natural History Society (Wilber 1861*d*:10) and later a member of the staff of each of the state agencies that followed, except for a period from 1928 (Cunningham 1928:275) to 1943 when the University of Illinois assumed full responsibility for the book collection.

The first librarian was Ira Moore, instructor in mathematics at Illinois State Normal University (Wilber 1861*d*:10; Hovey 1859:401). His duties were definitely stated in the Report of Committee on Library (Wilber 1861*d*:12):

It shall be the duty of the Librarian to arrange the books of the Society, to make and keep a catalogue of the same, to keep a record of the books drawn from the library as directed by the Society, and report to the Society at its annual meeting.

In a report to the Regent of the University of Illinois in 1886, Professor Forbes mentioned a librarian among the personnel of the State Laboratory (Burrill 1887*a*:101). Henry Clinton Forbes served as Librarian and Business Agent of the Laboratory from 1892 to 1902 (Pillsbury 1892:284; 1894:135; 1896:[14]; 1898:[15]; 1901:xvii; 1902:xx).

The policy of appointing professional librarians was started in 1906 with the appointment of Miss Edna Lucy Goss, B.L.S. (Pillsbury 1906:xxii) and has continued to the present.

FINANCIAL SUPPORT

Financial support for the library has always been considered of great importance. It was considered important even before the Illinois Natural History Society became a chartered organization. In

the Report of Committee on Library, the following provision for a library was made (Wilber 1861*d*:12): "That the Society devote all moneys obtained by donations and memberships to this important object [library], except so much as are necessary for expenses."

In an early report of the Director of the State Laboratory of Natural History, a plea was made for a public scientific library (Forbes 1878*b*:5-6):

A most indispensable requisite for thorough work in any direction is an increase of the Library. Much of the time and money already invested in the Laboratory collections and belongings must lie idle until this improvement is made. There is not anywhere within reach of our naturalists a scientific library sufficient to assist them to reliable original work in any department of natural history. Nothing which the State could do for science would so stimulate a productive activity among them as a moderate appropriation for a public scientific library; and there is evidently no place where this library may be so properly built up as in connection with the State Laboratory of Natural History. I have therefore included the sum of \$2,000 for this purpose in my estimates, and the further sum of \$200 for the services of a Librarian, to catalogue and thoroughly organize the accessions on the plan already in use. This plan of organization place[s] the resources of the library at the ready command of the investigator, without requiring that complete previous acquaintance with the literature of his subject which he can gain only by long use of a large library. It is proposed to use the money which may be voted for library purposes, first of all to procure those books now actually needed by our Illinois naturalists for the successful prosecution of the original investigations upon which they are at present engaged, and to provide for the future only when these present pressing needs have been supplied.

The state legislature granted part of the appropriation requested by Professor Forbes. In a subsequent report he made a statement concerning the value of the library (Forbes 1880*f*:9):

No expenditure made by the Laboratory during the last two years has been so immediately profitable, both to the work of the establishment and to the studies of other naturalists, as that made for new books. While the additions are very few compared with the literature needed, they have cleared the field of difficulties which have blocked the progress of our work for years, and have first made possible to the students of our local natural history, original work of a satisfactory character, in a few departments of zoölogy and botany.

The library received its support from appropriations made by the state legislature to the State Laboratory or Natural History Survey until the books were transferred to the University of Illinois, at which time the University assumed the responsibility for the book collection (Cunningham 1928:275-6).

After 100 years of library service to the staff and to the naturalists of the

state, we hope that a statement made by Professor Forbes a half century ago is still true and that the library will always maintain the high standard set for it by its founders. "Apart from its collections, . . . the most useful possession of the Laboratory is its library, which is the product of many years of careful selection and purchase of the literature of the world . . ." (Forbes 1909:55).

Former Technical Employees

Illinois Natural History Society, Illinois State Entomologist's Office, Illinois State Museum of Natural History, Illinois State Laboratory of Natural History, Illinois Natural History Survey

BESSIE B. EAST

FOLLOWING is a partial list of former employees of the Illinois Natural History Society (1858-1871), Illinois State Entomologist's Office (1867-1917), Illinois State Museum of Natural History (1871-1877), Illinois State Laboratory of Natural History (1877-1917), and Illinois Natural History Survey (since 1917). The list is not complete because early records are fragmentary or do not exist, and because, for the sake of brevity, it seemed desirable to omit the names of many short-term or part-time employees. A number of collaborators who worked closely with regular staff members are not listed, although they made contributions to the official publications. Because

of their important contributions to the work of the Natural History Society and the maintenance of its collections, the names of two early curators, C. D. Wilber (1858-1864) and Joseph A. Sewall (1864-1867), and of the first librarian, Ira Moore (1858-1863), have been included; all three were members of the staff of Illinois State Normal University.

The first official employee whose salary was paid from funds appropriated by the state legislature for that purpose was John Wesley Powell, appointed Curator in 1867. From this beginning, the staff has increased to its present total of 101. No present employees are included in the following list.

ADAMS, CHARLES CHRISTOPHER
Entomologist, 1896-1898

ADAMS, LEVERETT ALLEN
Zoologist, 1929

ALEXANDER, CHARLES PAUL
Entomologist, 1919-1922

ALEXOPOULOS, CONSTANTINE J.
Botanist, 1930-1931

AMES, RALPH WOLFLEY
Plant Pathologist, 1951-1952

ANDERSON, HARRY WARREN
Botanist, 1922

ANDERSON, JOHN M.
Biologist, 1939-1941

APPLE, JAMES WILBUR
Entomologist, 1943-1949

AUDEN, KENNETH FRANCIS
Entomologist, 1925-1927

BAKER, FRANK COLLINS
Zoologist, 1931-1932

BALDUF, WALTER VALENTINE
Entomologist, 1923

BARNICKOL, PAUL GEORGE
Aquatic Biologist, 1945-1948

BARRETT, E. G.
Botanist, 1931-1932

BEACH, ALICE MARIE
Entomologist, 1899-1900

BERGER, BERNARD GEORGE
Entomologist, 1941-1945

BETTEN, CORNELIUS
Entomologist, 1931

BROWN, FRANK ARTHUR
Zoologist, 1935

BURKS, BARNARD DE WITT
Entomologist, 1937-1949

BURRILL, THOMAS JONATHAN
Botanist, 1885-1892

BUTLER, CYRUS W.
Biologist, 1880-1882

CAMPANA, RICHARD JOHN
Plant Pathologist, 1952-1958

CAMPBELL, LEO
Botanist, 1930-1931

CHANDLER, STEWART CURTIS
Entomologist, 1917-1957

CHAPMAN, HERMAN HAUPT
Forester, 1922-1923

CHASE, ELIZABETH BROWN
Biologist, 1945-1948

CHOUINARD, CARROLL BENEDICT
Editor, 1931-1937

COMPTON, CHARLES CHALMER
Entomologist, 1921-1944

COQUILLET, DANIEL WILLIAM
Entomologist, 1881

- CRAIG, WALLACE
Aquatic Biologist, 1898-1899
- CRAWLEY, HENRI DOUGLAS
Forester, 1950-1951
- CREAGER, DON BAXTER
Plant Pathologist, 1939-1943
- CULVER, LAWSON BLAINE
Forester, 1947-1954
- DANIELS, EVE
Botanist, 1924-1926
- DAVIS, JAMES ELWOOD
Forester, 1935-1947
- DAVIS, JOHN JUNE
Entomologist, 1907-1911
- DECOURSEY, JOHN D.
Entomologist, 1929-1932
- DELONG, DWIGHT MOORE
Entomologist, 1934-1936, 1938, 1941, 1945
- DOZIER, HERBERT LAWRENCE
Entomologist, 1932
- DRIVER, ERNEST CHARLES
Zoologist, 1930
- DUGGAR, BENJAMIN MINGE
Botanist, 1895-1896
- DURHAM, LEONARD
Aquatic Biologist, 1947-1950
- EARLE, FRANKLIN SUMNER
Mycologist, 1886
- EDDY, SAMUEL
Botanist, 1925-1929
- ELDER, WILLIAM HANNA
Game Specialist, 1941-1943
- ENGELHARD, ARTHUR WILLIAM
Plant Pathologist, 1955-1956
- FARRAR, MILTON DYER
Entomologist, 1931-1946
- FELL, RACHEL M.
Botanist, 1881-1882
- FERRIS, JOHN MASON
Plant Pathologist, 1957-1958
- FISK, VERNON C.
Forester, 1921-1923
- FLINT, WESLEY PILLSBURY
Entomologist, 1907-1943
- FORBES, ERNEST BROWNING
Zoologist, 1894-1896, 1899-1901
- FORBES, HENRY CLINTON
Librarian, 1894-1902
- FORBES, STEPHEN ALFRED
Curator, State Museum of Natural History, 1872-1877; Director, State Laboratory of Natural History, 1877-1917; State Entomologist, 1882-1917; Chief, Natural History Survey, 1917-1930
- FOSTER, T. DALE
Zoologist, 1931-1932
- FRENCH, GEORGE HAZEN
Entomologist, 1877-1878
- FRISON, THEODORE HENRY
Entomologist, 1923-1930; Chief, Natural History Survey, 1930-1945
- GARMAN, PHILIP
Entomologist, 1914
- GARMAN, W. HARRISON
Zoologist, 1877-1889
- GIRAULT, ALECANDERE ARSENE
Entomologist, 1908-1911
- GLASGOW, ROBERT DOUGLASS
Entomologist, 1905-1909, 1912-1915, 1927
- GLENN, PRESSLEY ADAMS
Entomologist, 1911-1917
- GODING, FREDERICK WEBSTER
Entomologist, 1885
- GOFF, CARLOS CLYDE
Entomologist, 1927-1930
- GOSS, EDNA LUCY
Librarian, 1906-1908
- GROSS, ALFRED OTTO
Ornithologist, 1906-1907, 1909, 1912
- HANKINSON, THOMAS LEROY
Zoologist, 1911
- HARRIS, HUBERT ANDREW
Botanist, 1930-1933
- HART, CHARLES ARTHUR
Entomologist, 1880-1918
- HART, LYDIA MOORE
Artist, 1891-1898
- HAWKINS, ARTHUR STUART
Game Specialist, 1938-1945
- HAYES, WILLIAM PATRICK
Entomologist, 1926, 1928-1934
- HEMPEL, ADOLPH
Zoologist, 1894-1896
- HESSELSCHWERDT, ROBERT EDWARD
Zoologist, 1936-1942; Photographer, 1946-1948
- HOFFMAN, PAUL FREDRICK, JR.
Plant Pathologist, 1951-1954
- HOOD, JOSEPH DOUGLAS
Entomologist, 1910-1912
- HOTTES, FREDERICK CHARLES
Entomologist, 1928-1930
- HUNT, FRANCIS D.
Aquatic Assistant, 1925-1937
- HUNT, THOMAS FORSYTH
Entomologist, 1885-1886
- HUTCHENS, LYNN HENRY
Aquatic Biologist, 1936-1938, 1946-1947

- JANVRIN, CHARLES EDWIN
Librarian, 1912-1929
- JOHNSON, WILLIS GRANT
Entomologist, 1894-1896
- JORDAN, JAMES SCHUYLER
Game Specialist, 1948-1955
- KAHL, HUGO
Entomologist, 1892-1894, 1901-1902
- KELLEY, GRACE OSGOOD
Librarian, 1908-1912
- KNAB, FREDERICK
Artist, 1903-1905
- KNIGHT, HARRY HAZELTON
Entomologist, 1930, 1932-1933, 1937
- KNIGHT, KENNETH LEE
Entomologist, 1938-1939
- KOFOID, CHARLES ATWOOD
Aquatic Biologist, 1895-1900
- KRUMHOLZ, LOUIS A.
Zoologist, 1938-1941
- KUDO, RICHARD R.
Zoologist, 1930
- LARGE, THOMAS
Aquatic Biologist, 1899-1902
- LE BARON, WILLIAM
Entomologist, 1870-1875
- LEIGH, WALTER HENRY
Game Specialist, 1935-1938
- LOW, JESSOP BUDGE
Game Specialist, 1941-1943
- LUCE, WILBUR MARSHALL
Zoologist, 1929-1930, 1932
- LUETH, FRANCIS X.
Zoologist, 1939-1940
- MCCAULEY, WILLIAM EDWARD
Entomologist, 1934-1941
- MCCLURE, HOWE ELLIOTT
Entomologist, 1930-1933
- MCCORMICK, A. K.
Aquatic Biologist, 1881-1882
- MCDUGALL, WALTER BYRON
Botanist, 1928
- MALLOCH, JOHN RUSSELL
Entomologist, 1913-1921
- MALLY, FREDERICK WILLIAM
Entomologist, 1889-1890
- MALTBY, CORA M.
Librarian, 1885-1886
- MARTEN, JOHN
Entomologist, 1888-1894
- MIDDLETON, NETTIE
Entomologist, 1878-1880
- MILLER, AUGUST EDWARD
Entomologist, 1926-1928
- MILLER, ROSS JEWELL
Forester, 1947-1956
- MILNER, ANGE V.
Librarian, 1880-1882
- MOORE, IRA
Librarian, 1858-1863
- MOORE, THOMAS EDWIN
Entomologist, 1948-1956
- NYBERG, FLORENCE ANNA
Assistant to the Chief, 1922-1945
- O'DONNELL, DONALD JOHN
Zoologist, 1931-1937
- OESTERLING, H. CARL
Editor, 1926-1931
- PEAKE, CHARLES O.
Botanist, 1921-1923
- PEIRCE, ALAN STANLEY
Botanist, 1933-1934
- PEPOON, HERMAN S.
Botanist, 1931-1933
- PLUNKETT, ORDA ALLEN
Botanist, 1922
- PORTER, CHARLES LYMAN
Botanist, 1921-1922
- POWELL, JOHN WESLEY
Curator, 1867-1872
- POWERS, EDWIN BOOTH
Entomologist, 1917
- RASMUSSEN, DANIEL IRVIN
Biologist, 1931-1932
- RICHARDS, WILLIAM ROBIN
Entomologist, 1950-1953
- RICHARDSON, ROBERT EARL
Aquatic Biologist, 1903-1904,
1909-1933
- RIEGEL, GARLAND TAVNER
Entomologist, 1938-1942
- RIES, DONALD TIMMERMAN
Naturalist, 1938
- ROBERTSON, WILLIAM BECKWITH, JR.
Game Specialist, 1952-1956
- SAWYER, LESLIE EDWIN
Forester, 1929-1935
- SCHNEIDER, IRVING ROBERT
Plant Pathologist, 1954-1956
- SCHOPF, JAMES
Botanist, 1931
- SCHREDER, W. F.
Forester, 1921-1925
- SCOTT, CHARLES L.
Photographer, 1948-1951
- SELANDER, RICHARD B.
Entomologist, 1955-1958
- SEWALL, JOSEPH A.
Curator, 1864-1867
- SEYNOUR, ARTHUR BLISS
Botanist, 1881-1883, 1884, 1886

- SHELFORD, VICTOR ERNEST
Ecologist, 1914-1927
- SHOEMAKER, HURST
Zoologist, 1942, 1944
- SHROPSHIRE, LESLIE HAROLD
Entomologist, 1931-1942
- SIMMONS, LILLIAN MARGUERITE
Librarian, 1943-1952
- SMITH, DORA
Biologist, 1894
- SMITH, EMMA A.
Entomologist, 1877
- SMITH, FRANK
Zoologist, 1894-1897, 1907-1910
- SMITH, LINDLEY MALCOLM
Entomologist, 1907-1917
- SNOW, FRANCIS HUNTINGTON
Entomologist, 1892
- SNYDER, MARY JANE
Amanuensis and Editor, 1883-1925
- SOMMERMAN, KATHRYN MARTHA
Entomologist, 1939-1946
- SOWLS, LYLE K.
Game Specialist, 1940-1941
- SPOONER, CHARLES S.
Entomologist, 1917-1920
- SPOONER, CHARLES S., JR.
Biologist, 1939-1942
- STANLEY, WILLARD FRANCIS
Zoologist, 1935
- STOUT, GILBERT LEONIDAS
Botanist, 1926-1930
- SUMMERS, HENRY ELIJA
Entomologist, 1892-1893
- SURANY, PAUL
Entomologist, 1950-1955
- SURFACE, HARVEY ADAM
Zoologist, 1899
- TANQUARY, MAURICE COLE
Entomologist, 1910-1912
- TAYLOR, ESTES PARK
Entomologist, 1903-1905
- TEHON, LEO ROY
Botanist, 1921-1954; Acting Chief,
Natural History Survey, 1945-1946
- TELFORD, C. J.
Forester, 1921-1929
- THOMAS, CYRUS
Entomologist, 1875-1882
- THOMPSON, DAVID HIRAM
Zoologist, 1923-1944
- TITUS, EDWARD SHARP GAIGE
Entomologist, 1902-1903
- TOWNSEND, LEE HILL
Entomologist, 1932-1936
- TRUMBOWER, JOHN ABBOTT
Botanist, 1932-1933
- VAN CLEAVE, HARLEY JONES
Parasitologist, 1911-1912
- VASEY, GEORGE W.
Acting Curator, 1871-1872
- VESTAL, ARTHUR GIBSON
Botanist, 1909
- VON LIMBACH, BRUNO
Zoologist, 1940-1945
- WADLEY, FRANCIS MARION
Entomologist, 1920
- WALSH, BENJAMIN D.
Entomologist, 1867-1869
- WANDELL, WILLET NORBERT
Forester, 1945-1954
- WEBSTER, FRANCIS MARION
Entomologist, 1881-1884,
1902-1904
- WEED, CLARENCE MOORES
Entomologist, 1885-1888
- WEINMAN, CARL JOHN
Entomologist, 1937-1952
- WEST, JAMES ALEXANDER
Entomologist, 1905-1908
- WILBER, C. D.
Curator, 1858-1864
- WOLF, JOHN
Botanist, 1880
- WOOD, FRANK ELMER
Aquatic Biologist, 1905-1909
- WOODWORTH, C. W.
Entomologist, 1884-1886
- WRIGHT, JOHN McMASTER
Entomologist, 1943-1957
- YEAGER, LEE EMMETT
Forester, 1938-1945
- YOUNG, PAUL ALLEN
Botanist, 1922-1925
- YUASA, HACHIRO
Entomologist, 1921-1922
- ZETEK, JAMES
Entomologist, 1909-1911
- ZUCKERMAN, BERT MERTON
Plant Pathologist, 1951-1954

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Some Recent Publications of the
ILLINOIS NATURAL HISTORY SURVEY

BULLETIN

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ILLINOIS NATURAL HISTORY SURVEY
Bulletin

*Printed by Authority of
the State of Illinois*



Lead Poisoning
as a Mortality Factor
in Waterfowl Populations

FRANK C. BELLROSE

STATE OF ILLINOIS • WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION • VERA M. BINKS, *Director*
NATURAL HISTORY SURVEY DIVISION • HARLOW B. MILLS, *Chief*

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This paper is a contribution from the Section of Wildlife Research.

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A few of the 2,000 wild mallards that were victims of a lead poisoning outbreak near Grafton, Illinois, in January, 1948. (Photograph from Western Cartridge Company.)

Lead Poisoning as a Mortality Factor in Waterfowl Populations

FRANK C. BELLROSE

THE mortality resulting from lead poisoning in populations of wild waterfowl has been a cause of concern to conservationists for many years. This concern has grown out of the knowledge that lead poisoning is of common occurrence among waterfowl, that this poisoning results from the ingestion of lead by the birds in their feeding, and that large numbers of lead pellets fired from the guns of hunters lie in lakes and marshes visited by waterfowl.

Phillips & Lincoln (1930:166), over two decades ago, stated: "From this account it will be seen that lead poisoning due to eating shot is of common occurrence, and it seems reasonable to presume that the disease will continue and even increase in the great ducking marshes of the country. The ultimate conclusions as to its effect upon the supply of waterfowl are hazardous to imagine." A few years later Dr. E. C. O'Roke of the University of Michigan was quoted in *Michigan Waterfowl Management* (Pirnie 1935: 75-6) as follows: "Considering the enormous quantity of lead that there must be in the vicinity of blinds that have been shot over for decades, it is reasonable to conclude that the potential danger from lead poisoning is great and should be considered in any waterfowl management program. In the writer's opinion lead poisoning is the disease which takes the greatest toll of adult ducks in this section of the country."

This theme was reiterated by Cottam (1949:339-40) who, in discussing further needs in wildlife research, suggested that "direct and indirect effects of lead shot in the digestive tracts of birds may be an exceedingly important stumbling block in the restoration of waterfowl. At the close of the hunting season live birds are carrying in their bodies an alarming amount of lead, and this condition may be much more widespread than we have

realized. There is urgent need to ascertain the effects of the lead shot used in hunting."

These remarks point up the generally recognized need for further appraisals of the problem, which was brought home to officials of the Illinois Natural History Survey and Western Cartridge Company (the latter now the Winchester-Western Cartridge Division of Olin Mathieson Chemical Corporation) at the time of a publicized die-off of wild ducks, frontispiece, near Grafton, Illinois, in January of 1948 (Jordan & Bellrose 1951:10-1). As a result of a common interest in the problem of lead poisoning in waterfowl, the two groups supported a joint research project embracing the following objectives: (1) evaluation of losses from lead poisoning in wild waterfowl, (2) investigation of lead alloys and other metals as materials for possible use as nontoxic shot, and (3) determination of the physiological effects of lead poisoning in waterfowl.

The present paper is devoted primarily to the evaluation of losses resulting from lead poisoning in wild waterfowl populations. Two reports have been published which presented preliminary findings on this subject (Bellrose 1951; Jordan & Bellrose 1951). Efforts to develop a nontoxic shot were treated in a paper dealing with the value of various shot alloys in relation to lead poisoning (Jordan & Bellrose 1950); additional data on this subject are presented herein. Findings as to the physiological effects of lead poisoning on captive waterfowl have been discussed in a paper by Jordan & Bellrose (1951).

The approach toward evaluating the importance of lead poisoning in wild waterfowl was threefold: (1) appraisal of the incidence and magnitude of waterfowl die-offs resulting from lead poisoning, (2) appraisal of the incidence of

ingested lead shot among waterfowl populations in fall and early winter, and (3) appraisal of waterfowl losses resulting from the ingestion of various quantities of lead shot per bird.

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The writer is most grateful to the many persons in various parts of the North American continent who furnished material and data. Without their aid, it would have been impossible to appraise the importance of lead poisoning on such an extensive basis.

The sources of much of the information outside of Illinois are acknowledged in the text or tables. However, the sources of material and data related to the occurrence of lead shot in waterfowl gizzards have been so numerous as to make such acknowledgment cumbersome. Acknowledgment is made here to those persons who sent 100 or more waterfowl gizzards for examination: Harold M. Swope, Colorado; E. B. Chamberlain, Jr., Florida; William P. Baldwin, Jr., Georgia and South Carolina; Robert L. Salter, Idaho; James D. McCall and Russell E. Mumford, Indiana; Richard K. Yancey and Charles W. Bosch, Louisiana; Howard L. Mendall, Maine; Gordon T. Nightingale and Dave Grice, Massachusetts; Forrest B. Lee, Minnesota; Harvey Miller, Nebraska; Fred E. Wright, Nevada; T. Stuart Critcher and Yates M. Barber, Jr., North Carolina; Brandt V. Hjelle, North Dakota; William B. Morse, Oregon; Ray Murdy and Clair T. Rollings, South Dakota; J. R. Singleton, Texas; Allen G. Smith, Utah.

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Without the financial assistance provided by Olin Mathieson Chemical Corporation, much of this study would have been impossible.

LEAD POISONING DIE-OFFS

The most dramatic expressions of lead poisoning in waterfowl are die-offs in which large numbers of birds in relatively small areas perish in short periods of time. Most of those persons who are seriously concerned about lead poisoning among waterfowl have been convinced of the importance of the malady through witnessing one or more die-offs. Because

of its emotional impact on any person who sees it, a waterfowl die-off is an event that is remembered and chronicled for a number of years.

Three approaches have been made by the author of this paper in evaluating the importance of die-offs among waterfowl in the United States: (1) a study of the



Fig. 1.—Opened duck gizzards and the ingested lead shot they contained. Black spots on the horny linings of the gizzards mark areas of tissue destruction by lead salts.



Fig. 2.—Two mallard stomachs: the lower one from a lead-free duck, the upper from a lead-poisoned duck. The glandular stomach attached to the gizzard of the lead-poisoned mallard shows impaction of small grains. The impaction of food resulting from malfunctioning of the gizzard is one of the symptoms of lead poisoning in waterfowl.

literature, (2) personal on-the-spot investigations of die-offs in Illinois and Louisiana, and (3) a canvass of state and federal conservation agencies for recent records of lead poisoning outbreaks among waterfowl.

In studying several large outbreaks of lead poisoning in Illinois, 1940-1954, and at Catahoula Lake, Louisiana, 1953, the author and his associates undertook a tally of all dead and dying ducks found and of feathers marking the demise of birds. Rough compensations were made for areas not covered and for the time of each sampling in relation to the period of the outbreak. An estimate was made of the duck population in each area.

Samples of dead and dying ducks were collected. These ducks were sexed, aged, weighed, and fluoroscoped. Fluoroscopic procedure was similar to that described by Jordan & Bellrose (1950:158) and by Bellrose (1953:341). Examinations were made of lead shot pellets in gizzards of a number of dead ducks and were found to agree closely with fluoroscopic findings. Gizzards from lead-poisoned ducks are shown in figs. 1 and 2.

Early Die-Offs

Records of lead poisoning in North American waterfowl date back to the latter half of the nineteenth century. From remarks made by Phillips & Lincoln (1930:164), it is assumed that lead poisoning in waterfowl was known at least as early as 1874. According to them, the March, 1894, issue of the *American Field* carried a note reporting that two lots of ducks which were unfit for food (presumably as a result of lead poisoning) were seized at Galveston, Texas. These ducks had been taken at Stephenson Lake, where the disease had been noted for 20 years.

More than 60 years ago, George Bird Grinnell (1894:112) and E. Hough (1894:117) reported in *Forest and Stream* on some of the effects of lead poisoning on waterfowl as determined from observations made during the winter of 1893-94. A few years later, Grinnell (1901:598-601), in addition to reviewing his earlier account on the appearance and behavior of a sick goose and a sick swan at Currituck Sound, North Caro-

lina, stated that lead poisoning occurred among waterfowl in Texas at Galveston, at Stephenson Lake, and on Lake Surprise.

A half century ago, Bowles (1908:312-3) recorded the loss of a number of mallards (*Anas platyrhynchos*) from lead poisoning on the "Misqually" (presumably Nisqually) Flats of Puget Sound, Washington. McAtee (1908:472) in the same year gave an account of lead poisoning in canvasbacks (*Aythya valisineria*) at Lake Surprise, Texas.

Wetmore (1919:2) reported that several whistling swans (*Olor columbianus*) from Back Bay, Virginia, were examined by the U. S. Biological Survey in January of 1915. Twenty-two to 45 shot pellets were found in the gizzard of each swan, indicating that the birds had been affected by lead poisoning. He reported also that during the summers of 1915 and 1916 in the Bear River marshes of Utah many mallards and pintails (*Anas acuta*) were affected by lead poisoning. These ducks were found in the period June-September, and, although many died, the total was insignificant as compared with losses from other causes in the Bear River marshes.

In discussing lead poisoning, Phillips & Lincoln (1930:165-6) recorded an instance in which "thousands" of ducks were reported dying at Hovey Lake, Indiana, in February, 1922, from an unknown malady that was later diagnosed as lead poisoning. The report they found to be "much exaggerated." They observed that "Possibly the most serious condition exists in Louisiana, where duck mortality from this cause may sometimes be further complicated by internal parasites and possibly at times by lack of food"; that newspapers reported in January of 1925 that "thousands" of ducks were dying in Louisiana, apparently from lead poisoning, for all the specimens examined were found to have ingested lead shot; and that large numbers of ducks died from lead poisoning in the Jacobs and Pecan Lake region of Arkansas in January of 1925.

Van Tyne (1929:103-4) reported that at Houghton Lake, Michigan, in April of 1928, greater scaups (*Aythya marila*) died from lead poisoning. Of 10

stomachs examined by Van Tyne, most contained 40 to 60 pellets of lead, and one contained 80 pellets. Elsewhere in Michigan, Pirnie (1935:74-5) reported that the deaths of five Canada geese (*Branta canadensis*) in Barry County in the spring of 1933, and a similar loss in Cass County in April, 1935, apparently were the result of lead poisoning.

Munroe (1925:160) recorded that one adult trumpeter swan (*Olor buccinator*) and six cygnets had died from lead poisoning in British Columbia during the winter of 1925.

E. R. Kalmbach (unpublished report, March 6, 1930, in files of U. S. Fish and Wildlife Service) observed a lead poisoning die-off of ducks in the coastal marsh area south of Gueydan, Vermilion Parish, Louisiana, in February of 1930. In a 200-acre rice field he found 199 dead ducks: namely, 120 pintails, 71 mallards, and 8 lesser scaups (*Aythya affinis*). Kalmbach believed that the toll in the rice field was greater than that found in any other area of similar size, but that losses occurred throughout 300 or more square miles of marsh. Albert Bonin, a resident of that area, told Kalmbach that sick ducks had been observed in the Florence section for at least 30 years. In Bonin's experience, the spring of 1921 marked the severest outbreak noted in that region.

Shillinger & Cottam (1937:399) recorded the following waterfowl losses from lead poisoning, all in the fall and early winter of 1936: 8 ducks from the coast of North Carolina; 5 mallards from the Pamlico Sound area of Virginia; 14 ducks from Delaware Bay; 12 ducks from northern Ohio; and 100 ducks, most of them mallards, from Boyd Lake, Colorado. The same authors (1937:402) gave an account of a die-off of ducks at the Sand Lake National Wildlife Refuge, South Dakota, during November and December of 1935. Of 113 mallards examined there by John J. Lynch, 103 were deemed victims of lead poisoning. Deaths of 6 other individuals, representing four species of ducks, were attributed to this disease.

Recent Die-Offs

In this review of lead poisoning die-offs, it has been necessary to rely almost

entirely upon unpublished accounts for information up to 1937. Since that time only a few reports have been published (Mohler 1945; Bellrose 1947; Ayars 1947; Yancey 1953) but, fortunately, outbreaks have been recorded in letters and reported by biologists of state conservation agencies and the U. S. Fish and Wildlife Service.

Data on most of the known die-offs of waterfowl from lead poisoning for the period beginning with the winter of 1938-39 and extending through the winter of 1956-57 are summarized in table 1. These data have been obtained by contacting all state conservation agencies in the United States, as well as those in Ontario and British Columbia, plus the following branches of the U. S. Fish and Wildlife Service: Wildlife Refuges, Game Management, and Wildlife Research. Most of the information has been obtained from letters and file reports graciously made available by waterfowl biologists of these agencies.

In addition to the information presented in table 1, many details have been made available which could not readily be recorded in tabular form. Therefore, it seems advisable to give a flyway-by-flyway roundup of information on the occurrence of waterfowl die-offs resulting from lead poisoning.

Atlantic Flyway.—Lead poisoning in waterfowl apparently is not an important mortality factor in the Atlantic Flyway. The largest reported losses, table 1, amount to about 600 Canada geese and whistling swans which were picked up over a 10-year period in North Carolina.

The following comments, from letters by waterfowl biologists in that flyway, illustrate the paucity of reports of die-offs from this malady. Dr. C. H. D. Clarke (letter, April 4, 1955) of the Ontario Department of Lands and Forests reported: "I know of no die-off worthy of the name from lead poisoning in Ontario. From time to time we have picked up individual poisoned waterfowl at various places where they are concentrated."

Of the situation in Maine, Howard E. Spencer, Jr. (letter, March 28, 1955), wrote: "I have no knowledge of any die-offs which could be associated in any way with lead poisoning." From Vermont,

Table 1.—Important waterfowl die-offs, 1938–1957, which have been attributed to lead poisoning and for which adequate data have been reported.

LOCATION	TIME OF OCCURRENCE	PRINCIPAL SPECIES INVOLVED	NUMBER OF BIRDS PRESENT	NUMBER OF BIRDS LOST	PER CENT OF BIRDS LOST	AUTHORITY
ATLANTIC FLYWAY						
North Carolina						
Mattamuskeet National Wildlife Refuge	Jan., March, 1945–1954	Canada goose, whistling swan		580+		Richard E. Griffith (letter, April 1, 1955), U. S. Fish and Wildlife Service
MISSISSIPPI FLYWAY						
Minnesota						
Heron Lake	{ Dec., 1938 { Winter, 1939–40 Oct., 1939	Mallard Mallard Mallard	10,000	100+ 200+ 65+	1.0	Gustav Swanson and C. Gordon Fredline, reference cited in footnote to table 4
Lake Winnibigoshish	Dec., 1949	Canada goose	5,000	106	2.1	L. R. Jahn (Wisconsin P.-R. Quarterly Progress Report and letter, Feb. 16, 1955), Wisconsin Conservation Department
Rock County	April, 1954	Canada goose		120+		Richard E. Griffith (letter, April 1, 1955)
Lake Puckaway	Spring, 1948–1954	Whistling swan		130		
Green Bay						
Michigan						
Shiawassee National Wildlife Refuge	Winter, 1953–54 March–April, 1954	Mallard Whistling swan	200–2,500 200–3,000	75 100	3.8–30.0 5.0–33.3	
Iowa						
Carr and Mud lakes	Winter, 1940	Mallard		600		Everett B. Speaker (letter, Feb. 23, 1955) and James G. Sieh (letter, Feb. 22, 1955), Iowa Conservation Commission
Forney Slough	Winter, 1948	Mallard		1,500		Author of present paper
Lost Island Lake	Jan., 1954	Mallard		100		
Illinois						
Henry	Jan., 1940	Mallard	5,000–10,000	200–300	2.0–6.0	
Chatauqua National Wildlife Refuge	Winters, 1941–1957	Mallard	1,400,000	13,000	0.9	
Grafton	Jan., 1947–1948	Mallard	120,000	3,000	2.5	
Bachrown National Wildlife Refuge	Dec., 1953	Mallard	150,000	500	0.3	
Hull	Feb., 1955	Mallard	100,000	1,000	1.0	
Indiana						
Hovey Lake	{ Winters, 1947–1957 { Winter, 1953 Jan.–Feb., 1955–1957	Mallard Canada goose Mallard Canada goose		1,430 219 700 40		James D. McCall (letters, Feb. 5 and March 11, 1955), Indiana Department of Conservation; Martin 1957
Willow Slough						
Missouri						
Chariton County	Winter, 1949	Mallard	10,200	1,000	9.8	Charles T. Shanks (letter, Feb. 15, 1955), Missouri Conservation Commission; Kenneth Krumm (letter, March 4, 1958), U. S. Fish and Wildlife Service
Squaw Creek National Wildlife Refuge	Winters, 1945–1957	Mallard, pintail	1,400,000	16,000	1.1	
Swan Lake National Wildlife Refuge	Dec., 1952–1954	Mallard	450,000	800	0.2	

Mingo Swamp National Wildlife Refuge <i>Arkansas</i> Claypool Reservoir	Nov.-Dec., 1952-1954 Dec., 1953-Feb., 1954	Mallard Mallard	165,000 250,000	600+ 16,000	0.4 6.4	Richard E. Griffith (letter, April 1, 1955) John W. Perkins (letter, Feb. 12, 1954), U. S. Fish and Wildlife Service
<i>Louisiana</i> Catahoula Lake	Winters, 1950-1955	Mallard Pintail Mallard Pintail Blue and snow geese	138,000 380,000 10,000 25,000 25,000	15,000 5,300 600 1,400 300-400	10.9 1.4 6.0 5.6 1.2-1.6	Richard K. Yancey (letter, May 10, 1955), Louisiana Wildlife and Fisheries Commission; John J. Lynch (letter, Feb. 17, 1955), U. S. Fish and Wildlife Service
CENTRAL FLYWAY <i>South Dakota</i> Sand Lake National Wildlife Refuge Lake Andes National Wildlife Refuge <i>Nebraska</i> Salt Lake	Winters, 1945-1954 Winters, 1951-1954 March, 1945	Mallard Mallard Blue and snow geese Blue and snow geese	120,000-200,000 4,000	10,700+ 1,200-2,000 100 510	1.0-1.7 2.5	Richard E. Griffith (letter, April 1, 1955) Mohler (1945:49)
<i>Kansas</i> Reeves Lake (Grant County)	Jan., 1953	Mallard	25,000	200-250	0.8-1.0	George Schildman (Quarterly Progress Reports, Project 15-R-9), Nebraska Game, Forestation, and Parks Commission
<i>Texas</i> Lubbock County Muleshoe National Wildlife Refuge <i>Arkansas</i> County	Winter, 1944 Dec., 1946 Jan.-Feb., 1949	Ducks Ducks Lesser scaup	5,000-10,000 160 100	5,000-10,000 160 100		George W. Sciple (unpublished report), U. S. Fish and Wildlife Service Oscar L. Chapman (letter, June 18, 1945), U. S. Department of the Interior
PACIFIC FLYWAY <i>Utah</i> Bear River Migratory Bird Refuge	Winters, 1947-1954	Mallard, whistling swan, redhead	850,000	9,000-10,000	1.1-1.2	Richard E. Griffith (letter, April 1, 1955) Donald D. McLean (unpublished report), reference cited in footnote to table 4
<i>California</i> San Francisco and Suisun Bay <i>California</i> Salton Sea National Wildlife Refuge	1939 Winters, 1944-1954	Pintail Pintail, green-winged teal	400,000	4,000	1.0	Richard E. Griffith (letter, May 17, 1955)

William R. Miller (letter, May 19, 1955) reported: "I have on a few occasions seen what to my mind was a case of death due to lead poisoning." James A. Lee (letter, March 29, 1955) reported: "As far as I can ascertain, we have never had a waterfowl die-off in New Hampshire attributable to lead poisoning." Charles L. McLaughlin (letter, May 23, 1955) reported: "I have no authentic records of ducks dying of lead poisoning in Massachusetts, and it is my opinion that this type of mortality is unimportant in the state. A few years ago reports of large scale mortality from lead poisoning in the coastal wintering black ducks was reported, but investigation revealed that the mortality was due to starvation rather than lead." Ruth S. Billard (letter, May 3, 1955) reported as follows for the Connecticut State Board of Fisheries and Game: "We are not aware of any waterfowl succumbing from lead poisoning." Thomas J. Wright (letter, April 26, 1955) reported: "Rhode Island, to the best of my knowledge, has never had any waterfowl losses that could be attributed to lead poisoning."

From New York, Donald D. Foley (letter, May 3, 1955) wrote: "There are without doubt many instances of such poisoning in this state, particularly in late winter and early spring, of which we are not aware. However, we feel that the over-all picture is not too serious as to direct mortality." L. G. McNamara (letter, April 27, 1955) reported: "As far as we know, lead poisoning is not a problem in New Jersey." Robert E. Stewart (letter, May 21, 1955) of the U. S. Fish and Wildlife Service, in referring to the Maryland marshes, reported: "On several occasions, during the past years, diving ducks which appeared unable to fly were collected and found to contain worn lead pellets." In Delaware, Everett B. Chamberlain (letter, April 11, 1955) knew of only two duck deaths which were suspected to be from lead poisoning.

In Virginia, C. P. Gilchrist, Jr. (letter, June 20, 1955), expressed his belief that some ducks are lost to lead poisoning, but not in large enough numbers to be brought to the attention of the Commission of Game and Inland Fisheries.

Farther south, T. Stuart Critcher (let-

ter, May 13, 1955), reporting from North Carolina, remarked: "To my knowledge we have no records of losses in waterfowl populations as a result of lead poison. Undoubtedly, such losses do occur from time to time." Dr. J. H. Jenkins (letter, May 12, 1955) of the University of Georgia wrote: "I don't know of a single case of lead poisoning of waterfowl in Georgia. For one thing, there is very little shooting over established marshes." E. B. Chamberlain, Jr. (letter, April 22, 1955), reported concerning lead poisoning: "So far as we have been able to determine, there have never been any large scale losses of waterfowl in Florida due to this cause."

Mississippi Flyway.—All but three states in the Mississippi Flyway have reported die-offs of waterfowl as a result of poisoning from ingested lead shot, table 1. Among the largest losses have been those reported from Louisiana. The largest die-offs in Louisiana have been at Catahoula Lake in La Salle Parish, where 20-300 ducks are estimated to have died from lead poisoning in the period 1950-1955. Lead poisoning among the waterfowl of Catahoula Lake probably dates back farther than 1930, for E. R. Kalmbach in his 1930 report (on file, U. S. Fish and Wildlife Service) mentions a duck malady as occurring in previous years at that lake.

The largest known single outbreak of lead poisoning occurred in the Claypool Reservoir area near Weiner, Arkansas, between mid-December of 1953 and mid-February of 1954. John W. Perkins (letter, February 12, 1954), game agent for the U. S. Fish and Wildlife Service, estimated that during that period 16,000 ducks, most of them mallards, succumbed to lead poisoning.

A similar die-off of mallards had previously occurred there in early February of 1951. The die-off was investigated by John J. Lynch (letter, February 9, 1951) of the U. S. Fish and Wildlife Service, who reported seeing over 50 carcasses on less than 3 acres of the 1,300 acre reservoir. He concluded that the casualties "numbered in the thousands." Furthermore, Lynch stated that a die-off of similar proportions occurred on the same reservoir in the winter of 1948-49.

In Missouri, the largest reported die-off of ducks from lead poisoning took place at the Squaw Creek National Wildlife Refuge, where 10,000 out of 150,000–205,000 mallards died during the winter of 1956–57. In the previous winter, 5,000 mallards out of the 200,000 on the refuge died from lead poisoning. Other die-offs occurred there every winter at least as far back as 1945; reported mortality varied from 50 to 300 victims per year. Additional die-offs of mallards occurred at Dalton Cut-off in Chariton County in 1949 and at the Swan Lake National Wildlife Refuge in 1939, 1952, 1953, and 1954.

Hovey Lake, Posey County, Indiana, has been a trouble spot for many years. As mentioned earlier, Phillips & Lincoln (1930:165) reported ducks dying there from lead poisoning as far back as 1922. The largest die-off there in recent years, an estimated 1,000 ducks, took place during the winter of 1947–48 (James D. McCall, letter, February 5, 1955). Reported losses since then have been sporadic and rather small, except for the death of 219 Canada geese in 1953 and 120 in 1955–56 (Martin 1957:114). Small die-offs, aggregating 678 birds, are reported to have occurred at Hovey Lake, the Kankakee State Game Preserve area (Starke County), and the Willow Slough State Game Preserve (Newton County) during January and February, 1955.

Since 1947, wherever large numbers of mallards have wintered in central Illinois, there have been some outbreaks of lead poisoning. Most of the reported die-offs have occurred on, or in the vicinity of, the Chautauqua National Wildlife Refuge, near Havana, where 13,000 ducks are estimated to have died from lead poisoning in the period 1941–1957, table 1. The largest single outbreak of lead poisoning among waterfowl of Illinois occurred there in January and February of 1957, when an estimated 5,000 succumbed. The second largest die-off occurred at Stump Lake, north of Grafton, where 3,000 mallards were victims of lead poisoning in January, 1948.

In Iowa, sporadic outbreaks of lead poisoning among ducks have been noted since 1936, according to Everett B. Speaker (letter, February 23, 1955), but only one

die-off amounted to over 1,000 birds, table 1. That one took place at Forney Slough, in Fremont County, during the winter of 1948.

Reported losses from lead poisoning among waterfowl in the lake states of Minnesota, Wisconsin, and Michigan have been minor, table 1. In Wisconsin, small losses of whistling swans occurred in the Green Bay area in the springs of 1948–1954. L. R. Jahn (letter, February 16, 1955) reported that, although ducks were victims of lead poisoning in both spring and fall, their losses had been sporadic. H. J. Miller (letter, February 23, 1955) wrote that Michigan had not known an appreciable die-off of ducks from lead poisoning since the taking of waterfowl records was begun in 1940. In the spring of 1942, 16 whistling swans were found dead from lead poisoning on widely separated marshes of southeastern Michigan. In the winter of 1953–54, 100 whistling swans and 75 mallards were reported as dying from lead poisoning at the Shiawassee National Wildlife Refuge, near Saginaw (Richard E. Griffith, letter, April 1, 1955).

After studying the mortality in large populations of ducks wintering, 1949–1952, on the Detroit River in Michigan, Hunt & Ewing (1953:362, 367) considered lead poisoning to be of little importance as a mortality factor.

In Ohio, lead poisoning has evidently been a minor problem, for Delmar Handley (letter, April 28, 1955) stated that only a few ducks and geese had been found afflicted by this disease. A suspected case of lead poisoning in Tennessee waterfowl was reported by Parker Smith (letter, May 5, 1955) as affecting 40 or 50 mallards along the Obion River in February, 1954.

In three states of the Mississippi Flyway, Kentucky, Mississippi, and Alabama, lead poisoning losses have not been reported (letters: Frank Dibble, April 12, 1955; W. Walter Beshears, Jr., May 9, 1955; and Alec Bumsted, March 1, 1955), but some losses undoubtedly occur in those states.

Central Flyway.—Although die-offs of waterfowl from lead poisoning have occurred at several places in the Central Flyway, they have not been so large as

those in the Mississippi Flyway, table 1. Largest losses in the Central Flyway have been reported from the Sand Lake National Wildlife Refuge area of South Dakota, where more than 10,700 mallards succumbed to lead poisoning over a span of 10 winters.

A large die-off of ducks reported in Lubbock County, Texas, during the winter of 1944 was a most unusual one. Details were reported in a letter (June 18, 1945) from Oscar L. Chapman, then Assistant Secretary of the Department of the Interior, to the Secretary of War, Henry L. Stimson. Excerpts are as follows: "During the past winter approximately 800 wild ducks were found dead at two small lakes on the grounds of the Lubbock Army Air Field, Texas. Field studies conducted by the Fish and Wildlife Service of this Department revealed that these losses were due primarily to lead poisoning resulting from ingestion of lead shot which drop into one of these lakes during skeet practices. Studies conducted by Army personnel indicated that 80 per cent of the dead ducks examined contained lead pellets in their gizzards. . . . It is estimated that the annual loss from the two lakes is between 5,000-10,000 ducks, many of which perish on their northward migration. This estimate is substantiated by numerous reports of emaciated dead and live ducks being found or seen in areas north of Lubbock."

In Nebraska, George V. Schildman (letter, March 5, 1955) reported sizable die-offs of blue geese (*Chen caerulescens*) and lesser snow geese (*Chen hyperborea*) from lead poisoning, table 1. In regard to loss of ducks, he stated: "The numerous rainwater basins in Clay, Fillmore, and York counties provide some losses each spring. . . . The losses are commonplace, but—to my knowledge—haven't been conspicuous and concentrated. However, these basins cover an extensive area, and the total loss may be considerable."

According to Richard E. Griffith (letter, April 1, 1955): "Minor losses have been reported from the Salt Plains Refuge (Oklahoma), usually in single isolated cases. An occasional bird with lead poisoning is picked up on other refuges throughout the Southwest, but in most in-

stances it is felt the shot was ingested prior to arrival." Griffith reported some fatalities among mallards at the Fort Peck Game Range in Montana, where 5,000 to 17,000 winter. Elsewhere in Montana, Wynn G. Freeman (letter, April 23, 1955) reported he had found no waterfowl suffering from lead poisoning.

Other waterfowl biologists in the Central Flyway who have yet to find mortality in waterfowl from lead poisoning are B. A. Fashingbauer (letter, February 17, 1955), North Dakota; Robert L. Patterson (letter, February 8, 1955), Wyoming; and Levon Lee (letter, February 19, 1955), New Mexico.

Pacific Flyway.—The largest outbreaks of lead poisoning among waterfowl of the Pacific Flyway have been reported from California, table 1. In 1939, ducks estimated at 9,500 died from lead poisoning in the Central Valley, San Francisco Bay, and Suisun Bay areas of California, table 1, but it is not known to what extent die-offs approach this number every year, for the problem was investigated in detail in only that year by the California Department of Fish and Game. In the winters beginning in 1944 and ending in 1954, 4,000 ducks were estimated to have become victims of lead poisoning at the Salton Sea National Wildlife Refuge in southern California.

Both the Tule Lake and the Lower Klamath National Wildlife refuges in northern California, according to Richard E. Griffith (letter, May 17, 1955), have sections heavily shot over, and yet reported losses from lead poisoning have been surprisingly low.

From Utah, Noland F. Nelson (letter, February 19, 1955) reported regarding lead poisoning: "During the past 10 years of waterfowl management work on Utah's marshlands, I have observed no large die-offs of waterfowl resulting from lead poisoning. However, a few lead poisoning losses have been recorded every year. These recorded losses were almost always during the winter and early spring months on some of the areas of heavy shooting around Great Salt Lake. . . . A few emaciated mallard, pintail, shoveler, and whistling swan have been examined almost every winter and a large per cent have contained ingested lead shot.

The keeper of a local aviary rescued 33 sick whistling swans one winter and 28 died from lead poisoning."

In discussing losses of waterfowl from lead poisoning at the Bear River Migratory Bird Refuge, Utah, Richard E. Griffith (letter, April 1, 1955) emphasized that the loss cited, table 1, was a minimum one and should not be construed as a reliable indicator of total mortality. He reported that outbreaks of lead poisoning occurred when ice restricted the birds to a limited feeding area. The development of this situation was most apparent among the 10,000-12,000 whistling swans wintering at the refuge, for they began to die from lead poisoning as soon as the feeding areas became restricted by ice.

Thirteen trumpeter swans affected by lead poisoning were found by Dr. Ian McT. Cowan (Tener 1948:12) in February of 1943 on Vancouver Island, British Columbia. However, only a very few ducks have been found ill from lead poisoning in that province (E. W. Taylor, letter, March 22, 1954).

In regard to lead poisoning in Washington, Henry A. Hansen (letter, February 26, 1955) wrote: "It has been a rare and isolated case that weak or dead ducks have been found to have lead shot in their gizzards in this state since we organized the waterfowl research project in 1947. In no instance have we found a trouble spot that might require remedial action."

Chester E. Kebbe (letter, April 21, 1955) reported that, although an outbreak of lead poisoning had not been noticed in Oregon, he believed that research would reveal large numbers of waterfowl dying each year from ingested shot. Richard E. Griffith (letter, May 17, 1955) reported that records at the Malheur National Wildlife Refuge in southwestern Oregon indicated that there had been no losses from this malady in the previous 7 years. A few waterfowl, mostly diving ducks, were victims of lead poisoning at that refuge in 1942.

C. Vic Oglesby (letter, March 31, 1955) reported: "There have been no major die-offs nor any approaching even moderate die-offs in Nevada within the past 10 years. A very few birds, primarily shovelers, fall victim to lead poisoning each fall on the Stillwater Wildlife Man-

agement Area located near Fallon, Nevada. This is our largest public hunting area and bears the bulk of the waterfowl shooters within the state."

In Arizona, no losses of waterfowl from lead poisoning have been reported during the past 10 years, according to Wesley B. Fleming (letter, February 8, 1955).

Undoubtedly not all the outbreaks of lead poisoning among waterfowl during the past decade have been reported. However, it is believed that outbreaks discussed in this paper include the most important die-offs from lead poisoning, and that these outbreaks represent a cross section of such conditions in the United States. Today there are only a few places in this country where 1,000 or more ducks might succumb from lead poisoning and not be noticed. Past experience shows that the public becomes alarmed when large numbers of dead ducks are observed and that it reports such events to conservation authorities or the press.

Moreover, waterfowl are prone to concentrate in and around refuges; refuge personnel would be among the first to become aware of and report any unusual waterfowl mortality. Since the early 1930's, there have been numerous federal refuges, manned with technically trained personnel, well distributed throughout the four flyways.

In addition to the waterfowl die-offs that attract public attention, there are the scattered day-to-day losses that pass unnoticed. These day-to-day losses are extensive; their magnitude is explored later in this paper on the basis of the incidence of ingested shot in waterfowl populations and the toxicity of various doses of lead shot.

Lead poisoning outbreaks have occurred more commonly in the Mississippi Flyway than in all the other flyways combined. In both the Mississippi and Central flyways, mallards have been the principal victims in all but a few die-offs. A rough estimation of the annual rate of loss of mallards in outbreaks of lead poisoning in the Mississippi Flyway is 1 per cent.

Frequency of Die-Offs

Some areas have outbreaks of lead poisoning in waterfowl rarely, some occa-

sionally, and others with rather consistent frequency. For example, in Illinois there has been but one outbreak of lead poisoning near Henry in 18 years; near Grafton there have been two outbreaks in 12 years; at the Chautauqua National Wildlife Refuge there have been outbreaks in 10 of the last 13 years.

The frequency and magnitude of lead poisoning outbreaks in a particular area are influenced largely by the following factors: the size of late fall and winter populations of mallards and other species of ducks with similar feeding habits; the kind and amount of food available; the amount of lead shot present as a result of shooting pressure; the availability of shot, determined by bottom conditions, water levels, and ice cover.

One reason that the Chautauqua National Wildlife Refuge area has been the scene of many outbreaks of lead poisoning in waterfowl is that generally 100,000 to 400,000 mallards winter there, making it usually the area of largest winter concentration in Illinois. Another reason is that nearby Quiver Creek, which remains partly open during the coldest weather, attracts a large proportion of the wintering population to its shot-laden stream bed.

Water levels, food, and a lack of ice cover combined to cause the exceptionally large die-off of 5,000 mallards in the Chautauqua area during the winter of 1956-57. A rise in water resulted in the flooding of millet and smartweed beds adjacent to the refuge shortly after the hunting season closed. This area had been heavily shot over, and mallards congregated there for a week before a freeze-up forced them to leave. Most of them moved to Quiver Creek. Two to 3 weeks later, mallards in the Quiver Creek area commenced dying by the hundreds.

Other areas in the Mississippi Flyway where there have been consistently frequent outbreaks of lead poisoning include Catahoula Lake, Louisiana, 4 out of 6 years; Claypool Reservoir, Arkansas, 3 out of 8 years; and Squaw Creek National Wildlife Refuge, Missouri, 8 out of 13 years.

Seasons of Die-Offs

As shown by data in table 1, most waterfowl die-offs from lead poisoning have

occurred during the late fall and early winter months, after the close of the hunting season. Only a very few die-offs have been noted during the hunting season, even though in the southern zone the season has usually extended to January 10 or 15. Two large outbreaks have been reported during the hunting season: One of these occurred at Catahoula Lake, Louisiana, during the last two weeks of November and the first week of December in 1950; the other took place in the Claypool Reservoir area of Arkansas between mid-December of 1953 and early February of 1954.

Outbreaks of lead poisoning are unusual during the early fall months. Hunter activity keeps ducks out of heavily gunned areas where shot pellets are most heavily deposited, and, as shown later, a sizable number of the ducks suffering from the effects of lead poisoning are shot by hunters.

Outbreaks of lead poisoning seldom have been noted among waterfowl during the spring. Principal losses at this season have been among swans and geese. Whistling swans have been recorded as dying during the spring at Green Bay, Wisconsin, and on the Shiawassee National Wildlife Refuge, Michigan, table 1. A die-off of Canada geese took place in April, 1954, at Lake Puckaway, Wisconsin. In Nebraska, losses of blue geese and snow geese have occurred for a number of years during March and April. Greater scaups were reported by Van Tyne (1929:103-4) as dying at Houghton Lake, Michigan, during April, 1928. In the spring of 1921 near Florence, Louisiana, many ducks died from lead poisoning, according to Albert Bonin, quoted in an unpublished report by E. R. Kalmbach.

There are no records to indicate that in recent years wild waterfowl have died from lead poisoning during the summer months. However, Wetmore (1919:2) stated that during the summers of 1915 and 1916 he handled many ducks affected by lead poisoning in the Bear River Delta of Great Salt Lake, Utah. In spite of numerous and intensive investigations on botulism and other waterfowl problems at the Bear River Migratory Bird Refuge, lead poisoning losses have not been recorded there during the summer since

Wetmore (1919) reported on his field work of 1915 and 1916.

Species Affected by Die-Offs

Individuals of most species of waterfowl have been recorded at one time or another as victims of lead poisoning. In addition to those species listed in table 1, the following species have been reported as victims: trumpeter swan, white-fronted goose (*Anser albifrons*), gadwall (*Anas strepera*), baldpate (*Mareca americana*), blue-winged teal (*Anas discors*), cinnamon teal (*Anas cyanoptera*), shoveler (*Spatula clypeata*), canvasback, greater scaup, common goldeneye (*Bucephala clangula*), and ruddy duck (*Oxyura jamaicensis*). The largest number of species reported from any one area was found by Donald D. McLean (unpublished report, California Department of Fish and Game) in the San Francisco and Suisun Bay areas of California. He reported 257 pintails, 45 shovelers, 15 baldpates, 13 green-winged teals (*Anas carolinensis*), 7 mallards, 2 lesser Canada geese, 1 cinnamon teal, and 1 canvasback in a group of waterfowl which had succumbed from lead poisoning.

Although individuals of many species have died from lead poisoning, it is evident that the mallard has been the principal victim in outbreaks of lead poisoning across the nation, table 1. In the Pacific Flyway the pintail has made up the largest number of victims. In the Mississippi Flyway, however, where mallards and pintails have frequented the same areas, mallard losses have been proportionately greater, table 1. Die-offs of the Canada goose, blue goose, and snow goose have been reported for several places, table 1, but losses in these die-offs have been comparatively small.

An investigation of a lead poisoning outbreak at Catahoula Lake, Louisiana, in January of 1953 pointed up important differences in the mortality rates of species. During the period of the outbreak, the waterfowl population was composed of 30,000 pintails, 25,000 mallards, 5,000 green-winged teals, and small numbers of a few other species. Although pintails outnumbered mallards in the population, 5,500 mallards and 1,000 pintails were estimated to have died from lead poison-

ing. In a 3-day period, 243 mallards and only 26 pintails were picked up. Not a single dead or incapacitated green-winged teal was found.

From these observations, it was deduced that the habits of the several species of ducks were such as to account for the different mortality rates. Observations of the feeding ducks plus unpublished food habits studies of ducks at Catahoula Lake by Richard K. Yancey of the Louisiana Wild Life and Fisheries Commission suggested that both feeding traits and food preferences were involved. Ducks of all three species, mallard, pintail, and green-winged teal, were feeding extensively in flooded beds of chufa (*Cyperus esculentus*), but mallards were puddling more commonly into the bottom for tubers of this plant than were pintails, which were probably feeding more commonly on the floating seeds. Green-winged teals appeared to be feeding almost entirely on floating seeds.

Apparently, in puddling into the bottom mud, mallards came into contact with the lead shot more frequently than did pintails, and pintails more frequently than did green-winged teals. The form of the food they consumed undoubtedly influenced mortality among those ducks ingesting shot. Jordan & Bellrose (1951:18) reported that ducks that fed on small seeds were less affected by ingested lead than were those that fed on corn. The tubers of chufa and the kernels of corn appear to have similar physical properties and they may be expected to have similar effects.

Incidence of Lead Shot in Die-Offs

Biologists investigating outbreaks of lead poisoning among waterfowl in the Mississippi Flyway, 1938-1955, examined samples of dead and dying mallards for ingested shot, tables 2 and 3. Although 10.4 per cent of the drakes, table 2, and 13.0 per cent of the hens, table 3, found in the outbreaks carried no shot in their gizzards, most, if not all, of these were lead-poisoned victims. James S. Jordan (unpublished report) found in controlled experiments with captive mallards that 21 per cent of those dosed with one to four No. 6 shot pellets had no pellets in their gizzards at time of death.

Table 2.—Incidence of various ingested shot levels found among drake mallards picked up level is meant the number of ingested lead shot pellets found in a gizzard.) For each state are

LOCATION	0 PELLET		1 PELLET		2 PELLETS		3 PELLETS		4 PELLETS		5 PELLETS	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
South Dakota	4	11.8	17	50.0	8	23.5	5	14.7	0	0.0	0	0.0
Minnesota...	17	13.8	36	29.3	22	17.9	15	12.2	10	8.1	4	3.3
Missouri.....	6	14.0	8	18.6	5	11.6	6	14.0	9	20.9	5	11.6
Illinois.....	37	11.9	90	29.0	49	15.8	36	11.6	18	5.8	23	7.4
Arkansas....	3	4.1	6	8.2	20	27.4	8	11.0	5	6.9	3	4.1
Louisiana...	5	4.6	3	2.8	15	13.9	16	14.8	20	18.5	15	13.9
Total.....	72	.....	160	.....	119	.....	86	.....	62	.....	50	.....
Average.....	.....	10.4	.....	23.2	.....	17.2	.....	12.4	.....	9.0	.....	7.2

Table 3.—Incidence of various ingested shot levels found among hen mallards picked up level is meant the number of ingested lead shot pellets found in a gizzard.) For each state

LOCATION	0 PELLET		1 PELLET		2 PELLETS		3 PELLETS		4 PELLETS		5 PELLETS	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
South Dakota	0	0.0	12	48.0	7	28.0	3	12.0	3	12.0	0	0.0
Minnesota...	11	15.5	30	42.3	13	18.3	7	9.9	3	4.2	3	4.2
Missouri.....	3	11.1	7	25.9	3	11.1	6	22.2	5	18.5	1	3.7
Illinois.....	32	18.1	57	32.2	30	17.0	19	10.7	7	4.0	5	2.8
Arkansas....	6	22.2	7	25.9	2	7.4	3	11.1	2	7.4	1	3.7
Louisiana...	8	5.9	11	8.1	21	15.6	31	23.0	16	11.9	18	13.3
Total.....	60	.....	124	.....	76	.....	69	.....	36	.....	28	.....
Average.....	.....	13.0	.....	26.8	.....	16.5	.....	14.9	.....	7.8	.....	6.1

It is apparent that most, if not all, waterfowl found dead without ingested shot in a lead poisoning outbreak had previously ingested lead, but that the lead had passed from their digestive tracts at such late stages of illness that the birds failed to recover. The low proportion of free-flying, lead-poisoned mallards found without ingested shot, as compared with the proportion of lead-poisoned penned birds without ingested shot, suggests that birds in the wild that succeed in voiding shot are more likely to survive than are penned birds.

Considerable variation was evident in the amounts of ingested lead shot in mallard drakes found dead or dying in four areas. The lowest number of shot pellets per duck was among those affected by lead poisoning at the Sand Lake National Wildlife Refuge, South Dakota, in December of 1951, fig. 3. The next smallest

number of ingested shot pellets per duck was among birds picked up, 1941–1954, in the vicinity of the Chautauqua National Wildlife Refuge, Illinois. The mallards of the Claypool Reservoir, Arkansas, and the Catahoula Lake, Louisiana, outbreaks had a larger number of ingested shot pellets per duck than did those of the Illinois outbreaks, fig. 3.

Differences between the four areas in numbers of pellets per drake are believed to have resulted mainly from the differences in (1) availability of shot and (2) diet. The quantity of shot ingested by ducks of a given species is roughly proportional to the availability of shot. Diet has an important influence on the survival of ducks that have ingested lead, according to Jordan & Bellrose (1951:18–21), who reported that the harmful effect of ingested lead was most evident in ducks fed on whole corn and much less

in a dead or moribund condition in lead poisoning die-offs in six states, 1938-1955. (By shot given the number and per cent of drakes represented at each shot level.

6 PELLETS		7 PELLETS		8 PELLETS		9 PELLETS		10 PELLETS		OVER 10 PELLETS		TOTAL	
Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	34	100.0
8	6.5	2	1.6	1	0.8	0	0.0	3	2.4	5	4.1	123	100.0
1	2.3	1	2.3	1	2.3	1	2.3	0	0.0	0	0.0	43	99.9
9	2.9	5	1.6	7	2.3	4	1.3	6	1.9	26	8.4	310	99.9
6	8.2	2	2.7	4	5.5	6	8.2	2	2.7	8	11.0	73	100.0
10	9.3	6	5.6	5	4.6	2	1.8	4	3.7	7	6.5	108	100.0
34	.....	16	.....	18	.....	13	.....	15	.....	46	.....	691	.....
.....	4.9	.....	2.3	.....	2.6	.....	1.9	.....	2.2	.....	6.7	.....	100.0

in a dead or moribund condition in lead poisoning die-offs in six states, 1938-1955. (By shot are given the number and per cent of hens represented at each shot level.

6 PELLETS		7 PELLETS		8 PELLETS		9 PELLETS		10 PELLETS		OVER 10 PELLETS		TOTAL	
Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	25	100.0
2	2.8	0	0.0	1	1.4	1	1.4	0	0.0	0	0.0	71	100.0
0	0.0	0	0.0	2	7.4	0	0.0	0	0.0	0	0.0	27	99.9
5	2.8	1	0.6	2	1.1	1	0.0	1	0.6	17	9.6	177	99.5
2	7.4	2	7.4	0	0.0	0	0.0	1	3.7	1	3.7	27	99.9
10	7.4	8	5.9	2	1.5	5	3.7	1	0.7	4	3.0	135	100.0
19	.....	11	.....	7	.....	7	.....	3	.....	22	.....	462	.....
.....	4.1	.....	2.4	.....	1.5	.....	1.5	.....	0.6	.....	4.8	.....	100.0

evident in ducks fed on leafy vegetation and the seeds of tame rice, millet, and smartweed.

The high percentage of birds with a small number of pellets per bird among the victims in South Dakota probably was a result of (1) lack of easy availability of shot and (2) accelerated losses induced by cold weather and the high toxicity of lead when associated with the corn diet to which the birds were restricted during the winter. Mallards wintering in Illinois, too, were largely restricted to a corn diet, but they had available to them much more shot.

The large numbers of shot pellets per bird found in mallard drakes in Arkansas and Louisiana die-offs indicate the availability of large quantities of shot. The small number of drakes without ingested shot, table 2, suggests an excellent survival of those that had voided shot. Appar-

ently, the mallard drakes of Arkansas and Louisiana had a better survival rate than those of South Dakota and Illinois because they had a better diet and milder weather.

AVAILABILITY OF LEAD

The availability of lead shot to waterfowl utilizing a particular body of water is determined by the following factors: (1) the shooting intensity, or amount of shot deposited on the bottom, (2) the firmness of the bottom material, (3) the size of the shot pellets deposited, (4) the depth of water above the bottom, and (5) ice cover.

The amount of lead deposited on lake and marsh bottoms as shot pellets from the guns of waterfowl hunters is tremendous. A conservative estimate of the number of shells fired for every duck

bagged is five; if every shell were of 12 gauge and contained No. 6 shot, then about 1,400 shot pellets would be deposited for every duck bagged.

In Illinois, the annual kill at some public shooting grounds has been as high as six ducks per acre, but for all Illinois duck hunting areas over a period of years the kill has averaged about one and one-half ducks per acre per year. The amount of lead shot deposited in Illinois River valley lakes is calculated to be approximately 2,100 pellets per acre per year.

Because of the scattered distribution of blinds, many acres of waterfowl habitat are untouched by spent shot, while small areas near blinds have an annual deposition of shot many times as great as the calculated average for the larger acreage of which they are a part. Most blinds are located on or adjacent to the best waterfowl feeding grounds. In such situations, waterfowl are more likely to pick up shot in their feeding activities than if the blinds, and therefore the pellets, were more evenly distributed.

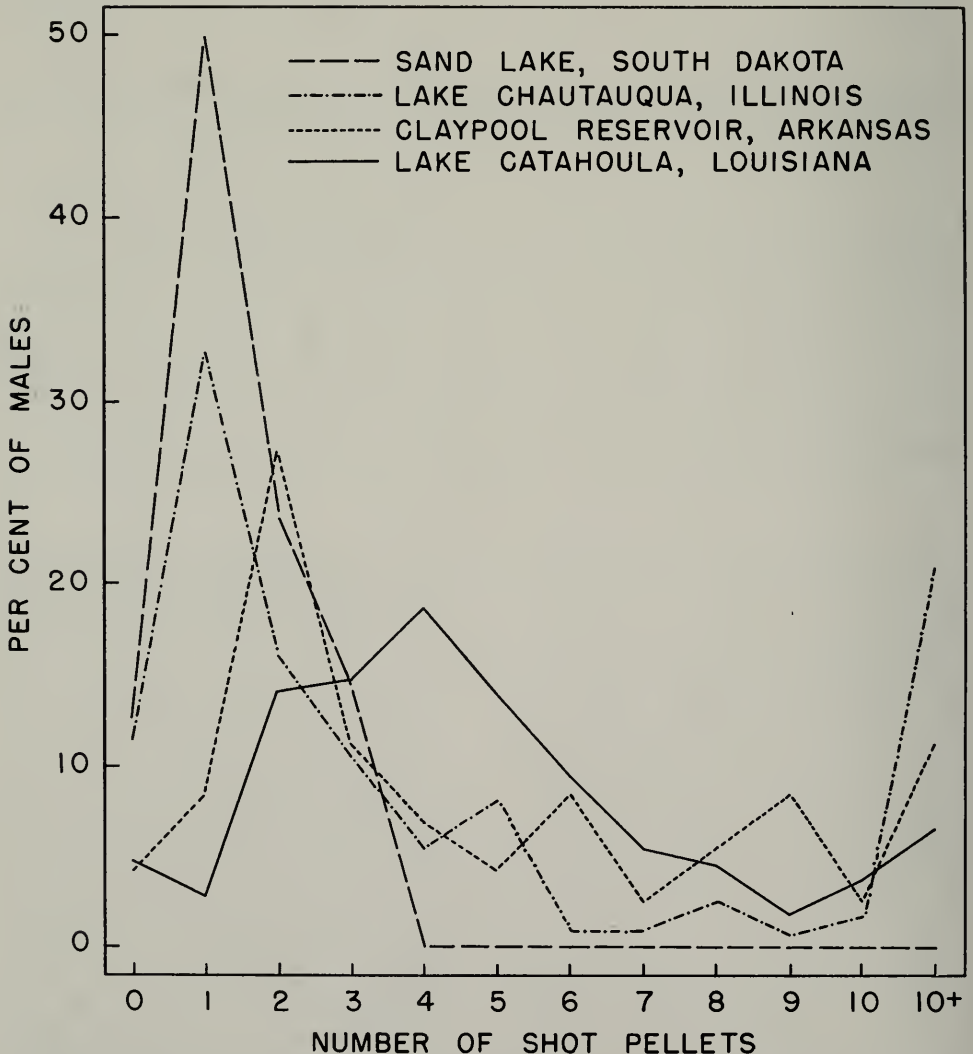


Fig. 3.—Incidence of various levels of ingested lead shot found in gizzards of drake mallards picked up in a dead or moribund condition in each of four areas in which lead poisoning die-offs occurred, 1941-1954. Data, except those for Illinois, are from table 2.

A number of surveys have been made of lake and marsh bottoms in an effort to ascertain the availability of lead shot to waterfowl. Wetmore (1919:9-10), in his pioneering investigation of lead poisoning, examined mud from two areas at the mouth of the Bear River in Utah. In one area he found no shot pellets within 30 to 70 yards of a blind, but he found pellets at sampled 20-yard intervals from 70 yards to as far as 210 yards from the shooting point. He found most pellets at a distance of 130 yards, where he recovered 1 to 12 in each sieve filled with mud. In the other area, Wetmore found 1 to

13 pellets at each sampling point; most of the pellets had penetrated through 10 to 12 inches of a soft upper layer of mud to a lower layer of hardened clay.

More recent studies, table 4, show the concentrations of lead pellets in bottom samples, most of them taken without specific orientation to shooting blinds. The bottom material sampled varied in thickness from 2 to 10 inches.

The greatest concentration of lead shot that has been reported was at Lake Puckaway, Wisconsin, table 4. Hartmeister & Hansen (1949:18-22), after investigating three Wisconsin shooting areas, re-

Table 4.—Number of lead shot pellets per square foot and per acre found in samples of the bottom soils of various lakes and marshes used extensively by waterfowl in North America. The bottom samples varied from approximately one-half inch to 10 inches in thickness.*

STATE	AREA	YEAR AND SEASON	NUMBER OF SQUARE FEET IN SAMPLE	NUMBER OF PELLETS PER SQUARE FOOT	NUMBER OF PELLETS PER ACRE
California...	Sacramento Valley.....	1939, 1940	60	0.45	19,602
	North Bay, San Francisco....	Springs	120	0.78	33,977
	Suisun Bay.....		260	0.58	25,265
	Delta.....		80	0.20	8,712
	South Bay, San Francisco....		240	0.79	34,412
	San Joaquin Valley.....		120	1.37	59,677
	South Coast.....		40	0.48	20,908
Minnesota...	Lakes on Carlos Avery Refuge.....	1939-1940 Winter	80	0.41	17,859
	Lakes adjacent to Carlos Avery Refuge.....		94	0.37	16,117
	Rice Lake.....		53	0.55	23,958
	Rush Lake.....		11	0.00	0
	Heron Lake.....		36	1.47	64,032
	24 Lakes.....		249	0.14	6,098
	Wisconsin...	Lake Puckaway.....	1949	100	2.71	118,048
Clam Lake.....		Winter	67	1.06	46,174
Horicon Marsh.....			53	0.08	3,485
Manitoba...	Portage Creek, Delta Marsh	1950	186	1.17	50,965
	Cadham Point, Delta Marsh	Summer	195	0.39	16,988
Michigan....	Saginaw Bay.....	?	45	0.27	11,761
	Maumee Bay.....	?	200	0.27	11,761
Indiana.....	Willow Slough.....	1956	14	0.93	40,511
		Spring, Fall	14	1.07	46,609
Illinois.....	Quiver Lake.....	1950	22	0.00	0
	Moscow Bay.....	Summer	60	0.04	1,742

* Sources of data: California: "Lead poisoning of California waterfowl," unpublished report by Donald D. McLean, Bureau of Game Conservation, California Division of Fish and Game; Minnesota: unpublished reports by Gustav Swanson and C. Gordon Fredine, in Cooperative Wildlife Investigations, University of Minnesota and Minnesota Division of Game and Fish, Vol. 1, 1937-1939; Vol. 2, 1939-1940; Wisconsin: Hartmeister & Hansen 1949; Manitoba: "Occurrence of lead shot in a waterfowl breeding marsh," by George K. Brakhage, unpublished quarterly report of the Missouri Wildlife Research Unit, July-September, 1950; Michigan: "Waterfowl survey of Saginaw Bay, Lake St. Clair, Detroit River, Lake Erie and the marshes adjacent to these waters," by Herbert J. Miller, unpublished final report, P-R Project 13-R, Michigan Department of Conservation, January 1, 1943; Indiana: Martin 1957.

ported 2.71 pellets per square foot (equivalent to 118,048 pellets per acre) at Lake Puckaway, less than half as many pellets per square foot at Clam Lake, and a "negligible amount of lead shot available to waterfowl" on Horicon Marsh. Lake Puckaway, they reported, has a bottom of sand and gravel covered by a thin layer of vegetable matter 1 to 6 inches in depth. Clam Lake has a similar bottom. The difference between the areas in number of pellets per square foot may reflect differences in hunting pressure.

Hartmeister & Hansen (1949:19) concluded: "Sampling on Horicon marsh revealed a practically negligible amount of lead shot available to waterfowl, in spite of the fact that this area is probably as heavily hunted as any lake or marsh in the state of Wisconsin. Obviously, lead shot are soon made unavailable to waterfowl where deep layers of muck and peat are present."

Bottom samples were taken at the Carlos Avery Refuge in Minnesota 5 years after it had been closed to shooting; yet shot pellets were about as numerous there as in adjacent lakes that were hunted during the 5-year period (unpublished Minnesota report cited in table 4 footnote). At Rush Lake, a mud-bottomed water area, no lead shot was found in samples taken 15 years after it had been closed to hunting. The highest concentration of lead shot found in the Minnesota lakes sampled was at Heron Lake, which has a hard clay bottom and had been heavily shot over, table 4.

Bottom samples taken at Willow Slough in Indiana by Dale N. Martin (1957:113) revealed about the same concentration of lead shot pellets on October 17, 1956, as on April 26, 1956, table 4. Apparently, during the 6-month period the shot had not settled deeper into the bottom. The bottom area sampled was composed of one-half to 1.5 inches of silt and plant debris over firm sand.

In California waterfowl areas, Donald D. McLean (unpublished report cited in table 4 footnote) took bottom samples at levels of 0-2 inches, 4-6 inches, and 8-10 inches below the surface of the bottom. At these three levels he found 61 per cent of the shot in the top layer, 30 per cent in the middle layer, and 9 per cent in the

lowest layer. There was a noticeable difference between places; areas with hard bottoms had most of the shot pellets at depths of less than 6 inches while areas with soft bottoms had a greater proportion of shot deeper in the soil. McLean reported that at the Bolsa Chica Club, in southern California, there was a heavy concentration of shot lying on hardpan under 5.5 inches of soft mud.

Both Portage Creek and Cadham Point in the Delta Marsh of Manitoba are traditional shooting sites. Portage Creek receives much heavier shooting pressure than does Cadham Point, and shot pellets were more numerous there, table 4. In view of the soft mud bottoms of both areas, the amount of shot found was surprisingly high. George K. Brakhage stated in an unpublished report cited in a table 4 footnote that the highest concentrations of shot in the Cadham Point area were along those transects nearest the decoy placement. In Michigan, Herbert J. Miller stated in an unpublished report cited in a table 4 footnote that at Maumee Bay shot pellets were twice as numerous in areas protected from severe wave action as in the exposed areas. Part of this difference may have resulted from differences in shooting pressure, but Miller believed that the wave action and currents were largely responsible in that they covered much of the lead with sediment.

Bottom samples taken during the summer of 1950 from two heavily shot-over lakes in the Illinois River valley showed few lead shot pellets, table 4; samples were taken from the top 2 inches of the bottoms of these lakes. Undoubtedly only a small amount of lead shot was found because the expended shot sank in the soft mud and during spring floods was covered by a layer of silt. A study on the silting of Lake Chautauqua (Stall & Melsted 1951:10), an Illinois River valley lake, showed an average annual silt accumulation of 110 acre-feet in a basin of 3,562 acres.

In water areas with silt or peat bottoms, there is, apparently, only a slight carry-over of lead shot (within the soil depths at which most ducks search for food) from one season to the next. Lead shot is, therefore, most readily available to waterfowl in the fall and winter, dur-

ing and immediately following the hunting season. High water levels during the spring over much of the fall waterfowl habitat, which includes most shooting grounds, greatly diminish the availability of lead shot. Most breeding grounds are lightly hunted; therefore, waterfowl are only slightly exposed to lead shot during the breeding season.

As part of a study on lead shot in mud-bottomed lakes, an experiment was conducted by the writer at Quiver Lake, in

The data in table 5 show that the smaller the shot size, the smaller the amount of recovered lead. Evidently wave action dislodged quantities of shot pellets, especially 7½'s, and scattered them outside the pipes. From the distribution of the remaining pellets, there was, with the exception of 7½'s on the moderately firm bottom, evidence that the larger the size, the more prone the pellets were to sink in the bottom soil. In the soft bottom soil, most of the shot had settled to

Table 5.—Data indicating the penetration of lead shot pellets into bottom soil of two different types at Quiver Lake, near Havana, Illinois. Figures show for each of five pipes, 8 inches in diameter, placed with upper mouth flush with lake bottom, the number of grams of shot pellets recovered at various soil depths, September 3, 1953, and the percentage of the recovered shot that was recovered at each depth. At the upper mouth of each pipe, 150 grams of shot pellets, No. 7½ or No. 6, had been deposited on August 13, 1952.

DEPTH OF SOIL	SOFT BOTTOM				MODERATELY FIRM BOTTOM					
	No. 7½ Shot		No. 6 Shot		No. 7½ Shot		No. 6 Shot		No. 4 Shot	
	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered	Grams Recovered	Per Cent Recovered
0-1 inch	26.0	35.6	20.0	18.8	31.4	55.2	70.7	76.8	71.0	56.5
1-2 inches	40.8	55.9	81.0	76.1	15.1	26.5	18.1	19.7	46.0	36.6
2-3 inches	4.0	5.5	4.5	4.2	8.4	14.8	2.2	2.4	5.8	4.6
3-4 inches	1.5	2.0	0.9	0.9	1.5	2.6	1.0	1.1	2.1	1.7
4-5 inches	0.7	1.0	0.0	.....	0.5	0.9	0.0	.....	0.7	0.6
Total	73.0	100.0	106.4	100.0	56.9	100.0	92.0	100.0	125.6	100.0

the Illinois River valley, near Havana. Two areas of the lake bed were selected: one soft, the other moderately firm. In each area, three ceramic pipes, each 8 inches in diameter, were sunk into the soil of the lake bottom during August of 1952, a period in which the water was only a few inches deep; the upper mouth of each pipe was flush with the top layer of soil of the lake bottom. On the soil in the upper mouth of each pipe, 150 grams of shot pellets were deposited: in each of the two areas were one pipe with No. 4 shot, one with No. 6 shot, and one with No. 7½ shot.

Slightly over a year later, September 3, 1953, five 1-inch layers of soil were removed from each of five pipes and screened for lead shot. The sixth pipe, the one in soft mud that contained 4's, had been dislodged and could not be used further in the experiment.

the 1-2-inch layer, but, in the moderately firm bottom soil, the bulk of the shot was in the top 1-inch layer. However, in both bottom types, some shot had settled to the 4-5-inch layer.

Ground and aerial observations of dabbling ducks feeding in Illinois marshes indicate that most of these ducks feed on or in the top inch of the bottom material. Shovelers and green-winged teals have been watched for many hours wading through shallow water and skimming the surface of the bottom. From the air, their "mud trails" in otherwise clear water give further evidence of their characteristic feeding activities. Blue-winged teals may feed in a manner similar to that commonly observed for green-wings, but they appear to do more tipping-up to puddle deeper into the bottom mud.

Pintails do considerable skimming of the bottom in water only a few inches

deep, but, in deeper water, they are prone to puddle out pockets several inches in depth. Mallards, in Illinois at least, dig deeper pockets than do pintails, but these are seldom more than 6 inches in depth. According to Wetmore (1919:3), mallards and pintails dig away mud to a depth of 6 to 18 inches and over an area 1 to 15 feet in diameter as they search for food. Such extensive digging on the part of ducks has been observed by the present writer only around trap sites where large numbers of birds have sifted through bottom soil day after day for bait. Under such circumstances, mallards have created holes as large as 2 feet in depth, 25 feet in length, and 10 feet in width.

Field observations and food habits studies indicate that, where underwater leafy aquatics occur, baldpates and gadwalls feed almost entirely upon these plants, seldom, if ever, sifting through bottom soils for food.

Not only does the depth at which lead shot occurs in bottom soils determine its availability to different species of ducks; the depth of water above the bottom is also a factor. Species of ducks differ to some extent in preferred feeding depths. Dabbling ducks usually utilize waters less than 15 inches in depth, and diving ducks feed at depths of many feet. Among the diving ducks, redheads (*Aythya americana*) and ring-necked ducks (*Aythya collaris*) are prone to feed in shallower water than are lesser scaups and goldeneyes.

When, in late fall or winter, ice fails to cover waterfowl feeding grounds that have been heavily shot over, the stage may be set for a large die-off of ducks. Ice almost invariably forms first on the shoal water of ponds, marshes, and lake margins such as are commonly used by ducks for feeding and hunters for shooting. The sealing of these waters by ice makes the large quantities of shot on such areas unavailable to waterfowl. At the same time it may cause the ducks to congregate in spring holes and spring-fed streams not covered by ice. If such areas have been heavily hunted, they are potential sources of large die-offs caused by lead poisoning.

The extent to which the various species of waterfowl are exposed to shot pellets on the bottoms of marshes and lakes

is influenced by the feeding habits of the birds and by the kinds of foods available, as well as by the numbers of shot pellets available.

INGESTED LEAD SHOT IN MIGRATING DUCKS

The incidence of ingested lead shot in migrating waterfowl populations (the percentages of ducks that carried ingested lead at the time gizzards were collected) was determined by (1) fluoroscopic examination of live-trapped ducks, (2) compilation of data obtained from other investigators who had examined waterfowl gizzards for food content, and (3) fluoroscopic and direct examination (Bellrose 1951:126-7) of gizzards numbering many thousands that co-operating biologists had collected, especially for this study, from ducks in hunters' bags. Most of the data were from ducks migrating southward in fall and early winter.

Shot in Live-Trapped Ducks

During the fall months of 1948, 1949, 1950, and 1953, 5,148 mallards were live-trapped and fluoroscoped at the Chautauqua National Wildlife Refuge, near Havana, Illinois, fig. 4. Ingested lead shot was found in the gizzards of 10.14 per cent of these birds, but more than two-thirds of the gizzards with shot contained only one pellet each, table 6. Because the refuge has been closed to hunting since 1944, it is doubtful if much, or any, of the lead was picked up at the trapping site.

Almost twice as many juvenile as adult male mallards carried ingested shot, table 6. The data indicate that more hens than drakes carried ingested shot, but the sample on which the data are based is believed biased by an unduly large proportion of hens fluoroscoped late in the season, when the incidence of birds carrying shot was at its highest.

Pintails, blue-winged teals, and wood ducks (*Aix sponsa*) were caught in baited traps during September at Moscow Bay, 10 miles south of Havana. Examination of these birds by fluoroscopy revealed an incidence of ingested lead that was unusually high for these species, table 7. The high incidence may have occurred because the traps were on a heavily shot-

over area, which, combined with intensive feeding by the ducks, resulted in exposure of the birds to unusually large quantities of lead.

At the trapping site, lead shot was available equally to the three species, and, in September, it was unlikely that the birds were obtaining shot elsewhere. Yet, among the species, there were differences in incidence of ingested shot, table 7. Proportionally more pintails than wood ducks and proportionally more woodies than blue-winged teals carried ingested shot. Apparently, there is a relationship between the weight of a duck and its intake of food and lead. Perhaps under similar conditions of food and feeding, the duck species with the largest individuals have the highest percentages of individuals with ingested lead shot, table 7.

In two of the three species, table 7, an appreciably greater percentage of juveniles than of adults carried ingested lead shot; in the pintail there was little difference in shot incidence between age groups. In the pintail, blue-winged teal, and wood duck, there were only slight differences between the sexes with respect to incidence of shot, but, in the lesser scaup, proportionally twice as many drakes as hens carried ingested shot, table 7. The lesser scaups represented in table 7 were trapped on another area near Havana in April, 1953.

The seasonal incidence of ingested lead shot among mallards trapped at the Chautauqua National Wildlife Refuge during the fall months of 1949 and 1950 is shown in table 8. Most of the mallard groups fluoroscoped early in the season had a



Fig. 4.—An X-ray head and fluoroscopic screen used at the Havana laboratory of the Illinois Natural History Survey to determine the incidence of ingested lead shot in wild waterfowl trapped alive as well as in dead and moribund birds picked up in the field. Each bird was placed in the cone, which was rotated in front of the fluoroscopic screen. This procedure presented to view more than one plane of the bird's body and thereby resulted in more precise location of pellets than was possible in a single plane view. (Photograph from the *Journal-Star*, Peoria, Illinois.)

Table 6.—Incidence of various ingested shot levels found among mallards trapped and fluoroscoped at the Chautauqua National Wildlife Refuge near Havana, Illinois, during the fall months, 1948-1950 and 1953. (By shot level is meant the number of ingested lead shot pellets found in a gizzard.) For each sex and age class are given the number and per cent of fluoroscoped ducks represented at each shot level.

SEX AND AGE CLASS	NUMBER FLUOROSCOPED	1 PELLET		2 PELLETS		3 PELLETS		4 PELLETS		5 PELLETS		OVER 5 PELLETS		TOTAL DUCKS WITH SHOT	
		Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Male, adult.....	3,290	186	5.65	39	1.19	12	0.36	7	0.21	1	0.03	4	0.12	249	7.57
Male, juvenile.....	1,558	156	10.01	32	2.05	13	0.83	15	0.96	5	0.32	4	0.26	225	14.44
Male, all ages.....	4,848	342	7.05	71	1.46	25	0.52	22	0.45	6	0.12	8	0.17	474	9.78
Female, all ages.....	300	28	9.33	12	4.00	2	0.67	1	0.33	4	1.33	1	0.33	48	16.00
Total.....	5,148	370	7.19	83	1.61	27	0.52	23	0.45	10	0.19	9	0.17	522	10.14
Average.....															

Table 7.—Incidence of ingested lead shot among ducks of four species trapped and fluoroscoped near Havana, Illinois, at various times, 1949-1953.

SPECIES	YEAR	MONTH	ADULTS		JUVENILES		DRAKES		HENS	
			Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead	Number Examined	Per Cent With Lead
Pintail.....	1950	September	66	12.1	87	11.5	96	11.5	57	12.3
Blue-winged teal..	1949-1951	September	273	5.5	1,677	7.6	850	8.1	1,100	6.7
Wood duck.....	1950	September	308	6.8	340	11.8	409	9.5	239	9.2
Lesser scaup.....	1953	April					400	9.0	112	4.5

lower percentage of individuals with ingested shot than had groups fluoroscoped later in the season. The decline in the incidence of ingested shot among birds fluoroscoped in the December 20-24 period may have occurred as a result of the freeze-up of the lakes a week or two before, or as a result of a rapid die-off of lead-poisoned birds in a period of cold weather.

Erratic changes in incidence of ingested shot from period to period were evidence of population changes brought about by the arrival and departure of migrating mallards that varied greatly from flight to flight in the amounts of ingested lead they carried.

A few waterfowl in Illinois have been fluoroscoped in late winter or spring for evidence of ingested lead shot. Ingested shot was found in a moderate percentage of the lesser scaups examined, table 7. It was found in a very small percentage of the birds in one group of pintails; it was not found in another group of pintails nor in a sample of Canada geese, table 9.

Many ducks in other states have been fluoroscoped for evidence of ingested lead shot, table 10. In Michigan, small percentages of mallards and black ducks (*Anas rubripes*) were found to carry ingested lead during the winter and spring months. Lesser scaups that were fluoroscoped during the spring months contained

no ingested shot. Examination of wintering ducks (most of them black ducks, canvasbacks, lesser scaups, and redheads) by Hunt & Ewing (1953:362) along the Detroit River disclosed that less than 4 per cent of 7,700 ducks fluoroscoped had lead in their gizzards.

Of more than 1,000 ducks, most of them black ducks, that were fluoroscoped during the fall, winter, and spring months in New York, only a very small proportion carried ingested lead, table 10. Only a small proportion of mallards trapped during the winter months in South Dakota had lead in their gizzards.

Of six species of ducks fluoroscoped during the summer months in the Great Salt Lake Basin of Utah, the mallard was the only species in which a moderately large proportion of individuals carried ingested lead, table 10.

An astoundingly large proportion of the mallards, pintails, and redheads, and a smaller proportion of the blue-winged teals fluoroscoped during the summer at Delta Marsh, Manitoba, carried ingested lead shot, table 10. All of the redheads and most of the blue-winged teals and pintails were juveniles. The findings of Elder (1950:501) agree with Illinois data in indicating that juvenile ducks are more likely to ingest lead shot than are adults; at Delta, over twice as large a percentage of juveniles as of adult mal-

Table 8.—Periodic incidence of ingested lead shot among mallards trapped at the Chautauau National Wildlife Refuge near Havana, Illinois, during the fall months of 1949 and 1950.

PERIOD	NUMBER OF DUCKS FLUOROSCOPED		NUMBER OF DUCKS WITH SHOT		PER CENT OF DUCKS WITH SHOT		
	1949	1950	1949	1950	1949	1950	Average
Oct. 26-30.....	129	2	6	1	4.65	50.00	5.34
Oct. 31-Nov. 4...	224	153	8	6	3.57	3.92	3.71
Nov. 5-9.....	161	408	14	19	8.70	4.66	5.80
Nov. 10-14.....	194	435	12	32	6.19	7.36	7.00
Nov. 15-19.....	361	382	22	44	6.09	11.52	8.88
Nov. 20-24.....	385	333	30	33	7.79	9.91	8.77
Nov. 25-29.....	352	194	40	22	11.36	11.34	11.36
Nov. 30-Dec. 4...	150	69	11	20	7.33	28.99	15.07
Dec. 5-9.....	274	24	30	11	10.95	45.83	13.76
Dec. 10-14.....	54	3	6	1	11.11	33.33	12.28
Dec. 15-19.....	22	12	6	2	27.27	16.67	23.53
Dec. 20-24.....	64	54	7	6	10.94	11.11	11.02
Total.....	2,370	2,069	192	190			
Average.....					8.10	9.18	8.60

lards were found with lead in their gizzards, and over three times as large a percentage of juvenile as of adult pintails carried ingested lead.

On other breeding ground areas—Whitewater Lake, Manitoba, and Eyebrow Lake, Saskatchewan—Elder (1950: 501) examined 3,300 ducks during the summer months of 1948 and 1949 and found that less than 1 per cent of the individuals of any species carried ingested lead. Undoubtedly, most breeding ground areas would show a low incidence of in-

gested shot among waterfowl. The Delta Marsh, which is one of the most heavily shot-over areas in Canada, is an exception.

Shot in Ducks Bagged by Hunters

With the help of wildlife biologists in almost every state of the Union and some Canadian provinces, the Illinois Natural History Survey obtained data on the ingested lead shot found in the gizzards of more than 40,000 waterfowl bagged by hunters in the autumn and early winter

Table 9.—Incidence of ingested lead among pintails and Canada geese trapped and fluoroscoped in Union County and pintails trapped and fluoroscoped in Henderson County, Illinois, 1952 and 1953.

SPECIES	PLACE	YEAR	MONTH	NUMBER EXAMINED	PER CENT WITH LEAD
Pintail.....	Henderson County	1952	April	42	0.24
Pintail.....	Union County	1953	February	95	0.00
Canada goose.....	Union County	1953	February	61	0.00

Table 10.—Incidence of ingested lead shot among waterfowl fluoroscoped in several areas and at different seasons during the period 1941–1954.

AREA	SPECIES	YEAR	SEASON	NUMBER FLUOROSCOPED	PER CENT WITH INGESTED SHOT
Michigan*.....	Mallard and black duck.....	1941, 1942	Winter	682	1.2
	Mallard and black duck.....		Spring	182	0.4
	Lesser scaup.....	1941, 1942	Spring	105	0.0
New York†.....	Black duck.....	1949–1953	Fall, Winter, Spring	1,063	0.1
	Other species.....			144	0.0
South Dakota‡.....	Mallard.....	1950–1954	Winter	3,115	3.1
Utah**.....	Mallard.....	1950, 1951	Summer	122	5.7
	Gadwall.....	1950, 1951	Summer	16	0.0
	Baldpate.....	1950, 1951	Summer	98	0.0
	Pintail.....	1950, 1951	Summer	2,199	0.6
	Green-winged teal.....	1950, 1951	Summer	213	0.0
	Shoveler.....	1950, 1951	Summer	77	1.3
Manitoba††.....	Mallard.....	1948, 1949	Summer	537	18.4
	Pintail.....	1948, 1949	Summer	391	15.6
	Blue-winged teal.....	1948, 1949	Summer	549	4.9
	Redhead.....	1948, 1949	Summer	52	48.1

*From "Waterfowl survey of Saginaw Bay, Lake St. Clair, Detroit River, Lake Erie and the marshes adjacent to these waters," by Herbert J. Miller. Unpublished final report, P-R Project 13-R, Michigan Department of Conservation, January 1, 1943.

†From letter of February 18, 1954, by Donald D. Foley, New York Conservation Department.

‡From letter of March 7, 1955, by Ray Murdy, South Dakota Department of Game, Fish and Parks.

**Summarized from Heuer 1952.

††Summarized from Elder 1950:501.

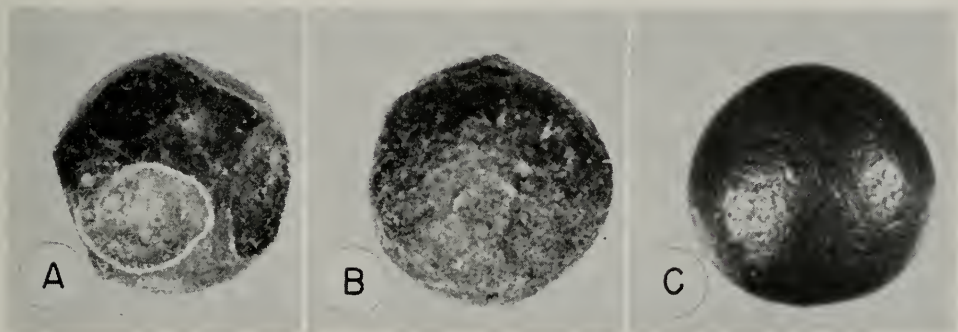


Fig. 5.—Shot pellets from the gizzards of wild ducks bagged by hunters. Pellets *A* and *B* were from the same gizzard. Pellet *A* entered the gizzard lumen from the charge that killed the bird. Pellet *B* had been ingested previously. Pellet *A* exhibits craters caused by the striking of this pellet against others in passage through the shotgun barrel. Pellet *B* has been somewhat smoothed by abrasion in the gizzard; under magnification, the surface of this pellet shows pitting and flaking. Pellet *C*, another ingested pellet from another gizzard, shows surface erosion resulting from the action of digestive juices in the gizzard.

months of the period 1938–1953. Lead pellets, two ingested and one not ingested, are shown somewhat magnified in fig. 5. The number of shot pellets and the species of ducks represented were known for each of 36,145 gizzards; data from these gizzards were used in an analysis of the incidence of shot among each of the principal kinds of waterfowl of North America, table 11.

Variations in Shot Incidence Among Species.—The incidence of ingested lead shot was about seven times as great among ducks as among geese, table 11. Less than 1 per cent of the Canada geese and less than 3 per cent of the blues and snows were found to have lead in their gizzards; the numbers of shot pellets per gizzard were exceedingly low.

There was a wide range in incidence of ingested shot among the different kinds of ducks, table 11. Kinds in which less than 2 per cent of the gizzards contained lead were bufflehead (*Bucephala albeola*), green-winged teal, mergansers (*Mergus* spp.), wood duck, shoveler, and gadwall. Kinds in which lead was found in more than 2 and less than 5 per cent of the gizzards were blue-winged teal, baldpate, and common goldeneye; in more than 5 and less than 10 per cent, ruddy duck, mallard, black duck, and pintail; in more than 10 per cent, canvasback, lesser scaup, redhead, and ring-necked duck.

It is apparent that, with the exception of the last-named group, all of which be-

long to the genus *Aythya*, there is no relationship between the incidence of shot and the phylogeny of the birds.

Shillinger & Cottam (1937:402) believed that ingestion of lead shot was related to the availability, or lack of availability, of grit, for they stated: "While lead poisoning is widely distributed throughout all sections of this country, evidence seems to indicate that it is more severe in those sections where there is a deficiency of available gravel that may serve as grit in the gizzard of the birds."

Tener (1948:38) believed grit preferences to be a factor influencing shot ingestion by waterfowl. He noted that only fine sand appeared in baldpate and green-winged teal gizzards, and that a large proportion of the gizzards of these species contained no shot. He speculated that lead pellets were too large to be selected as grit by these species.

If waterfowl were prone to pick up lead shot for grit, then it would seem reasonable to expect many species which pick up large-sized grit particles to have ingested more shot pellets than the numbers recorded for them in table 11. Ducks that commonly pick up grit particles that are larger than a No. 6 shot and that show a low incidence of shot are wood duck, bufflehead, and common goldeneye. The gizzards of geese contain quantities of large grit particles, but the incidence of shot among geese is lower than among ducks, table 11.

Evidence that the size of grit usually ingested by individuals of a species of water bird is not related to the ingestion of shot by individuals of that species is apparent from a study of the stomach contents of 792 coots (*Fulica americana*). Lead shot was found by Jones (1940:11) in only 12, or 1.5 per cent, of 792 stomachs. Gravel was found in all but 7 of the 792 stomachs and averaged 33 per cent of the gross contents. The low incidence of shot in the stomachs was attributed by Jones to the habit that the coots have of dabbling for food on the surface of the water as well as to their inability to sift through bottom material with their chicken-like bills. Yet it is reasonable to assume that they could pick up shot pellets with their bills as readily as they could pick up grit particles.

Food preferences and feeding habits of the various species of waterfowl appear to be largely responsible for the differences in the incidence of ingested shot among the species. The following discussion of feeding habits tends to support this thesis. Figures in parentheses following the name of a kind of waterfowl indicate the percentage of gizzards in which shot pellets were found, as presented in table 11.

Shovelers (1.60) and green-winged teals (1.36) feed on the surfaces of mud flats and marsh bottoms. Gadwalls (1.84) and baldpates (3.17) feed upon the vegetative parts of aquatic plants and seldom have occasion to dig into the bottom soil where shot pellets are present.

Wood ducks (1.58) feed so extensively on fruits of woodland plants (Martin, Zim, & Nelson 1951:65) that they seldom puddle or sift through lake and marsh bottoms for food. Mergansers (1.46) feed principally on fish and therefore have less occasion to ingest shot than have species which search through bottom materials for food.

Common goldeneyes (3.52) and buffleheads (0.69) are prone to frequent large, open bodies of water, over which there is little shooting, and more than 70 per cent of their food is made up of animal life, especially crustaceans and insect larvae (Cottam 1939:132). These animal organisms are found at or near the surface of the bottom; ducks feeding upon

them need not sift bottom material, as do those feeding upon the tubers, rootstocks, and seeds of aquatic plants.

Mallards (6.79) and pintails (8.87) do considerable feeding in grainfields, which may somewhat reduce their exposure to deposited lead shot. However, when feeding in lakes and marshes, they are, for the most part, active in heavily shot-over areas. Moreover, their habit of puddling deep into the bottom soil for seeds exposes them to deposited lead more frequently than other dabbling species, excepting the black duck, which behaves similarly.

Redheads (13.57), ring-necked ducks (14.18), canvasbacks (11.84), and lesser scaups (13.09) normally dive for food in comparatively shallow water in their search for seeds, tubers, and rootstocks of aquatic plants. Plant items, according to Cottam (1939:53), make up 60 to 90 per cent of the food of these ducks. The combined effect of feeding in heavily shot-over waters and the types of food taken result in a higher frequency of ingested shot pellets in this group of diving ducks than in any other group or species of waterfowl.

Regional Variations in Shot Incidence.—The incidence of ingested lead shot among ducks of 11 important species was determined for each of the North American flyways by examination of 39,610 gizzards collected in the fall and early winter months of 1938–1954, table 12.

The incidence of ingested lead was lowest in ducks of the Central Flyway. There were only small differences between the figures for North Dakota, South Dakota, Nebraska, and Colorado; for Texas the incidence of shot was several times as high as that for any other state in the flyway. In the Dakotas, only the shoveler, redhead, and canvasback showed an appreciable incidence of ingested lead, whereas in Texas most species showed a high incidence of such lead.

The incidence of ingested shot pellets was about twice as high among ducks of the Atlantic Flyway as among those of the Central Flyway, table 12. The incidence figures were higher for Massachusetts, North Carolina, and South Carolina and Georgia than for Maine, New York,

a group of other Atlantic states, and Florida. With few exceptions, waterfowl gizzards from the above states came from areas near or on the Atlantic Coast; most samples from New York and Florida

were from the interior areas of those states. Species in the Atlantic Flyway with the highest incidence of ingested lead shot were the pintail, canvasback, and redhead. Next in order were the mallard

Table 12.—Regional incidence of ingested lead shot among ducks of 11 important species; the United States and Canada, 1938–1954.

FLYWAY	MALLARD		BLACK DUCK		GADWALL		BALDPATE		PINTAIL	
	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
ATLANTIC										
Maine.....	7	14.3	725	4.8	1	0.0	.....	.....	13	15.4
Massachusetts.....	.....	.....	1,268	7.5	.....	.....	4	0.0	.....	.....
New York.....	77	6.5	425	4.5	1	0.0	12	0.0	32	12.5
Pennsylvania, New Jersey, Delaware, Maryland, Virginia.....	59	1.7	207	2.9	14	21.4	5	0.0	13	61.5
North Carolina.....	.....	.....	30	10.0	.....	.....	50	4.0	18	0.0
South Carolina and Georgia.....	77	9.1	66	13.6	95	3.2	38	0.0	56	10.7
Florida.....	3	0.0	5	0.0	15	0.0	15	13.3	15	20.0
<i>Total.....</i>	<i>223</i>	<i>.....</i>	<i>2,726</i>	<i>.....</i>	<i>126</i>	<i>.....</i>	<i>124</i>	<i>.....</i>	<i>147</i>	<i>.....</i>
<i>Average.....</i>	<i>.....</i>	<i>6.3</i>	<i>.....</i>	<i>6.1</i>	<i>.....</i>	<i>4.8</i>	<i>.....</i>	<i>3.2</i>	<i>.....</i>	<i>15.7</i>
MISSISSIPPI										
Minnesota.....	371	12.4	9	11.1	18	5.6	23	0.0	102	12.7
Illinois.....	5,259	7.9	27	18.5	109	0.0	162	0.0	951	5.9
Indiana.....	247	23.5	93	28.0	13	0.0	17	5.9	34	11.8
Missouri.....	415	2.4	4	0.0	8	12.5	8	0.0	35	2.9
Tennessee.....	696	11.6	17	5.9	174	1.2	38	5.3	102	4.9
Arkansas.....	3,494	7.2	.....	.....	.....	.....	.....	.....	.....	.....
Louisiana.....	319	15.1	7	0.0	127	2.4	38	2.7	160	28.1
<i>Total.....</i>	<i>10,801</i>	<i>.....</i>	<i>157</i>	<i>.....</i>	<i>449</i>	<i>.....</i>	<i>286</i>	<i>.....</i>	<i>1,384</i>	<i>.....</i>
<i>Average.....</i>	<i>.....</i>	<i>8.4</i>	<i>.....</i>	<i>21.0</i>	<i>.....</i>	<i>1.6</i>	<i>.....</i>	<i>1.4</i>	<i>.....</i>	<i>9.0</i>
CENTRAL										
North Dakota.....	1,186	1.9	.....	.....	171	0.6	74	1.4	161	0.6
South Dakota.....	1,123	2.6	.....	.....	9	0.0	13	0.0	26	0.0
Nebraska.....	1,252	3.1	.....	.....	2	0.0	63	0.0	8	0.0
Colorado.....	292	2.1	.....	.....	.....	.....	.....	.....	.....	.....
Texas.....	65	15.4	.....	.....	18	11.1	25	0.0	51	15.7
<i>Total.....</i>	<i>3,918</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>200</i>	<i>.....</i>	<i>175</i>	<i>.....</i>	<i>246</i>	<i>.....</i>
<i>Average.....</i>	<i>.....</i>	<i>2.7</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>1.5</i>	<i>.....</i>	<i>0.6</i>	<i>.....</i>	<i>3.7</i>
PACIFIC										
British Columbia.....	138	17.4	.....	.....	2	0.0	37	0.0	55	16.4
Washington.....	598	5.0	.....	.....	6	0.0	120	1.7	118	11.0
Oregon.....	214	4.7	.....	.....	9	0.0	57	7.0	102	7.8
Idaho.....	502	5.8	.....	.....	.....	.....	29	3.5	23	13.0
Utah.....	1,086	12.5	.....	.....	285	2.1	451	3.8	2,776	7.9
Nevada.....	30	20.0	.....	.....	22	0.0	7	0.0	25	12.0
California.....	697	7.4	.....	.....	158	1.3	383	4.7	1,596	9.9
<i>Total.....</i>	<i>3,265</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>482</i>	<i>.....</i>	<i>1,084</i>	<i>.....</i>	<i>4,695</i>	<i>.....</i>
<i>Average.....</i>	<i>.....</i>	<i>8.8</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>1.7</i>	<i>.....</i>	<i>3.9</i>	<i>.....</i>	<i>8.8</i>

and the lesser scaup, the black duck, and the ring-necked duck.

The incidence of ingested shot among ducks of the Pacific Flyway was only slightly higher than that found in the At-

lantic Flyway, table 12. Ducks near Vancouver, British Columbia, showed a higher incidence of ingested shot than did those in any other area of the flyway. In contrast, ducks in adjacent Washington

data are from 39,610 gizzards collected during fall and early winter months from hunters in

GREEN-WINGED TEAL		SHOVELER		REDHEAD		RING-NECKED DUCK		CANVASBACK		LESSER SCAUP		TOTAL DUCKS	
Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
99	3.0					90	3.3			40	7.5	975	4.8
15	6.7					3	0.0			79	2.5	1,369	7.2
55	1.8			66	6.1	9	0.0	27	11.1	213	8.0	917	5.8
38	2.6			2	0.0	2	0.0	5	20.0	4	0.0	349	5.7
33	3.0			68	11.8	4	0.0	93	11.8	5	0.0	301	8.3
42	2.4	8	0.0			61	9.8	1	0.0	5	0.0	449	7.1
12	0.0	5	0.0			25	4.0	2	0.0	6	0.0	103	5.8
294	2.7	13		136	8.8	194	5.2	128	11.7	352	6.3	4,463	6.3
18	0.0	40	2.5	44	15.9	79	29.1	132	4.6	88	12.5	924	11.8
400	0.8	60	0.0	15	13.3	120	17.5	224	7.6	451	11.5	7,778	7.3
17	5.9	12	0.0	7	14.3	50	26.0	16	0.0	20	20.0	526	20.5
56	0.0	9	0.0	8	12.5	20	10.0	3	0.0	32	3.1	598	2.7
63	3.2	18	11.1	4	0.0	266	14.7	31	16.1	95	23.2	1,504	9.3
157	3.8	13	0.0			70	7.1	7	0.0	107	26.2	3,494	7.2
												1,005	14.0
711	1.7	152	2.0	78	14.1	605	17.0	413	6.8	793	14.9	15,829	8.6
9	0.0	29	0.0	90	7.8			194	5.2	47	2.1	1,961	2.2
19	0.0	18	5.6	20	0.0	5	0.0	13	7.7	33	0.0	1,279	2.4
46	0.0							11	0.0	24	4.2	1,406	2.8
11	9.1	7	14.3	194	10.3	25	8.0	4	25.0	30	3.3	292	2.1
												430	10.7
85	1.2	54	3.7	304	8.9	30	6.7	222	5.4	134	2.2	5,368	3.1
29	0.0	2	50.0			1	0.0			10	20.0	274	13.1
125	0.0	7	0.0	6	16.7	3	0.0	7	14.3	8	25.0	998	4.9
41	2.4	10	10.0			1	0.0	4	25.0	4	0.0	442	5.7
7	0.0	1	0.0	1	0.0					6	16.7	569	6.0
1,201	0.5	791	1.0	209	23.4			793	11.9	13	7.7	7,605	7.1
25	0.0	46	2.2	4	25.0	1	0.0	6	33.3	1	0.0	167	7.8
281	1.8	650	1.7	54	5.6			61	21.3	15	0.0	3,895	6.7
1,709	0.7	1,507	1.5	274	19.7	6		871	12.7	57	10.5	13,950	6.8

Table 13.—Incidence of ingested lead shot among ducks of 10 species at Hovey Lake, near Mount Vernon, Indiana; the data are from gizzards collected in the waterfowl hunting seasons of 1949, 1950, and 1951.

SPECIES	1949		1950		1951	
	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot	Number Examined	Per Cent With Shot
Mallard.....	90	35.6	56	12.5	61	9.9
Black duck.....	39	43.6	18	16.7	19	15.8
Gadwall.....	5	0.0	5	0.0	3	0.0
Baldpate.....	4	0.0	3	0.0	4	0.0
Pintail.....	17	5.9	6	0.0	3	0.0
Green-winged teal.....	7	0.0	3	0.0	2	0.0
Shoveler.....	2	0.0	2	0.0	7	0.0
Ring-necked duck.....	15	46.7	16	5.9	10	20.0
Canvasback.....	4	0.0	6	0.0	5	0.0
Lesser scaup.....	4	25.0	6	0.0	7	28.6
<i>Total</i>	<i>187</i>	.....	<i>121</i>	.....	<i>121</i>	.....
<i>Average</i>.....	.....	31.5	.....	7.1	.....	10.7

showed the lowest incidence of shot for the flyway; gizzards collected from Washington were from numerous areas scattered over the state.

Among the ducks of Utah and Nevada, the incidence of ingested shot was slightly greater than the average for the flyway. Among the ducks of Oregon and Idaho, the incidence figure was below the flyway average. The incidence figure for the ducks of California approximated the flyway average. The data from Utah were obtained from material collected at the

Bear River Migratory Bird Refuge; the data from Nevada were obtained largely at the Stillwater Wildlife Management Area. Material from Oregon, Idaho, and California were from numerous, widely distributed areas.

In the Pacific Flyway, the incidence of ingested shot was highest among the redhead, canvasback, and lesser scaup, lower in the mallard and pintail, and still lower in the baldpate, gadwall, shoveler, and green-winged teal.

The incidence of ingested shot was

Table 14.—Incidence of ingested lead shot among ducks of 12 species in Illinois; the data are from gizzards collected in the fall months, 1938–1953, from waterfowl hunters in the Illinois and Mississippi river valleys.

SPECIES	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Number Examined	Number With Shot	Per Cent With Shot	Number Examined	Number With Shot	Per Cent With Shot
Mallard.....	4,784	405	8.47	475	7	1.47
Gadwall.....	104	0	0.00	5	0	0.00
Baldpate.....	154	0	0.00	8	0	0.00
Pintail.....	920	52	5.65	31	4	12.90
Green-winged teal.....	373	3	0.80	27	0	0.00
Blue-winged teal.....	121	1	0.83	8	0	0.00
Shoveler.....	57	0	0.00	3	0	0.00
Wood duck.....	19	0	0.00	7	0	0.00
Redhead.....	12	2	16.67	2	0	0.00
Ring-necked duck.....	113	19	16.81	7	2	28.57
Canvasback.....	88	10	11.36	136	7	5.15
Lesser scaup.....	144	34	23.61	307	18	5.86
<i>Total</i>	<i>6,889</i>	<i>526</i>	.....	<i>1,016</i>	<i>38</i>	.....
<i>Average</i>.....	.....	.....	7.64	.....	.....	3.74

higher among ducks of the Mississippi Flyway than among those of any other flyway, table 12. The highest incidence figure for the Mississippi Flyway was for ducks taken in Indiana; these figures were not typical for the state, as the bulk of the samples on which they were based were from Hovey Lake, near Mount Vernon. Hovey Lake is noted for lead poisoning losses in waterfowl.

The incidence of ingested shot was high among the ducks of Louisiana and Minnesota; moderately high for those of Illinois, Tennessee, and Arkansas; and quite low for those of Missouri.

The gizzard collections from Minnesota, Illinois, and Missouri constituted representative samples for those states. In Tennessee, almost all the data were from Reelfoot Lake. In Arkansas, the gizzards were from ducks shot at clubs within a 35-mile radius of Stuttgart. Both Reelfoot Lake and the Stuttgart area provide a large share of the duck hunting in their respective states. Material from Louisiana was largely from Catahoula Lake and the Delta region of the Mississippi River.

In the Mississippi Flyway, the incidence figure for lead shot was higher in the black duck than in any other species, but the data were biased by the large number of black duck gizzards taken at Hovey Lake, Indiana, where the incidence of lead was extremely high. It was very high in the ring-necked duck, lesser scaup, and redhead; it was moderately high in the pintail, mallard, and canvasback; it was low in the shoveler, green-winged teal, gadwall, and baldpate.

The variation in the proportion of ducks with shot in their gizzards at Hovey Lake was very pronounced over a 3-year period, table 13. In 1949, the highest incidence of ingested shot found anywhere in the United States was recorded at Hovey Lake, but in 1950 and 1951 the figure for the area was close to the average for the Mississippi Flyway.

The extremely high incidence figures for Hovey Lake in 1949 were probably influenced by the hunters' kill of a large number of ducks affected by lead poisoning. Up to the end of the 1949 hunting season, the Indiana Department of Conservation permitted hunters to jump-shoot

ducks. Since that time, duck hunting at Hovey Lake has been restricted to blinds. Jump shooters, in wading the brush-covered shore of Hovey Lake, hunted a zone in which ducks suffering from lead poisoning were prone to concentrate. Because the sick ducks had difficulty in flying, hunters bagged unusually large numbers of them.

A reduction in the incidence of ingested lead occurred in the mallard in 1951 at Hovey Lake, evidently because high water, which raised the lake level during the latter part of the hunting season, made lead shot less easily available to this duck. The increased depth failed to reduce the ingestion of shot by diving ducks.

A comparison of the incidence of ingested shot in ducks taken along the Illinois River with those taken along the Mississippi River in Illinois, table 14, disclosed a marked difference between the two areas. The figure for the Illinois River is more than twice that for the Mississippi. The differences in shot incidence between the two areas were especially marked in the mallard, canvasback, and lesser scaup, the only species that were represented by adequate samples in both areas.

The Mississippi River normally carries a much heavier load of sediment than does the Illinois River. Data presented by Suter (1948, plate 1) for the period 1935-1945 showed that the Illinois River at Peoria carried an average of 100 p.p.m. for 300 days per year, whereas the Mississippi River at Quincy carried an average of almost 300 p.p.m. for the same number of days. Apparently lead shot is covered more quickly in the Mississippi, with its heavier load of sediment, than in the Illinois.

Periodic Variations in Shot Incidence.—The incidence of ingested lead shot in mallard populations migrating through the Illinois River valley in autumn was determined for weekly periods by examination of 2,499 gizzards collected from hunters in 1938-1940, table 15.

As in the case of mallards which were live-trapped and fluoroscoped, table 8, the percentage of hunter-killed birds that carried ingested shot was lower early in the season than late; up to mid-November, 5.7 per cent of the gizzards examined con-

tained shot, while after mid-November 7.8 per cent contained shot.

The incidence of shot among hunter-killed birds, table 15, varied from week

Table 15.—Periodic incidence of ingested lead shot among mallards in Illinois; the data are from 2,499 gizzards collected from waterfowl hunters in the Illinois River valley, 1938–1940.*

PERIOD	NUMBER OF GIZZARDS EXAMINED	PER CENT WITH SHOT
Oct. 11–17...	82	2.44
18–24.....	227	7.05
25–31.....	456	3.73
Nov. 1–7.....	377	8.75
8–14.....	296	4.73
15–21.....	455	7.69
22–28.....	324	9.88
Nov. 29–Dec. 5	216	7.41
Dec. 6–12....	66	0.00

*Data from food habits study of Illinois ducks by Harry G. Anderson, June 1, 1939–June 30, 1941, leader of Federal Aid Project 2-R, Illinois Natural History Survey and Illinois Department of Conservation, co-operating.

Table 16.—Incidence of ingested lead shot among ducks of seven species at or near the Bear River Migratory Bird Refuge, Utah, summer and fall, 1950 and 1951. Summer data are based upon fluoroscopy of ducks apparently suffering from botulism; fall data are from duck gizzards collected from hunters.

SPECIES	1950		1951	
	Per Cent With Shot		Per Cent With Shot	
	Summer	Fall	Summer	Fall
Mallard.....	3.2	15.1	14.3	8.9
Gadwall.....	0.0	0.7	0.0	2.7
Baldpate.....	0.0	3.2	0.0	3.9
Pintail.....	0.6	10.0	0.6	5.8
Green-winged teal.....	0.0	0.2	0.0	0.2
Shoveler.....	1.8	0.9	0.0	1.1
Redhead.....	0.0	21.1	0.0	23.2
Average.....	0.8	6.7	0.7	5.6

to week as in live-trapped mallards, table 8. In Minnesota, as in Illinois, a pronounced weekly variation in the incidence of ingested lead has been reported (Reid 1948:126). These periodic variations in the incidence figures appear attributable in part to population shifts associated with migration.

Figures on the occurrence of ingested shot among waterfowl taken during the summer and fall months at or near the

Bear River Migratory Bird Refuge, Utah, are given in table 16. Ingestion of shot was uncommon during the summer months, except for the mallard in 1951, but it was relatively common for several species in the fall.

It is evident that much of the lead ingested by ducks in Illinois and in Utah had been fired from hunters' guns in the same year it was picked up by the ducks. Apparently, much of the shot fired by duck hunters during a hunting season penetrates sufficiently deep into lake and marsh bottoms by the following summer to be out of reach of feeding waterfowl.

Data in table 11 and those reported by Shillinger & Cottam (1937:401) permit a comparison of the incidence of ingested lead among waterfowl in two periods separated by more than 20 years. According to Arnold L. Nelson (letter, December 13, 1955), 77 per cent of the gizzards reported on by Shillinger & Cottam were collected in the period 1908–1916; all gizzards represented in table 11 were col-

Table 17.—Incidence of ingested lead shot among mallards taken in two different periods of years in the Illinois River valley; data are from gizzards collected from hunters.

YEARS	NUMBER OF GIZZARDS EXAMINED	NUMBER WITH SHOT	PER CENT WITH SHOT
1938–1940	2,371	165	6.96
1948–1950	2,005	240	11.97

lected in the period 1938-1953. The comparison is limited to six species of ducks—mallard, pintail, redhead, ring-necked duck, canvasback, and lesser scaup—which are listed in both periods.

In five of the six species (the exception, lesser scaup), the incidence of ingested shot recorded for the 1938-1953 period, table 11, was much higher than that for the earlier period. The per cent of gizzards containing shot increased for the five species as follows: mallard from 2.41 to 6.79, pintail from 1.14 to 8.87, redhead from 3.14 to 13.57, ring-necked

duck from 3.29 to 14.18, and canvasback from 9.77 to 11.84.

Shillinger & Cottam (1937:401) reported lead in 39.42 per cent of the lesser scaup gizzards, but over one-third of their sample was from the vicinity of Marquette, Wisconsin, where shot was found in 76.5 per cent of the gizzards. The large sample from an atypical area materially biased the results.

The incidence of ingested lead among mallards in the Illinois River valley during two different periods—1938-1940 and 1948-1950—is shown in table 17. In a

Table 18.—Incidence of various ingested shot levels found among ducks of seven species; data are from 2,184 duck gizzards (each of which contained ingested lead) collected during the fall and early winter months from hunters in North America, 1938-1954. (By shot level is meant the number of ingested shot pellets found in a gizzard.) For each species are given the number and per cent of ducks represented at each shot level.

SPECIES	1 PEL-LET		2 PEL-LETS		3 PEL-LETS		4 PEL-LETS		5 PEL-LETS		6 PEL-LETS		OVER 6 PELLETS		TOTAL	
	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Mallard.....	757	65.3	194	16.7	80	6.9	31	2.7	24	2.1	9	0.8	64	5.5	1,159	100.0
Black duck.....	120	65.6	27	14.8	15	8.2	6	3.3	1	0.6	3	1.6	11	6.0	183	100.0
Pintail.....	241	60.0	51	12.7	27	6.7	19	4.7	12	3.0	1	0.2	51	12.7	402	100.0
Redhead.....	56	69.1	11	13.6	4	4.9	0	0.0	1	1.2	1	1.2	8	9.9	81	100.0
Ring-necked duck.....	65	65.7	10	10.1	9	9.1	2	2.0	0	0.0	2	2.0	11	11.1	99	100.0
Canvasback.....	107	74.3	13	9.0	12	8.3	4	2.8	1	0.7	3	2.1	4	2.8	144	100.0
Lesser scaup.....	67	57.8	19	16.4	12	10.3	3	2.6	0	0.0	1	0.9	14	12.0	116	100.0
Total.....	1,413		325		159		65		39		20		163		2,184	
Average.....		64.7		14.9		7.3		3.0		1.8		0.9		7.4		100.0

Table 19.—Incidence of high levels of ingested lead shot (20 or more pellets in gizzard) among ducks of seven species; data are from gizzards collected from North American hunters in the autumn and early winter months, 1938-1954.

SPECIES	NUMBER OF GIZZARDS WITH PELLETS	NUMBER OF PELLETS IN INDIVIDUAL GIZZARDS	NUMBER OF DUCKS	PER CENT OF GIZZARDS WITH 20 OR MORE PELLETS EACH
Mallard.....	1,159	20, 60, 93, 107, 137	5	0.43
Black duck.....	183	25	1	0.55
Pintail.....	402	20, 20, 22, 23, 25, 38, 48, 60, 110	9	2.24
Redhead.....	81		0	0.00
Ring-necked duck	99	31, 37, 65	3	3.03
Canvasback.....	144	53	1	0.69
Lesser scaup.....	116	21, 21, 43, 46, 52, 58, 64, 172	8	6.90
Total.....	2,184		27	
Average.....				1.24

decade, the incidence figure for Illinois mallards almost doubled.

Increases in the percentage of waterfowl ingesting lead have paralleled increases in the number of waterfowl hunters. Because there is expectation that the number of duck hunters will continue to increase, it can be anticipated that lead poisoning will become a greater hazard to waterfowl than it is at present.

Incidence of Various Shot Levels.

—The incidence of various levels of ingested lead shot found among ducks of seven species in North America in the autumn and early winter months of 1938–1954 is shown in table 18 and fig. 6. (By level of ingested lead shot, or shot level, is meant the number of ingested shot pellets found in a gizzard.) The various shot levels have an important bearing on the rate of mortality in ducks for, as will be shown later, the larger the number of ingested shot pellets per duck, the higher is the death rate, other factors being equal.

Of 2,184 duck gizzards that contained lead when collected from hunters in many parts of North America in 1938–1954,

64.7 per cent contained one pellet each, table 18; 14.9 per cent contained two pellets each. Only 7.4 per cent of the gizzards containing shot pellets contained more than six pellets each.

Comparatively few ducks killed by North American hunters during the fall months in the period 1938–1954 carried 20 or more ingested shot pellets each, table 19. The maximum number of pellets recorded was 172, in a lesser scaup gizzard. Cottam (1939:39) reported 1 to 58 pellets in individual gizzards of lesser scaups shot near Marquette, Wisconsin, in April, 1909; Shillinger & Cottam (1937:403) reported that 179 pellets were found in the gizzard of a pintail victim of lead poisoning.

Data in table 19 indicate that pintails, ring-necked ducks, and lesser scaup ducks are more likely to have large numbers of pellets per gizzard than are the ducks of other species.

The large numbers of shot pellets found in gizzards of pintails, ring-necks, and lesser scaups are probably a reflection of the ability of these species to tolerate the toxic effects of lead, as well as a reflection

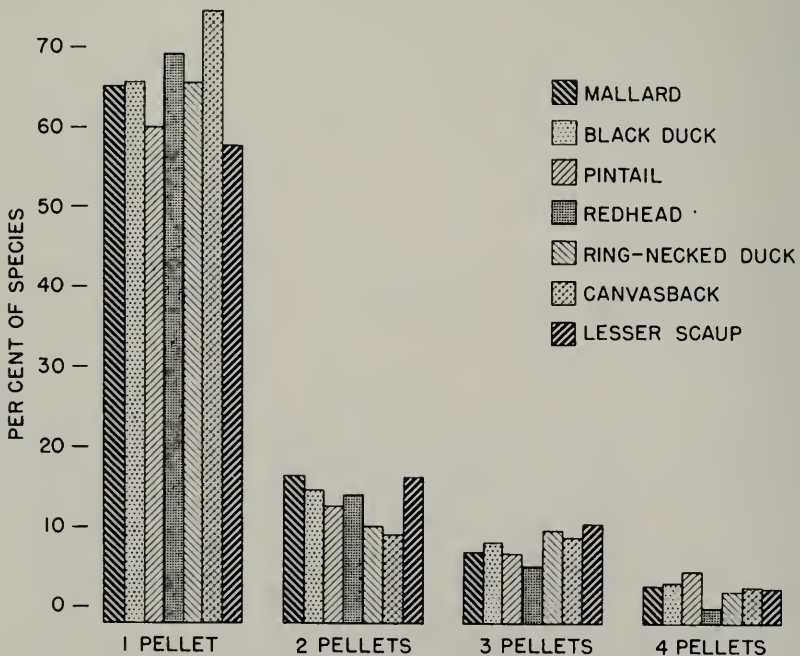


Fig. 6.—Incidence of four levels of ingested shot found in gizzards of ducks of seven species in the autumn and early winter months of 1938–1954. Data are from table 18 and represent ducks shot by hunters in many parts of North America.

of their proclivity to pick up large numbers of pellets. For example, pintails are only slightly more prone than mallards to ingest shot, table 11, but the percentage of gizzards containing 20 or more shot pellets each was almost six times as great in pintails as in mallards, table 19. The percentage of gizzards containing ingested shot was about the same in redheads, ring-necked ducks, canvasbacks, and lesser scaups, table 11, but larger percentages of

LEAD IN WILD MALLARDS DOSED AND RELEASED

Certain effects of lead poisoning on mallards in the wild were determined by the following experiment. In the autumns of 1949, 1950, and 1951, several thousand migrating mallards were trapped at Lake Chautauqua. Some of these ducks were dosed with either one, two, or four No. 6 shot pellets each, then banded, and

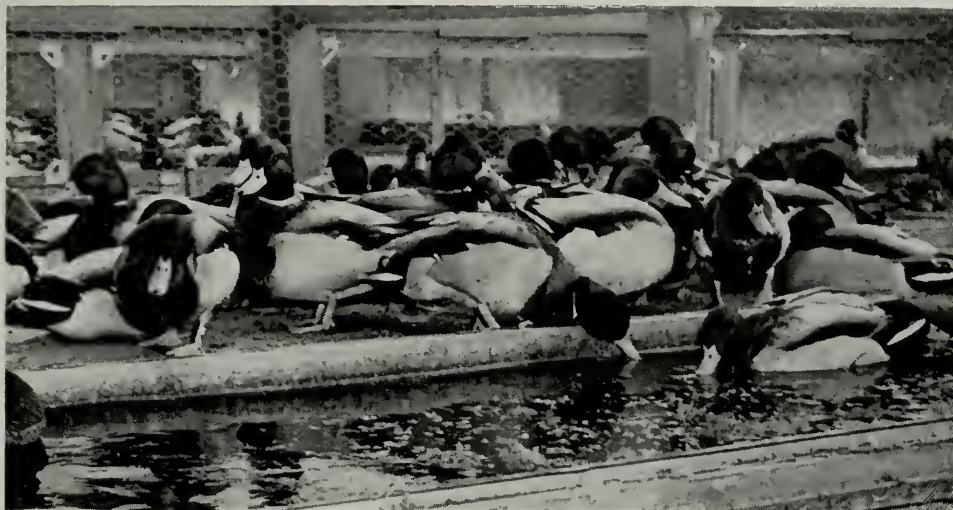


Fig. 7.—Penned mallards, dosed with lead shot, feeding upon coontail, apparently one of the best vegetable foods for alleviating the effects of ingested lead.

gizzards with 20 or more shot pellets each were found among the ring-necked ducks and scaups.

As shown by Jordan & Bellrose (1951: 18), the ability of ducks to survive lead poisoning is influenced by the physical form of the food consumed. The higher survival rate of pintails than of mallards may be related to the greater numbers of small seeds and the paucity of corn in the diet of the pintails. Lesser scaups, which consume at least twice as much animal life per bird as any other ducks listed in table 19 (Cottam 1939:53), apparently can tolerate lead to a greater degree than the ducks of other species. Thus, it appears that animal matter is more favorable than vegetable matter to survival of ducks that have ingested lead, and that various forms of vegetable matter differ greatly in their effects on birds that have ingested lead, fig. 7.

released. Other ducks trapped at the same time were banded and released, undosed, to serve as controls.

In 1949 and 1950, the trapped mallards were taken to the Havana field laboratory of the Illinois Natural History Survey, where they were fluoroscoped before being banded and released. Ducks known to carry ingested lead when trapped were not included in the experiment. In 1951, when the X-ray unit was being repaired and could not be used for fluoroscopy, undoubtedly some ducks carrying ingested lead when trapped were released as dosed or control birds. The number of these was, of course, unknown but it was probably relatively small.

In 1949, only adult mallard drakes were included in the experiment. In 1950 and 1951, both adult and juvenile drakes and, in 1951, hens also were included in the experiment.

the birds treated with lead were bagged at about the same rate as the untreated controls, tables 21-23. During the subsequent 6-10-day period, there was a pronounced increase in the bag of treated ducks, especially in those dosed with two or four shot pellets each.

In the dosed wild mallards, the ingestion of lead shot did not appear to affect behavior until after the first 5 days. In the mallards that were dosed with one shot pellet each, and that did not die of lead poisoning, the behavior appeared to be most severely affected in the 6-15-day period after ingestion; in mallards that were dosed with two or four shot pellets

each, and that survived, the period in which behavior was severely affected appeared to be longer. The data suggest that most wild mallards that become affected by lead poisoning during the hunting season either die in the second or third week following ingestion of shot or they begin their recovery by the early part of the fourth week.

Penned wild mallards that were dosed with lead exhibited weakness and fatigue during the second and third weeks after being dosed; these symptoms increased in severity during the third and fourth weeks (Jordan & Bellrose 1951:5-6). The keel bone became prominent, and often the

Table 21.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one No. 6 lead shot pellet each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1949-50. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1949; 559 of the birds were dosed and 560 were not dosed.

DAYS AFTER DOSAGE	0 PELLET		1 PELLET		TOTAL	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-5.....	5	45.5	6	54.5	11	100.0
6-10.....	2	28.6	5	71.4	7	100.0
11-15.....	1	11.1	8	88.9	9	100.0
16-20.....	4	57.1	3	42.9	7	100.0
21-25.....	2	50.0	2	50.0	4	100.0
26-60.....	5	45.5	6	54.5	11	100.0
Total.....	19	.....	30	.....	49	.....

Table 22.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one or with two No. 6 lead shot pellets each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1950-51. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1950; 391 were dosed with one pellet each, 392 were dosed with two pellets each, and 389 were not dosed.

DAYS AFTER DOSAGE	0 PELLET		1 PELLET		2 PELLETS		TOTAL	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-5.....	8	38.1	6	28.6	7	33.3	21	100.0
6-10.....	3	13.0	8	34.8	12	52.2	23	100.0
11-15.....	7	21.9	8	25.0	17	53.1	32	100.0
16-20.....	6	22.2	5	18.5	16	59.3	27	100.0
21-25.....	4	36.4	3	27.2	4	36.4	11	100.0
26-60.....	5	33.3	7	46.7	3	20.0	15	100.0
Total.....	33	.....	37	.....	59	.....	129	.....

Table 23.—Relative hunting vulnerability exhibited by wild drake mallards dosed with one or with four No. 6 lead shot pellets each and those not dosed, as measured by band recoveries in each of six periods, fall and early winter, 1951–52. The data are for birds trapped, banded, and released at the Chautauqua National Wildlife Refuge in the fall months of 1951; 504 were dosed with one pellet each, 504 were dosed with four pellets each, and 507 were not dosed.

DAYS AFTER DOS- AGE	0 PELLETT		1 PELLETT		4 PELLETTs		TOTAL	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-5	9	29.0	11	35.5	11	35.5	31	100.0
6-10	4	11.4	9	25.7	22	62.9	35	100.0
11-15	7	16.3	10	23.3	26	60.5	43	100.0
16-20	6	22.2	8	29.7	13	48.1	27	100.0
21-25	4	30.8	6	46.2	3	23.1	13	100.0
26-60	7	25.0	11	39.3	10	35.7	28	100.0
Total	37	.....	55	.....	85	.....	177	.....

wings of an affected duck assumed a "roof-shaped" or drooping appearance.

Symptoms typical of those found during the fourth week in penned birds appear in wild ducks mainly at times of severe die-offs. Apparently, at other times, affected ducks either recover or are taken by hunters or predators in a shorter period of time and in a less extreme state of emaciation.

Effect of Lead on Migration Rate

That lead poisoning has a pronounced effect upon the migration of ducks is indi-

cated by differences in miles traveled by groups of mallards undosed and by similar groups of mallards dosed with one, two, or four No. 6 shot pellets each, tables 24–26. In 1949, a group of mallards dosed with one shot pellet each had a larger percentage of its bands recovered within a 50-mile radius of the banding station than had the undosed control group, table 24. In 1950, a group of mallards dosed with one pellet each had a somewhat smaller percentage of its bands recovered within the 50-mile zone than had the controls, but a group of mallards

Table 24.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife refuge in the fall months of 1949; 559 of the birds were dosed with one No. 6 shot pellet each and 560 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

MILES FROM PLACE OF BANDING	0 PELLETT		1 PELLETT	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-50	11	55.0	21	60.0
51-100	1	5.0	1	2.9
101-150	0	0.0	0	0.0
151-200	4	20.0	1	2.9
201-300	3	15.0	5	14.3
301-400	1	5.0	7	20.0
401 and over	0	0.0	0	0.0
Total	20	100.0	35	100.0

dosed with two pellets each had a much larger percentage of its recoveries fall within the 50-mile zone than had the control group, table 25. In 1951, one shot pellet for each bird seemed to have little effect on migration, but four pellets for each bird greatly retarded migration. Less than 5 per cent of the bands recovered from the mallards dosed with four pellets each were taken farther than 50 miles from the banding station, table 26.

Manifestly, the weakness and fatigue

associated with lead poisoning reduces the movement of ducks. The larger the amount of ingested lead per bird, the greater is apt to be the reduction of movement by the affected segment of the population. In areas where lead poisoning is of outbreak proportions, it is reasonable to conclude that the bulk of the sick birds have picked up shot within their daily feeding radius, usually less than 50 miles. Conversely, it can be assumed that only a small percentage of the ducks that have

Table 25.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife Refuge in the fall months of 1950; 391 of the birds were dosed with one No. 6 shot pellet each, 392 were dosed with two pellets each, and 389 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

MILES FROM PLACE OF BANDING	0 PELLET		1 PELLET		2 PELLETS	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-50.....	14	58.3	16	53.3	33	76.7
51-100.....	1	4.2	0	0.0	1	2.3
101-150.....	0	0.0	0	0.0	1	2.3
151-200.....	1	4.2	0	0.0	0	0.0
201-300.....	1	4.2	3	10.0	5	11.6
301-400.....	7	29.2	11	36.7	3	7.0
401 and over.....	0	0.0	0	0.0	0	0.0
<i>Total</i>	<i>24</i>	<i>100.1</i>	<i>30</i>	<i>100.0</i>	<i>43</i>	<i>99.9</i>

Table 26.—Effect of ingested lead shot on migration of mallards, as measured by distances traveled by dosed and by undosed birds before they were shot by hunters. The data are for birds trapped and released at the Chautauqua National Wildlife Refuge in the fall months of 1951; 504 of the birds were dosed with one No. 6 shot pellet each, 504 were dosed with four pellets each, and 507 were not dosed. Figures show for dosed and for undosed ducks the per cent of recovered bands (those recovered in year of banding and for which distance data are available) that were recovered at various distances from the point of banding and release.

MILES FROM PLACE OF BANDING	0 PELLET		1 PELLET		4 PELLETS	
	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period	Number of Bands Recovered in Period	Per Cent of Bands Recovered in Period
0-50.....	36	69.2	51	67.1	94	95.9
51-100.....	4	7.7	7	9.2	0	0.0
101-150.....	0	0.0	1	1.3	1	1.0
151-200.....	2	3.9	4	5.3	0	0.0
201-300.....	4	7.7	7	9.2	1	1.0
301-400.....	6	11.5	4	5.3	1	1.0
401 and over.....	0	0.0	2	2.6	1	1.0
<i>Total</i>	<i>52</i>	<i>100.0</i>	<i>76</i>	<i>100.0</i>	<i>98</i>	<i>99.9</i>

become ill from lead poisoning have migrated farther than 50 miles from where they ingested shot.

Effect of Lead on Year-of-Banding Mortality Rate

The mortality rates of the dosed and the undosed mallards in the year of banding or the first year (to end of following August) after being banded and released are indicated by data in table 27. Each

1950:8-12) as to have only a minor effect upon the mortality rates.

Most of the year-of-banding mortality rates for the undosed, or control, groups in the experiment were lower than even the lowest of the year-of-banding mortality rates for mallards reported by Bellrose & Chase (1950:8-12). In the Bellrose & Chase study, a correction factor was used for bandings made during the hunting season, and mortality rates were

Table 27.—The year-of-banding mortality rates of wild, free-flying mallards undosed and of similar mallards dosed with one, two, or four No. 6 lead shot pellets each. The data are for mallards trapped, banded, and released at the Chautauqua National Wildlife Refuge near Havana, Illinois. The mortality rates were derived as explained in the section entitled "Effect of Lead on Year-of-Banding Mortality Rate."

YEAR OF BANDING	SEX OF DUCK*	AGE OF DUCK†	SHOT DOSE	NUMBER OF DUCKS BANNED	BAND RECOVERIES IN YEAR OF BANDING		BAND RECOVERIES FIRST 4 YEARS AFTER BANDING		MORTALITY RATE (PER CENT)	
					Number	Per Cent	Number	Per Cent	Year of Banding	Difference Between Dosed and Undosed Ducks
1949 . . .	M	A	0	560	19	3.39	143	25.53	13.3	
	M	A	1	559	35	6.26	155	27.73	22.6	9.3
1950 . . .	M	A	0	278	33	11.87	106	38.13	31.1	
	M	A	1	274	45	16.42	103	37.59	43.7	12.6
	M	A	2	277	74	26.71	99	35.74	74.7	43.6
	M	J	0	111	17	15.32	43	38.74	39.5	
	M	J	1	117	15	12.82	35	29.91	42.9	3.4
	M	J	2	115	21	18.26	49	42.61	42.9	3.4
1951 . . .	M	A	0	300	24	8.00	77	25.67	31.2	
	M	A	1	324	42	12.96	91	28.09	46.2	15.0
	M	A	4	284	58	20.42	80	28.17	72.5	41.3
	M	J	0	207	23	11.11	73	35.27	31.5	
	M	J	1	180	24	13.33	66	36.67	36.4	4.9
	M	J	4	220	41	18.64	65	29.55	63.1	31.6
1939-1943‡	F	?	0	7,897	390	4.94	1,094	13.85	35.6	
1951 . . .	F	?	1	501	87	17.37	151	30.14	57.6	22.0

* M= male; F=female.

† A=adult; J=juvenile.

‡ No control hens were available at time of 1951 experiment; so recoveries for the first 4 years from bandings of hen mallards at the Chautauqua National Wildlife Refuge, 1939-1943, were used for the control data.

mortality rate was derived by comparing the shrinkage in the population in the year of banding (as measured by year-of-banding band recoveries) to the population at the time of banding (as measured by the total band recoveries at the end of the fourth year after banding). For example, the mortality rate for adult undosed males released in 1949 was found by dividing 19 by 143, table 27. Although not all mallards of a banded group are dead by the end of the fourth year after being banded, the proportion of the group alive is so small (Bellrose & Chase

calculated from the corrected percentages, rather than the numbers, of bands recovered.

In each year and in each sex and age class for which data were collected, the mallards dosed with lead shot had a higher mortality rate during the year of banding than the control, or undosed, mallards, table 27.

For adult drake mallards dosed with one shot pellet each, in 1949, 1950, and 1951, the year-of-banding mortality rates were 9.3, 12.6, and 15.0 per cent, respectively, greater than the mortality rates for

the controls. Adult drake mallards dosed with two shot pellets each in 1950 had a year-of-banding mortality rate that was 43.6 per cent greater than that of drakes of the same age class used as controls in the same year. Adult drakes dosed with four pellets each in 1951 had a year-of-banding mortality rate that was slightly, and unaccountably, lower than that of birds of the same sex and age class dosed with two pellets each in 1950.

Juvenile drake mallards in 1950 and 1951 had lower year-of-banding mortality

for the undosed hens banded and released in 1939-1943.

At the Rocky Mountain Arsenal, near Denver, Colorado, wild mallards were banded, dosed with lead shot, and released in late winter months, 1950 and 1951, by Johnson A. Neff and Charles C. Sperry of the U. S. Fish and Wildlife Service and Irving R. Poley of the Colorado Department of Game and Fish, table 28. Band data for 1951 were not used because, as Neff (letter, February 5, 1955) reported, a chemical pollution of the water

Table 28.—Number and per cent of bands recovered, 1950-1954, from mallards trapped, banded, and released at the Rocky Mountain Arsenal, Denver, Colorado, February 13-March 21, 1950. Before release, half of the males and half of the females were dosed with six No. 6 shot pellets each, and the others were released, undosed, to serve as controls.*

SEX	SHOT DOSE	NUMBER OF DUCKS BANDED	NUMBER OF BANDS RECOVERED	PER CENT OF BANDS RECOVERED
Male.....	0	200	56	28.0
Male.....	6	200	19	9.5
Female.....	0	125	13	10.4
Female.....	6	125	12	9.6

*Experiments conducted by Johnson A. Neff and Charles C. Sperry of the U. S. Fish and Wildlife Service and Irving R. Poley of the Colorado Department of Game and Fish.

rates than those of adult drakes dosed with the same number of pellets each. One group of juvenile drakes dosed with one shot pellet each and another group dosed with two shot pellets each in 1950 had year-of-banding mortality rates only 3.4 per cent greater than the rate for the controls. Juvenile drakes dosed with four pellets each in 1951 had a mortality rate that was 31.6 per cent greater than that of the juvenile controls but 9.4 per cent less than that of adult drakes dosed with the same number of pellets each in the same year.

Because in 1951 no mallard hens were banded and released to serve as controls for 501 hens dosed in that year with one shot pellet each, no comparison of band recovery rates could be made between dosed and undosed females released in the same year. However, band recovery figures were available for 7,897 undosed mallard hens banded and released in the period 1939-1943. The year-of-banding band recovery rate for the hens dosed, banded, and released in 1951 was 22.0 per cent greater than the recovery rate

may have caused mortality which would bias subsequent band recoveries.

Wild mallards were caught in the late winter months of 1950 and divided into two groups, each consisting of 200 drakes and 125 hens that at the time of capture were free of lead in their gizzards, as determined from fluoroscopy. The ducks were banded, those in one group were dosed with six No. 6 lead shot pellets each, and all were immediately released. The difference in band recoveries between the control and the dosed groups from the 1950 hunting season through the 1954 season provided an index to the magnitude of mortality caused by the ingestion of six No. 6 shot pellets per duck, table 28.

If there had been no mortality from lead poisoning among the dosed mallards, the number of band recoveries in the subsequent hunting seasons would have been similar for the dosed and the undosed groups. The fact that there were almost three times as many band recoveries in subsequent hunting seasons from the undosed drakes as from the dosed drakes, table 28, suggests that the mortality ratio

between drakes that ingest six lead pellets each and those that ingest no lead is approximately 3 to 1. The difference in band recoveries between undosed and dosed hens was so slight as to indicate little mortality from lead poisoning.

An apparent reason for the large difference in the mortality rates between the Colorado drakes and hens is that in late winter and early spring hens are less susceptible than drakes to lead poisoning. Illinois experiments made with captive mallards under controlled conditions showed that during the spring hens are less susceptible to lead poisoning than are drakes (Jordan & Bellrose 1951:21). With the approach of the breeding season, the consumption of food by captive hens greatly increased until it exceeded that by captive drakes. Apparently the greater food consumption by hens during this particular period was the primary factor responsible for the greater survival rate of the Colorado hens. Illinois data suggest that, during the fall, hen mallards are much more susceptible than drakes to lead poisoning. The year-of-banding mortality rate for wild, free-flying mallard hens dosed with one No. 6 lead pellet each was about one-fourth greater than the highest year-of-banding mortality rate for mallard drakes similarly dosed, table 27. Among penned mallards, the mortality rate of hens was approximately double the mortality rate of drakes except in spring (Jordan & Bellrose 1951:21).

As shown by differences in mortality rates between dosed and undosed birds, at each shot level tested juvenile drakes were much less susceptible to lead poisoning than were adult drakes, table 27. The lower susceptibility of the juveniles was more marked at the one- and two-shot levels than at the four-shot level. The greater food intake by juveniles seems to account for their lower susceptibility (Jordan & Bellrose 1951:20).

There is good evidence that the drake class of the mallard population is composed almost equally of adults and juveniles. The following mortality rates have been calculated on the assumption that the numbers of adults and juveniles are equal and that the percentages on which the rates are based (in farthest right column of table 27) hold true throughout

the populations: In mallard drakes, one No. 6 shot pellet per bird produces an increase in the mortality rate of about 9 per cent (12.6 and 3.4, 15.0 and 4.9 averaged); two pellets about 23 per cent (43.6 and 3.4 averaged); four pellets about 36 per cent; and six pellets about 50 per cent.

Because of the smaller number of experiments conducted with hens than with drakes, it is more difficult to appraise mortality from lead poisoning in the hens. However, the available data suggest that, among hens and drakes with identical ingested shot levels, hens probably suffer twice as great a mortality as drakes in the fall and a small fraction of the mortality of drakes in late winter and spring.

PREVENTING LEAD POISONING

When Green & Dowdell (1936) reported on the apparent feasibility of a lead-magnesium alloy shot for the prevention of lead poisoning in waterfowl, conservationists anticipated the eventual development of this or some other shot that would prove to be nontoxic to waterfowl and acceptable to hunters. However, no shot (with the possible exception of iron shot) has been developed which meets the requirements of both nontoxicity to waterfowl and present shooting standards.

A study of shot alloys by Jordan & Bellrose (1950) at the Havana laboratory of the Illinois Natural History Survey did not substantiate the findings of Green & Dowdell (1936:487-8) that lead-magnesium shot, upon its disintegration in the gizzard of a duck, fig. 8, did not cause lead poisoning. On the contrary, Jordan & Bellrose (1950:166-7) found that lead-magnesium shot, in spite of its disintegration in the gizzard, was as toxic as commercial lead shot.

Two other types of lead alloy shot tested by Jordan & Bellrose (1950:165-7), lead-tin-phosphorus shot and lead-calcium shot, were not less toxic than commercial shot.

A proposal to coat commercial shot pellets with a nylon plastic was investigated. Theoretically, at least, pellets so coated would have a good opportunity to pass out of the gizzard before the plastic was abraded away and the lead exposed. It

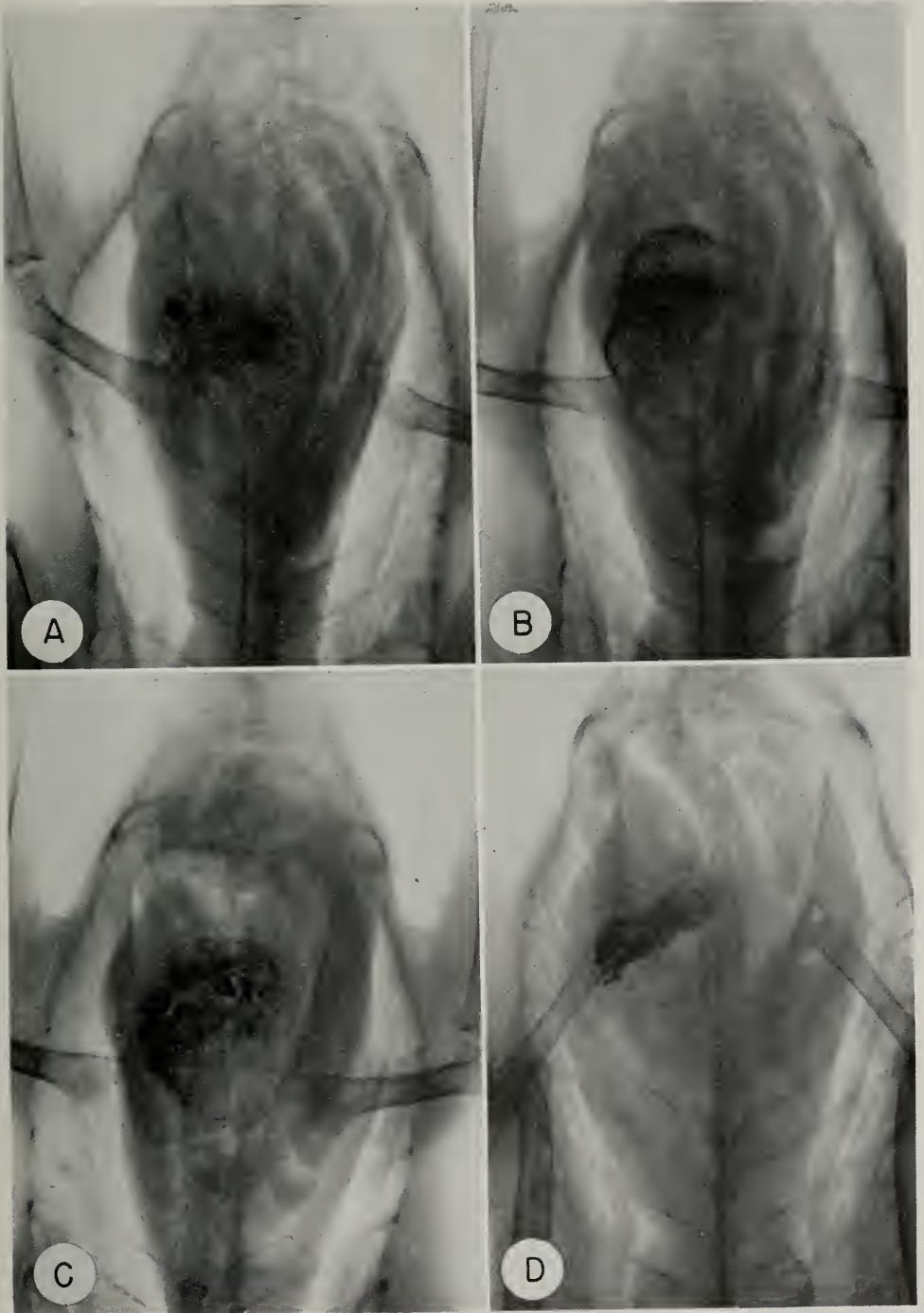


Fig. 8.—The breakup of three lead alloy shot pellets containing magnesium (2 per cent) in the gizzard of a mallard; *A*, 1 hour after ingestion; *B*, 24 hours after ingestion; *C*, 96 hours after ingestion; *D*, 144 hours after ingestion. As shown in *D*, the gizzard has failed to expel a large proportion of the lead particles. Despite its disintegration in the gizzard, the lead alloy shot containing magnesium was as toxic as commercial lead shot.

Table 29.—Relative effectiveness of iron shot and commercial lead shot as measured by the per cent of sample (game-farm mallards) bagged with No. 4 and No. 6 shot fired from 12-gauge full-choke gun at each of four ranges, 1950 and 1951.

RANGE IN YARDS	IRON SHOT				LEAD SHOT			
	No. 4		No. 6		No. 4		No. 6	
	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged	Number in Sample	Per Cent Bagged
35.....	6	100	6	100	10	100	10	100
40.....	20	90	20	90	20	100	20	90
50.....	20	75	20	55	24	88	28	79
60.....	20	45	8	12	20	70	18	22

was found, through administering pellets of nylon plastic to mallards at the Havana laboratory, that this material was very resistant to abrasion. However, efforts to coat shot pellets with nylon plastic were unsuccessful. Metallurgists of the Winchester-Western Cartridge Division of the Olin Mathieson Chemical Corporation were unable to coat commercial lead shot with nylon plastic because the spread between the melting point of lead and the congealing point of the nylon plastic was too small.

Several metals generally regarded as being nontoxic to waterfowl were considered as substitutes for lead. Domestic availability, price, physical and mechanical properties, and corrosion resistance were the judgment criteria. Of all the metals considered, iron was the only one available in sufficient quantity and low

enough in price to warrant further investigation. From the standpoint of properties alone (excluding availability and price), there are metals that would make as good or even better shot pellets. Gold is an extreme example. It is soft, nontoxic, noncorrosive, and heavier than lead. However, its price and lack of availability immediately rule it out.

Pellets made from an iron alloy were tested at the Illinois Natural History Survey Havana laboratory for toxicity to waterfowl. Penned wild mallards were dosed, each with 10 No. 6 iron pellets. The ducks showed no ill effects as a result of the ingestion of iron.

The Winchester-Western Cartridge Division expended considerable time and effort in the development of a satisfactory shot of iron alloy. Early difficulties in making true spheres, excessive abrasion

Table 30.—Relative effectiveness of iron shot and commercial lead shot as measured by the average number of No. 4 and No. 6 pellets that hit the trunks of game-farm mallards, and the per cent of pellets hitting the trunks that penetrated to the trunk cavities, at each of four ranges, 1950 and 1951. The shot was fired from a 12-gauge full-choke gun.

RANGE IN YARDS	IRON SHOT				LEAD SHOT			
	No. 4		No. 6		No. 4		No. 6	
	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities	Average Number of Trunk Hits	Per Cent of Trunk Hits Penetrating to Trunk Cavities
35...	8 3	60	16.2	43	6 6	65	11.6	47
40...	6 8	39	11.8	27	5.7	68	8.8	41
50...	3 9	21	4.9	17	3 2	59	5.2	33
60...	2 4	17	1.9	2	2 5	48	3.4	18

of gun barrels, and range limitations were for the most part overcome. A special shooting process (Patent No. 2,544,678) was developed. By repeated annealing in furnaces with controlled atmospheres, the iron alloy was substantially reduced in hardness. Many thousands of shot shells fired with iron shot loads showed that soft iron had little, if any, adverse effect on modern gun barrels and adjustable chokes.

One of the principal disadvantages of using iron shot for shot shell loads is that its lower density reduces its effectiveness at maximum ranges. In 1950 and 1951, the relative killing power of iron shot and of lead shot was investigated by shooting game-farm mallards under controlled conditions (Bellrose 1953:353-5).

No. 4 and No. 6 shot were used at ranges of 35, 40, 50, and 60 yards, table 29. Iron shot and lead shot fired from a 12-gauge, full-choke gun showed no difference in killing power at 35 yards, but iron shot declined in relative effectiveness as the ranges increased.

At ranges of 35 and 40 yards, the number of pellets hitting the trunks of ducks averaged higher for iron shot than for lead shot, table 30. For comparable ranges and shot sizes, the percentage of pellets hitting the trunks that penetrated to the body cavities was greater for lead shot.

The greater number of hits registered on game-farm ducks by iron shot than by lead shot at the short ranges can be explained by the larger load of iron pellets in each shot shell. Because of the lower density of iron, more iron pellets than lead pellets of the same size can be loaded in a shot shell having the same powder charge. A standard 12-gauge duck load contains about 169 No. 4 lead pellets; such a load would contain about 250 iron pellets. Because the impact potential of shot at long range increases with increases in size of shot, some compensation can be made for the relative decline in killing power of iron shot at long range by using iron shot one size larger than that customarily used in lead shot, that is, No. 4 instead of No. 5 in a given situation.

There are no insurmountable obstacles to the use of iron shot for waterfowl hunting. The conclusion which Winchester-Western drew from extensive research

was that an iron shot acceptable for most shot shell requirements could be produced. However, the required manufacturing investment would be large, and this factor, coupled with uncertainty concerning customer acceptance, convinced Winchester-Western that manufacture of iron shot was not feasible unless drastic action was needed to save waterfowl from serious lead poisoning losses.

If drastic action should at any time be necessary, the U. S. Fish and Wildlife Service could require waterfowl hunters to shoot only shells containing iron shot; shells with such a load could be so marked that inspection by conservation officers would insure compliance with regulations.

DISCUSSION

The incidence of ingested lead shot in the segment of a duck population harvested by waterfowlers is not representative of the entire population nor the entire year. It is representative of only a part of the population (the segment harvested) and a short period of time (the time of sampling).

The percentage of ducks that have ingested shot at some time during the year, or during the period in which most ingestion of shot occurs, may be calculated through application of correction factors that take into account (1) the fact that ducks carrying lead are more vulnerable to hunting than are lead-free ducks and (2) the fact that most ducks ingesting lead either void the lead or die of poisoning within about 4 weeks.

As shown by experiments in which wild mallards were trapped, banded, and released, some dosed with lead and others not dosed, the birds dosed with one No. 6 shot pellet each were about 1.5 times (1.19-1.84, table 20) as vulnerable to hunting as were the controls; those dosed with two pellets each were 1.89 times as vulnerable as the controls; and those dosed with four pellets each were 2.12 times as vulnerable. The incidence of lead in an entire population at any one time is therefore less than the incidence of lead in the segment of the population taken by hunters; for the populations discussed in this paper the incidence of lead can be calculated by applying 1.5, 1.9, and

2.1 as correction factors at the one-, two-, and four-pellet levels.

Application of the correction factor designed to nullify hunting bias at the one-pellet level indicates that during the hunting season an average of 2.96 per cent of the mallards of North America are carrying one ingested lead pellet each, table 31. The application of correction factors at other shot levels is shown in table 31. The correction factors for three-, five-, and six-plus-pellet levels were derived through interpolation or extrapolation.

Daily during the fall and winter months, some ducks in the North American population are ingesting shot pellets, some are voiding them, some are dying from their effects, and some are recovering.

Unpublished Natural History Survey reports of laboratory studies by James S. Jordan show that penned wild mallards that have ingested one or more No. 6 shot pellets each may eliminate the pellets as early as the first week after ingestion or they may retain them as long as several weeks, until the pellets have become thin wafers 0.05 inch or less in diameter. The appearance of lead pellets that have spent various periods of time in the gizzards of ducks is shown in fig. 9.

The penned wild mallards that were dosed by Jordan with one No. 6 shot pellet each and that showed few or no indications of lead poisoning had eliminated the pellets by the thirty-first day. The average period of lead retention by the ducks in this category was 18 days. Mallards that were dosed with two or with four pellets each and that showed no significant manifestation of lead poisoning had eliminated the pellets about as rapidly as those dosed with one pellet each.

The penned mallards that were dosed with one No. 6 shot pellet each and that showed moderate to severe effects of lead poisoning had eliminated no pellets in the first week; at the end of 4 weeks, only 27 per cent of these ducks had voided all the pellets with which they had been dosed.

Twenty-one per cent of 119 penned mallards that had eliminated all shot pellets they had been given (one to four pellets each) died from lead poisoning. A study of the history of these ducks led to the conclusion that a large proportion of the ducks that retain lead shot for 3 or more weeks die from its effects.

As previously discussed, most mallards in the wild that die from lead poisoning perish in the second or third week after they have ingested lead. Most mallards

Table 31.—Estimated percentages of North American mallard population lost as a result of lead poisoning. The figures for the various shot levels have been corrected for hunting bias and population turnover. (By shot level is meant the number of ingested shot pellets found in the gizzard of a duck.)

SHOT LEVEL	SHOT INCIDENCE*	HUNTING BIAS CORRECTION FACTOR†	SHOT INCIDENCE CORRECTED FOR HUNTING BIAS‡	SHOT INCIDENCE CORRECTED FOR TURN-OVER**	MORTALITY RATE (PER CENT)††	PER CENT OF POPULATION LOST‡‡
1.....	4.44	1.5	2.96	17.76	9	1.60
2.....	1.14	1.9	0.60	3.60	23	0.83
3.....	0.47	2.0§§	0.24	1.44	30§§§	0.43
4.....	0.18	2.1	0.09	0.54	36	0.19
5.....	0.14	2.2§§§	0.06	0.36	43§§§	0.15
6.....	0.05	2.3§§§§	0.02	0.12	50§§§§	0.06
6+.....	0.38	2.4§§§§	0.16	0.96	75§§§§	0.72
Total.....	6.80	.....	4.13	24.78	.....	3.98

*From table 11.

†From table 20, nearest 0.1.

‡Derived as explained on pages 279 and 280 (at one-pellet level: $4.44 \times 1.5 = 2.96$).

**Turnover correction factor 6, derived as explained on page 281.

††Derived as explained on page 276. These figures are for mallard drakes of the Mississippi Flyway, but they are applicable to the continental mallard population.

‡‡Derived by multiplying mortality rate (per cent) by shot incidence corrected for turnover.

§§§Derived by interpolation or extrapolation from available data.

that ingest lead have either died or recovered within 4 weeks.

Observations in the field and in the laboratory indicate that a mallard that survives ingestion of lead will have eliminated the lead 18 days, on the average, after ingestion; a mallard that dies with lead still in its gizzard will die 21 days, on the average, after ingestion. Because of these observations, 20 days have been

populations ingest lead shot. Malysheff (1951), after making chemical analyses for lead in the bones and livers of waterfowl taken in the Lower Fraser Valley of British Columbia, reported that 52.1 per cent of the 79 mallards he examined had at one time or another in their lives ingested lead; at the time of examination only about 16 per cent of the mallards had lead in their gizzards and about 36

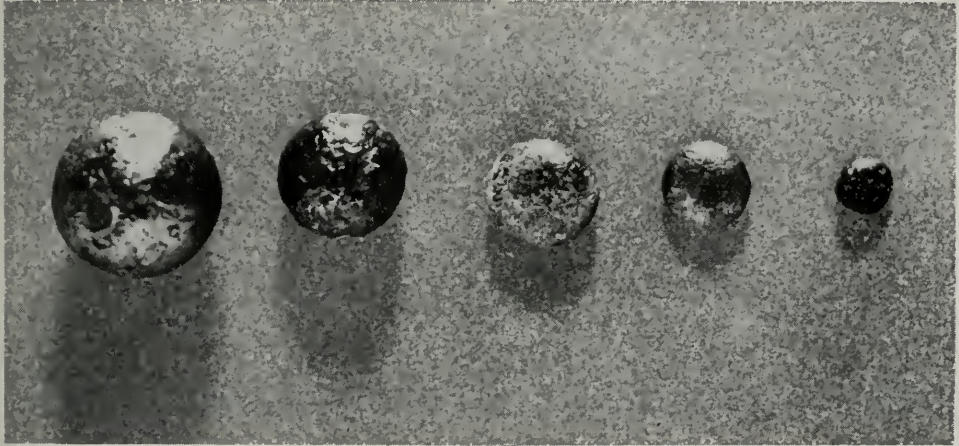


Fig. 9.—The appearance of No. 6 lead shot pellets that spent various periods of time in the gizzards of ducks.

chosen as the average period of turnover of leaded mallards in the wild.

As indicated by the presence of lead in duck gizzards collected from hunters and by lead poisoning die-offs, the lead poisoning "season" (the period of greatest exposure to lead deposited in feeding areas from the guns of hunters) is a 120-day period that begins with November and ends with February. If, as believed, mallard gizzards collected at any one time are representative of only a 20-day turnover period, the number of mallards ingesting lead in the 120-day lead poisoning "season" is six times the average of the numbers obtained from samples taken in the "season." Then the factor to be used in correcting for turnover is 6.

This correction factor applied to incidence figures corrected for hunting bias indicates that approximately one-fourth of the wild mallards of North America in any one year ingest lead shot, table 31.

There is evidence that a much larger proportion than one-fourth of some duck

per cent had survived previous lead ingestion. Malysheff found that 38.2 per cent of 35 pintails showed evidence of lead; 22.9 per cent had lead in their gizzards at the time of examination, and approximately 15 per cent had survived previous lead ingestion.

Mortality rates for Mississippi Flyway mallards dosed with lead shot are presented in table 31; the figures have been adjusted for survival differences between adults and juveniles, as discussed on page 276. Figures for dosages of three, five, six, and six-plus pellets have been derived by interpolation or extrapolation.

If the lead poisoning mortality rates for mallards in other parts of North America are approximately the same as in the Mississippi Flyway, then for the entire North American mallard population the annual loss due to lead poisoning can be calculated, table 31. The figure 1.60 derived for the per cent of the mallard population lost as a result of ingestion of one shot pellet per duck has greater

reliability than the other figures, as it is based on a greater number of field data.

The calculations on which the figures in table 31 are based have many shortcomings. However, the figure 3.98 arrived at as the percentage of the mallard population lost as a result of ingestion of lead shot is at least a "calculated estimate."

The figures in table 31 need qualification and interpretation. They do not take into account the number of mallards carrying lead that are harvested by hunters and so are not wasted. Because ducks carrying lead are more vulnerable to hunting than are ducks that are free of lead, table 20, a considerable proportion of the mallards classified as lost in table 31 are bagged by hunters. The results of twice-weekly surveys of public shooting grounds in central Illinois during recent hunting seasons indicate that the waste, or unharvested loss, due to lead poisoning is about one-fourth less than the 3.98 per cent calculated as the total loss, or approximately 3 per cent.

The estimated 3 per cent waste due to lead poisoning represents day-to-day, non-catastrophic losses and does not include such spectacular losses as those associated with die-offs, in which large proportions of localized populations fall victim to lead poisoning. On the basis of data in table 1, it is estimated that, for mallards of the Mississippi Flyway, to the 3 per cent waste mentioned above should be added 1 per cent to cover the die-off losses, a total of 4 per cent. For mallards of other flyways, the die-off losses are markedly less, table 1.

Mallards have made up the bulk of the ducks found in important lead poisoning die-offs in the United States in recent years, table 1. This fact is construed to mean that the mallard is more susceptible to lead poisoning than other species of waterfowl.

Most available evidence points to the pintail as the species second to the mallard in susceptibility to lead poisoning, table 1. Malysheff (1951) found the pintail even more susceptible than the mallard in small samples taken in British Columbia. Although, as table 11 indicates, in North America as a whole a greater percentage of pintails than of mallards ingested shot, the influence of the more beneficial diet

of the pintail is evinced by the relatively lower losses among ducks of this species on areas where both pintail and mallard have been involved in important lead poisoning die-offs, table 1.

The extremely low shot incidence found in the blue-winged teal, green-winged teal, shoveler, and wood duck precludes lead poisoning as a cause of appreciable losses in these species. In addition to having a low rate of shot ingestion, the baldpate and the gadwall feed largely upon leafy aquatic vegetation, food highly beneficial in alleviating the effects of ingested lead; mortality from lead poisoning is considered to be almost negligible in these species.

Noticeable lead poisoning die-offs are extremely rare in the redhead, ring-necked duck, canvasback, and lesser scaup, table 1, even though these species have the highest incidence of ingested shot recorded among waterfowl, table 11. It must be concluded, therefore, that lead poisoning is not an important mortality factor in ducks of the genus *Aythya*. This fact seems attributable to their beneficial diets.

In spite of a low rate of shot ingestion by Canada, blue, and snow geese, table 11, these species have become victims of lead poisoning die-offs on a surprisingly large number of occasions, table 1, but, in each case, the per cent of the population lost has been low. Inasmuch as these geese feed primarily on corn in the areas where the die-offs have occurred, diet appears as an important factor contributing to their mortality.

As mentioned above, approximately 4 per cent of the mallard population of the Mississippi Flyway is wasted annually as a result of lead poisoning. The annual mallard waste in other flyways is estimated to be between 3 and 4 per cent. The annual waste due to lead poisoning among all species of waterfowl in all North American flyways is estimated to be between 2 and 3 per cent of the population.

Several students of waterfowl have feared that in addition to direct losses due to lead poisoning there are possible indirect losses, such as lead-induced sterility. Wetmore (1919:11) and Shillinger & Cottam (1937:400) are among the authors who have voiced concern over possi-

ble sterility. This concern has been fostered by evidence that lead reduced the virility of domestic poultry and acted as an abortifacient in mammals.

In two laboratory studies which have been made on the effect of ingested lead on sterility in waterfowl, the conclusion was reached that the lead had little perceptible effect upon reproduction. Of the first study, with game-farm mallards, Cheatum & Benson (1945:29) stated that: "These few data indicate that among the mallard drakes used, those which recovered from lead poisoning did not exhibit a significant loss of fertility." From the second study, in 1948 and 1949, in which both drake and hen game-farm mallards were used, Elder (1954:322) concluded that: "Leaded birds received 18 shot while on a grain diet, and the resulting toxemia was very severe. However, normal birds did not exceed leaded birds in fertility, embryonic success, or hatchability. But in both years the normal hens surpassed leaded hens in fecundity for the season."

Rarely do waterfowl in the wild ingest as many as 18 shot pellets per duck, and seldom do waterfowl in the wild recover from toxemia as severe as that exhibited by ducks in the 1949 experiments by Elder.

At the present time, lead poisoning losses in waterfowl do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting. Should lead poisoning become a serious menace to waterfowl populations, iron shot provides a possible means of overcoming it.

Although lead poisoning apparently does not at the present time cause mortality of such magnitude as to endanger the North American waterfowl population, it nevertheless poses an important problem for the future. In the past, the incidence of lead poisoning has increased as numbers of waterfowl hunters have increased. Because further increases in the numbers of these hunters are expected, the search for the best possible solution to the lead poisoning problem should be continued.

From a compassionate as well as a management viewpoint, lead poisoning is a

problem that should concern every sportsman. Birds that die from lead poisoning suffer for 2 or 3 weeks preceding death.

SUMMARY

1. The mortality resulting from lead poisoning in wild waterfowl has been a cause of concern to conservationists for many years.

2. A publicized die-off of ducks from lead poisoning near Grafton, Illinois, in January, 1948, brought the problem to the attention of officials of the Western Cartridge Company (now Winchester-Western Cartridge Division of Olin Mathieson Chemical Corporation) and the Illinois Natural History Survey. This resulted in a joint research project on lead poisoning in waterfowl; research was conducted largely at the field laboratory of the Survey on the Chautauqua National Wildlife Refuge, Havana.

3. The objects of the research project were threefold: (1) evaluation of losses from lead poisoning in wild waterfowl, (2) investigation of lead alloys and other materials for possible use as nontoxic shot, and (3) determination of the physiological effects of lead poisoning on waterfowl. This paper is concerned primarily with an evaluation of the losses from lead poisoning.

4. The approach toward evaluating the importance of lead poisoning involved appraisal of (1) the incidence and magnitude of waterfowl die-offs resulting from lead poisoning, (2) the incidence of ingested lead shot among waterfowl populations in fall and early winter, and (3) the extent of waterfowl losses resulting from the ingestion of various quantities of lead shot.

5. The history of lead poisoning in North American waterfowl dates back to the latter half of the nineteenth century. Losses in the nineteenth century or early twentieth century were reported from Stephenson Lake and Lake Surprise, Texas; Currituck Sound, North Carolina; Puget Sound, Washington; Back Bay, Virginia; and Hovey Lake, Indiana.

6. A survey conducted among state and federal conservation agents and agencies indicates that in recent years the waterfowl losses from lead poisoning have

been largest in the Mississippi Flyway and have been followed in order by losses in the Pacific, Central, and Atlantic flyways.

7. In recent years, certain areas in the United States have been the scenes of several sizable die-offs of waterfowl affected by lead poisoning. Among these areas are Catahoula Lake, Louisiana; Claypool Reservoir, Arkansas; Lake Chautauqua National Wildlife Refuge, Illinois; and Squaw Creek National Wildlife Refuge, Missouri.

8. Most of the notable waterfowl die-offs from lead poisoning have occurred in late fall and early winter months, after the close of the hunting seasons. Few losses of ducks have been noted in the spring, but losses of whistling swans and of Canada, blue, and snow geese have been reported at that time. There are no recent records of waterfowl succumbing from lead poisoning during the summer months.

9. The mallard has been the principal species involved in sizable lead poisoning die-offs across the nation. The pintail has predominated in losses recorded in the Pacific Flyway. Where both species occur together in the Mississippi Flyway, losses in the mallard have been relatively higher.

10. In the Mississippi Flyway, 1938-1955, 10.4 per cent of the mallard drakes and 13.0 per cent of the mallard hens picked up in die-offs carried no ingested shot. In experiments with penned mallards dosed with one to four No. 6 shot pellets each, 21 per cent voided shot before death. These figures suggest that birds in the wild that succeed in voiding shot are more likely to survive than are penned birds that void shot.

11. Data from four widely separated areas in which die-offs of mallards occurred indicate that differences between the areas in the numbers of ingested shot pellets per drake resulted mainly from differences in availability of shot and in diet of ducks in the die-off areas.

12. The availability of lead shot pellets to waterfowl on a particular body of water is determined by (1) the shooting intensity, or amount of shot on the bottom, (2) the firmness of the bottom material, (3) the size of the shot pellets in-

olved, (4) the depth of water above the bottom, and (5) ice cover.

13. The extent to which various species of waterfowl are exposed to shot pellets on the bottoms of marshes and lakes is influenced by the feeding habits of the birds and by the kinds of food available, as well as by the numbers of shot pellets available.

14. The incidence of ingested shot pellets in migrating waterfowl populations was determined by (1) fluoroscopic examination of live-trapped ducks, (2) compilation of data obtained from investigators who had examined waterfowl gizzards for food content, and (3) fluoroscopic and direct examination of gizzards, numbering many thousands, obtained from ducks in hunters' bags.

15. Fluoroscopy of trapped ducks caught at baited traps on a heavily shot-over area revealed that the birds had ingested abnormally large numbers of shot pellets. Among three species, blue-winged teal, wood duck, and pintail, feeding together, there appeared to be a relation between the percentage of ducks ingesting shot pellets and the size of individuals. The species with the largest individuals had the highest percentage of individuals with ingested lead. In two of the species, an appreciably greater percentage of juveniles than of adults carried ingested lead.

16. Fluoroscopy by wildlife technicians on waterfowl breeding grounds during the summer months revealed a low incidence of ingested shot among ducks in Utah and Saskatchewan, but a high incidence among those at the Delta Marsh, Manitoba, which is one of the most heavily shot-over areas in Canada.

17. Examination of 36,145 gizzards of waterfowl bagged by hunters in North America revealed many differences among species in incidence of ingested lead. Less than 1 per cent of the Canada geese and less than 3 per cent of the blues and snows had lead in their gizzards. Among the ducks, the percentages carrying ingested lead were as follows: less than 2 per cent of the buffleheads, green-winged teals, mergansers, wood ducks, shovelers, and gadwalls; between 2 and 5 per cent of the blue-winged teals, baldpates, and common goldeneyes; between 5 and 10 per cent of the ruddy ducks, mallards,

black ducks, and pintails; more than 10 per cent of the canvasbacks, lesser scaups, redheads, and ring-necked ducks.

18. A study of the feeding habits of the various species of ducks in relation to shot incidence indicated that grit preferences do not influence shot ingestion.

19. The incidence of ingested lead shot was lowest among waterfowl of the Central Flyway, higher among those of the Atlantic, slightly higher still among those of the Pacific, and highest among those of the Mississippi Flyway. State and local variations in shot incidence within each flyway were numerous. The incidence of ingested lead was more than twice as high among ducks taken along the Illinois River as among those taken along the Mississippi.

20. Examination of live and hunter-killed ducks indicated that much of the lead ingested by waterfowl had been fired from the guns of hunters in the season of ingestion. Apparently, much of the shot fired during a hunting season eventually penetrated so deep into lake and marsh bottoms that by the following summer it was out of the reach of waterfowl.

21. Increases in the percentage of waterfowl ingesting lead have paralleled increases in the number of waterfowl hunters. Because there is expectation that the number of duck hunters will continue to increase, it can be anticipated that lead poisoning will become more prevalent among waterfowl than it is at present.

22. The magnitude of the shot level (number of pellets in a gizzard) has an important bearing on the rate of mortality of waterfowl. Among 2,184 gizzards containing lead shot, 64.7 per cent contained only one pellet each, 14.9 per cent contained two pellets each, and only 7.4 per cent more than six pellets each.

23. A field experiment showed that ducks afflicted with lead poisoning during the hunting season are more likely to be bagged than are healthy birds. Wild mallards that were dosed with one No. 6 shot pellet each and released were 1.5 times as vulnerable to hunting as were undosed controls; those dosed with two shot pellets each were 1.9 times as vulnerable; and those dosed with four shot pellets each were 2.1 times as vulnerable.

24. Among the dosed wild mallards, the ingestion of lead shot pellets did not appear to affect behavior until after the first 5 days. Among birds dosed with one shot pellet each, and that did not die of lead poisoning, the period of affliction appeared to persist for about 15 days; among those dosed with two to four shot pellets each, the period was longer.

25. The weakness and fatigue apparent in dosed wild mallards that suffered from lead poisoning reduced the ability of the ducks to migrate. The larger the number of ingested shot pellets per bird, the greater was the reduction in movement. Band recoveries from a group of mallards dosed with four pellets each showed that less than 5 per cent of the birds migrated farther than 50 miles from the banding station at which they were dosed.

26. Among the dosed wild mallards in 1950 and 1951, at each dosage level the mortality rate from lead poisoning was higher for adult drakes than for juvenile drakes. During the fall months, mortality was higher among hens than among drakes, but by late winter the situation was reversed. Differences in mortality rates among mallards of different ages and sexes were attributed primarily to differences in the quality and quantity of food consumed.

27. In a population of wild mallard drakes, a population made up equally of adults and juveniles, one No. 6 pellet per bird is estimated to cause an increase in mortality rate of about 9 per cent, two pellets per bird an increase of about 23 per cent, four pellets per bird an increase of about 36 per cent, and six pellets per bird an increase of about 50 per cent.

28. An effort to find a lead alloy shot pellet that was nontoxic to waterfowl was unsuccessful. However, iron shot was found to be nontoxic. Most of the difficulties of manufacturing iron shot pellets were overcome by technicians of the Winchester-Western Cartridge Division of the Olin Mathieson Chemical Corporation. At present the principal disadvantage in using iron shot pellets for waterfowl hunting is that they are less effective at maximum ranges than are lead pellets.

29. In determining the importance of

lead poisoning in a waterfowl population, it is necessary to eliminate the hunting bias of samples and to ascertain the period of turnover of migrating mallards that are carrying lead in their gizzards.

30. Incidence figures corrected for hunting bias and turnover suggest that approximately one-fourth of the wild mallards of North America in any year ingest lead shot.

31. It is estimated that, each year, approximately 4 per cent of the mallards in the Mississippi Flyway die in the wild as a result of lead poisoning and that an additional 1 per cent of the mallards in the flyway are afflicted with lead poisoning but are bagged by hunters.

32. For all waterfowl species in North America, the annual loss due to lead poisoning is estimated to be between 2 and 3 per cent of the population.

33. Two studies made outside of Illinois indicate that lead poisoning in waterfowl does not seriously curtail the reproductive capacity of ducks that recover from the malady.

34. At the present time, lead poisoning losses do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting. Should lead poisoning become a more serious menace to waterfowl populations, iron shot provides a possible means of overcoming it. Because of the increasing numbers of waterfowl hunters and the increasing incidence of lead poisoning, as well as because of the suffering that results among waterfowl seriously afflicted with the malady, the search for the best possible solution to the lead poisoning problem should be continued.

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ILLINOIS NATURAL HISTORY SURVEY

Bulletin

Printed by Authority of
the State of Illinois



Food Habits
of Migratory Ducks
in Illinois

HARRY G. ANDERSON

STATE OF ILLINOIS • WILLIAM G. STRATTON, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION • VERA M. BINKS, *Director*

NATURAL HISTORY SURVEY DIVISION • HARLOW B. MILLS, *Chief*

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This paper is a contribution from the Section of Wildlife Research.

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Aerial view of property belonging to a duck hunting club in the Illinois River valley. The buildings are surrounded by water, uncultivated bottomland, and cropland. Material for the duck food study reported here was obtained from this club and many others like it along the Illinois and Mississippi rivers.

Food Habits of Migratory Ducks in Illinois *

HARRY G. ANDERSON†

TWENTY-FIVE years ago the waterfowl population of North America had dropped to such a low point that management of this resource became an important concern of both state and federal wildlife agencies. As a basis for an effective, long-time program of management for the waterfowl of the Mississippi Flyway, detailed information about the diet of ducks that migrate through Illinois was considered essential.

More than 30 years of drainage, siltation, and pollution had materially reduced the extent and quality of the Illinois feeding grounds that waterfowl had used for centuries. Fortunately for some species of ducks, in the 1930's, mechanical corn pickers came into widespread use in the state. Mechanical picking left more waste corn in the fields and made it more easily available than did picking by hand. Mallards and black ducks were quick to take advantage of the new food supply.

Previous to 1938, only a small amount of research had been done on the food habits of ducks using Illinois as a stopover on their migration flights. An analysis of the contents of 185 duck gizzards collected in Illinois had been made by Martin & Uhler (1939:5), and a study of the contents of 79 duck gizzards collected from the Starved Rock Pool near Ottawa and the Duck Island area near Banner, Illinois, had been made by Bellrose (1938). The need for more data on the food habits of waterfowl in Illinois resulted in the investigation herein reported.

Formally designated as Project 2-R, "Correlation of Food Supplies With Food Uses Among Illinois Game Birds," the investigation was a unit in the program made possible by the Federal Aid in Wildlife Restoration Act and was approved in May, 1939, by the Bureau of Biological

Survey of the United States Department of Agriculture (now Fish and Wildlife Service of the United States Department of the Interior). The project was officially begun on June 1, 1939, and terminated on June 30, 1941. Part of the material and information on which the investigation was based was collected in 1938. Some of the data derived from the project have been included in previous publications (Hawkins, Bellrose, & Anderson 1939; Bellrose & Anderson 1940, 1943; Bellrose 1941, 1959). Delay in publication of the final report on the project resulted largely from the author's service in the armed forces during World War II and subsequent employment elsewhere.

Supervision of Project 2-R was assigned to the Illinois Natural History Survey by the Illinois Department of Conservation. The project was administered by the late Dr. Theodore H. Frison, representing the Natural History Survey, and Anton J. Tomasek, representing the Department of Conservation. Dr. Lee E. Yeager, Arthur S. Hawkins, and Frank C. Bellrose provided technical supervision; all three were members of the Natural History Survey staff at the time of the investigation.

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*Federal Aid Project 2-R. Supervision of this project was assigned by the Illinois Department of Conservation to the Illinois Natural History Survey.

†Leader, Federal Aid Project 2-R, June 1, 1939-June 30, 1941; now employed by the United States Fish and Wildlife Service.

his aid in identifying seeds; William Marquardt, Robert Welk, and William Robertson for their statistical assistance; Dr. Harlow B. Mills and Dr. Thomas G. Scott for their many helpful suggestions; and Frank C. Bellrose and James S. Ayars for their assistance in the writing and editing of this report.

Finally, the author extends his thanks to a great many individual hunters and duck clubs for whole-hearted co-operation in the field investigations and in the preservation of material.

STUDY PROCEDURE

Two general steps were involved in the study procedure: (1) the collection of duck gizzards from strategic locations along the Illinois River and the Mississippi River and (2) the laboratory analysis of collected material.

The limited duration of this investigation made it desirable to choose collection sites that would yield a large quantity of gizzards within the short time of three hunting seasons and that would provide representative samples of the important duck species using the major river valleys in Illinois, frontispiece. Twenty-one sites were selected along the Illinois River between Ottawa and Florence, Illinois, and 11 sites were selected along the Mississippi River between Rock Island and Quincy, Illinois, fig. 1. Gizzards were obtained during the hunting seasons of 1938, 1939, and 1940 by Arthur S. Hawkins and Frank C. Bellrose of the Illinois Natural History Survey and the author.

Arrangements were made for collecting the gizzards of ducks taken by members of duck hunting clubs, by individual hunters, and others. At most hunting clubs, members had their ducks dressed as they brought the birds in from marshes or lakes, fig. 2; the clubs were a source of large numbers of gizzards. Individual or freelance hunters often hired local professional duck pickers to clean their kills; these pickers were another source of gizzards.

Co-operators were supplied with jars partially filled with a 10 per cent formaldehyde solution; each jar bore a printed label denoting a species of duck. Duck pickers were instructed to drop each giz-

zard into an appropriate jar. Gizzards were collected from the co-operators once each week and stored until such time as their contents could be analyzed.

During the three fall hunting periods of 1938-1940, 4,977 gizzards were collected, table 1; 90.52 per cent (4,505) of the gizzards came from locations along the Illinois River and 9.48 per cent (472)



Fig. 1.—Map showing the areas from which duck gizzards were collected in the autumns of 1938, 1939, and 1940 between Ottawa and Florence on the Illinois River and between Rock Island and Quincy on the Mississippi River.

came from collecting sites along the Mississippi River. The sample from the Illinois River valley represented 1.6 per cent of the 1938 kill estimated for that region, 2.2 per cent of the 1939 kill, and 0.5 per cent of the 1940 kill. A breakdown of the number of gizzards obtained from 17 species of ducks is given in table 1 by year and river system. The species are listed



Fig. 2.—Picking ducks at a hunting club in the Illinois River valley. Duck gizzards collected from this and similar clubs provided most of the material on which the present study is based. As ducks were dressed, each gizzard was placed in a jar containing a formaldehyde solution and bearing a printed label that denoted the duck species represented. Nearly 5,000 gizzards representing 17 species of ducks were collected.

Table 1.—Number of waterfowl gizzards collected in Illinois, 1938–1940, at stations along the Illinois and Mississippi rivers.

KIND OF DUCK	1938		1939		1940		TOTAL
	ILLINOIS RIVER	MISSISSIPPI RIVER	ILLINOIS RIVER	MISSISSIPPI RIVER	ILLINOIS RIVER	MISSISSIPPI RIVER	
Common mallard*	822	38	1,289	42	428	206	2,825
American pintail..	268	9	467	.....	115	22	881
Lesser scaup.....	73	53	66	.....	.....	28	220
Blue-winged teal..	57	6	63	1	1	1	129
Green-winged teal	199	2	164	.....	3	25	393
Baldpate.....	87	1	61	.....	4	7	160
Ring-necked duck..	97	7	16	.....	.....	.....	120
Gadwall.....	26	3	59	.....	6	4	98
Canvasback.....	14	4	9	.....	1	.....	28
Shoveler.....	25	2	34	.....	.....	1	62
Ruddy duck.....	.....	.....	1	.....	4	.....	5
Wood duck.....	6	3	4	.....	9	4	26
Plack duck*.....	.....	.....	10	.....	1	.....	11
Redhead.....	12	2	.....	.....	.....	.....	14
Common goldeneye	2	1	.....	.....	.....	.....	3
Greater scaup.....	.....	.....	.....	.....	1	.....	1
Oldsquaw.....	.....	.....	.....	.....	1	.....	1
<i>Total.....</i>	<i>1,688</i>	<i>131</i>	<i>2,243</i>	<i>43</i>	<i>574</i>	<i>298</i>	<i>4,977</i>

*An unknown, but probably small, number of gizzards of the black duck may be included with gizzards of the common mallard. Some hunters did not distinguish between these two species. Gizzards from individuals listed here in the black duck category were from birds identified by the author.

in descending order of the estimated numbers of individuals in the fall flight.

The procedure in making analyses of the gizzard contents was in accordance with standard practices followed by the United States Bureau of Biological Survey (now United States Fish and Wildlife Service) for food habits studies (Cottam 1936:9-10). The contents were separated first into organic and inorganic substances and the volume of each expressed as a percentage of the total volume. The organic foods were then separated into plant and animal foods and the volume of each group expressed as a percentage of the total organic volume. As an example, the contents of a mallard gizzard were 8 cc. (80 per cent) organic material and 2 cc. (20 per cent) inorganic material. Of the total organic foods, 6 cc. (75 per cent) consisted of plant foods and 2 cc. (25 per cent) of animal foods.

Inorganic material was found in the gizzards in small to large amounts and

consisted primarily of sand, gravel, and calcareous shell material. Individual particles were classified as to size in millimeters as well as to type and volume.

An effort was made to identify each item in the organic contents, even though it constituted only a trace or a fraction of 1 per cent of the volume, tables 38 and 39. The technical names of most identifiable plant items listed in table 38 were taken from *Gray's Manual of Botany* (Fernald 1950). The technical names of animal items listed in table 39 were taken from several authorities and depended upon the groups of animals involved. Seeds of some of the duck food plants discussed in this report are shown in fig. 3.

FOODS OF VARIOUS SPECIES

Data obtained from this study provided important facts about food preferences of each of the species of ducks represented. The proportions of plant and animal foods

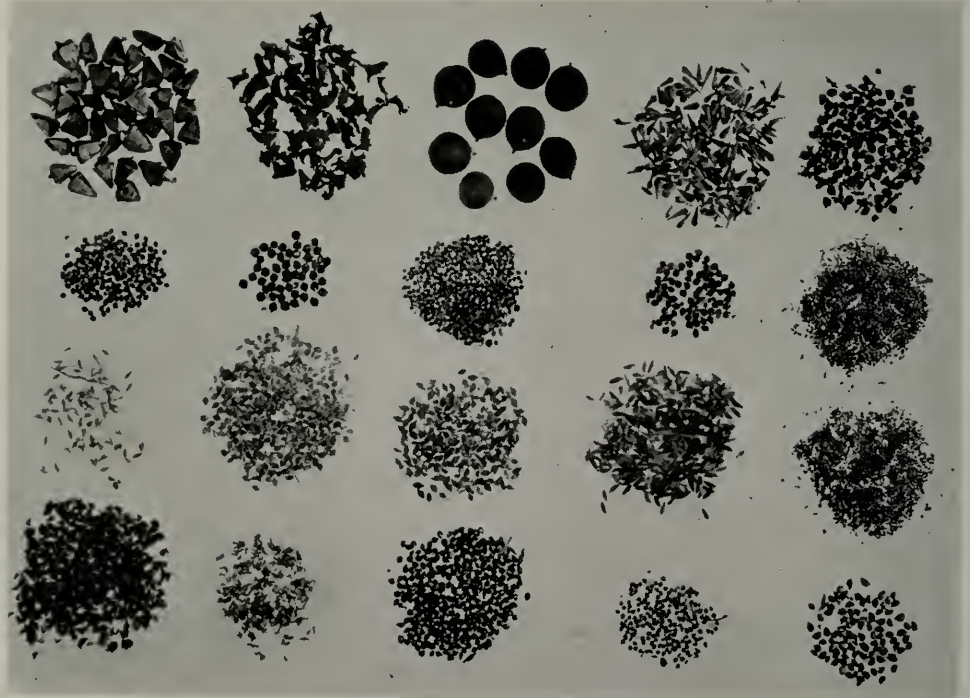


Fig. 3.—Seeds included in the autumn diet of ducks migrating through Illinois: (top row, left to right) giant bur-reed, pickerelweed, American lotus, buttonbush, longleaf pondweed; (second row, left to right) nodding smartweed, large-seeded smartweed, swamp smartweed, marsh smartweed, chufa; (third row, left to right) Walter's millet, Japanese millet, wild millet, rice cutgrass, water-hemp; (bottom row, left to right) duck-potato, lophotocarpus, American bulrush, soft-stem bulrush, sago pondweed.

in the gizzards of the most important species are shown in fig. 4.

Common Mallard *Anas platyrhynchos*

Because hunters co-operating in this study seldom distinguished between the common mallard, *Anas platyrhynchos*, and the black mallard or black duck, *A. rubripes*, undoubtedly a few of the 2,825 gizzards labeled as those of common mallards, table 2, were from black ducks.

A mallard gizzard was assumed to be full if its gross contents amounted to 16 cc.

or more. The contents of individual gizzards ranged from 0.5 to 24.0 cc. and averaged 8.28 cc. per gizzard. Fewer than 250 of the mallard gizzards were less than one-quarter full or more than three-quarters full. Most of the gizzards with small amounts of food were collected early in the season, while most of those nearly full were collected between November 20 and December 5, a time when corn was available in large quantities.

The gross contents of the 2,825 mallard gizzards amounted to 22,379.73 cc., of which 37.25 per cent (8,335.46 cc.) was

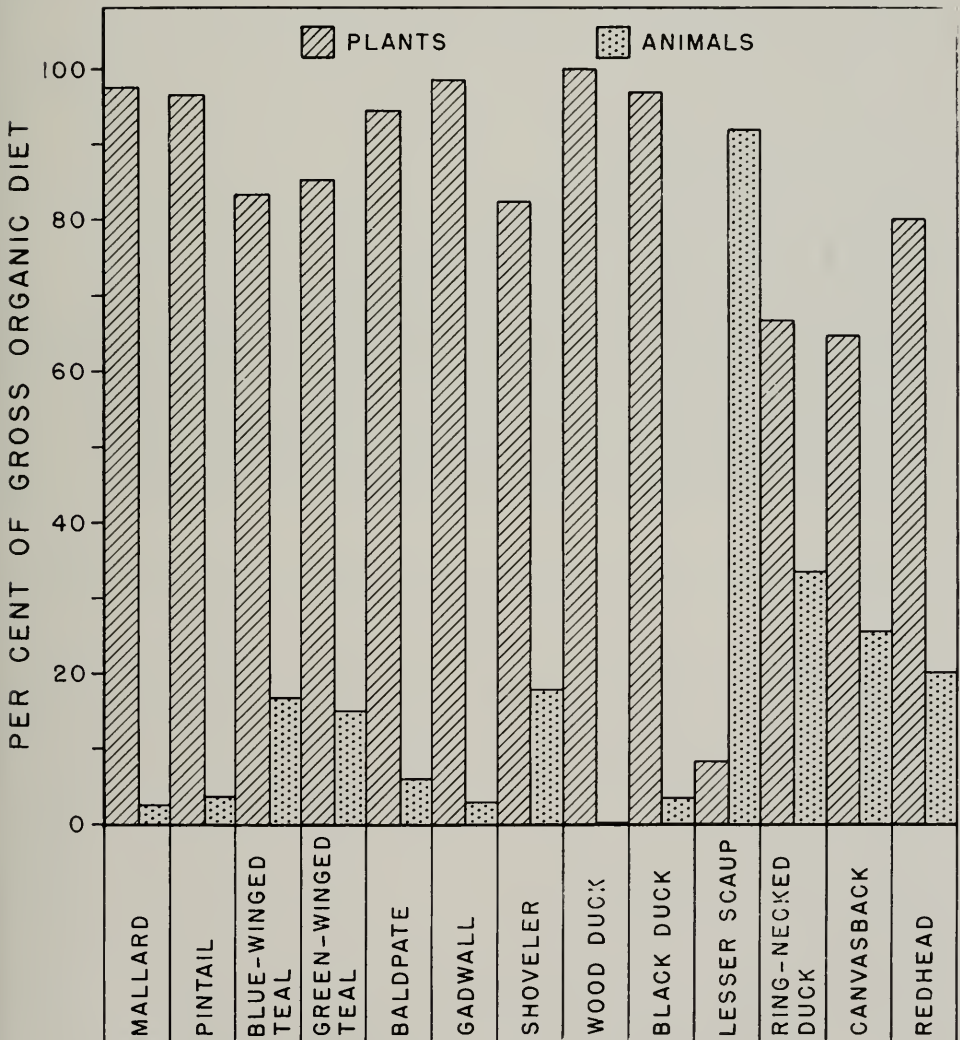


Fig. 4.—Volumetric percentages of plant and of animal material in nearly 5,000 duck gizzards collected in Illinois in the autumns of 1938, 1939, and 1940. Each of the most important duck species is considered separately.

Table 2.—Mallard gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	282	272	306	.....	860
1939.....	389	325	396	207	1,317
1940.....	149	120	258	107	634
Total.....	820	717	960	314	2,811*

*Fourteen gizzards could not be dated to bimonthly periods; hence, they are not included in this total. However, they are included in tables 3 and 4.

Table 3.—The most important plant foods identified in 2,825 mallard gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTI- METERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		13,725.53	97.73
<i>Zea mays</i> , corn.....	1,256	6,652.11	47.37
<i>Leersia oryzoides</i> , rice cutgrass.....	575	1,801.33	12.83
<i>Ceratophyllum demersum</i> , coontail.....	406	1,085.11	7.73
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	1,315	583.40	4.15
<i>pensylvanicum</i> , large-seeded smartweed.....	419	172.68	1.23
<i>lapathifolium</i> , nodding smartweed.....	587	125.39	0.89
<i>hydropiperoides</i> , mild water-pepper.....	147	61.12	0.44
<i>punctatum</i> , dotted smartweed.....	133	40.54	0.29
<i>persicaria</i> , lady's thumb.....	43	12.59	0.09
<i>hydropiper</i> , water-pepper.....	62	7.50	0.05
<i>sagittatum</i> , arrow-leaved tearthumb.....	3	0.60	0.004
<i>scandens</i> , climbing false buckwheat.....	10	0.38	0.003
<i>amphibium</i> , water lady's thumb.....	1	0.05	0.0004
Unidentified.....	8	2.16	0.02
<i>Echinochloa</i>			
<i>crusgalli</i> , wild millet.....	391	684.14	4.87
<i>walteri</i> , Walter's millet.....	94	127.13	0.91
Unidentified.....	1	1.40	0.01
<i>Cyperus</i>			
<i>esculentus</i> , chufa.....	190	185.39	1.32
<i>erythrorhizos</i> , red-rooted nut-grass.....	96	152.70	1.09
<i>strigosus</i> , nut-grass.....	113	125.55	0.89
Unidentified.....	15	39.18	0.28
<i>Acnida altissima</i> , water-hemp.....	298	358.78	2.55
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	823	191.96	1.37
<i>pectinatus</i> , sago pondweed.....	409	75.22	0.54
<i>foliosus</i> , leafy pondweed.....	104	23.49	0.17
<i>pusillus</i> , small pondweed.....	57	10.30	0.07
<i>perfoliatus</i> , thoroughwort pondweed.....	3	8.40	0.06
<i>praelongus</i> , white-stem pondweed.....	4	1.40	0.01
<i>amplifolius</i> , large-leaved pondweed.....	2	0.11	0.0008
Unidentified.....	29	1.54	0.01
<i>Sagittaria</i>			
<i>latifolia</i> , duck-potato.....	89	177.41	1.26
<i>cuneata</i> , wapato.....	1	0.50	0.004
Unidentified.....	1	1.30	0.009
<i>Triticum aestivum</i> , wheat.....	38	154.40	1.10
<i>Cephalanthus occidentalis</i> , buttonbush.....	382	147.43	1.05
Other plants.....	1,919	712.84	5.08

grit and 62.75 per cent (14,044.27 cc.) was organic in substance, tables 3 and 4. In 80 per cent of the mallard gizzards, the organic matter consisted of plant parts exclusively.

Plant Foods (97.73 Per Cent of Organic Contents).—Plant parts, which formed nearly 98 per cent of the food in the mallard gizzards, appeared in all but

some gizzards, leaves and stems of coontail, and rootstocks or tubers of rice cutgrass, chufa, and duck-potato constituted the entire plant contents.

Listed in table 3 are the most important plant foods found in the mallard gizzards collected for this study. Corn made up almost half of the total volume of plant foods; the amount of corn in the gizzards

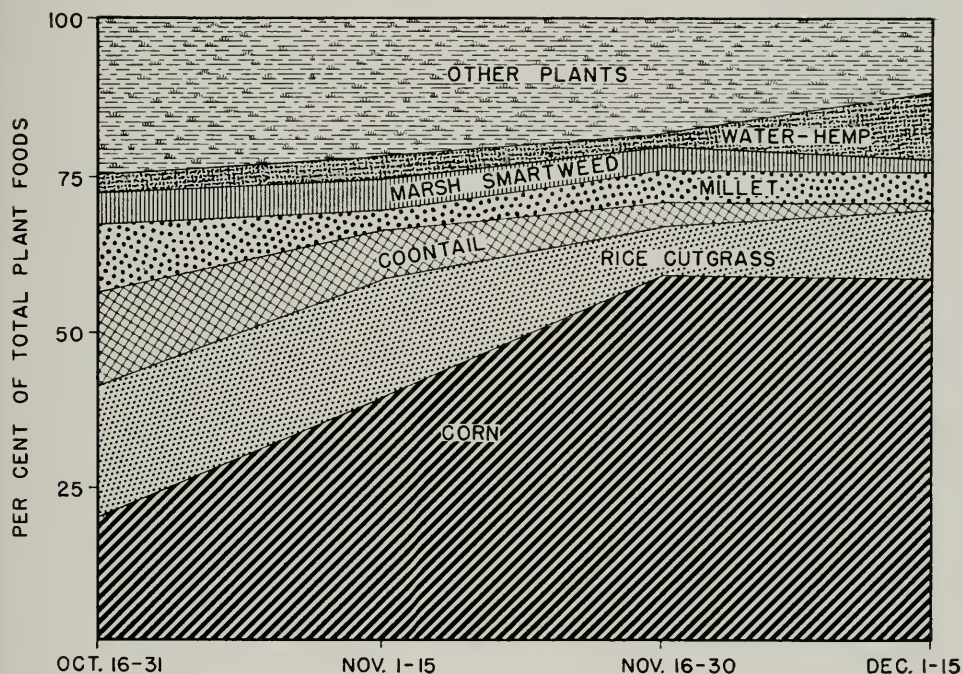


Fig. 5.—Principal plant foods consumed by mallards in Illinois from mid-October to mid-December, 1938-1940, as determined by volumetric analyses of gizzard contents. The curves represent the averages for the periods indicated.

13 of the gizzards. The plant contents of individual mallard gizzards ranged from a trace to 20 cc. and averaged 4.86 cc. per gizzard. The proportion of the organic contents made up of plant structures ranged from 95.17 per cent in 1938 to 99.28 per cent in 1940. Field observations in the areas from which the gizzards were collected in the 3-year period showed that water levels fluctuated from year to year, thus allowing native food plants to be more easily accessible in some years than in others.

Although there was some plant debris that could not be identified (0.02 per cent), 101 species of plants in the mallard gizzards were identified. Most of the material was in the form of seeds, but, in

was proportionally greater late in the season than early, fig. 5. Rice cutgrass, coontail, wild millet or barnyard grass, and marsh smartweed comprised more than half of the volume of native wild foods. The volume of emergent and moist-soil plant parts was four times as great as the volume of submergent vegetation.

Plant species that individually made up less than 1.0 per cent of the total organic volume had been ingested either in small units by a large number of mallards or in large volumes by a few birds. Some of the plant particles may have been taken incidentally along with more desirable foods.

Animal Foods (2.27 Per Cent of Organic Contents).—Animal matter was found in mallard gizzards taken in each

Table 4.—The most important animal foods identified in 2,825 mallard gizzards collected in Illinois, 1938-1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL .....	.....	318.74	2.27
BRYOZOA statoblasts.....	20	0.30	0.002
MOLLUSCA			
GASTROPODA, snails			
<i>Stagnicola</i>	1	0.60	0.004
<i>Planorbis</i>	2	1.50	0.01
<i>Helisoma trivolvis</i>	2	0.47	0.003
<i>Carinifex newberryi</i>	1	0.40	0.003
<i>Physa</i>	4	1.20	0.009
<i>Campeloma</i>	11	9.60	0.07
<i>Annicola</i>	4	3.30	0.024
<i>Flummicola</i>	1	3.80	0.03
<i>Pleurocera</i>	6	2.20	0.02
Unidentified Gastropoda.....	45	22.40	0.16
PELECYPODA, mussels			
Sphaeriidae			
<i>Pisidium</i>	1	1.30	0.009
<i>Musculium transversum</i>	7	9.20	0.07
<i>Sphaerium</i>	11	20.90	0.15
Unidentified Sphaeriidae.....	1	2.70	0.02
Unionidae, fresh-water clams.....	5	3.40	0.02
Unidentified Pelecypoda.....	11	10.70	0.08
UNIDENTIFIED MOLLUSCA.....	16	8.20	0.06
ARTHROPODA			
CRUSTACEA			
Ostracoda.....	2	t	.....
Malacostraca			
Decapoda, <i>Cambarus virilis</i> , crayfish.....	10	20.40	0.14
Amphipoda, <i>Gammarus</i>	2	0.07	0.0005
Isopoda, <i>Asellus</i>	6	0.58	0.004
INSECTA			
Neuroptera, <i>Corydalis cornuta</i> , hellgrammites... ..	1	0.50	0.004
Ephemeroptera, <i>Hexagenia</i> nymphs, mayflies... ..	49	15.12	0.11
Odonata			
Anisoptera, dragonflies			
<i>Aeshna</i>	2	0.30	0.002
<i>Gomphus notatus</i>	1	0.40	0.003
Unidentified Anisoptera.....	1	0.20	0.001
Zygoptera, Coenagrionidae nymphs, damselflies.....	7	8.00	0.06
Unidentified odonata nymphs.....	4	1.40	0.01
Homoptera, Cicadellidae, leafhoppers.....	2	0.20	0.001
Hemiptera			
Corixidae, <i>Corixa</i> , water boatmen.....	169	75.79	0.54
Notonectidae, <i>Notonecta</i> , backswimmers.....	2	0.30	0.002
Nepidae, <i>Ranatra</i> , waterscorpions.....	1	0.60	0.004
Belostomatidae, water bugs.....	17	15.20	0.11
Gerridae nymphs, water striders.....	1	t	.....
Lygaeidae, <i>Lygaeus</i> , chinch bugs.....	1	t	.....
Pentatomidae, stink bugs.....	3	0.40	0.003
Unidentified Hemiptera.....	1	0.40	0.003
Coleoptera			
Carabidae, ground beetles.....	28	0.61	0.004
Halipidae.....	2	0.07	0.0005
Dytiscidae, diving beetles.....	121	13.39	0.10
Gyrinidae, whirligig beetles.....	4	0.42	0.003
Hydrophilidae, water scavenger beetles.....	6	6.60	0.05
Staphylinidae, rove beetles.....	3	0.04	0.0003
Buprestidae, flatheaded wood borers.....	1	t	.....

Table 4.—Continued.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
Elmidae.....	1	t	.....
Scarabaeidae, <i>Aphodius distinctus</i> , scarab beetles.....	2	0.06	0.0004
Chrysomelidae, leaf beetles.....	4	0.26	0.002
Curculionidae, snout beetles.....	15	2.80	0.02
Unidentified Coleoptera.....	4	0.50	0.004
Trichoptera, caddisflies			
Hydroptilidae.....	28	0.77	0.005
Hydropsychidae, <i>Hydropsyche</i> larvae.....	5	8.20	0.06
Unidentified Trichoptera cases.....	7	3.16	0.02
Lepidoptera			
Noctuidae, cutworm moths.....	2	0.29	0.002
Unidentified Lepidoptera moths.....	1	0.10	0.0007
Diptera			
Chironomid larvae, midges.....	72	27.20	0.19
Tabanidae, horse flies.....	1	0.20	0.001
Unidentified Diptera.....	11	1.13	0.008
Hymenoptera			
Formicidae, ants.....	4	t	.....
Tiphiidae, <i>Tiphia</i> , tephid wasps.....	1	t	.....
Unidentified Insecta.....	10	3.77	0.03
ARACHNIDA.....	13	0.62	0.004
ACARINA, water mites.....	19	t	.....
CHORDATA			
PISCES, fish.....	14	0.22	0.002
AMPHIBIA, frogs.....	1	1.00	0.007
NONFOOD			
PARASITIC WORMS.....	1	0.20	0.001
FEATHERS.....	43	4.90	0.03
UNIDENTIFIED.....	3	0.20	0.001

of the collecting periods of the fall months, the greatest volume from November 16 to freeze-up. Even though animal foods were found in 580 mallard gizzards, they appeared to be relatively unimportant in the fall diet. The animal remains in individual gizzards amounted to only a trace, except in a few gizzards which held as much as 12 cc. each.

An animal group was considered an important source of mallard food if it provided at least 0.1 per cent of the total organic contents. Of the animal foods found in the mallard gizzards, table 4, about two-thirds of the volume consisted of insects and approximately one-third of snails and mussels.

Inorganic Contents (37.25 Per Cent of Total Contents).—Grit and other inorganic material in individual mallard gizzards varied from a trace to 9.4 cc. and averaged 2.95 cc. per gizzard. Except for calcareous material in one gizzard, the inorganic contents consisted of stones ranging in size from minute to 19 mm. (largest

dimension); however, in most instances, the stones did not exceed 4 mm.

American Pintail *Anas acuta*

In about 80 per cent of the pintail gizzards collected, table 5, the organic contents consisted of plant material exclusively. Vegetation was found in 99 per cent of the gizzards. These percentages seem to indicate that the pintail, in Illinois at least, utilizes vegetation to a slightly greater degree than does the mallard. Of the pintail gizzards collected, 31 came from the Mississippi River area and 850 from the Illinois River valley.

A pintail gizzard was assumed to be full if the gross contents amounted to 14.0 cc. or more; the average was 6.2 cc., and the extremes ranged from a trace to 16.5 cc. Approximately 210 gizzards were either less than one-quarter or more than three-quarters full, and only 6 were classified as full. In no collecting period were the proportions of full and nearly full gizzards

significantly greater than in any other. Fatty tissue was much in evidence around most of the pintail gizzards.

The gross contents of 881 pintail gizzards amounted to 5,431.91 cc., of which 37.52 per cent (2,038.20 cc.) was grit and

Table 5.—Pintail gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15*	
1938...	135	71	71	.....	277
1939.....	202	86	92	87	467
1940.....	76	32	29	.....	137
Total.....	413	189	192	87	881

*No pintail gizzards collected in this period in 1938 and 1940; an early freeze occurred in 1938.

Table 6.—The most important plant foods identified in 881 American pintail gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....	.....	3,291.44	96.99
<i>Echinochloa</i>			
<i>crusgalli</i> , wild millet.....	198	436.65	12.88
<i>walteri</i> , Walter's millet.....	98	265.73	7.83
<i>Leersia oryzoides</i> , rice cutgrass.....	271	555.29	16.36
<i>Zea mays</i> , corn.....	138	532.92	15.70
<i>Cyperus</i>			
<i>erythrorhizos</i> , red-rooted nut-grass.....	183	298.72	8.80
<i>strigosus</i> , nut-grass.....	135	131.28	3.87
<i>esculentus</i> , chufa.....	83	55.10	1.62
Unidentified.....	4	8.40	0.25
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	422	126.97	3.74
<i>lapathifolium</i> , nodding smartweed.....	257	45.96	1.35
<i>hydropiperoides</i> , mild water-pepper.....	56	21.10	0.62
<i>pensylvanicum</i> , large-seeded smartweed.....	87	18.55	0.55
<i>punctatum</i> , dotted smartweed.....	36	15.24	0.45
<i>persicaria</i> , lady's thumb.....	49	5.32	0.16
<i>hydropiper</i> , water-pepper.....	16	2.95	0.09
<i>amphibium</i> , water lady's thumb.....	3	0.02	0.0006
Unidentified.....	2	0.30	0.009
<i>Ceratophyllum demersum</i> , coontail.....	110	216.25	6.37
<i>Aenida altissima</i> , water-hemp.....	198	117.88	3.47
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	223	48.01	1.41
<i>pectinatus</i> , sago pondweed.....	107	20.28	0.60
<i>foliosus</i> , leafy pondweed.....	61	16.79	0.49
<i>pusillus</i> , small pondweed.....	16	3.04	0.09
Other <i>Potamogeton</i>	4	t	.....
<i>Eragrostis hypnoides</i> , teal grass.....	45	81.30	2.40
<i>Cephalanthus occidentalis</i> , buttonbush.....	154	61.62	1.82
<i>Sagittaria</i>			
<i>latifolia</i> , duck-potato.....	29	36.56	1.08
Unidentified.....	1	0.01	0.0003
<i>Lemna</i>			
<i>minor</i> , lesser duckweed.....	34	33.69	0.99
Unidentified.....	1	1.8	0.05
Other plants.....	394	133.71	3.94

Table 7.—The most important animal foods identified in 881 American pintail gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		102.27	3.01
BRYOZOA statoblasts.....	15	1.44	0.04
MOLLUSCA			
GASTROPODA, snails			
<i>Planorbis</i>	2	t	.....
<i>Helisoma trivolvis</i>	1	0.70	0.02
<i>Gyraulus parvus</i>	1	0.10	0.003
<i>Physa gyrina</i>	1	0.10	0.003
<i>Campeloma</i>	4	3.70	0.11
<i>Lioptax subglobosus</i>	1	0.30	0.009
<i>Amnicola</i>	1	0.40	0.01
Unidentified Gastropoda.....	22	15.54	0.46
PELECYPODA, mussels			
Sphaeriidae			
<i>Pisidium</i>	4	5.08	0.15
<i>Musculium transversum</i>	2	2.70	0.08
<i>Sphaerium</i>	7	6.70	0.20
Unionidae, fresh-water clams.....	1	1.70	0.05
Unidentified Pelecyпода.....	8	4.30	0.13
UNIDENTIFIED MOLLUSCA.....	12	6.07	0.18
ARTHROPODA			
CRUSTACEA			
Ostracoda.....	3	0.50	0.01
Malacostraca			
Amphipoda, <i>Gammarus</i>	1	t	.....
Isopoda, <i>Asellus</i>	2	0.11	0.003
INSECTA			
Orthoptera, grasshoppers			
<i>Neoconocephalus</i>	1	0.20	0.006
Ephemeroptera, mayflies			
<i>Hexagenia</i> nymphs.....	9	4.50	0.13
<i>Caenis</i> nymphs.....	1	0.10	0.003
Odonata			
Anisoptera, dragonflies			
<i>Anax junius</i>	3	2.90	0.09
Anisoptera nymphs.....	1	0.10	0.003
Zygoptera, damselflies			
Coenagrionidae.....	1	0.10	0.003
Zygoptera nymphs.....	2	0.90	0.03
Unidentified Odonata.....	2	0.90	0.03
Hemiptera			
Corixidae, <i>Corixa</i> , water boatmen.....	27	6.73	0.20
Nepidae, <i>Ranatra</i> , waterscorpions.....	1	0.20	0.006
Pelastomatidae, predaceous water bugs.....	5	2.53	0.07
Miridae, <i>Lygus lineolaris</i>	1	0.02	0.0006
Lygaeidae, <i>Lygaeus kalmii</i> , chinch bugs.....	1	0.03	0.0009
Unidentified Hemiptera.....	1	t	.....
Coleoptera			
Carabidae, ground beetles			
<i>Casnonia pennsylvanica</i>	1	0.04	0.001
Unidentified Carabidae.....	9	t	.....
Halplidae.....	1	6.10	0.003
Dytiscidae, diving beetles			
<i>Colymbetes</i>	1	0.20	0.006
Unidentified Dytiscidae.....	41	7.30	0.22
Hydrophilidae larvae, water scavenger beetles	2	0.20	0.006
Staphylinidae, rove beetles.....	1	0.20	0.006
Scarabaeidae, <i>Aphodius distinctus</i> , scarab beetles.....	1	0.05	0.001

Table 7.—Continued.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
Chrysomelidae, leaf beetles			
<i>Diabrotica undecimpunctata howardi</i>	1	t	.....
<i>Lixus</i>	1	0.20	0.006
Unidentified Chrysomelidae.....	1	t	.....
Curculionidae, snout beetles.....	2	t	.....
Trichoptera			
Hydroptilidae cases, caddisflies.....	33	3.42	0.10
Hydropsychidae, <i>Hydropsyche</i>	1	0.30	0.009
Unidentified Trichoptera.....	5	0.25	0.007
Diptera			
Chironomidae larvae, midges.....	39	18.09	0.53
Unidentified Diptera.....	2	0.03	0.0009
Hymenoptera			
Ichneumonidae, ichneumon flies.....	1	t	.....
Tiphidae, <i>Tiphia</i>	1	0.10	0.003
Formicidae, ants.....	2	0.10	0.003
Unidentified Hymenoptera.....	1	0.96	0.03
Unidentified Insecta.....	1	t	.....
ARACHNIDA			
Araneae, spiders			
Argiopeidae.....	1	0.03	0.0009
Unidentified Araneae.....	1	t	.....
Unidentified Arachnida.....	3	t	.....
ACARINA, <i>Hydracarina</i> , water mites.....	18	0.22	0.006
CHORDATA			
PISCES, fish.....	2	t	.....
NONFOOD, feathers.....	15	1.23	0.04
UNIDENTIFIED.....	1	0.60	0.02

62.48 per cent (3,393.71 cc.) was organic material, tables 6 and 7.

Plant Foods (96.99 Per Cent of Organic Contents).—Plant parts, which formed approximately 97 per cent of the organic matter found in the pintail gizzards, appeared in all but eight of the gizzards. The plant contents of individual gizzards ranged from a trace to 14.0 cc. and averaged 3.7 cc. per gizzard. The volume of plant structures in the pintail gizzards was nearly 8 per cent greater in 1939 and 1940 than in 1938. More moist-soil plants were available to migrating ducks in 1939 and 1940 than in 1938, as indicated in a study by Bellrose (1941: 252-3). Moist-soil plants were more abundant along the Illinois River than along the Mississippi, a condition reflected in the larger percentage of structures of these plants noted in gizzards collected along the Illinois.

Some plant debris in the 881 pintail gizzards could not be identified; however, 73 species of emergent, submergent, moist-soil, and terrestrial plants were classified.

In most of these gizzards, seeds comprised the greater volume; in a few, the entire contents consisted of vegetative parts from such plants as rice cutgrass, duck-potato, and coontail.

Any plant providing at least 1.0 per cent of the total organic contents of gizzards of the pintail was regarded as an important source of food for this species, table 6. Principal food plants were the millets, rice cutgrass, corn, the nut-grasses, marsh smartweed, nodding smartweed, coontail, water-hemp, longleaf pondweed, teal grass, buttonbush, duck-potato, known also as common arrowhead, and duckweed.

Laboratory analyses of gizzard contents indicated that the pintails represented fed primarily on wild native plants, apparently taking corn only when the wild food supply was low. Field observations corroborated the laboratory findings; pintails were seldom observed among the mallard flocks flying to and from cornfields. It was noted that pintails used corn more frequently along the Mississippi River, where

moist-soil plants were decidedly less abundant, than in the Illinois River valley.

Animal Foods (3.01 Per Cent of Organic Contents).—Animal matter was found in a few pintail gizzards taken in each collecting period; it was most abundant during the period October 16–31. This type of food was found in 202 of the pintail gizzards, but only 8 contained animal matter exclusively.

Most pintail gizzards contained only traces of animal matter; however, one gizzard contained 11.5 cc. of midge larvae.

a larger percentage of animal matter than did those of the mallard or the pintail. Plant structures occurred in 53 per cent of the blue-winged teal gizzards analyzed. Most blue-winged teals leave Illinois before the middle of November, and only one gizzard representing the blue-wings was collected after that time, table 8. Only eight gizzards of the blue-winged teal were collected from the Mississippi River region.

A blue-winged teal gizzard was considered full if the gross contents amounted to

Table 8.—Blue-winged teal gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	62	.....	1	.....	63
1939.....	34	30	.....	.....	64
1940.....	2	.....	.....	.....	2
<i>Total</i>	98	30	1	0	129

The volume of animal foods averaged 0.51 cc. per gizzard.

An animal group represented by at least 0.1 per cent of the total organic volume was considered important in the diet of the pintail, table 7. Of the animal foods in the pintail gizzards, 49.62 per cent consisted of insects and 46.34 per cent represented the phylum Mollusca, about equally divided between snails and bivalves. Feathers, crustaceans, fish, water mites, and unidentified material were represented in the remaining percentage.

Inorganic Contents (37.52 Per Cent of Total Contents).—The volume of inorganic material in individual pintail gizzards ranged from a trace to 10.1 cc. and averaged 2.31 cc. per gizzard. Grit particles varied considerably in shape, roughness, and size. About 64 per cent of the particles ranged from minute to 4 mm., 26 per cent between 4 and 8 mm., and 10 per cent from 8 to 18 mm. (largest dimension).

Blue-Winged Teal

Anas discors

In the material collected for this study, gizzards of the blue-winged teal contained

3.7 cc. Degrees of fullness varied greatly among the samples, and the contents of the individual gizzards ranged from a trace to 3.9 cc.; the average amounted to 2.03 cc. per gizzard, slightly over half of the capacity.

The total contents of the 129 gizzards collected from blue-winged teals amounted to 261.87 cc., of which 39.35 per cent (103.05 cc.) was inorganic and 60.65 per cent (158.82 cc.) was organic material.

Plant Foods (83.63 Per Cent of Organic Contents).—Plant structures constituted more than four-fifths of the organic food present in the blue-winged teal gizzards. The plant contents of individual gizzards ranged from a trace to 3 cc.; the average was 1 cc. More moist-soil plants were accessible in 1939 and 1940 than in 1938; the plant contents per gizzard averaged 0.7 cc. in 1938, 1.3 cc. in 1939, and 0.9 cc. in 1940.

Thirty-nine species of plants from the gizzards of the blue-wings were identified. These plants were predominantly moist-soil species. The major portion of the material consisted of seeds and seed coats; however, stem and leaf fragments of coontail and sago pondweed were present.

A plant making up at least 1.0 per cent of the organic material was considered an important blue-winged teal food, table 9. Thirteen species and one genus, aggregating 76.66 per cent of the organic contents, were in this category: three nut-grasses, two millets, coontail, water-hemp, marsh

diet than that of the mallard or the pintail. In the majority of blue-winged teal gizzards containing animal parts, the animal contents ranged in volume from 0.1 to 1.0 cc.; some gizzards contained only a trace of animal matter and others as much as 2 cc. each. The animal groups considered

Table 9.—The most important plant foods identified in 129 blue-winged teal gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....	.....	132.82	83.63
<i>Cyperus</i>			
<i>erythrorhizos</i> , red-rooted nut-grass.....	81	66.00	41.56
<i>strigosus</i> , nut-grass.....	33	4.50	2.83
<i>esculentus</i> , chufa.....	18	4.80	3.02
Unidentified.....	1	0.20	0.13
<i>Echinochloa</i>			
<i>crusgalli</i> , wild millet.....	15	7.30	4.60
<i>walteri</i> , Walter's millet.....	5	2.80	1.76
<i>Ceratophyllum</i>			
<i>demersum</i> , coontail.....	9	4.46	2.81
Unidentified.....	4	4.30	2.71
<i>Acnida altissima</i> , water-hemp.....	47	6.68	4.21
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	43	4.66	2.93
<i>lapathifolium</i> , nodding smartweed.....	45	0.79	0.50
<i>pensylvanicum</i> , large-seeded smartweed.....	12	0.48	0.30
<i>punctatum</i> , dotted smartweed.....	9	0.03	0.02
Other <i>Polygonum</i>	10	t	.....
<i>Eragrostis hypnoides</i> , teal grass.....	12	5.92	3.73
<i>Cephalanthus occidentalis</i> , buttonbush.....	15	3.97	2.50
<i>Panicum dichotomiflorum</i> , fall panic-grass.....	4	3.10	1.95
<i>Lemna minor</i> , lesser duckweed.....	6	2.89	1.82
<i>Leersia oryzoides</i> , rice cutgrass.....	10	2.53	1.59
<i>Potamogeton</i>			
<i>epiphydrus</i> , ribbon-leaf pondweed.....	1	1.30	0.82
<i>nodosus</i> , longleaf pondweed.....	10	0.55	0.35
<i>pectinatus</i> , sago pondweed.....	5	0.27	0.17
Other <i>Potamogeton</i>	4	0.01	0.01
Other plants.....	96	5.28	3.32

smartweed, teal grass, buttonbush, fall panic-grass, lesser duckweed, rice cutgrass, and the pondweeds as a group.

Any plant species or group represented by less than 1.0 per cent of the organic contents was considered to be of secondary importance. Plant parts of species in this category were found in many gizzards in small volumes, or in a few gizzards in large volumes.

Animal Foods (16.37 Per Cent of Organic Contents).—Because the blue-winged teal feeds extensively in shallow water areas, animal foods might be expected to constitute a greater part of its

most important were those that contributed at least 0.1 per cent each to the organic contents, table 10.

About 74 per cent of the volume of animal material in the gizzards of blue-wings consisted of insects. The Mollusca group made up about 17 per cent of the animal material. The crustaceans comprised about 5 per cent.

Inorganic Contents (39.35 Per Cent of Total Contents).—Grit present in individual blue-winged teal gizzards ranged in volume from a trace to 2 cc. and averaged 0.4 cc. Particles varied in size from sand to gravel stones of 4 mm. (largest

Table 10.—The most important animal foods identified in 129 blue-winged teal gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		26.00	16.37
BRYOZOA statoblasts.....	11	0.80	0.50
MOLLUSCA			
GASTROPODA, snails			
<i>Gyraulus parvus</i>	1	0.10	0.06
Unidentified Gastropoda.....	6	0.90	0.57
PELECYPODA, mussels			
<i>Pisidium</i>	1	0.20	0.13
<i>Sphaerium</i>	3	0.70	0.44
UNIDENTIFIED MOLLUSCA.....	10	2.50	1.57
ARTHROPODA			
CRUSTACEA			
Copepoda.....	1	1.00	0.63
Ostracoda.....	11	0.40	0.25
INSECTA			
Ephemeroptera, <i>Hexagenia</i> , mayflies.....	3	0.10	0.06
Hemiptera, <i>Corisca</i> , water boatmen.....	29	8.35	5.25
Coleoptera			
Carabidae, ground beetles.....	1	t	
Dytiscidae, diving beetles.....	4	0.10	0.06
Gyrinidae, whirligig beetles.....	1	t	
Curculionidae, snout beetles.....	1	0.10	0.06
Trichoptera			
Hydroptilidae cases, caddisflies.....	14	0.10	0.06
Unidentified Trichoptera cases.....	1	0.10	0.06
Diptera, Chironomidae, midges.....	26	9.25	5.82
Unidentified Insecta.....	1	1.20	0.75
ARACHNIDA.....	1	t	
ACARINA, <i>Hydracarina</i> , water mites.....	5	0.10	0.06
NONFOOD, feathers.....	1	t	

dimension) ; however, the particles seldom exceeded 2 mm. each.

Green-Winged Teal

Anas carolinensis

The green-winged teal gizzards collected for this study contained a larger proportion of animal matter than was found in gizzards of the mallard, pintail, or blue-winged teal; yet the green-winged teal proved to be very much a vegetarian. Twenty-seven of the gizzards listed in table 11 were collected along the Mississippi River and 366 along the Illinois River.

A green-winged teal gizzard was considered full if the gross contents amounted to 3.5 cc. or more. The contents of individual gizzards ranged in volume from 0.4 to 4.5 cc. and averaged 1.0 cc. per gizzard. Over four-fifths of the gizzards were more than one-fourth full.

The total contents of all green-winged

teal gizzards amounted to 778.30 cc., of which 41.94 per cent (326.45 cc.) was inorganic and 58.06 per cent (451.85 cc.) was organic.

Plant Foods (84.96 Per Cent of Organic Contents).—Plant parts were found in 390 of the 393 green-winged teal gizzards collected; only grit was present in the other 3. Plant food in individual gizzards ranged from a trace to 2.8 cc. in volume and averaged 0.98 cc. per gizzard. As with gizzards of the blue-winged teal and the pintail, the green-winged gizzards contained a larger proportion of plant material in 1939 and 1940 than in 1938, probably because of greater availability of moist-soil species. The average volume of plant material per gizzard was 0.78 cc. in 1938, 1.22 cc. in 1939, and 0.90 cc. in 1940. The quantity of plant structures was greater in green-winged teal gizzards collected along the Illinois River than in those obtained along the Mississippi River.

This fact probably reflected differences in plant food availability.

In the gizzards of the green-wings, there was some plant debris (0.09 per cent) that could not be identified; struc-

tures representing 63 species of emergent, moist-soil, submergent, and terrestrial plants were identified. Seeds and seed-coat fragments comprised the bulk of the plant structures, although coontail stems

Table 11.—Green-winged teal gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	85	62	54	.....	201
1939.....	31	51	47	35	164
1940.....	5	6	14	3	28
Total.....	121	119	115	38	393

Table 12.—The most important plant foods identified in 393 green-winged teal gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....	.....	383.91	84.96
<i>Cyperus</i>			
<i>erythrorhizos</i> , red-rooted nut-grass.....	212	135.98	30.09
<i>strigosus</i> , nut-grass.....	90	29.30	6.48
<i>esculentus</i> , chufa.....	73	19.06	4.22
<i>ferax</i>	7	0.90	0.20
<i>Echinochloa</i>			
<i>crusgalli</i> , wild millet.....	75	31.20	6.90
<i>walteri</i> , Walter's millet.....	39	14.51	3.21
Unidentified.....	1	t	.....
<i>Eragrostis</i>			
<i>hypnoides</i> , teal grass.....	30	21.72	4.81
Unidentified.....	2	0.40	0.09
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	10	10.85	2.40
<i>lapathifolium</i> , nodding smartweed.....	128	5.12	1.13
<i>pennsylvanicum</i> , large-seeded smartweed.....	35	3.00	0.66
<i>punctatum</i> , dotted smartweed.....	14	0.11	0.02
<i>hydropiper</i> , water-pepper.....	5	0.10	0.02
<i>persicaria</i> , lady's thumb.....	14	0.05	0.01
Other <i>Polygonum</i>	11	1.55	0.34
<i>Lemna minor</i> , lesser duckweed.....	58	17.92	3.97
<i>Ceratophyllum demersum</i> , coontail.....	26	16.65	3.68
<i>Juncus</i> , bog rush.....	23	11.78	2.61
<i>Leersia oryzoides</i> , rice cutgrass.....	34	8.97	1.99
<i>Achnida altissima</i> , water-hemp.....	131	8.27	1.83
<i>Potamogeton</i>			
<i>foliosus</i> , leafy pondweed.....	23	3.45	0.76
<i>nodosus</i> , longleaf pondweed.....	27	2.50	0.55
<i>pusillus</i> , small pondweed.....	11	0.81	0.18
<i>pectinatus</i> , sago pondweed.....	15	0.49	0.11
<i>epiphydrus</i> , ribbon-leaf pondweed.....	1	0.05	0.01
Other <i>Potamogeton</i>	4	0.15	0.03
<i>Zea mays</i> , corn.....	12	7.05	1.56
<i>Cephalanthus occidentalis</i> , buttonbush.....	35	5.46	1.21
<i>Sagittaria latifolia</i> , duck-potato.....	21	4.63	1.02
Other plants.....	251	21.88	4.84

and leaves and duckweed particles were numerous.

Plant foods that contributed at least 1.0 per cent each to the total organic contents

of the gizzards of green-wings and in the aggregate amounted to more than 75 per cent of the organic contents were three nut-grasses, two millets, teal grass, marsh

Table 13.—The most important animal foods identified in 393 green-winged teal gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		67.94	15.04
BRYOZOA statoblasts.....	69	5.33	1.18
MOLLUSCA			
GASTROPODA, snails			
<i>Gyraulus parvus</i>	1	0.08	0.02
<i>Physa gyrina</i>	1	1.70	0.38
Unidentified Gastropoda.....	26	8.26	1.83
PELECYPODA, <i>Sphaerium</i> , seed shells.....	1	0.10	0.02
UNIDENTIFIED MOLLUSCA.....	15	4.56	1.01
ARTHROPODA			
CRUSTACEA			
Branchiopoda			
Fairy shrimps.....	1	1.30	0.29
Unidentified Branchiopoda.....	2	0.10	0.02
Copepoda			
<i>Cyclops</i>	3	1.40	0.31
<i>Canthocampus</i>	2	t	
Unidentified Copepoda.....	1	1.20	0.27
Ostracoda			
<i>Candona</i>	2	0.02	0.004
<i>Cypris</i>	1	0.01	0.002
Unidentified Ostracoda.....	57	1.43	0.32
Malacostraca			
Amphipoda, <i>Gammarus</i>	3	t	
Isopoda, <i>Asellus</i>	2	0.10	0.02
INSECTA			
Orthoptera, Tettigoniidae, grasshoppers.....	1	0.30	0.07
Ephemeroptera, mayflies			
<i>Hexagenia</i> nymphs.....	2	0.30	0.07
<i>Caenis</i> nymphs.....	1	t	
Odonata			
Anisoptera, <i>Aeshna</i> , dragonflies.....	3	0.30	0.07
Zygoptera, Coenagrionidae, damselflies.....	4	3.60	0.80
Odonata nymphs.....	3	1.50	0.33
Hemiptera, <i>Corixa</i> , water boatmen.....	58	15.34	3.39
Coleoptera			
Carabidae, ground beetles.....	8	0.11	0.02
Dytiscidae, diving beetles.....	33	0.67	0.15
Gyrinidae, whirligig beetles.....	2	t	
Staphylinidae, rove beetles.....	1	t	
Elmidae.....	1	t	
Chrysomelidae, <i>Diabrotica undecimpunctata howardi</i> , leaf beetles.....	1	t	
Unidentified Coleoptera.....	1	0.05	0.01
Trichoptera			
Hydroptilidae cases, caddisflies.....	43	1.24	0.27
Unidentified Trichoptera.....	3	0.20	0.04
Diptera, Chironomidae larvae, midges.....	66	17.24	3.82
Hymenoptera			
Ichneumonidae, ichneumon flies.....	1	0.05	0.01
Formicidae, ants.....	1	t	
Unidentified Insecta.....	2	0.12	0.03
ARACHNIDA.....	1	t	
ACARINA, <i>Hydracarina</i> , water mites.....	20	0.04	0.009
NONFOOD, feathers.....	12	1.29	0.29

smartweed, nodding smartweed, lesser duckweed, coontail, rice cutgrass, water-hemp, the pondweeds as a group, corn, buttonbush, and duck-potato, table 12. Most of these plants grow on mud flats or moist sand bars.

Animal Foods (15.04 Per Cent of Organic Contents).—Animal matter appeared in more than half of the gizzards of the green-winged teals and in a few gizzards in greater volume than the plant foods. It was found in gizzards collected in all four periods but in the greatest percentage in those collected from October 16 through November 15.

Individual gizzards of the green-winged teals contained a trace to 3.1 cc. of animal parts and averaged 0.31 cc. More than a third of them contained 0.1 to 1.0 cc. of

animal matter each. An animal group representing at least 0.1 per cent of the total organic contents of the gizzards of these teals was considered important, table 13.

Insects comprised a little less than two-thirds of the volume of animal matter in gizzards of the green-wings. In greatest volumes were midge larvae, water boatmen, and Odonata nymphs. The Mollusca group, represented principally by snails, made up 21.64 per cent of the animal contents. Other important animal foods were Bryozoa statoblasts and crustaceans.

Inorganic Contents (41.94 Per Cent of Total Contents).—In most of the green-winged teal gizzards collected, almost one-half of the gross contents consisted of inorganic material. The volume of inorganic matter in individual gizzards

Table 14.—Baldpate gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	64	23	1	.....	88
1939.....	19	30	3	9	61
1940.....	4	6	1	.....	11
Total.....	87	59	5	9	160

Table 15.—The most important plant foods identified in 160 baldpate gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....	.....	318.75	93.66
<i>Ceratophyllum demersum</i> , coontail.....	116	237.93	69.91
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	24	5.77	1.70
<i>pectinatus</i> , sago pondweed.....	10	4.20	1.23
<i>foliosus</i> , leafy pondweed.....	4	4.10	1.20
<i>Leersia oryzoides</i> , rice cutgrass.....	12	12.60	3.70
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	60	10.87	3.19
<i>pensylvanicum</i> , large-seeded smartweed.....	5	0.25	0.07
<i>lapathifolium</i> , nodding smartweed.....	18	0.14	0.04
<i>hydropiperoides</i> , mild water-pepper.....	5	0.10	0.03
<i>punctatum</i> , dotted smartweed.....	5	0.03	0.01
Other <i>Polygonum</i>	1	0.10	0.03
<i>Cephalanthus occidentalis</i> , buttonbush.....	28	9.20	2.70
<i>Ulothrix zonata</i> , algae.....	3	8.60	2.53
<i>Zea mays</i> , corn.....	4	6.80	2.00
<i>Sagittaria latifolia</i> , duck-potato.....	3	5.10	1.50
<i>Lemna minor</i> , lesser duckweed.....	7	4.20	1.23
Other plants.....	56	8.76	2.57

ranged from a trace to 1.9 cc. and averaged 0.8 cc. Gravel particles varied in size from minute to 9 mm. (largest dimension), but seldom exceeded 3 mm. Very little other inorganic material was present in gizzards containing grit particles 7, 8, or 9 mm. in size.

Baldpate

Mareca americana

Analyses of the contents of gizzards collected for this study indicated that in Illinois the baldpate, or widgeon, during the fall months is primarily a vegetarian; it appears to ingest animal foods only incidentally with plant parts. Because the baldpate reaches its peak population in this state early in the fall, most of the gizzards representing this species were obtained during the first two collecting periods, table 14. Of the 160 samples, only 8 were

collected from stations along the Mississippi River.

A baldpate gizzard, about as large as that of a mallard or pintail, was considered to have a capacity of 13 cc. Gross contents of individual gizzards ranged from 1.4 to 11.0 cc. and averaged 4.99 cc. Nearly one-fifth of the gizzards were less than one-quarter full and none was full. Even on gizzards in which the contents averaged less than half the gizzard capacity, fatty tissue was prevalent.

The gross material in the 160 gizzards of baldpates totaled 799.82 cc. Of this amount, 57.45 per cent (459.50 cc.) consisted of grit and the remaining 42.55 per cent (340.32 cc.) consisted of plant and animal parts.

Plant Foods (93.66 Per Cent of Organic Contents).—In 1938, plant structures made up 91 per cent of the organic

Table 16.—The most important animal foods identified in 160 baldpate gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		21.57	6.34
BRYOZOA statoblasts.....	5	0.20	0.06
MOLLUSCA			
GASTROPODA, snails			
<i>Gyraulus parvus</i>	1	0.30	0.09
<i>Physa</i>	1	0.20	0.06
Unidentified Gastropoda.....	3	2.10	0.62
UNIDENTIFIED MOLLUSCA shells.....	1	0.10	0.03
ARTHROPODA			
CRUSTACEA, <i>Asellus</i>	1	0.05	0.015
INSECTA			
Ephemeroptera, <i>Hexagenia</i> nymphs, mayflies... .	1	0.10	0.03
Odonata nymphs, dragonflies.....	1	1.20	0.35
Homoptera, Cicadellidae, leafhoppers			
<i>Draeculacephala</i>	1	t	.....
Unidentified Homoptera.....	1	t	.....
Hemiptera			
<i>Corixa</i> , water boatmen.....	17	14.00	4.11
<i>Lygus lineolaris</i>	1	t	.....
Coleoptera			
Carabidae, <i>Omophron</i>	1	0.20	0.06
Dytiscidae, diving beetles.....	4	1.90	0.56
Scarabaeidae, <i>Geotrupes</i> , scarab beetles.....	1	0.20	0.06
Chrysomelidae, <i>Diabrotica</i> , leaf beetles.....	1	t	.....
Trichoptera			
Hydroptilidae cases, caddisflies.....	5	0.02	0.006
Unidentified Trichoptera cases.....	2	0.10	0.03
Diptera			
Chironomidae larvae, midges.....	2	0.90	0.26
Unidentified Diptera larvae.....	1	t	.....
ARACHNIDA.....	1	t	.....
ACARINA, <i>Hydracarina</i> , water mites.....	2	t	.....
NONFOOD, feathers.....	2	t	.....

contents of the baldpate gizzards; in 1939 and 1940 they represented 100 per cent of the organic material. Volumes in individual gizzards varied considerably; in a number of gizzards only a trace of plant material was found, while in others the plant contents ranged up to 6.5 cc. The average was 1.99 cc., a rather low volume for the size of the gizzard.

Plant debris amounting to 0.33 per cent of the organic contents of the baldpate gizzards could not be keyed to species because of its finely ground condition; however, 34 species of plants were identified. The bulk of this plant material consisted of stems and leaves of coontail. The remaining plant material, except for algae and duckweed, consisted of seeds and seed coats.

Of 11 plants important to the baldpate (plants constituting at least 1.0 per cent of the total organic contents of the baldpate gizzards collected), coontail appeared to be the most important, table 15. Nearly three-fourths of the organic volume consisted of this plant. Field observations showed that baldpate concentrations were usually found in lakes or sloughs where coontail beds flourished. Corn was found in only four baldpate gizzards, and this was probably bait. Moist-soil plants in some gizzards indicated the birds had fed on flooded mud flats.

Plant species of lesser importance, those that contributed less than 1.0 per cent of the organic contents of the baldpate gizzards, were taken by only a few baldpates but in fairly large amounts. Most of these were moist-soil plants important to the teal and the pintail.

Animal Foods (6.34 Per Cent of Organic Contents).—Most of the animal foods found in the baldpate gizzards, table 16, were species associated with submerged plant beds and had been ingested probably

while the birds were browsing on coontail. Volumes in individual gizzards ranged from a trace to 6.8 cc., most of them less than 0.5 cc.

Aquatic insects, most of them water boatmen, comprised more than four-fifths of the animal material found in the baldpate gizzards. The Mollusca group was represented only by univalves. Bryozoans, water mites, crustaceans, and feathers were present in very small amounts.

Inorganic Contents (57.45 Per Cent of Total Contents).—The inorganic material in individual baldpate gizzards varied in volume from 0.5 to 5.1 cc. and averaged 2.87 cc. Most of the grit consisted of fine, white sand crystals. In four-fifths of the gizzards, stones were less than 2 mm. in size (largest dimension). In the remaining 20 per cent, there were, in addition to the fine sand, a few stones ranging from 3 to 10 mm. in size.

Gadwall

Anas strepera

This study indicated that the gadwall, like the baldpate, is primarily a vegetarian in the fall months in Illinois. Four-fifths of the gadwall gizzards collected for this study contained no animal material. Material was collected for the first three of the four collecting periods in the years of this study, table 17. Of the 98 gizzards obtained, only 7 were from the Mississippi River.

A gadwall gizzard was considered to have a capacity of 14 cc. None was filled to capacity; the contents of individual gizzards ranged in volume from 1.0 to 10.5 cc. and averaged 5.2 cc. One gizzard was completely empty; its condition indicated the bird was emaciated and probably sick. About one-tenth of the gizzards were less than one-quarter full; in these the con-

Table 17.—Gadwall gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	19	4	6	.....	29
1939.....	7	38	14	.....	59
1940.....	1	9	.....	.....	10
Total.....	27	51	20	0	98

tents were mostly grit. No gizzard was more than three-quarters full; yet most birds were apparently healthy when shot, since fatty tissue was evident.

The total contents of the gadwall gizzards amounted to 509.29 cc., of which 74.04 per cent (377.10 cc.) was grit and 25.96 per cent (132.19 cc.) was organic

material. Vegetable foods comprised 97.21 per cent and animal foods 2.79 per cent of the organic contents, tables 18 and 19.

Plant Foods (97.21 Per Cent of Organic Contents).—Plant items were found in 89 of the 98 gadwall gizzards; only gritty material was found in the remaining 9. The plant food contents of indi-

Table 18.—The most important plant foods identified in 98 gadwall gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
<i>TOTAL PLANT</i>		128.50	97.21
<i>Ceratophyllum demersum</i> , coontail.....	48	94.98	71.85
Algae.....	13	9.80	7.41
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	18	4.32	3.27
<i>lapathifolium</i> , nodding smartweed.....	10	0.10	0.08
<i>pensylvanicum</i> , large-seeded smartweed.....	5	0.02	0.02
Other <i>Polygonum</i>	3	t	.....
<i>Echinochloa crusgalli</i> , wild millet.....	10	3.30	2.50
<i>Digitaria</i>			
<i>sanguinalis</i> , crab-grass.....	1	2.50	1.89
<i>ischaemum</i> , smooth crab-grass.....	1	0.30	0.23
<i>Leersia oryzoides</i> , rice cutgrass.....	8	1.80	1.36
<i>Scirpus</i>			
<i>acutus</i> , hard-stem bulrush.....	2	1.30	0.98
<i>fluvialis</i> , river-bulrush.....	2	0.25	0.19
<i>validus</i> , soft-stem bulrush.....	2	0.10	0.08
<i>Potamogeton nodosus</i> , longleaf pondweed.....	6	1.60	1.21
<i>Heteranthera dubia</i> , mud-plantain.....	1	1.40	1.06
Other plants.....	47	6.73	5.09

Table 19.—The most important animal foods identified in 98 gadwall gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
<i>TOTAL ANIMAL</i>		3.69	2.79
MOLLUSCA, shells.....	1	t	.....
ARTHROPODA			
CRUSTACEA, Ostracoda.....	1	t	.....
INSECTA			
Hemiptera, <i>Corixa</i> , water boatmen.....	8	0.33	0.25
Coleoptera			
Dytiscidae, diving beetles.....	6	t	.....
Scarabaeidae, <i>Aphodius distinctus</i> , scarab beetles.....	1	0.02	0.02
Trichoptera, Hydroptilidae, caddisflies.....	4	t	.....
Lepidoptera larvae, moths.....	1	t	.....
Diptera			
Orthorrhapha, Chironomidae larvae, midges.....	3	2.90	2.19
Cyclorrhapha.....	1	0.02	0.02
ARACHNIDA.....	1	0.10	0.08
ACARINA, <i>Hydracarina</i> , water mites.....	1	t	.....
NONFOOD, feathers.....	6	0.32	0.24

vidual gizzards varied from a trace to 6 cc. and averaged 1.3 cc.

Thirty-four species of plants from the gadwall gizzards were identified; 0.88 per cent of the plant material was too finely ground to be recognized. The major portion of the plant material consisted of the stems and leaves of coontail and the entire plants and particles of duckweed and algae.

Plant groups contributing at least 1.0 per cent each to the organic contents of the

tals, each under 1 mm. in size. Occasionally, a stone up to 5 mm. (largest dimension) was found.

Shoveler
Spatula clypeata

Analyses of the contents of the duck gizzards collected in 1938, 1939, and 1940 indicated that, although animal foods are more readily consumed by the shoveler than by any other species of the dabbling group, this duck is still very much a vege-

Table 20.—Shoveler gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	19	1	7	.....	27
1939.....	9	23	.....	2	34
1940.....	.....	1	.....	.....	1
Total.....	28	25	7	2	62

gadwall gizzards were coontail, algae, marsh smartweed, wild millet, crab-grass, rice cutgrass, longleaf pondweed, and mud plantain, table 18. Coontail comprised nearly three-fourths of the organic contents. Moist-soil plant parts were found in the gizzards of gadwalls that had apparently visited flooded mud flats.

Twenty-six species of plants contributed less than 1.0 per cent each to the organic contents of the gadwall gizzards. Some of these plants had been taken in large amounts by only a few gadwalls and some had been taken in small amounts by a comparatively large number of birds.

Animal Foods (2.79 Per Cent of Organic Contents).—Animal organisms were present in one-fourth of the gadwall gizzards. The animal contents of individual gizzards ranged from a trace to 1.7 cc. and averaged 0.14 cc. Only two groups of animals, the water boatmen and midge larvae, made up as much as 0.1 per cent of the organic contents, table 19.

Inorganic Contents (74.04 Per Cent of Total Contents).—Grit predominated in the gross contents of the gadwall gizzards. In individual gizzards, grit ranged in volume from a trace to 6.6 cc. and averaged 3.85 cc. per gizzard. The grit was mostly in the form of fine, white sand crys-

talline during the fall months in Illinois. Because of their rather unsavory flavor, shovelers are, by some hunters, allowed to pass; or, if one of these ducks is killed, usually it is left in the marsh. Because this situation prevailed in 1938–1940, an adequate sample of shoveler gizzards was difficult to obtain, table 20. Only 3 of the 62 gizzards collected were obtained from Mississippi River stations.

A shoveler gizzard was considered full if its gross contents amounted to 6 cc. Contents of individual gizzards ranged in volume from 0.7 to 7.0 cc. and averaged 3.3 cc. Only 4 of the 62 shoveler gizzards were less than one-quarter full, and 16 were more than three-quarters full. Shovelers represented by these gizzards appeared to have obtained an adequate food supply during their autumn stay in Illinois.

The total contents of the shoveler gizzards amounted to 204.86 cc., of which 51.89 per cent (106.30 cc.) was inorganic and 48.11 per cent (98.56 cc.) was organic. The supposition that the unsavory flavor of the shoveler results from a diet of animal food was not substantiated by the present study. Plant structures formed 82.36 per cent and animal matter only 17.64 per cent of the organic material of

the shoveler gizzards collected, tables 21 and 22.

Plant Foods (82.36 Per Cent of Organic Contents).—The shoveler, more than any other species of duck, skims food from the surfaces of lake and marsh bottoms in very shallow water, much of it less than an inch in depth. Because of this

Nine plants, each represented by at least 1.0 per cent of the organic contents, provided the bulk of the food in the shoveler gizzards, table 21. Plants making up less than 1.0 per cent each of the total organic contents were not considered important even though they appeared in large volumes in a few gizzards. Their occurrence

Table 21.—The most important plant foods identified in 62 shoveler gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....	.....	81.17	82.36
<i>Cyperus</i>			
<i>erythrorhizos</i> , red-rooted nut-grass.....	26	28.56	28.98
<i>esculentus</i> , chufa.....	4	1.75	1.78
<i>strigosus</i> , nut-grass.....	8	0.90	0.91
<i>Cephalanthus occidentalis</i> , buttonbush.....	24	16.50	16.74
<i>Zea mays</i> , corn.....	8	11.10	11.26
<i>Ceratophyllum demersum</i> , coontail.....	12	9.10	9.23
<i>Echinochloa</i>			
<i>crusgalli</i> , wild millet.....	11	5.12	5.19
<i>walteri</i> , Walter's millet.....	1	0.20	0.20
<i>Nelumbo lutea</i> , American lotus.....	1	2.00	2.03
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	33	1.18	1.20
<i>pennsylvanicum</i> , large-seeded smartweed.....	4	0.30	0.30
<i>lappathifolium</i> , nodding smartweed.....	9	0.12	0.12
<i>punctatum</i> , dotted smartweed.....	4	0.10	0.10
Other <i>Polygonum</i>	11	t	.....
<i>Eragrostis hypnoides</i> , teal grass.....	1	1.60	1.62
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	13	0.67	0.68
<i>pectinatus</i> , sago pondweed.....	3	0.40	0.41
Other <i>Potamogeton</i>	11	0.10	0.10
Other plants.....	45	1.47	1.49

habit, the shoveler ingests large numbers of moist-soil plant seeds. The percentage of these seeds was greater in the shoveler gizzards collected in 1939 and 1940 than in those collected in 1938 probably because of the greater accessibility and availability of the seeds on inundated mud flats in the later years. The plant contents of individual gizzards ranged from a trace to 6.3 cc. and averaged 1.3 cc.

Parts of plants representing 42 species and some debris that could not be identified were found in the shoveler gizzards. The bulk of the vegetative structures was seeds and seed fragments of moist-soil plants, some stems and leaves of coontail, and seeds of the buttonbush, plant foods similar to those consumed by the blue-winged teal and the green-winged teal.

in only a few gizzards indicated a local feeding condition.

Animal Foods (17.64 Per Cent of Organic Contents).—Animal matter appeared in 50 of the 62 shoveler gizzards, but exclusively in only 6. The animal contents of individual gizzards varied from a trace to 2.4 cc.; most gizzards contained less than 1 cc. each of animal structures. Insect adults and larvae comprised 61.13 per cent and the Mollusca group 20.24 per cent of the volume of animal foods in the shoveler gizzards, table 22.

Inorganic Contents (51.89 Per Cent of Total Contents).—The volume of inorganic material in individual shoveler gizzards ranged from 0.6 to 5.5 cc. and averaged 1.71 cc. per gizzard. Most of the gravel particles were less than 2 mm. in

Table 22.—The most important animal foods identified in 62 shoveler gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
<i>TOTAL ANIMAL</i>		17.39	17.64
BRYOZOA statoblasts.....	12	0.70	0.71
MOLLUSCA			
GASTROPODA, snails			
<i>Gyraulus parvus</i>	1	t	.....
Unidentified Gastropoda.....	5	1.20	1.22
PELECYPODA, mussels			
<i>Pisidium</i>	1	0.02	0.02
Unidentified Pelecypoda.....	1	1.30	1.32
UNIDENTIFIED MOLLUSCA.....	6	1.00	1.01
ARTHROPODA			
CRUSTACEA			
Copepoda, <i>Canthocampus</i>	2	0.70	0.71
Ostracoda.....	28	1.84	1.87
INSECTA			
Ephemeroptera, <i>Hexagenia</i> , mayflies.....	2	0.10	0.12
Hemiptera			
<i>Corixa</i> , water boatmen.....	26	8.84	8.96
Unidentified Hemiptera.....	1	0.05	0.05
Coleoptera			
Carabidae, ground beetles.....	1	t	.....
Dytiscidae, diving beetles.....	8	0.15	0.15
Gyrinidae, whirligig beetles.....	1	t	.....
Staphylinidae, rove beetles.....	1	0.05	0.05
Scarabaeidae, scarab beetles			
<i>Aphodius</i>			
<i>distinctus</i>	1	0.05	0.05
<i>femoralis</i>	1	0.05	0.05
Trichoptera, Hydroptilidae cases, caddisflies.....	4	0.44	0.45
Diptera			
Chironomidae larvae, midges.....	4	0.60	0.61
Unidentified Diptera.....	1	0.30	0.30
Unidentified Insecta.....	1	t	.....
ACARINA, <i>Hydracarina</i> , water mites.....	4	t	.....
NONFOOD, feathers.....	1	t	.....

size (largest dimension); a few stones were as large as 5 mm.

Wood Duck *Aix sponsa*

Because the wood duck was legally protected at the time of this study, only a few gizzards of this species were available for examination. A small sample was obtained from confiscated birds. Twenty-six gizzards were collected: 9 in the period October 15–31 and 17 in the period November 1–15, 1938, 1939, and 1940. Seven of the gizzards were collected from Mississippi River stations.

A wood duck gizzard was considered full if the gross contents amounted to 9 cc. The contents of individual gizzards ranged in volume from 2 to 10 cc. and averaged 5.6 cc. per gizzard.

The gross contents of all wood duck gizzards collected amounted to 171.38 cc., of which 29.00 per cent (49.70 cc.) was grit and 71.00 per cent (121.68 cc.) was organic substance. Of the organic material, plant foods amounted to 99.85 per cent and animal foods to only 0.15 per cent, tables 23 and 24.

Plant Foods (99.85 Per Cent of Organic Contents).—The wood duck, as indicated by the small sample of gizzards collected, can be considered a vegetarian during the fall months in Illinois. Plant structures appeared in all the wood duck gizzards collected. The plant contents of individual gizzards ranged in volume from 0.8 to 9.6 cc. and averaged 4.7 cc. per gizzard.

Examination of the contents of the wood duck gizzards indicated that during

the autumn months the wood duck diet in Illinois is similar to the mallard diet in that corn is the major food. In the years of this study, wood ducks were frequently observed flying to and from mechanically picked cornfields located close to the wooded lakes and sloughs where these ducks congregated. Twenty-two plant species were identified in the wood duck gizzards collected, but only eight of these were represented by at least 1.0 per cent each of the organic contents, table 23.

Plants of secondary importance (those that contributed less than 1.0 per cent each to the total organic contents of the wood duck gizzards) were not found in large quantities in any of these gizzards. The only plants in this group worthy of mention were the lotus and the dogwood.

Animal Foods (0.15 Per Cent of Organic Contents).—This study indicated that animal organisms are relatively unimportant to the wood duck during the fall months in Illinois, table 24.

Table 23.—The most important plant foods identified in 26 wood duck gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		121.50	99.85
<i>Zea mays</i> , corn.....	11	58.87	48.38
<i>Quercus</i>			
<i>palustris</i> , pin oak.....	1	5.80	4.77
Unidentified.....	2	12.40	10.19
<i>Echinochloa crusgalli</i> , wild millet.....	1	14.70	12.08
<i>Ceratophyllum</i>			
<i>demersum</i> , coontail.....	2	2.80	2.30
Unidentified.....	1	5.10	4.19
<i>Cephalanthus occidentalis</i> , buttonbush.....	6	5.21	4.28
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	5	5.20	4.27
<i>pectinatus</i> , sago pondweed.....	1	t	.....
<i>Leersia oryzoides</i> , rice cutgrass.....	3	4.60	3.78
<i>Vitis cordifolia</i> , frost grape.....	2	2.50	2.05
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	7	1.09	0.90
<i>hydropiperoides</i> , mild water-pepper.....	1	0.40	0.33
Other <i>Polygonum</i>	7	t	.....
Other plants.....	10	2.83	2.33

Table 24.—The most important animal foods identified in 26 wood duck gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		0.18	0.15
ARTHROPODA, INSECTA			
Orthoptera, grasshoppers			
Rhopidophorinae.....	1	t	.....
Unidentified Saltatoria.....	1	0.02	0.02
Hemiptera			
<i>Corixa</i> , water boatmen.....	2	t	.....
Unidentified Hemiptera.....	1	0.02	0.02
Coleoptera, Chrysomelidae, leaf beetles			
<i>Diabrotica undecimpunctata howardi</i>	1	0.02	0.02
Unidentified Coleoptera.....	1	0.02	0.02
NONFOOD, feathers.....	1	0.10	0.08
UNIDENTIFIED ANIMAL.....	1	t	.....

Table 25.—The most important plant foods identified in 11 black duck gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		46.60	96.88
<i>Ceratophyllum demersum</i> , coontail.....	6	19.00	39.50
<i>Echinochloa crusgalli</i> , wild millet.....	1	7.60	15.80
<i>Leersia oryzoides</i> , rice cutgrass.....	1	4.70	9.77
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	7	3.70	7.69
<i>pectinatus</i> , sago pondweed.....	1	0.70	1.46
<i>pusillus</i> , small pondweed.....	1	0.05	0.10
<i>Zea mays</i> , corn.....	1	3.30	6.86
<i>Cephalanthus occidentalis</i> , buttonbush.....	3	2.70	5.61
<i>Acnida altissima</i> , water-hemp.....	1	2.70	5.61
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	5	1.60	3.33
Other <i>Polygonum</i>	4	t	.....
Other plants.....	8	0.55	1.14

Inorganic Contents (29.00 Per Cent of Total Contents).—Inorganic material, present in all wood duck gizzards examined, ranged in volume from 0.4 to 5.6 cc. in individual gizzards and averaged 1.9 cc. per gizzard. Most of the gravel particles were under 2 mm. in size (largest dimension); however, a few stones ranged in size up to 12 mm. In the gizzards in which corn predominated as food, grit particles seldom exceeded 2 mm. in size.

Black Duck *Anas rubripes*

Few gizzards labeled as those of black ducks were examined. Co-operators seldom distinguished between the common mallard and the black duck or black mal-

lard; for accuracy, the writer did not designate as black duck gizzards any he had not collected personally. Eleven gizzards known to be those of the black duck were obtained in 1939 and 1940 in the period October 15–November 15.

The capacity of a black duck gizzard was considered to be 17 cc. None of the black duck gizzards examined was completely full. The contents of individual gizzards ranged in volume from 0.6 to 10.2 cc. and averaged 6.9 cc. per gizzard.

The gross contents of the black duck gizzards amounted to 75.60 cc., of which 36.38 per cent (27.50 cc.) was grit and 63.62 per cent (48.10 cc.) was organic matter. Plant parts comprised 96.88 per cent of the foods, while animal structures

Table 26.—The most important animal foods identified in 11 black duck gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		1.50	3.12
MOLLUSCA			
PELECYPODA, mussels.....	1	0.30	0.62
UNIDENTIFIED MOLLUSCA.....	1	0.50	1.04
ARTHROPODA, INSECTA			
Ephemeroptera, <i>Hexagenia</i> , mayflies.....	1	0.60	1.25
Coleoptera			
Dytiscidae, diving beetles.....	2	t	.....
Hydrophilidae, water scavenger beetles.....	1	0.10	0.21
Trichoptera, caddisflies.....	1	t	.....

amounted to 3.12 per cent, tables 25 and 26.

Plant Foods (96.88 Per Cent of Organic Contents).—Plant parts appeared in all black duck gizzards collected. The plant contents of individual gizzards ranged in volume from 0.1 to 8.7 cc. and averaged 4.2 cc. per gizzard. Twenty plant species were identified; the nine that were considered important constituted 95.63 per cent of all organic foods, table 25.

In general, the diet of the black duck was similar to that of the common mallard. Corn might have been more important on the list of foods of the black duck if collections had been made later in the fall and if a larger sample had been taken.

Animal Foods (3.12 Per Cent of Organic Contents).—Only a few kinds of animal organisms were represented in the 11 black duck gizzards, table 26.

Inorganic Contents (36.38 Per Cent of Total Contents).—Gravel was present in all black duck gizzards collected; in individual gizzards, it ranged in volume

from a trace to 4.5 cc. Stones varied in size from minute to 9 mm. (largest dimension); however, most inorganic particles were less than 2 mm. in size.

Lesser Scaup
Aythya affinis

Lesser scaups are usually considered omnivorous feeders, but this study indicated their preference for animal foods during the fall months in Illinois. Data were obtained from 220 lesser scaup gizzards collected in the periods shown in table 27. Of the total, 81 were from the Mississippi River and 139 from the Illinois River stations.

A lesser scaup gizzard was considered full if its gross contents amounted to 5.7 cc. or more. The contents of individual lesser scaup gizzards ranged in volume from a trace to 10.5 cc. and averaged 2.86 cc. Approximately one-third of the gizzards were less than one-quarter full; four of these were empty and showed indications of lead poisoning. Only 10 were more than three-quarters full. Fatty tissue surrounded most of the gizzards.

Table 27.—Lesser scaup gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....		58	68		126
1939.....		19	37	10	66
1940.....	1	2	25		28
<i>Total</i>	<i>1</i>	<i>79</i>	<i>130</i>	<i>10</i>	<i>220</i>

Table 28.—The most important plant foods identified in 220 lesser scaup gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS ¹)	PER CENT OF TOTAL ORGANIC CONTENTS
<i>TOTAL PLANT</i>		39.49	9.65
<i>Potamogeton</i>			
<i>pectinatus</i> , sago pondweed.....	32	4.29	1.05
<i>nodosus</i> , longleaf pondweed.....	58	3.41	0.83
<i>foliosus</i> , leafy pondweed.....	12	3.00	0.73
<i>pusillus</i> , small pondweed.....	6	0.67	0.16
Other <i>Potamogeton</i>	7	0.15	0.04
<i>Ceratophyllum demersum</i> , coontail.....	21	9.71	2.37
Other plants.....	212	18.26	4.46

Table 29.—The most important animal foods identified in 220 lesser scaup gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		369.87	90.35
BRYOZOA statoblasts	1	t	
MOLLUSCA			
GASTROPODA, snails			
<i>Gyraulus parvus</i>	2	t	
<i>Viviparus viviparus</i>	2	4.90	1.20
<i>Campeloma</i>	16	29.00	7.08
<i>Lioplax subcarinata</i>	8	4.35	1.06
<i>Amnicola</i>			
<i>peracuta</i>	1	0.50	0.12
Unidentified <i>Amnicola</i>	15	23.30	5.69
(<i>Probythinella</i>)			
<i>binneyana</i>	29	23.25	5.68
Unidentified <i>Amnicola</i> (<i>Probythinella</i>).....	1	1.50	0.37
<i>Flummicola</i>	3	2.80	0.68
<i>Somatogyrus</i>			
<i>subglobosus</i>	2	0.30	0.07
Unidentified <i>Somatogyrus</i>	1	0.80	0.20
<i>Pleurocera</i>	11	3.40	0.83
<i>Neritina</i>	2	2.50	0.61
Unidentified Gastropoda.....	57	80.88	19.76
PELECYPODA, mussels			
Sphaeriidae			
<i>Pisidium</i>	8	12.70	3.10
<i>Musculium transversum</i>	9	13.10	3.20
<i>Sphaerium</i>			
<i>stamineum</i>	1	0.40	0.10
Unidentified <i>Sphaerium</i>	27	71.60	17.49
Unidentified Sphaeriidae.....	9	34.30	8.38
Unionidae, fresh-water clams.....	12	10.59	2.59
Unidentified Pelecypoda.....	8	1.14	0.28
UNIDENTIFIED MOLLUSCA.....	23	31.11	7.60
ARTHROPODA			
Crustacea			
<i>Cambarus virilis</i> , crayfish.....	1	0.10	0.02
INSECTA			
Ephemeroptera, <i>Hexagenia</i> nymphs, mayflies.....	30	13.56	3.31
Odonata, <i>Anax junius</i> , dragonflies.....	2	0.70	0.17
Hemiptera			
Corixidae, <i>Corixa</i> , water boatmen.....	7	1.00	0.24
Gerridae, <i>Gerris remigis</i> , water striders.....	1	0.20	0.05
Coreidae, squash bugs.....	1	0.12	0.03
Unidentified Hemiptera.....	1	0.10	0.02
Coleoptera			
Carabidae, ground beetles.....	1	t	
Dytiscidae, diving beetles.....	6	0.50	0.12
Hydrophilidae, water scavenger beetles.....	1	t	
Scarabaeidae, <i>Aphodius femoralis</i>	1	0.10	0.02
Curculionidae, snout beetles.....	1	t	
Trichoptera, Hydroptilidae cases, caddisflies.....	1	t	
Diptera			
Chironomidae larvae, midges.....	1	0.20	0.05
Anthomyiidae.....	2	0.29	0.07
Unidentified Diptera.....	2	t	
Hymenoptera, Formicidae, ants.....	1	0.08	0.02
ARACHNIDA			
Araneae, spiders.....	1	t	
Unidentified Arachnida.....	2	0.10	0.02
NONFOOD, feathers.....	2	0.40	0.10
UNIDENTIFIED.....	1	t	

The gross contents of the 220 lesser scaup gizzards amounted to 630.26 cc., of which 35.05 per cent (220.90 cc.) was grit and 64.95 per cent (409.36 cc.) was organic material. Reflecting the apparently carnivorous appetite of the lesser scaups in Illinois, animal matter amounted to 90.35 per cent of the organic foods, while plant structures constituted only 9.65 per cent.

Plant Foods (9.65 Per Cent of Organic Contents).—In Illinois, lesser scaup ducks do much of their feeding on submergent vegetation at water depths of 3 to

important single plant, it was second in importance to the pondweeds as a group.

Animal Foods (90.35 Per Cent of Organic Contents).—Animal matter was found in lesser scaup gizzards taken in all collecting periods, but in greatest amounts in those taken in the last 2 weeks of November. It was found in four-fifths of the lesser scaup gizzards, exclusively in one-fifth. The animal contents of individual gizzards ranged in volume from a trace to 9.5 cc. and averaged 1.68 cc. per gizzard.

The principal animals represented in the gizzards of lesser scaups, table 29,

Table 30.—Ring-necked duck gizzards collected in Illinois in approximately 2-week periods, 1938–1940.

YEAR	NUMBER OF GIZZARDS				TOTAL
	OCTOBER 16-31	NOVEMBER 1-15	NOVEMBER 16-30	DECEMBER 1-15	
1938.....	2	52	50	.....	104
1939.....	4	6	3	3	16
1940*.....	.....	.....	.....	.....	0
Total.....	6	58	53	3	120

*In this year, no ring-necked ducks were found among the ducks bagged and used for collection material.

5 feet and on mollusks and other animals at depths up to 15 feet.

Plant structures were found in 140 of the 220 lesser scaup gizzards collected. Only 13.33 per cent of the organic contents of the gizzards collected in 1938 consisted of plant material. Comparable figures were 16.51 per cent for 1939 and 42.50 per cent for 1940; stable water conditions in 1940 resulted in a marked increase in submergent plant beds (Bellrose 1941:249–50, 252).

Plant material ranged in volume from a trace to 3.7 cc. in individual lesser scaup gizzards and averaged 0.18 cc. per gizzard. The bulk of the plant material was composed of seeds and seed fragments of several submergent plants and the stems and leaves of coontail.

In all, 38 plant species were identified in the gizzards of lesser scaups; however, only a few of these were represented by at least 0.5 per cent each of the organic diet, table 28. Three species of pondweed contributed a large volume of plant material and occurred in a large number of gizzards. Although coontail was the most

were from the Mollusca phylum, which accounted for 95.28 per cent of the animal foods. Snails contributed 47.98 per cent of the animal material and the bivalves 38.89 per cent. Shells of the brackish water snail (*Neritina*) occurred in two gizzards. The snails of this genus apparently were ingested on the wintering grounds and the shells retained in the gizzards through the breeding season. Most aquatic insects in the gizzards were adult mayflies or larvae. No fish fragments were found.

Inorganic Contents (35.05 Per Cent of Total Contents).—No attempt was made to segregate gravel from calcareous shell material in the lesser scaup gizzards; both materials act as grinding agents. Gravel was present in all of the gizzards; individual particles ranged from minute to 11 mm. in size (largest dimension).

Ring-Necked Duck *Aythya collaris*

Although ring-necked ducks are excellent divers and can obtain food at considerable depths, they prefer shallow waters,

marshes, and sloughs. Of the 120 ring-necked duck gizzards collected, table 30, 7 were from the Mississippi River region and 113 from the Illinois River valley.

A ring-necked duck gizzard was considered full if the gross contents amounted to 8.5 cc. or more. The contents of individual gizzards ranged in volume from 0.4 to 11.0 cc. and averaged 3.7 cc. per gizzard. Most of the gizzards were surrounded by heavy fatty tissue.

The gross contents of the 120 gizzards of ring-necks amounted to 445.65 cc., of which 41.31 per cent (184.10 cc.) was grit and 58.69 per cent (261.55 cc.) was organic material. Plants comprised 65.93 per cent of the organic foods, and animal matter made up 34.07 per cent, tables 31 and 32.

Plant Foods (65.93 Per Cent of Organic Contents).—Plant structures were present in nearly all the ring-necked duck

gizzards. The plant contents of individual gizzards varied from a trace to 9.1 cc. and averaged 1.44 cc. per gizzard. Most of the gizzards contained less than 2 cc. of plant material each; the few with more than 2 cc. contained plant material exclusively. Plant material in the gizzards of ring-necked ducks increased from 64.10 per cent of organic contents in 1938 to 75.20 per cent in 1939, paralleling the increase in duck food plants in Illinois River valley lakes (Bellrose 1941:249-53).

Although the gizzards of ring-necks contained some unidentifiable plant debris, 44 species of submergent, emergent, and moist-soil plants were recognized. Seeds and seed fragments formed the bulk of the structures; however, the stems and leaves of coontail and the tubers of duck-potato and chufa were present.

The 11 plants most important to the ring-neck (plants that contributed 1.0 per

Table 31.—The most important plant foods identified in 120 ring-necked duck gizzards collected in Illinois, 1938-1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		172.45	65.93
<i>Ceratophyllum demersum</i> , coontail.....	35	45.54	17.41
<i>Zea mays</i> , corn.....	10	36.40	13.92
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	50	20.38	7.79
<i>pectinatus</i> , sago pondweed.....	34	8.25	3.15
<i>pusillus</i> , small pondweed.....	11	3.56	1.36
<i>foliosus</i> , leafy pondweed.....	5	3.20	1.22
<i>gramineus</i> , variable-leaf pondweed.....	1	0.40	0.15
<i>praelongus</i> , white-stem pondweed.....	1	0.30	0.11
Other <i>Potamogeton</i>	2	0.20	0.08
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	54	13.61	5.20
<i>lapathifolium</i> , nodding smartweed.....	36	1.25	0.48
<i>pensylvanicum</i> , large-seeded smartweed.....	10	0.74	0.28
<i>punctatum</i> , dotted smartweed.....	1	0.30	0.11
<i>hydropiper</i> , water-pepper.....	1	0.20	0.08
Other <i>Polygonum</i>	2	0.10	0.04
<i>Cyperus</i>			
<i>erythrorhizos</i> , red-rooted nut-grass.....	13	7.85	3.00
<i>esculentus</i> , chufa.....	2	0.10	0.04
<i>Sagittaria latifolia</i> , duck-potato.....	1	6.70	2.56
<i>Cephalanthus occidentalis</i> , buttonbush.....	19	3.78	1.45
<i>Scirpus</i>			
<i>fluvialis</i> , river-bulrush.....	15	3.27	1.25
<i>acutus</i> , hard-stem bulrush.....	7	0.45	0.17
<i>validus</i> , soft-stem bulrush.....	3	0.02	0.01
Unidentified.....	1	0.03	0.01
<i>Sparganium</i>			
<i>eurycarpum</i> , giant bur-reed.....	8	1.13	0.43
Unidentified.....	10	2.44	0.93
Other plants.....	67	12.25	4.68

cent or more each to the organic contents of the gizzards representing this species, table 31) totaled almost 60 per cent of the volume of food in the gizzards.

Parts of the secondary food plants were found in relatively large quantities in a few gizzards of the ring-necks, but in most gizzards only traces or small quantities were noted.

Animal Foods (34.07 Per Cent of Organic Contents).—Animal matter was found in 80 ring-necked duck gizzards and was represented in the four collecting periods. The animal contents of individual gizzards varied from a trace to 7.6 cc. and averaged 0.73 cc. per gizzard. Only four

gizzards contained animal food exclusively.

Of the total animal material in the gizzards of the ring-necks, mollusks represented more than 70 per cent by volume; more than half of the volume of mollusks consisted of univalves, table 32. Adults and larvae of insects constituted nearly 25 per cent of the volume of animal matter. Bryozoan statoblasts, fish, crustaceans, spiders, and water mites were present in insignificant amounts.

Inorganic Contents (41.31 Per Cent of Total Contents).—The volume of inorganic material in the gizzards of the ring-necks ranged from a trace to 7 cc. and

Table 32.—The most important animal foods identified in 120 ring-necked duck gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		89.10	34.07
BRYOZOA statoblasts	2	1.20	0.46
MOLLUSCA			
GASTROPODA, snails			
<i>Stagnicola</i>	2	5.10	1.95
<i>Physa</i>	1	0.20	0.08
<i>Viviparus viviparus</i>	1	0.20	0.08
<i>Ambicula (Probythinella) binneyana</i>	3	2.40	0.92
<i>Campeloma</i>	4	3.70	1.41
<i>Flumnicola</i>	2	0.70	0.27
<i>Somatogyrus subglobosus</i>	1	0.60	0.23
<i>Pleurocera</i>	1	0.20	0.08
Unidentified Gastropoda.....	14	20.29	7.76
PELECYPODA, Sphaeriidae, mussels			
<i>Pisidium</i>	4	4.30	1.64
<i>Musculium transversum</i>	3	5.20	1.99
<i>Sphaerium</i>	5	9.20	3.52
UNIDENTIFIED MOLLUSCA.....	9	13.40	5.12
ARTHROPODA			
CRUSTACEA, <i>Gammarus fasciatus</i> , gammarid	1	t	.....
INSECTA			
Ephemeroptera, <i>Hexagenia</i> nymphs, mayflies	7	8.20	3.13
Hemiptera			
Corixidae, <i>Corixa</i> , water boatmen	17	2.36	0.90
Belostomatidae, <i>Benacus</i> nymphs, water bugs	1	0.12	0.05
Coleoptera			
Carabidae, ground beetles.....	4	0.68	0.26
Dytiscidae, diving beetles.....	6	0.06	0.02
Gyrinidae, whirligig beetles.....	1	0.05	0.02
Scarabaeidae, <i>Aphodius distinctus</i> , scarab beetles.....	1	0.60	0.23
Chrysomelidae, <i>Chaetocnema</i> , leaf beetles.....	1	t	.....
Unidentified Coleoptera.....	1	t	.....
Trichoptera.....	6	0.10	0.04
Diptera, Chironomidae larvae, midges.....	19	9.33	3.57
Hymenoptera, Ichneumonidae, ichneumon flies	1	t	.....
ARACHNIDA, Araneae, spiders.....	1	t	.....
ACARINA, <i>Hydracarina</i> , water mites.....	5	0.01	0.004
CHORDATA, Pisces.....	1	t	.....
NONFOOD, feathers.....	5	0.90	0.34

averaged 1.53 cc. per gizzard. Gravel particles ranged in size from minute to 13 mm. (largest dimension). In 80 per cent of the gizzards, grit particles seldom exceeded 3 mm. each. Apparently calcareous shell material served as grit, for gravel was absent from many gizzards.

Canvasback *Aythya valisineria*

The canvasback is an omnivorous feeder in Illinois, this study indicated. Many of the canvasback gizzards collected (61 per

cent) contained only vegetable matter, while a few (8 per cent) contained animal matter exclusively. Because few canvasbacks were killed in Illinois while field work for this study was being done, only a small number of canvasback gizzards were collected. Of the 23 collected, 18 were obtained in 1938, 9 in 1939, and 1 in 1940; 4 of these were from the Mississippi River area. One gizzard was taken in the period October 15–31, 13 in November 1–15, 13 in November 16–30, and 1 in December 1–15.

Table 33.—The most important plant foods identified in 28 canvasback gizzards collected in Illinois, 1938–1940.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		89.32	65.00
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	20	34.26	24.93
<i>pectinatus</i> , sago pondweed.....	7	11.62	8.46
<i>pusillus</i> , small pondweed.....	1	0.20	0.15
<i>foliosus</i> , leafy pondweed.....	1	0.10	0.07
<i>Sagittaria latifolia</i> , duck-potato.....	6	24.91	18.13
<i>Ceratophyllum demersum</i> , coontail.....	7	15.00	10.91
Other plants.....	43	3.23	2.35

Table 34.—The most important animal foods identified in 28 canvasback gizzards collected in Illinois, 1938–1940.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		48.10	35.00
MOLLUSCA			
GASTROPODA, snails			
<i>Amnicola</i>	1	2.30	1.67
<i>Flumnicola</i>	1	1.30	0.95
Unidentified Gastropoda.....	1	2.70	1.96
PELECYPODA, mussels			
<i>Sphaerium</i>	1	1.10	0.80
Unidentified Pelecypoda.....	1	2.70	1.97
ARTHROPODA, INSECTA			
Ephemeroptera, <i>Hexagenia</i> nymphs, mayflies.....	3	0.95	0.69
Hemiptera, <i>Corixa</i> , water boatmen.....	2	0.10	0.07
Coleoptera			
Carabidae, ground beetles.....	1	t	.....
Dytiscidae, diving beetles.....	1	0.05	0.04
Dryopidae.....	1	t	.....
Curculionidae, snout beetles.....	1	0.20	0.14
Diptera			
Chironomidae larvae, midges.....	5	32.00	21.28
Tabanidae, <i>Tabanus</i> larvae, horse flies.....	1	0.30	0.20
Unidentified Diptera larvae.....	1	4.30	2.86
CHORDATA, Pisces.....	1	t	.....
NONFOOD, feathers.....	1	0.10	0.07

Table 35.—The most important plant foods identified in 14 redhead gizzards collected in Illinois, 1938.

PLANT	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL PLANT.....		40 30	77.93
<i>Potamogeton</i>			
<i>nodosus</i> , longleaf pondweed.....	7	17.03	32.93
<i>pectinatus</i> , sago pondweed.....	6	0 27	0.52
Other <i>Potamogeton</i>	1	t	.....
<i>Ceratophyllum demersum</i> , coontail.....	4	7.40	14.31
<i>Echinochloa crusgalli</i> , wild millet.....	2	4 30	8.32
<i>Zea mays</i> , corn.....	1	2 60	5.03
<i>Polygonum</i>			
<i>coccineum</i> , marsh smartweed.....	5	1 89	3.66
<i>laphifolium</i> , nodding smartweed.....	4	0 35	0.68
<i>pennsylvanicum</i> , large-seeded smartweed.....	2	0 25	0.48
<i>punctatum</i> , dotted smartweed.....	1	0 10	0.19
<i>Scirpus</i>			
<i>validus</i> , soft-stem bulrush.....	5	0 80	1.55
<i>fluvialis</i> , river-bulrush.....	4	0.15	0.29
<i>Ambrosia</i>			
<i>artemisiifolia</i> , common ragweed.....	1	t	.....
Unidentified.....	1	0.65	1.26
Other plants.....	8	4 51	8.72

A canvasback gizzard was considered full if the gross contents amounted to 14.5 cc. or more. The contents of individual gizzards ranged in volume from 0.8 to 17.5 cc. and averaged 7.91 per gizzard.

In this study, 221.72 cc. of material was obtained from the 28 canvasback gizzards; of this material, 38.02 per cent (84.30 cc.) was grit and 61.98 per cent (137.42 cc.) was organic material. Plant structures comprised 65.00 per cent and animal parts 35.00 per cent of the organic foods, tables 33 and 34.

Plant Foods (65.00 Per Cent of Organic Contents).—Plant structures were found in nearly all the canvasback gizzards collected; the plant food contents of individual gizzards ranged from 0.1 to 12.0 cc. and averaged 3.14 per gizzard.

Plants that furnished at least 1.0 per cent each of the organic contents of the canvasback gizzards were considered important, table 33. These were longleaf and sago pondweeds, duck-potato, and coontail, which together amounted to nearly two-thirds of the organic material. Twenty plant species that individually contributed less than 1.0 per cent of the organic contents were considered of secondary importance. Some of these may have been important locally but in most

canvasback gizzards they were found in small quantities.

Animal Foods (35.00 Per Cent of Organic Contents).—Animal parts were found in two-fifths of the canvasback gizzards; the animal contents of individual gizzards varied from a trace to 11.3 cc. and averaged 1.72 cc. per gizzard. Animal forms considered important were those that contributed at least 0.5 per cent each to the organic contents, table 34.

Inorganic Contents (38.02 Per Cent of Total Contents).—The volume of inorganic material in individual gizzards of the canvasback varied from 0.5 to 5.5 cc. each. The quantity of gravel was smaller in gizzards containing snail parts than in others; evidently the shell material took the place of stones. Gravel particles ranged from minute to 11 mm. in size (largest dimension); most stones were no larger than 2 mm.

Redhead

Aythya americana

Fourteen gizzards of the redhead duck were collected, all in the period November 1–15, 1938. Data from this small sample have limited value.

The capacity of a redhead gizzard was considered to be 14 cc.; however, none of

Table 36.—The most important animal foods identified in 14 redhead gizzards collected in Illinois, 1938.

ANIMAL	OCCURRENCE (NUMBER OF GIZZARDS)	VOLUME (CUBIC CENTIMETERS)	PER CENT OF TOTAL ORGANIC CONTENTS
TOTAL ANIMAL.....		11.41	22.07
BRYOZOA statoblasts.....	1	t	
ARTHROPODA			
INSECTA			
Ephemeroptera, <i>Hexagenia</i> , mayflies.....	1	0.30	0.58
Hemiptera, <i>Corixa</i> , water boatmen.....	1	0.01	0.02
Coleoptera, Dytiscidae, diving beetles.....	1	t	
Trichoptera.....	2	1.50	2.90
Lepidoptera.....	1	0.09	0.17
Diptera, Chironomidae larvae, midges.....	6	9.50	18.37
ARACHNIDA			
Argiopoidea, spiders.....	1	0.01	0.02
Unidentified Arachnida.....	1	t	
ACARINA, <i>Hydracarina</i> , water mites.....	1	t	
NONFOOD, feathers.....	1	t	

the gizzards collected contained this volume of material. Gross contents of individual gizzards ranged from 3.2 to 10.0 cc. each and averaged 6.47 cc. per gizzard. Of the 90.61 cc. of material, 42.93 per cent (38.90 cc.) was grit and 57.07 per cent (51.71 cc.) was organic substance. Plants contributed 77.93 per cent of the organic contents and animal organisms 22.07 per cent, tables 35 and 36.

Plant Foods (77.93 Per Cent of Organic Contents).—Plant structures were found in 13 of the 14 redhead gizzards; the plant contents of individual gizzards ranged in volume from 0.8 to 6.9 cc. and averaged 3.1 cc. per gizzard. The bulk of the material consisted of longleaf pondweed seeds. Nineteen food plants were identified; six species contributed at least 1.0 per cent each to the organic contents, table 35. Seeds of the alkali bulrush, a western species not indigenous to Illinois, were found in one gizzard.

Animal Foods (22.07 Per Cent of Organic Contents).—Animal organisms were present in 12 of the 14 redhead gizzards; the animal matter in individual gizzards ranged from a trace to 4.3 cc. Midges were found in six of the gizzards, table 36.

Inorganic Contents (42.93 Per Cent of Total Contents).—The grit contents of individual gizzards of the redhead ranged from 0.9 to 4.8 cc. and averaged 2.78 cc. per gizzard. A major portion of

the inorganic material consisted of quartz particles varying in size from minute to 2 mm. (largest dimension); the material included an occasional stone up to 11 mm.

Ruddy Duck *Oxyura jamaicensis*

Only five ruddy duck gizzards were collected for this study. All were obtained between October 15 and November 15, 1939 and 1940. The gross contents of these gizzards amounted to 16.6 cc., of which 63.86 per cent (10.6 cc.) was grit and 36.14 per cent (6.0 cc.) was organic material. Of the organic food, plant structures amounted to 23.33 per cent and animal matter to 76.67 per cent.

Plant Foods (23.33 Per Cent of Organic Contents).—Plant parts appeared in three of the five ruddy duck gizzards; only a trace in two and 1.4 cc. in the other. Four species of plants were represented: coontail made up almost 100 per cent of the bulk; longleaf pondweed, leafy pondweed, and wild millet appeared as traces.

Animal Foods (76.67 Per Cent of Organic Contents).—Animal structures were found in all five ruddy duck gizzards. The animal contents of individual gizzards ranged from a trace to 1.7 cc. Midge larvae comprised almost 100 per cent of the animal matter; water boatmen and water beetles appeared as traces.

Inorganic Contents (63.86 Per Cent of Total Contents).—Gravel made up

nearly two-thirds of the gross contents of the ruddy duck gizzards. The inorganic contents of individual gizzards ranged from 1.2 to 4.0 cc. and averaged 2.1 cc. Most gravel particles were each smaller than 2 mm. (largest dimension).

Common Goldeneye *Bucephala clangula*

Only three goldeneye gizzards were obtained for this study, all of them in the period November 14-30, 1938. The total gross contents amounted to 2.6 cc., of which 50.00 per cent (1.3 cc.) was grit and 50.00 per cent (1.3 cc.) was organic material. Longleaf pondweed, which constituted 15.38 per cent of the organic contents, was the only important plant species represented, while mayfly nymphs, which constituted 84.62 per cent of the organic contents, was the only animal food.

Greater Scaup *Aythya marila*

The gizzard of one greater scaup was collected on November 16, 1940. It contained grit material amounting to 1.0 cc. and no animal or plant structures.

Oldsquaw *Clangula hyemalis*

The gizzard of one oldsquaw duck was obtained in the fall of 1940. It contained

2.7 cc. of material, of which 11.11 per cent (0.3 cc.) was grit and 88.89 per cent (2.4 cc.) consisted of plant and animal matter. Coontail made up the entire plant contents (41.67 per cent of the organic material), while fish bones, midges, and snails made up the animal contents (58.33 per cent of the organic material).

PLANT FOODS

Data derived from analyses of the contents of waterfowl gizzards collected in Illinois in the autumns of 1938, 1939, and 1940 were used in making evaluations of the most important plants utilized as food by waterfowl migrating through the state.

Although no completely satisfactory evaluations of the importance of various kinds of food plants are possible, a rough evaluation of each of the most important kinds was given by an index figure obtained by multiplying the number of gizzards in which the kind of plant was found (occurrences) by the actual figure indicating the percentage it constituted of the total plant volume (for example, for *Zea mays*, multiplying 1,445 by 39.36, figures derived from table 38).

The nineteen species of plants that were most utilized by ducks in their southward migrations through Illinois are listed in table 37. These plants were the favored

Table 37.—Occurrence-percentage index ratings of plant foods identified in duck gizzards collected along the Illinois River, Ottawa to Florence (4,505 gizzards), and along the Mississippi River, Rock Island to Quincy (472 gizzards), 1938-1940 (derived from table 38).

PLANT	INDEX NUMBER
<i>Zea mays</i> , corn.....	56,875
<i>Leersia oryzoides</i> , rice cutgrass.....	11,862
<i>Polygonum cocineum</i> , marsh smartweed.....	8,249
<i>Ceratophyllum demersum</i> , coontail.....	7,734
<i>Echinochloa crusgalli</i> , wild millet.....	4,605
<i>Potamogeton nodosus</i> , longleaf pondweed.....	2,293
<i>Cyperus erythrorhizos</i> , red-rooted nut-grass.....	2,289
<i>Acnida altissima</i> , water-hemp.....	1,849
<i>Polygonum lapathifolium</i> , nodding smartweed.....	1,111
<i>Cephalanthus occidentalis</i> , buttonbush.....	956
<i>Polygonum pennsylvanicum</i> , large-seeded smartweed.....	635
<i>Cyperus strigosus</i> , nut-grass.....	605
<i>Cyperus esculentus</i> , chufa.....	554
<i>Echinochloa walteri</i> , Walter's millet.....	537
<i>Potamogeton pectinatus</i> , sago pondweed.....	427
<i>Sagittaria latifolia</i> , duck-potato.....	232
<i>Scirpus fluviatilis</i> , river-bulrush.....	156
<i>Eragrostis hypnoides</i> , teal grass.....	116
<i>Sparganium eurycarpum</i> , giant bur-reed.....	112

Table 38.—Plant foods of ducks taken along the Illinois River, Ottawa to Florence (4,505 gizzards), and along the Mississippi River, Rock Island to Quincy (472 gizzards), 1938–1940.

PLANT	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents	Occur- rence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents
<i>TOTAL PLANT</i>		17,234.88	94.82		1,342.78	90.36
<i>Zea mays</i> , corn.....	1,262	6,429.05	35.38	183	883.20	59.44
<i>Leersia oryzoides</i> , rice cutgrass.....	880	2,339.58	12.87	41	52.62	3.54
<i>Ceratophyllum demersum</i> , coontail....	795	1,751.63	9.64	14	24.10	1.62
<i>Echinochloa</i>						
<i>crusgalli</i> , wild millet.....	669	1,165.32	6.41	46	30.22	2.03
<i>walteri</i> , Walter's millet.....	243	410.67	2.26			
Unidentified.....	2	1.40	0.01			
<i>Cyperus</i>						
<i>erythrorhizos</i> , red-rooted nut-grass..	613	683.11	3.76	4	6.90	0.46
<i>strigosus</i> , nut-grass.....	378	289.13	1.59	6	3.60	0.24
<i>esculentus</i> , chufa.....	384	267.42	1.47	1	t	
<i>ferax</i>	3	0.20	t	4	0.70	0.05
Unidentified.....	20	47.78	0.26			
<i>Polygonum</i>						
<i>coccineum</i> , marsh smartweed.....	1,995	760.02	4.18	17	1.32	0.09
<i>lappathifolium</i> , nodding smartweed..	1,028	161.01	0.89	117	19.65	1.32
<i>pensylvanicum</i> , large-seeded smart- weed.....	480	141.63	0.78	119	56.19	3.78
<i>hydropiperoides</i> , mild water-pepper.	219	82.32	0.45	6	0.40	0.03
<i>punctatum</i> , dotted smartweed.....	173	35.31	0.19	36	21.36	1.44
<i>persicaria</i> , lady's thumb.....	101	11.71	0.06	15	6.25	0.42
<i>hydropiper</i> , water-pepper.....	61	6.75	0.04	28	4.00	0.27
<i>scandens</i> , climbing false buckwheat	7	0.33	t	4	0.15	0.01
<i>sagittatum</i> , arrow-leaved tearthumb	2	0.20	t	1	0.40	0.03
<i>amphibium</i> , water lady's thumb...	1	0.05	t	3	0.02	t
<i>aviculare</i> , prostrate knotweed.....				1	t	
Unidentified.....	15	2.71	0.01	4	1.70	0.11
<i>Potamogeton</i>						
<i>nodosus</i> , longleaf pondweed.....	1,252	329.65	1.81	22	5.40	0.36
<i>pectinatus</i> , sago pondweed.....	596	104.22	0.57	34	21.77	1.47
<i>foliosus</i> , leafy pondweed.....	179	40.03	0.22	42	14.10	0.95
<i>pusillus</i> , small pondweed.....	98	17.76	0.10	6	0.87	0.06
<i>perfoliatus</i> , thoroughwort pondweed	3	8.40	0.05			
<i>praelongus</i> , white-stem pondweed...	5	1.70	0.01			
<i>amplifolius</i> , large-leaved pondweed	2	0.11	t			
<i>epihydus</i> , ribbon-leaf pondweed...	2	0.05	t	2	1.30	0.09
<i>gramineus</i> , variable-leaf pondweed..				1	0.40	0.03
Unidentified.....	44	2.04	0.01	5	0.20	0.01
<i>Acnida altissima</i> , water-hemp.....	691	494.59	2.72	4	0.32	0.02
<i>Sagittaria</i>						
<i>latifolia</i> , duck-potato.....	156	254.41	1.40	11	3.44	0.23
<i>cuneata</i> , wapato.....	1	0.50	t			
Unidentified.....	2	1.31	0.01			
<i>Cephalanthus occidentalis</i> , buttonbush	660	252.88	1.39	30	4.77	0.32
<i>Eragrostis</i>						
<i>hypnoides</i> , teal grass.....	114	188.71	1.04			
Unidentified.....	2	0.40	t			
<i>Triticum aestivum</i> , wheat.....	46	169.90	0.93	1	4.40	0.30
<i>Lemna</i>						
<i>minor</i> , lesser duckweed.....	152	95.91	0.53	8	8.30	0.56
Unidentified.....	2	3.20	0.02			

Table 38.—Continued.

PLANT	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents	Occurrence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents
<i>Spartanium</i>						
<i>curycarpum</i> , giant bur-reed.....	286	60.36	0.33	24	6.57	0.44
Unidentified.....	134	31.74	0.17	16	6.61	0.44
<i>Scirpus</i>						
<i>fluvialis</i> , river-bulrush.....	464	47.97	0.25	46	8.83	0.58
<i>atrovirens</i> , green bulrush.....	3	9.50	0.05			
<i>acutus</i> , hard-stem bulrush.....	171	8.90	0.05	52	14.39	0.97
<i>validus</i> , soft-stem bulrush.....	72	3.58	0.02	27	2.10	0.14
<i>paludosus</i> , alkali bulrush.....	5	3.30	0.02	5	1.80	0.12
<i>americanus</i> , American bulrush.....				5	2.30	0.15
Unidentified.....	2	1.63	0.01	1	0.70	0.05
Algae.....	45	58.29	0.32	9	21.50	1.45
<i>Nelumbo lutea</i> , American lotus.....	43	55.60	0.31	1	1.00	0.07
<i>Quercus</i>						
<i>alba</i> , white oak.....	3	16.90	0.09			
<i>palustris</i> , pin oak.....				1	5.80	0.39
Unidentified acorns.....	8	38.10	0.21	2	12.40	0.83
<i>Fagopyrum sagittatum</i> , common buck- wheat.....	8	37.40	0.21			
<i>Rumex</i>						
<i>altissimus</i> , pale dock.....	62	27.05	0.15	11	11.60	0.78
<i>acetosella</i> , field sorrel.....	1	t		2	t	
Unidentified.....	10	0.08	t	2	0.50	0.03
<i>Bidens</i>						
<i>frondosa</i> , beggar-ticks.....	11	20.68	0.11	3	0.73	0.05
Unidentified.....	29	1.95	0.01	2	0.10	0.01
<i>Ambrosia</i>						
<i>artemisiifolia</i> , common ragweed.....	28	7.94	0.04	5	0.10	0.01
<i>trifida</i> , great ragweed.....	20	7.55	0.04	1	0.20	0.01
<i>psilostachya</i> , western ragweed.....	85	1.07	t	1	t	
Unidentified.....	1	0.65	t			
<i>Najas</i>						
<i>guadalupensis</i> , southern naiad.....	18	14.35	0.08	1	0.50	0.03
<i>flexilis</i> , northern naiad.....	16	1.10	t			
Unidentified.....	3	1.30	0.01			
<i>Eleocharis</i>						
<i>palustris</i> , common spike-rush.....	69	8.44	0.05	11	0.80	0.05
<i>obtusata</i> , blunt spike-rush.....	99	4.22	0.02	20	1.31	0.09
<i>parvula</i> , dwarf spike-rush.....	1	2.00	0.01			
Unidentified.....	8	t				
<i>Heteranthera dubia</i> , mud-plantain.....	5	14.30	0.08			
<i>Juncus</i> , bog-rush.....	24	12.58	0.07			
Bark, roots, and wood.....	8	8.15	0.04	4	1.03	0.07
<i>Ranunculus</i> , buttercup.....	7	8.10	0.04			
<i>Nymphaea tuberosa</i> , yellow water-lily.....	10	6.58	0.04	1	t	
<i>Chenopodium</i>						
<i>album</i> , lamb's-quarters.....	12	6.41	0.04	4	t	
Unidentified.....	1	t				
<i>Alisma subcordatum</i> , water-plantain.....	1	6.20	0.03			
<i>Salix</i> , willow.....	16	6.17	0.03	2	2.60	0.17
<i>Cornus</i> , dogwood.....	75	6.04	0.03	8	0.20	0.01
<i>Lippia lanceolata</i> , fog-fruit.....	219	5.60	0.03	8	0.90	0.06
<i>Vigna sinensis</i> , cow-pea.....	1	5.20	0.03			
<i>Myriophyllum</i>						
<i>heterophyllum</i> , water-milfoil.....	10	0.50	t			
Unidentified.....	60	4.23	0.02	26	2.78	0.19

Table 38.—Continued.

PLANT	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents	Occurrence (Number of Giz- zards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents
<i>Spartina pectinata</i> , prairie cord-grass .	2	4.20	0.02			
<i>Carex</i>						
<i>rostrata</i> , beaked sedge				1	0.10	0.01
Unidentified	33	4.13	0.02	9	3.20	0.22
<i>Lophotocarpus</i>	12	4.10	0.02			
<i>Ipomea hederacea</i> , ivy-leaved morning- glory	35	4.04	0.02	1	t	
<i>Zannichellia palustris</i> , horned pond- weed	5	3.60	0.02			
<i>Sida spinosa</i> , prickly sida	34	3.56	0.02	5	0.20	0.01
Gramineae	2	3.30	0.02			
<i>Paspalum</i>						
<i>ciliatifolium</i> , ciliate-leaved paspalum	2	3.25	0.02	1	1.50	0.10
Unidentified	1	t				
<i>Vitis</i>						
<i>cordifolia</i> , frost grape	4	0.25	t	2	2.50	0.17
Unidentified	56	2.82	0.02	10	17.72	1.19
<i>Potentilla</i> , cinquefoil	1	3.00	0.02			
<i>Digitaria</i>						
<i>sanguinalis</i> , crab-grass	3	2.50	0.01	2	0.30	0.02
<i>ischaemum</i> , smooth crab-grass	4	0.30	t	2	0.50	0.03
<i>Anacharis canadensis</i> , waterweed	1	2.10	0.01			
<i>Panicum</i>						
<i>dichotomiflorum</i> , fall panic-grass . . .	38	1.90	0.01	7	4.90	0.33
<i>capillare</i> , old-witch grass	18	0.11	t	2	t	
Bean, navy	1	1.50	0.01			
<i>Verbena</i>						
<i>hastata</i> , blue vervain	1	0.80	t			
Unidentified	4	0.05	t			
<i>Abutilon theophrasti</i> , velvet-leaf	37	0.83	t	1	0.03	t
<i>Hibiscus</i>						
<i>militaris</i> , scarlet rose-mallow	2	0.50	t	2	t	
Unidentified	5	0.06	t			
<i>Setaria</i>						
<i>italica</i> , German millet	3	6.40	0.04			
<i>glauca</i> , yellow foxtail	17	0.50	t	5	0.10	0.01
<i>viridis</i> , green foxtail	1	t		1	t	
<i>Celtis occidentalis</i> , hackberry	1	0.50	t			
Compositae	1	0.40	t			
<i>Crataegus</i> , hawthorn	2	0.30	t			
<i>Solanum</i> , nightshade	1	0.30	t			
Leguminosae	1	0.30	t			
<i>Rhus</i>						
<i>glabra</i> , smooth sumac	18	0.18	t	7	0.20	0.01
<i>radicans</i> , poison ivy	6	0.10	t	1	t	
Unidentified	1	t		1	t	
<i>Phaseolus</i> , wild bean	1	0.20	t			
<i>Strophostyles</i>						
<i>helvola</i> , trailing wild bean	1	0.10	t			
Unidentified	2	t				
<i>Pontederia cordata</i> , heart-shaped pickerelweed	2	0.08	t			
<i>Cladium mariscoides</i> , twig-rush	16	0.07	t	2	0.04	t
<i>Cassia fasciculata</i> , partridge-pea	1	0.03	t			
<i>Amaranthus</i>						
<i>retroflexus</i> , green amaranth	1	t				
Unidentified	1	0.01	t			

Table 38.—Continued.

PLANT	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Gizzards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents	Occurrence (Number of Gizzards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents
<i>Rubus</i>						
<i>flagellaris</i> , northern dewberry.....	4	0.02	t			
Unidentified.....	5	t				
<i>Ammannia coccinea</i> , tooth-cup.....				4	3.10	0.21
<i>Avena sativa</i> , oats.....	1	t				
<i>Convolvulus arvensis</i> , field-bindweed.....				1	t	
<i>Cuscuta</i> , dodder.....	17	t		3	0.10	0.01
<i>Diodia teres</i> , buttonweed.....	1	t				
<i>Geum</i> , avens.....				1	t	
<i>Phytolacca americana</i> , common pokeweed.....	5	t		1	t	
<i>Portulaca</i> , purslane.....				1	2.30	0.15
<i>Rosa</i> , rose.....	3	t				
<i>Sorghum vulgare</i> , sorghum.....				1	1.40	0.09
<i>Prunus</i> , cherry.....	2	t				
<i>Symphoricarpos orbiculatus</i> , coral- berry.....				3	1.10	0.07
<i>Trifolium</i> , clover.....	1	t				
Unidentified plant.....	73	63 68	0.35	23	18.09	1.22

ones in each of the 3 years of this study; from year to year the relative positions of some of them changed within the group as a result of changes in abundance or accessibility.

Food plants favored by the various species of ducks differed with the feeding habits of the birds. Foods utilized by ducks of the teal size were mainly from small-seeded plants, while those utilized by the mallard were principally from corn and from large-seeded native wild plants. The puddlers fed principally on emergent and moist-soil plants, while the divers fed largely on submergent plants. There were exceptions in each waterfowl group, however, such as the gadwall and the baldpate, which fed primarily on a submergent plant, coontail, and the ring-necked duck and the redhead, which fed extensively on emergent plants.

Of the plants represented in the gizzards collected for this study, 95 native wild plants and 4 domestic plants were identified to species, table 38. The 19 important species listed in table 37 and discussed in the following pages constituted 92.91 per cent of the total plant material. Analyses of gizzard contents showed that the plants increased or decreased in use-

fulness to ducks during the fall season as weather conditions and water levels varied.

Corn *Zea mays*

Corn was the most important food both in volume and in number of duck gizzards in which it was found (occurrences), table 38. It comprised 37.20 per cent of all organic foods in the gizzards, primarily because it was the staple food of the mallard, which made up over 50 per cent of the duck flight. It appeared in 1,445 gizzards, of which 86.92 per cent were mallard and 9.55 per cent were pintail. Of the 26 wood duck gizzards that were collected, 11 contained corn.

Use of this grain depended largely upon the time of corn harvest. In 1939, corn ripened early, and harvesting was well along by October 15; in that year, mallard gizzards collected early in the season were gorged with kernels of waste corn. However, in 1940, corn harvesting did not commence until late in October or early November, and native wild foods appeared in gizzards in large volumes until the waste corn was available. The volume of corn increased from October 16 to De-

ember 15, even though the number of duck gizzards containing corn decreased.

Rice Cutgrass *Leersia oryzoides*

Rice cutgrass, fig. 6, was shown by this study, tables 37 and 38, to be the most important wild native food plant in Illinois during the autumn. This plant was spotty in distribution, but apparently wherever the seeds, rootstocks, and tender shoots were accessible they were avidly

consumed. Pintails and mallards were the most important consumers. As many as 2,000 seeds were taken from a single pintail gizzard.

Plant structures of rice cutgrass, found in 921 duck gizzards, comprised 12.17 per cent of the entire organic contents of the 4,977 gizzards examined. Rice cutgrass provided a good, staple food throughout the fall months. The volume of rice cutgrass structures in gizzards decreased gradually from 16.83 per cent of the plant



Fig. 6.—Rice cutgrass (*Leersia oryzoides*), known also as saw-grass. This plant grows on moist soil in shallow water. Ducks feed on the seeds and rootstocks.

foods in late October to 11.75 per cent in early December.

Marsh Smartweed

Polygonum coccineum

Marsh smartweed, fig. 7, ranked fourth among wild native food plants in percentage of total organic contents of the duck gizzards examined, table 38; it was second among wild plants and third among all plants in the occurrence-percentage index rating, table 37. In the region and years of this study it was an abundant plant, but

in much of the region it was low in seed production. In a few areas where water level conditions were favorable, it produced an abundance of seeds in 1938 and 1939. Because of sporadic seed production (Low & Bellrose 1944:14), this plant varied from year to year in usefulness as a source of duck food. All important species of ducks fed on the seeds, but these seeds seldom made up the bulk of the plant food for any one duck.

Marsh smartweed seeds were found in a large number of gizzards (2,012), but



Fig. 7.—Marsh smartweed (*Polygonum coccineum*), sometimes called redtop because of its pink-red blossoms. When it grows in water 6 to 18 inches deep it produces seed that rates high as duck food.

never in large quantities. Because the seeds drop early in the fall, this smartweed is considered a good early season source of food. In October, this plant represented 5.50 per cent of the plant food but, by early December, only 1.85 per cent. Marsh smartweed rated as an important

baldpate and gadwall were the most avid feeders. During October, when waste corn was scarce, mallards fed extensively on coontail.

Coontail structures, which were found in 809 gizzards, represented 9.03 per cent of the total organic contents of all giz-



Fig. 8.—Coontail or hornwort (*Ceratophyllum demersum*). A favorite food of baldpates, gadwalls, and ring-necked ducks, it grows best in stable or semistable waters that are fairly clear and protected from wave action. Ducks feed principally on the leaves and stems.

waterfowl food plant despite the relatively small quantities of its seed ingested by individual birds.

Coontail

Ceratophyllum demersum

Coontail, fig. 8, which occurred commonly in all stable and semistable water areas involved in the study, ranked second among wild native food plants in percentage of the total organic contents of all duck gizzards examined, table 38, but it rated fourth in the occurrence-percentage index, table 37. Seed production of coontail was low in the years of this study; leaves and stems were the principal structures found in the gizzards. This study showed that all species of ducks of which there was an adequate sample fed upon this plant; the

zards. Analyses showed that utilization of coontail rapidly decreased during the fall season, from 16.84 per cent of the volume of plant foods in October to 2.20 per cent in December. Despite the decrease in volume, coontail appeared to be an important source of food through most of the fall.

Wild Millet

Echinochloa crusgalli

Because some difficulty was experienced in separating the seeds of wild millet from the seeds of Japanese millet, *Echinochloa frumentacea*, undoubtedly some seeds classified as wild millet were those of the Japanese species. However, in the years in which gizzards were collected for this study, the acreage of Japanese millet in Illinois was comparatively small.

Wild millet, fig. 9, ranked third among wild native food plants in percentage of the total organic contents of all duck gizzards examined, table 38. Although its occurrence was spotty in the Illinois and Mississippi river valleys in the years of this study, it ranked fifth in the occurrence-percentage index, table 37. During 1939 and 1940, water level conditions in some areas were very favorable for luxuriant growth and heavy seed production of millets (Bellrose 1941:253). Seeds of the wild millet were found in the gizzards of most ducks and were especially numerous in those of pintails, mallards, and green-winged teals. A few pintail gizzards held as many as 1,000 seeds each, and the craws another 3,500.

Wild millet seeds or other plant parts appeared in 715 gizzards and constituted

6.08 per cent of the total organic contents of the gizzards examined. The heaviest consumption of wild millet occurred in October, when this plant represented 10.76 per cent of the plant foods in the gizzards; the consumption decreased to 3.90 per cent by December, probably as a result of a decline in availability of millet seed and a shift by the mallard and the pintail to a corn diet.

Because the seeds remained on the plants until late fall, wild millet proved to be an excellent source of food for ducks; also, the rank stem growth provided protective cover.

Longleaf Pondweed

Potamogeton nodosus

The longleaf pondweed, fig. 10, is considered one of the good duck food plants

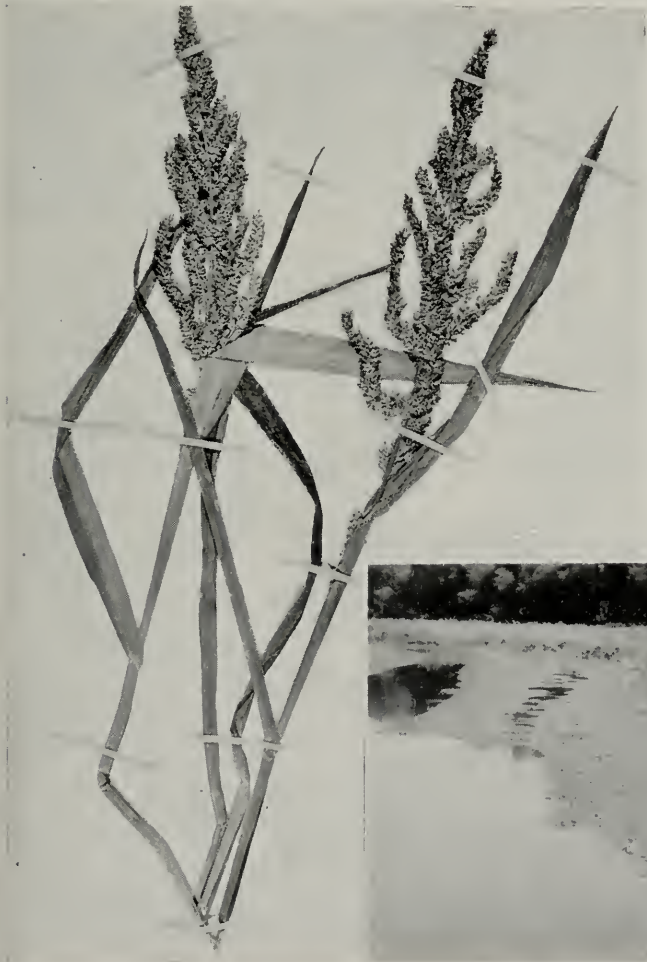


Fig. 9.—Wild millet (*Echinochloa crusgalli*). Known also as barnyard-grass, this moist-soil plant produces seeds that are consumed in large quantities by mallards, pintails, teals, and other ducks. The inset shows wild millet growing on a mud flat from which water has receded. In 1939 and 1940, water levels along the Illinois River were especially favorable for growth and seed production of millets. The millets provide cover as well as food for ducks.

in many parts of the United States. In Illinois, it was present in small amounts in nearly all the river-bottom lakes in the region and years involved in the present study; usually it produced an abundance of seed. In the gizzards of all important species of waterfowl included in this report, the seeds and occasionally the stems or leaves were found.

Longleaf pondweed plant parts, found in 1,274 gizzards, amounted to 1.70 per cent of the total organic contents of all gizzards examined, table 38. It ranked sixth in the occurrence-percentage index, table 37. Apparently, use of this plant varied from one period to another, but at no time did it constitute more than a supplemental food.

Red-Rooted Nut-Grass

Cyperus erythrorhizos

Red-rooted nut-grass, a moist-soil plant that grows on mud flats and mud banks of both the Illinois and Mississippi river valleys, ranked sixth among food plants in percentage of total organic contents of gizzards examined, table 38, and seventh in the occurrence-percentage index, table 37. Because growing conditions were

much better for plants of this type in 1939 and 1940 than in 1938 (Bellrose 1941: 252-3), the volume of seed and its accessibility to ducks was greater. This nut-grass was found in significant amounts in the gizzards of several of the important duck species; it made up the largest percentages of organic material in gizzards of the blue-winged teal, green-winged teal, and shoveler. In most cases, the entire seed head had been clipped off; in other cases, individual seeds had been strained from the bottom ooze or from the water surface. Some pintail gizzards contained amounts estimated at 25,000 seeds each.

This plant was represented in 617 gizzards, table 38, and constituted 3.71 per cent of the plant contents or 3.51 per cent of the total organic contents of all duck gizzards examined. There appeared to be little change in the rate of its utilization as the fall months advanced. This nut-grass appeared to be an excellent all-season duck food.

Water-Hemp

Acnida altissima

Water-hemp, or pigweed, fig. 11, an important moist-soil plant that occurs on



Fig. 10.—Longleaf pondweed (*Potamogeton nodosus*), known also as deer's tongue. Ducks feed on the seeds of this plant.



Fig. 11.—Water-hemp or pigweed (*Acnida altissima*). This plant grows well on mud flats.

ently, the usage of this food plant throughout the fall changed little as long as the seeds were accessible. An early freeze would probably have lessened its use, but the 1938–1940 study did not indicate any decrease in percentage of use as the season progressed. Water-hemp can be considered a good all-fall food for most species of dabbling ducks.

Nodding Smartweed *Polygonum lapathifolium*

Nodding smartweed, fig. 12, grew abundantly along the margins of most Illinois rivers and bottomland lakes in 1938–1940. Gizzard analyses showed that most of the important species of waterfowl fed on the seeds in significant amounts. Seed, produced in abundance, seemed to serve principally as a supplemental food, as it never constituted a complete feeding.

Seeds of nodding smartweed, present in 1,145 gizzards, table 38, constituted 0.92 per cent of the total organic contents of all gizzards examined. The period of



Fig. 12.—Nodding smartweed (*Polygonum lapathifolium*). The long, drooping, densely flowered spikes distinguish this plant from other smartweeds.

mud flats, ditchbanks, and similar areas, is a good source of duck food in seasons favorable to its growth. It ranked eighth in the occurrence-percentage index, table 37. This plant is subject to poor seed yields when growing conditions are unfavorable, such as occurred in 1938 and 1939. In those years, it was represented in only about 1 per cent of the total organic contents of the duck gizzards examined, but in 1940, a year in which beds were abundant and luxuriant, its volume increased to 8.18 per cent. The puddle ducks, especially the mallard, pintail, and both teals, used this plant. It was not uncommon to find 40,000 seeds in a mallard gizzard, or 25,000 to 30,000 in a pintail or teal gizzard. Only the seeds and seed heads of this plant were used.

Water-hemp seeds or seed heads, found in 695 gizzards, table 38, made up 2.52 per cent of the total organic contents of all gizzards included in this study. Appar-

greatest consumption occurred the latter half of October; during the fall the proportion of these seeds in the gizzards dropped from 1.62 per cent to 0.56 per cent of the plant foods.

This smartweed can be considered only a fair source of all-fall food, except lo-



Fig. 13.—Large-seeded smartweed (*Polygonum pensylvanicum*), known also as Pennsylvania smartweed. A moist-soil plant, this smartweed ranked below marsh smartweed and nodding smartweed as an Illinois duck food in the years of this study.

cally where the plant is easily accessible. It ranked ninth in the occurrence-percentage index, table 37.

Buttonbush

Cephalanthus occidentalis

This shrub is very abundant in the valleys of both the Illinois and the Mississippi rivers. Even though its seeds are a fair duck food, the buttonbush is not a desirable plant to have in a waterfowl habitat,

as it tends to crowd out more favorable duck food plants. However, this shrub is less undesirable in a waterfowl habitat than lotus or river bulrush, which have little value as duck food plants. Seeds of the buttonbush were found in small quantities in the gizzards of all important species of dabbling ducks.

Present in 690 gizzards, the seeds of the buttonbush represented 1.31 per cent of the total organic contents of all gizzards, table 38. Throughout the fall season, the percentage of seeds consumed varied very little from week to week. Buttonbush may be considered as a fair supplemental duck food plant, table 37.

Large-Seeded Smartweed

Polygonum pensylvanicum

The large-seeded smartweed, fig. 13, ranked eleventh in the occurrence-percentage index, table 37. Utilization of this plant by ducks in Illinois was subject to change from year to year and place to place and was dependent principally on accessibility. For instance, along the Mississippi River, where this smartweed appeared to be easily accessible during the years of this study, it ranked first among native foods, table 38. The seed was the only part of this plant found in the duck gizzards examined.

Seeds of this smartweed, in 599 gizzards, table 38, made up 1.01 per cent of the entire organic contents of all gizzards. Apparently the seeds were eaten throughout the fall, but were more important in the diet during the latter part of November and December than at other times.

Nut-Grass

Cyperus strigosus

Like the red-rooted nut-grass, this species grows on certain mud flats and other moist areas. It ranked high among the important foods preferred by the pintail, blue-winged teal, and green-winged teal in the years of this study. Apparently both seeds and seed heads were avidly consumed. Some pintail and teal gizzards contained as many as 10,000 seeds each.

Structures of this plant, found in 384 gizzards, constituted 1.58 per cent of the total plant contents and 1.49 per cent of the total organic contents of the gizzards examined, table 38. Apparently heaviest



Fig. 14.—Chufa (*Cyperus esculentus*), one of several nut-grasses that grow on moist soil in Illinois. Ducks feed upon the seeds and tubers.

use of this plant occurred during November, when its principal consumers were most abundant.

As with most moist-soil plants, in years and in places in which the seed was present and accessible, this nut-grass was a good source of waterfowl food during the fall months. It ranked twelfth in the occurrence-percentage index, table 37.

Chufa

Cyperus esculentus

Chufa, fig. 14, occurred rather sporadically on mud flats, ditchbanks, and other moist ground in the areas from which gizzards were collected. It was a preferred food of the blue-winged teal, green-winged teal, and pintail, which consumed seeds, seed heads, and tubers. Several hundred seeds were taken from a few of the teal gizzards.

Structures of this plant were found in 385 gizzards and constituted 1.36 per cent of the total organic contents of the gizzards examined, table 38. As with the other moist-soil plants, chufa received the heaviest use during November. This nut-grass furnished good waterfowl food during the fall months when water conditions made the plants accessible. It ranked third

among nut-grasses in the occurrence-percentage index, table 37.

Walter's Millet

Echinochloa walteri

Although the seeds of Walter's millet, fig. 15, are much smaller than those of the wild millet, they were eagerly consumed by the ducks represented in this study. Walter's millet often volunteers in muck areas generally wetter than those containing wild millet. Seeds of Walter's millet were found in the gizzards of most puddle ducks—in relatively largest amounts in gizzards of the pintail, green-winged teal, and blue-winged teal. The fruit is more



Fig. 15.—Walter's millet (*Echinochloa walteri*), sometimes called corn grass. Its small seeds are consumed in considerable numbers by mallards, pintails, and teals.

persistent than that of the wild millet and is therefore available for waterfowl later in the season.

Walter's millet was represented in 243 stomachs, table 38, and constituted 2.09 per cent of the total organic contents of all gizzards. It is a good source of late-fall waterfowl food. It ranked fourteenth in the occurrence-percentage index, table 37.

Sago Pondweed

Potamogeton pectinatus

Sago pondweed, fig. 16, according to Martin & Uhler (1939) is one of the most important duck food plants in the United States. In 1938-1940, this plant appeared to be relatively unimportant in Illinois; here the plant was spotty in distribution and it produced very little seed (Bellrose 1941:266). Although sago ranked low among the important plants in the present study, table 37, most species of ducks, especially the divers, fed on the limited seed supply, tubers, and leaf structures.

Portions of the plant, found in 630 gizzards, represented only 0.64 per cent of

the total organic contents of all gizzards examined, table 38. In no half-month period did it vary considerably in volume or number of occurrences from the average.

If this plant had been more abundant and if it had produced more seed, it undoubtedly would have ranked much higher in the food preference list.

Duck-Potato

Sagittaria latifolia

The duck-potato, fig. 17, was shown by this study to rank low among the important duck food plants in Illinois, table 37. Although it occurred sparingly in the areas from which gizzards were collected in 1938-1940, it produced a moderate amount of seed (Low & Bellrose 1944:13). Analyses of gizzard contents showed that most species of waterfowl fed on the seeds and tender roots; however, only the large ducks were able to use the tubers. The usefulness of this plant seemed to be partly dependent upon accessibility—on water levels sufficiently high to allow the ducks to feed in the duck-potato beds.

Structures of this plant, found in 167 gizzards, comprised 1.31 per cent of the



Fig. 16.—Sago pondweed (*Potamogeton pectinatus*), known also as teal grass and eel grass. Ducks feed upon its seed, foliage, and tubers.



Fig. 17.—Duck-potato (*Sagittaria latifolia*), known also as arrowhead, wapato, or boot-jack. Ducks value it more for its seed than for its tubers.

total organic contents of the gizzards collected for examination, table 38. The plant apparently increased in duck food value as the fall season waned. In October, it represented less than 1 per cent of the plant contents of gizzards, but 3 per cent by December. This plant may be considered a fair duck food throughout the fall, increasing in importance as the season advances.

River-Bulrush

Scirpus fluviatilis

River-bulrush seeds occurred in about one-tenth of the duck gizzards collected in 1938–1940 from areas along the Illinois and Mississippi rivers, table 38. The total quantity of river-bulrush seeds was only 0.29 per cent of all the organic food.

The number of gizzards in which river-bulrush seeds were found (510) is considered large in view of the fact that seed production of this plant is poor in Illinois (Bellrose & Anderson 1943:430). Evidently the seeds are very palatable.

Teal Grass

Eragrostis hypnoides

Teal grass was found to be another moist-soil plant that ranked among the

important sources of duck food in the period of this study, table 37. Under certain conditions, when water levels were sufficiently high to flood the plants growing along ditchbanks and mud flats, it ranked much higher than when conditions were less favorable. It appeared among the important native foods because of large numbers of seeds consumed by a relatively small number of ducks. The green-winged teal, blue-winged teal, and pintail fed more upon this plant than did other species of ducks.

Seeds of teal grass, found in 114 gizzards, constituted 0.96 per cent of the total organic contents, table 38. After November 15, utilization of this plant rapidly decreased. The drop was due partly to ice fringes that prevented ducks from having access to the seeds and partly to a decrease in numbers of the ducks that were the principal consumers of these seeds. Teal grass may be considered a fair source of early-fall food but a poor source of late-fall food.

Giant Bur-Reed

Sparganium eurycarpum

Giant bur-reed occurred in small beds scattered among the bottomland lakes of the Illinois River valley in the years gizzards were collected for this study. Despite the very limited occurrence of giant bur-reed, a comparatively large number of gizzards, 286 from the Illinois River valley and 24 from the Mississippi River valley, contained seeds of this plant, table 38. The high rate of utilization indicates that ducks found the nutlike seeds of the giant bur-reed very palatable, but that the small quantity available limited the importance of giant bur-reed, which ranked last among the 19 most important plants, table 37.

ANIMAL FOODS

This study indicated that animal foods were not important in the diet of most species of waterfowl migrating through Illinois in the autumns of 1938, 1939, and 1940, although impressive numbers of animal groups were found in the gizzards collected. The lesser scaup duck, ring-necked duck, shoveler, blue-winged teal, and green-winged teal were among the

Table 39.—The most important animal foods of ducks taken along the Illinois River, Ottawa to Florence (4,505 gizzards), and along the Mississippi River, Rock Island to Quincy (472 gizzards), 1938–1940.

ANIMAL	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Gizzards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents	Occurrence (Number of Gizzards)	Volume (Cubic Centi- meters)	Per Cent of Organic Contents
TOTAL ANIMAL.....		941.57	5.18		143.24	9.64
BRYOZOA, moss animals.....	136	9.97	0.05			
MOLLUSCA						
GASTROPODA, snails						
<i>Stagnicola</i>	3	5.70	0.03			
<i>Planorbis</i>	2	1.50	0.01	2	t	
<i>Helisoma</i>	3	1.17	0.01			
<i>Gyraulus</i>	7	0.58	t			
<i>Carinifex</i>	1	0.40	t			
<i>Physa</i>	7	3.40	0.02	1	t	
<i>Viviparus</i>	2	4.90	0.03	1	0.20	0.01
<i>Campeloma</i>	26	34.20	0.19	9	11.80	0.79
<i>Lioplax</i>	8	3.25	0.02	2	1.80	0.12
<i>Annicola</i>	45	43.15	0.24	10	13.80	0.93
<i>Flummicola</i>	4	5.50	0.03	3	3.10	0.21
<i>Somatogyrus</i>	3	0.90	t	1	0.80	0.05
<i>Pleurocera</i>	16	5.50	0.03	2	0.30	0.02
<i>Neritina</i>	2	2.50	0.01			
Unidentified Gastropoda.....	167	143.49	0.79	12	10.78	0.72
PELECYPODA, mussels						
Sphaeriidae						
<i>Pisidium</i>	15	17.70	0.10	4	5.90	0.40
<i>Musculium</i>	20	27.50	0.15	1	2.70	0.18
<i>Sphaerium</i>	45	94.50	0.52	11	16.20	1.09
Unidentified Sphaeriidae.....	6	23.30	0.13	4	13.70	0.92
Unionidae, fresh-water clams.....	9	10.80	0.06	9	4.89	0.33
Unidentified Pelecy-poda.....	28	17.64	0.10	2	2.80	0.19
UNIDENTIFIED MOLLUSCA.....	81	48.94	0.27	13	18.50	1.24
ARTHROPODA						
CRUSTACEA						
Branchiopoda.....	3	1.40	0.01			
Copepoda.....	9	4.30	0.02			
Ostracoda.....	105	4.20	0.02			
Malacostraca.....	27	18.91	0.10	2	2.50	0.17
INSECTA						
Orthoptera.....	3	0.52	t	1	t	
Neuroptera, hellgrammites.....	1	0.50	t			
Ephemeroptera, mayflies						
<i>Hexagenia</i>	80	31.25	0.17	29	13.68	0.92
<i>Caenis</i>	2	0.10	t			
Odonata						
Anisoptera, dragonflies.....	9	2.80	0.02	4	2.10	0.14
Zygoptera, damselflies.....	17	14.00	0.08	1	t	
Unidentified Odonata.....	6	3.60	0.02			
Homoptera						
Cicadellidae, leafhoppers.....	3	0.20	t	1	t	
Hemiptera						
Corixidae, water boatmen.....	329	128.52	0.71	37	4.33	0.29
Notonectidae, backswimmers.....	2	0.30	t			
Nepidae, waterscorpions.....	2	0.80	t			
Belastomatidae, water bugs.....	22	17.73	0.10	1	0.12	0.01
Gerridae, water striders.....	2	0.20	t			
Miridae, <i>Lygus</i> , plant bugs.....	1	t		1	0.02	t
Lygaeidae, chinch bugs.....	1	t		1	0.03	t

Table 39.—Continued.

ANIMAL	ILLINOIS RIVER			MISSISSIPPI RIVER		
	Occurrence (Number of Gizzards)	Volume (Cubic Centimeters)	Per Cent of Organic Contents	Occurrence (Number of Gizzards)	Volume (Cubic Centimeters)	Per Cent of Organic Contents
Coreidae, squash bugs.....				1	0.12	0.01
Pentatomidae, stink bugs.....	3	0.40	t			
Unidentified Hemiptera.....	5	0.57	t			
Coleoptera						
Carabidae, ground beetles.....	46	1.32	0.01	8	0.12	0.01
<i>Omophron</i>				1	0.20	0.01
Halipidae.....	3	0.17	t			
Dytiscidae, diving beetles.....	227	23.97	0.13	8	0.35	0.02
Gyrinidae, whirligig beetles....	8	0.37	t	1	0.10	0.01
Hydrophilidae, water scavenger beetles.....	6	0.90	t	4	6.00	0.40
Staphylinidae, rove beetles.....	6	0.29	t			
Puprestidae, fatheaded wood borers.....	1	t				
Drvipidae.....	1	t				
Elmidae.....	2	t				
Scarabaeidae, scarab beetles....	6	0.86	t	3	0.27	0.02
Chrysomelidae, leaf beetles.....	12	0.50	t			
Curculionidae, snout beetles....	17	2.90	0.02	3	0.20	0.01
Unidentified Coleoptera.....	6	0.55	t			
Trichoptera, caddisflies						
Hydroptilidae.....	132	5.99	0.03	1	t	
Hydropsychidae.....	13	11.66	0.06			
Unidentified Trichoptera.....	19	2.25	0.01			
Lepidoptera	4	0.39	t	1	0.09	0.01
Diptera, flies						
Chironomidae, midges.....	238	127.61	0.70	10	4.70	0.32
Tabanidae, horse flies.....	2	0.50	t			
Anthomyiidae.....	1	0.09	t	1	0.20	0.01
Unidentified Diptera.....	14	5.63	0.03	3	0.10	0.01
Hymenoptera						
Ichneumonidae, ichneumons....	3	0.05	t			
Tiphiidae, <i>Tiphia</i> , tiphid wasps	2	0.10	t			
Formicidae, ants.....	6	0.10	t	2	0.08	t
Unidentified Hymenoptera.....	1	0.96	t			
Unidentified Insecta.....	15	5.09	0.03			
ARACHNIDA	21	0.72	t	7	0.14	0.01
ACARINA, water mites	75	0.37	t			
CHORDATA						
PISCES, fish	18	0.72	t	1	t	
AMPHIBIA, frogs	1	1.00	t			
UNIDENTIFIED ANIMAL	4	0.80	t	2	t	
NONFOOD						
PARASITIC WORMS	1	0.20	t			
FEATHERS	83	8.72	0.05	8	0.52	0.03

species that were the principal consumers of animal foods.

Animal parts constituted 5.52 per cent of the organic contents of all waterfowl gizzards collected in the years of the study. The two outstanding animal groups were mollusks and insects, table 39. The former comprised 55.66 per cent of the total

animal foods and the latter 39.32 per cent. Crustaceans comprised 2.89 per cent of the animal foods.

Mollusca

Snails comprised 49.47 per cent of the Mollusca and 27.54 per cent of the animal foods, while mussels constituted 39.36

per cent of the Mollusca and 21.90 per cent of the animal foods, table 39.

Fresh-water snails found in the largest numbers of duck gizzards were *Ammicola*, *Campeloma*, and *Pleurocera*. Fragments of a brackish water snail, *Neritina*, were found in two gizzards. The mussels identified were of no commercial use; most of them were small and thin shelled. Genera represented included *Sphaerium*, *Pisidium*, and *Musculium*.

Insecta

The insects represented 2.17 per cent of the total organic foods and 39.32 per cent of the total animal foods in the gizzards examined, table 39. Many species of insects were represented in gizzards collected prior to November 15, but after this date the volume and the number of species of insects decreased. This decrease was due in part to a decline in the populations of ducks that feed upon insects and in part to a decline in the number of insects available.

Among the insect material found in greatest volume in the duck gizzards were Odonata nymphs, midge larvae, mayfly nymphs, fig. 18, caddisfly larvae, and water boatmen.

Crustacea

In the duck gizzards collected, Crustacea constituted only a small portion of the animal foods, table 39; in greatest volume were the crayfish (Malacostraca). The minute forms appeared in many gizzards but in negligible volumes; among them were water fleas (Branchiopoda), amphipods and pillbugs (Malacostraca), and ostracods.

Bryozoa

These small animal forms appeared most often as traces in the duck gizzards collected. The winter buds or statoblasts of *Pectinatella* and *Plumatella* probably had been eaten along with other foods.

Amphibia

Frog bones appeared in only one gizzard.

Arachnida

A few spiders and water mites were found in the contents of the gizzards col-



Fig. 18.—Mayfly nymph of the genus *Hexagenia*. This is one of the animal foods consumed by ducks that migrate through Illinois in autumn.

lected; they were not considered important waterfowl foods.

Pisces

Fish vertebrae and scales were occasionally found in the duck gizzards collected. Mallards and black ducks have been known to feed extensively on gizzard shad, *Dorosoma cepedianum*.

GRIT

Generally grit is considered to have two functions in avian nutrition: (1) assisting the gizzard in the grinding of food and (2) furnishing necessary minerals for metabolism and reproduction (Nestler 1946: 137). Because grit invariably appeared in the gizzards examined in the present study, it seems reasonable to conclude that adequate supplies of hard, nonfriable particles were available to waterfowl in the Mississippi Flyway. Experiments with captive wild mallards have shown, moreover, that the grit demands of waterfowl may be low even in areas of grit abundance. When supplied with granite grit, each of 30 mallards under observation at the Havana laboratory of the Illinois Natural History Survey took an average of slightly less than one piece per day for a period of 14½

Table 40.—Grit contents of duck gizzards collected in Illinois, 1938–1940.

SPECIES	AVERAGE GIZZARD CAPACITY (CUBIC CENTIMETERS)	AVERAGE GRIT CONTENTS PER GIZZARD (CUBIC CENTIMETERS)	AVERAGE PER CENT OF GIZZARD CAPACITY OCCUPIED BY GRIT
Mallard.....	16.0	2.95	18.44
Pintail.....	14.0	2.31	16.50
Baldpate.....	13.0	2.87	22.08
Gadwall.....	14.0	3.85	27.50
Wood duck.....	9.0	1.91	21.22
Green-winged teal.....	3.5	0.83	23.71
Blue-winged teal.....	3.7	0.40	10.81
Shoveler.....	6.0	1.71	28.50
Canvasback.....	14.5	3.01	20.76
Redhead.....	14.0	2.78	19.86
Lesser scaup.....	5.7	1.00	11.76
Ring-necked duck.....	8.5	1.53	18.00

months. Though additional grit was easily available, some mallards retained the same particles for as long as 7½ months.

Evidence of the ability of ring-necked pheasants and bobwhites to retain grit in their gizzards for 6 weeks or more has been presented by Gerstell (1942:72–9) and Nestler (1946:141). Grit as a grinding agent in the gizzards of the bobwhite quail, *Colinus virginianus*, was not essential for growth, health, or reproduction, Nestler found.

In gizzards collected for the present study, grit occupied an average of 10.81 to 28.50 per cent of the gizzard capacity in the various species of ducks, table 40. The data indicate no correlation between amount of grit and size of duck, type of food (plant or animal), type of feeder (puddler or diver), or feeding habitat.

Grit in the gizzards collected for the present study was composed principally of rough, angular particles of quartz and chert and some limestone. Particles were

Table 41.—The number of ducks of various species represented by gizzards collected in Illinois in 1938–1940 and the number of these gizzards that contained lead shot pellets, some worn (ingested) and some unworn (embedded).

SPECIES	NUMBER OF GIZZARDS EXAMINED	NUMBER OF GIZZARDS WITH SHOT	NUMBER OF PELLETS		
			Worn	Unworn	Total
Mallard.....	2,825	250	404	140	544
Pintail.....	881	71	104	42	146
Baldpate.....	160	4	3	3	6
Gadwall.....	98	2		2	2
Wood duck.....	26				
Green-winged teal.....	393	5	66	4	70
Blue-winged teal.....	129	3	1	2	3
Shoveler.....	62				
Canvasback.....	28	4	9		9
Redhead.....	14	2	5	1	6
Lesser scaup.....	220	43	450	19	469
Ring-necked duck.....	120	22	129	19	148
Black duck.....	11	3	6		6
Ruddy duck.....	5				
Common goldeneye.....	3				
Greater scaup.....	1				
Oldsquaw.....	1				
Total.....	4,977	409*	1,177	232	1,409

*Of these gizzards, 190 represented ducks in which shot had entered the gizzards at the time the birds were killed. The other 219 represented ducks that had ingested shot.

measured in millimeters across the widest dimension regardless of the shape. These varied from minute to 19 mm. in size; most of them were under 2 mm. Grit in mallard, pintail, ring-necked duck, and lesser scaup gizzards consisted mostly of stones over 3 mm. in size. Baldpate and gadwall gizzards seldom contained gritty material larger than sand particles. Teal and shoveler gizzards seldom contained stones over 2 mm.

The frequency with which sand occurred to the exclusion of stones in the baldpate and gadwall gizzards suggests a relationship between the food habits and physical composition of the grit ingested by these species. Baldpates and gadwalls generally feed on soft, leafy aquatic plants, which are likely to require little or no grinding during the digestive processes, and the sand recovered from the gizzards

of these ducks may have been taken only because it adhered to the food; or it may have been unintentionally taken during normal feeding activity.

Shell fragments, rather than stones, were found in the gizzards of many lesser scaups, ring-necked ducks, redheads, goldeneyes, and shovelers. Many other particles classified as inorganic material were found in the gizzards examined. Fossil fragments of crinoid stems, wood, coral, and brachiopod shells were not uncommon. Muskrat and fish teeth were numerous. Most of these items were rough and angular, serving as excellent grinding agents.

LEAD SHOT

Lead shot pellets were found in the gizzards of most of the species of ducks included in this study, table 41. Some of

Table 42.—The number of duck gizzards collected in Illinois in each of 3 years, the number and percentage of these that contained lead shot pellets, and the number of pellets per gizzard among the gizzards that contained lead.

YEAR	NUMBER OF GIZZARDS EXAMINED	NUMBER OF GIZZARDS WITH SHOT	PER CENT OF GIZZARDS WITH SHOT	TOTAL NUMBER OF PELLETS	NUMBER OF PELLETS PER GIZZARD WITH SHOT
1938.....	1,814	159	8.8	998	6.3
1939.....	2,291	191	8.3	332	1.7
1940.....	872	59	6.8	79	1.3
Total.....	4,977	409*	.....	1,409	.....

*Of these gizzards, 190 represented ducks in which shot had entered the gizzards at the time the birds were killed. The other 219 represented ducks that had ingested shot.

Table 43.—The number of duck gizzards collected in Illinois by 2-week periods, 1938-1940, the number and percentage of these that contained lead shot, and the number of worn (ingested) pellets per gizzard among the gizzards that contained lead.

PERIOD	NUMBER OF GIZZARDS EXAMINED	NUMBER OF GIZZARDS WITH SHOT	PER CENT OF GIZZARDS WITH SHOT	NUMBER OF WORN PELLETS	NUMBER OF WORN PELLETS PER GIZZARD WITH SHOT
October					
15-30.....	1,607	89	5.5	84	0.94
November					
1-15.....	1,466	101	6.9	297	2.9
November					
15-30.....	1,424	185	13.0	746	4.0
December					
1-15.....	480	34	7.1	50	1.5
Total.....	4,977	409*	.....	1,177	.....

*Of these gizzards, 190 represented ducks in which shot had entered the gizzards at the time the birds were killed. The other 219 represented ducks that had ingested shot.

these pellets had been ingested by ducks in their feeding and some had become lodged in the gizzards at the time the birds were killed.

The lining of many gizzards containing lead shot was dark green in color. Any duck from which a gizzard of this color had been taken was considered to have been sick before it was shot.

Water levels and firmness of lake or marsh bottoms are among the factors that determine the accessibility and availability of lead shot to waterfowl (Bellrose 1959:249). Although the percentage of gizzards containing lead pellets did not vary greatly from year to year for the 3-year period of the study, the average number of pellets per gizzard changed materially, table 42.

Probably the lead shot was consumed in the season it was deposited rather than in a subsequent season (Bellrose 1959:266). The gizzard contents showed an increase in percentage of gizzards with lead shot as well as an increase in the number of pellets per gizzard as the autumn progressed, table 43.

SUMMARY

1. In the autumns of 1938, 1939, and 1940, duck gizzards totaling 4,977 were collected from hunting clubs and individual hunters at 21 sites along the Illinois River between Ottawa and Florence and 11 sites along the Mississippi River between Rock Island and Quincy. The following 17 duck species were represented: mallard, pintail, green-winged teal, blue-winged teal, baldpate, gadwall, shoveler, black duck, wood duck, lesser scaup, ring-necked duck, redhead, canvas-back, ruddy duck, greater scaup, common goldeneye, and oldsquaw.

2. Analyses of the gizzard contents were made in accordance with the procedure instituted and followed by the U. S. Fish and Wildlife Service, Department of the Interior.

3. The analyses indicated that, during the fall, most species of ducks in Illinois are predominantly vegetarians, that most of them feed principally on native wild plants, and that the lesser scaup is the only species with a diet predominantly animal.

4. Corn made up nearly half of the organic contents of mallard gizzards. Native wild foods were present in relatively greater quantities in gizzards of the wood duck, pintail, redhead, baldpate, green-winged teal, and ring-necked duck, all of which included corn in their diets.

5. Of the 95 wild plants and 4 cultivated plants found in the gizzards and identified to species, the following 19 were most important: corn, rice cutgrass, marsh smartweed, coontail, wild millet, longleaf pondweed, red-rooted nut-grass, water-hemp, nodding smartweed, buttonbush, large-seeded smartweed, nut-grass, chufa, Walter's millet, sago pondweed, duck-potato, river-bulrush, teal grass, and giant bur-reed.

6. The relative positions of the important food plants changed from year to year as accessibility and availability varied.

7. The importance of a plant species to a species of duck depended on the size of the duck and the type of feeding habitat frequented by the duck.

8. The dabbling ducks fed primarily on emergent and moist-soil plants and the diving ducks more frequently on submergent plants. Animal foods were more important to diving ducks than to dabbling ducks.

9. Snails and mussels provided the largest animal food volume and occurred in the largest number of gizzards. Insects were second in volume and occurrence.

10. Grit constituted about 11 to 28 per cent of the gross contents of the gizzards of various duck species. Most of the stones were less than 2 mm. in size; the sizes ranged from minute to 19 mm. in size (largest dimension).

11. More than 200 of the gizzards examined contained lead shot pellets that had been ingested.

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ILLINOIS NATURAL HISTORY SURVEY
Bulletin

Printed by Authority of
the State of Illinois



Hook-and-Line Catch
in Fertilized and
Unfertilized Ponds

DONALD F. HANSEN
GEORGE W. BENNETT
ROBERT J. WEBB
JOHN M. LEWIS

STATE OF ILLINOIS • WILLIAM G. STRATTON, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION • VERA M. BINKS, *Director*
NATURAL HISTORY SURVEY DIVISION • HARLOW B. MILLS, *Chief*

ILLINOIS NATURAL HISTORY SURVEY

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This paper is a contribution from the Section of Aquatic Biology.

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Hook-and-Line Catch in Fertilized and Unfertilized Ponds

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EXPERIMENTS carried on in the United States during the past 30 years have shown that the total weight of fish in a pond, that is, the standing crop, may be increased two to six times through the use of fertilizers (Davis & Wiebe 1931; Smith & Swingle 1939; Smith & Moyle 1945; Surber 1945, 1948*b*; Swingle 1947; Ball 1949; Ball & Tait 1952).

These experiments have quite naturally led to the speculation that fertilization is a means of improving hook-and-line fishing. While the practice of fertilizing ponds has been widely recommended to pond owners, few attempts have been made to measure the effect of fertilization on angling results. In published studies of angling in ponds (King 1943; Swingle 1945; Smith 1952, 1954) results have been inconclusive with respect to the effect of fertilization on catch of fish per hour.

Studies of the effects of fertilization on aquatic plant life, on animals eaten by fish, and on fish crops have been reviewed by Neess (1949), Maciolek (1954), and Mortimer & Hickling (1954).

The objective of the pond fertilization experiment reported in this paper was to measure the effect of certain fertilization practices on sport fishing for largemouth bass, *Micropterus salmoides* (Lacépède), and bluegills, *Lepomis macrochirus* Rafinesque, in small ponds located in a region of relatively unproductive soils. From catch records gathered over a 6-year period, 1947-1952, from three fertilized ponds and three unfertilized or control ponds, we have been able to compare the sizes of the fish caught, the annual hook-and-line yields, and the catch rates in terms of fish per fisherman-hour. The six ponds used in the experiment are lo-

cated at the University of Illinois College of Agriculture Dixon Springs Experiment Station in Pope County, southern Illinois.

The methods of stocking and fertilizing were, in part, variations of those first proposed by Swingle & Smith (1941:224-5, 1942:12-3, 16-8). Recommendations of Swingle & Smith for minimum fertilization were followed closely during the last 2 years of the 6-year study.

A census of the fish population of each of the ponds was made in the fall of 1953. In the census operations all fish in the ponds were killed with rotenone so that we were able to compare standing crops of fishes in the ponds that had been treated with fertilizer for an extended period (7 years) with the standing crops in the ponds that had not been treated with fertilizer. In addition, we were able to compare the standing crop of fishes in each pond with the hook-and-line fish yields and catch rates recorded during the last 3 years of angling.

Published data on angling success in ponds stocked with only largemouth bass and bluegills are scarce. The present study demonstrates the value of this popular combination of fishes, as well as the effect of fertilization, in southern Illinois ponds.

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*Robert J. Webb is Superintendent and John M. Lewis is Assistant Superintendent of the University of Illinois College of Agriculture Dixon Springs Experiment Station.

Lawrence B. Miller, Roger H. Bray, Russell T. Odell, Herman L. Wascher, J. B. Fehrenbacher, and the late Robert F. Fuellenman. H. W. Norton, Professor of Agricultural Statistical Design and Analysis, Animal Science Department, has examined the data and has verified certain conclusions reached in this study.

Water samples from the experimental ponds were analyzed by T. E. Larson of the Illinois Water Survey. Fishing boats were provided by the Illinois Department of Conservation through the courtesy of Sam A. Parr, formerly Superintendent of the Division of Fisheries, now Administrative Assistant. Help with fertilizing the ponds or with the rotenone census was given by R. Weldon Larimore, William N. Nuess, Robert Crompton, and the late Dan Avery, employed by the Illinois Natural History Survey, and by Ray Brown, Guy Bellamy, Leonard Durham, and Oliver Dick, employed by the Department of Conservation.

Charles Stubbs in 1947, Maurice G. Kellogg in 1948, 1949, and 1950, Stacy Gebhards in 1951, and Charles R. Peters in 1952 served as test anglers. The photograph for the frontispiece and the aerial photographs were made by Charles Scott, formerly employed by the Illinois Natural History Survey and now picture editor of the *Milwaukee Journal*. The other photograph was taken by George W. Bennett. The manuscript was read by William C. Starrett and edited by James S. Ayars and Mrs. Diana R. Braverman, all of the Illinois Natural History Survey staff.

EXPERIMENTAL PONDS AND THEIR WATERSHEDS

The ponds selected for use in this experiment—Lauderdale, Hooker, Phelps, Wells, Boaz, and Elam, figs. 1-6—are stock-watering ponds built at the Dixon Springs Experiment Station in the period 1935-1940. All have earthen dams. All are fenced and, during the years of the experiment, cattle seldom had access to them. They are all within a 2-mile radius of the Experiment Station headquarters.

In September, 1951, at a time when these ponds were full of water, they ranged in surface area from 0.92 to 1.55

acres, and from 8.5 to 15.0 feet in maximum depth, table 1. Since the only source of water for the ponds was surface runoff, there was always a reduction in water area and in depth during dry weather of late summer. Presumably these water level reductions varied in the six ponds in accordance with relative size of drainage areas, number of domestic animals using the water, shape of the pond basins, and rates of runoff, evaporation, and underground seepage. In the fall of 1953, after one of the driest summers on record, the reduction in surface area of the various ponds ranged from 13 per cent in one pond to 49 per cent in another, table 1. There was little difference between the late summer levels of 1953 and those of 1952, another dry year. We have estimated from general observations that late summer water levels in 1952 and 1953 were 1 to 2 feet lower than those of most other years represented in this study. Although in 1953 Wells Pond showed the greatest reduction in surface area, in most years Phelps Pond showed the greatest reduction.

The test anglers made weekly measurements of surface water temperatures through the summers of 1947 and 1948. Temperatures above 90 degrees F. were rarely encountered in the series of weekly readings. The maximum surface temperature reading at any of the ponds was 94 degrees, observed at Boaz Pond, first on July 29 and again on August 5, 1947, and at Phelps Pond on July 12, 1948.

Temperature measurements made at 2-foot depth intervals on August 12, 13, and 14, 1947, table 2, showed marked thermal stratification in five of the six ponds.

Chemical analyses of water from the ponds, table 3, were made from samples collected March 19, 1947, before the fertilization experiment was begun. The watersheds of all of these ponds had been fertilized prior to the time the water analyses were made, but Lauderdale Pond was the only one that had received direct fertilization. Before the experiment reported here was planned, this pond had been treated on two occasions in an attempt to improve fishing: on August 17, 1945, with 80 pounds of ammonium sulfate, 32 pounds of 63 per cent superphos-



Fig. 1.—Aerial view of Lauderdale Pond, 0.9 acre, October, 1950. The fields on two sides of the pond had been plowed and reseeded a few weeks before the picture was made.



Fig. 2.—Aerial view of Hooker Pond, 1.33 acres, October, 1950.

Table 1.—Depth and area of each of the six Dixon Springs ponds used in fertilization study, as observed at full stage in September, 1951, and at the time of the rotenone census, September, 1953. The levels observed in 1953 were probably as low as or lower than any levels that occurred during the fishing period.

POND	FULL STAGE, SEPTEMBER, 1951		LOWEST OBSERVED DROUGHT STAGE, SEPTEMBER, 1953		REDUCTION IN AREA, PER CENT
	Depth in Feet	Area in Acres	Depth in Feet	Area in Acres	
FERTILIZED					
Lauderdale.....	11.5	0.92	9.8	0.76	17
Hooker.....	14.0	1.33	10.6	1.03	23
Phelps.....	8.5	1.04	4.5	0.70	33
UNFERTILIZED					
Wells.....	15.0	0.97	12.0	0.49	49
Boaz.....	10.5	1.01	6.8	0.66	35
Elam.....	9.0	1.55	6.8	1.35	13

phate, and 25 pounds of ground limestone; and on September 8, 1945, with 80 pounds of ammonium sulfate, 100 pounds of 20 per cent superphosphate, and 25 pounds of ground limestone.

An unusual characteristic of the Dixon Springs ponds was their relatively low total hardness; according to T. E. Larson, Illinois Water Survey, these waters are among the softest surface waters in Illinois.

Under the crop rotation systems followed by University of Illinois agronomists at the Dixon Springs Experiment Station, the fields surrounding the ponds were kept in pasture most of the time. New rotations were begun on the watershed of each of these ponds within the

period of the study: Phelps in 1948, Hooker in 1949, Wells and Lauderdale in 1950, Boaz (east half) in 1949, Boaz (west half) in 1951, and Elam in 1952. In each pasture reseeded, winter wheat or rye was planted with various grasses in the fall of the year, while legumes were broadcast the following spring. Corn was planted in the spring prior to the fall seeding on the Boaz west field in 1951 and on the Elam watershed in 1952.

Until dense pasture growth was re-established, silt from the fields was washed into the ponds after each hard rain. Silting occurred even though grass buffer strips surrounded the ponds.

The Dixon Springs Experiment Station lies in an unglaciated region where the

Table 2.—Water temperature (in degrees F.) measured at 2-foot intervals and on bottom in the six Dixon Springs ponds, August 12-14, 1947.

DEPTH IN FEET	LAUDERDALE (DEPTH 8 FEET)* AUGUST 12	HOOKER (DEPTH 10 FEET)* AUGUST 12	PHELPS (DEPTH 5 FEET)* AUGUST 13	WELLS (DEPTH 10 FEET)* AUGUST 12	BOAZ (DEPTH 8½ FEET)* AUGUST 13	ELAM (DEPTH 6 FEET)* AUGUST 14
Surface.....	89.2	85.8	86.4	87.1	86.0	83.1
2.....	84.6	83.1	83.1	85.6	82.0	83.1
4.....	83.1	82.8	81.7	84.9	72.7	84.2†
6.....	77.7	80.6	.....	75.6	66.9	82.4
8.....	72.0	72.7	.....	72.7	64.8	.....
Bottom.....	72.0	68.0	78.4	68.7	64.4	82.4

*Depth of water at point of temperature readings, not necessarily the greatest depth in the pond at the time. The bottom reading is for this depth. Examples: The bottom reading for Lauderdale is for a depth of 8 feet; the bottom reading for Hooker is for a depth of 10 feet.

†This figure probably represents an error in recording.



Fig. 3.—Aerial view of Phelps Pond, 1.04 acres, October, 1950. Exposed mud flats resulting from loss of water may be seen around the margin of the pond.



Fig. 4.—Aerial view of Wells Pond, 0.97 acre, October, 1950. The cypress trees in the water and the pines in the fenced area surrounding the pond had been planted.

Table 3.—Mineral composition (parts per million) of water collected from the six Dixon Springs ponds on March 19, 1947, prior to fertilization.

MINERAL	LAUDER-DALE*	HOOKE* [*]	PEHELPS*	WELLS	BOAZ	ELAM
Iron—filtered.....	0.3	0.3	0.6	0.3	1.7	0.7
Iron—unfiltered.....	0.6	0.4	1.1	0.5	2.8	1.0
Phosphate†.....	0.2	0.2	0.2	0.3	0.8	0.6
Calcium.....	8.1	6.0	8.8	6.6	7.0	7.6
Magnesium.....	1.3	0.2	0.4	0.0	0.0	0.0
Sodium and potassium.....	1.8	4.6	0.0	0.9	4.4	3.4
Sulfate.....	11.7	10.5	8.2	7.0	12.3	10.1
Nitrate‡.....	1.0	0.4	0.5	0.5	2.0	0.8
Chloride.....	1.0	5.0	2.0	2.0	3.0	3.0
Methyl orange alkalinity.....	16.0	8.0	12.4	8.0	9.0	12.0
Total hardness.....	26.0	16.0	24.0	16.0	18.0	19.0

*Pond selected for fertilization.

†As orthophosphate PO_4 (includes organic phosphorus).

‡Includes N in the form of ammonia and nitrate but not in the form of nitrite or as organic nitrogen.

terrain is a mixture of gently rolling land and steep hills. Numerous sandstone outcrops are present. The region was completely forested at the time of settlement, and considerable woodland still exists. During the many decades in which the cleared land was used extensively for growing corn and wheat, most of the slopes suffered from erosion. With the recent trend toward permanent pastures or crop rotations that include pasture, the rate of erosion on slopes has been greatly retarded.

The level of productivity of a fish pond and its capacity for providing good fishing are generally assumed to be determined to a great extent by the level of plant nu-

trients in the soils of the pond bottom and of the watershed. In common with soils over most of Pope County, those at the Experiment Station have low natural fertility. Recent tests of soils in Pope and Hardin counties showed 96 per cent of the samples deficient in available phosphorus (Thor & Jacob 1955). The soils on the watersheds of the ponds used in the pond fertilization study belong to two soil types. Grantsburg silt loam covers the hilltops and lesser slopes, and Manitou silt loam covers the steeper slopes (Fehrenbacher 1959).

These soil types, which are closely related, are described by Fehrenbacher (1959) as grayish yellow or brownish

Table 4.—Available phosphorus and potassium (as pounds per acre in the upper 6 2/3 inches of soil) and the pH of soils of the fields draining into four of the six Dixon Springs ponds. The ratings, such as "high," are based on a system used by the University of Illinois Soil Testing Laboratory.

NAME OF POND WATERSHED	MOST RECENT YEAR OF SOIL TREATMENT PRECEDING SOIL TEST*	DATE OF SOIL SAMPLE	POUNDS PER ACRE		pH
			Available Phosphorus	Available Potassium	
Phelps....	1948	January 6, 1957	66 (Medium to high)	187 (High)	6.3
Wells.....	1952	February 10, 1956	84 (High)	110 (Slight)	6.2
Boaz†.....	1936	August 14, 1951	10 (Very low)	265 (Very high)	6.0
Elam.....	1952‡	August 8, 1952	12 (Very low)	95 (Slight)	5.9

*Kinds and amounts of fertilizer materials used are shown in table 5.

†The soil test was made on the west half of the Boaz watershed.

‡Spring.



Fig. 5.—Aerial view of Boaz Pond, 1.01 acres, October, 1950.



Fig. 6.—Aerial view of Elam Pond, 1.55 acres, October, 1950.

gray silt loams, which, if untreated, are strongly acid, low to very low in available phosphorus, low to medium in available potassium, and low in organic matter. University of Illinois agronomists have found that in order to farm these soils at a profit it is generally necessary to treat them with crushed limestone and with either rock phosphate or superphosphate. They have also found that it may be profitable to use complete fertilizers on seed beds and as top dressing on poorly growing pastures.

Soil tests were available for the fields draining into four of the six experimental ponds, table 4; tests were not available for the other two fields. The fact that the soil tests on these fields show only slight acidity and that some of them show high amounts of available phosphorus and potassium is explained by the soil treatments made in connection with field crop studies. Table 5 is a record of all soil treatments applied in the period 1935-1953 to the fields draining into the six ponds. Prior to the soil tests recorded in table 4, all of

Table 5.—Soil treatment dates and materials (in pounds per acre) applied to the fields draining into the six Dixon Springs ponds. The east and west halves of Hooker and Boaz watersheds were treated separately. The manner of treatment, where known, is indicated by a letter.* The watershed area indicated for each pond includes pasture but not woodland.

WATERSHED NAME AND AREA	DATE OF SOIL TREATMENT	Limestone	Rock Phosphate	SUPERPHOSPHATE			AMMONIUM NITRATE 33 PER CENT	MURIATE OF POTASH 60 PER CENT	COMPLETE FERTILIZER				BARNYARD MANURE	
				20 Per Cent	32-36 Per Cent	45-48 Per Cent			2-12-6	4-16-16	5-20-20	8-8-8		
Lauderdale, 5 acres	1937	8,000T			200									
	1950 (fall) †	6,000M	1,000M	100D							180			
	1952 (spring)						100T		100T					
	1952 (fall)						100T		100T					
Hooker, east half, 9-10 acres	1935	8,000T												
	1949 (fall) †	8,000M	1,000M											
	1953 (spring)								200T					
Hooker, † west half, 9-10 acres	1946-1948 †	? †						200D						
	1949 (spring)			? †				? †						
	1951 (fall)							200D						
Phelps, 5 acres	1937	8,000T												
	1948 (fall) †	8,000M	600M											
Wells, 3-5 acres	1937 (fall)	7,000T			200									
	1950 (fall) †	8,000M	1,000M									350D		
	1952 (fall)								200T					
Boaz, east half, 4-5 acres	1936	8,000T												
	1949 (fall) †	8,000M	1,000M											
	1953 (spring)						130T		43T					
Boaz, west half, 4-5 acres	1936	8,000T												
	1951 (spring) **	4,000M	1,000M											
	1951 (fall) **	8,000M	1,000M				100D				100D			
	1953 (spring)								200T					
Elam, 6-7 acres	1936	8,000T			200									
	1952 (spring) †	6,000M	1,000M									200	8,000	
	1952 (fall)								200D					

*The letter following quantity signifies manner of application, where known: T = top dressing; M = mixed with upper 4 to 6 inches of soil; D = drilled with seed 1 or 2 inches below soil surface.

†The west half of the Hooker watershed is privately owned; the record of fertilization was based on the owner's memory. The soil had probably been treated with limestone, according to the owner, at some time within the period 1946-1948. Treatment with fertilizer was made in the spring of 1949 and consisted of 100 pounds per acre of either superphosphate or 2-12-6 applied with a seed drill.

‡At time of reseeded of field.

**Limestone and rock phosphate applied to part of west half of Boaz in spring and to remainder of west half in fall.

the pond watersheds had been treated with crushed limestone to reduce acidity; three watersheds, Phelps, Wells, and Elam, had been treated with phosphate. The west half of Boaz had not been treated with phosphate at the time of the soil test. The phosphate treatment on the Elam watershed was made a few months before the soil test, but the phosphate had not yet become well mixed with the soil. The Wells and Elam watersheds had been treated with potassium through applications of complete fertilizer a few months before the soil tests.

EXPERIMENTAL PROCEDURES

Each of the six Dixon Springs ponds used in the fertilization study was stocked at the beginning of the experiment with known numbers of bass and bluegills. Chemical fertilizers were added to three

May, 1946; Hooker (fertilized), Phelps (fertilized), Boaz (control), and Elam (control) in September of the same year.

Stocking the Ponds

The rates at which the Dixon Springs ponds were stocked with bass and bluegills were close approximations of the rates suggested by Swingle & Smith (1942:13) for ponds in Alabama; these authors recommended 100 bass and 1,500 bluegill fingerlings per acre in ponds that were to be fertilized, 30 bass and 400 bluegill fingerlings per acre in ponds that were not to be fertilized. The actual numbers of fish used in the Dixon Springs ponds and the per-acre rates, based on area of the ponds at full stage, are given in table 6. On the basis of reduced late summer water areas of these ponds, the stocking rates were of course higher than those shown.

The ponds were stocked between October 30 and November 9, 1946. The

Table 6.—Number of largemouth bass and bluegills, and number of fish per acre, released in the six Dixon Springs ponds October 30–November 9, 1946. The bass measured 6.0 to 10.0 inches, the bluegills 1.0 inch, at the time of release.

POND (WITH SURFACE AREAS IN ACRES)	LARGEMOUTH BASS		BLUEGILLS	
	Total Number	Number Per Acre	Total Number	Number Per Acre
FERTILIZED				
Lauderdale (0.92).....	100	109	1,500	1,630
Hooker (1.33).....	118	89	1,500	1,127
Phelps (1.04).....	95	91	1,300	1,250
UNFERTILIZED				
Wells (0.97).....	35	36	400	412
Boaz (1.01).....	30	30	400	396
Elam (1.55).....	33	21	480	310

of the ponds, Lauderdale, Hooker, and Phelps. The other three, Wells, Elam, and Boaz, were maintained as controls. Records were kept of the stocking rates, the times and rates of fertilization, the numbers of hours of fishing, and the numbers and weights of fish caught in each of the ponds.

Fish populations that were in the six ponds previous to the beginning of the experiment had been eliminated by rotenone treatment 2 to 6 months before the experimental stocking was done: Lauderdale (fertilized) and Wells (control) in

largemouth bass used for stocking were 6 to 10 inches long (total length) and bluegills were all about 1 inch long. All fish used in stocking had been collected from nearby Lake Glendale during the draining of the lake in October, 1946. Other bass of 9 to 10 inches obtained from Lake Glendale during the draining operation were found, when aged by scale examination, to be in their third, fourth, fifth, or possibly sixth years. The 9- to 10-inch bass in their fifth or sixth years were considered somewhat stunted. It is assumed that the 1-inch bluegills and 6-

Table 7.—Fertilization record of Lauderdale, Hooker, and Phelps ponds, showing dates of application, number of treatments per year, and per-acre rates of application of chemical fertilizers and ground limestone.

YEAR	PERIOD OF TREATMENT	LAUDERDALE (0.92 Acre)			HOOKER (1.33 Acres)			PHELPS (1.04 Acres)		
		Number of Treatments	Pounds Per Acre at Each Treatment		Number of Treatments	Pounds Per Acre at Each Treatment		Number of Treatments	Pounds Per Acre at Each Treatment	
			Chemical Fertilizer*	Lime-stone		Chemical Fertilizer*	Lime-stone		Chemical Fertilizer*	Lime-stone
1947...	May 26–Sept. 13†	4	100 (9.0-13.6-2.8)	17	100 (7.2-10.8-2.3)	4	100 (6.9-10.3-2.2)	13		
1948...	May 10–July 30	4	100 (9.0-13.6-2.8)	17	100 (7.2-10.8-2.3)	4	100 (6.9-10.3-2.2)	13		
1949...	May 13–Sept. 14	4	100 (9.0-13.6-2.8)	17	100 (7.2-10.8-2.3)	4	100 (6.9-10.3-2.2)	13		
1950...	April 11–Aug. 11†	9	100 (9.1-9.0-4.5)	0	100 (7.2-7.2-3.6)	5	100 (6.9-6.9-3.5)	0		
1951...	April 18–Aug. 16	8	100 (9.1-9.0-4.5)	0	100 (7.2-7.2-3.6)	8	100 (6.9-6.9-3.5)	0		
1952...	April 17–Aug. 8	8	100 (9.1-9.0-4.5)	0	100 (7.2-7.2-3.6)	8	100 (6.9-6.9-3.5)	0		
1953...	May 13–July 23	8	100 (7.6-7.8-3.8)	0	100 (7.8-7.9-3.8)	8	100 (7.7-7.8-3.8)	0		

*Weight of fertilizer including fillers. In parentheses, the N-P-K formula or pounds of nitrogen as N, phosphorus as P₂O₅, and potassium as K₂O in 100 pounds of material applied. †Nitrogen was supplied by ammonium sulfate (1947–1949) or ammonium nitrate (1950–1953). Phosphorus and potassium were supplied by superphosphate and muriate of potash. ‡Last treatment dates in 1947: Lauderdale, July 25; Hooker, September 13; Phelps, July 19. ††Last treatment dates in 1950: Lauderdale and Hooker, August 11; Phelps, July 14.

inch bass were hatched in 1946. Green sunfish that later were caught occasionally in two of the ponds, Phelps and Boaz, may have been placed there accidentally with the 1-inch bluegills. The sizes of the fish used were the sizes most readily available from Lake Glendale. Whereas Swingle & Smith (1942:13) suggested the use of fingerling bass and bluegills where both species were to be used in stocking in the fall of the year, we departed from their recommendation by using small adult bass as well as bass fingerlings.

Each of the largemouth bass placed in the ponds was marked by removal of a pectoral fin clipped close to the body; the bluegills were not marked.

Fertilizing the Ponds

Chemical fertilizers, which contained nitrogen, phosphorus, and potassium (N-P-K), were applied to Lauderdale, Hooker, and Phelps each year, 1947–1953; no fertilizer was used in Wells, Boaz, or Elam.

Numbers of treatments, periods of treatments in different years, and N-P-K formulas are given in table 7. In terms of the number of treatments given and total quantity of nitrogen, phosphorus, and potassium introduced during any single year, fertilization was lighter during the first 3 years than during the last 4, except that in 1950 the quantity of phosphorus applied to Phelps was slightly less than was applied in any of the previous 3 years. As recommended by Swingle & Smith (1942:16), crushed limestone was used in addition to the nitrogen, phosphorus, and potassium fertilizers when ammonium sulfate was used to supply nitrogen (1947–1949). It was intended that the three ponds to be fertilized should be dosed at the same rates. Dosages applied were computed from areas obtained from the best maps available in 1947. When the ponds were mapped by plane table in 1951, the maps that had been used were found to contain errors. These errors account for the different amounts of N-P-K applied to the three ponds in the years previous to 1953, table 7.

The methods of treating the three fertilized ponds in the Dixon Springs experiment were similar to those described by Swingle & Smith (1942:16–8). These

authors recommended a formula for the amount of fertilizer to be used at each application but allowed for considerable flexibility in the number of applications to be given within a year. The N-P-K formula used in the ponds at Dixon Springs in 1947-1949 was similar to, but was heavier in phosphorus than, the one described by Swingle & Smith. The dosage rate used at Dixon Springs in 1950-1953 was a still closer approximation of the Swingle & Smith rate. The Swingle & Smith technique of dosing ponds as often as necessary to maintain blooms of plankton algae was followed only in 1950. Numbers of applications in other years (four per year in the period 1947-1949 and eight per year in the period 1951-1953) were selected arbitrarily. The Swingle & Smith recommendation that fertilization be delayed in the spring until danger of overflow is past, usually April or May in Alabama, could not easily be followed at Dixon Springs, where rains heavy enough to cause overflow of the ponds often occur as late as June or July.

Dosages were based on pond areas at full stage and were not reduced when pond areas shrank in midsummer. No attempt was made to replace fertilizer losses which may have occurred through overflow of water.

The chemical compounds used as sources of nitrogen, phosphorus, and potassium were ammonium sulfate (or nitrate), superphosphate, and muriate of potash. These compounds were weighed separately as needed, then mixed, and broadcast into the shallow water along the shore of each of the three ponds selected for fertilization; most of the fertilizer fell where the water was 2 to 4 feet deep. Distribution of fertilizer was always made around the entire pond.

When the ponds were treated only four times a year (1947-1949) the individual treatments were usually spaced 2 to 4 weeks apart. Treatments were postponed if blooms of algae were so dense as to obscure the Secchi disc at a depth of 24 inches or less.

They were postponed in 1947, also, during the period of decay of aquatic plants (mainly *Chara* spp.) that had been killed by earlier treatments. When the ponds were treated eight times a year (1951-

1953) many of the treatments were given at 1-week intervals, without regard to the density of the blooms, or to the transparency of the water, as measured by the depth at which a Secchi disc was visible. There was no indication that these closely spaced treatments had any adverse effect upon the fish populations; dead fish were not reported in any of the ponds.

Collecting Fishing Data

Creel data were obtained through controlled public fishing and through test fishing by Illinois Natural History Survey employees. Since two of the ponds—Lauderdale and Wells—were fished almost exclusively by the test anglers and since certain data presented here from all six ponds were gathered entirely by the test anglers, it is appropriate to describe test fishing routines in some detail.

At least one test angler fished each pond once a week from early June to early September, or about 12 times a summer. Occasionally one of the test anglers was joined by another fisherman, usually a fellow staff member. The test angler fished one fertilized pond and one control pond on each fishing day; Lauderdale was paired with Wells, Hooker with Boaz, and Phelps with Elam. Each pond was fished alternately in the morning of one week and the afternoon of the following week. The senior author of this paper, as well as the regular test angler, fished the six ponds throughout the summers of 1948 and 1949. In the other years of the experiment the test fishing was done principally by one man.

Ordinarily a test angler fished the ponds for 2 hours on each visit, spending about 1 hour fishing with fly rod and/or casting rod with artificial baits and 1 hour fishing with fly rod and natural baits, usually worms.

All captured fish were placed on stringers until the end of the 2-hour fishing period; then each fish was measured and weighed. Bass measuring 10.0 inches (total length) or longer and bluegills measuring 6.0 inches (total length) or longer were kept; the others were returned to the pond. Considerable mortality occurred in hot weather, notably among small fish.

The fish caught by the test anglers were measured to the nearest tenth of an

inch and they were weighed to the nearest 4-gram interval on a John Chatillon & Sons 1,000-gram spring scale. The weights were later converted to pounds.

Public fishing was allowed in four of the ponds, Hooker, Phelps, Boaz, and Elam, under a special permit system. A grocery in Glendale and the Lake Glendale bathhouse were used as permit stations. Fishermen were allowed to fish in Lauderdale and Wells if they accompanied the test anglers on regularly scheduled trips; few permit fishermen took advantage of this arrangement. Lauderdale and Wells were excluded as regular permit ponds in order to be assured of an equal or nearly equal amount of fishing time on one fertilized pond and one control pond. Under the now widely used permit system, each fisherman selected the pond where he wished to fish and was issued a 1-day permit for that pond in exchange for his state fishing license. At the end of his period of angling the fisherman submitted his fish for counting and weighing and recovered his state fishing license. Information recorded for each permit fishing period included time spent, types of baits used (plugs, flies, worms), and, for each species of fish, weight of the fish kept and an estimate of the number thrown back. The fish caught by the permit fishermen were not measured or weighed individually.

One boat was kept on each pond for use by test anglers and permit fishermen. Fishermen supplied their own oars or sculling paddles. The use of minnows for bait was prohibited in order to guard against contamination of the ponds with unwanted species. Earthworms or catalpa worms were by far the most popular baits used by permit fishermen; plugs were next in popularity.

Throughout the experiment, anglers were limited by state law to 10 bass a day; they were also limited to 50 bluegills a day until that limit was removed on July 1, 1951. These creel limits were seldom approached by either the test anglers or the permit fishermen. A 10-inch legal size limit on bass was in force throughout the state until July 1, 1951. People fishing on the six Dixon Springs ponds were asked to continue observing the 10-inch limit until termination of the experiment.

The ponds were open to fishing each day from 6 A.M. to 9 P.M., May 15 through the first Monday in September.

The permit fishermen were not informed as to which ponds were treated with fertilizer, nor were they often reminded that a test of pond fertilization was in progress.

Although fishing regulations were posted at each pond there were some violations, including poaching.

Censusing the Fish Populations

In order to determine the standing crops of fish (numbers and weights) in the Dixon Springs ponds, we killed the fish with rotenone and censused the populations in the period September 8-17, 1953.

Cube powder (5 per cent rotenone content) was applied to the ponds at the rate of 3 pounds of powder per acre-foot of water. Fish were collected, counted, and weighed on the day the rotenone was introduced and on each of the succeeding three days. Because insignificant numbers of fish were found on the fourth day after treatment, no counts were made on that day or later.

POND FERTILIZATION AND PLANT LIFE

The use of chemical fertilizers in the Dixon Springs ponds resulted in increased abundance of plankton algae in each of the treated ponds and in periodic heavy growths of filamentous algae, particularly in one pond. The fertilization program was detrimental to the growth of rooted aquatics.

Blooms of plankton algae, similar to those described by Swingle & Smith (1942), appeared in the fertilized ponds each year. The blooms occurred after two to four applications of fertilizer. The number of treatments required to produce these blooms varied with the pond and the year. Blooms were much heavier in some years than others. They were light at Lauderdale, for example, in 1950 and 1951. The effect of blooms on water transparency may be seen in table 8. Light blooms were sometimes observed in the control ponds but these blooms seldom lasted for more than 1 week at a time.

Once the blooms were established in the fertilized ponds they lasted as long as 2 to 8 weeks without further additions of fertilizer. When a bloom began to disappear, an additional application of fertilizer usually resulted in an increase in its density within 1 or 2 days. Ball & Tanner (1951:9) found that in North Twin Lake, Michigan, an increase in plankton followed each application of fertilizer.

In the Dixon Springs ponds, surface growths of filamentous algae—probably stimulated by the pond treatments—were a hindrance to fishing in some years, but perhaps did not seriously affect fish yields or catch rates. Such growths were present in all three fertilized ponds in the summer of 1947, the first year in which fertilizer

was used, and were especially heavy at Lauderdale Pond in the summers of 1948, 1950, and 1951. At various times during these 3 years filamentous algae covered 25 to 75 per cent of the surface of Lauderdale Pond, fig. 7. Anglers sometimes had to clear away algae before fishing their favorite spots. However, Lauderdale produced by far the best fishing in spite of this growth of filamentous algae. Surface growths were sometimes observed on the control ponds, but they covered only small areas and were present for only very short periods. The floating algae on Lauderdale was identified as *Rhizoclonium* sp.

Heavy growths of filamentous algae in chemically fertilized ponds have been re-

Table 8.—Average depths (in inches) at which a Secchi disc was visible below the surface of each of the six Dixon Springs ponds (weekly observations averaged by months), monthly averages for fertilized and for unfertilized ponds, and differences between monthly averages. The lower transparency of the fertilized ponds generally resulted from blooms of plankton algae.

YEAR AND MONTH	FERTILIZED				UNFERTILIZED				DIFFERENCE BETWEEN AVERAGES	
	Lauderdale	Hooker	Phelps	Average	Wells	Boaz	Elam	Average	Fertilized Clearer	Unfertilized Clearer
1947										
June*	56	.....	.....	56	36	.....	.....	36	.....	.....
July....	51	33	51	45	41	11	62	38	7	.....
August.	15	17	15	16	36	6†	63	35	.....	19
1948										
June...	17	26	25	23	31	16	30	26	.....	3
July....	17	21	22	20	37	20	31	29	.....	9
August.	20	16	18	18	25	21	29	25	.....	7
1949										
June...	30	21	23	25	37	33	30	33	.....	8
July....	14	20	19	18	39	35	33	36	.....	18
August.	22	19	12	18	39	35	36	37	.....	19
1950										
June...	39	13	16	22	28	28	33	30	.....	8
July....	34	12	11	19	29	39	36	35	.....	16
August.	58‡	15	12	28	30	36	38	35	.....	7
1951										
June...	14	39	14	22	26	23	38	29	.....	7
July....	35	33	20	29	50	35	42	42	.....	13
August.	43	27	13	28	20	48	56	41	.....	13
1952										
June...	12	13	9	11	31	44	39	38	.....	27
July....	14	12	12	13	14	40	22	25	.....	12
August.	11	19	9	13	16	39	20	25	.....	12

*Readings were begun late in the month. A single reading at Hooker was recorded as "very clear." A single reading at Elam was recorded as 38 inches; no readings were made at Phelps or Boaz during June.

†The low readings at Boaz in 1947 were the result of nearly continuous muddiness, for which no cause could be found.

‡The reading was 108 inches at Lauderdale Pond on August 27, 1950. This was the highest reading made at any time in any of the six ponds.



Fig. 7.—Lauderdale Pond, August, 1950, with surface partially covered with a growth of filamentous algae, after the pond had been fertilized.

ported by Patriarce & Ball (1949:29) in southern Michigan, by Surber (1945:388) in West Virginia, by Zeller (1953:286) in Missouri, and by Smith & Swingle (1942) in Alabama.

Bottom-inhabiting filamentous algae (unidentified) were sometimes present in both fertilized and unfertilized ponds at Dixon Springs, but usually for only brief periods. However, such algae were found to be a nuisance to fishermen at Lauderdale throughout the summer of 1952.

Dense stands of *Chara* in the three fertilized ponds died in 1947, after three fertilizer applications; for as long as fertilizer was used (from the spring of 1947 through the summer of 1953) this plant remained extremely scarce. *Chara* nearly covered the bottoms of the three control ponds throughout the study. An increase in abundance of *Chara* was seen in Lauderdale, Hooker, and Phelps during 1954 and 1955, the first years after 1947 in which no fertilizer was used; however, in 1956 *Chara* had still not regained its prefertilization abundance.

The disappearance of submerged weeds in ponds treated with chemical fertilizers was observed by Swingle & Smith (1942). These authors recommended winter fertilization to destroy undesirable submerged aquatic plants and periodic fertilization to prevent their re-establishment. Surber (1948a) reported that a variety of rooted aquatic plants had been killed after use of a chemical fertilizer at Deer Lake, New Jersey. Ball & Tanner (1951:11) found that chemical fertilizer all but destroyed *Chara* and *Potamogeton* in North Twin Lake, Michigan, but that each returned to its former abundance the year following termination of fertilization of the lake.

POND FERTILIZATION AND FISHING SUCCESS

The pond fertilization program at Dixon Springs can be evaluated by comparing the three fertilized ponds, Lauderdale, Hooker, and Phelps, with the three control or unfertilized ponds, Wells,

Table 9.—Numbers of largemouth bass, in various length classes, caught by Illinois Natural History Survey test anglers in three fertilized ponds at Dixon Springs. Bass of less than 10 inches in length were returned to the water. Numerals in boldface type represent bass (marked by fin removal) used in stocking the ponds.

LENGTH CLASS, INCHES*	LAUDERDALE						HOOKER						PHELPS					
	1947	1948	1949	1950	1951	1952	1947	1948	1949	1950	1951	1952	1947	1948	1949	1950	1951	1952
4.5.....							1											
5.0.....		1					2											1
5.5.....		1		3			2		1				1	1				
6.0.....		1	3			2			3	1			1	1				1
6.5.....	1		2	7		3		2	1		4		1	1				1
7.0.....			2	9		1	2	7	2		7		3	2				1
7.5.....		1	4	3				15	4	2		1	1	2	2			2
8.0.....	1		2	2	1	1	2	14	2	4	3		3	1				
8.5.....	1	12	2			1	51	11	4	4	2		62	6	1			1
9.0.....		5	1		5		73	2	9	9			8	18	1			3
9.5.....	10	1	2		7	1	42	3	6	8	1		6	4	2	2	2	
10.0.....	15	1	5	8	4		31	2	8	7			4	9	3	2	1	1
10.5.....	5		1	9	2	8	2	22	1	8			7					1
11.0.....	20		3	3	2	5	1	31		6					2			
11.5.....	5	6	2	5	1	6		3		2							1	1
12.0.....	3	3	1	1	3	4	1			2					1	2	1	1
12.5.....	2	1		1	1	1												1
13.0.....				1	1	3										1		1
13.5.....				1	1													
14.0.....					1					1								
14.5.....				1														
15.0.....																		
15.5.....						1												
16.0.....					1													
16.5.....			1															
17.0.....				1	1													
17.5.....					1	1												
18.0.....																		
18.5.....																		
19.0.....																		
19.5.....																		
20.0.....																		
20.5.....						1												
Total.....	69	23	34	57	26	39	25	22	60	40	52	17	28	26	43	8	8	14
Number in 10-inch class or larger..	50	11	16	33	13	30	7	9	5	9	24	0	4	16	7	3	6	4
Average length of fish, 10-inch class or larger..	10.8	11.7	11.4	11.4	11.7	12.0	10.6	10.9	10.4	10.1	10.6	.....	10.0	10.2	10.3	10.8	11.7	12.0
Per cent in 10-inch class or larger..	72	48	47	58	50	77	28	41	8	23	46	0	14	61	16	38	75	29

*Each number designating inches represents the mid-point in a length class; for example, the number 4.5 includes the bass of 4.3–4.7 inches total length.

Table 10.—Numbers of largemouth bass, in various length classes, caught by Illinois Natural History Survey test anglers in three unfertilized ponds at Dixon Springs. Bass of less than 10 inches in length were returned to the water. Numerals in boldface type represent bass (marked by fin removal) used in stocking the ponds.

LENGTH CLASS, INCHES*	WELLS						BOAZ						ELAM					
	1947	1948	1949	1950	1951	1952	1947	1948	1949	1950	1951	1952	1947	1948	1949	1950	1951	1952
5.0.....		1																
5.5.....						1								1	2			
6.0.....		3		1							1			7	2	1	1	1
6.5.....		5	4			1		2	4				4	1	5		2	
7.0.....		5	2					3	1		1		4	8	6	1	1	
7.5.....		5		1	1			1	3	1	1		8	9	5		1	
8.0.....		3	3	1		3		2	7	4	1			15	1	4	2	
8.5.....		5	6		1			7	4	4	2		3	7	3	2	1	
9.0.....		4	4	1			1	4	4				3	8	3	5		
9.5.....		8	10	4	1			2	9	3	3		2	7	8	3		
10.0.....	3	1	3	2	1	2	2	1	3	2	3		1	1	3	7	6	
10.5.....	3	1	3	6	4	2	4		2	2	1		5	1	4	6	1	
11.0.....	3	1	4	1	1				4		1		2	2	6	6	1	
11.5.....	1		1	1	1	3	2			1			2			4	4	
12.0.....	3		1	2	4	2					2			3		2	4	
12.5.....	2		1		2	3				1		2			1		1	
13.0.....		3			2	1			1	1	1						1	
13.5.....		2			1	1		1			1							
14.0.....						2		1										
14.5.....						1		1										
15.0.....		1	1											1	1			
15.5.....				1														
16.0.....															1			
16.5.....																		
17.0.....																		
17.5.....																		
18.0.....																		
18.5.....																		
19.0.....																		
19.5.....																		
20.0.....																		
20.5.....																		
Total.....	15	50	44	20	19	22	9	12	30	34	16	13	8	43	71	50	36	21
Number in 10-inch class or larger ..	15	11	15	12	16	17	8	4	2	12	7	9	8	5	9	18	20	12
Average length of fish, 10-inch class or larger ..	11.1	12.4	11.2	11.2	11.7	12.1	10.6	13.0	10.3	11.0	11.2	11.3	11.0	11.5	11.9	10.6	10.7	11.8
Per cent in 10-inch class or larger ..	100	22	34	60	84	77	89	33	7	35	44	69	100	12	13	36	56	57

*Each number designating inches represents the mid-point in a length class; for example, the number 5.0 includes the bass of 4.8-5.2 inches total length.

Boaz, and Elam, with respect to the sizes of fish caught, the annual fish yields, and the catches per fisherman-hour.

Sizes of Fish Caught

Length distributions of all bass and all bluegills caught by the test anglers are shown for the six ponds in tables 9, 10, 12, and 13; these tabulations include the

bass under 10 inches and the bluegills under 6 inches that were put back in the ponds after measurement. The average weights of fish caught and kept by test anglers and permit fishermen are shown in tables 11 and 14; lengths of fish caught by permit fishermen were not recorded.

Few of the bass caught by test anglers measured more than 13 inches; the only

Table 11.—Average weights (in pounds) of individual largemouth bass harvested by hook and line from each of the Dixon Springs ponds in each of 6 years. Data from which the figures were derived are in table 20.

POND	1947	1948	1949	1950	1951	1952	AVERAGE
FERTILIZED							
Lauderdale.....	0.60	0.71	0.57	0.68	0.83	0.70	0.68
Hooker.....	0.63*	0.72	0.63	0.60	0.63	0.53	0.62
Phelps.....	0.50*	0.43	0.50*	0.53	0.71	0.75	0.57
<i>Average</i>							<i>0.62</i>
UNFERTILIZED							
Wells.....	0.73	0.92	0.63	0.71	0.68	0.92	0.77
Boaz.....	0.67*	1.13	0.57	0.58	0.64	0.83	0.74
Elam.....	0.63*	0.64	0.91	0.64	0.72	0.74	0.71
<i>Average</i>							<i>0.74</i>

*Average based on fewer than 10 specimens, as shown in table 20.

Table 12.—Numbers of bluegills, in various length classes, caught by Illinois Natural History Survey test anglers in three fertilized ponds at Dixon Springs. Bluegills of less than 6 inches in length were returned to the water.

LENGTH CLASS, INCHES*	LAUDERDALE					HOOKER					PHELPS				
	1948	1949	1950	1951	1952	1948	1949	1950	1951	1952	1948	1949	1950	1951	1952
3.0.....															
3.5.....		1			1								2		
4.0.....	1		2					1	1			1	4		6
4.5.....	1	3	6	2	3			4	1			4	1	4	5
5.0.....	4	1	13	1		2	3	3	1	3	3		3		5
5.5.....	6	1	27	9	4		6	7	2	2	1	4	4	2	9
6.0.....	19	9	40	5	6	1	2	7	4	2	2	9	3	10	16
6.5.....	60	17	27	16	19	7	3	10	22	1	2	15	2	21	8
7.0.....	20	25	17	30	43	19	5	8	27	1	20	11	4	12	8
7.5.....	1	16	33	37	40	3	9	1	4		4	24	4	4	7
8.0.....		1	14	22	22		8	3	2			1	5	4	9
8.5.....			1	11	5			3						1	3
<i>Total</i>	<i>112</i>	<i>74</i>	<i>180</i>	<i>133</i>	<i>143</i>	<i>32</i>	<i>37</i>	<i>47</i>	<i>63</i>	<i>9</i>	<i>37</i>	<i>65</i>	<i>35</i>	<i>55</i>	<i>76</i>
Number in 6-inch class or larger.....	100	68	132	121	135	30	27	32	59	4	28	60	18	52	51
Average length of fish, 6-inch class or larger....	6.5	6.9	6.8	7.4	7.3	6.9	7.3	6.9	6.8	6.4	7.0	6.9	7.2	6.8	6.9
Per cent in 6-inch class or larger.....	89	92	73	91	94	94	73	68	94	44	76	92	51	94	67

*Each number designating inches represents the mid-point in a length class; for example, the number 4.0 includes the bluegills of 3.8-4.2 inches total length.

ones over 16 inches were caught in a fertilized pond, Lauderdale. The bass of 10 inches or longer taken by the test anglers from fertilized ponds, table 9, were smaller on an average than those from the control ponds, table 10; those from the three fertilized ponds averaged 11.5, 10.5, and 10.8 inches; those from the three control ponds averaged 11.6, 11.2, and 11.3 inches. The individual

bass harvested by test anglers and permit fishermen from the control ponds had a higher average weight than those from the fertilized ponds, table 11.

The number of captures of marked bass, those with which the ponds had been stocked in 1946, are indicated in tables 9 and 10. Few marked bass were caught after the second season of fishing. The marked bass grew faster in some ponds

Table 13.—Numbers of bluegills, in various length classes, caught by Illinois Natural History Survey test anglers in three unfertilized ponds at Dixon Springs. Bluegills of less than 6 inches in length were returned to the water.

LENGTH CLASS, INCHES*	WELLS					BOAZ					ELAM				
	1948	1949	1950	1951	1952	1948	1949	1950	1951	1952	1948	1949	1950	1951	1952
3.0.....				2	1				1			1			
3.5.....		5	1	2	1	1	1					1	2	1	3
4.0.....	2	5	4	5	1	3	1	1	4		1	23	6	5	4
4.5.....	8	16	6	8	3	12		6	4	1	3	22	7	10	4
5.0.....		12	37	11	3	16	6	17	2	1	9	9	14	16	2
5.5.....	1	11	23	11	7	4	9	8	11	3	12	8	22	35	1
6.0.....	5	5	13	13	15	2	25	9	24	2	7	4	24	31	8
6.5.....	16	5	13	11	7	6	10	8	28	6	13	9	14	51	49
7.0.....	7	19	18	17	8	6	4	3	36	5	12	15	12	16	45
7.5.....		8	4	18	13	2	2	1	4			3	1	2	1
8.0.....				5	8		1		1	1			1	1	
8.5.....					4										
Total.....	39	86	119	103	71	52	59	53	115	19	58	95	103	168	117
Number in 6-inch class or larger.....	28	37	48	64	55	16	42	21	93	14	33	31	52	101	103
Average length of fish, 6-inch class or larger...	6.5	6.9	6.6	6.9	7.0	6.8	6.3	6.4	6.6	6.7	6.6	6.8	6.4	6.5	6.7
Per cent in 6-inch class or larger.....	72	43	40	62	77	31	71	40	81	74	57	33	50	60	88

*Each number designating inches represents the mid-point in a length class; for example, the number 4.0 includes the bluegills of 3.8–4.2 inches total length.

Table 14.—Average weights (in pounds) of individual bluegills harvested by hook and line from each of the Dixon Springs ponds in each of 5 years. Data from which the figures were derived are in table 20.

POND	1948	1949	1950	1951	1952	AVERAGE
FERTILIZED						
Lauderdale.....	0.21	0.25	0.26	0.32	0.28	0.26
Hooker.....	0.24	0.28	0.31	0.27	0.27	0.27
Phelps.....	0.25	0.28	0.32	0.31	0.31	0.29
Average.....						0.27
UNFERTILIZED						
Wells.....	0.23	0.21	0.21	0.24	0.28	0.24
Boaz.....	0.22	0.20	0.20	0.19	0.26	0.21
Elam.....	0.22	0.17	0.30	0.20	0.20	0.22
Average.....						0.22

than in others. The rate of stocking of the fertilized ponds, which was three times that of the control ponds, may have resulted in at least a temporary state of overcrowding and a consequent retardation in growth of the bass placed in two of the fertilized ponds, Phelps and Hooker. Size distributions of bass caught by test fishermen in 1947 and 1948 indicated no overcrowding in Lauderdale or in any of the controls.

While the size distributions of bluegills caught from fertilized and control ponds were similar, the fertilized ponds yielded bluegills of larger average size, and more bluegills of extra large size (8–8½ inches), than the control ponds, tables 12 and 13. The individual bluegills kept by the test anglers and permit fishermen, 1948–1952, averaged at least one-fourth pound every year at Phelps and in 4 out of 5 years at Lauderdale and Hooker, table 14. In each of the control ponds, Wells, Boaz, and Elam, the individual bluegills averaged one-fourth pound or heavier in only 1 out of 5 years. For all years combined, bluegills harvested from the fertilized ponds averaged 0.27 pound per fish, those from the controls 0.22 pound.

The three largest bluegill specimens caught by the test anglers came from the fertilized ponds; their lengths and weights were 8.6 inches and 0.51 pound, 8.7 inches and 0.53 pound, 8.7 inches and 0.55 pound. However, these were not the largest bluegills caught in the fertilized ponds. On June 3, 1951, a permit fisherman on Phelps Pond caught 12 bluegills that averaged 0.63 pound per fish.

Annual Hook-and-Line Yields

The recorded hook-and-line yields from the ponds in this experiment are probably not the maximum yields of which the ponds were capable. More fishing might have been done, and more fish might have been removed, if the ponds had been open to year-round fishing, and if there had not been many other places to fish in the neighborhood—other farm ponds, Lake Glendale, and large and small streams. Some fishermen may have avoided the experimental ponds because they preferred fishing where permission to fish and reporting of catches were not required. The

true hook-and-line yields were somewhat higher than the recorded yields because the records did not include the fish taken by poachers.

Fishing effort in man-hours per acre and yield in terms of the number and weight of bass and bluegills harvested per acre are given in table 15. The actual recorded numbers and weights of fish removed from the ponds, data from which per-acre yields were computed, are shown in table 20. Yields of bluegills from most ponds increased somewhat between the early and late years of the experiment. During 1947, in the first summer of fishing, the yield of bass measuring 10 inches or larger was much greater from Lauderdale Pond than from Hooker or Phelps or from any of the control ponds, table 15. This high 1947 yield, 51 fish per acre (47 fish), was not equaled in later years at Lauderdale or at any of the other ponds during the period of the study reported here.

The annual hook-and-line yield of bass and bluegills combined averaged 48 pounds per acre from the fertilized ponds and 25 pounds per acre from the control ponds, table 16. The highest recorded 1-year yield from a fertilized pond (Lauderdale) was 88 pounds per acre, from a control pond (Boaz) 42 pounds per acre, table 15. Presumably, higher yields from the fertilized ponds can be attributed for the most part to the better bluegill fishing. It should be noticed that the fertilized ponds were fished more intensively than the controls. In fertilized and control ponds where total hours of fishing were about the same for the whole experiment (Lauderdale and Wells, Phelps and Boaz), the bluegill yields of fertilized ponds exceeded the bluegill yields of the controls in both numbers and pounds per acre, table 16.

For the control ponds in the 5 years in which both species were caught, the total bass yield in pounds (actual, not per acre) almost equaled the total yield of bluegills, table 17; the bass yield exceeded the bluegill yield in two of the control ponds. In the fertilized ponds the total bluegill yield in pounds was three times the bass yield.

Published data showing the effect of pond fertilization on hook-and-line yields

are scarce; no such data have been found for ponds stocked with bass and bluegills alone. Dugan (1951:415) published annual yields of a number of fertilized ponds in West Virginia, some of which contained a bass-bluegill combination, but he did not have yield data from unfertilized ponds containing this combination. In two of the West Virginia ponds, yields of

bass and bluegills were higher than the yields in the fertilized ponds at the Dixon Springs Experiment Station, but the West Virginia ponds were fished more intensively.

In Alabama, Swingle (1945:305) showed a large difference in annual hook-and-line yields between a fertilized pond and an unfertilized pond, each containing

Table 15.—Man-hours of fishing per acre and number and weight of fish per acre removed by hook and line from each Dixon Springs pond during the years 1947–1952. Catch data from which figures were derived are in table 20. Years in which fertilizers were applied to pond watersheds are indicated by S (for spring preceding the fishing season) and F (for fall near the end of the fishing season). Additional data on watershed fertilization are shown in table 5.

POND	YEAR	MAN-HOURS OF FISHING PER ACRE	LARGEMOUTH BASS		BLUEGILLS		TOTAL POUNDS PER ACRE
			Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	
FERTILIZED Lauderdale (0.92 acre)	1947	42	51	30	.....	.....	30
	1948	70	15	11	129	27	38
	1949	78	25	14	101	25	39
	1950F	58	37	25	151	39	64
	1951	56	13	11	150	48	59
	1952SF	58	36	25	223	63	88
Hooker (1.33 acres)	1947	71	6	3	.....	.....	3
	1948	151	19	14	131	32	46
	1949S*F*	216	30	19	127	36	55
	1950	162	19	11	133	41	52
	1951F*	108	18	11	217	59	70
	1952	120	14	7	72	20	27
Phelps (1.04 acres)	1947	32	2	1	.....	.....	1
	1948F	93	13	6	35	9	15
	1949	50	8	4	66	18	22
	1950	105	14	8	101	33	41
	1951	101	13	10	110	34	44
	1952	151	12	9	160	49	58
UNFERTILIZED Wells (0.97) acre	1947	28	15	11	.....	.....	11
	1948	74	13	12	27	6	18
	1949	76	20	12	48	10	22
	1950F	52	14	10	58	12	22
	1951	50	20	13	70	16	29
	1952F	47	25	23	59	16	39
Boaz (1.01 acres)	1947	24	6	4	.....	.....	4
	1948	134	15	17	62	14	31
	1949F*	151	14	8	119	24	32
	1950	36	12	7	30	6	13
	1951S*F*	57	14	9	88	17	26
	1952	109	40	33	35	9	42
Elam (1.55 acres)	1947	16	5	3	.....	.....	3
	1948	35	7	5	24	5	10
	1949	45	7	6	43	7	13
	1950	76	25	16	26	8	24
	1951	32	12	8	74	15	23
	1952SF	58	12	9	114	23	32

*Only part of watershed treated with fertilizer in this season.

Table 16.—Average annual number of man-hours of fishing per acre and average annual hook-and-line yield of largemouth bass and bluegills per acre for the 5-year period 1948–1952 at the six Dixon Springs ponds. Data for individual years are shown in table 15.

POND	MAN-HOURS OF FISHING PER ACRE	LARGEMOUTH BASS		BLUEGILLS		TOTAL POUNDS OF FISH PER ACRE
		Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	
FERTILIZED						
Lauderdale....	64	25	17	151	40	57
Hooker.....	151	20	12	136	38	50
Phelps.....	100	12	7	94	29	36
<i>Average</i>		<i>19</i>	<i>12</i>	<i>127</i>	<i>36</i>	<i>48</i>
UNFERTILIZED						
Wells.....	60	18	14	52	12	26
Boaz.....	97	19	15	67	14	29
Elam.....	49	13	8	56	12	20
<i>Average</i>		<i>17</i>	<i>12</i>	<i>58</i>	<i>13</i>	<i>25</i>

Table 17.—Total weight of largemouth bass and bluegills harvested from the Dixon Springs ponds over the 5 years 1948–1952, the ratio of bass weight to bluegill weight for each pond, and, for each species, the ratio of weight harvested from fertilized ponds to weight harvested from controls. Basic data from which figures were derived are in table 20; the 1947 data have been omitted because in that year bluegills had not reached sizes that most fishermen would keep.

POND	FIVE-YEAR YIELD		BASS: BLUEGILLS
	Largemouth Bass, Pounds	Bluegills, Pounds	
FERTILIZED			
Lauderdale.....	79	186	1 : 2.4
Hooker.....	83	250	1 : 3.0
Phelps.....	37	148	1 : 4.0
<i>Average</i>	<i>66</i>	<i>195</i>	<i>1 : 3.0</i>
UNFERTILIZED			
Wells.....	69	60	1 : 0.9
Boaz.....	74	70	1 : 0.9
Elam.....	69	90	1 : 1.3
<i>Average</i>	<i>71</i>	<i>73</i>	<i>1 : 1.0</i>
Fertilized	0.9	2.7	.....
Unfertilized	1.0	1.0	.....

six hook-and-line species including bass and bluegills. Swingle showed that over a 5-year period the yield of the fertilized pond was almost 10 times the yield of the other pond. The extent to which this difference in yield may have been due to a difference in the total hours of fishing on the two ponds was not indicated.

A creel census at Broadacres Lake, North Carolina (King 1943:209), showed the annual yield of largemouths, bluegills, and rough fish was higher the year before

chemical fertilizer was used than the year the fertilizer was applied. However, the decline in yield after fertilization was not so pronounced in Broadacres Lake as in nearby Kinney Cameron Lake, which had not been fertilized.

Catch Rates

Before we consider the catch rates for fish that were actually harvested from the Dixon Springs ponds, we shall examine the catch rates for fish of various sizes

Table 18.—Numbers of largemouth bass in various length categories captured per hour of fishing by Illinois Natural History Survey test anglers in the period 1947–1952. Catch data on which figures are based are in tables 9 and 10. Bass measuring 10.0 inches or larger were the only ones kept by the test fishermen.

LENGTH CATEGORY, INCHES*	FERTILIZED PONDS						UNFERTILIZED PONDS									
	Lauderdale (229 Hours)		Hooker (178 Hours)		Phelps (179 Hours)		Three-Pond Average, Number Per Hour		Wells (220 Hours)		Boaz (160 Hours)		Elam (189 Hours)		Three-Pond Average, Number Per Hour	
	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour
4 or larger.....	248	1.08	216	1.21	127	0.71	1.00	170	0.77	114	0.71	229	1.21	0.90		
6 or larger.....	243	1.06	210	1.18	124	0.69	0.98	168	0.76	114	0.71	217	1.15	0.87		
8 or larger.....	204	0.89	160	0.90	104	0.58	0.79	140	0.64	96	0.60	150	0.79	0.68		
10 or larger.....	153	0.67	54	0.30	40	0.22	0.40	86	0.39	42	0.26	72	0.38	0.34		
12 or larger.....	37	0.16	2	0.01	7	0.04	0.07	39	0.18	12	0.08	15	0.08	0.11		
14 or larger.....	9	0.04	1	.....	.....	.....	.....	6	0.03	2	0.01	3	0.02	0.02
16 or larger.....	6	0.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....
18 or larger.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
20 or larger.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

*Each length category is based on a length class from table 9 or 10; for example the length category "6 or larger" includes bass of 5.8 inches total length and larger.

Table 19.—Numbers of bluegills in various length categories captured per hour of fishing by Illinois Natural History Survey test anglers in the period 1948–1952. Catch data on which figures are based are in tables 12 and 13. Bluegills measuring 6.0 inches total length or larger were the only ones kept by the test fishermen.

LENGTH CATEGORY, INCHES*	FERTILIZED PONDS						UNFERTILIZED PONDS									
	Lauderdale (195 Hours)		Hooker (151 Hours)		Phelps (159 Hours)		Three-Pond Average, Number Per Hour		Wells (195 Hours)		Boaz (141 Hours)		Elam (164 Hours)		Three-Pond Average, Number Per Hour	
	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour	Number	Per Hour
3 or larger.....	642	3.29	188	1.24	268	1.69	2.07	418	2.14	298	2.11	541	3.30	2.52		
4 or larger.....	640	3.28	188	1.24	266	1.67	2.06	406	2.08	295	2.09	533	3.25	2.47		
5 or larger.....	622	3.19	181	1.20	240	1.51	1.97	348	1.78	263	1.87	448	2.73	2.13		
6 or larger.....	556	2.85	152	1.01	209	1.31	1.72	232	1.19	186	1.32	320	1.95	1.60		
7 or larger.....	338	1.73	93	0.62	121	0.76	1.04	129	0.66	66	0.47	110	0.67	0.60		
8 or larger.....	76	0.39	16	0.11	23	0.14	0.21	17	0.09	3	0.02	2	0.01	0.04		

*Each length category is based on a length class from table 12 or 13; for example, the length category "4 or larger" includes bluegills of 3.8 inches total length and larger.

caught by the test anglers; these fish included some too small to keep.

The efforts of fish managers often are directed toward increasing the numbers of large fish in a population by reducing the abundance of small fish, that is, by thinning stunted populations. These efforts may not be appreciated by a group of fishermen who are less concerned with the size of fish than with the number of fish they catch. This group includes many children and some adults.

The rates at which the test anglers at the Dixon Springs ponds caught bass and bluegills above certain minimum lengths are shown in tables 18 and 19. The catch rates for bass less than 10 inches long and bluegills less than 6 inches long are not harvest rates, since these fish were returned to the ponds after they were measured; some of these fish may have been caught more than once.

The fisherman who prizes any fish, no matter how small, would have found the fertilized ponds slightly better than the control ponds for bass fishing but the control ponds slightly better than the fertilized ponds for bluegill fishing. The control ponds proved better than the fertilized ponds for the capture of bluegills measuring 5 inches or larger. The fisherman interested in keeping only the fish of moderate to large sizes, for example, bass over 12 inches and bluegills over 7 inches, might have found the control ponds a little more satisfactory for bass fishing and the fertilized ponds a little more satisfactory for bluegill fishing. The bass fisherman interested in keeping only extra large fish would have found all of the ponds disappointing.

Catch Rates for Fish That Were Harvested.—We turn now to a consideration of catch rates based on fish that were actually harvested.

The hook-and-line catch rates for fish harvested from the six ponds at Dixon Springs are given in table 20. It is evident from this table that Lauderdale produced better fishing each year (bass rates added to bluegill rates) in terms of both number and pounds per man-hour than any of the other ponds. It was the only fertilized pond that consistently produced better catch rates (bass and bluegill combined) than any of the control ponds.

Lauderdale produced better bass fishing, in terms of number of fish per man-hour, than any of the controls in 5 out of 6 years and, in terms of pounds per man-hour, than any of the controls in 3 out of 6 years, figs. 8 and 9. In 4 out of 6 years the other fertilized ponds produced poorer bass fishing than any of the control ponds. However, as mentioned earlier, bass fishing in Phelps Pond may have been poorer than it should have been in the first year of fishing as a result of relatively heavy stocking.

In each year but 1949 Lauderdale led all other ponds in bluegill fishing, figs. 10 and 11; in that year Phelps led in both number and pounds of bluegills per man-hour. In several different years some of the control ponds had bluegill catch rates that were equal to or better than the catch rates in Hooker or Phelps.

The catch rates averaged for six seasons of bass fishing and five of bluegill fishing are shown for each pond at the bottom of table 20. Lauderdale ranked well above any of the other ponds in catch rates (bass rates added to bluegill rates). Hooker and Phelps ranked below Wells and Elam and about on a par with Boaz.

The three fertilized ponds ranked 1, 5, and 6 in terms of both number and weight of bass kept per hour; 1, 3, and 4 in terms of number of bluegills kept per hour; and 1, 2, and 3 in terms of weight of bluegills kept per hour. In terms of the weight of bluegills kept per hour, two of the fertilized ponds, Phelps and Hooker, outranked the controls by very small margins. However, the fact that all three fertilized ponds outranked the three controls is a strong indication that fertilization was a benefit to bluegill fishing, though the benefit may have been small.

At Broadacres Lake, North Carolina, King (1943:209) found that the catch rate was a little lower the year fertilizer was used than the year before. At Crecy Lake in New Brunswick, Smith (1954:2) observed a better catch rate of brook trout after the lake had been fertilized, but this better catch rate may have been due in part to other management efforts carried on at the same time, for example, the addition of young trout.

There is a statistical possibility that the fertilized ponds, Lauderdale, Hooker,

Table 20.—Hook-and-line yield and rate of yield (number and weight per man-hour of fishing) of largemouth bass and bluegills removed from Dixon Springs ponds, 1947-1952. At bottom of table (all years), hours of fishing and numbers and pounds of fish are given as totals for entire experiment; rates of catch are averages of averages given in upper part of table, rather than rates obtainable by dividing total catch by total man-hours of fishing.

YEAR AND POND	ACTUAL MAN-HOURS OF FISHING	MAN-HOURS OF FISHING PER ACRE	LARGEMOUTH BASS				BLUEGILLS						
			Number Kept	Number Kept Per Hour	Pounds Kept	Pounds Kept Per Hour	Number Kept	Number Kept Per Hour	Pounds Kept	Pounds Kept Per Hour			
1947													
FERTILIZED													
Lauderdale.....	39	42	47	1.21	28	0.72							
Hooker.....	95	71	8	0.08	5	0.05							
Phelps.....	33	32	2	0.06	1	0.03							
<i>Average.....</i>				<i>0.45</i>		<i>0.27</i>							
UNFERTILIZED													
Wells.....	27	28	15	0.56	11	0.41							
Boaz.....	24	24	6	0.25	4	0.17							
Elam.....	25	16	8	0.32	5	0.20							
<i>Average.....</i>				<i>0.38</i>		<i>0.26</i>							
1948													
FERTILIZED													
Lauderdale.....	64	70	14	0.22	10	0.16	119	1.86	25	0.39			
Hooker.....	201	151	25	0.12	18	0.09	175	0.87	42	0.21			
Phelps.....	97	93	14	0.14	6	0.06	36	0.37	9	0.09			
<i>Average.....</i>				<i>0.16</i>		<i>0.10</i>		<i>1.03</i>		<i>0.23</i>			
UNFERTILIZED													
Wells.....	72	74	13	0.18	12	0.17	26	0.36	6	0.08			
Boaz.....	135	134	15	0.11	17	0.13	63	0.47	14	0.10			
Elam.....	54	35	11	0.20	7	0.13	37	0.69	8	0.15			
<i>Average.....</i>				<i>0.16</i>		<i>0.14</i>		<i>0.51</i>		<i>0.11</i>			
1949													
FERTILIZED													
Lauderdale.....	72	78	23	0.32	13	0.18	93	1.29	23	0.32			
Hooker.....	288	216	40	0.14	25	0.09	169	0.59	48	0.17			
Phelps.....	52	50	8	0.15	4	0.08	69	1.33	19	0.37			
<i>Average.....</i>				<i>0.20</i>		<i>0.12</i>		<i>1.07</i>		<i>0.29</i>			
UNFERTILIZED													
Wells.....	74	76	19	0.26	12	0.16	47	0.64	10	0.14			
Boaz.....	153	151	14	0.09	8	0.05	120	0.78	24	0.16			
Elam.....	70	45	11	0.16	10	0.14	66	0.94	11	0.16			
<i>Average.....</i>				<i>0.17</i>		<i>0.12</i>		<i>0.79</i>		<i>0.15</i>			

and Phelps, would have ranked better as bluegill fishing ponds than the controls even if no fertilizer had been used. H. W. Norton, statistician in the University of

Illinois Animal Science Department, tells us that where relative productivity of ponds is unknown the random selection of the three most productive ponds as the

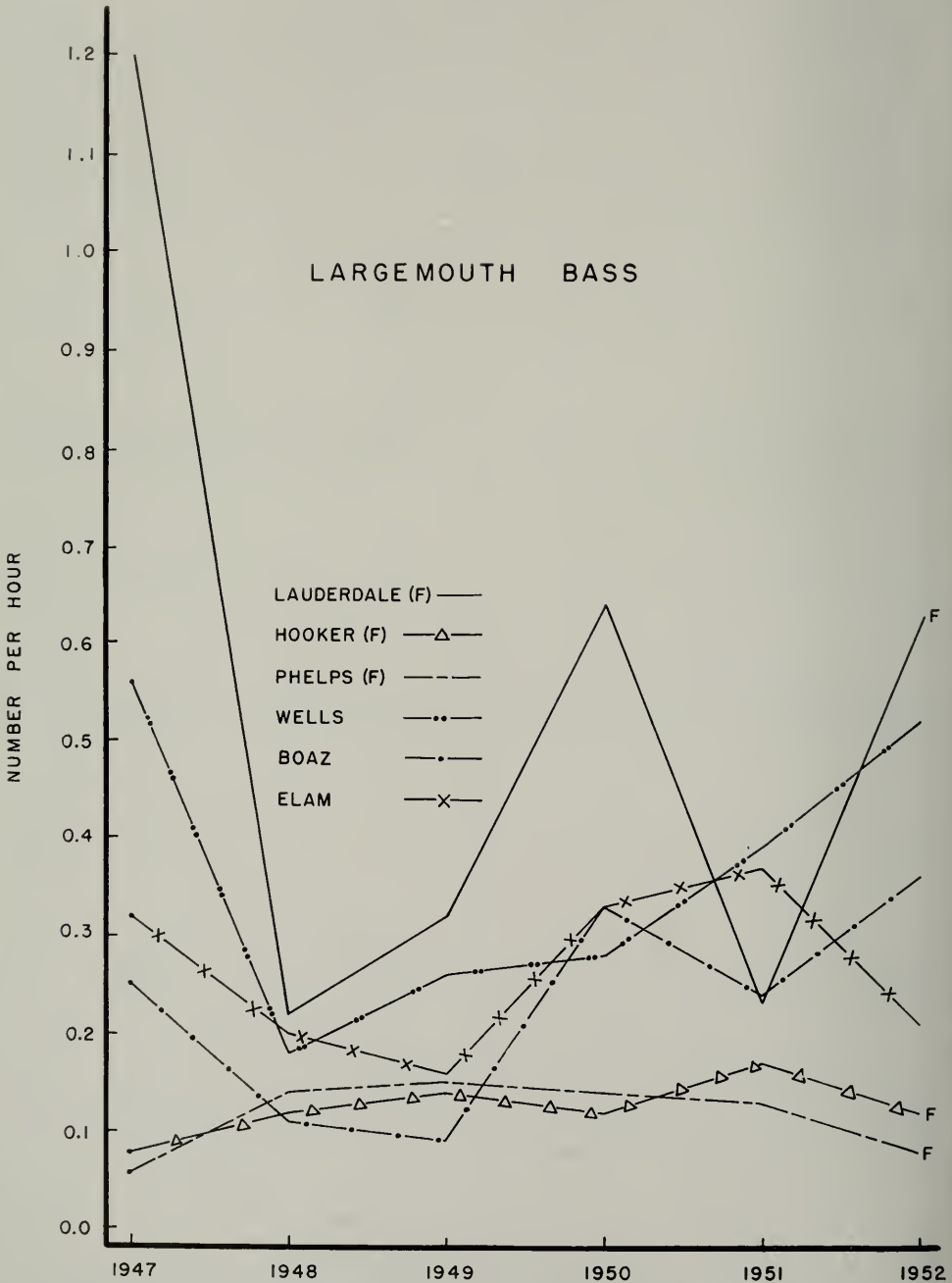


Fig. 8.—Number of largemouth bass kept per man-hour of angling in fertilized (F) and unfertilized ponds; data from table 20.

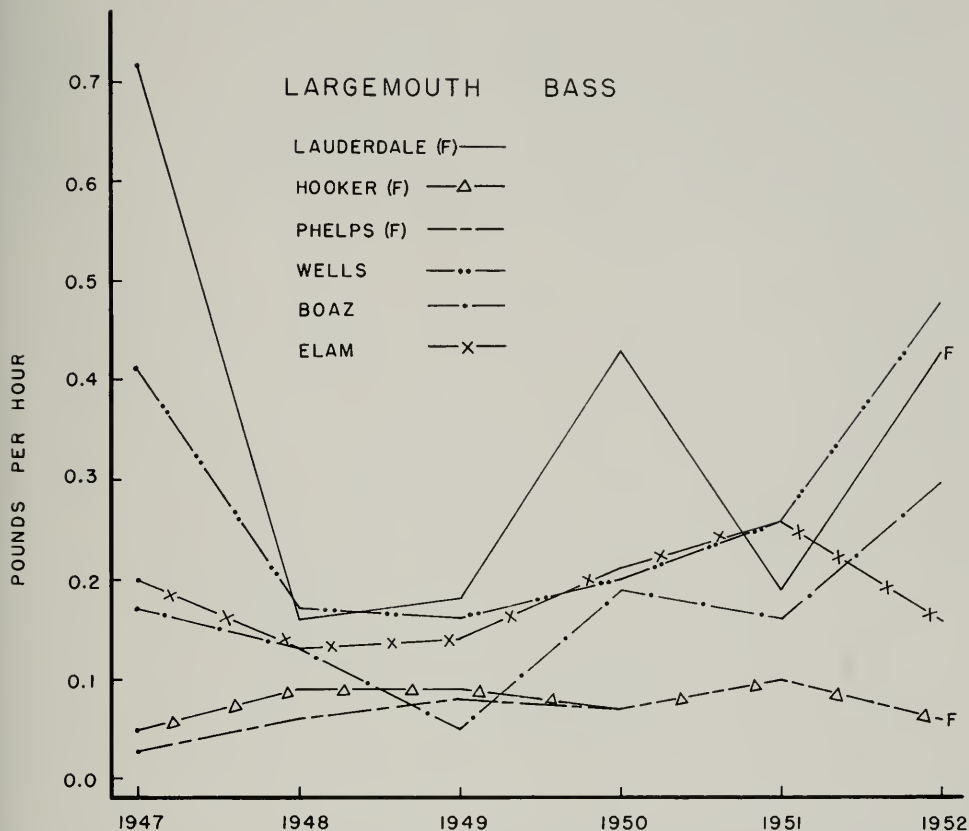


Fig. 9.—Weight of largemouth bass kept per man-hour of angling in fertilized (F) and unfertilized ponds; data from table 20.

ones to receive treatment could occur once in 20 times. Although the ponds were chosen for fertilization on an arbitrary rather than on a purely random basis, we had no advance knowledge of how the six ponds might rank as fish-producing waters.

The wide variation in catch rates for the three fertilized ponds at Dixon Springs points to the need for studies of catch rates on ponds before, as well as after, fertilization. A study of this kind is now in progress. Wells, Boaz, and Elam, the three control ponds of the study reported here, were restocked in 1954 and fertilized for two seasons. Bluegill catch rates in each of these ponds were better after fertilization than before.

The fact that bass fishing in both Hooker and Phelps for the period 1947–1952 was inferior to bass fishing in each of the control ponds, table 20, suggests

several possible conclusions: (1) fertilization was of no help to bass fishing, (2) the benefits of fertilization varied greatly from pond to pond, or (3) no positive correlation existed between the fish population of a pond and the catch rate. The rotenone census of the fish populations showed that poor bass fishing in Hooker and Phelps may not have been due to scarcity of usable-sized fish in these ponds so much as to the difficulty of catching them.

That fishing for both bass and bluegills was generally much better in Lauderdale than in the other fertilized ponds is not easily explained, unless possibly by the lighter fishing pressure, as discussed in the section “Fishing Pressures and Catch Rates.” At the time of the 1953 rotenone census, the number per acre of usable-sized bass was smaller in Lauderdale than in Phelps; the number per acre of usable-

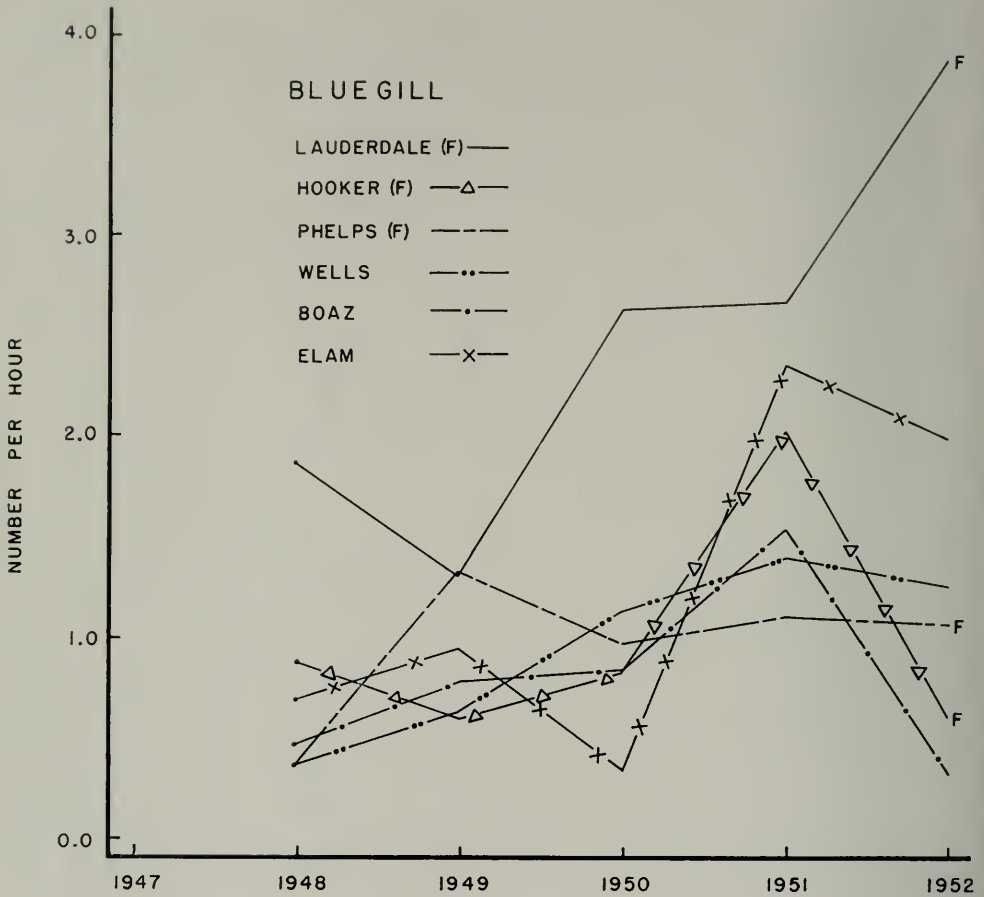


Fig. 10.—Number of bluegills kept per man-hour of angling in fertilized (F) and unfertilized ponds; data from table 20.

sized bluegills was smaller in Lauderdale than in Phelps or Hooker, table 24.

Three factors may have been favorable to the growth of fish in Lauderdale for 1 or 2 years at the beginning of the study but not during the last 4 years. (1) Before the stocking of the ponds for the experiment reported here, fish-food organisms—*invertebrates* as well as larval amphibians—had a longer time to build up their populations in Lauderdale than in Hooker or Phelps. In 1946 Lauderdale was without fish for 6 months prior to stocking (May to November), Hooker and Phelps for only 2 months (September to November). Brown & Ball (1943: 267) showed that certain fish-food organisms as well as fish were destroyed by the rotenone treatment of Third Sister Lake, Michigan. Ball & Hayne (1952:

44-5) showed evidence of an expansion in fish-food organisms in a lake after all fish had been removed. (2) In November, 1946, Lauderdale was given a slightly heavier stocking in terms of fish per acre than the other ponds; this heavier stocking might account for the better bass fishing in 1947. Presumably the initial advantage in numbers would have ceased to be a factor in 1948 or 1949, when the offspring of the fish used in stocking the pond reached harvestable size. (3) Lauderdale had been dosed with fertilizer in 1945.

As a result of an error in the reported area of the pond, Lauderdale received more fertilizer in terms of pounds per acre at full stage than either Hooker or Phelps. However, water levels in mid-summer were always much lower in Phelps than in Lauderdale, so that Phelps

was probably dosed at least as heavily as Lauderdale after about the middle of July each year.

We have shown in table 8 that Lauderdale was often clearer than Hooker and Phelps, a condition that might have assisted fish both in finding food and in locating baits. On the other hand, it is

possible that the clearer water increased the chances that the fish might be frightened by fishermen.

Trends in Catch Rates.—Certain trends in the yearly catch rates were observed for both fertilized and unfertilized ponds at Dixon Springs, but trends differed from one pond to another. In some

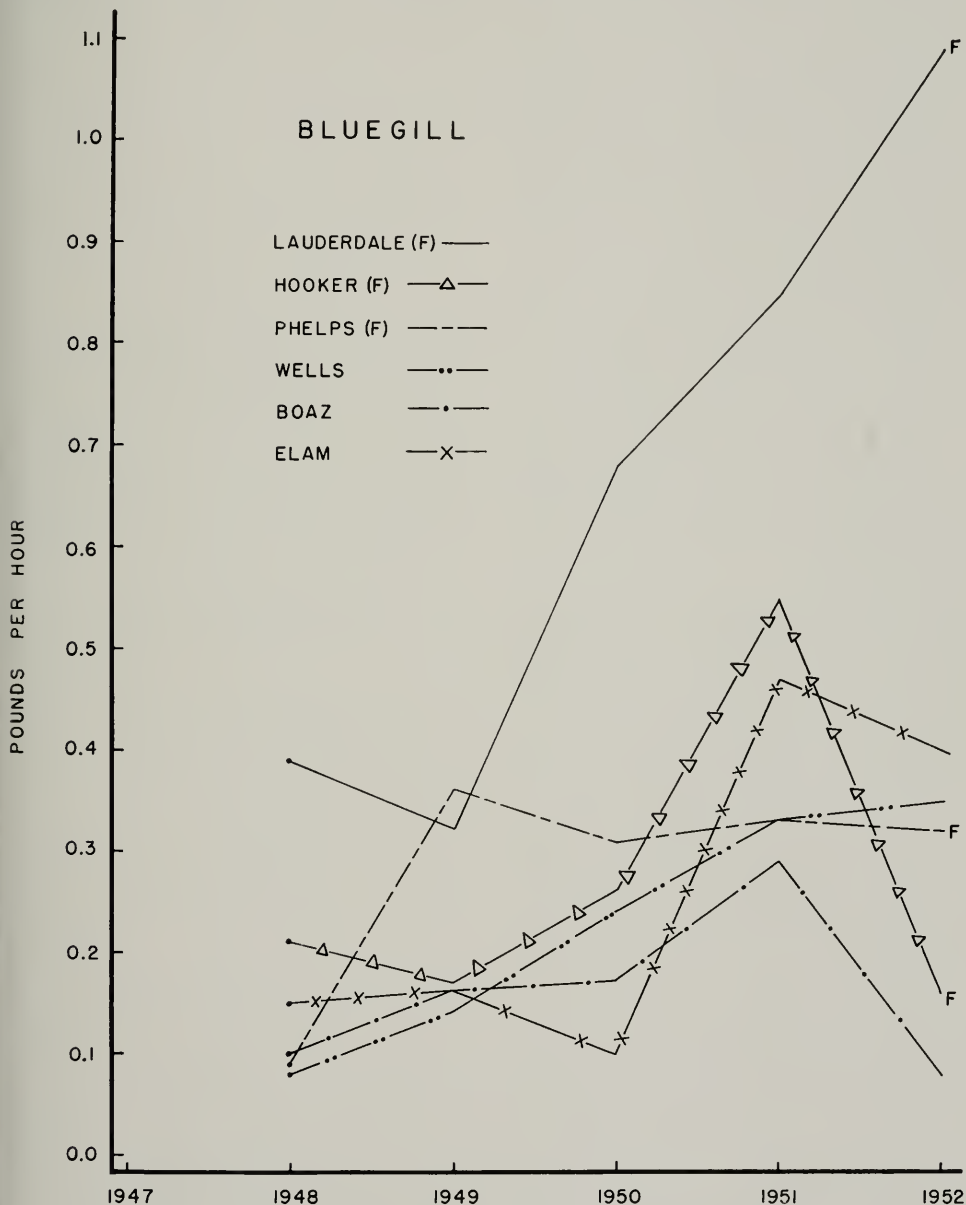


Fig. 11.—Weight of bluegills kept per man-hour of angling in fertilized (F) and unfertilized ponds; data from table 20.

Table 21.—Hook-and-line yield and rate of yield (number and weight per man-hour of fishing) of largemouth bass and bluegills from selected Dixon Springs ponds; fertilized (F) and unfertilized or control (C) ponds having similar fishing intensities are paired or grouped. Data are from table 20.

YEAR AND POND	ACTUAL HOURS OF FISHING	HOURS OF FISHING PER ACRE	LARGEMOUTH BASS				BLUEGILLS						
			Number Kept	Number Kept Per Hour	Pounds Kept	Pounds Kept Per Hour	Number Kept	Number Kept Per Hour	Pounds Kept	Pounds Kept Per Hour			
1947													
Phelps (F).....	33	32	2	0.06	1	0.03							
Wells (C).....	27	28	15	0.56	11	0.41							
1948													
Lauderdale (F).....	64	70	14	0.22	10	0.16	119	1.86	25	0.39			
Wells (C).....	72	74	13	0.18	12	0.17	26	0.36	6	0.08			
1949													
Lauderdale (F).....	72	78	23	0.32	13	0.18	93	1.29	23	0.32			
Wells (C).....	74	76	19	0.26	12	0.16	47	0.64	10	0.14			
Phelps (F).....	52	50	8	0.15	4	0.08	69	1.33	19	0.37			
Elam (C).....	70	45	11	0.16	10	0.14	66	0.94	11	0.16			
1950													
Lauderdale (F).....	53	58	34	0.64	23	0.43	139	2.62	36	0.68			
Wells (C).....	50	52	14	0.28	10	0.20	56	1.12	12	0.24			
1951													
Lauderdale (F).....	52	56	12	0.23	10	0.19	138	2.65	44	0.85			
Wells (C).....	49	50	19	0.39	13	0.27	68	1.39	16	0.33			
Boaz (C).....	58	57	14	0.24	9	0.16	89	1.53	17	0.29			
1952													
Lauderdale (F).....	53	58	33	0.62	23	0.43	205	3.87	58	1.09			
Elam (C).....	90	58	19	0.21	14	0.16	177	1.97	36	0.40			
Hooker (F).....	160	120	19	0.12	10	0.06	96	0.60	26	0.16			
Boaz (C).....	110	109	40	0.36	33	0.30	35	0.32	9	0.08			

ponds, bass catch rates changed only slightly during the experiment; in others, catch rates were high at the beginning, dropped off for 1 or 2 years, and then improved toward the end of the experiment. The notion of many fishermen in Pope and Johnson counties that bass fishing in small ponds is best the first year they are fished was borne out in the fishing results only at Lauderdale and Wells, figs. 8 and 9.

The observed depression in bass catch rates seen in some of the ponds in the second or third year after being stocked probably was due to a reduction in the numbers of the original stock of bass as a result of angling and natural mortality, combined with a delay in population replacement through reproduction.

In all of the ponds except Phelps and Lauderdale, figs. 10 and 11, bluegill catch rates were highest during the fourth year of bluegill fishing (the fifth year after stocking). Phelps Pond furnished its best bluegill fishing in the second year and Lauderdale in the fifth year of bluegill fishing. The most common trend in bluegill catch rates—one that was exhibited by four of the six ponds—was a general improvement in rates over the first 4 years of bluegill fishing, 1948–1951. Three of these four ponds showed conspicuous declines in catch rates in the fifth year, 1952.

Fishing Pressures and Catch Rates.—Bennett & Weiss (1959) recently showed that ponds in Illinois subjected to comparatively light fishing pressures—Ridge Lake, Big Pond, and the ponds in the present experiment—provided better catch rates than ponds in the Busch Wildlife Area, Missouri, that were subjected to extremely heavy fishing pressures.

Although we were unable to discover a clearcut relationship between fishing pressures and catch rates in the Dixon Springs ponds, we found that the two ponds with the smallest total number of man-hours of fishing, Lauderdale (fertilized) and Wells (unfertilized), had the highest catch rates of bass of desirable sizes, table 20.

We have tried in the following discussion to eliminate fishing pressure as a possible factor in catch rate calculations

by comparing only those ponds that were fished at approximately equal rates, table 21.

Under equal or nearly equal fishing pressures, bass fishing was in some instances better in the fertilized ponds, in other instances better in the controls, but bluegill fishing was consistently better in the fertilized ponds.

The catch rates shown for Lauderdale (fertilized) and Wells (control) are of special interest because fishing in these two ponds was done almost entirely by the Natural History Survey test anglers, assuring that not only the number of hours but fishing skills and fishing methods were nearly the same in a given year.

In the 4 years that Lauderdale and Wells are represented in table 21, bluegill fishing in terms of number of fish caught per hour was 1.9 to 5.2 times as good in Lauderdale as in Wells—in terms of pounds caught per hour, 2.3 to 4.9 times as good in Lauderdale as in Wells. In the same 4 years, bass fishing was notably better in Lauderdale than in Wells in 1 year, better in Wells than in Lauderdale in 1 year.

Over the entire period of study, total hours of fishing were nearly equal for Lauderdale (fertilized) and Wells (unfertilized), each fished about 300 hours, and for Phelps (fertilized) and Boaz (unfertilized), each fished in the neighborhood of 500 hours, table 20 (bottom). The catch rates for bass, in 6 years of fishing, were better in Lauderdale than in Wells but better in Boaz than in Phelps. The catch rates for bluegills, in 5 years of fishing, were considerably better in Lauderdale than in Wells and somewhat better in Phelps than in Boaz.

Fertilization Rates and Catch Rates.—As described in the section "Fertilizing the Ponds," the N-P-K formulas used in the period 1947–1949 were different from the ones used in later years, table 7. As a consequence of changes in the fertilizer formula and in the number of treatments, the ponds received about 2.0 times as much nitrogen, 1.3 times as much phosphorus (P_2O_5), and about 3.2 times as much potassium (K_2O) in 1951 and in later years as they had received each year in the period 1947–1949. Although the number of fertilizer applica-

Table 22.—Catch rates (number and weight of fish per man-hour of fishing) of largemouth bass and bluegills from Dixon Springs ponds in two periods, one of comparatively light (1947–1949) and one of comparatively heavy (1951, 1952) fertilization. Details of pond fertilization program are shown in table 7. Figures were derived from data in table 20.

PERIOD OF FERTILIZATION	LARGEMOUTH BASS		BLUEGILLS*	
	Number Per Hour	Pounds Per Hour	Number Per Hour	Pounds Per Hour
LIGHT (1947–1949)				
Fertilized ponds.....	0.27	0.16	1.05	0.26
Unfertilized ponds.....	0.23	0.17	0.65	0.13
<i>Difference</i>	+0.04	-0.01	+0.40	+0.13
HEAVY (1951, 1952)				
Fertilized ponds.....	0.23	0.16	1.88	0.55
Unfertilized ponds.....	0.35	0.27	1.46	0.32
<i>Difference</i>	-0.12	-0.11	+0.42	+0.23

*Bluegill fishing in 1948, 1949, 1951, and 1952 but not in 1947.

tions given annually in 1951–1953 was double the number given in 1947–1949, the amount of phosphorus (the component generally considered to be most important in pond fertilization) was increased only about one-third.

Catch rates may be compared for the years under the lighter treatment (1947–1949 for bass, 1948 and 1949 for bluegills) with the years under the heavier rates (1951 and 1952), table 22. Bass fishing, as judged by differences in catch rates between fertilized and unfertilized ponds, was relatively better under the lighter treatment; bluegill fishing—especially in pounds caught per hour—was better under the heavier treatment. Since bluegill catch rates improved in the control ponds as well as in the fertilized ponds during the period of the heavier treatments, bluegill fishing might have improved in the fertilized ponds even if the rate of fertilization had not been increased.

POND FERTILIZATION AND STANDING CROPS

When the standing crops of the Dixon Springs ponds were determined by rotenone censuses in September, 1953, the ponds had been closed to all fishing for the 12-month period preceding the census. Fertilization of Lauderdale, Hooker, and Phelps had been continued during the summer of 1953 in approximately the same manner as in 1951 and 1952, table 7. For

each pond the standing crop in pounds per acre was computed from the reduced area of the pond at the time of the census, rather than from the area at full stage. Both full stage and reduced areas are shown in table 1.

Studies by Brown & Ball (1943), Ball (1948), Carlander & Lewis (1948), and Krumholz (1950a) demonstrated that in some situations considerable percentages of the populations of fish killed by rotenone are not recovered in the census operations. A possible hindrance to the recovery of fish in the control ponds at Dixon Springs was a dense growth of *Chara* in which dying and dead fish might have become entangled. The possibility that the *Chara* interfered with the recovery of fish was not investigated by underwater examination. We know of no reason other than the possible effect of *Chara* to believe that the percentage of fish recovered was different in fertilized than in unfertilized ponds.

Bass collected from the ponds after the rotenone treatment were grouped into two length categories—those 10.0 inches (total length) or larger and those smaller than 10.0 inches. The bluegills collected from the first four ponds examined (Lauderdale, Phelps, Wells, and Boaz) were divided into four length categories as follows: 1.0–1.9, 2.0–3.4, 3.5–5.9, and 6.0 inches or larger. Natural size groupings permitted the rapid sorting of fish into the various length categories, for the most

part without actual measurement. Bluegills collected from the other two ponds (Hooker and Elam) were grouped into two categories: under 6.0 inches and 6.0 inches or larger.

The populations of the first four ponds varied considerably with respect to abundance of bluegills in the four length categories, table 23. The variations appear to have been unrelated to the fertilization program. Lauderdale Pond was characterized by an absence of bluegills 1.0–1.9 inches long, by an abundance of bluegills 2.0–3.4 inches long, and a relative scarcity of bluegills 3.5–5.9 inches long and 6.0 inches or larger. This pond, in which bluegill fishing had been better than in any other, was more remarkable for the weight of 2.0–3.4-inch bluegills (95 pounds per acre) than for the weight of bluegills measuring 6.0 or larger.

Two population characteristics were seen in these four ponds, table 23. (1) While the ponds appeared to be quite densely populated with bluegills under 3.5 inches, they showed no evidence of overpopulation with bluegills of 3.5 inches or longer. (2) In number of bluegills per acre in each of the four ponds, great differences existed between the two smaller length categories and only minor differences between the two greater length categories.

Of the fish that, according to tables 12 and 13, were likely to be caught by anglers (those 3.5 inches or larger), the ones measuring 3.5–5.9 inches were about as numerous as those of greater lengths.

The number and weight of bass and bluegills (in two length categories for each species) recovered from each of the six ponds in the rotenone census are shown in table 24. Just as there was overlap in the catch rates for fertilized and unfertilized ponds, there was also overlap in the standing crops. Bass 10 inches or larger, bluegills 6 inches or larger, and bluegills smaller than 6 inches were a little more abundant in the fertilized ponds, while bass smaller than 10 inches were more abundant in the control ponds, table 24. Bass of all lengths were more abundant in the control ponds, while bluegills of all lengths were more abundant in the fertilized ponds. The weight per acre of bass of all lengths was nearly the same in fertilized as in control ponds; the weight per acre of bluegills of all lengths was higher in the fertilized ponds.

The three fertilized ponds averaged 292 pounds of fish per acre (bass and bluegills of all lengths); the controls averaged 238 pounds per acre (ratio 1.2:1).

In Alabama ponds treated nine times a season with 6-8-4 fertilizer at the rate of 100 pounds per acre per treatment and NaNO_3 at the rate of 10 pounds per acre per treatment—roughly equivalent to the annual treatments applied at Dixon Springs in the period 1951–1953—Swingle (1947:24) found that the average standing crop (weight per acre) of bass and bluegills of all sizes in three fertilized ponds was about double the standing crop in the control pond (ratio 2.0:1). In this Alabama observation, an overlap was

Table 23.—Standing crops, in terms of number and weight (per acre), of bluegills recovered in the rotenone censuses of four of the six Dixon Springs ponds, September 8–17, 1953; the fish were separated into four length categories. The data from Hooker and Elam ponds are not included in this table because the bluegills from those ponds were separated into only two length groups, under 6 inches and 6 inches and longer.

TOTAL LENGTH, INCHES	FERTILIZED PONDS				UNFERTILIZED PONDS			
	Lauderdale		Phelps		Wells		Boaz	
	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre
1.0–1.9.....			9,070	10	12,428	27	921	1
2.0–3.4.....	11,531	95	227	3	408	6	3,925	21
3.5–5.9.....	314	21	676	50	451	27	876	56
6.0 or larger...	463	129	706	146	463	108	624	133

found between fertilized and control ponds in standing crops of bass but not of bluegills.

In another experiment in which Alabama ponds were treated 12 times a season with 6.6-8-2, each time at the rate of 120 pounds per acre, Swingle (1947:22) found that the average of the standing crops of bass and bluegills of all sizes in three fertilized ponds was nearly three times the standing crop in the control pond (ratio 2.9:1).

That Alabama ponds showed a better response to fertilization than the Dixon Springs ponds under similar treatment is possibly explained by differences in natural fertility of the Alabama and Illinois ponds in question. It might be easier through direct fertilization to double or triple a low standing crop of fish in an area of low soil fertility than in one of somewhat higher soil fertility. The untreated Alabama ponds, 6 to 12 months after being stocked, contained 100 to 125 pounds of bass and bluegills per acre (Swingle 1947:22, 24), whereas the three untreated ponds at Dixon Springs, 6 years after being stocked, contained 169 to 308 pounds of bass and bluegills per acre, table 24. It is possible that in the 6- to 12-month periods between the stocking and draining of the Alabama ponds the standing crops had not had time to reach maximum levels. Krumholz (1948:405, 409) found that ponds stocked in May or June with bluegills alone or with bluegills, largemouth bass, and other species contained much larger standing crops the second October than the first October after being stocked.

Ball & Tait (1952:6, 17) used somewhat less fertilizer in southern Michigan ponds than was used at Dixon Springs in 1951-1953 and obtained a slightly better response from the treatments. Three Michigan ponds were treated five times a season with 10-6-4 fertilizer at the rate of 100 pounds per acre each time. The fertilized ponds had standing crops of bass and bluegills that averaged 365 pounds per acre, and three similar, unfertilized ponds had standing crops that averaged 261 pounds per acre (ratio 1.4:1). There was a very wide range in the standing crops of the fertilized ponds, 165 to 721 pounds per acre; the

standing crops of the unfertilized ponds ranged from 209 to 379 pounds per acre.

In West Virginia, Surber (1948*b*) studied the effect of various rates of application of 10-5-5 fertilizer on the bluegill production in hatchery ponds. Three groups of ponds were treated five to seven times a growing season at rates of 100, 200, or 300 pounds of 10-5-5 fertilizer per treatment. Combining the data of Surber (1948*b*:201-2) for summer and fall hatchery crops (but omitting the data from a pond in which there was abnormally high mortality) we find that crop weights were 1.9, 2.3, and 2.3 times as large in the three groups of fertilized ponds as in the control ponds.

STANDING CROPS AND FISHING SUCCESS

For many years aquatic biologists have been interested in the standing crops of lakes and ponds as a basis for predicting hook-and-line yields. Thompson (1941:213) thought that central Illinois lakes stocked with bass, bluegills, and crappies could give sustained annual hook-and-line yields that would amount to half their carrying capacities. He thought that the corresponding yields for southern Illinois lakes might be close to three-fourths of their carrying capacities. By carrying capacity, Thompson meant the total amount of fish in a lake at saturation point, or the maximum standing crop. Krumholz (1950*b*:29) estimated that Indiana ponds were capable of giving sustained annual yields of "as much as half and perhaps more" of their standing crops. Neither Thompson nor Krumholz speculated on the amount of fishing time that might be required to bring about such yields.

We may now compare the hook-and-line yields of the Dixon Springs ponds during the last 3 years of fishing with the standing crops as observed in the 1953 censuses, table 25. The hook-and-line yields were for the most part made up of bass more than 10 inches and bluegills more than 6 inches total length; the standing crops included all fish, irrespective of size.

For each Dixon Springs pond, the 1952 yield alone, as well as the average yield

for the years 1950, 1951, and 1952, amounted to a much smaller percentage of the standing crop, as observed in September, 1953, table 25, than the sustained yield estimates of Thompson and Krumholz. Percentages were higher in the fertilized than in the control ponds. The most heavily fished ponds in 1952 were Hooker, Phelps, and Boaz. The 1952 fish yields in these three ponds were respectively 11, 19, and 14 per cent of their observed standing crops. The largest yield in relation to standing crop (28 per cent) was recorded from Lauderdale Pond, where fishing in 1952 was lighter, rather than heavier, than in Hooker, Phelps, or Boaz. If, as is possible, fewer fish were recovered in the rotenone censuses than were actually present, the true percentage values would be even lower than those shown. On the other hand, if unreported yields of fish taken by poachers could be determined and included in the calculations, the percentages for at least some of the ponds might be higher than those shown.

Figures representing the 1952 bass harvest and the numbers and weights of harvestable bass in the ponds at the time of the 1953 census are shown in table 26. Similar figures for bluegills are shown in table 27. If the 1953 fish census gave a close approximation of the population of harvestable fish in 1952, the efficiency of

the 1952 fish harvest (the fish caught in relation to the fish present) appears to have been greater for bass in the control ponds and for bluegills in the fertilized ponds.

The relations between catch per hour and the abundance of fish of desirable sizes are shown for bass in table 28 and for bluegills in table 29. Data in these tables, especially the ratios expressed, seem to indicate that in the fertilized ponds bass fishing was poorer than would be expected from the numbers of 10-inch or larger bass present and that bluegill fishing was better than would be expected from the populations of 6-inch or larger bluegills.

Swingle (1945:305) observed that the catch in fertilized ponds was usually greater than would be expected from the increases in their fish-carrying capacities, but he did not say whether his observation applied to both bass and bluegills. He attributed the phenomenon to the blooms of microscopic algae, which he believed helped to conceal the anglers from the fish they were trying to catch. Results of the Dixon Springs experiment indicate that if plankton algae helped to conceal the fishermen from the bass it may also have helped to conceal baits from these fish.

We have ordinarily assumed that the pond containing the largest population of

Table 25.—Standing crop of largemouth bass and bluegills (fish of all sizes) in the 1953 rotenone census of the six Dixon Springs ponds, and the hook-and-line yield of largemouth bass and bluegills during the last years of the experiment, 1950–1952. Yield data are from table 15, standing crop data from table 24.

POND	STANDING CROP, POUNDS PER ACRE	ANNUAL HOOK-AND-LINE YIELD, POUNDS PER ACRE		YIELD AS A PERCENTAGE OF STANDING CROP	
		1952	1950–1952 Average	1952	1950–1952 Average
FERTILIZED					
Lauderdale.....	318	88	70	28	22
Hooker.....	255	27	50	11	20
Phelps.....	302	58	48	19	16
<i>Average</i>				20*	19*
UNFERTILIZED					
Wells.....	237	39	30	16	13
Boaz.....	308	42	27	14	9
Elam.....	169	32	26	19	15
<i>Average</i>				16*	12*

*Average of three percentages directly above.

fish of desirable sizes is the one likely to provide the best fishing. However, surprisingly little correlation was found between numbers of bass and bluegills of

Table 26.—The 1952 hook-and-line yield of largemouth bass (number and pounds per acre) as a percentage of the 1953 rotenone census figure in each of the Dixon Springs ponds; also the ratio of fertilized to unfertilized ponds in number and pounds of bass per acre. Basic data are from tables 15 and 24.

POND	LARGEMOUTH BASS 10-INCHES OR LARGER, 1953 ROTENONE CENSUS		LARGEMOUTH BASS YIELD, 1952 FISHING SEASON*		1952 YIELD AS A PERCENT- AGE OF 1953 CENSUS FIGURE	
	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre
FERTILIZED						
Lauderdale.....	58	70	36	25	62	36
Hooker.....	49	43	14	7	29	16
Phelps.....	64	67	12	9	19	13
<i>Average</i>	57	60	21	14	37†	22†
UNFERTILIZED						
Wells.....	55	45	25	23	45	51
Boaz.....	59	62	40	33	68	53
Elam.....	24	21	12	9	50	43
<i>Average</i>	46	43	26	22	54†	49†
Fertilized	1.24	1.40	0.81	0.64	.....	.....
Unfertilized	1.00	1.00	1.00	1.00	.....	.....

*The hook-and-line yields of bass from Lauderdale and Wells were made up of fish measuring at least 10.0 inches total length. No measurements of bass caught by permit fishermen were recorded, but these fishermen were supposed not to keep bass less than 10.0 inches in length.

†Average of three percentages directly above.

Table 27.—The 1952 hook-and-line yield of bluegills (number and pounds per acre) as a percentage of the 1953 rotenone census figure for each of the Dixon Springs ponds; also the ratio of fertilized to unfertilized ponds in number and pounds of bluegills per acre. Basic data are from tables 15 and 24.

POND	BLUEGILLS 6 INCHES OR LARGER, 1953 ROTENONE CENSUS		BLUEGILL YIELD, 1952 FISHING SEASON*		1952 YIELD AS A PERCENT- AGE OF 1953 CENSUS FIGURE	
	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre	Number Per Acre	Pounds Per Acre
FERTILIZED						
Lauderdale.....	463	129	223	63	48	49
Hooker.....	629	147	72	20	11	14
Phelps.....	706	146	160	49	23	34
<i>Average</i>	599	141	151	44	27†	32†
UNFERTILIZED						
Wells.....	463	108	59	16	13	15
Boaz.....	624	133	35	9	6	7
Elam.....	442	81	114	23	26	28
<i>Average</i>	510	107	69	16	15†	17†
Fertilized	1.18	1.31	2.19	2.75	.....	.....
Unfertilized	1.00	1.00	1.00	1.00	.....	.....

*The hook-and-line yields of bluegills from Lauderdale and Wells were made up of bluegills measuring at least 6.0 inches total length. The sizes of fish taken from the other ponds were not governed by restrictions on fishermen.

†Average of three percentages directly above.

desirable sizes in the several ponds in the 1953 census and the record of fishing success in the same ponds in the preceding years, tables 26-29. Lauderdale, the pond

Table 28.—Number and pounds (per acre) of largemouth bass of at least 10.0 inches total length in the 1953 rotenone census, the hook-and-line catch rate for 1952, and the average annual hook-and-line catch rate for 1950-1952 in each of the Dixon Springs ponds; also the ratio of fertilized to unfertilized ponds in number and pounds of bass per acre and per hour. Basic data are from tables 20 and 24.

POND	LARGEMOUTH BASS 10 INCHES OR LARGER, 1953 ROTENONE CENSUS		LARGEMOUTH BASS, CATCH PER MAN-HOUR*			
			1952		1950-1952 AVERAGE	
	Number Per Acre	Pounds Per Acre	Number Per Hour	Pounds Per Hour	Number Per Hour	Pounds Per Hour
FERTILIZED						
Lauderdale....	58	70	0.62	0.43	0.50	0.35
Hooker.....	49	43	0.12	0.06	0.14	0.08
Phelps.....	64	67	0.08	0.06	0.12	0.08
Average.....	57	60	0.27	0.18	0.25	0.17
UNFERTILIZED						
Wells.....	55	45	0.52	0.48	0.39	0.32
Boaz.....	59	62	0.36	0.30	0.31	0.22
Elam.....	24	21	0.21	0.16	0.30	0.21
Average.....	46	43	0.36	0.31	0.33	0.25
Fertilized	1.24	1.40	0.75	0.58	0.76	0.68
Unfertilized	1.00	1.00	1.00	1.00	1.00	1.00

*Information on the sizes of bass in the catch is in the first footnote to table 26.

Table 29.—Number and pounds (per acre) of bluegills of at least 6.0 inches total length in the 1953 rotenone census, the hook-and-line catch rate for 1952, and the average annual hook-and-line catch rate for 1950-1952 in each of the Dixon Springs ponds; also the ratio of fertilized to unfertilized ponds in number and pounds of bluegills per acre and per hour. Basic data are from tables 20 and 24.

POND	BLUEGILLS 6 INCHES OR LARGER, 1953 ROTENONE CENSUS		BLUEGILLS, CATCH PER MAN-HOUR*			
			1952		1950-1952 AVERAGE	
	Number Per Acre	Pounds Per Acre	Number Per Hour	Pounds Per Hour	Number Per Hour	Pounds Per Hour
FERTILIZED						
Lauderdale....	463	129	3.87	1.09	3.05	0.88
Hooker.....	629	147	0.60	0.16	1.15	0.32
Phelps.....	706	146	1.06	0.32	1.03	0.32
Average.....	599	141	1.84	0.52	1.74	0.51
UNFERTILIZED						
Wells.....	463	108	1.24	0.35	1.25	0.31
Boaz.....	624	133	0.32	0.08	0.89	0.18
Elam.....	442	81	1.97	0.40	1.55	0.32
Average.....	510	107	1.18	0.28	1.23	0.27
Fertilized	1.17	1.32	1.56	1.86	1.41	1.85
Unfertilized....	1.00	1.00	1.00	1.00	1.00	1.00

*Information on sizes of bluegills in the catch is in the first footnote to table 27.

that had generally furnished the highest yields and catch rates did not at the time of the census contain the largest population of fish of desirable sizes, while Phelps, which had consistently furnished poorer fishing than Lauderdale, contained a relatively large population of bass and bluegills of desirable sizes, tables 28 and 29.

Assuming that our data were adequate for the comparison just made, we may conclude that our failure to find a closer relationship between standing crops and fishing success was due to one or both of the following reasons: (1) the standing crops were not the same in all years of the experiment; (2) catch rates were greatly affected by some factor other than the size of the standing crops.

FIELD FERTILIZATION AND FISHING SUCCESS

The application of chemical fertilizers to fields draining into ponds is sometimes thought to be a benefit to fish production and fishing in such bodies of water. This line of thinking is consistent with the widely accepted idea that fertility of the land comprising the watershed of a lake or river has a profound effect on fish production. Little has been said in the literature of pond fertilization, however, concerning the extent of the benefits to pond fishing that may be derived from watershed treatment.

The quantity of fertilizer that might reach a pond in runoff from its watershed would vary from one pond to another and would be difficult to estimate. It would depend, for example, on the size of watershed, the kind and amount of fertilizer used, and the extent to which it was mixed with the soil as it was applied. It would also depend on the time lapse between fertilizer applications and occurrence of rainstorms, the severity of the storms, the tendency of the soil to erode, and the density of protective vegetation. Part of the fertilizer washed from fields into ponds would later be lost over the pond spillway.

Phosphorus applied to fields as rock phosphate is slowly soluble and, theoretically, would be of less benefit to a pond than phosphorus applied as superphosphate, which is readily soluble. However,

phosphorus applied to fields in the form of superphosphate combines rapidly, in the presence of moisture, with elements in the soil to form slowly soluble calcium phosphate and relatively insoluble compounds with iron and aluminum. Except for the superphosphate that might be washed from a field into a pond very soon after a soil treatment, the phosphorus carried into a pond from its watershed would be in a relatively insoluble state. Nitrogen and potassium would be present in runoff for a comparatively short time, probably less than a year. Nitrogen is taken up quickly by plants or is lost into the air, while potassium salts tend to leach downward into the soil, where they cannot be removed by water running over the soil surface.

In the period 1935-1937, previous to the beginning of the study reported here, fields surrounding each of the Dixon Springs ponds were given an application of crushed limestone, and fields surrounding three of the six ponds (Lauderdale, Wells, and Elam) were treated with superphosphate, table 5.

In the course of the study, the watershed of each pond was again treated with crushed limestone; for the first time each watershed was treated with rock phosphate and each watershed except that of Phelps was treated one or more times with chemical fertilizers supplying nitrogen, phosphorus, and potassium, separately or all three in combination, table 5. Barnyard manure was applied to one of the fields.

Actual demonstrations of the effect, on fishing success, of crushed limestone applied to ponds or pond watersheds in the United States seem to be lacking. In Europe, Schaeperclaus (1933:162) reported that applying lime to pond bottoms protects the health of fish and produces favorable "biological conditions, which react to increase the yield." Because the watersheds of all Dixon Springs ponds received approximately equal applications of limestone, no conclusions can be drawn as to what effect, if any, liming of the watersheds had on fishing success in these ponds.

Although phosphorus is generally believed to be important as a pond fertilizer, its value to fishing when applied to pond

watersheds is difficult or impossible to determine from data gathered in the Dixon Springs experiment.

The water of Boaz, the only control pond that had no record of superphosphate, rock phosphate, or complete fertilizer application to its watershed until 1949, had a higher phosphate content in 1947 than the water of any of the other five ponds at Dixon Springs, table 3.

It is interesting to compare catch rates

in Boaz with catch rates in the other control ponds before rock phosphate was applied to part of the Boaz watershed in the fall of 1949. Superphosphate had been applied to the Elam watershed in 1936 and to the Wells watershed in 1937. In the years 1947-1949, bass fishing was not so good in Boaz as in Wells or Elam. In 1948 and 1949, bluegill fishing was slightly better in Boaz than in Wells but not quite so good as in Elam, table 30.

Table 30.—Catch rates (number and pounds of fish removed per hour of fishing) at Dixon Springs ponds, 1947-1952. Years in which fertilizers were applied to pond watersheds are indicated by S (for spring preceding the fishing season) and F (for fall near the end of the fishing season). Data are from table 20. Additional data on watershed fertilization are in table 5.

POND	YEAR	LARGEMOUTH BASS		BLUEGILLS	
		Number Per Hour	Pounds Per Hour	Number Per Hour	Pounds Per Hour
FERTILIZED Lauderdale.....	1947	1.21	0.72		
	1948	0.22	0.16	1.86	0.39
	1949	0.32	0.18	1.29	0.32
	1950F	0.64	0.43	2.62	0.68
	1951	0.23	0.19	2.65	0.85
	1952SF	0.62	0.43	3.87	1.09
Hooker.....	1947	0.08	0.05		
	1948	0.12	0.09	0.87	0.21
	1949S*F*	0.14	0.09	0.59	0.17
	1950	0.12	0.07	0.82	0.26
	1951F*	0.17	0.10	2.02	0.55
	1952	0.12	0.06	0.60	0.16
Phelps.....	1947	0.06	0.03		
	1948F	0.14	0.06	0.37	0.09
	1949	0.15	0.08	1.33	0.36
	1950	0.14	0.07	0.96	0.31
	1951	0.13	0.10	1.08	0.33
	1952	0.08	0.06	1.06	0.32
UNFERTILIZED Wells.....	1947	0.56	0.41		
	1948	0.18	0.17	0.36	0.08
	1949	0.26	0.16	0.64	0.14
	1950F	0.28	0.20	1.12	0.24
	1951	0.39	0.26	1.39	0.33
	1952F	0.52	0.48	1.24	0.35
Boaz.....	1947	0.25	0.17		
	1948	0.11	0.13	0.47	0.10
	1949F*	0.09	0.05	0.78	0.16
	1950	0.33	0.19	0.83	0.17
	1951S*F*	0.24	0.16	1.53	0.29
	1952	0.36	0.30	0.32	0.08
Elam.....	1947	0.32	0.20		
	1948	0.20	0.13	0.68	0.15
	1949	0.16	0.14	0.94	0.16
	1950	0.33	0.21	0.34	0.10
	1951	0.37	0.26	2.35	0.47
	1952SF	0.21	0.16	1.97	0.40

*Only part of watershed treated with fertilizer in this season.

Bass catch rates improved in Wells Pond in 1951, following fertilizer treatment of its watershed in the fall of 1950, and in Boaz Pond in 1950 and 1952, following treatment of half of its watershed in 1949 and the other half in 1951, table 30. A drop in the bass catch rate occurred in Elam Pond in 1952, after treatment of its watershed in the spring of that year.

Bluegill catch rates rose slightly in Boaz in 1950, following treatment of half of its watershed in the fall of 1949, and in Wells Pond in 1951, following treatment of its watershed the previous fall. The bluegill catch rates improved in Boaz in 1951, following treatment of part of the watershed in the spring of that year, but they declined in 1952, after treatment of another part of the watershed in the autumn of 1951. They declined in Elam in 1952, following application of fertilizer to its watershed in the spring of that year.

That the field treatments may not have been the cause of improved bluegill catch rates in Wells is indicated by the trend in catch rates leading up to the field treatment of 1950; bluegill catch rates were showing year-to-year improvement before this treatment.

Examination of the catch rates for the directly fertilized ponds, Lauderdale, Hooker, and Phelps, in the fishing seasons following both direct and indirect fertilization shows that in some cases bluegill fishing was better in the season after a field treatment than before, table 30. However, in most of the cases the improved fishing could have been caused by the increased rates of pond fertilization, which were begun in the spring of 1950, rather than by the field fertilization.

While the evidence that field fertilization may have helped fishing in the Dixon Springs ponds is inconclusive, we should perhaps state our conclusion on pond fertilization as follows: that, in addition to any improvement in fishing success that might have resulted from watershed treatments, there is evidence of improvement in bluegill fishing from direct fertilization of the ponds. The pond owner who strives for better bluegill fishing should therefore not depend upon field fertilization, but should apply fertilizer directly to the pond.

ECONOMICS OF POND FERTILIZATION

Some pond owners will be interested in knowing whether the higher fish yields from fertilized ponds offset the cost of the fertilizers.

At current (1960) prices quoted by dealers in farm fertilizers, the treatments used on the Dixon Springs ponds in 1947-1949 would cost approximately \$10 per surface acre of water per year; the various treatments used on the three ponds in 1950 would average close to \$15 an acre, and the treatments used in 1951-1953 would cost \$20 per acre per year. In the following computations, cost for fertilizing the ponds does not include wages for men to do the mixing and spreading.

For the 5-year period 1948-1952, the average annual hook-and-line yield (bass and bluegills combined) from the fertilized ponds was 48 pounds per acre and from the control ponds 25 pounds per acre, table 16. Although the fertilized ponds were fished somewhat more heavily than the controls, we will assume that most of the 23 pounds greater annual yield of the fertilized ponds was attributable to fertilization. Dressed weights of bass and bluegills would amount to about two-thirds of their live weights. The 23 pounds additional fish yield would therefore shrink to about 15 pounds in dressing. The average yearly cost for fertilizer over the 5 years, 1948-1952, was about \$15 per acre; therefore the cost of the extra yield was approximately \$1.00 per pound of dressed fish.

Using data in table 16, we can make a similar computation for the same period for certain fertilized and unfertilized ponds having nearly equal fishing pressures: Lauderdale and Phelps to represent the fertilized ponds, Wells and Boaz the untreated ponds. The total fishing pressure for the two fertilized ponds (164 hours per acre per year) was nearly the same as that for the two control ponds (157 hours per acre per year). The per-acre yield averaged 47 pounds annually from the two fertilized ponds, 28 pounds annually from the two controls, a difference of 19 pounds as live fish or 13 pounds as dressed fish. Here the larger yield of the fertilized ponds was obtained

at a cost of about \$1.15 per pound of dressed fish.

Using selected data in table 15, we can compare costs for the periods of comparatively light and comparatively heavy fertilizer treatments. In the following computations, we have omitted data for 1947, as before, and have also omitted data for 1950, when the three ponds were fertilized at three different rates. For 1948 and 1949, the annual yields from the fertilized ponds averaged 15 pounds per acre more than the yields from the controls—10 pounds in terms of dressed fish. Since the annual cost of fertilizer in 1948 and 1949 was about \$10 per acre, the additional yield of dressed fish cost approximately \$1.00 per pound. For 1951 and 1952, the annual yield was 26 pounds greater per acre in the fertilized ponds than in the controls, or 17 pounds dressed weight. The cost of fertilizer during this period was about \$20 an acre, making the cost of the additional yield approximately \$1.18 per pound of dressed fish.

Also, we can estimate the cost per pound of fish attributed to fertilization in each of 4 years by comparing the records for Lauderdale and Wells, two ponds that were fished at nearly the same rates in most years, especially 1948–1951, and were fished in nearly the same way by the test anglers. As table 15 shows, the per-acre yield of bass and bluegills from Lauderdale was greater than that from Wells by 20 pounds in 1948, 17 pounds in 1949, 42 pounds in 1950, and 30 pounds in 1951. When we divide the appropriate cost figures, \$10 an acre in 1948 and 1949, \$20 an acre in 1950 and 1951, by the dressed weights (13, 11, 28, and 20 pounds), we find that the greater yields from Lauderdale Pond cost approximately \$0.77 a pound in 1948, \$0.91 in 1949, \$0.71 in 1950, and \$1.00 in 1951.

In the vicinity of Dixon Springs, the approximate retail price of dressed carp from the Ohio River is 25 cents a pound, of dressed channel catfish 60 cents a pound. If we were to judge the pond fertilization program at Dixon Springs solely by the dollar and cents food value of the fish produced, we should conclude that fertilization was not economically justified.

However, as a rule pond owners will not base their decisions to fertilize or not to fertilize their ponds solely on economic grounds. Instead, they will base such decisions largely on the belief that fertilization will or will not provide them and their families with more fishing fun.

In some instances, the size of the pond, the type of ownership, and the financial position of the owner will influence the decision. For example, a pond of an acre or more might be left unfertilized and a pond of one-half acre might be fertilized, because the smaller pond requires a smaller outlay for fertilizer. A pond owned by a single individual might be left unfertilized and an equivalent pond owned by a club might be fertilized, because the cost of the club-owned pond can be borne by several members and requires no great outlay for any one individual. A pond might be left unfertilized if owned by a person who has a small cash income, or who fishes principally for food, and an equivalent pond might be fertilized if owned by an individual who has a moderate or large cash income, or who fishes principally for sport.

As the Dixon Springs experiment shows, ponds seem to differ in their responses to fertilization; fertilization might be economically profitable in some ponds but not in others.

ANGLERS' EVALUATION OF PONDS

While we have shown that pond fertilization was of some benefit to bluegill fishing, there is a question whether the differences between fertilized and unfertilized ponds in the quality of fishing were great enough to be detected by fishermen. No comments were heard or reported that would indicate that the permit fishermen thought that Hooker and Phelps (the two permit ponds that were fertilized) provided them with better fishing than the unfertilized permit ponds or other unfertilized ponds in the neighborhood. The test anglers, who visited all six ponds at weekly intervals, generally had the most success at Lauderdale Pond. Their preferences were recorded only after the 1952 fishing season, but it was obvious from our conversations with them that Lauderdale was the favorite among the six ponds.

Charles R. Peters, test angler in 1952, stated that Lauderdale had given him the most pleasure, and he rated the other ponds in the following order: Elam, Phelps, Wells, Boaz, and Hooker. Thus, he ranked the fertilized ponds first, third, and sixth. Examination of his catch records suggests that his reaction to various ponds might have been affected more strongly by his success in catching bluegills than by his success in catching bass.

Use by the public was somewhat more intensive for the two permit ponds that were fertilized (Hooker and Phelps—especially Hooker) than for the two that were not (Boaz and Elam), table 20. It seems doubtful, however, if catch rates were enough higher for the fertilized ponds to explain their greater popularity with fishermen. Hooker and Phelps ponds were seldom as good as the unfertilized ponds for bass fishing and in some years were not so good as one or more unfertilized ponds for bluegill fishing. Time spent by permit fishermen in the 6 years of the experiment totaled 924 hours at Hooker, 374 hours at Phelps, 356 hours at Boaz, and 217 hours at Elam. The 6-year average catch-per-man-hour rate for bass in the most heavily fished fertilized pond (Hooker) was below the rate for the least fished control pond open to the public (Elam). The bluegill fishing in Hooker was inferior to that in Elam in terms of number of fish per hour but essentially the same in pounds per hour.

The differences in fishing pressure on the four permit ponds may have been related to the various inconveniences fishermen put up with in getting to and from each pond, such as the number of gates to be opened and closed, the number of fences to be climbed, or the walking distance to the pond. Hooker Pond was the easiest to reach, Elam Pond the most difficult. The inconveniences of reaching Phelps and Boaz were about equal. Quite possibly the availability of shade, ease of walking around the ponds, and general attractiveness of the ponds were factors that made the fishermen decide to fish certain ponds more often than others. Fishermen were not guided to the fertilized ponds by news releases or other publicity; only a few of them knew that some ponds were being treated.

SUMMARY

1. Six ponds, each of about 1-1½ acres, in southern Illinois were used in an experiment, 1947-1952, to measure the effect of pond fertilization on sport fishing. The effect of fertilization was measured by the sizes of the fish caught, the annual hook-and-line yields, and the catch rates per fisherman-hour.

2. The ponds were stocked with large-mouth bass 6 to 10 inches long (total length) and bluegills about 1 inch long.

3. Three of the ponds were treated with chemical fertilizers containing nitrogen, phosphorus, and potassium, in some years at rates less than, and in others at rates approximately equal to, the minimum rate suggested for ponds in Alabama by Swingle & Smith (1942:16-8). The other three ponds (the controls) were not treated.

4. Creel data were obtained through (1) public fishing under a permit system that allowed fishermen relatively free access to four of the ponds and (2) test fishing by anglers (one each year) employed by the Illinois Natural History Survey to fish each of the six ponds for a 2-hour period each week.

5. In 1953, after the ponds had been closed to fishing for a year, the fish in all six ponds were killed with rotenone, and a census was made of the fish population of each pond.

6. Growths of filamentous algae, which appeared on the fertilized ponds in some years, were at times a hindrance to fishermen.

7. Dense stands of a water plant, *Chara* spp., died in the fertilized ponds in the first summer of treatment, while equally dense stands of this plant continued to grow in the control ponds.

8. Blooms of plankton algae were denser and more prolonged in the fertilized than in the control ponds.

9. The bass taken from the fertilized ponds averaged smaller but the bluegills larger than those from the control ponds. Bluegills of 8-8½ inches were more common from fertilized than from unfertilized ponds.

10. During the 5 years of fishing for both bass and bluegills (in the year after the ponds were stocked, bluegills were too

small to be kept), the total harvest of bass, by weight, was slightly less from the fertilized ponds than from the controls; the bluegill harvest from the fertilized ponds was 2.7 times that from the controls. The ratio by weight of bass to bluegills was 1:3 in the fertilized ponds, 1:1 in the controls.

11. One of the fertilized ponds was superior to all others in both bass and bluegill fishing. The three fertilized ponds ranked 1, 5, and 6 in terms of both number and weight of bass harvested per hour; 1, 3, and 4 in terms of number of bluegills harvested per hour; and 1, 2, and 3 in terms of weight of bluegills harvested per hour.

12. There is a statistical possibility that through chance alone the fertilized ponds would have ranked better than the controls as bluegill fishing ponds even if no fertilizer had been used.

13. No well-defined year-to-year trend in catch rates for bass was observed during the experiment. The trend in bluegill fishing in both fertilized and control ponds was toward year-to-year improvement in the first 4 years of bluegill fishing.

14. The two ponds, one fertilized and one control, with the smallest total number of man-hours of fishing had the highest catch rates of harvestable bass. Under equal or nearly equal fishing pressures, bass fishing was in some instances better in the fertilized ponds, in other instances better in the controls; bluegill fishing was consistently better in the fertilized ponds.

15. In September, 1953, the standing crops of bass and bluegills (all sizes) in the three fertilized ponds averaged 292 pounds per acre, in the three controls 238 pounds per acre (ratio 1.2:1). The num-

ber of bass 10 inches or longer was approximately the same in fertilized as in control ponds; the number of bluegills 6 inches or longer was 1.3 times as great in fertilized as in unfertilized ponds.

16. The hook-and-line yields of bass and bluegills in 1952, the last year the ponds were fished, were equivalent to 20 per cent of the 1953 standing crops in the fertilized ponds and 16 per cent of the standing crops in the control ponds.

17. Judged by the populations of fish of desirable sizes present at the time of the 1953 census (bass 10 inches or longer, bluegills 6 inches or longer), the hook-and-line harvest appears to have been more efficient for bass in the control ponds and more efficient for bluegills in the fertilized ponds.

18. Surprisingly little correlation was found between numbers of bass and bluegills of harvestable sizes in the ponds in 1953 and the record of fishing success in the preceding years.

19. The fertilization program used at Dixon Springs was of apparent benefit to bluegill fishing but of doubtful benefit to bass fishing; any benefits derived from direct fertilization of ponds were in addition to benefits that may have resulted from fertilization of the pond watersheds.

20. Comparison of yields from the fertilized and unfertilized ponds at Dixon Springs shows that the greater yields of fish from the fertilized ponds were obtained at costs estimated to range from \$0.71 to \$1.18 a pound.

21. Whether the improvement in the quality of bluegill fishing attributed to fertilization was great enough to be detected by fishermen is questionable for at least two of the three fertilized ponds.

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Printed by Authority of
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Sex Ratios and Age Ratios in North American Ducks

FRANK C. BELLROSE
THOMAS G. SCOTT
ARTHUR S. HAWKINS
JESSOP B. LOW

STATE OF ILLINOIS

OTTO KERNER, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION

WILLIAM SYLVESTER WHITE, *Director*

NATURAL HISTORY SURVEY DIVISION

HARLOW B. MILLS, *Chief*

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*Employed on co-operative projects with one of several agencies: University of Illinois, Illinois Agricultural Extension Service, Illinois Department of Conservation, National Science Foundation, United States Department of Agriculture, United States Fish and Wildlife Service, United States Public Health Service, and others.

This paper is a contribution from the Section of Wildlife Research.

FOREWORD

THE present publication illustrates again the importance of continuing certain types of research over a long period of time in order to get data which allow for significant deductions to be made. Further, as the investigation reported here is in a sense pioneering work, much thought has had to go into data analysis, into weighing the importance of data, and into attempts to find the significance and relative importance of the many facts discovered. These operations have necessitated the delay of publication until it was felt that the data and conclusions could withstand the inspection of waterfowl scientists and other biologists and, more importantly, contribute significantly to our understanding of North American waterfowl.

Certainly, the analysis of the data and the developing of the philosophy of the place of sex ratios and age ratios in population mechanics was not an easy task; the data have been about as abstruse as any collected in waterfowl research.

The project was conceived by Arthur S. Hawkins in 1938, while he was employed by the Illinois Natural History Survey, and great credit for far-sightedness must go to him. It must be remembered that, at the time of the project's initiation, even good

aging techniques were still to be perfected. When Mr. Hawkins entered the armed forces in 1941, Mr. Bellrose took over the study. Dr. Low contributed to the project in Illinois from 1941 to 1943 and furnished Utah data after he left Illinois.

Through the last 20 years, Mr. Bellrose has carried the brunt of the load, and in recent years Dr. Scott has contributed immeasurably to data analysis and the preparation of the study for publication, as well as arranging with the National Science Foundation for the financing of publication costs. Others, mentioned in the text, have given unselfishly of their time and talents.

Last, but by no means least, we should mention the long hours—often extending into the night—spent by James S. Ayars, Technical Editor, in working with the authors and the data. His was, as usual, a heavy and significant contribution.

It is my hope, as well as that of the authors, that this contribution will be of value in the understanding and the management of waterfowl populations over a wide area and for a long time to come.

HARLOW B. MILLS, *Chief*
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Trapping and banding ducks at the Chautauqua National Wildlife Refuge near Havana, Illinois, November, 1939.

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Determining the sex and age of ducks killed by hunters in the Illinois River valley, November, 1952.

Sex Ratios and Age Ratios in North American Ducks

FRANK C. BELLROSE, THOMAS G. SCOTT,
ARTHUR S. HAWKINS, AND JESSOP B. LOW*

MANAGEMENT of waterfowl includes the intelligent manipulation of their populations. The sex classes and age classes of various species of ducks constitute measurable elements of the populations. The present study deals primarily with sex ratios and age ratios and the ways in which they relate to population productivity. Nearly three decades ago Leopold (1933:165-6) wrote: "All measurements of either game population or game productivity are enhanced in their significance and value if the sex and age as well as the number of individuals be determined."

Although observations on the age ratios of ducks have been recorded for more than a decade and on the sex ratios for more than two decades, the true relationship of these ratios to productivity has not been well understood. Much of the difficulty in understanding this relationship has stemmed from observed differences in sex and age ratios between species, regions, and seasons. Often the reported samples have favored one sex or age class so markedly as to indicate bias.

Some investigators of sex ratios in waterfowl have pointed out mathematical bias resulting from shortcomings in the techniques used and biological bias resulting from unusual responses of the birds to seasonal changes. Early in this study it was apparent that age ratio data were subject to bias resulting from the same causes. Moreover, there appeared to be additional causes for bias in the data relating to both sex and age ratios. Despite many difficulties in obtaining reliable data, progress has been made in interpreting the role of sex and age ratios in the productivity of waterfowl.

In this paper, sex ratios are expressed usually as the per cent of a population consisting of drakes, the ratio of hens to drakes, or the number of drakes per hen; age ratios as the per cent of a population consisting of juveniles (ducks that have reached the flying stage but have not completed 1 year of life), the number of juveniles per adult, or the ratio of adults to juveniles.

The statistical significance of differences among samples or among assumed ratios was determined by either making chi-square tests or referring to tables presented by Mainland, Herrera, & Sutcliffe (1956). These methods assume that the samples taken were independent observations of the characteristics being measured and that the samples were taken from homogeneous populations. It seems likely that often these assumptions were not entirely met. Therefore, the results of these tests should be viewed cautiously. In those instances in which there is a very low probability that the differences could have been due to chance, it seems very likely that the differences were real.

Technical names and all but one of the common names of ducks discussed in this paper are from the Fifth Edition of the *Check-List of North American Birds* (Anonymous 1957). Because of its wide usage among hunters and its inclusion in the Fourth Edition of the *Check-List*, the name *baldpate* was used in place of *American widgeon*. The listing of species in the tables is in accordance with the phylogenetic arrangement that was in use at the time the greater part of the study reported here was being made.

ACKNOWLEDGMENTS AND SOURCES OF DATA

The study on which this paper is based was begun in 1938. Most of the data presented here were collected by personnel of the Illinois Natural History Survey

*Frank C. Bellrose and Thomas G. Scott are members of the staff of the Illinois Natural History Survey. The other two authors were members of the staff in the initial stages of the project reported here. Arthur S. Hawkins is now Biologist, United States Fish and Wildlife Service, stationed at Minneapolis, Minnesota; Jessop B. Low is Leader, Utah Cooperative Wildlife Research Unit, Utah State University, Logan.

from inspection of trapped ducks and bagged ducks taken in Illinois from early autumn of 1939 through 1959. Other extensive data were obtained as follows: from Arthur S. Hawkins and employees of the Delta Waterfowl Research Station and the Canadian Wildlife Service, who checked the age and sex of ducks in Manitoba in 1946 and several subsequent years; from Hawkins and John J. Lynch of the U. S. Fish and Wildlife Service and Frank C. Bellrose, who checked hunters' bags in the Stuttgart, Arkansas, area at various times from 1946 through 1959; from Jessop B. Low, who obtained bag inspection data in Utah in 1943 and 1944; and from Noland F. Nelson of the Utah Department of Fish and Game, who continued this work from 1946 through 1950.

Data obtained from biologists other than the authors of this paper have been acknowledged, when possible, in connection with the table or graph presenting the data. Uncredited data from certain areas should be ascribed to the individuals listed below: John M. Anderson, data from Winous Point Gun Club, near Sandusky, Ohio; George C. Arthur, Illinois Department of Conservation, data from the Mississippi River in Illinois; Merrill C. Hammond, U. S. Fish and Wildlife Service, data from North Dakota; L. R. Jahn, Wildlife Management Institute, and Ralph Hopkins, Wisconsin Conservation Department, data from Wisconsin; Herbert J. Miller and personnel of Pittman-Robertson Project No. 45-R, Michigan Department of Conservation, data from Michigan; Charles T. Shanks, Missouri Conservation Commission, data from Missouri; Harvey W. Miller and John H. Wampole, formerly with the Nebraska Game, Forestation, and Parks Commission, data from Nebraska; T. Stuart Critcher and Yates M. Barber, North Carolina Wildlife Resources Commission, data from North Carolina; and Charles K. Rawls, Jr., Tennessee Game and Fish Commission, data from Tennessee.

Roberts Mann, David H. Thompson, and John Jedlicka of the Forest Preserve District of Cook County, along with personnel of the Illinois Natural History Survey, co-operated in the banding program at McGinnis Slough, Cook County,

Illinois. Robert D. Crompton and other field assistants of the Illinois Natural History Survey conducted the banding programs at Lake Chautauqua, Mason County, Illinois.

Aelred D. Geis of the U. S. Fish and Wildlife Service and Stuart H. Mann of the Illinois Natural History Survey assisted in the statistical analysis of the sex and age ratio data and gave valuable suggestions for improving the manuscript. George H. Kelker of Utah State University read the manuscript and made helpful comments. Mrs. Frances D. Robbins, formerly with the Illinois Natural History Survey, and Ralph E. Yeatter, now and for many years a member of the Survey staff, aided in the preparation of the paper. James S. Ayars of the Natural History Survey edited the manuscript.

Appreciation is extended to all who assisted in the gathering of data and the preparation of the paper.

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SEX RATIOS

For several decades, waterfowl hunters and ornithologists have noted a lack of balance in the ratios of drakes to hens in the populations of various species of ducks. Some of them have called attention to the greater numbers of drakes and have expressed concern because they believed the "extra" drakes served no useful reproductive function. Others have called attention to the unequal sex ratios as possible signs of sick populations.

For example, Leopold (1933:111) in discussing sex ratios in ducks stated:

All of Lincoln's evidence points toward the existence of a seriously deranged sex ratio. How long it has existed, or what causes it, remains unknown. It is barely possible, of course, that it always has existed, and represents a normal condition, but this seems improbable, especially in a group of species less strongly monogamous than most other birds. The reader should note that here again we have an excess of males associated with a known decline in population, and a known trend toward adversity in recent climatic and range conditions.

Although unbalanced sex ratios among ducks were noted many years ago, little

research was done on the subject until about 1940.

Determining the causes of unbalance in sex ratios among ducks is difficult because the birds have a high degree of mobility and because each of the species involved has its own population structures, migration schedules, and migration routes. Also, in some species the drakes and hens do not migrate at the same times or along the same routes. In short, the determination of sex composition in duck populations presents a difficult sampling problem complicated by differences in species, seasons, and places, and by sampling techniques that are inadequate.

Previous Sex Ratio Studies

In order to provide for an understanding of the various ways in which calculated sex ratios may vary with sampling methods or with location and season of observation, a brief review of the most important papers on waterfowl sex ratios is offered.

Over 25 years ago Lincoln (1932) asked and answered the question: "Do drakes outnumber sies?" Since that time, observers have agreed unanimously with Lincoln's answer that drakes outnumber hens in the North American duck population. There has been but little agreement, however, on the degree of unbalance or the reliability of the various methods used to obtain sex ratio data.

Lincoln (1932:3, 16) assumed that drakes and hens were taken in traps in the same proportions in which they occurred in nature but that hunters selected drakes in preference to hens. He found that drakes comprised 59.7 per cent of 40,904 ducks representing 10 species trapped and banded in North America and included in his study.

From extensive observations made during trapping and banding of ducks at Avery Island, Louisiana, during 1934-1938, McIlhenny (1940:91-3) concluded that there was a seasonal variation in sex ratios and presented data on the pintail (*Anas acuta*), blue-winged teal (*Anas discors*), ring-necked duck (*Aythya collaris*), and lesser scaup (*Aythya affinis*) which showed that, while drakes consistently outnumbered hens, the difference was less marked in autumn than in winter

and spring. Of 51,884 ducks of nine species banded by McIlhenny, 67 per cent were drakes, and only 33 per cent were hens. McIlhenny (1940:87), like Lincoln, believed that hunters selected drakes in preference to hens.

In Minnesota, Erickson (1943:32-3) recorded the sex of 6,008 ducks of 15 species observed in the field during the spring migration periods of 1938, 1939, and 1940; drakes comprised 65 per cent of the populations sampled. There were significant differences between sex ratios in two periods, one early and one late in the spring. Erickson concluded from his study that "the disparity of the sex ratios obtained by trapping have been overemphasized."

On the basis of limited data, Petrides (1944:565-67) concluded that the available evidence, though inadequate, indicated "that banding traps may be less attractive to female than male ducks." He compared the sex ratios of 6,359 banded ducks—mallard (*Anas platyrhynchos*), pintail, and lesser scaup—killed by hunters, and represented by return cards in the files of the U. S. Fish and Wildlife Service, with the sex ratios of trapped ducks of the same species as recorded by Lincoln (1932:16) prior to hunting. He found that there was "negligible sex selection by hunters." Sight observations that Petrides (1944:568-70) made in and near Washington, D. C., in 1941-1943 on 25,870 ducks (most of them pintails) showed 56 per cent were drakes. After examination of the locations of banding stations, Petrides suggested that early studies of the sex ratios of banded ducks "might have been affected by faulty geographic sampling as well as by selectivity of traps."

On the West Coast, Beer (1945:118-20) found that sex ratios obtained from field observations were more reliable than those obtained from inspection of hunters' bags. He reported that the calculated sex ratios for most species of ducks remained the same throughout winter as well as early and late in the period of migration. His data, which included 10,180 ducks of 15 species, showed a drake to hen ratio of 1.18:1 (54 per cent drakes).

In eastern Washington, Yocom (1949:226-7), after comparing sex ratios from

hunters' reports (176 males to 100 females) with those from field observations in November and December (118 males to 100 females), decided that selective shooting accounted for the larger numbers of drakes among mallards reported by hunters. In 8,805 mallards observed in the field from late November to mid-March, the drake to hen ratio was 109:100.

Johnsgard & Buss (1956:384-5) took sex ratios of ducks in central Washington from February 15 to May 16, 1954. From their observations they concluded:

Sex ratios of any single species varied at any given time as a result of at least two influences. First, sex ratios were more unbalanced on areas subject to human disturbance. Paired birds were the first to flush and the last to return to a disturbed area. . . .

Second, sex ratios during any single period varied with the characteristics of the habitat.

After taking sex ratios of four species of ducks in the Netherlands, Lebret (1950:17) stated:

Sex-ratio field counts of migratory duck do not reveal the sex-ratio in the species as a whole, but only differences in the migration of the sexes—provided the difficulty of different sex distribution within the sample areas had been eliminated.

Each of the methods of sampling for sex ratios—field observations, trapping, and inspection of hunters' bags—has inherent weaknesses that produce biased data. Only by determining the magnitude of bias and correcting for it when necessary can the degree of unbalance in sex ratios among waterfowl be ascertained.

Sex Criteria

The sex of a duck may be determined by one or more of the following characteristics: (1) plumage, (2) bill color, and (3) presence or absence of a penis. As a means for distinguishing sex, each characteristic has advantages and disadvantages.

In most species of ducks, differences in the plumage color between drakes and hens usually make possible the distinguishing of sexes at considerable distances in the field. However, at certain times of the year, the plumages of hens and drakes of most species are so similar as to make field separation difficult or impossible.

Drakes in eclipse plumage are so similar in appearance to hens of the same species that usually a bird in this condition

must be in the hand before the sex can be ascertained. The sex of ducks in juvenile plumage also is difficult to ascertain unless the birds are in the hand; in some species no plumage differences are visible until the ducklings are several weeks old. For example, in the wood duck (*Aix sponsa*), the two white bars which extend upward behind each eye of the male and serve to distinguish the male from the female do not begin to appear until the duckling is 4 to 5 weeks of age. In the redhead (*Aythya americana*), the male first shows the distinguishing marks, delicate white vermiculations of the scapulars and interscapulars, at an age of 5 to 6 weeks (Weller 1957:19). In the canvasback (*Aythya valisineria*), the male can be separated from the female by gray vermiculations on the scapulars of the male at the age of about 4 weeks (Dzubin 1959:289).

The black duck (*Anas rubripes*) is the only common duck in the United States in which drake and hen adult plumage at all times of the year are so similar as to make difficult the distinguishing of sex. Several other ducks have plumages in which the drake and hen are very similar, but these kinds are generally uncommon and have very limited ranges in the United States. They include the black-bellied tree duck (*Dendrocygna autumnalis*), fulvous tree duck (*Dendrocygna bicolor*), Mexican duck (*Anas diazi*), and mottled duck (*Anas fulvigula*).

The bill color is of most value for distinguishing the sex in certain species when the individuals are juveniles or are adults in eclipse plumages. On the bills of most species there are fine shades of color difference that distinguish between the sexes. In certain dabbling species, the hen is characterized by dark dots, spots, or blotches at the base and sides of the upper mandible; rarely are such markings found on the bill of the drake. Species in this category are the mallard, black duck, gadwall (*Anas strepera*), green-winged teal (*Anas carolinensis*), blue-winged teal, and shoveler (*Spatula clypeata*).

The most reliable characteristic for sexing ducks in which the plumage does not readily distinguish the sexes is the presence or absence of a penis, fig. 1. The technique of examining the cloaca for the

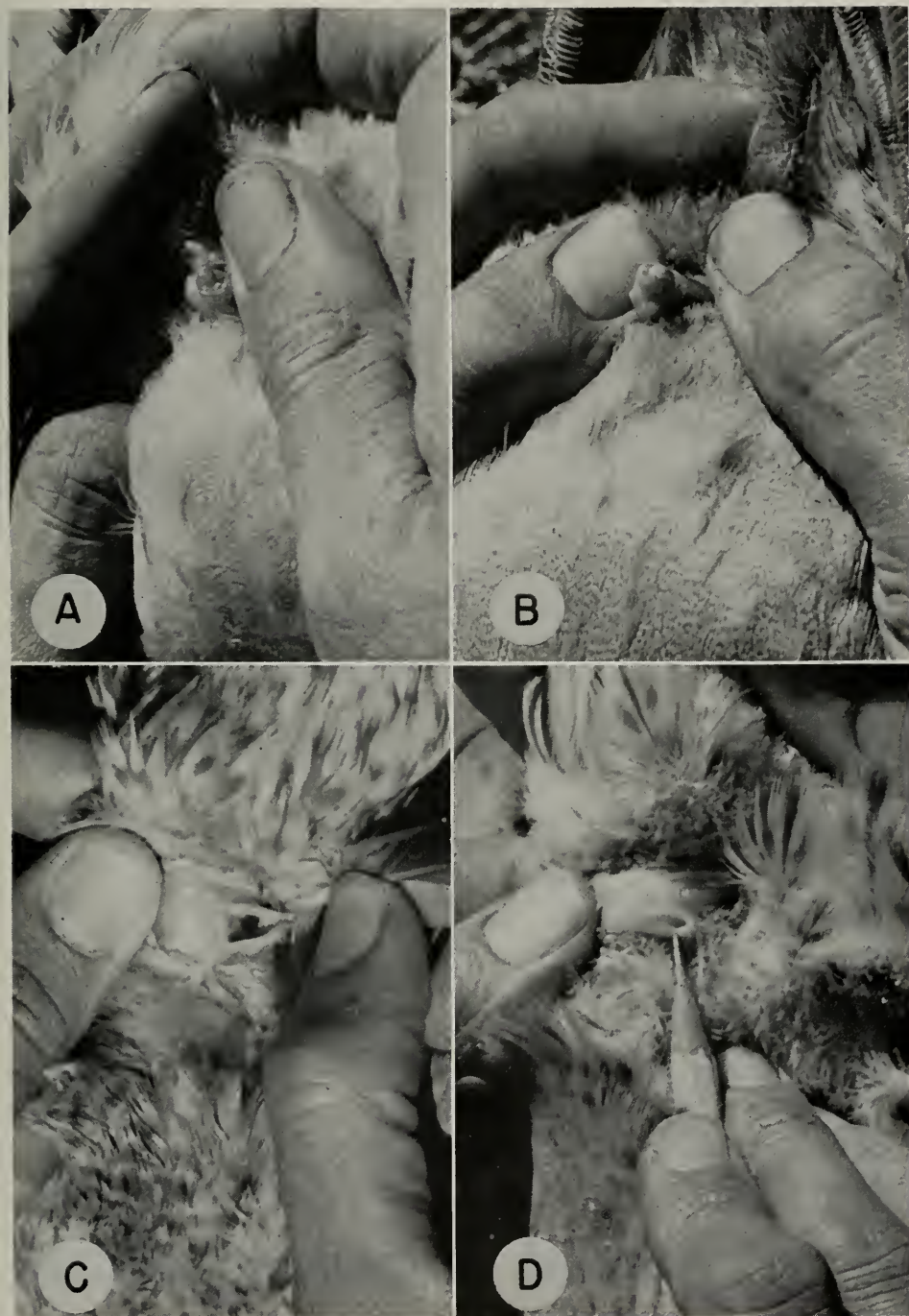


Fig. 1.—Waterfowl being sexed and aged by examination of cloaca; *A*, juvenile male mallard, with small penis; *B*, adult male mallard, with large penis; *C*, juvenile female mallard, with closed oviduct and with bursa of Fabricius disclosed by feather probe (bursa present in juvenile, both female and male, absent in adult); *D*, adult female mallard, with open oviduct (oviduct open in adult female, closed in juvenile).

occurrence of the penis has been described by Hochbaum (1942:302). Ducklings only a few days old have been successfully sexed by this method.

In the study reported here, trapped or bagged ducks that could not be readily sexed by plumage or by bill color were sexed by cloacal characters.

Sampling Populations for Sex Ratios

In the present study, several methods were used to sample waterfowl populations for sex ratios. These were (1) examination of trapped ducks, (2) inspection of ducks in hunters' bags, (3) obser-

vation of ducks in the field, and (+) examination of disease victims. In endeavoring to determine the true sex ratios existing among ducks in nature, we found that certain biases were implicit in each method. Biases in some methods were such that they could be corrected or adjusted to the extent that fairly valid ratios could be derived.

Following is a review of the four methods used in sampling duck populations for sex ratios, the advantages of these methods, and the disadvantages.

Examination of Trapped Ducks.—From the start of trapping and banding

Table 1.—Drake percentages in mallards trapped and banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, and in year-of-banding recoveries, 1939–1944 and 1947–1950. Preponderance of drakes or hens recovered is indicated by differences in percentage points: + for drakes, — for hens.

YEAR	DUCKS TRAPPED AND BANDED			RECOVERIES IN YEAR OF BANDING			DIFFERENCE IN PERCENTAGE POINTS
	Total Number	Number Drakes	Per Cent Drakes	Total Number	Number Drakes	Per Cent Drakes	
1939.....	3,474	2,574	74.1	142	114	80.3	+ 6.2
1940.....	5,840	4,262	73.0	442	332	75.1	+ 2.1
1941.....	4,834	3,200	66.2	143	100	69.9	+ 3.7
1942.....	6,854	4,859	70.9	512	393	76.8	+ 5.9
1943.....	6,445	4,655	72.2	374	284	75.9	+ 3.7
1944.....	3,465	2,734	78.9	222	181	81.5	+ 2.6
1947.....	1,786	1,481	82.9	80	65	81.3	- 1.6
1948.....	1,667	1,332	79.9	17	15	88.2	+ 8.3
1949.....	3,254	2,478	76.2	128	99	77.3	+ 1.1
1950.....	1,116	808	72.4	68	51	75.0	+ 2.6
<i>All years.....</i>	<i>38,735</i>	<i>28,383</i>	<i>73.3</i>	<i>2,128</i>	<i>1,634</i>	<i>76.8</i>	<i>+ 3.5</i>

Table 2.—Drake percentages in black ducks trapped and banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, and in year-of-banding recoveries, 1939–1944 and 1947–1950. Preponderance of drakes or hens recovered is indicated by differences in percentage points: + for drakes, — for hens.

YEAR	DUCKS TRAPPED AND BANDED			RECOVERIES IN YEAR OF BANDING			DIFFERENCE IN PERCENTAGE POINTS
	Total Number	Number Drakes	Per Cent Drakes	Total Number	Number Drakes	Per Cent Drakes	
1939.....	132	102	77.3	5	4	80.0	+ 2.7
1940.....	189	161	85.2	13	10	76.9	- 8.3
1941.....	549	329	59.9	7	5	71.4	+ 11.5
1942.....	507	348	68.6	56	42	75.0	+ 6.4
1943.....	417	303	72.7	28	18	64.3	- 8.4
1944.....	276	185	67.0	21	15	71.4	+ 4.4
1947.....	174	133	76.4	.....	.....	.....	.....
1948.....	112	87	77.7	.....	.....	.....	.....
1949.....	571	381	66.7	25	14	56.0	- 10.7
1950.....	150	110	73.3	9	5	55.6	- 17.7
<i>All years ...</i>	<i>3,077</i>	<i>2,139</i>	<i>69.5</i>	<i>164</i>	<i>113</i>	<i>68.0</i>	<i>- 0.6</i>

operations in 1939 at the Chautauqua National Wildlife Refuge, near Havana, in Mason County, Illinois, records were kept of the sex of each duck that was trapped and banded. In all of these records, the relative numbers of drakes among the mallards and black ducks were so high as to arouse suspicion that the baited, funnel-type traps being used were selective for drakes, tables 1 and 2. At McGinnis Slough, in Cook County, the relative numbers of drakes among mallards and black ducks taken in similar traps were somewhat lower, tables 3 and 4, but they were high enough to indicate that the traps tended to take disproportionate numbers of drakes.

Drakes made up about three-fourths of the mallards taken in banding traps at Lake Chautauqua in the years 1939-1944 and 1947-1950, table 1. Evidence that,

among mallards, the drakes are trapped much more readily than the hens is found by comparing figures derived from trapping and banding (73.3 per cent drakes, table 1) with figures derived from inspection of hunters' bags (56.5 per cent drakes for the years 1939-1950 in table 13, or 53.8 per cent drakes after a correction factor of 1.05 has been applied to compensate for hunter preference for drakes). Mallards entered the Lake Chautauqua traps at the rate of 1.4 drakes to 1 hen. The use of data derived by one method to check on the data derived by another is discussed in the section on inspection of hunters' bags.

Further evidence that mallard drakes are trapped much more readily than the hens is found by comparing the relative numbers of birds of each sex that were re-trapped in the same season at two Illinois

Table 3.—Drake percentages in mallards trapped and banded at McGinnis Slough, Cook County, Illinois, and in year-of-banding recoveries, 1941-1947. Preponderance of drakes or hens recovered is indicated by differences in percentage points: + for drakes, — for hens.

YEAR	DUCKS TRAPPED AND BANDED			RECOVERIES IN YEAR OF BANDING			DIFFERENCE IN PERCENTAGE POINTS
	Total Number	Number Drakes	Per Cent Drakes	Total Number	Number Drakes	Per Cent Drakes	
1941	312	195	62.5	21	14	66.7	+ 4.2
1942	1,882	1,128	59.9	143	92	64.3	+ 4.4
1943	3,009	1,922	63.9	138	78	56.5	- 7.4
1944	1,778	967	54.4	168	100	59.5	+ 5.1
1945	2,287	1,492	65.2	170	107	62.9	- 2.3
1946	1,624	860	53.0	126	61	48.4	- 4.6
1947	970	556	57.3	56	37	66.1	+ 8.8
<i>All years</i>	<i>11,862</i>	<i>7,120</i>	<i>60.0</i>	<i>822</i>	<i>489</i>	<i>59.5</i>	<i>- 0.5</i>

Table 4.—Drake percentages in black ducks trapped and banded at McGinnis Slough, Cook County, Illinois, and in year-of-banding recoveries, 1941-1947. Preponderance of drakes or hens recovered is indicated by differences in percentage points: + for drakes, — for hens.

YEAR	DUCKS TRAPPED AND BANDED			RECOVERIES IN YEAR OF BANDING			DIFFERENCE IN PERCENTAGE POINTS
	Total Number	Number Drakes	Per Cent Drakes	Total Number	Number Drakes	Per Cent Drakes	
1941	659	406	61.6	38	26	68.4	+ 6.8
1942	1,069	645	60.3	91	47	51.7	- 8.6
1943	962	595	61.9	44	24	54.6	- 7.3
1944	852	490	57.5	93	55	59.1	+ 1.6
1945	716	462	64.5	54	42	77.8	+ 13.3
1946	629	385	61.2	38	24	63.2	+ 2.0
1947	659	388	58.9	23	10	43.5	- 15.4
<i>All years</i>	<i>5,546</i>	<i>3,371</i>	<i>60.8</i>	<i>381</i>	<i>228</i>	<i>59.8</i>	<i>- 1.0</i>

banding stations, tables 5 and 6. Chi-square tests disclosed that the relative number of drakes retrapped was signifi-

the sexes in proneness to enter traps. Hawkins found in banding blue-winged teals near the Pas, Manitoba, in 1951 that 39.0

Table 5.—Number of drake and hen mallards trapped and banded, and number and per cent of each group retrapped at least once in the same season, at the Chautauqua National Wildlife Refuge, near Havana, Illinois, 1940 and 1941. Sex selectivity of baited traps is indicated by the ratio of drakes to hens among retrapped ducks.

YEAR	PERIOD	NUMBER OF DRAKES		PER CENT OF DRAKES RE-TRAPPED	NUMBER OF HENS		PER CENT OF HENS RE-TRAPPED	RATIO OF RE-TRAPPED HENS TO RE-TRAPPED DRAKES
		Trapped and Banded	Re-trapped		Trapped and Banded	Re-trapped		
1940	Oct. 11-24	793	168	21.2	507	83	16.4	1:1.29
	Oct. 25-Nov. 7	591	111	18.8	102	3	2.9	1:6.48
	Nov. 8-21	918	86	9.4	284	11	3.9	1:2.41
	Nov. 22-Dec. 15	1,939	110	5.7	667	43	6.5	1:0.87
	<i>Oct. 11-Dec. 15</i>	<i>4,241</i>	<i>475</i>	<i>11.2</i>	<i>1,560</i>	<i>140</i>	<i>9.0</i>	<i>1:1.24*</i>
1941	Nov. 1-7	595	36	6.1	299	8	2.7	1:2.26
	Nov. 8-21	563	97	17.2	218	19	8.7	1:1.98
	Nov. 22-Dec. 5	1,476	115	7.8	716	33	4.6	1:1.70
	Dec. 6-25	529	22	4.2	353	3	0.9	1:4.76
	<i>Nov. 1-Dec. 25</i>	<i>3,163</i>	<i>270</i>	<i>8.5</i>	<i>1,586</i>	<i>63</i>	<i>4.0</i>	<i>1:2.13†</i>

*Probability of difference being due to chance less than 0.02 ($X^2=5.95$, 1 d.f.).
 †Probability of difference being due to chance less than 0.0005 ($X^2=33.67$, 1 d.f.).

Table 6.—Number of drake and hen mallards trapped and banded, and number and per cent of each group retrapped at least once in the same season, at Spring Lake National Wildlife Refuge, near Savanna, Illinois, 1946. Sex selectivity of baited traps is indicated by the ratio of drakes to hens among retrapped ducks.

PERIOD	NUMBER OF DRAKES		PER CENT OF DRAKES RE-TRAPPED	NUMBER OF HENS		PER CENT OF HENS RE-TRAPPED	RATIO OF RE-TRAPPED HENS TO RE-TRAPPED DRAKES
	Trapped and Banded	Re-trapped		Trapped and Banded	Re-trapped		
Oct. 17-24.....	173	117	67.6	121	53	43.8	1:1.54
Oct. 15-31.....	209	103	49.3	129	38	29.5	1:1.67
Nov. 1-7.....	445	171	38.4	258	75	29.1	1:1.32
Nov. 8-14.....	568	129	22.7	367	72	19.6	1:1.16
Nov. 15-21.....	189	28	14.8	108	9	8.3	1:1.78
<i>Oct. 17-Nov. 21.....</i>	<i>1,584</i>	<i>548</i>	<i>34.6</i>	<i>983</i>	<i>247</i>	<i>25.1</i>	<i>1:1.38*</i>

*Probability of difference being due to chance less than 0.0005 ($X^2=25.39$, 1 d.f.).

cantly greater than the relative number of hens retrapped.

Records obtained from blue-winged teals trapped and banded and later retrapped in 1944 at McGinnis Slough (Mann, Thompson, & Jedlicka 1947: 141) indicate that, at that time and place, there was no important difference between

per cent of the drakes and 31.5 per cent of the hens trapped and banded were later retrapped.

The greater tendency for mallard drakes than for hens to enter the baited, funnel-type traps at Lake Chautauqua was remarkably consistent through most of the autumn; the drake percentage in

traps increased as the drake percentage in the population increased (indicated by bag checks, fig. 2).

In the mallard and the black duck, differences in behavior may contribute to differences in numbers between males and females trapped or retrapped. One differ-

blind near the traps on Lake Chautauqua showed that, when mallards were massed around the traps, the drakes were more forceful than hens in pushing their way into the traps.

Chi-square tests of data in tables 1, 2, 3, and 4 indicate that in both the mallard

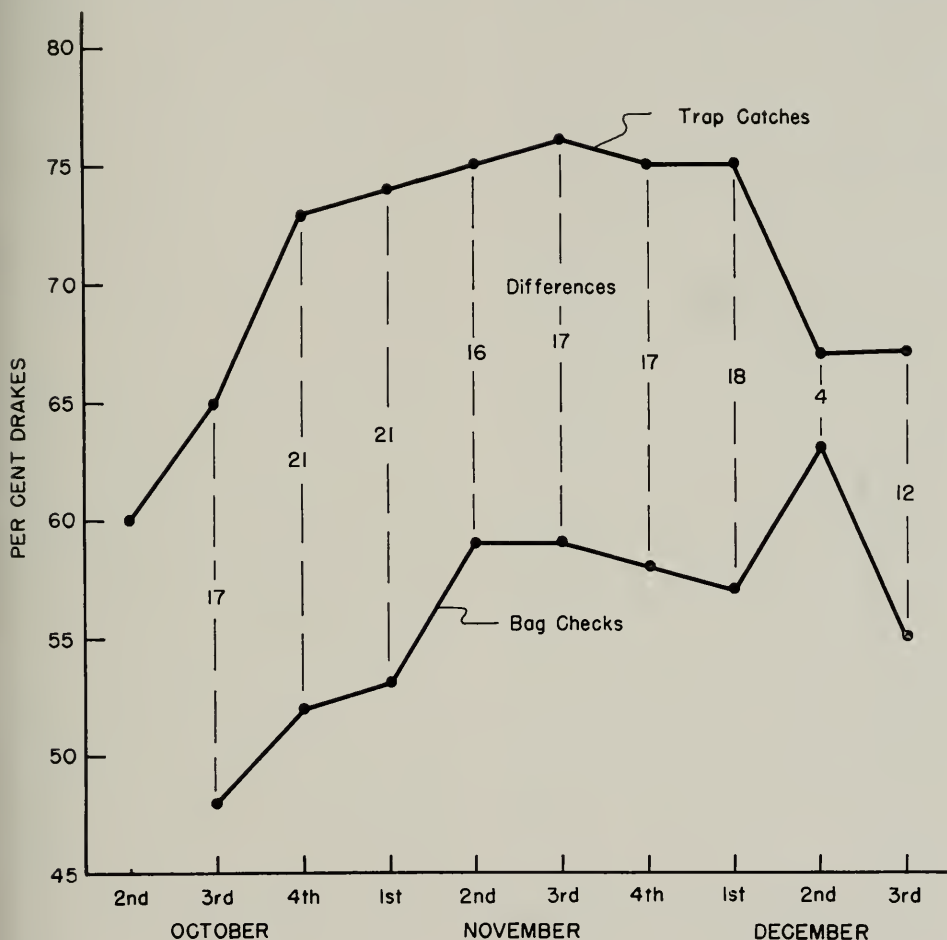


Fig. 2.—Week-to-week changes in the drake percentage of the autumn flight of mallards in Illinois, as indicated by two sampling methods: checks of mallards in hunters' bags and inspection of mallards caught in banding traps. Bag data are for the Illinois River valley, 1939-1949; trap data are for Lake Chautauqua, 1939-1944 and 1947.

ence in behavior is the greater aggressiveness of the drakes; this may occur because of differences in food demands during the fall. Studies on food consumption of penned wild mallards (Jordan 1953:122) revealed that, during the fall and winter, drakes consumed 15 per cent more food than did hens. Observations made from a

and the black duck the propensity of drakes to enter traps was significantly greater at Lake Chautauqua than at McGinnis Slough. The population density was much greater at Lake Chautauqua than at McGinnis Slough. Consequently, the competition for bait at trap sites was greater, the aggressiveness of drakes was

greater, and the trap catch of drakes was greater at Lake Chautauqua than at McGinnis Slough.

Not all traps have been found selective for drakes. Merrill C. Hammond, biologist of the U. S. Fish and Wildlife Service, in an unpublished report prepared in 1949, stated that he captured more hens than drakes in a gate-type trap placed on shore adjacent to marsh vegetation in the Lower Souris National Wildlife Refuge in north-central North Dakota. He speculated that because of nesting activity hens were more accustomed than drakes to walking on land through tall vegetation; therefore, they would enter a trap on the shore more readily than drakes.

Supporting evidence for Hammond's speculation was obtained by Hawkins at Delta, Manitoba, in 1950. He found that in two funnel-type traps placed only a few yards apart, one in the water and the other on land, the trap in water captured 2.2 drake mallards per hen, whereas the trap on land captured only 1.5 drake mallards per hen.

Inspection of Hunters' Bags.—Inspection of ducks in hunters' bags in fall and early winter for obtaining sex ratio data was found to have some advantages. Late-molting adult drakes can be separated from hens, which they resemble during the eclipse molt, and the sexes of juveniles can be distinguished; comparisons can then be made between sex ratios of adults and those of juveniles. Available data indicate that most sex ratios derived from inspection of hunters' bags are only slightly biased, usually in favor of drakes.

Tendencies for hunters to bag proportionately more ducks of one sex than those of the other depend (1) partly upon the chronology of migration of the ducks, (2) partly upon the preferences of hunters, and (3) partly upon hunting conditions and upon skill of hunters.

Differences in chronology of migration may expose birds of one of the sexes to a greater number of hunters or make them more vulnerable to hunting than birds of the other sex.

A striking example of the relationship between the chronology of migration and shooting pressure was found in the redhead. Adult drake redheads move from

their breeding grounds in southern Manitoba to more northern marshes for molting, while the hens remain on the breeding grounds, according to Milton W. Weller in an unpublished report prepared at the University of Missouri in 1954. Because bag checks showed that adult drakes comprised only a small proportion of a large kill of redheads made in southern Manitoba, Weller deduced that the southward migration of adult drake redheads involved much longer flights than the migration of adult hens. Evidence suggesting that the migration of adult drake redheads to the wintering grounds consists of long flights is given by band recoveries reported by Cartwright & Law (1952:11), who showed a much lower year-of-banding recovery rate for these birds than for juvenile males or for females.

Geis (1959:256-7) found that, among canvasbacks, adult hens and juveniles of both sexes had a higher percentage of band recoveries early in the hunting season than did adult drakes, while adult drakes had a higher percentage of band recoveries on the wintering grounds than did either adult hens or juveniles. Band recovery rates indicate that adult drakes in the canvasback, like those in the redhead, make longer flights along migration routes than do adult hens.

That hunters may prefer to shoot ducks of one sex rather than those of the other is shown by interviews with hunters and by analysis of data on duck kill. It seems logical to assume that hunters, faced with a species having a drake more brilliantly colored than the hen and given an equal opportunity at birds of each sex, would pick the more brightly colored bird, as McIlhenny (1940:87) suggested.

In Illinois, the mallard and the black duck have similar habits and behavior. On the wing, the black duck drake is identical in appearance to the hen, whereas the mallard drake, during most of the Illinois hunting season, is readily distinguishable from the hen.

That under certain circumstances hunters demonstrate a preference for drakes that are brightly colored and readily distinguishable from hens may be shown through study of the results of banding operations at Lake Chautauqua, 1939-

1944 and 1947-1950, tables 1 and 2. The drake percentage among the birds trapped can be compared with the drake percentage among the birds represented by band recoveries. Too few black ducks were banded to permit valid comparisons each year; however, when the data for the black duck were totaled for the 10 years of study, no marked hunter preference for drakes was evident in this species. In the case of the mallard, the preponderance of drakes among the banded ducks recovered indicated a consistent year-to-year tendency for hunters to select drakes to a somewhat greater extent than hens, there being only 1 year (1947) in which hunter preference for drakes was not evident.

In the period 1939-1950, the drake percentage among 2,128 mallards reported shot in the year they were banded (76.8 per cent) was shown by a chi-square test to be significantly greater than the drake percentage among 38,735 mallards that were trapped and banded (73.3 per cent), table 1. These percentage figures indicate that drakes were 1.05 times as likely to be taken by hunters as were hens. This estimate of the greater likelihood of mallard drakes being taken by hunters can be used as a correction factor to compensate for hunter preference in calculations employing other data involving the same species, the same area, the same period of years, and the same time of year. The ducks represented in table 13 were mallards shot by hunters in approximately the same area and times of year as those represented in table 1. Calculations based on data in table 13 show that for 1939-1950, the period of years covered in table 1, 56.5 per cent of the mallards checked in hunters' bags were drakes. Allowance can be made for hunter preference for drakes by applying the correction factor 1.05 to this percentage figure. The result is 53.8 per cent, which is believed to represent the average drake component of the fall populations of mallards in the Illinois River valley in the period 1939-1950.

That the degree to which hunters select drakes rather than hens may be influenced by hunting conditions and by the skill of the hunters, as well as by personal preferences of hunters, can be shown by comparison of band recovery

data from mallards banded at Lake Chautauqua with similar data from mallards banded at McGinnis Slough, tables 1 and 3. Bandings at Lake Chautauqua were made in the heart of the duck hunting club area of Illinois, where ducks were comparatively numerous and where hunters, many of them experienced shots, could afford to be selective of their targets. Bandings at McGinnis Slough were in an area where competition for ducks was much keener than near Lake Chautauqua and where hunters tended to shoot at extreme ranges. Analysis of band recovery data for mallards banded at McGinnis Slough showed no hunter preference for drakes, table 3.

Even hunters who have access to the best shooting areas vary from year to year in the degree to which they choose drakes. At Stuttgart, Arkansas, in 1946, when hunting conditions were unfavorable because high water had dispersed the ducks through the swamps and when the bag limit was seven ducks, drakes comprised only 51.0 per cent of 3,350 mallards checked in hunters' bags. In the 1947 season, when hunting was much better in the Stuttgart region and the bag limit was only four, drakes comprised 59.5 per cent of the 3,317 mallards checked. Of the Stuttgart region in the hunting season of 1945-46, Hawkins, Bellrose, & Smith (1946:398) wrote: "Hunting is so good in the Grand Prairie area that the better hunters can, and a few do, deliberately select drakes." In the sample of bagged ducks they inspected, 55.8 per cent were drakes.

Field Observations.— Observations on living ducks in the field are a means of providing sex data on large samples of many species. With such data, no compensation is needed for differences in trap and hunter selectivity. It is almost impossible, however, to make a sufficient number of random counts to insure an adequate cross section of the population of a flyway or other large area. Field counts of the drakes and hens in duck populations are more readily taken in late winter and early spring than at any other time. Early in the fall the juvenile and eclipse plumages make distinguishing between the sexes difficult, and hunting activity at that time usually makes ducks

Table 7.—Drake percentages in pintails, redheads, and lesser scaups observed in the field on the Lower Souris National Wildlife Refuge, North Dakota, 1948.*

SPECIES	DATE	NUMBER OF DUCKS	PER CENT DRAKES
Pintail	April 22	75	56
	May 6	157	70
	May 13	204	82
Redhead	May 21	133	77
	May 6	66	53
	May 13	143	61
Lesser scaup	May 21	137	58
	April 22	243	59
	May 5 and 6	486	61
	May 13	120	68

*Unpublished data collected by Merrill C. Hammond, Biologist, U. S. Fish and Wildlife Service.

wary and difficult to approach. In winter and spring, ducks are less wary, and most of them are in their nuptial plumage; thus, in most species, the sex of each bird can be distinguished in the field with facility.

In field tests conducted in 1947 by University of Wisconsin students in game management and ornithology, the observations of several students were remarkably uniform with respect to the sex ratios they found in flocks numbering up to several hundred ducks. It seems safe to assume that field observations conducted with reasonable care can provide accurate sex ratios for flocks of ducks present in late winter and early spring.

Merrill C. Hammond of the U. S. Fish and Wildlife Service (unpublished data) found marked variations among waterfowl sex ratios observed on different sample areas or at different times, table 7. In a report, he pointed out the care necessary in making sex ratio counts in the spring on the breeding grounds (Hammond 1949: 8-9). He concluded from his observations that:

These wide differences between certain sample areas where all [or] very nearly all of the population was counted indicate that on any given day the population on a marsh or water area is not entirely homogeneous with respects to distribution of the sexes. As Hochbaum and others have pointed out, the mated birds may frequent areas near to nesting habitats, while excess males may associate with a few females on open sloughs, channels or bays. Individual flocks and groups, even using similar habitats, for one reason or another may at times vary greatly.

A few field observations on living ducks were used in the present study to provide sex ratio data on several duck species.

Examination of Disease Victims.

—At times ducks that are victims of disease offer waterfowl biologists opportunities to obtain sex ratio data. Although available information indicates that botulism and fowl cholera are not more specific for one sex than the other, it is suggested that sex ratio counts of living ducks in a disease area be made concurrently with counts of the disease victims for purposes of evaluating the relative susceptibility of drakes and hens.

Sex ratios among ducks that were victims of disease in several parts of North America were considered in the study reported here.

Sex Ratios in Different Age Classes

It is important to determine sex ratios of ducks in the different age classes as a means of discovering at what stage, or stages, of life disparity in numbers between the sexes occurs. Are there more males than females at hatching? During the first year? During adult life?

For convenience in studying sex ratios in wild birds, Mayr (1939:156-7) grouped sex ratios into three classes based upon age of birds: (1) primary sex ratio: the ratio between the sexes at fertilization; (2) secondary sex ratio: the ratio between the sexes at hatching; (3) tertiary sex ratio: the ratio between the sexes during adult life.

It is considered desirable in the present study to amend Mayr's classification to include a sex ratio for juveniles. The revised classification is as follows:

1. Primary sex ratio: the ratio between the sexes at fertilization.
2. Secondary sex ratio: the ratio between the sexes at hatching.
3. Tertiary sex ratio: the ratio between the sexes from the time of hatching to adulthood (the beginning of the first breeding season).
4. Quaternary sex ratio: the ratio between the sexes in adult life.

Primary Sex Ratios.—There is little available information on the primary sex ratio in ducks. Among wood ducks a primary sex ratio of 51 males to 49 females was determined for 574 fertile eggs by

checking the sex of 85 duck embryos that died, 419 ducklings that died from paratyphoid, and 70 survivors. Hochbaum (1944:51) similarly classified embryonic and hatched ducklings of the canvasback and found 344 males and 345 females.

Secondary Sex Ratios.—The secondary sex ratios found by Sowls (1955: 164) for four species of ducks are recorded in table 8. Statistical analysis of the data, which are from a study at Delta, Manitoba, revealed that at hatching the sex ratios of mallard, pintail, redhead, and canvasback ducklings did not depart significantly from a 50:50 ratio. However, in each of the four species, males exceeded females in numbers; when the data for all four species were combined, there was a slight but statistically significant preponderance of males. The findings suggest that the female embryos in these species were not as hardy as the embryos of the males. They are supported by the

Table 8.—Male percentages found at hatching of artificially incubated eggs of four duck species at Delta,* Manitoba, and one, the wood duck, in Illinois.

SPECIES	NUMBER OF DUCKLINGS			PER CENT MALE
	Male	Female	Total	
Wood duck...	548	564	1,112	49.3 NS
Mallard*....	394	369	763	51.6 NS
Pintail*....	424	405	829	51.1 NS
Redhead*....	342	294	636	53.8 NS
Canvas-back*....	315	307	622	50.6 NS

NS = Not significantly different from 50 per cent at the 0.05 probability level.
*Sowls 1955:164.

Table 9.—Drake percentages in juveniles of four species of ducks trapped in Manitoba, 1948–1950.

SPECIES	NUMBER OF DUCKS TRAPPED	PER CENT DRAKES
Mallard.....	1,720	50.2 NS
Pintail.....	767	43.5*
Blue-winged teal....	4,613	47.9*
Redhead.....	757	47.3 NS
All species.....	4,857	47.9*

NS = Not significantly different from 50 per cent at the 0.05 probability level.
*Significantly lower than 50 per cent at the 0.05 probability level.

Table 10.—Drake percentages in juveniles of nine species of ducks trapped in Saskatchewan, 1947–1950.*

SPECIES	NUMBER OF DUCKS TRAPPED	PER CENT DRAKES
Mallard.....	308	51.6 NS
Gadwall.....	725	49.5 NS
Baldpate.....	672	56.5**
Pintail.....	273	55.3 NS
Green-winged teal...	27	44.4 NS
Blue-winged teal....	245	48.6 NS
Shoveler.....	490	50.6 NS
Canvasback.....	69	56.5 NS
Lesser scaup.....	87	51.7 NS
All species.....	2,896	51.9

NS = Not significantly different from 50 per cent at the 0.05 probability level.
*Unpublished data provided by John J. Lynch, U. S. Fish and Wildlife Service.
**Significantly greater than 50 per cent at the 0.01 probability level.

Table 11.—Drake percentages in juveniles of eight species of ducks trapped in Alberta, 1947–1950.*

SPECIES	NUMBER OF DUCKS TRAPPED	PER CENT DRAKES
Mallard.....	209	51.2 NS
Gadwall.....	26	57.7 NS
Baldpate.....	116	50.9 NS
Pintail.....	714	54.3**
Green-winged teal...	18	50.0 NS
Blue-winged teal....	164	56.1 NS
Shoveler.....	311	50.5 NS
Lesser scaup.....	43	60.5 NS
All species.....	1,601	53.3

NS = Not significantly different from 50 per cent at the 0.05 probability level.
*Unpublished data provided by Allen G. Smith, U. S. Fish and Wildlife Service.
**Significant departure from 50 per cent at the 0.05 probability level.

finding that females made up 52.7 per cent of 165 dead canvasback embryos reported by Hochbaum (1944:51). In an Illinois incubation experiment involving over 1,000 wood duck eggs, slightly more, but not significantly more, than half of the ducklings at hatching were females, table 8.

Tertiary Sex Ratios.—Tertiary sex ratios were derived from figures of juvenile ducks live trapped on the Canadian breeding grounds, most of them during July and August, tables 9–11. These ducks were 1 to 2 months in age. The juveniles in Manitoba were obtained by

drive trapping and bait trapping, while those in Saskatchewan and Alberta were obtained by drive trapping only.

Sex ratios of ducklings in three of the four species trapped in Manitoba, table 9, showed relatively greater numbers of hens than of drakes. Statistical analysis showed that the pintails and blue-winged

teals of Manitoba had highly significant excess numbers of hens. Of nine species of ducks trapped in Saskatchewan, only the baldpate (*Mareca americana*) had a significantly higher number of drakes, table 10. Of eight species of ducklings that were trapped in Alberta, table 11, seven had sex ratios that did not depart

Table 12.—Drake percentages in ducks of nine species, juvenile and adult classes, checked in hunters' bags in Manitoba, 1946–1949.

SPECIES	JUVENILES		ADULTS	
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes
Mallard.....	6,473	53.2**	1,786	49.3 NS
Gadwall.....	339	60.2**	137	43.1 NS
Baldpate.....	822	51.0 NS	147	59.2*
Pintail.....	1,145	51.7 NS	293	38.6**
Green-winged teal.....	257	57.2*	58	24.1**
Shoveler.....	342	50.9 NS	81	32.1**
Redhead.....	1,110	51.0 NS	139	51.8 NS
Canvasback.....	2,116	39.8**	232	49.1 NS
Lesser scaup.....	558	47.1 NS	302	60.3**
<i>All species.....</i>	<i>13,162</i>	<i>50.5</i>	<i>3,175</i>	<i>48.7</i>

NS = Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

Table 13.—Drake percentages in mallards, juvenile and adult classes, checked in hunters' bags in Illinois, 1939–1955 and 1959.

YEAR	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE PERCENTAGES	PER CENT DRAKES IN BOTH CLASSES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes		
1939.....	1,337	54.6**	924	65.7**	+ 11.1	59.6
1940.....	2,093	49.3 NS	1,471	58.5*	+ 9.2	53.1
1941.....	2,255	45.4**	2,226	68.7**	+ 23.3	57.0
1942.....	980	46.9 NS	829	67.4**	+ 20.5	56.3
1943.....	939	56.1**	483	67.5**	+ 11.4	60.0
1944.....	1,176	48.5 NS	991	68.5**	+ 20.0	57.6
1945.....	898	50.7 NS	1,149	67.0**	+ 16.3	59.8
1946.....	731	42.0**	586	61.1**	+ 19.1	50.5
1947.....	572	49.1 NS	242	67.8*	+ 18.7	54.5
1948.....	924	50.5 NS	291	60.8**	+ 10.3	53.0
1949.....	294	57.1*	303	67.7**	+ 10.6	63.5
1950.....	351	46.4 NS	230	63.5**	+ 17.1	53.2
1951.....	517	49.5 NS	302	60.9**	+ 11.4	53.7
1952.....	754	52.7 NS	453	62.0**	+ 9.3	56.2
1953.....	687	48.6 NS	465	64.5**	+ 15.9	55.0
1954.....	218	51.8 NS	240	70.8**	+ 19.0	61.8
1955.....	478	55.6**	268	64.5**	+ 8.9	58.8
1959.....	63	52.4 NS	184	66.3**	+ 13.9	62.8
<i>All years....</i>	<i>15,267</i>	<i>50.4 NS</i>	<i>11,637</i>	<i>65.2**</i>	<i>+ 14.8</i>	<i>57.0</i>

NS = Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

significantly from 50:50; the pintail had significantly more drakes.

Among 419 captive wood duck ducklings that died from paratyphoid in a hatchery at Barrington, Illinois, 51.5 per cent were females. Of 96 young wood ducks that died from other causes early in life, 48.8 per cent were females.

Information on the sex ratios of juvenile ducks 4 to 9 months old was ob-

dent in the calculated sex ratios for juveniles, tables 13 and 14. Highly significant deviations from a 50:50 sex ratio in the juvenile class occurred for the pintail, green-winged teal, and canvasback. The most marked deviation in the juvenile class was for the canvasback; in this species the drake segment was 39.8 per cent of 2,116 juvenile birds inspected early in the fall in Manitoba, table 12,

Table 14.—Drake percentages in ducks of nine species, juvenile and adult classes, checked in hunters' bags in Illinois, 1939–1949.

SPECIES	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE (-) PERCENTAGES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes	
Black duck.....	371	51.7 NS	194	70.6**	+ 18.9
Gadwall.....	613	51.1 NS	182	58.2*	+ 7.1
Baldpate.....	1,128	51.5 NS	416	61.8**	+ 10.3
Pintail.....	2,281	58.3**	1,200	62.7**	+ 4.4
Green-winged teal.....	399	60.9**	160	57.5 NS	- 3.4
Shoveler.....	516	55.4*	110	52.7 NS	- 2.7
Ring-necked duck.....	717	53.8*	190	51.0 NS	- 2.8
Canvasback.....	352	64.5**	171	66.1**	+ 1.6
Lesser scaup.....	841	54.2*	441	61.0**	+ 6.8
<i>All species.....</i>	<i>7,218</i>	<i>55.6**</i>	<i>3,064</i>	<i>61.4**</i>	<i>5.8</i>

NS = Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

tained from the inspection of hunters' bags in Manitoba, Illinois, and other parts of the Mississippi Flyway.

In Manitoba during early fall, the sex ratios for a group of juvenile ducks taken by hunters were nearly balanced, table 12. Four of the nine species represented, the mallard, gadwall, green-winged teal, and canvasback, departed significantly from balanced sex ratios. The slight preponderance of males for the mallard (53.2 per cent males) was statistically significant because of the very large sample size. The gadwall and the green-winged teal had significantly more males than females, while the canvasback had significantly more females.

In Illinois, drakes made up 49.3 per cent of 12,550 juvenile mallards in hunters' bags inspected in the period 1939–1950 and 50.4 per cent of 15,267 inspected in the period 1939–1955 and 1959, table 13. Perhaps because of differences in migration schedules, considerable differences among species were evi-

and 64.5 per cent of 352 juvenile birds checked later in Illinois, table 14.

When sex ratios were calculated for juveniles from many areas in the Mississippi Flyway for 1946–1948, tables 15–17, the effect of seasonal and regional variations in the data appeared to be minimized. Deviations from a 50:50 sex ratio among juveniles were significant or highly significant statistically for only three species in 1946 and two species in 1948, tables 15 and 17. In 1947, deviations from a 50:50 ratio in juveniles were significant for one species and highly significant for four of the species listed, table 16.

The above data, obtained from trapping of ducks in the breeding season and from checking hunters' bags during the fall, indicate that the sex ratios in the tertiary or juvenile age class are close to 50:50. Local variations that exist appear to result from different seasonal movements of birds of the two sexes.

Quaternary Sex Ratios.—Populations of adult ducks normally show much

larger drake segments than do those of juveniles. Exceptions are evident in the adult ducks shot by hunters in Manitoba, table 12. The data reveal for adult mallards, gadwalls, pintails, green-winged teals, shovellers, and canvasbacks in this area more hens than drakes. For pintails, green-winged teals, and shovellers, the excess of hens was highly significant. This situation came about through the move-

ment of many adult drakes from the area prior to the opening of the hunting season. Of the species for which records are available, only baldpates, redheads, and lesser scaups showed more drakes than hens in hunters' bags in Manitoba.

Statistical analysis of data obtained from inspection of adult ducks in hunters' bags to the south, in Illinois, revealed that in most years there were significantly

Table 15.—Drake percentages in ducks of 12 species, juvenile and adult classes, checked in hunters' bags in the Mississippi Flyway, 1946.

SPECIES	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE (-) PERCENTAGES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes	
Mallard.....	5,350	47.5**	3,593	57.1**	+ 9.6
Black duck.....	966	47.3 NS	215	68.3**	+ 21.0
Gadwall.....	474	49.7 NS	249	55.0 NS	+ 5.3
Baldpate.....	462	46.1 NS	119	60.5*	+ 14.4
Pintail.....	681	54.9*	426	65.0**	+ 10.1
Green-winged teal.....	360	51.6 NS	157	52.2 NS	+ 0.6
Blue-winged teal.....	411	46.9 NS	122	35.2**	- 11.7
Shoveler.....	380	49.4 NS	125	42.4 NS	- 7.0
Redhead.....	806	52.4 NS	204	55.3 NS	+ 2.9
Ring-necked duck.....	416	51.4 NS	113	55.7 NS	+ 4.3
Canvasback.....	1,663	45.1**	208	44.2 NS	- 0.9
Lesser scaup.....	510	48.6 NS	232	51.7 NS	+ 3.1
<i>All species.....</i>	<i>12,479</i>	<i>48.3</i>	<i>5,763</i>	<i>56.4</i>	<i>8.1</i>

NS = Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

Table 16.—Drake percentages in ducks of 12 species, juvenile and adult classes, checked in hunters' bags in the Mississippi Flyway, 1947.

SPECIES	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE (-) PERCENTAGES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes	
Mallard.....	7,094	52.5**	2,604	60.8**	+ 8.3
Black duck.....	1,021	49.9 NS	398	55.0 NS	+ 5.1
Gadwall.....	647	51.3 NS	208	63.5**	+ 12.2
Baldpate.....	750	48.4 NS	236	60.6**	+ 12.2
Pintail.....	1,261	53.2*	437	53.8 NS	+ 0.6
Green-winged teal.....	574	62.2**	173	50.9 NS	- 11.3
Blue-winged teal.....	1,235	41.1**	360	31.4 NS	- 9.7
Shoveler.....	284	50.7 NS	56	39.3 NS	- 11.4
Redhead.....	396	52.8 NS	91	35.2**	- 17.6
Ring-necked duck.....	291	46.4 NS	85	48.2 NS	+ 1.8
Canvasback.....	562	38.8**	143	61.5**	+ 22.7
Lesser scaup.....	468	46.4 NS	310	66.1**	+ 19.7
<i>All species.....</i>	<i>14,583</i>	<i>50.8 NS</i>	<i>5,101</i>	<i>56.8**</i>	<i>6.0</i>

NS = Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

more drakes than hens in the samples, tables 13 and 14. Records on 9,725 adult mallards over a period of 12 years, 1939–1950, revealed an average of 65.7 per cent drakes, with annual percentages ranging from 58.5 to 68.7 per cent; records on 11,637 adult mallards for a period of 18 years, 1939–1955 and 1959, revealed an average of 65.2 per cent drakes, with annual percentages ranging from 58.5 to 70.8, table 13. The adult class of nine other species of ducks in hunters' bags over an 11-year period, 1939–1949, contained 61.4 per cent drakes; annual per-

centages ranged from 70.6 per cent drakes for the black duck to 51.0 per cent drakes for the ring-necked duck, table 14.

Statistical analysis of data compiled from the inspection of adult mallards, gadwalls, baldpates, pintails, green-winged teals, shovelers, and redheads in hunters' bags in Utah over a period of 6 years, 1943–1944 and 1946–1949, table 18, revealed a highly significant greater number of drakes than hens for all species excepting the redhead.

Data from the Mississippi Flyway for 3 years, 1946–1948, tables 15–17, indi-

Table 17.—Drake percentages in ducks of 11 species, juvenile and adult classes, checked in hunters' bags in the Mississippi Flyway, 1948.

SPECIES	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE (–) PERCENTAGES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes	
Mallard.....	7,416	52.5**	2,556	58.0**	+ 5.5
Black duck.....	871	47.2 NS	378	59.0**	+ 11.8
Gadwall.....	214	53.7 NS	31	58.0 NS	+ 4.3
Baldpate.....	1,068	49.5 NS	141	50.3 NS	+ 0.8
Pintail.....	727	51.8 NS	216	56.5 NS	+ 4.7
Green-winged teal.....	493	55.6*	130	49.2 NS	– 6.4
Blue-winged teal.....	255	47.5 NS	63	30.1**	– 17.4
Redhead.....	680	46.6 NS	82	51.2 NS	+ 4.6
Ring-necked duck.....	336	48.2 NS	66	56.0 NS	+ 7.8
Canvasback.....	520	48.5 NS	66	43.9 NS	– 4.6
Lesser scaup.....	547	49.2 NS	186	67.7**	+ 18.5
<i>All species.....</i>	<i>13,127</i>	<i>51.2 NS</i>	<i>3,915</i>	<i>58.1**</i>	<i>6.9</i>

NS=Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

Table 18.—Drake percentages in ducks of seven species, juvenile and adult classes, checked in hunters' bags in Utah, 1943, 1944, and 1946–1949.

SPECIES	JUVENILES		ADULTS		DIFFERENCE BETWEEN ADULT (+) AND JUVENILE (–) PERCENTAGES
	Number Checked	Per Cent Drakes	Number Checked	Per Cent Drakes	
Mallard.....	2,027	52.3*	2,350	62.3**	+ 10.0
Gadwall.....	1,679	53.5**	1,955	67.7**	+ 14.2
Baldpate.....	2,352	52.2*	1,183	61.5**	+ 9.3
Pintail.....	4,230	46.8**	6,499	53.6**	+ 6.8
Green-winged teal.....	2,828	58.0**	4,183	72.9**	+ 14.9
Shoveler.....	2,480	53.7**	1,674	65.6**	+ 11.9
Redhead.....	734	57.3**	214	48.6 NS	– 8.7
<i>All species.....</i>	<i>16,330</i>	<i>52.5**</i>	<i>18,058</i>	<i>62.3**</i>	<i>9.9</i>

NS=Not a significant departure from 50 per cent at the 0.05 probability level.

*Significant departure from 50 per cent at the 0.05 probability level.

**Significant departure from 50 per cent at the 0.01 probability level.

cate that adult drakes consistently, but not in all cases significantly, outnumbered adult hens in hunters' bags for mallards, black ducks, gadwalls, baldpates, pintails, and lesser scaups. By contrast, the records show that hens were more numerous than drakes among the blue-winged teals and shovelers inspected, and year-to-year variation was evident in sex ratios among green-winged teals, redheads, ring-necked ducks, and canvasbacks. Tables 15-17 indicate the statistical significance of the departure of these sex ratios from balanced sex ratios.

Seasonal Variations in Sex Ratios

Sex ratios for many species of ducks were found to vary from week to week in any given area as the composition of the local population changed with arrival and departure of flocks containing varying numbers of drakes and hens. The seasonal changes in sex ratios were ascertained through data obtained from trapping, inspection of hunters' bags, field observation, and tallies of victims of disease.

Sex Ratios in Fall and Winter.—The sex ratios of the most important species of ducks taken by hunters during the fall hunting season in areas from the breeding grounds to the wintering grounds are indicated in table 19. Sex ratios taken in southern Manitoba for the pintail, shoveler, and canvasback suggest that large numbers of drakes make an early depart-

ure from the heavily gunned marshes of Delta and Netley. This early movement may be initially either south or north, the direction depending somewhat upon the species. Information on the early flights of drake pintails, some of which arrive at the Gulf of Mexico in August, indicates that the initial movement of these birds is south. Records of large numbers of drake canvasbacks and redheads in northern Manitoba and Saskatchewan marshes suggest that these birds probably move north from their breeding grounds before they move south.

In most species of ducks for which data are available, drakes made up a smaller proportion of the hunters' kill in Manitoba than in three states to the south, North Dakota, Illinois, and Tennessee, table 19. These data indicate that in most species more drakes than hens left Manitoba in advance of the hunting season there. A trend toward an increasing drake predominance from north to south was evident as far south as Tennessee. In all but two species for which data are available, the gadwall and shoveler, the predominance of drakes was greater in Tennessee than in Illinois. In Louisiana, a significantly greater number of hens than of drakes was evident in two species, the mallard and the pintail, and approximately balanced sex ratios were evident in four species. In all six species it was apparent that more drakes than hens were

Table 19.—Drake percentages in 12 species of ducks

SPECIES	MANITOBA, 1946-1949		NORTH DAKOTA, 1949		ILLINOIS, 1939-1950	
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes
Mallard.....	8,259	52.4	2,212	57.5	22,275	56.5
Black duck.....					565	58.2
Gadwall.....	476	55.2	579	54.1	795	52.7
Baldpate.....	969	52.2	146	53.4	1,544	54.3
Pintail.....	1,438	49.0	210	53.0	3,481	59.8
Green-winged teal.....	315	51.1	86	53.5	559	59.9
Shoveler.....	423	47.3	137	51.0	626	54.9
Redhead.....			342	55.0		
Ring-necked duck.....					907	53.2
Canvasback.....	2,348	40.7	281	56.0	931	65.3
Lesser scaup.....	860	51.6	136	52.2	2,012	56.2
Ruddy duck.....						

*Sources of data for the various regions: Manitoba, Delta Waterfowl Research Station; North Dakota, Hjelle mission (personal communication); Louisiana, Richard Yancey, Louisiana Wild Life and Fisheries Commission (personal communication); North Carolina Wildlife Resources Commission (personal communication).

north of Louisiana during a large part of the hunting season.

For all species of ducks except the shoveler, the differences in sex ratios among the various regions were statistically significant. This conclusion must be taken with some reservations because the span of years involved was not the same for each of the various areas. Some of the observed differences could be due to time as well as geographic differences.

Among adult mallards bagged in Illinois, 1939-1955, there was a steady increase in the drake segment of the fall population through the third week in November, fig. 3. The ratio between the sexes then tended to stabilize for a period, followed by an increase in the drake segment in the wintering population, usually present in Illinois after the first week in December. In Utah, sex ratios of adult mallards bagged were relatively stable throughout the autumns of several years in which bag checks were recorded, fig. 4.

Adult pintails bagged in Illinois and those bagged in Utah showed little variation in sex ratios during the fall. Adult green-winged teals and shovelers bagged in Utah showed an increase in the drake segment as the season progressed, fig. 4.

In only a few species do there appear to be differences in seasonal movement between drakes and hens of the juvenile class. In Manitoba, the canvasback had an unusually large number of hens among

the juveniles bagged, table 12; in Illinois, on the other hand, this species had an unusually large number of drakes among the juveniles bagged, table 14. The drake segment of the juvenile mallard population bagged in Illinois increased through the second week of November and then tended to stabilize, fig. 3.

Sex ratios of ducks in the marshes adjacent to Great Salt Lake, Utah, have been quite variable from week to week and year to year in autumn.

The week-to-week variation in sex ratios among ducks of these marshes is understandable in view of the fact that in early summer the areas are the breeding grounds for ducks of many species, later a major molting area for transient pintails and green-winged teals, and still later one of the important migration areas for ducks in the Pacific Flyway. Chronological differences in movement of various groups of ducks—those that breed in the area, early migrants that wing-molt in the area, and large numbers of fall migrants that rest there—have resulted in ever-changing sex ratios.

Year-to-year variation in sex ratios is shown in data from the Bear River Migratory Bird Refuge at the north end of Great Salt Lake (Van Den Akker & Wilson 1951:379). In that area hens outnumbered drakes in 8 of 13 species in the period 1936-1940. However, during the hunting seasons in later years, 1943-1949,

checked in hunters' bags in seven regions in North America.*

TENNESSEE, 1951-1952		LOUISIANA, 1951		TEXAS COAST, 1947-1951		NORTH CAROLINA, 1948-1952		PROBABILITY THAT DIFFERENCES AMONG AREAS ARE DUE TO CHANCE
Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	
14,068	58.1	3,471	45.5	2,683	44.1	73	50.7	<0.0005
127	59.1					109	54.1	
2,007	45.8			696	43.7	228	57.9	<0.0005
317	64.3			620	53.7	644	54.2	<0.02>0.01
1,084	67.1	1,204	45.9	2,688	69.5	271	70.5	<0.0005
688	63.4	1,312	49.1	1,160	54.7	96	51.0	<0.0005
174	52.3			963	48.8	201	51.7	<0.20>0.10
107	65.4			1,782	45.6			<0.0005
3,080	69.2	1,351	51.9			104	61.5	<0.0005
544	69.1	78	51.4	227	48.0	349	41.8	<0.0005
516	66.1	752	49.5	456	62.9	48	40.0	<0.0005
282	63.8					392	53.6	

(1950:14); Illinois, authors of present paper; Tennessee, Charles K. Rawls, Jr., Tennessee Game and Fish Commission communication); Texas Coast, Singleton (1953:57); North Carolina, T. Stuart Critcher and Yates M.

at Ogden Bay, midway on the east side of Great Salt Lake, hens outnumbered drakes in only a few instances: in pintails 2 years and in redheads 1 year, table 20. When the statistical significance of the differences between the data for these years was investigated, the year-to-year fluctuations in sex ratios were found to be

highly significant for all species except the baldpate and the shoveler. Populations that were top-heavy with drakes were observed in this same area before the hunting seasons of 1944 and 1950. Ducks that were victims of botulism in the Ogden Bay area showed that adult drakes were much more abundant than adult

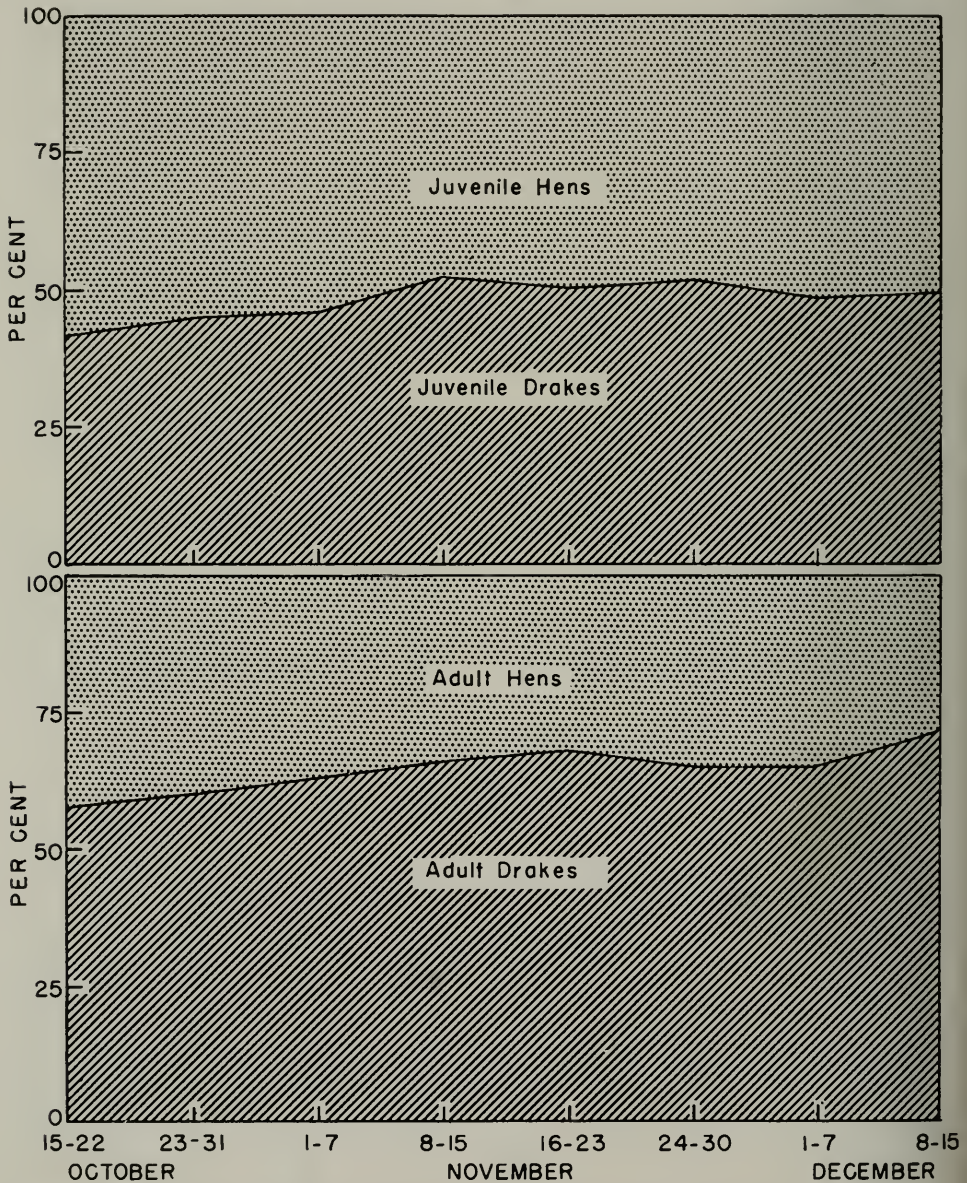


Fig. 3.—Drake-hen composition of the adult and juvenile segments of the autumn flight of mallards in Illinois, as indicated by data from checks of hunters' bags, in the autumns of 1939-1955. The drake segment of the juvenile mallard population increased through the second week in November and then became relatively stable.

Table 20.—Drake percentages in seven species of ducks checked in hunters' bags at Ogden Bay Bird Refuge, Utah, 1943-1949.*

SPECIES	1943		1944		1946		1947		1948		1949		PROBABILITY THAT DIFFERENCES AMONG YEARS ARE DUE TO CHANGE
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	
Mallard.....	208	61.5	318	65.4	848	59.3	2,239	58.8	1,276	54.8	1,528	56.8	<0.01>
Gadwall.....	275	53.8	241	54.8	462	61.9	1,342	58.9	653	55.9	1,636	63.4	>0.0005
Baldpate.....	150	54.7	426	55.9	187	53.5	801	59.3	1,136	52.1	824	54.0	>0.10
Pintail.....	259	58.7	.....	.....	2,193	45.6	5,872	51.6	2,148	45.1	3,464	56.6	<0.0005
Green-winged teal.....	281	60.1	273	61.5	2,615	74.8	3,374	63.9	1,543	63.9	1,884	60.2	<0.0005
Shoveler.....	171	52.6	423	62.2	802	58.6	2,209	58.6	1,113	55.4	1,249	59.8	<0.10>
Redhead.....	33	60.6	44	86.4	30	60.0	122	68.0	217	49.3	449	54.8	<0.0005

*Unpublished data for 1943-1949 supplied by Noland F. Nelson, Utah Fish and Game Department.

hens in late summer and early fall of these years, tables 21 and 22. At the Bear River Migratory Bird Refuge during the summer of 1952, drakes of several species were abnormally abundant among botulism victims, table 23.

Sex Ratios in Early Spring.—Periodic counts of ducks in late winter and

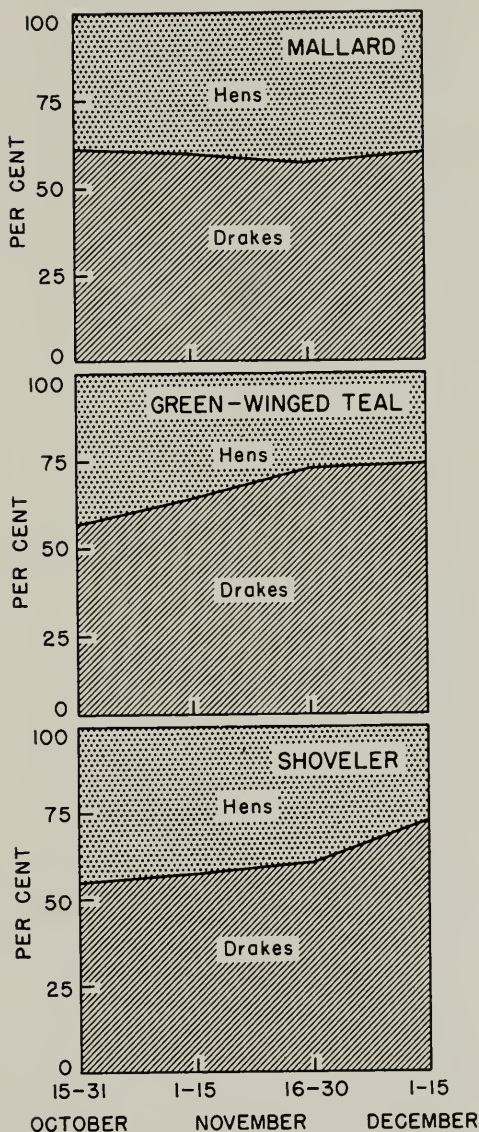


Fig. 4.—Drake-hen composition of the autumn flights of mallards, green-winged teals, and shovelers in Utah, as indicated by data from checks of hunters' bags, in the autumns of 1943, 1944, and 1946-1949.

early spring have revealed differences in the sequence of the northward migration of drakes and hens of the same species. The sequence in the migration of drakes and hens varies with the region, table 24. In the Illinois River valley, tallies of drakes and hens in late winter and spring were compiled for the years 1940-1946, fig. 5.

A preponderance of drakes was most pronounced for the mallard, pintail, canvasback, and ring-necked duck late in February. In the redhead and the lesser scaup, drakes predominated to the greatest extent in the second half of March; in the baldpate, in the second half of April.

Farther north in the Mississippi Flyway, in Minnesota, Erickson (1943:27) observed changes in the drake and hen segments of the populations during the spring migration periods of 1938-1940. Among

blue-winged teals, in 2 of the 3 years, the relative number of drakes was considerably greater in the first than in the second of the two parts into which Erickson divided the migration period. Among shovellers, in each of the 3 years, the relative number of drakes was greater in the second part than in the first part of the migration period. Among lesser scaups, drakes predominated throughout the migration period in each year, but to a lesser extent in the second part than in the first. Among ring-necked ducks, the sex ratios varied little between the two parts of each migration period or among the 3 years; the average male to female ratio for the 3 years was 1.36:1 in the first part and 1.43:1 in the second part of the migration period.

Near Minneapolis, in the spring of 1950, Nelson (1950:119) observed male to female ratios of approximately 1.3:1

Table 21.—Drake percentages in seven species of ducks, juvenile and adult classes, afflicted with botulism at Ogden Bay Bird Refuge, Utah, August 1 to September 29, 1944.*

SPECIES	ADULTS		JUVENILES	
	Number	Per Cent Drakes	Number	Per Cent Drakes
Mallard.....	77	71.43	43	48.84
Gadwall.....	7	14.29	10	40.00
Baldpate.....	29	86.21	9	44.44
Pintail.....	502	60.56	163	45.40
Green-winged teal.....	292	80.14	118	62.71
Cinnamon teal.....	17	58.82	32	65.63
Shoveler.....	89	69.66	71	71.83
<i>All species</i>	1,013	68.21	446	55.83

*Unpublished data from Noland F. Nelson, Utah Fish and Game Department.

Table 22.—Drake percentages in six species of ducks, juvenile and adult classes, afflicted with botulism at Ogden Bay Bird Refuge, Utah, late summer, 1950.*

SPECIES	ADULTS		JUVENILES	
	Number	Per Cent Drakes	Number	Per Cent Drakes
Mallard.....	4	50.00	12	83.33
Gadwall.....	3	66.66	7	14.29
Baldpate.....	63	52.38	71	45.07
Pintail.....	299	70.57	91	62.89
Green-winged teal.....	13	38.46	9	33.33
Shoveler.....	34	50.00	25	48.00
<i>All species</i>	416	64.90	215	53.85

*Unpublished data from Noland F. Nelson, Utah Fish and Game Department.

Table 23.—Drake percentages in four species of ducks, juvenile and adult classes, afflicted with botulism at the Bear River Migratory Bird Refuge, Utah, summer, 1952.*

PERIOD	PINTAIL				GREEN-WINGED TEAL				SHOVELER				MALLARD			
	Adult		Juvenile		Adult		Juvenile		Adult		Juvenile		Adult		Juvenile	
	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes	Num-ber	Per Cent Drakes
July 4th week...	98	76.5	84	78.6												
August 1st week...	237	75.1	249	69.5												
2nd week...	277	76.5	283	66.1			6	83.3	11	54.5			29	79.3	19	78.9
3rd week...	230	72.2	371	67.6	75	85.3	11	90.9	15	60.0			18	88.9	20	65.0
4th week...	1,183	64.3	1,209	53.2	373	69.2	50	78.0	44	75.0			51	76.5	36	83.3
September 1st week...	675	54.7	536	57.4	245	59.6	51	56.9	36	73.3			16	50.0	13	53.8
2nd week...	413	63.9	368	58.4	194	62.9	62	56.4	45	51.1			23	56.5	15	53.3

*Calculated from data in a report, "Sex and Age Ratio of Waterfowl Afflicted by *Clostridium botulinum*, Type C, on the Bear River Migratory Bird Refuge During Summer, 1952" by Jack P. Allen, Utah Cooperative Wildlife Research Unit, Logan.

among river ducks and approximately 2.0:1 among diving ducks.

In northwestern Iowa, Glover (1951: 486-91) recorded sex ratios for migrating waterfowl during spring in 1948 and 1949. The preponderance of drakes he observed among early arrivals of mallards and blue-winged teals declined somewhat, and thereafter the sex ratios of these species remained fairly constant. The sex ratios of gadwalls varied little during the spring. Drakes predominated in baldpate populations throughout the northward migration period, to the greatest extent toward the end of the period. The drake segment was greater than the hen segment among pintails and shovelers throughout the spring migration and showed peaks in late March, the middle of April, and early May. The drake segment among lesser scaups also exceeded the hen segment throughout the spring migration; a marked peak in drake abundance was reached during mid-April. Drakes predominated markedly among the first red-head arrivals, and again among the late departures. Among ring-necked ducks, a high peak in drake predominance occurred the first half of April; a near balance in sex ratios prevailed during the remainder of the spring migration season.

In the lower Souris National Wildlife Refuge, North Dakota, Merrill C. Hammond found marked variations in waterfowl sex ratios taken at different times during the spring, table 7. Pintail, lesser scaup, and redhead sex ratios were more heavily unbalanced in favor of drakes late in the spring than early. Changes in the sex ratios of pintails were significant at the 95 per cent level ($X^2=20.9$, 3 d.f.). The changes were not significant at the 95 per cent level for the lesser scaup ($X^2=3.1$, 2 d.f.) or the redhead ($X^2=1.2$, 2 d.f.).

In the Pacific Flyway, in western Washington, Beer (1945:119) calculated sex ratios of ducks from September through April. In December, mallard sex ratios were evenly balanced; in January, they were slightly in favor of drakes and, in February and March, slightly in favor of hens. The drake segment in the pintail population progressively declined from November through March. The sex ratio for lesser scaups was balanced in January,

Table 24.—Drake percentages in 10 species of ducks observed

SPECIES	CALIFORNIA, 1948-1951		OREGON, 1946-1948		WASHINGTON, 1943, 1944		NORTH DAKOTA, 1939-1942, 1947-1950		MANITOBA, 1939-1945	
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes
Mallard.....	1,039	55.4	5,589	55.9	1,652	50.7	3,202	51.7	2,423	50.6
Baldpate.....	432	45.8	30	53.3	4,999	53.3	911	57.2		
Pintail.....			4,561	57.4	622	52.2	10,173	52.7	3,250	51.9
Blue-winged teal.....							5,554	55.5		
Shoveler.....	362	69.6	2,823	59.1	101	53.5	2,000	53.7		
Redhead.....							1,805	54.8	926	58.1
Ring-necked duck.....	671	60.5					63	57.1		
Canvasback.....	370	53.0			316	67.7	826	62.6	2,916	65.4
Lesser scaup.....	371	67.4			911	59.8	7,401	64.0	10,387	66.8
Ruddy duck.....							1,886	64.7		

*Sources of data for the various regions: California and Oregon, Evenden (1952:393); Washington, Beer (1946:409); Minnesota, Erickson (1943:27); Illinois River Valley, authors of present paper (unpublished); Missouri, (1951:487, 490) for mallard, baldpate, pintail, blue-winged teal, and shoveler, and Glover (1951:489) and Lowford (1954:78).



Fig. 5.—Periodic changes in the drake percentage of the flight of each of seven species of ducks during spring migration in the Illinois River valley, 1940-1946. Data were obtained from counts of living birds. A preponderance of drakes was most pronounced for the mallard, pintail, canvasback, and ring-necked duck early in the migration period. For the lesser scaup, a preponderance of drakes was most pronounced in the second half of March.

mostly during the spring months in 10 regions of North America.*

MINNESOTA, 1938-1940		ILLINOIS RIVER VALLEY, 1940-1947		MISSISSIPPI RIVER VALLEY, ILLINOIS, 1948-1951		IOWA, 1938-1940, 1949		INDIANA, 1949-1952		ALL AREAS	PROBABILITY THAT DIFFERENCES AMONG AREAS ARE DUE TO CHANCE
Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Per Cent Drakes	
256	50.4	11,125	54.8	800	53.2	17,085	52.7	10,431	50.3	52.6	<0.001
126	54.8	1,238	61.6	78	53.8	1,390	56.0	1,759	55.5	54.6	<0.001
322	53.7	4,218	63.2	2,000	77.4	4,370	71.8	5,178	54.6	59.4	<0.001
447	59.7	297	64.6	.....	.....	3,782	59.6	1,644	56.8	59.3	<0.001
253	56.5	260	58.5	.....	.....	2,377	66.6	892	63.5	60.1	<0.001
210	61.0	7,880	68.1	.....	.....	4,385	58.6	1,275	60.7	60.2	<0.001
580	58.3	2,051	73.4	.....	.....	3,728	67.0	6,591	52.2	61.4	<0.001
147	64.0	6,164	79.4	3,678	75.2	2,049	65.0	2,016	65.3	66.4	<0.001
3,114	72.0	19,188	86.9	17,873	82.1	11,434	69.1	11,885	57.0	69.5	<0.001
80	48.8	460	77.4	.....	.....	1,976	65.8	438	53.4	62.0	<0.001

(1945:119); North Dakota, M. C. Hammond, U. S. Fish and Wildlife Service (unpublished); Manitoba, Hochbaum
Mississippi River Valley, Illinois, George Arthur, Illinois Department of Conservation (unpublished); Iowa, Glover
(1941:144) combined for redhead, ring-necked duck, canvasback, lesser scaup, and ruddy duck; Indiana, Mum-

but by April there were almost two drakes to every hen. In eastern Washington, Yocom (1949:226) found among mallards relatively more drakes during December than during other months of his study; the number of hens increased proportionally in January, and in February there were more hens than drakes.

In the first 4 months of 1948, sex ratios of mallards in the Texas Panhandle were obtained from counts of ducks presumed to be victims of fowl cholera, table 25. These data revealed statistically significant ($X^2=16.5$, 6 d.f.) chronological differences in sex ratios at the 95 per cent level. In winter the mallard drakes and

hens were about equal in number. The drake segment increased during the spring migration, and it was especially large at the end of the migration period. Inasmuch as hens were found by Singleton (1953:57) to predominate in mallard populations on the Texas coast during the hunting season, table 19, it is assumed that the progressive increase in the drake segment in the Panhandle resulted from the lingering of unmated drakes on the wintering grounds. Large numbers of mallards are paired during the fall and winter; probably some of the unmated drakes were juveniles that had lagged in testicular development while others were

Table 25.—Drake percentages in mallards and pintails found dead, presumably from fowl cholera, on the Muleshoe National Wildlife Refuge, Texas, 1948.

PERIOD	MALLARDS		PINTAILS	
	Number	Per Cent Drakes	Number	Per Cent Drakes
Jan. 4-Feb. 16	1,212	50.2	330	64.8
Feb. 17-20	436	54.6	98	60.2
Feb. 21-March 17	3,014	56.0	769	57.0
March 18-21	831	57.3	236	54.2
March 22-31	643	56.3	328	55.8
April 1-7	162	56.8	16	43.0
April 8-25	47	63.8	8	50.0
Jan. 4-April 25	6,345	55.0	1,785	57.9

adults in which the testes had not reached recrudescence.

Among pintails presumed to have died from fowl cholera in Texas in the first 4 months of 1948, the sex ratio trend was the opposite of the trend among mallards, table 25, from a population predominantly drakes at the start of the period toward a balanced population at the end. The change in pintail sex ratios was not significant at the 95 per cent level ($X^2=10.4$, 6 d.f.). Drakes were found to predominate in the pintail population along the Texas coast during the hunting season, table 19. It may be concluded that the pintail drakes tend to winter farther north than the hens but that most of the pintail population winters farther to the south,

in Mexico, than does the mallard population.

Sex Ratios in the Breeding Season.

—Seasonal changes in sex ratios of ducks observed on the Manitoba breeding grounds in 1947 and 1949 are shown for various species in tables 26 and 27. In April, the first flights arriving on the breeding grounds showed, with minor exceptions, a closer approach to a balance between the sexes than did subsequent populations on the breeding grounds, fig. 6. Somewhere between the mid-flyway areas and the breeding areas of southern Manitoba, late migration waves predominating in hens appeared to overtake early migration waves predominating in drakes. A tendency toward balanced sex ratios

Table 26.—Drake percentages in seven species of ducks observed in four periods of the spring months along study transects on the Manitoba breeding grounds, 1947.*

SPECIES	APRIL 15-30		MAY 1-15		MAY 16-31		JUNE 1-15	
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes
Mallard.....	162	52.5	341	67.5	150	77.5	308	78.0
Gadwall.....			72	54.0	45	55.5	89	56.0
Pintail.....	140	55.5	248	75.0	139	73.5	197	78.0
Blue-winged teal.....	41	62.0	297	58.0	153	59.0	283	71.0
Shoveler.....			240	55.5	60	58.0	135	69.5
Canvasback....	164	55.0	139	65.5	125	73.5	139	83.5
Lesser scaup....	48	67.0	616	66.5	118	61.0	211	65.5

*Data supplied by Arthur S. Hawkins, an author of this paper.

Table 27.—Drake percentages in 10 species of ducks observed in four periods in the Minnecosa pothole district of Manitoba, 1949.*

SPECIES	APRIL 21-25		APRIL 29-MAY 7		MAY 14-JUNE 6		JULY 5-26	
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes
Mallard.....	829	53.9	722	67.9	975	73.6	194	6.7
Gadwall.....			75	54.7	220	52.7	33	18.2
Baldpate.....	73	52.1	209	53.6	363	54.8	61	24.6
Pintail.....	213	59.2	235	74.0	274	76.6	67	4.5
Green-winged teal.....	52	53.8	198	53.5	164	63.4	40	27.5
Blue-winged teal.....	10		547	53.9	925	57.4	350	43.7
Shoveler.....	32	50.0	124	58.1	201	57.7	51	11.8
Redhead.....	64	51.6	114	52.6	231	55.4	34	20.6
Canvasback....	190	54.2	285	56.8	334	61.1	135	0.7
Lesser scaup...	163	65.0	442	60.2	459	58.8	166	48.8

*Unpublished data supplied by W. H. Kiel, University of Wisconsin.

among early arrivals on the breeding grounds evidently is observed in late March and early April on the Oka State Sanctuary in Russia, where the first mallards to arrive are paired (Teplov & Kar-tashev 1958:160).

The upward swing in the relative numbers of drakes among the mallards and pintails seen by observers in early May, tables 26 and 27, soon after arrival of the ducks on the breeding areas of Manitoba, may be indicative of the rate at which hens leave their mates to incubate.

By mid-July the relative number of

drakes among ducks seen on potholes in southwestern Manitoba, table 27 and fig. 6, had noticeably decreased in all species—less in the lesser scaup and the blue-winged teal than in the other species. At this time, the drakes were evidently leaving the breeding areas for the lakes or marshes where they would enter the eclipse molt.

A similar sequence in sex ratios was found in 1949 by I. G. Bue, then at the University of Minnesota, in ducks seen on stock ponds in western South Dakota, fig. 7. Between the first week of May

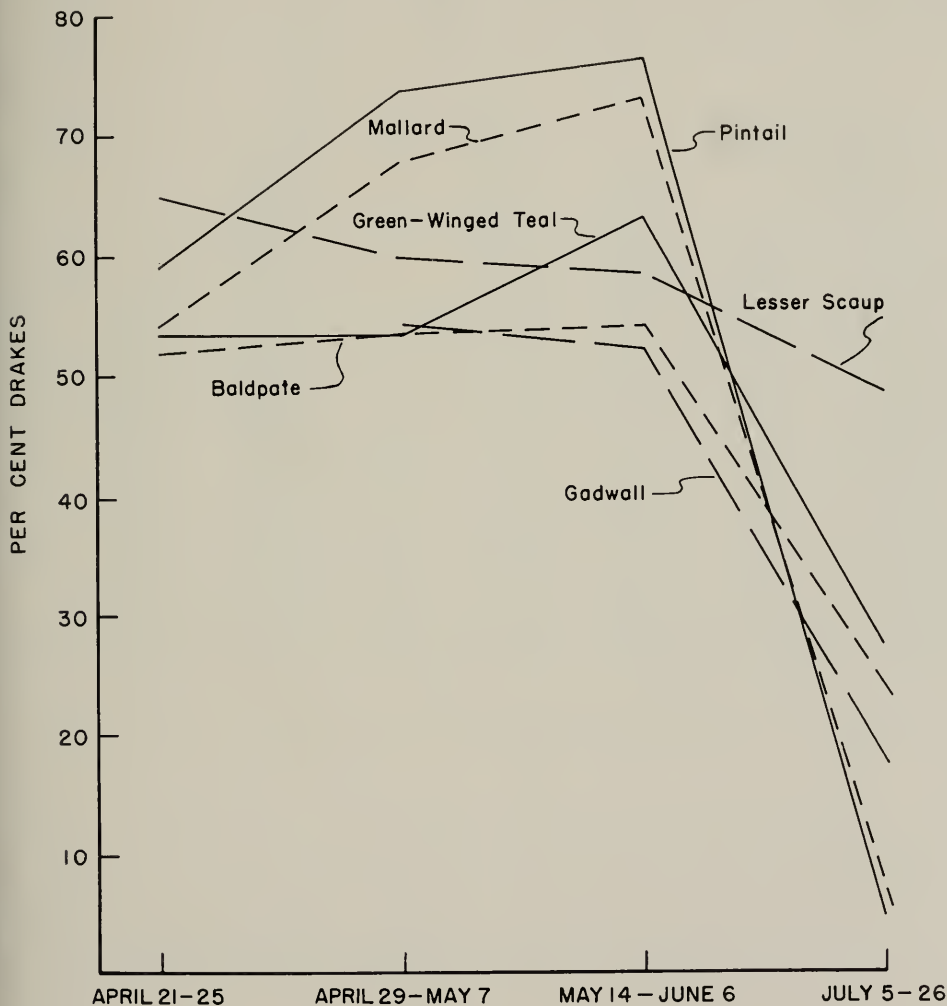


Fig. 6.—Periodic changes in the drake percentage in each of six species of ducks on a breeding grounds area near Minnedosa, Manitoba, April 21–July 26, 1949. Data were obtained from counts of living birds.

and the last, during the time pintail hens were leaving their mates to nest, the number of drakes increased from 57 to 81 per cent of the pintails observed. An abrupt decrease in the relative number of pintail drakes took place in the first half of June when many of them were departing for areas in which to molt. Mallard drakes were about 2 weeks later than pintails in their departure to molt, and blue-winged teal drakes were about 2 weeks later than the mallard drakes.

Sex ratios of ducks seen during the nest-

ing period may provide useful information on the destruction of duck nests. When their nests are destroyed, hens return to their waiting sites, where they can be seen by observers; this behavior results in an apparent increase in the relative number of hens in the populations. Lynch (1948:26) presented evidence to show increases in the relative numbers of paired mallards and pintails seen on a study area in southern Saskatchewan late in May, 1947. These increases may have been attributable to heavy nest losses re-

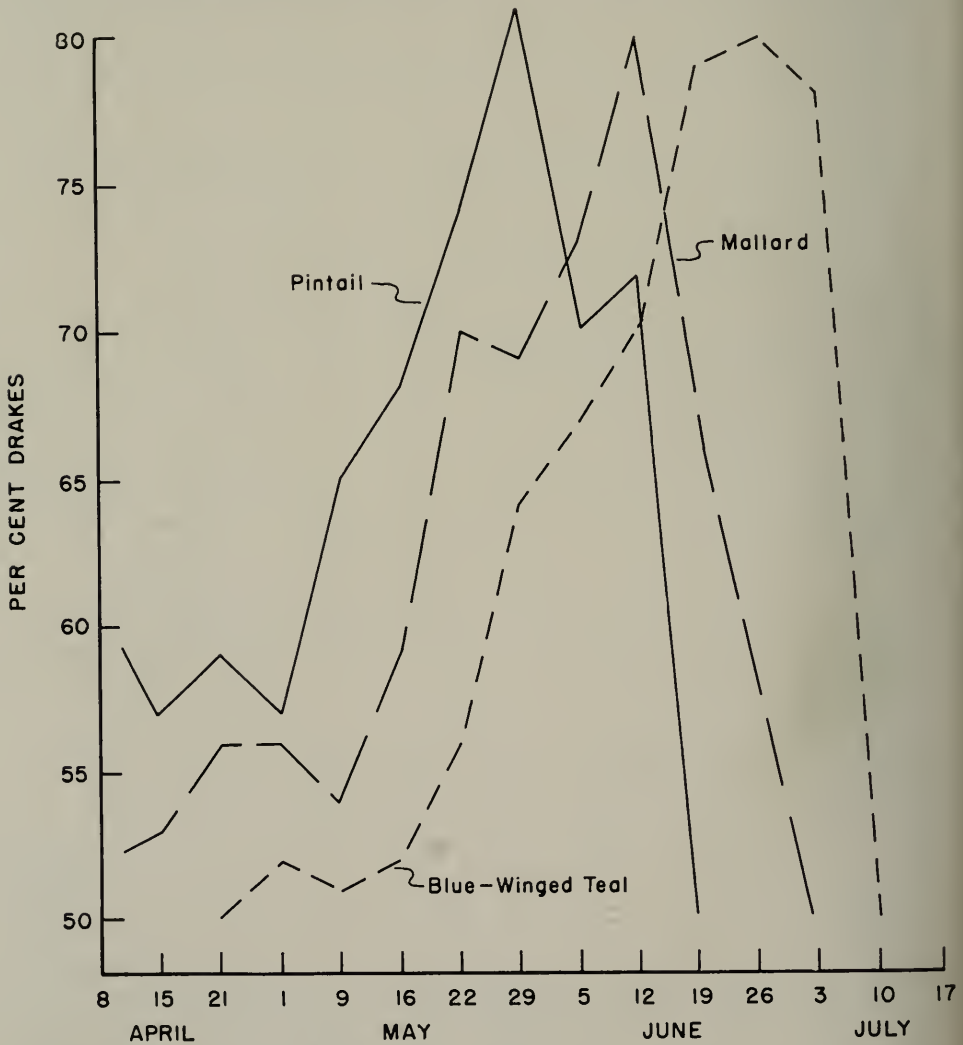


Fig. 7.—Periodic changes in the drake percentage in each of three species of ducks on stock ponds in western South Dakota, April 8–July 17, 1949. Data were obtained from counts of living birds and were provided by I. G. Bue, Commissioner, North Dakota Game and Fish Department, Bismarck, while at the University of Minnesota.

sulting from the plowing of wheat stubble in which hens were nesting.

Regional Variations in Sex Ratios

Sex ratios in ducks were found to vary with migration routes and wintering grounds, fig. 8.

The relative number of drakes among mallards reported bagged in the late

per cent hens) than drakes among 13,959 mallards trapped and banded in a period of about 12 years. More hens than drakes were reported among a few mallards in hunters' bags in eastern Wisconsin by Hopkins (1947:28), who also reported more hens than drakes among mallards that were trapped and banded in the area. The report by Hopkins is interpreted to

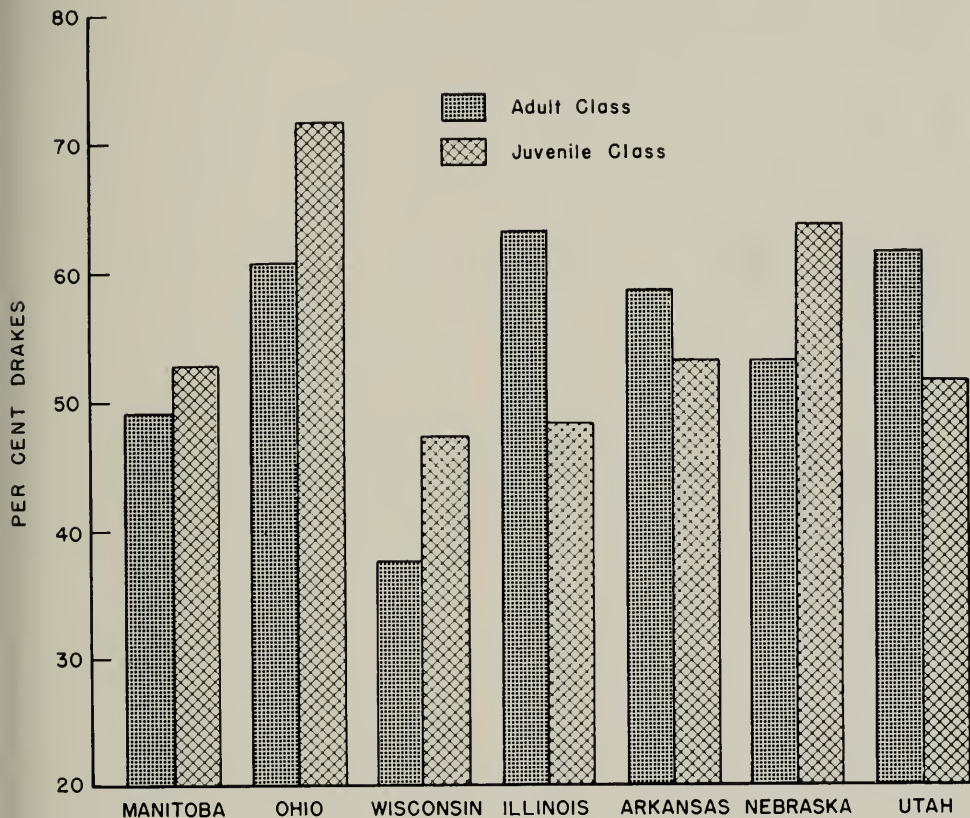


Fig. 8.—Drake percentage in juvenile and in adult mallards checked in hunters' bags in each of six states and the province of Manitoba, 1946-1948. More drakes than hens were checked in each state or province except Wisconsin.

1940's in Ohio was considerably more than the relative number among mallards reported bagged in Nebraska, fig. 8; the two areas are in approximately the same latitude but in different flyways. In each area more drakes than hens were bagged. The much greater kills among juvenile drakes than among adult drakes is unexplained.

A preponderance of hens was reported for an area in British Columbia by Munro (1943:247), who found more hens (54.3

mean that more hens than drakes of the mallard were in the area during the fall of 1946, the period covered by the report.

Drakes and hens apparently occur in various ratios in various areas of their wintering grounds. In Louisiana, table 19, inspection of hunters' bags showed that not only was the relative number of drakes low for all species but that hunters killed more hens than drakes in the mallard, pintail, green-winged teal, and lesser scaup. To the west, on the coast of

Texas, hunters bagged more hens than drakes in the mallard, gadwall, shoveler, redhead, and canvasback. On the Texas coast, the relative number of drakes was unusually high only in the pintail and lesser scaup, species in which a large part of the population winters in Mexico.

In every duck species for which comparable figures were collected, the drake segment was larger in Tennessee, an area representing the northern part of the wintering grounds in the Mississippi Flyway, than in Louisiana, at the southern extremity of the flyway, table 19. Sex ratios obtained for the mallard, baldpate, and green-winged teal from inspection of ducks found dead in the Texas Panhandle, table 31, favored drakes to a greater extent than did sex ratios for these same species obtained from inspection of hunters' bags on the Texas coast, table 19. Drakes predominated in pintails about equally in these two Texas areas. In Texas coast mallards cited by Singleton (1953:57), the sex ratio for adults was almost evenly balanced; however, among juveniles, there were substantially more hens than drakes. Relatively greater numbers of hens than of drakes may occur in waterfowl populations to the south, in Mexico.

Although drakes greatly predominated among lesser scaups taken on the Texas coast, table 19, hens predominated among redheads and canvasbacks. Because only small numbers of redheads and canvasbacks are known to winter north of the Texas coast in the Central Flyway and because of the known preponderance of drakes in these species, it is assumed that large numbers of drakes of these species winter farther south on the Gulf Coast, in Mexico.

In the Currituck Sound area of North Carolina, where many species of ducks winter, bag checks in 1948-1952 showed the number of drakes to be relatively low for the green-winged teal, shoveler, canvasback, lesser scaup, and ruddy duck (*Oxyura jamaicensis*), table 19. Because large numbers of these ducks winter to the north of Currituck Sound, it is believed that the drakes of these species may be more numerous in those areas. The relatively large numbers of drakes among bagged pintails and gadwalls at Curri-

tuck Sound suggest that populations of these species to the south have proportionally fewer drakes.

During the spring migration, the regional variations in the sex ratios of ducks are even more pronounced than they are during the fall migration. Table 24 shows the variations in sex ratios among several species of ducks in 10 regions of North America. The mallard and the blue-winged teal showed less regional variation in sex ratios than the other species. In no region did the drake percentage for the mallard deviate more than 3.3 percentage points from the average for all regions represented. The comparable figure for the blue-winged teal was 5.3. Drakes formed more than 60 per cent of the population of eight species in Illinois, six in Iowa, and three each in California, North Dakota, and Indiana, table 24.

Illinois appears to be on a major flyway route for male ducks during the spring. In most species migrating through Illinois, the number of drakes in the spring, table 24, is relatively larger than the number of drakes in the fall, table 14. There is evidence that adult drakes of certain species, especially the divers, make longer flights during the fall migration than do the hens and the juveniles of both sexes. The probability that, in the fall, adult drakes of these species pass over Illinois, or move more quickly through the state than do the hens and juveniles, suggests one explanation for the pronounced differences between fall and spring sex ratios.

Sex ratios of ducks show less deviation from balanced sex ratios in northern areas than in other areas of the Mississippi Flyway in spring, table 24. In Minnesota, North Dakota, and Manitoba, sex ratio data were collected primarily on extensive lakes and marshes frequented by large numbers of transient ducks. Because of the location of the area, the size of the samples, and the period of years over which data were collected, the sex ratios from North Dakota appear to represent the various species in spring better than the sex ratios from other areas.

Mortality Factors Affecting Sex Ratios

As an approach to an evaluation of factors that contribute to deviations from

Table 28.—Drake percentage in each of 10 species of ducks banded by Ducks Unlimited* in the prairie provinces of Canada, 1939–1950, and the drake percentage in the year-of-banding recoveries. The difference between these two percentages for each species is a measure of hunter selectivity for that species, + for drakes, — for hens.*

SPECIES	DUCKS BANDED			YEAR-OF-BANDING RECOVERIES			DIFFERENCE BETWEEN PERCENTAGES	PROBABILITY THAT PERCENTAGE DIFFERENCE IS DUE TO CHANCE
	Number	Number Drakes	Per Cent Drakes	Number	Number Drakes	Per Cent Drakes		
Mallard.....	21,021	10,405	49.5	2,131	1,131	53.1	+ 3.6	<0.001
Gadwall.....	1,355	602	44.4	134	68	50.8	+ 6.4	<0.20>0.10
Baldpate.....	1,940	991	51.1	168	86	51.2	+ 0.1	>0.99
Pintail.....	9,479	3,697	39.0	582	263	45.2	+ 6.2	<0.01>0.005
Green-winged teal.....	1,973	1,031	52.3	70	35	50.0	- 2.3	<0.70>0.60
Blue-winged teal.....	12,343	6,171	50.0	341	168	49.3	- 0.7	<0.80>0.75
Shoveler.....	686	346	50.4	41	29	70.7	+ 20.3	<0.01>0.005
Redhead.....	2,042	1,100	53.9	266	148	55.6	+ 1.7	<0.60>0.50
Canvasback.....	511	245	47.9	60	27	45.0	- 2.9	<0.60>0.50
Lesser scaup....	5,134	2,615	50.9	320	159	49.7	- 1.2	<0.70>0.60

*Data calculated from Cartwright & Law (1952:10–2).

balanced sex ratios in ducks, it is desirable to examine the influence of each of the several factors responsible for mortality in these birds. The principal agents that contribute to mortality in ducks are (1) hunters, (2) disease, (3) predators, (4) agricultural operations, and (5) natural stress.

We seek to answer this question: Are hunters, disease, predators, agricultural operations, and natural stress responsible for greater loss in the ducks of one sex than in those of the other?

Hunting and Sex Ratios.—The data on hunter kill of ducks banded in Canada, 1939–1950, and recovered in the year of banding, table 28, reflect the country-wide influence of hunting on the drake-hen ratios because the banding was done on the breeding grounds during late summer and early fall at or before the beginning of the hunting season and the southward migration period.

Statistical treatment of the data showed that hunters took a highly significant greater number of drakes than of hens in the mallard, gadwall, pintail, and shoveler. Hunters took fewer, but not significantly fewer, drakes than hens in the green-winged teal, blue-winged teal, canvasback, and lesser scaup.

Data for black ducks banded at Lake Chautauqua and at McGinnis Slough and for mallards banded at McGinnis Slough,

tables 2, 3, and 4, showed no significantly greater hunter kill in one sex than in the other for the period of study. Data for mallards banded at Lake Chautauqua, table 1, showed a greater hunter kill in drakes than in hens; the difference in hunter kill between the sexes was statistically significant and similar to that for mallards banded in Canada, table 28.

In most species in which hunting takes a greater toll of one sex than of the other, the male segment bears the greater loss. However, the effect of hunting on the sex ratios of the entire North American duck population is probably insignificant.

Disease and Sex Ratios.—Although numerous diseases afflict ducks, only three are known to cause large losses among these birds: (1) botulism, (2) fowl cholera, and (3) lead poisoning.

Botulism.—Botulism in ducks occurs in both Canada and the United States; it is most prevalent among the populations in the Prairie Provinces, the Northern Plains States, and the Western States. The time of botulism outbreaks usually is from midsummer to early autumn.

According to Hammond (1950:213),

There appears to be no selectivity of sexes as far as *Clostridium* toxin is concerned and the ratio of sexes appearing in the studies is a reflection of the differential utilization. If males were attracted to areas at a time when toxin was potent and available a preponderance of males appeared in the collection.

Table 29.—Drake percentages in seven species of ducks found dead or incapacitated, presumably from botulism, at Whitewater Lake, Manitoba, in 7 weeks of 1949.*

SPECIES	JULY 14-20		JULY 21-27		JULY 28-AUGUST 6		AUGUST 7-14		AUGUST 15-21		AUGUST 22-28		AUGUST 29-SEPTEMBER 4		ENTIRE PERIOD	
	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes	Num-ber of Ducks	Per Cent of Drakes
Mallard.....	35	88.6	967	96.1	861	86.5	194	92.2	200	71.0	158	60.1	150	53.3	2,565	89.3
Gadwall.....	1	.....	22	72.7	100	76.0	125	85.6	127	66.0	30	43.3	27	48.1	432	71.7
Baldpate.....	9	88.8	234	89.7	151	86.0	100	91.0	.....	.....	.....	.....	13	38.5	507	87.8
Pintail.....	7	100.0	303	88.7	273	75.4	196	78.5	.....	76.4	76	63.1	217	48.8	1,212	72.4
Green-winged teal.....	.....	.....	107	90.6	23	78.2	20	80.0	24	29.2	.....	.....	84	58.3	258	72.5
Blue-winged teal.....	17	82.3	337	83.3	90	77.7	66	71.2	88	52.3	21	57.1	33	39.4	652	74.1
Showeler.....	5	100.0	22	72.7	35	68.5	117	72.6	116	52.6	73	58.9	129	63.6	497	63.6

*Data obtained by F. Graham Cooch, Dominion Wildlife Service, and Arthur S. Hawkins, U. S. Fish and Wildlife Service.

Hammond (1950:212) found a ratio of 161 drakes to 100 hens among 8,395 adult ducks affected by botulism on four national wildlife refuges in North Dakota, 1937-1947. The relative number of hens increased progressively from July through September.

An inspection of ducks that presumably were victims of botulism at Whitewater Lake, Manitoba, between mid-July and early September, 1949, revealed a preponderance of drakes, table 29. There was an increase in the proportional number of hens among the victims in some species in late August; however, the hens in most species did not suffer severe losses, possibly because the disease abated in early September, before large numbers of hens arrived.

Waterfowl afflicted with botulism at the Ogden Bay Bird Refuge, Utah, in 1944 and 1950 and at the Bear River Migratory Bird Refuge, Utah, in 1952 showed a preponderance of drakes among both adults and juveniles, tables 21, 22, and 23. A comparison of the sex ratios of ducks dying from botulism in late summer of 1944, table 21, with those killed by hunters during autumn of the same year, table 20, indicated for three species proportionally greater numbers of drakes among the birds dying of the disease. The fact that, in Utah, drakes were relatively more abundant late in the summer than during the autumn may have accounted, at least in part, for relatively higher numbers of drakes among disease victims than among shot birds.

The habit of drake dabblers, while undergoing the eclipse molt, of frequenting large lakes with extensive marshes appears to expose drakes more than hens to botulism toxin. The worst known botulism areas, such as Whitewater Lake in Manitoba, Johnstone Lake in Saskatchewan, Medicine Lake in Montana, and the marshes about Great Salt Lake, Utah, are places where drakes, in much greater numbers than hens, annually gather for the wing-molt.

Fowl Cholera.—In North America, the largest losses of migratory waterfowl from fowl cholera appear to be those reported for the Panhandle of Texas by Petrides & Bryant (1951:193). Other severe losses from this disease have been reported from

the south end of San Francisco Bay northward through the delta and into the lower Sacramento Valley (Rosen & Bischoff 1950:147-8).

Although Petrides & Bryant (1951: 203) found some indication that the smaller the duck the more susceptible it is to fowl cholera, the weight difference between drakes and hens in any one species is not great enough to account for a material difference in mortality rates. A small number of drake-hen ratios for mallards and pintails, living birds and victims of fowl cholera, in the Texas Panhandle in 1944-1946, table 30, suggest that the disease is not markedly selective of either sex.

Sex ratios for several hundred ducks presumably dying from fowl cholera in the Texas Panhandle in 1944-1946 and 1948 are given in tables 30 and 31. The loss of pintail drakes was proportionally greater in 1948 than in 1944-1946. The loss of mallard drakes showed approxi-

mately equal percentages in the two periods. In each period, the loss was proportionally greater among pintail drakes than among mallard drakes.

Available evidence suggests that fowl cholera is not an important cause of differences in mortality rates between the sexes. In the recorded outbreaks of this disease among ducks, drakes have predominated in the populations and have suffered losses proportionally no greater than those of hens.

Lead Poisoning.—Among migratory waterfowl, lead poisoning is more widespread geographically than either botulism or fowl cholera. It has been estimated (Bellrose 1959:282) that among all species of waterfowl in North America 2 to 3 per cent die from this disease each year.

Following experiments with penned wild mallards, Jordan & Bellrose (1951: 21) concluded that:

The hen mortality from lead poisoning was found to be double the drake mortality, except

Table 30.—Drake percentages among pintails and mallards in the Panhandle of Texas, 1944-1946, as determined by (1) counts of ducks believed to be victims of fowl cholera and (2) visual observations of healthy ducks.*

PERIOD	PINTAIL			MALLARD		
	Fowl Cholera Counts		Visual Observations	Fowl Cholera Counts		Visual Observations
	Number of Ducks	Per Cent Drakes	Per Cent Drakes	Number of Ducks	Per Cent Drakes	Per Cent Drakes
March 4-16, 1944.....	311	70	.....	187	58	.....
Feb. 4-18, 1945.....	552	55	56	281	51	48
March 19, 1945.....	222	64	65	64	70	.....
Feb.-March, 1946.....	1,008	63	71	346	56	.....

*By Arthur S. Hawkins and U. S. Game Management Agents L. J. Merroka, Floyd A. Thompson, and M. H. Boone.

Table 31.—Drake percentages in four species of ducks found dead, presumably from fowl cholera, on areas in the Panhandle of Texas, winter and early spring, 1944-1946 and 1948.*

SPECIES	1944-1946		1948	
	Number of Ducks	Per Cent Drakes	Number of Ducks	Per Cent Drakes
Mallard.....	878	55.8	4,348	54.4
Baldpate.....			860	62.6
Pintail.....	2,093	62.1	7,447	67.7
Green-winged teal.....			192	57.3

*Data for 1944-1946 from table 30. Data for 1948 from U. S. Game Management Agent L. J. Dugger.

Table 32.—Drake percentages among mallards picked up dead or incapacitated from lead poisoning in several areas of the Mississippi Flyway during late fall and winter, 1939–1955.

PLACE	YEAR	NUMBER CHECKED	PER CENT DRAKES
Sand Lake, South Dakota.....	1951	59	57.6
Heron Lake, Minnesota.....	1939	194	63.4
Lake Chautauqua, Illinois.....	1941–1955	753	62.8
Batchtown, Illinois.....	1953	47	68.1
Chariton County, Missouri.....	1949	53	64.2
Claypool Reservoir, Arkansas.....	1954	100	73.0
Catahoula Lake, Louisiana.....	1953	243	44.4

in the spring season when hens entered the breeding phase. At this season the food intake of penned wild hens increased steadily until it equaled, then exceeded, that of penned wild drakes. During this period hens proved to be less susceptible to lead poisoning than were drakes. At all other seasons hens ate less food than did drakes.

In field experiments with mallards, some of which had been dosed with lead shot and some of which had not been dosed, Bellrose (1959:276) found that:

Because of the smaller number of experiments conducted with hens than with drakes, it is more difficult to appraise mortality from lead poisoning in the hens. However, the available data suggest that, among hens and drakes with identical ingested shot levels, hens probably suffer twice as great a mortality as drakes in the fall and a small fraction of the mortality of drakes in late winter and spring.

Actual counts of mallards picked up dead or incapacitated from lead poisoning in the Mississippi Flyway during late fall and early winter show a large preponderance of drakes, table 32. Field observations on healthy ducks in the region also show a preponderance of drakes in the wintering populations. Because most outbreaks of lead poisoning that have been reported are from the northern periphery of the wintering grounds and because drakes greatly predominate in wintering populations in those areas, undoubtedly an appreciably greater number of drakes than of hens have died from this disease.

Predators and Sex Ratios.—Investigations of predation on waterfowl are not adequate to provide a substantial basis for appraising the role of predation in selective mortality for drakes or hens. The hens, while incubating eggs for 3 or 4 weeks, and later, in caring for the flightless young for 6 to 10 weeks, may be ex-

posed to greater predation than drakes. During the molt or flightless period, when the tendency of hens is to remain on small bodies of water, while drakes congregate on large lakes or marshes, the hens may be subjected to greater predation than drakes. Moreover, the poor physical condition resulting from the stress of egg laying and molting may also cause the hens to be more vulnerable to predation.

Kalmbach (1937:383–4), in summarizing the fate of 512 duck nests on the prairie breeding grounds in Canada, reported that eight egg-laying or incubating hens were known to have been killed by predators. Other hens may have been killed by predators without leaving evidence; 40 nests had been deserted, and 53 had been destroyed by unknown agents.

In a study that included 340 "active" duck nests in southeastern Saskatchewan during 1953, Stoudt & Buller (1954: 58–9) found seven nesting hens that had been killed by predators. During three seasons on a 1.5 square mile study area near Minnedosa, Manitoba, Alex Dzubin of the Canadian Wildlife Service (letter, March 26, 1955) found 13 hens and 6 drakes killed by predators, mowers, or muskrat traps. Because his study area was atypical in being flanked by paved highways along two boundaries, as well as by telephone and electric power wires, ducks killed by colliding with cars or by flying into wires were not included in his figures.

During a study of the fate of nests on farm land near Delta Marsh on the Portage Plains of Manitoba, 608 nests of seven species of ducks were examined (Milonski 1958:223, 225); although many nests were believed to have been lost to predation (striped skunks de-

stroyed 7 per cent of the pintail nests and 51 per cent of the mallard nests) only five hens were known to have been killed by predators.

On Illinois study areas, raccoons destroyed 304 out of 1,579 wood duck nests and killed 103 hens in a period of 7 years. Minks killed other nesting wood duck hens, and even fox squirrels were responsible for the death of several hens. Census records indicate that during the nesting period wood duck drakes suffered negligible losses.

Agricultural Operations and Sex Ratios.—Losses resulting from mowing or combining operations on farm land are selective for nesting hens. Such losses would affect only species nesting in crops subject to mowing or combining. It seems probable that the mallard, pintail, gadwall, green-winged teal, blue-winged teal, baldpate, and shoveler would be most extensively concerned. The potential loss of nesting hens is great, because extensive areas of farm land are included in the breeding grounds. As long ago as 1948, Lynch (1948:28) pointed out that the 75,000 square miles comprising southern Saskatchewan is far from being a vast undisturbed prairie and that “three-fourths of this ‘Duck-Factory’ are grain-fields. The remainder is heavily grazed.”

According to Forrest Lee of the Minnesota Department of Conservation (letter, January 9, 1955), the loss of blue-winged teal hens from mowing may be appreciable in Minnesota. One farmer near Hutchinson, despite the use of a flushing bar, in 1 year destroyed three hens while he was mowing an alfalfa field. A normally productive pond on his farm had no broods in that year. Interviews with a large number of farmers in the area indicated that such losses were not unusual.

Of 122 mallard and blue-winged teal nesting hens for which there was a chance of being killed (on nests destroyed directly or indirectly) in the mowing of 592 acres of hay on Horicon National Wildlife Refuge, Mayville, Wisconsin, only 5 were killed (Labisky 1957:195-7). It was believed that this low vulnerability of nesting hens resulted because “dabbling ducks generally rise swiftly and nearly vertically from the nest when flushed by

the mowing machine, thus avoiding the cutting bar.”

While making observations on 608 nests of seven species of ducks on farm land near the Delta Marsh in Manitoba, Milonski (1958:223) found only two hens killed in mowing operations.

The available data indicate that losses of nesting hens resulting directly from agricultural operations do not contribute importantly to imbalance in adult sex ratios.

Stress and Sex Ratios.—Little is known about stress, as defined by Selye (1956:3), in its relation to mortality in ducks. Kabat *et al.* (1956:44) found that in pheasants (*Phasianus colchicus*) the “seasonal variation in resistance to the applied stress and survival time was related to the physiological condition of the hen at particular times of the year.” In July and August, pheasant hens that had completed or were about to complete their egg laying and were molting flight feathers were in their poorest physical condition of the year. Survival of pheasant hens under applied stress was shortest in June, July, and August and longest in April, immediately prior to egg laying (Kabat *et al.* 1956:12). The average survival period in July was 13 days in one year and 18 days in another, compared to 21 days in October, 27 days in December, 29 days in January, 34 days in February, 40 days in April, 22 days in May, 17 days in June, and 13 days in August.

Without doubt the greatest energy drain experienced by duck hens in the entire year occurs during late spring and summer as a result of egg laying, incubation, brooding of young, and post-nuptial molt. This sequence of activity probably places the hens in much greater jeopardy to stress than the drakes, which experience marked depletion of energy only through the period of the post-nuptial molt.

Harold C. Hanson of the Illinois Natural History Survey has determined (manuscript in preparation) that among Canada geese (*Branta canadensis*) the stress of the molt is especially severe on the female following the energy demands of egg laying and caring for the young and that this produces a differential effect on the sexes which may be the primary cause

for the preponderance of males in adult populations.

Evaluation of Mortality Factors.—Information available on the principal mortality factors affecting sex ratios in the North American duck population indicates that hunters and disease take relatively more drakes than hens and that predators may take relatively more hens than drakes.

From the time of hatching to the beginning of the breeding season, only slight

the imbalance between the sexes in this population.

Influencing the age composition, and therefore to a large extent the sex ratios of the population, are (1) productivity and (2) mortality.

The more productive a species of waterfowl, the greater is apt to be the proportion of juveniles in its population at the opening of the hunting season. The greater the proportion of juveniles in a population, the more nearly balanced is

Table 33.—Shooting losses, as measured by per cent of banded ducks recovered in year of banding, and drake percentage in the population of each of seven species of ducks.

SPECIES	NUMBER OF DUCKS BANNED*	PER CENT OF BANDED DUCKS RECOVERED IN YEAR OF BANDING*	DRAKE PERCENTAGE IN POPULATION†
Dabbling Ducks			
Mallard.....	22,636	10.0	52.6
Baldpate	2,020	8.7	54.6
Pintail	9,951	6.1	59.4
Shoveler.....	749	5.9	60.1
Diving ducks			
Redhead	2,067	13.1	60.2
Canvasback.....	531	12.2	66.4
Lesser scaup.....	6,567	6.7	69.5

*Data from waterfowl bandings on Canadian breeding grounds by Ducks Unlimited (Cartwright & Law, 1952:10-1).

†Data from summary column, table 24.

changes take place in the sex ratios of the yearling class of a duck population. Mortality factors that operate through most of the first year of life affect the two sexes about equally or the drakes slightly more than the hens. Available information is not sufficient to permit appraisal of the influence of predation on sex ratios. However, during the breeding season appreciable losses occur among hens; these losses, most of which appear to be attributable to predation, agricultural operations, and natural stress, may account for the predominance of drakes in the adult class.

Sex Ratios and Age Composition of Populations

The age composition of a duck population is reflected in its sex ratios. Because of an approximate balance between the sexes in the juvenile class and an appreciable imbalance in the adult class, the greater the proportion of old birds in any given population, the greater is apt to be

its sex ratio. Some species of ducks are consistently more productive than other species. Most of the highly productive species have high shooting losses and, hence, high mortality rates.

An inverse relationship between shooting losses and the size of the drake segments is shown in table 33 for four species of dabbling ducks. The higher the shooting loss, the smaller is the imbalance between the sexes in these species.

Some species of ducks suffer excessive hunting losses in the juvenile age class. Mortality in the fall is so high in the juvenile class that birds over a year old greatly predominate in the spring populations. In these species there is a great imbalance in the sex ratios of spring populations. High vulnerability to hunting is shown in table 45 for juveniles of two species of diving ducks, the redhead and the canvasback.

Of the redhead, Hickey (1952:80) concluded that, "in the past," the kill

rate for juveniles has been about 50 per cent, whereas the kill rate for adults has been 20 or 30 per cent; the annual mortality rates have been about 70 per cent for juveniles and about 55 per cent for adults. Of the canvasback, Geis (1959: 254-5) reported that the year-of-banding recovery rates (per cent of birds banded that were shot by hunters and had bands recovered within a year of the time of banding) were 22 per cent for juveniles and 14 per cent for adults; the annual rates for mortality from all causes were 77 per cent for juveniles and 35 to 50 per cent for adults. Mallard drakes banded as juveniles in Illinois had a first-year mortality rate of about 55 per cent; mallard drakes banded as adults had a first-year mortality rate of 36 per cent and an average mortality rate of about 40 per cent (Bellrose & Chase 1950:8-9).

The high mortality rate in the juvenile class of redheads and canvasbacks has resulted in relatively large numbers of old birds in the breeding populations of these species and consequently a large preponderance of drakes, table 33.

Extremely large drake segments noted in lesser scaup populations are evidently not related to high juvenile mortality resulting from hunting. The vulnerability rate of juveniles in this species, table 45, is insufficient to account for the large imbalance between the sexes, table 33. The causes of the imbalance seem to be (1) low shooting pressure on the species, table 45, (2) a low reproductive rate, table 62, and consequently (3) a relatively small number of juveniles in the population, table 53.

Variations in the age composition of waterfowl populations are largely responsible for variations in sex ratios among species of ducks. Sex ratios of various species of ducks in the spring in North Dakota, table 24, indicate that the mallard has relatively the largest number of yearlings in its breeding populations; this species is followed in order by the pintail, shoveler, redhead, blue-winged teal, ring-necked duck, baldpate, canvasback, lesser scaup, and ruddy duck.

The Question of Surplus Drakes

It seems reasonable to question the value of those drakes in excess of the

number needed to provide mates for the hens in waterfowl populations. In the event such drakes do not play an essential role in species survival, an effort should be made to provide for their utilization.

While drakes outnumber hens in all species studied, drakes occur in relatively greater numbers among the diving ducks than among dabblers, table 24. Examination of available knowledge on the reproductive biology characterizing these two subfamilies reveals nothing which suggests that extra drakes may be more essential to the maintenance of populations of diving ducks than of dabblers.

The hens of diving ducks engage in less reneesting activity than do the hens of dabbling ducks, and some observers feel that diving duck drakes tend to be more persistent in remaining with nesting hens than do the drakes of dabbling ducks. Species differences in this respect were observed among dabbling ducks by Sowls (1955:101), who wrote that while

late-season or reneesting courtship flights of mallards, gadwalls and pintails were common, we seldom saw them in the shovellers and blue-winged teal. I suspect that the difference occurred because of the length of time the drakes stayed with their hens after the clutches were laid. Blue-winged teal and shoveller drakes did not abandon their hens until incubation was well advanced; while mallard, pintail and gadwall drakes abandoned their hens shortly after the clutches were completed.

Robert I. Smith of the Illinois Natural History Survey (personal communication, December 9, 1960) also observed that blue-winged teal and shoveler drakes tend to remain with their hens longer than do the drakes of mallards, pintails, and gadwalls; in exceptional cases, mallard, pintail, and gadwall drakes may remain with their hens throughout and even beyond the incubation period. On the breeding grounds, drakes outnumber hens to a greater extent among pintails, blue-winged teals, and shovelers than among mallards and gadwalls, table 34. A pattern of sorts seems apparent here, but it does not afford obvious support of a need for extra drakes in reproduction.

The superficially excessive number of drakes may be significant to population dynamics among waterfowl in ways which are not directly related to the insurance of successful reproduction. At

times, harassment of nesting hens by idle drakes may result in an important amount of nest desertion and possibly a reduction in productivity. Along with the severe stress of reproductive activity, harassment by drakes may contribute indirectly to mortality among hens. It is conceivable, too, that, if extra drakes are truly surplus, they may also create undesirable stress by occupying space and consuming food essential to the welfare of the productive segment of the population.

Perhaps insight into the value of extra drakes could be obtained through an experimental procedure designed to reduce the number of drakes in a subpopulation of a species having a large drake segment. Reduction of drake numbers could possibly be accomplished by deliberate hunting of drakes in places and at times when they were concentrated apart from the hens or when they could be decoyed from the hens and brought within shooting range. Teplov & Kartashev (1958:159, 161), reporting on observations made on the Oka State Sanctuary and on adjacent shooting areas in Russia, indicated that hunters are "permitted in spring to obtain the drakes of all species and also geese on passage. The most general method of obtaining waterfowl in spring is the shooting of Mallard drakes which go to a decoy duck." In Russia, the killing of female ducks is forbidden in spring. Such an experiment as that outlined above would meet the added objective of determining whether regulated hunting might be directed at what is possibly a truly expendable part of the waterfowl population.

Sex Ratios as Measures of Production

Because sex ratios reflect the age composition of a duck population, analysis of year-to-year differences in the sex ratios of a species offers a method of diagnosing the yearly changes in production. Also, because sex ratios for each species of waterfowl vary from season to season within any year, as a result of hunting and natural phenomena, the sex ratios obtained during a particular season (fall, winter, spring, or summer) should be compared with the sex ratios obtained during only corresponding seasons of other years. A

Table 34.—Drake percentages in 12 species of ducks observed in the breeding grounds region of North America, 1935—1942, 1947—1950.*

SPECIES	SASKATCHEWAN				MINNESOTA				MANITOBA						NORTH DAKOTA						AVER-AGE				
	1935		1936		1937		1938		1939		1940		1941		1942		1947		1948			1949		1950	
Mallard.....	62.8†	60.6†	61.9†	50.0	50.0	51.1											53.5	50.0	51.9	51.2	51.1				
Gadwall.....			52.9	62.5	52.6	53.3											53.3	52.9	53.9	52.0	52.8				
Baldpate.....	74.3†	77.1†	58.7†	51.3	56.5	53.9											63.3	55.1	57.6	56.6	56.4				
Green-winged teal.....	55.2	54.7	57.5	63.6	57.3	55.4											58.9	53.7	52.4	52.5	54.2				
Blue-winged teal.....	59.4	57.8	53.8	56.8	54.4	61.4											61.7	57.9	54.1	53.7	54.7				
Shoveler.....			50.5	50.8	58.8	64.6											55.2	55.7	53.1	53.5	55.1				
Redhead.....	55.0	55.4	52.8	58.5	57.6	58.9											55.5	55.8	55.9	52.6	55.9				
Ring-necked duck.....	60.4	55.1	57.1	66.6	74.2	50.0											66.4	63.2	64.0	63.2	64.0				
Canvasback.....	61.1	60.9	61.0	74.4	70.6	69.4											64.3	61.2	67.2	54.3	63.5				
Lesser scaup.....	77.4	69.5	69.6														76.0	61.2	67.2	54.3	66.1				
Ruddy duck.....																	61.6	67.3	61.6	67.4	67.8				

*Sources of data for the various regions: Saskatchewan, Furniss (1935:278; 1938:22); Minnesota, Erickson (1943:27); Manitoba, Hochbaum (1944:15); North Dakota, M. C. Hammond; U. S. Fish and Wildlife Service (personal communication).
†These figures from Furniss (1935:278; 1938:22) are believed to be too high in drakes because tallies were made during nesting period; they are not included in the averages.

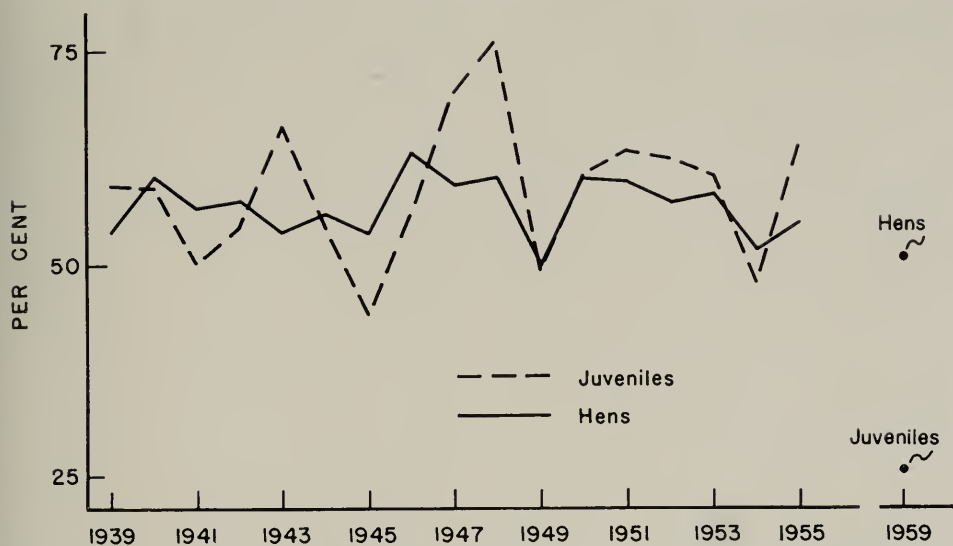


Fig. 9.—Year-to-year changes in the hen percentage and in the juvenile percentage in mallards checked in hunters' bags in the Illinois River valley, 1939–1955 and 1959. Percentages have been adjusted so that the means for juveniles and hens are equal.

comparison of the sex ratios in the summer of one year with the sex ratios in the winter of the same or another year would be biased by the disproportionate hunting losses of juveniles, which have approximately balanced sex ratios.

As a means of measuring yearly production, sex ratios have certain basic advantages over age ratios. For many species of ducks, such as the divers, age ratio data, derived from bag checks during the autumn, are difficult to obtain in adequate numbers. For the most important species, it is much easier to obtain large samples of sex ratio data from field observations than to obtain large samples of age ratio data from bag inspections. Less skill is required to determine the sex of a duck in nuptial plumage than the age of a duck in any plumage.

To test the validity of sex ratios as criteria of duck production, we have made a comparison, fig. 9, of sex ratios with age ratios, which are direct reflections of production. Both ratios were obtained from mallards killed by Illinois hunters in 1939–1955 and 1959. We have also made, for several species of ducks, comparisons of sex ratios derived from observations on the breeding grounds, table 34, with the number of juveniles per hen killed in Illinois, table 62.

As shown in fig. 9, the sex ratios (per cent hens) and the age ratios (per cent juveniles) obtained from mallards killed by Illinois hunters differed markedly in several years. The fluctuations in age ratios tended to be of greater magnitude than those in sex ratios; the peaks were higher in age ratios than in sex ratios, and the troughs were deeper. An over-all correlation of +0.59 suggests that only fair agreement exists between the sex ratios and the age ratios. We conclude that sex ratios derived from bag inspections provide a fair index to productivity but not so good an index as age ratios.

Sex ratios obtained on the breeding grounds, table 34, do not appear to provide a more reliable index to production than sex ratios calculated from bag inspections in Illinois. Data for the breeding seasons of 1935–1942 and 1947–1950 (except certain data from Furniss, table 34) show that the drake percentages for the mallard, gadwall, pintail, green-winged teal, and ring-necked duck did not, in any season for which figures are available, deviate from the average for the species by as much as 5 per cent. This lack of deviation indicated relatively stable populations; data in table 62, showing the number of juveniles per adult hen for the years 1946–1949, indicated increasing

populations for all of the above-mentioned species except the gadwall.

AGE RATIOS

Two commonly used indicators of waterfowl production are brood densities (the number of broods per unit of area on the breeding grounds) and age ratios (the mathematical relationship between adults and juveniles old enough to fly).

Brood density surveys supply information of value for making pre-season adjustments in hunting regulations. However, data on brood densities are not believed to constitute precise indices of production. Substantial proportions of the broods present in an area are missed by observers employing survey techniques usually considered practicable (Anderson 1953:8-10). Correction for unobserved broods may never yield to reliable standardization, for the percentage of broods not found by observers varies with many factors such as time of day, time of season, habitat, area, and waterfowl population densities.

Age ratios are believed to afford a more promising basis than brood counts for measuring waterfowl production, although they, like data on brood densities, are seldom true indices of production.

This section of the paper is written with the intention of opening the way to a more effective use of age ratios in waterfowl management. The following aspects of age ratios and their use are considered: age criteria, sampling methods for obtaining age ratios, seasonal and regional variations in age ratios, factors tending to bias age ratios, age ratios as measures of production, environment in relation to production, production in different species, and the place of age ratios in population management.

Age Criteria

In 1938, when biologists of the Delta Waterfowl Research Station at Delta, Manitoba, and of the Illinois Natural History Survey at Havana, Illinois, initiated waterfowl research programs involving the inspection of large numbers of ducks bagged by hunters, the need for finding consistently reliable external characteristics by which to separate juveniles from

adults was recognized. The best external indication of age known at that time had been pointed out by Pirnie (1935:275). It was based on the appearance of the tips of tail feathers, those of adults being rounded or pointed, those of juveniles being blunt or notched. However, in the mallard, an important species in Illinois and at Delta, young birds were known to replace their juvenile feathers with adult feathers early in the fall; hence, they could not be accurately aged by this characteristic throughout the hunting season. In some species, notably those in the genus *Aythya*, the tail feather criterion was found to be more persistent than in the mallard, but, even so, it was not reliable throughout the hunting season.

During the fall of 1938, biologists at the Delta and Illinois stations searched for some characteristic by which to separate juveniles from adults in the mallard and other early-molting species. The search at Delta was concentrated on plumage, while that in Illinois was concerned with a character, pointed out by Ticehurst (1938:772-3) as being related to immaturity: striae "at the tip of the nail of both upper and lower mandibles." The Illinois group also investigated various parts of the skeleton that might exhibit differences in ossification between juveniles and adults. At that time, neither group was successful in the search for a characteristic by which to separate ducks into the two age classes.

In the following winter, Gower (1939:427) called attention to the bursa of Fabricius as a criterion of age in ducks. A short time later Hochbaum (1942:301), aided by the findings of Gower and the work of Owen (1866:244-5), learned that juvenile drakes of 5 to 10 months of age could be separated from adult drakes by the size of the penis, fig. 1. This finding, put to use in the summer and fall of 1939, provided a method of differentiating between juveniles and adults of both live and dead drakes. The new method proved faster and easier to use than the bursal method. Also, it provided for accurate separation of drakes from hens in all stages of plumage. However, the bursa was found to persist for several weeks after the transition from juvenile- to adult-type penis and therefore provided a

basis for separating juveniles from adults over a longer period of time than that afforded by the penis.

Hochbaum (1942:303-4) pointed out that the oviduct, which opens into the cloaca in adult females, is sealed by a membrane in immature females, fig. 1. Wildlife technicians in Illinois have found

collected from duck hunters and shipped to a central point for interpretation by trained personnel.

Sampling for Age Ratios

Data on the age ratios of ducks may be obtained by examination of birds trapped for banding, shot by hunters, or killed by

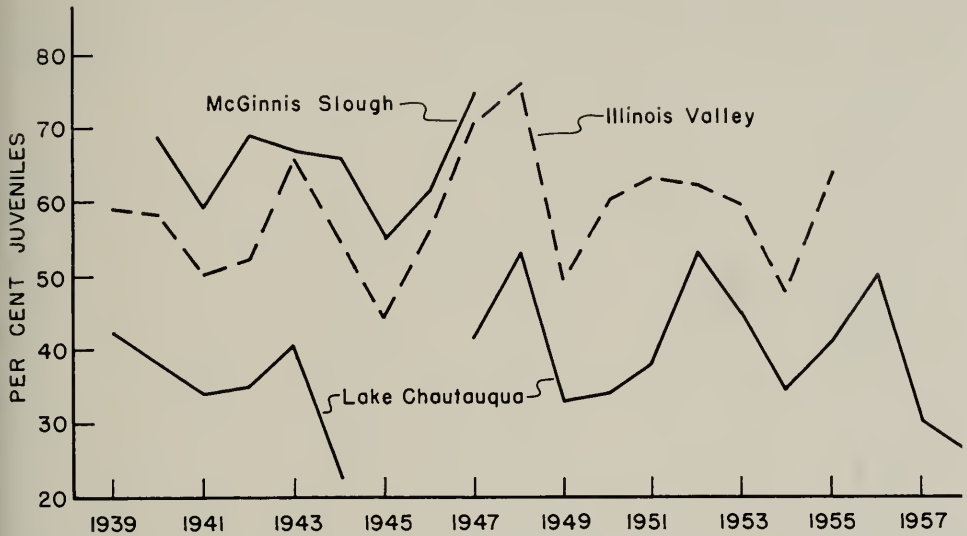


Fig. 10.—Year-to-year changes in the juvenile percentage in mallard drakes trapped at McGinnis Slough and at Lake Chautauqua and in mallards checked in hunters' bags in the Illinois River valley, 1939-1957.

that, until at least mid-January, the presence of a closed oviduct and a bursa unfailingly indicates a juvenile hen. Occasionally, a hen is found that shows an open oviduct and a small bursa; such a bird is considered adult. Most wildlife technicians have restricted their aging of hens to individuals that have been bagged by hunters. However, Hanson (1949) developed a technique that can be used for aging live females in both ducks and geese.

In 1958, after completion of most of the field work for the study reported here. Carney & Geis (1960:376-9) found that, in certain species of ducks, juveniles and adults could be identified with a high degree of accuracy on the basis of differences in the wing plumage. The technique described by these authors makes possible the extensive sampling of age ratios of ducks in all four flyways of North America. Large numbers of wings could be

disease. It seems desirable that the relative merits of these sources of data be appraised. In the present study, all three sources of data were used for obtaining age ratios.

Examination of Trapped Ducks.—

A comparison of the age ratios of mallard drakes trapped at Lake Chautauqua, table 35, and the age ratios of mallard drakes and hens taken by hunters in the Illinois River valley, table 36, discloses marked disparity in the number of juveniles per adult between the trapped ducks and the harvested ducks. The data show relatively fewer juveniles among the drakes trapped at Lake Chautauqua than among the ducks taken by hunters in the Illinois River valley, tables 35 and 36 and fig. 10. However, among drake mallards captured at McGinnis Slough in traps similar to those used at Lake Chautauqua, a higher proportion consisted of juveniles, table 37 and fig. 10, than among mallard drakes

trapped at Lake Chautauqua or mallards bagged in the vicinity of that lake.

Despite marked differences in the size of samples between trapped and shot mallards, the two sampling procedures indicated similar year-to-year trends in age ratios, fig. 10. The statistical correlation in the annual changes in age ratios between mallard drakes trapped at Lake Chautauqua and mallards shot along the Illinois River was found to be significant

($r = +0.96$, 13 d.f.) at the 99 per cent level.

Mallards inspected in hunters' bags in the Illinois River valley (1939-1949) and mallard drakes taken in traps at Lake Chautauqua (1939-1944 and 1947) showed similar trends in age ratios for most of the hunting season, fig. 11. The trends tended to be parallel except in early December. The correlation between age ratios calculated weekly for the samples

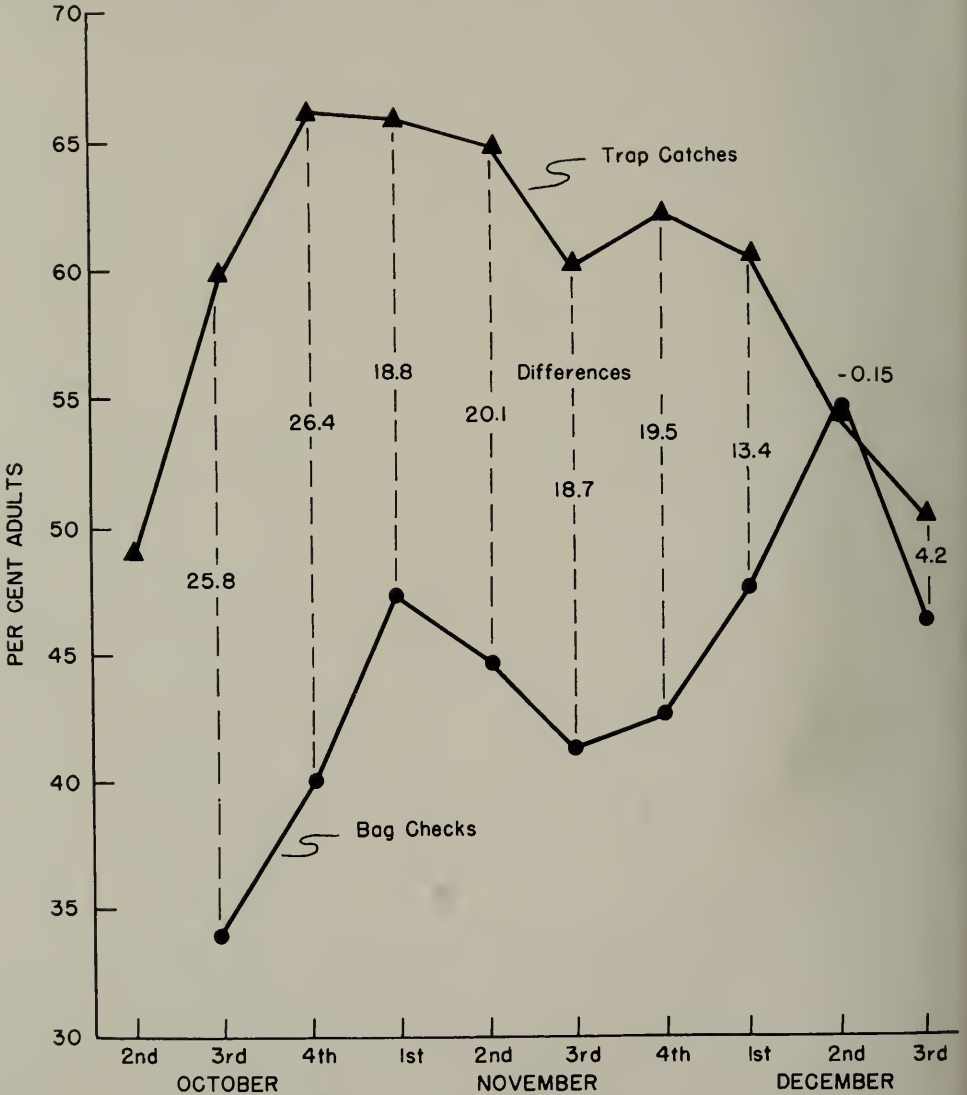


Fig. 11.—Week-to-week changes in the adult percentage of the autumn flight of mallards in Illinois, as indicated by two sampling methods: checks of mallards in hunters' bags and inspection of mallard drakes caught in banding traps. Bag data are for the Illinois River valley, 1939-1949; trap data are for Lake Chautauqua, 1939-1944 and 1947.

of trapped and shot mallards was significant ($r=+0.94$, 7 d.f.) at the 99 per cent level.

Behavior may well account for the large juvenile proportion in the mallard drakes taken in traps at McGinnis Slough, fig. 10, and the small proportion in those taken in traps at Lake Chautauqua. As discussed

under sex ratios, mallard drakes were observed to be more aggressive than hens in pushing their way into the traps at Lake Chautauqua. Perhaps adults shouldered young birds aside in aggressive efforts to get at the bait. Lake Chautauqua had a much greater density of mallards and comparatively less natural food than McGin-

Table 35.—Number of juveniles per adult among mallard drakes trapped and banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, 1939–1944 and 1947–1959.

YEAR	NUMBER OF DRAKES TRAPPED AND BANDED	PER CENT JUVENILES	JUVENILES PER ADULT	APPROXIMATE 95 PER CENT CONFIDENCE LIMITS
1939.....	2,574	42.3	0.73	0.67–0.80
1940.....	4,262	37.9	0.61	0.57–0.66
1941.....	3,200	34.1	0.52	0.47–0.56
1942.....	4,859	35.3	0.55	0.51–0.58
1943.....	4,655	40.6	0.68	0.64–0.73
1944.....	2,734	22.6	0.29	0.26–0.32
1947.....	1,481	41.1	0.70	0.62–0.78
1948.....	1,332	53.1	1.13	1.01–1.27
1949.....	3,597*	33.1	0.50	0.45–0.54
1950.....	1,984*	34.1	0.52	0.47–0.57
1951.....	3,801*	37.7	0.61	0.56–0.65
1952.....	4,493	53.7	1.16	1.09–1.24
1953.....	1,048	44.9	0.82	0.72–0.92
1954.....	901	34.4	0.52	0.46–0.60
1955.....	998	41.1	0.70	0.61–0.79
1956.....	632	50.1	1.01	0.86–1.17
1957.....	856	29.6	0.42	0.35–0.49
1958.....	736	25.8	0.35	0.28–0.42
1959.....	93	9.7	0.11	0.04–0.18

*This figure differs from the corresponding figure in table 39 because it includes ducks banded with reward bands, which have shown a higher rate of return than standard bands (Bellrose 1955).

Table 36.—Number of juveniles per adult among mallard drakes and hens checked in hunters' bags in Illinois, principally the Illinois River valley, 1939–1955 and 1959.

YEAR	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT	APPROXIMATE 95 PER CENT CONFIDENCE LIMITS
1939.....	2,261	59.1	1.45	1.32–1.58
1940.....	3,564	58.7	1.42	1.33–1.52
1941.....	4,481	50.3	1.01	0.95–1.08
1942.....	1,809	54.2	1.18	1.07–1.30
1943.....	1,422	66.0	1.94	1.73–2.18
1944.....	2,167	54.3	1.19	1.09–1.30
1945.....	2,047	43.9	0.78	0.67–0.92
1946.....	1,317	55.5	1.25	1.11–1.40
1947.....	814	70.3	2.36	2.03–2.78
1948.....	1,215	76.0	3.18	2.78–3.63
1949.....	597	49.2	0.97	0.79–1.18
1950.....	581	60.4	1.53	1.28–1.82
1951.....	819	63.1	1.71	1.48–1.99
1952.....	1,209	62.3	1.65	1.46–1.87
1953.....	1,152	59.6	1.48	1.34–1.63
1954.....	458	47.6	0.91	0.75–1.10
1955.....	746	64.1	1.78	1.34–2.22
1959.....	247	25.5	0.34	0.30–0.38

Table 37.—Number of juveniles per adult among mallard drakes trapped and banded at McGinnis Slough, Cook County, Illinois, 1940–1947.

YEAR	NUMBER OF DRAKES TRAPPED AND Banded	PER CENT JUVENILES	JUVENILES PER ADULT	APPROXIMATE 95 PER CENT CONFIDENCE LIMITS
1940.....	267	68.5	2.18	1.68–2.85
1941.....	195	59.5	1.47	1.11–1.98
1942.....	1,128	69.0	2.22	1.96–2.54
1943.....	1,922	67.1	2.04	1.85–2.25
1944.....	967	65.9	1.93	1.69–2.22
1945.....	1,492	54.9	1.22	1.09–1.36
1946.....	860	61.5	1.60	1.39–1.85
1947.....	556	74.3	2.89	2.40–3.55

nis Slough. This situation may have resulted in greater competition for food at Lake Chautauqua and consequently greater aggressiveness on the part of the adult mallard drakes. The greater frequency of juvenile drakes in traps at McGinnis Slough than at Lake Chautauqua may have resulted in part from greater wariness on the part of adult drakes. With an abundance of natural food at McGinnis Slough, many adults may have avoided the traps or ignored the foods they contained. Apparently, in one case (Lake Chautauqua) the traps were selective for adults while in the other (McGinnis Slough) they were selective for juveniles.

There was a significant correlation at the 99 per cent level between the age ratios of drake mallards trapped at McGinnis Slough, table 37, and the age ratios of mallards taken by hunters in the Illinois River valley, table 36 ($r=+0.93$, 6 d.f.).

Data obtained from retrapping mallard

drakes previously trapped and banded at Lake Chautauqua, table 38, indicated that the banding traps there were selective, sometimes for juveniles and sometimes for adults. During the period October 4–24, juveniles re-entered the traps with greater frequency than adults ($X^2=31.14$, 1 d.f., significant at the 99 per cent level). In contrast, during the period October 25–December 25, adults re-entered the traps with greater frequency than juveniles ($X^2=12.90$, 1 d.f., significant at the same level). These retrap data showed that early in the season, when mallard numbers were low and food competition was at a minimum, banding traps were selective for juveniles, but, when mallard numbers increased and food competition became greater, the traps were selective for adults. The bulk of the mallard population arrived in Illinois after October 25, and the banding traps at Lake Chautauqua were on the whole highly selective for adults.

A correlation, significant at the 99 per cent level, was found in each year for the

Table 38.—Number of adult and of juvenile mallard drakes trapped and banded and the per cent retrapped during two periods at the Chautauqua National Wildlife Refuge, near Havana, Illinois, 1940–1943.

PERIOD	ADULTS			JUVENILES			RATIO OF PER CENT OF ADULTS RETRAPPED TO PER CENT OF JUVENILES RETRAPPED
	Number		Per Cent Retrapped	Number		Per Cent Retrapped	
	Trapped and Banded	Re-trapped		Trapped and Banded	Re-trapped		
Oct. 4–24.....	1,305	297	22.8	1,026	340	28.2	1:1.24
Oct. 25–Dec. 25.	9,322	991	10.6	5,265	462	8.8	1:0.83

Table 39.—Comparative vulnerability (to hunting) of adult and juvenile mallard drakes banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, 1939–1944 and 1947–1952; vulnerability measured by year-of-banding recoveries. Ducks banded with reward bands (Be.rose 1955) in 1949, 1950, and 1951 were not included in this table.

YEAR	NUMBER OF DRAKES BANDED		YEAR-OF-BANDING RECOVERIES		NUMBER BANDED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
1939.....	1,486	1,088	65	49	22.9	22.2	1:1.03
1940.....	2,647	1,615	132	200	20.1	8.1	1:2.48
1941.....	2,110	1,090	57	43	37.0	25.4	1:1.46
1942.....	3,142	1,717	216	177	14.6	9.7	1:1.51
1943.....	2,763	1,892	138	146	20.0	13.0	1:1.54
1944.....	2,117	617	125	56	16.9	11.0	1:1.54
1947.....	871	610	31	34	28.1	17.9	1:1.57
1948.....	624	708	5	11	124.8	64.4	1:1.94
1949.....	1,286	1,192	46	53	28.0	22.5	1:1.24
1950.....	449	359	24	27	18.7	13.3	1:1.41
1951.....	583	325	20	12	29.2	27.1	1:1.08
1952.....	2,082	2,411	60	151	34.7	16.0	1:2.17
<i>All years.....</i>	<i>20,160</i>	<i>13,624</i>	<i>919</i>	<i>959</i>	<i>21.9</i>	<i>14.2</i>	<i>1:1.54</i>

relative constancy between the age ratios of mallard drakes banded at McGinnis Slough and of those banded at Chautauqua ($r=+0.98$, 5 d.f.), tables 35 and 37.

In spite of trap bias, ducks taken in traps are believed to provide a rough index to relative changes in age ratios.

Inspection of Hunters' Bags.—It became apparent early in the study that juvenile ducks were more readily taken by hunters than were adults. Tests suggested that data obtained by trapping and banding ducks could be used to correct for the greater vulnerability of the juveniles. The following equation was used for this purpose:

Number of adults banded during current season but before end of hunting season

Vulnerability quotient $V = \frac{\text{Number of year-of-banding band recoveries from adults}}{\text{Number of juveniles banded during current season but before end of hunting season}}$

Number of juveniles banded during current season but before end of hunting season

Number of year-of-banding band recoveries from juveniles

An example of the use of the equation with banding data for 1940 in table 39 follows:

$$V = \frac{\frac{2,647}{132}}{\frac{1,615}{200}} = \frac{20.1}{8.1} = 2.48$$

Mallards were banded at one or more stations in Illinois each year from October, 1939, through 1952, and the data obtained were used for determining the yearly variations in comparative vulnerability of juvenile and adult drakes, tables 39 and 40. Adult drakes banded at McGinnis Slough, table 40, experienced relatively greater losses from hunting than did those banded at Lake Chautauqua, table 39. The number of juvenile drakes banded per juvenile recovery was about the same at both places. The data indicate that greater hunting pressure was exerted on adult drakes banded at McGinnis Slough than on those banded at Chautauqua.

Black duck drakes banded at McGinnis Slough had about the same loss of juveniles to hunting, table 41, as did mallard drakes banded there, table 40. Black duck drakes banded at Lake Chautauqua, table 42, like mallard drakes banded there, table 39, experienced a lower rate of hunting loss among adults than did black duck drakes banded at McGinnis Slough, table 41. Apparently, in mallard and black duck drakes banded at Lake Chautauqua, the relatively lower hunting losses in adults resulted from the greater protection afforded them outside the banding station area. The Chautauqua National Wildlife Refuge is about 10 times as large as

Table 40.—Comparative vulnerability (to hunting) of adult and juvenile mallard drakes banded at McGinnis Slough, Cook County, Illinois, 1942–1947; vulnerability measured by year-of-banding recoveries.

YEAR	NUMBER OF DRAKES BANDED		YEAR-OF-BANDING RECOVERIES		NUMBER BANDED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
1942.....	350	778	26	66	13.5	11.8	1:1.14
1943.....	632	1,290	21	57	30.1	22.6	1:1.33
1944.....	330	637	33	67	10.0	9.5	1:1.05
1945.....	673	819	38	69	17.7	11.9	1:1.49
1946.....	331	529	20	41	16.6	12.9	1:1.29
1947.....	143	413	8	29	17.9	14.2	1:1.26
<i>All years.....</i>	<i>2,459</i>	<i>4,466</i>	<i>146</i>	<i>329</i>	<i>16.8</i>	<i>13.6</i>	<i>1:1.24</i>

Table 41.—Comparative vulnerability (to hunting) of adult and juvenile black duck drakes banded at McGinnis Slough, Cook County, Illinois, 1940–1947; vulnerability measured by year-of-banding recoveries.

YEAR	NUMBER OF DRAKES BANDED		YEAR-OF-BANDING RECOVERIES		NUMBER BANDED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
1940.....	33	48	4	6	8.3	8.0	1:1.04
1941.....	153	253	10	16	15.3	15.8	1:0.97
1942.....	231	414	15	32	15.4	12.9	1:1.19
1943.....	259	336	8	16	32.4	21.0	1:1.54
1944.....	167	323	16	39	10.4	8.3	1:1.25
1945.....	166	296	11	31	15.1	9.6	1:1.57
1946.....	128	257	6	18	21.3	14.3	1:1.49
1947.....	117	271	1	9	.....	.....	.....
<i>All years.....</i>	<i>1,254</i>	<i>2,198</i>	<i>71</i>	<i>167</i>	<i>17.7</i>	<i>13.2</i>	<i>1:1.34</i>

Table 42.—Comparative vulnerability (to hunting) of adult and juvenile black duck drakes banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, 1939–1944 and 1947–1950; vulnerability measured by year-of-banding recoveries.

YEAR	NUMBER OF DRAKES BANDED		YEAR-OF-BANDING RECOVERIES		NUMBER BANDED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
1939.....	55	47	2	2	27.5	23.5	1:1.17
1940.....	93	68	4	6	23.3	11.3	1:2.06
1941.....	181	148	1	4	181.0	37.0	.....
1942.....	225	123	22	20	10.2	6.2	1:1.65
1943.....	188	115	9	9	20.9	12.8	1:1.63
1944.....	119	66	7	8	17.0	8.3	1:2.05
1947.....	70	63	.....	.....	.....	.....	.....
1948.....	39	48	.....	.....	.....	.....	.....
1949.....	216	165	3	11	72.0	15.0	1:4.80
1950.....	98	12	4	1	24.5	12.0	1:2.04
<i>All years.....</i>	<i>1,284</i>	<i>855</i>	<i>52</i>	<i>61</i>	<i>24.7</i>	<i>14.0</i>	<i>1:1.76</i>

McGinnis Slough; also, several other refuges occur within the 25- to 30-mile feeding radius of mallards congregating at Chautauqua, whereas none occurs within that distance of McGinnis Slough. It seems evident that adult mallards and

drakes became less vulnerable, table 44, presumably as a result of increased experience with hunters. During the early part of the season, the juveniles were bagged about four times as readily as adults; late in the season they were bagged only about

Table 43.—Comparative vulnerability (to hunting) of adult and juvenile blue-winged teal drakes and hens banded in Illinois at McGinnis Slough, Cook County, 1942–1947, and at Moscow Bay, Mason County, 1949–1951; vulnerability measured by year-of-banding recoveries.

YEAR	NUMBER OF DUCKS BANDED		YEAR-OF-BANDING RECOVERIES		NUMBER BANDED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
1942.....	156	535	7	29	22.3	18.5	1:1.21
1943.....	131	424	2	16	65.5	26.5	1:2.47
1944.....	304	534	8	45	38.0	11.9	1:3.19
1945.....	193	444	8	23	24.1	19.3	1:1.25
1946.....	90	686	1	9	90.0	76.2	1:1.18
1947.....	65	234	1	6	65.0	39.0	1:1.67
1949.....	169	1,071	0	34	.....	31.5	.....
1950.....	152	505	2	22	76.0	23.0	1:3.30
1951.....	210	1,189	4	33	52.5	36.0	1:1.46
<i>All years. . .</i>	<i>1,470</i>	<i>5,622</i>	<i>33</i>	<i>217</i>	<i>44.6</i>	<i>25.9</i>	<i>1:1.72</i>

black ducks at Chautauqua made good use of their acquired knowledge of protected areas.

Blue-winged teals banded at McGinnis Slough and Moscow Bay experienced greater differences between the two age groups in vulnerability to hunting, table 43, than did mallard drakes banded at Lake Chautauqua, table 39, or McGinnis Slough, table 40. Although blue-winged teals are generally considered to be less wary than mallards and black ducks, the development of wariness by juvenile blue-winged teals may be as rapid as that by juvenile mallards when the birds are subjected to hunting. Vulnerability in the blue-winged teal, as in other species, probably is related to the amount of experience that juveniles have had with hunters. Most of the juvenile blue-winged teals arrive in Illinois in advance of the open season in the northern zone and therefore are inexperienced with hunters at the time of their arrival. Most juvenile mallards and black ducks have been subjected to hunting by the time they reach Illinois.

Data collected in 1940, 1942, 1943, and 1952 showed that, as the hunting season progressed in Illinois, juvenile mallard

one and one-half times as readily. Thus, age ratios obtained from hunters' bags on major wintering grounds would be less biased by the greater vulnerability of juveniles than samples taken earlier on breeding or migration areas. The year-to-year variations in the amount of hunting experience juveniles receive before they reach Illinois may be an important factor in determining the year-to-year variations in the vulnerability of juveniles in this state, tables 39 and 40. Mallard age ratios obtained from bag checks on the breeding grounds appear to be the ratios most biased by juvenile vulnerability, and those obtained on the wintering grounds are probably the least biased, table 52.

The relative vulnerability of juveniles and adults of several duck species have been calculated from recovery of birds banded on the Canadian breeding grounds, table 45. The recovery data for the teals and the shoveler show either no greater vulnerability among juveniles than among adults or a greater vulnerability among adults. However, as recovery data for blue-winged teals banded in Illinois over a period of several years show a markedly greater vulnerability of juveniles, table

43, it is suspected that some unusual local conditions affected the Canadian bandings of these three species. Perhaps many juvenile teals and shovelers lost bands, for, until 1957, the banding office at the Patuxent Research Center, Laurel,

Table 44.—Seasonal change in comparative vulnerability (to hunting) of adult and juvenile mallard drakes banded at the Chautauqua National Wildlife Refuge, near Havana, Illinois, in 1940, 1942, 1943, and 1952.

WEEK	NUMBER OF DRAKES BANNED (CUMULATIVE)		NUMBER OF RECOVERIES FOR WEEK		NUMBER BANNED PER RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
Oct. 4-10.....	112	90	0	0			
Oct. 11-17.....	493	452	1	6	493.0	75.3	1:6.55
Oct. 18-24.....	1,700	1,224	8	24	212.5	51.0	1:4.17
Oct. 25-31.....	3,268	2,111	9	28	363.1	75.4	1:4.82
Nov. 1-7.....	4,913	3,363	14	34	350.9	98.9	1:3.55
Nov. 8-14.....	6,360	4,561	35	55	181.7	82.9	1:2.19
Nov. 15-21.....	8,025	6,116	29	51	276.7	119.9	1:2.31
Nov. 22-28.....	9,752	7,025	48	78	203.2	90.1	1:2.26
Nov. 29-Dec. 5.	10,319	7,398	73	88	141.4	84.1	1:1.68
Dec. 6-12.....	10,464	7,483	70	96	149.5	78.0	1:1.92
Dec. 13-19.....	10,629	7,626	65	51	163.5	149.5	1:1.09
Dec. 20-26.....	10,634	7,635	31	35	343.0	218.1	1:1.57
Dec. 27-Jan. 2..	10,634	7,635	30	15	354.5	509.0	1:0.70
Jan. 3-9.....	10,634	7,635	22	24	483.4	318.1	1:1.52
Jan. 10-16.....	10,634	7,635	5	6	2,126.8	1,272.5	1:1.67
Jan. 17-23.....	10,634	7,635	2	0			
<i>All weeks</i>							
<i>Total.....</i>	<i>10,634</i>	<i>7,635</i>	<i>442</i>	<i>591</i>			
<i>Average.....</i>					<i>24.0</i>	<i>12.9</i>	<i>1:1.86</i>

Table 45.—Comparative vulnerability (to hunting) of adults and juveniles, both drakes and hens, of 10 species of ducks banded by Ducks Unlimited* in the prairie provinces of Canada, 1946-1954; vulnerability measured by year-of-banding recoveries.

SPECIES	NUMBER OF DUCKS BANNED		YEAR-OF-BANDING RECOVERIES		NUMBER BANNED PER YEAR-OF-BANDING RECOVERY		RATIO OF ADULT TO JUVENILE VULNERABILITY
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
Mallard.....	4,672	10,159	396	1,130	11.8	9.0	1:1.31
Gadwall.....	133	351	5	31	26.6	11.3	1:2.35
Baldpate.....	491	765	17	76	28.9	10.1	1:2.86
Pintail.....	5,257	3,013	155	169	33.9	17.8	1:1.90
Green-winged teal.....	391	1,223	12	36	32.6	34.0	1:0.96†
Blue-winged teal.....	1,809	2,716	42	63	43.1	43.1	1:1.00†
Shoveler.....	117	261	7	12	16.7	21.7	1:0.77†
Redhead.....	715	358	32	56	22.3	6.4	1:3.48
Canvasback....	50	125	4	29	12.5	4.3	1:2.91
Lesser scaup....	393	1,716	14	119	28.1	14.4	1:1.95

*Compilation by William Leitch, Chief Biologist, Ducks Unlimited; data are from bandings by field personnel qualified to separate adult and juvenile ducks.

†This ratio probably incorrect, perhaps partly as a result of loss of bands by newly banded juveniles and unusually heavy losses among juveniles between banding and opening of hunting season.

Maryland, recommended size 6 for the shoveler, although a size 5 is large enough for that species. Many banders used size 5 to mark green-winged teals, although size 4 is the proper size. Perhaps natural mortality was unusually severe in the young teals and shovelers between the time of banding and the opening of the hunting season; very few bands are recovered from ducks that are not bagged by hunters. Still another possible explanation for unexpectedly low relative vulnerability rates for juveniles on the Canadian breeding grounds has been posed by Robert I. Smith of the Illinois Natural History Survey. Smith has observed on the breeding grounds that fall flocking behavior of juveniles differs from that of adults. Prior to migration, juveniles tend to congregate, while many adults remain as single hens of male-female pairs. The nature and time of this flocking behavior, Smith believes, varies with species and with the success and duration of the nesting season. Flock size is probably inversely correlated with vulnerability, thus tending to give greater protection to the congregated juveniles than to the single adult hens or paired adults.

Band recovery data showed pronounced differences among species in the vulnerability rates of juveniles banded in Canada, table 45. Among species other than the teals and the shoveler, juveniles were least vulnerable to the gun in the mallard

and most vulnerable in the redhead. Other data obtained from bandings at national wildlife refuges also disclosed wide variations in juvenile vulnerability; they showed the mallard with a comparatively low juvenile vulnerability rate, followed by the pintail, and showed the redhead with the highest vulnerability rate.

Thus, the gun vulnerability of juveniles compared to that of adults was found to vary by place, time of hunting season, year, and species.

Gun vulnerability figures for correcting age ratios obtained by checking hunters' bags in one or more flyways can best be obtained by banding adults and juveniles in southern Canada just prior to the opening of the hunting season.

When adequate data from banded ducks are available, they provide a means of testing for and, if necessary, correcting for the relatively greater vulnerability of juveniles. We believe that age ratios of ducks obtained from bag samples and corrected for the greater vulnerability of juveniles offer the best means of determining the adult-juvenile composition of duck populations. However, before these data are used to evaluate production, an appraisal of the influence of season and geography on age ratio samples is needed.

Examination of Disease Victims.

—At times, age ratios have been obtained from large samples of ducks which have been victims of disease. During fowl

Table 46.—Juvenile percentages among botulism victims in five species of ducks at the Bear River Migratory Bird Refuge, Utah, during late summer, 1952.*

PERIOD	MALLARD		PINTAIL		GREEN-WINGED TEAL		SHOVELER		BALDPATE	
	Number	Per Cent Juveniles	Number	Per Cent Juveniles	Number	Per Cent Juveniles	Number	Per Cent Juveniles	Number	Per Cent Juveniles
August										
1st week.....	48	39.6	486	51.2						
2nd week.....	38	52.6	560	50.5						
3rd week.....	34	44.1	601	61.7	128	41.4	26	57.7		
4th week.....	87	41.4	2,392	50.6	651	42.7	94	46.8	26	38.5
September										
1st week.....	29	44.8	1,211	44.3	431	43.6	81	38.3	65	52.3
2nd week.....	38	39.5	781	47.1	371	47.7	107	42.1	62	46.8

*Calculated from data in a report, "Sex and Age Ratio of Waterfowl Afflicted by *Clostridium botulinum*, Type C, on the Bear River Migratory Bird Refuge During Summer, 1952," by Jack P. Allen, Utah Cooperative Wildlife Research Unit, Logan.

cholera epizootics in wild ducks, records have been made of the species and sex affected, but little attention has been given to the ages of victims. In Utah, large numbers of waterfowl that were victims of botulism at the Ogden Bay Bird Refuge were classified as juveniles or adults by Noland F. Nelson, tables 21 and 22, and ducks lost to botulism at the Bear River Migratory Bird Refuge were similarly classified by Jack P. Allen, table 46. The degree to which botulism toxin is selective for the two age groups has not been investigated.

Epizootics resulting in extensive loss of waterfowl cannot be relied upon as dependable sources of data on age ratios because of irregular occurrence and site limitations. However, advantage should be taken of such occasions for the purpose of obtaining supplementary age data and for investigating the extent to which disease may be selective for age classes.

Seasonal Variations in Age Ratios

Because adults and juveniles, like drakes and hens, have different migration schedules, age ratios calculated for any given area have seasonal variations.

Differential migratory movements of adult and juvenile age groups often originate on the breeding grounds, where most of the adult drakes of most species leave their mates early in the nesting period to congregate on large lakes and marshes; these areas may be in the immediate breeding area or up to hundreds of miles distant. After the broods become independent, the hens leave them and molt their flight feathers but usually remain in the area where they nested (Hochbaum 1944: 119, 122). Hens that have been unsuccessful in their nesting efforts may join the drakes on the lakes or marshes, where they molt.

Certain large lakes and marshes on the breeding grounds serve ducks as gathering areas preceding southward migration. One of these areas is the Delta Marsh at the south end of Lake Manitoba, Canada. The number of juveniles per adult among mallards in hunters' bags on that marsh was checked for several weeks in 1946 and 1947, tables 47 and 48. There was a reduction in the number of juveniles per adult from the third week to the fourth

week in September, 1946, followed by a gradual increase in the number of juveniles per adult until the first week in November, when a very sharp decrease took place. There was a marked decrease in the number of juveniles per adult in the period October 20-25, 1947. When the

Table 47.—Number of juveniles per adult among mallards checked in hunters' bags on the Delta Marsh, Manitoba, in each of 6 weeks in the autumn of 1946.

PERIOD	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT
September			
3rd week..	707	67	2.03
4th week..	146	49	0.96
October			
1st week...	329	54	1.17
2nd week..	231	61	1.57
3rd week..	196	63	1.70
November			
1st week...	33	15	0.18

Table 48.—Number of juveniles per adult among mallards checked in hunters' bags on the Delta Marsh, Manitoba, in each of three periods in the autumn of 1947.

PERIOD	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT
Oct. 10.....	121	72	2.57
Oct. 13-18...	174	71	2.45
Oct. 20-25...	163	51	1.04

changes in these age ratios were tested statistically, it was found that in both years the changes were significant at the 99 per cent level (1946, $X^2=55.04$, 5 d.f.; 1947, $X^2=19.34$, 2 d.f.).

A late hatch, sometimes as a result of delay in initial nesting and sometimes as a result of severe losses of early nests, may delay the appearance of juvenile mallards in Illinois, as in 1939, 1943, 1945, 1947, 1949, and 1950, fig. 12. The effect of a late hatch may be shown in the degree of retention of juvenile plumage by young during the southward migration, as was evident in juvenile mallards in Illinois in 1950 and 1953. Breeding grounds surveys indicated a delayed or extended hatch in 1950 (Hawkins 1950:42; Sowls 1950:

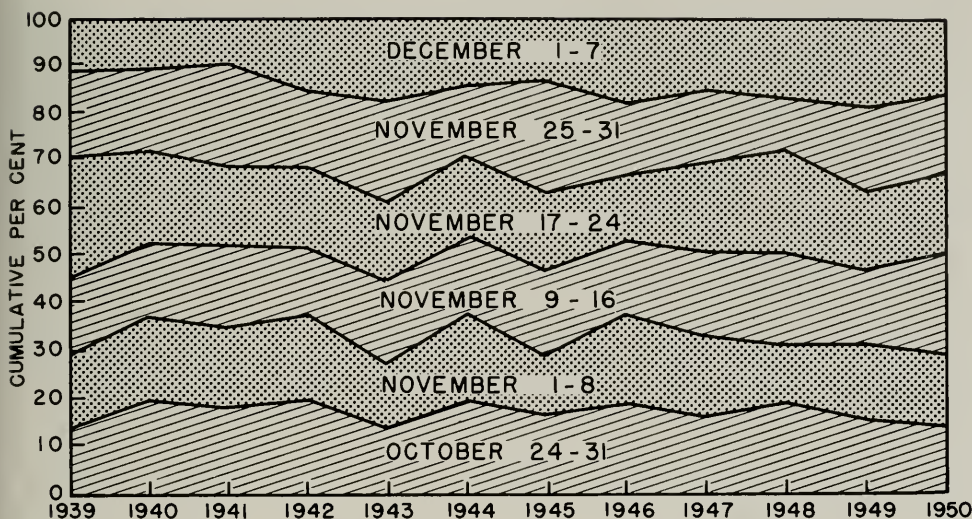


Fig. 12.—Year-to-year variations in the seasonal migration of juvenile mallards through the Illinois River valley, 1939-1950, as shown by the proportion of each year's juvenile flight that was in the valley in each of 6 weeks in autumn.

60) and in 1953 (Lynch & Gollop 1954:47; Gollop 1954:67; Hawkins 1954:77).

That the age composition of the mallard population in Illinois varied from week to week in the fall is shown by checks of hunters' bags, table 44. In any one year, pronounced week-to-week variations in the age composition of mallards taken by hunters in Illinois suggest that there may be many migratory movements, some scarcely detectable, within a local population.

The adult-juvenile composition of the mallard flight in Illinois for the period 1939-1949 is reflected in fig. 13. Generally, juveniles made up a greater part of the mallard bag early in the season than later. The juvenile proportion in hunters' bags soon declined, as indicated by data collected during the first half of November; it recovered somewhat during the second half of November but declined again during the first 2 weeks of December. The decline in December resulted as juveniles moved farther south and large numbers of adults moved into Illinois from the north.

In 6 of 7 years, juvenile mallards in Arkansas formed a greater proportion of the hunters' bags in the second than in the first of two periods during which data were collected, table 49. The findings shown in fig. 13 and tables 49 and 50

suggest that, between the mid-flyway areas (Illinois) and the wintering grounds (Arkansas), juveniles may be more prone to leisurely migration than adults.

The daily change in age composition of the mallard bag at Stuttgart, Arkansas, for December 2-11, 1950, is given in table 50. A marked change in the relative number of juveniles in the bag occurred on December 8. A large southward flight of mallards from Illinois on December 7, as a result of zero weather and snow, contained a relatively large number of juve-

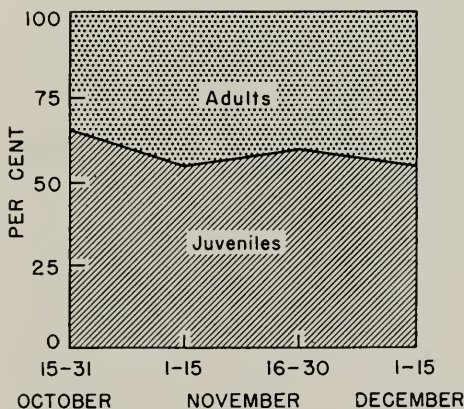


Fig. 13.—Juvenile-adult composition of the autumn flight of mallards in Illinois, as indicated by checks of hunters' bags in the autumns of 1939-1949.

Table 49.—Number of juveniles per adult among mallards checked in hunters' bags at Stuttgart, Arkansas, in 12 hunting seasons.

HUNTING SEASON	PERIOD OF SAMPLING	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT	PROBABILITY THAT CHANGE RESULTED FROM CHANCE
1946.....	Nov. 23-26	1,889	55	1.22	<0.05>0.025
	Nov. 27-Dec. 1	1,461	52	1.08	
1947.....	Dec. 8-11	2,064	59	1.44	<0.005
	Dec. 12-14	1,253	67	2.03	
1948.....	Nov. 26-31	2,035	68	2.12	<0.10>0.05
	Dec. 2-4	965	71	2.45	
1949.....	Nov. 18-21	1,830	47	0.89	<0.05>0.10
	Dec. 26-27	274	51	1.04	
1950.....	Dec. 2-11	3,712	42	0.72	<0.50>0.25
	Dec. 28-29	149	46	0.85	
1951.....	Nov. 22-23	500	59	1.44	<0.05>0.025
	Dec. 1-8	2,500	64	1.78	
1952.....	Dec. 6-9	997	65	1.86	.....
1953.....	Nov. 27-28	341	43	0.74	<0.50>0.25
	Dec. 21-22	230	48	0.92	
1954-55.....	Jan. 4-5	408	49	0.96	.....
1955-56.....	Jan. 7-8	458	58	1.38	.....
1958.....	Dec. 8-10	1,139	32	0.47	.....
1959.....	Nov. 30-Dec. 1	1,053	23	0.29	.....

nile ducks. Its impact on age ratios in Arkansas seemed apparent. When age ratios before and after the influx of the juvenile mallards from Illinois into Arkansas were statistically compared, the difference was found to be significant ($X^2=45.6$, 1 d.f.) at the 99 per cent level.

Because Utah is a breeding ground for several species of ducks, an important molting area for several species, and an important migration area for many species, it might be anticipated that age ratios in this state would show a complex relationship to migration.

Records on ducks taken in traps at Ogden Bay, Utah (Fuller & Low 1951:42), indicated that "the earlier arrivals were immature birds, adults showing up more frequently from the last of August, . . ." This evidence from trapping operations late in summer plus declining numbers of juvenile pintails during the fall in the bags of Utah hunters, fig. 14, suggest the possibility of a pronounced movement of juvenile pintails through Utah before the hunting season. According to J. B. Gollop of the Canadian Wildlife Service (personal communication), there was good

evidence in Saskatchewan in 1952 that a mass exodus of juvenile pintails occurred during late August.

A tally of adult and juvenile ducks that were victims of botulism during August and the first half of September, 1952, on the Bear River Migratory Bird Refuge, table 46, also provides data on the age

Table 50.—Number of juveniles per adult among mallards checked in hunters' bags at Stuttgart, Arkansas, in each of 10 days in December, 1950.

DATE	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT
Dec. 2.....	535	39.6	0.66
3.....	771	38.9	0.64
4.....	584	38.2	0.62
5.....	345	33.3	0.50
6.....	59	32.2	0.48
7.....	100	38.0	0.61
8.....	240	58.3	1.41
9.....	372	46.5	0.87
10.....	469	48.0	0.92
11.....	237	47.3	0.89
Dec. 2-11.....	3,712	42.0	0.72

ratios of ducks in a Utah area before the hunting season. These data, unlike the data from ducks trapped at Ogden Bay, do not show a large juvenile duck population prior to the hunting season. Perhaps adults are more susceptible to botulism than juveniles, or perhaps there were differences in age composition between the duck populations on these two marshes, which are about 25 miles apart. Such differences were reflected in hunters' bags checked on the two marshes, tables 55, 56, and 57. Further study of the composition of Utah duck populations seems very desirable, because of the differences in age ratios and the importance of seasonal influences on age ratios in that state.

Mallard migration in Utah in six autumns of the 1940's, fig. 14, was somewhat similar to that in Illinois, fig. 13. Juveniles were most abundant early in the

season; their proportion in the bag steadily decreased to the November 16-30 period, after which it remained fairly constant. In Utah, the age pattern of migrating pintails tended to reflect that of migrating mallards, fig. 14. The green-winged teal showed a rather steady decrease in the relative number of juveniles as the season progressed, while the shoveler had a ratio of adults to juveniles that remained about the same throughout the season.

Thus, in the selection of strategic sites for collecting age data on ducks, and in the evaluation of age ratios, migration schedules of waterfowl must be considered. In some species, much of the migration occurs outside of the hunting season; in such species, age ratios calculated from data collected from hunters' bags may not be representative of the populations. Un-

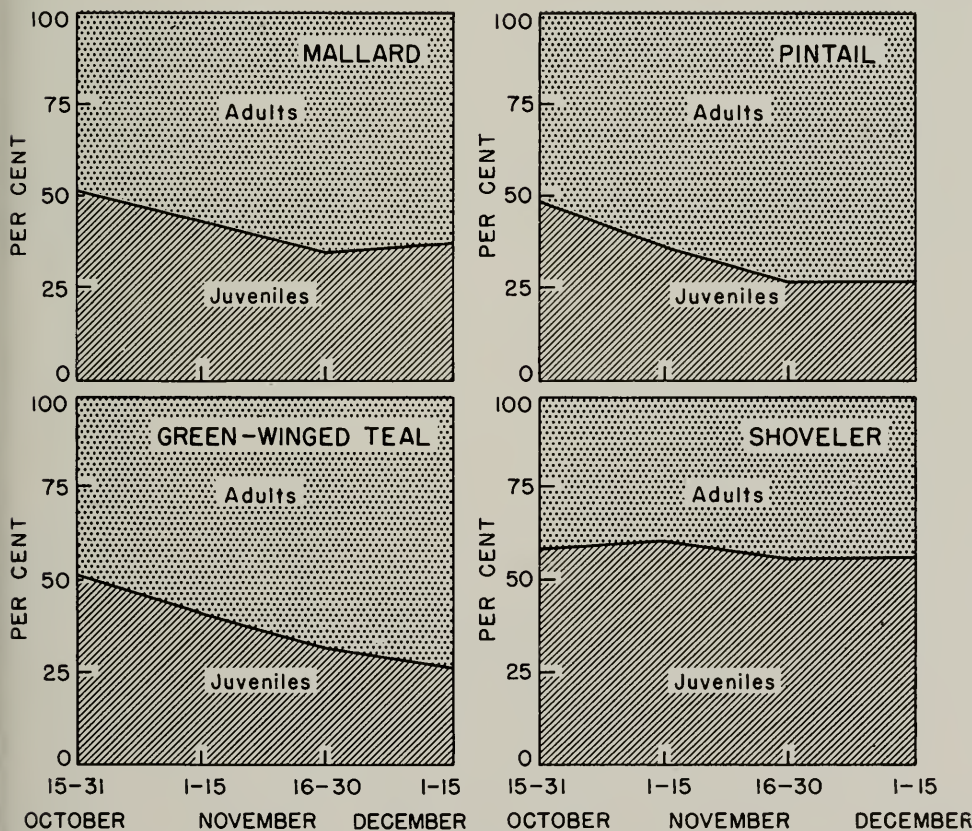


Fig. 14.—Juvenile-adult composition of the autumn flights of mallards, green-winged teals, pintails, and shovelers in Utah, as indicated by checks of hunters' bags in the autumns of 1943, 1944, and 1946-1949.

less traps are operated effectively throughout the period of migration, they, too, will provide biased data.

Age ratios obtained from mallards while on their wintering grounds undoubtedly are relatively unbiased by seasonal movements. It should not be assumed that a similar statement would be true for all species. For example, in the pintail, birds of the two sexes and ages tend to flock separately in winter, and shifting of these flocks along the Texas coast is common.

Regional Variations in Age Ratios

Regional variations in the age ratios of ducks first became apparent to the writers when data on the ducks checked in hunters' bags in Utah, Texas, and Illinois during the fall of 1943 were compared. Since that time, data which provide for further evaluation of regional differences in age ratios have become available, tables 51-57.

Mallards.—The juvenile percentage in mallards checked in hunters' bags in

each of eight areas of the Mississippi Flyway is shown in fig. 15. Juveniles made up a large proportion of the ducks that were taken in Manitoba because the adult drakes tend to migrate from there early, and the juveniles are more vulnerable to shooting early in the hunting season than at any other time. It is not known why the juvenile proportion of the mallards taken by hunters in Ohio (the marshes at Sandusky Bay) was so much greater than that taken by hunters in Michigan (the Pointe Mouillee Marsh, which is less than 50 miles from Sandusky Bay).

The progressive north to south decrease in the juvenile proportion of the mallard population, as shown by checks of hunters' bags in Manitoba, the Upper Mississippi areas, the Illinois River valley areas, and the Arkansas areas, table 51 and fig. 15, reflects both a progressive decline in the juvenile population and a decline in vulnerability to hunting as a consequence of increasing wariness among juveniles.

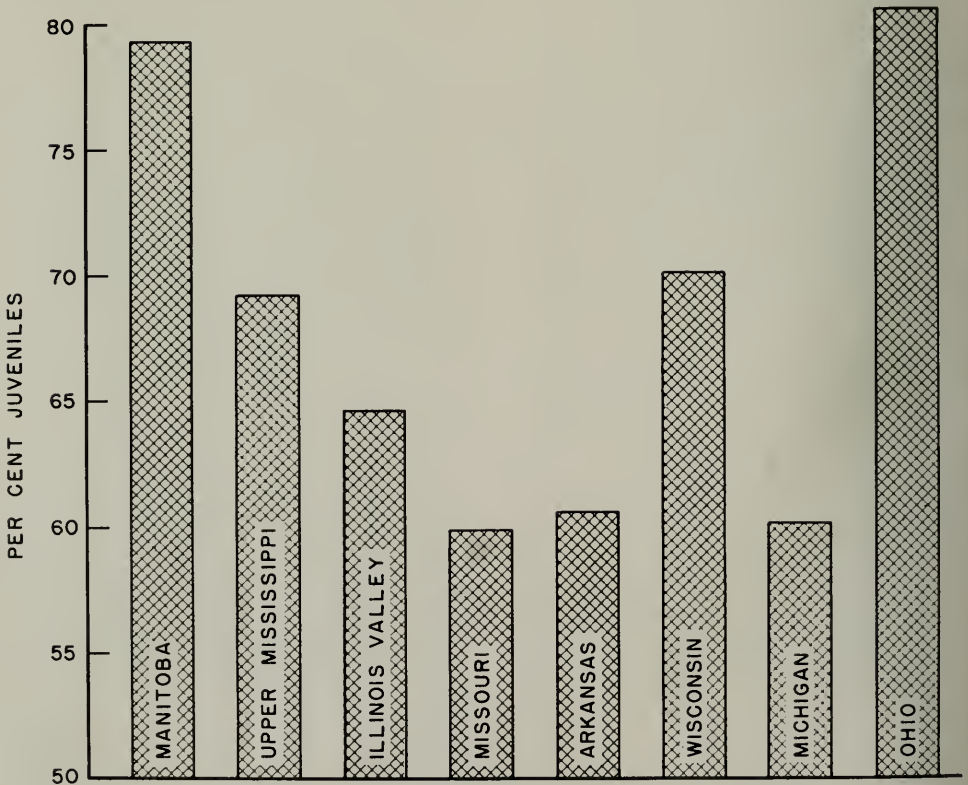


Fig. 15.—Juvenile percentage in mallards checked in hunters' bags in each of eight areas of the Mississippi Flyway, 1946-1949.

One question of concern to students of age ratios is: "Can age ratios at any one place be used to indicate yearly changes in production?" Table 51 and fig. 16 show the yearly trends in the juvenile proportion of the mallard population in a number of areas. Bag checks in Manitoba are in general agreement with those in the Mississippi River basin areas in showing increases in the juvenile component in

1947 and 1948 and a decrease in 1949. Year-to-year differences in the time of departure of adults and juveniles from the breeding grounds probably explain some of the differences between mallard age ratios taken in Manitoba and those taken in the Mississippi River basin areas.

Year-to-year changes in the juvenile proportion of the mallard populations of the Great Lakes areas—principally the

Table 51.—Number of juveniles per adult among mallards checked in hunters' bags in 13 regions of North America, 1946–1949.

REGION	1946		1947		1948		1949		1946–1949		
	Number of Ducks Checked	Juveniles Per Adult	Number of Ducks Checked	Juveniles Per Adult	Number of Ducks Checked	Juveniles Per Adult	Number of Ducks Checked	Juveniles Per Adult	Number of Ducks Checked	Juveniles Per Adult	
The Pas, Manitoba.....			1,032	14.71			1,537	8.80	2,569	10.63	
Netley, Manitoba.....			903	4.17	1,248	5.71	893	2.92	3,044	4.29	
Delta, Manitoba.....	1,874	1.46	496	1.70	251	5.12			2,621	1.62	
Upper Mississippi River....	490	1.29	653	2.72	1,192	3.00	235	0.93	2,570	2.18	
Wisconsin.....	333	3.44	287	3.95	820	3.69	1,821	1.76	3,261	2.33	
Michigan.....	271	2.15	212	1.08	357	1.25	242	1.82	1,082	1.50	
Ohio.....	993	4.84	940	3.22	819	6.04	735	2.62	3,487	3.90	
Indiana.....						369	0.86	677	1.19	1,046	1.07
Illinois River valley.....	1,317	1.25	814	2.36	1,215	3.18	597	0.97	3,943	1.77	
Missouri.....	327	1.75	518	1.76	408	2.92	1,094	1.04	2,347	1.48	
Arkansas.....	3,350	1.16	3,317	1.63	3,000	2.22	2,104	0.91	11,771	1.43	
Nebraska.....			2,514	1.88	1,749	1.81	1,252	0.99	5,515	1.60	
Utah.....	853	1.16	2,067	0.66	1,216	0.74	1,062	0.88	5,198	0.78	

Table 52.—Number of juveniles per adult among mallards checked in hunters' bags in Manitoba, Illinois, and Arkansas, 1946–1955 and 1959.

YEAR	NUMBER OF JUVENILES PER ADULT			DIFFERENCE IN NUMBERS OF JUVENILES PER ADULT	
	Manitoba (Delta)	Illinois (Illinois River Valley)	Arkansas (Stuttgart)	Manitoba and Illinois	Illinois and Arkansas
1946.....	1.46	1.25	1.16	0.21	0.09
1947.....	1.70	2.36	1.63	0.66*	0.73
1948.....	5.12	3.18	2.22	1.94	0.96
1949.....		0.97	0.91		0.06
1950.....		1.53	0.73		0.80
1951.....		1.71	1.71		0.00*
1952.....		1.65	1.86		0.21*
1953.....		1.48	0.82		0.66
1954.....	1.62	0.91	1.04	0.71	0.13*
1955.....		1.78	1.40		0.38
1959.....	0.78	0.34	0.29	0.44	0.05
Average.....	2.14†	1.61† 1.56‡	1.25‡	0.53	0.31

*Only in 1947 did Illinois exceed Manitoba in number of juveniles per adult; only in 1951, 1952, and 1954 did Illinois fail to exceed Arkansas in number of juveniles per adult.

†For years in which data were available for both Manitoba and Illinois.

‡For years in which data were available for both Illinois and Arkansas.

Horicon Marsh in Wisconsin, the Pointe Mouillee Marsh in Michigan, the marshes at Sandusky Bay in Ohio—show little correlation with changes in the Mississippi River basin areas, fig. 16. However, the Great Lakes areas are frequented by only a small proportion of the mallard population of the Mississippi Flyway; these areas are to the east of the principal routes used by mallards migrating between their breeding and wintering areas.

There was reasonably close agreement in the year-to-year fluctuations in the number of juvenile mallards per adult in hunters' bags in the Mississippi River basin areas: the Upper Mississippi River, the Illinois River valley, and the Stuttgart, Arkansas, area, table 51 and fig. 16. There was a highly significant relationship between the age ratios of mallards bagged in the Upper Mississippi River area, Illinois River valley, Missouri, and Arkansas during the period 1946–1949, table 51, as demonstrated by a correlation coefficient of $r = +0.969$ or higher, which indicated that the probability that the correlation was due to chance was less than 0.01.

The age ratios for mallards bagged in the Illinois River valley were close to those for mallards taken in the Stuttgart,

Arkansas, area in all but 2 (1950 and 1953) of 11 years (1946–1955 and 1959), table 52 and fig. 16. The lack of agreement in the age ratios from the two areas in 1950 and 1953 is believed to have been related to a delayed hatch on the breeding grounds followed by a somewhat delayed movement of juveniles to Illinois, where a high kill of these young birds occurred.

In 1950, mild weather induced large numbers of mallards to remain on the breeding grounds until November 7, when a severe cold front resulted in an unusually large exodus. The ducks moved rapidly down the flyway, and the adults passed through Illinois without stopping so long as is customary. Because of the unusually rapid movement from the breeding grounds to the heavily shot mid-flyway areas, juvenile mallards had not been much exposed to hunting by the time they arrived in Illinois and, thus, were more vulnerable to hunting than in most other years.

Fluoroscopy of live-trapped ducks in 1953, in revealing an unusually low percentage of juveniles with shot wounds, indicated that the young of that year, like those of 1950, had not been much exposed to hunting before their arrival in Illinois.

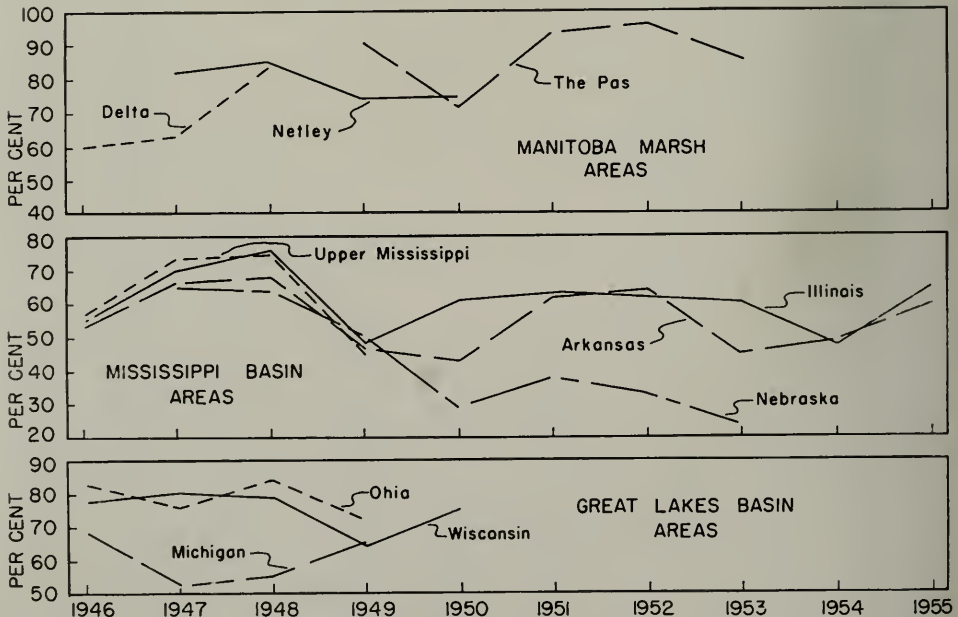


Fig. 16.—Year-to-year changes in the juvenile percentage in mallards checked in hunters' bags in each of several areas of North America, 1946–1955.

Table 53.—Number of juveniles per adult in five species of ducks checked in hunters' bags in seven regions of North America, 1948.

REGION	BLACK DUCK		PINTAIL		BALDPATE		REDHEAD		LESSER SCAUP	
	Number Checked	Juveniles Per Adult	Number Checked	Juveniles Per Adult	Number Checked	Juveniles Per Adult	Number Checked	Juveniles Per Adult	Number Checked	Juveniles Per Adult
Manitoba.....			145	4.88	337	11.37	388	24.00	275	2.59
Wisconsin.....	208	3.35	248	4.66	547	10.11	212	6.77	296	2.12
Michigan.....	374	1.08	102	0.96	191	3.00	56	2.70	117	3.76
Ohio.....	419	3.54	258	6.14	79	4.26				
Indiana.....	67	1.78								
Illinois River valley.....	58	2.82	126	2.03						
Utah.....			2,210	0.79	1,142	2.32	206	3.76		

The lack of hunting experience by juveniles before reaching Illinois in 1950 and 1953, plus the abnormally rapid flight of adults through Illinois in 1950, resulted in the unusually large differences between Illinois and Arkansas in the number of juveniles per adult in the mallard bag in those years, table 52.

With infrequent exceptions, such as those in 1950 and 1953, it appears that age ratios taken along the main stem of the Mississippi Flyway from Delta, Manitoba, to Stuttgart, Arkansas, provide an index to the yearly productivity of the mallard in the flyway.

Other Species.—Considerable regional variation in the number of juveniles per adult was found in 1948 for each of five species of ducks checked in hunters' bags in Manitoba, states of the Mississippi Flyway, and Utah, table 53. Two of the four species checked in Manitoba had more juveniles per adult in that province than in other localities.

Regional variations in age ratios among the several species and within any given

Table 54.—Number of juveniles per adult among mallards checked in hunters' bags in two regions of the Illinois River valley, 1939.

REGION	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT
Upper.....	1,203	60.4	1.52
Lower.....	1,058	57.7	1.36

species probably result in part from differences in seasonal movements among the species and between juveniles and adults. It is assumed that regional variations in age ratios derived from inspection of hunters' bags would be most pronounced in those species of ducks that depart from the breeding grounds early in the migration season. Because the hunting seasons for the various states do not coincide and because the migration schedules of adults and juveniles of a given species may differ, adults of a species may receive greater hunting pressure in one state, juveniles in another.

In an unpublished report for 1954, Milton W. Weller, then of the University of Missouri, pointed out the diverse movements of the two redhead age classes in Manitoba. Many adult redheads moved northward to molting areas following the breeding season, while most juveniles remained on breeding areas. The redhead bag in the molting areas showed a low juvenile percentage, whereas the bag in the breeding areas showed a high juvenile percentage. Weller speculated that differences in the migration schedules of adults and juveniles might influence bag data all along the migration routes.

The juvenile component in the population of each duck species investigated has tended to be so low in Utah, tables 53 and 55, as to warrant special attention. The marshes around Great Salt Lake have long been the scene of unusually heavy concentrations of early-migrating waterfowl. As census records showed, peaks in

waterfowl populations at the Bear River Migratory Bird Refuge in 1946, 1947, and 1948 occurred before the season opened (Van Den Akker & Wilson 1951: 373). Because juveniles in hunters' bags decreased proportionately as the hunting season progressed, fig. 14, the possibility is raised that flights which are top-heavy in juveniles may leave Utah before the hunting season opens. If this assumption is substantiated in subsequent investigations, it would partially account for the

abnormally large number of adults in the bags of Utah hunters.

No doubt some differences between the age ratios representing various bag inspection stations have resulted from differences in the character and size of areas sampled. In some cases, age ratio data representing a checking station may be from only a single, relatively small area, such as the Delta Marsh or Netley Marsh in Manitoba. In other cases, the data may be from many marshes representing many

Table 55.—Number of juveniles per adult in five species of ducks checked in hunters' bags in two areas adjacent to the Great Salt Lake, Utah, in 1947.

SPECIES	NUMBER OF DUCKS CHECKED		JUVENILES PER ADULT		PROBABILITY THAT DIFFERENCE IS DUE TO CHANCE
	Ogden Bay	Farmington Bay	Ogden Bay	Farmington Bay	
Mallard.....	677	373	0.68	1.01	<0.005
Gadwall.....	398	276	2.36	0.85	<0.0005
Baldpate.....	422	276	3.70	1.76	<0.0005
Pintail.....	1,374	1,281	1.25	0.75	<0.0005
Green-winged teal..	727	446	1.62	2.22	<0.025
Shoveler.....	419	357	2.19	3.01	<0.005

Table 56.—Number of juveniles per adult in six species of ducks checked in hunters' bags in two areas adjacent to the Great Salt Lake, Utah, in 1948.

SPECIES	NUMBER OF DUCKS CHECKED		JUVENILES PER ADULT		PROBABILITY THAT DIFFERENCE IS DUE TO CHANCE
	Ogden Bay	Farmington Bay	Ogden Bay	Farmington Bay	
Mallard.....	817	247	0.88	0.77	<0.20>0.10
Gadwall.....	429	205	1.01	1.20	<0.40>0.30
Baldpate.....	1,142	320	2.30	2.44	<0.90>0.80
Pintail.....	2,210	761	0.78	0.64	<0.0005
Green-winged teal..	1,069	395	0.88	0.78	<0.30>0.20
Shoveler.....	687	386	2.06	1.96	<0.80>0.70

Table 57.—Number of juveniles per adult in six species of ducks checked in hunters' bags in two areas adjacent to the Great Salt Lake, Utah, in 1949.

SPECIES	NUMBER OF DUCKS CHECKED		JUVENILES PER ADULT		PROBABILITY THAT DIFFERENCE IS DUE TO CHANCE
	Ogden Bay	Farmington Bay	Ogden Bay	Farmington Bay	
Mallard.....	541	380	0.66	0.87	<0.05
Gadwall.....	1,153	322	0.48	0.85	<0.0005
Baldpate.....	296	334	3.00	0.90	<0.0005
Pintail.....	2,027	871	0.51	0.54	<0.50>0.40
Green-winged teal..	1,212	567	0.52	0.77	<0.0005
Shoveler.....	555	614	1.04	1.12	<0.60>0.50

acres. For example, mallards checked at Stuttgart, Arkansas, were shot on at least 20 different swamp or reservoir tracts scattered over an area having a 25-mile radius. Most of the mallards checked in the Illinois River valley were bagged at 10 clubs distributed over a linear distance of 100 miles.

Only a slight difference in the number of juvenile mallards per adult between populations of the upper and lower sections of the Illinois River valley was found in 1939, table 54. This difference was not significant at the 90 per cent level ($X^2=1.79$, 1 d.f.).

Much greater differences in number of juveniles per adult for several species of ducks were found between populations of two marshes 25 miles apart and adjacent to the Great Salt Lake, Utah, in 1947-1949, tables 55-57. The probability that the differences were the result of chance is shown in tables 55-57. There was a statistically significant difference between age ratios in the two areas in 11 of 18 tests.

These data suggest that the age composition of migrating flocks differs and that fortuitous circumstances result in flocks especially numerous in birds of one age

class or the other in a particular marsh. Where only one waterfowl area in a region has been sampled, as Winous Point in Ohio or Pointe Mouillee in Michigan, the age ratios derived may or may not reflect those for the entire region.

For species other than the mallard, regional data are not adequate to permit evaluation of the age ratios derived in any one area. For each of these species, we have compiled data from as many areas as possible in the Mississippi Flyway on the assumption that data for the total flyway represent the species better than the data from any one area and reflect year-to-year changes in the age composition of the population.

Factors Affecting Age Ratios

Age ratios can be used for appraising the productivity of ducks if the data on which they are based have been carefully evaluated as to the effect of seasonal, regional, and shooting biases. Sufficient data for calculating age ratios corrected for differences between juveniles and adults in vulnerability to hunting have been accumulated for the mallard in the Mississippi Flyway, table 58 and fig 17. Most of the data used in the table and graph

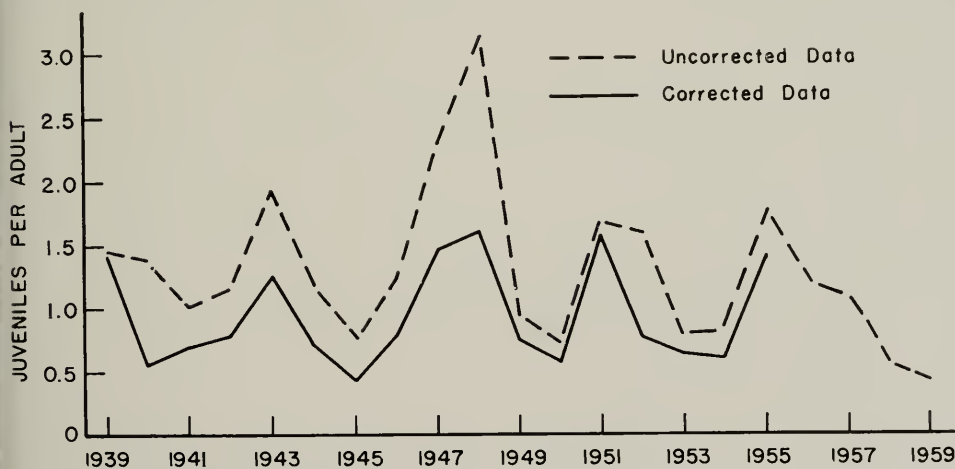


Fig. 17.—Uncorrected and corrected numbers of juvenile mallards per adult in bags of Mississippi Flyway hunters in each of several years; uncorrected numbers, 1939-1959; corrected numbers, which compensate for differences in hunting vulnerability between adults and juveniles, 1939-1955. Points on the graph for 1939-1955 are based principally on Illinois data, table 58. Points for 1956-1959 are based on data from Missouri, table 59. Because data for 1955 showed the number of juveniles per adult among Illinois mallards (1.78) to be about 10 per cent less than the number among Missouri mallards (1.99), the point for each year in the period 1956-1959 represents a figure that is 10 per cent less than the corresponding figure in table 59.

Table 58.—Number of juveniles per adult and per hen in mallard populations of the Mississippi Flyway, principally Illinois, 1939–1955; the uncorrected numbers are based upon data from inspection of hunters' bags; the corrected numbers compensate for differences between juveniles and adults in vulnerability to hunting.

YEAR	NUMBER OF JUVENILES IN BAG	RATIO OF ADULT TO JUVENILE VULNERABILITY TO HUNTING (DRAKES)	CORRECTED NUMBER OF JUVENILES IN POPULATION	NUMBER OF ADULTS IN BAG	UNCORRECTED NUMBER OF JUVENILES PER ADULT IN BAG	CORRECTED NUMBER OF JUVENILES PER ADULT IN BAG	NUMBER OF ADULT HENS IN BAG	CORRECTED NUMBER OF JUVENILES PER ADULT HEN IN BAG
1939	1,337	1:1.03	1,298	924	1.45	1.40	317	4.09
1940	2,093	1:2.48	844	1,471	1.42	0.57	610	1.39
1941	2,255	1:1.46	1,544	2,226	1.01	0.69	697	2.22
1942	980	1:1.51	653	829	1.18	0.79	270	2.42
1943	939	1:1.54	610	483	1.94	1.26	157	3.89
1944	1,176	1:1.54	764	991	1.19	0.77	312	2.45
1945	898	1:1.78*	504	1,149	0.78	0.44	379	1.33
1946	731	1:1.57*	466	586	1.25	0.80	228	2.04
1947	572	1:1.57	364	242	2.36	1.50	78	4.67
1948	924	1:1.94	476	291	3.18	1.64	114	4.18
1949	294	1:1.24	237	303	0.97	0.70	98	2.42
1950	1,627†	1:1.27†	1,281	2,234†	0.73	0.57	928	1.38
1951	517	1:1.08	479	302	1.71	1.59	118	4.06
1952	753	1:2.17	347	456	1.65	0.76	172	2.02
1953	257†	1:1.27†	202	314†	0.82	0.64	97	2.08
1954	218	1:1.55	141	240	0.91	0.59	70	2.01
1955	478	1:1.55	308	268	1.78	1.44	95	3.24
Average					1.43†	0.95†		2.70†
All years	16,049		10,518	13,309	1.21**	0.79**	4,740	2.22**

*Ratio based on data from McGinnis Slough, as explained on page 451.

†Numbers of juveniles and adults for 1950 and 1953 from Arkansas, the ducks included in table 49; numbers of juveniles and adults for other years from Illinois, the ducks included in table 36; ratio of adult to juvenile vulnerability for 1950 and 1953 explained on page 451, ratios for most other years from table 39.

‡Average of yearly figures above.

**Average based on total numbers of individuals.

were collected in Illinois, from both Illinois River and Mississippi River areas. Data from Arkansas were used for 1950 and 1953 because unusual breeding grounds and migration conditions in those years had less influence on the migration in that state than in Illinois. Data from Missouri were used for 1956–1958 because no data were available for Illinois in those years and because data from both states for 1955 permitted correction of the Missouri data. An appraisal of the effect of seasonal, regional, and hunting bias on the age ratios calculated for the mallard in the Mississippi Flyway is given below.

Seasonal Bias.—Age ratios have been determined for large numbers of population samples by inspection of ducks in hunters' bags throughout many hunting seasons in Illinois. Although the Illinois hunting seasons have varied as to opening date and length, most of each southward mallard migration has occurred during the open season (Bellrose 1944:346–50). Inasmuch as sample size was determined partly by hunter success, which in turn was determined partly by population size, the numbers of birds in the samples were approximately proportional to the numbers of birds in the populations sampled. For these reasons, we believe that in most years there was little, if any, seasonal bias in the age ratios derived from checking mallards in hunters' bags in Illinois.

Regional Bias.—Unpublished population data and records from the recovery of bands indicate that the largest segments of the mallard population in the Mississippi Flyway visit the Illinois River valley. The ducks in hunters' bags have been examined each year at numerous places throughout the valley, thereby minimizing the effect of data obtained from aberrant local concentrations of particular age groups. In 1950, an abnormal migration resulted in relatively large numbers of adult mallards passing more rapidly than usual through the Illinois River valley. In both 1950 and 1953, juvenile mallards appeared unusually vulnerable to Illinois hunters. We believe that the duck kill checked in Arkansas provided the more valid data for the Mississippi Flyway in 1950 and 1953, and we have used Arkansas data, derived from table 49, for

calculating the numbers of mallard juveniles per adult for those years. For the other years included in table 52, the differences between Illinois and Arkansas in number of juveniles per adult were not so great as to warrant special treatment of the data.

Hunting Bias.—The year-to-year variations in the vulnerability figures for mallards, table 39, make it desirable to evaluate the age ratios, or number of juveniles per adult, derived from inspection of hunters' bags.

Most of the band recovery data from which the ratios of adult to juvenile vulnerability were derived, table 39, were obtained from ducks banded at the Chautauqua National Wildlife Refuge, which is in the center of the area in which bagged ducks were sampled for age. Because no ducks were banded at Chautauqua in 1945 and 1946, in those years banding data from McGinnis Slough, table 40, were used, and adjustments, based on several years of vulnerability rates, were made for differences between the two stations.

Because the Arkansas kill data for 1950 and 1953, table 49, were believed to be more valid than the Illinois data, the numbers of juveniles and adults inspected in hunters' bags in Arkansas were chosen as base figures for these years, table 58. The 1:1.27 ratio of adult to juvenile vulnerability for 1950 and 1953, table 58, was assigned rather arbitrarily. As table 44 indicates, mallard juveniles are about half as vulnerable to hunting in December as in November. Illinois data for several years showed that the difference between adult and juvenile mallard drakes in vulnerability to hunting averaged 0.54 (1:1.54 ratio, table 39). The largest part of the Illinois mallard kill was in November. In December, when the birds were in Arkansas, the difference between the adult and juvenile kill figures should have averaged about half of 0.54, or 0.27, and the ratio of adult to juvenile vulnerability should have averaged about 1:1.27.

Table 58 shows for each year in the period 1939–1955 the ratio of adult to juvenile vulnerability among banded mallard drakes and the actual (uncorrected) number of juveniles per adult checked in hunters' bags in the Mississippi Flyway,

principally Illinois. It is apparent that the ratio of adult to juvenile vulnerability has no correlation with the number of juveniles per adult bagged by hunters.

Table 58 shows also for each year the number of juveniles per adult and per adult hen among mallards checked in the bags of Mississippi Flyway hunters, each number corrected for the greater vulner-

population between the breeding grounds and Illinois.

Both shrinkage in the juvenile segment of mallard populations and seasonal declines in the vulnerability rates of the juveniles are indicated by the progressively smaller relative numbers of juveniles in hunters' bags as the ducks moved down the flyway from Manitoba to Illinois to

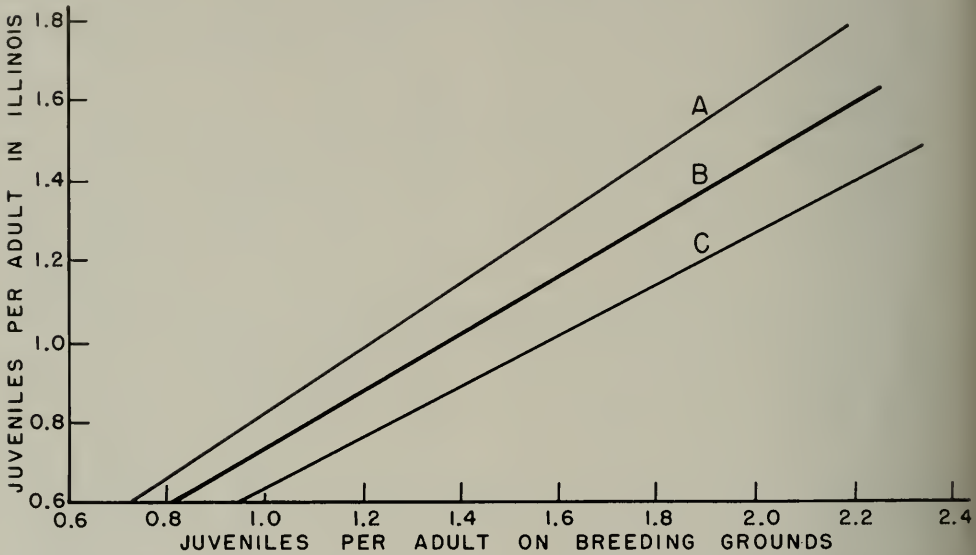


Fig. 18.—Numbers of juvenile mallards per adult on the breeding grounds just prior to the hunting season, as calculated from numbers of juveniles per adult in Illinois during the hunting season; each of the Illinois numbers on which curves *A*, *B*, and *C* are based has been adjusted to compensate for a greater shooting loss among juveniles than among adults before reaching Illinois: *A*, 2.0 juveniles per adult, *B*, 2.5 juveniles per adult, and, *C*, 3.0 juveniles per adult.

ability of juveniles. For the period 1939–1955, the corrected figure was 0.95 juvenile per adult and 2.7 juveniles per adult hen. These figures probably reflect the age composition of mallard populations in the Illinois River valley for the 17-year period quite well, for inaccuracies in the yearly vulnerability rates would tend to cancel each other out over the period.

Trends in the age composition of mallard populations in the Illinois River valley reflect trends in the age composition of mallard populations on the breeding grounds prior to the hunting season. However, population figures obtained in Illinois do not represent the true age composition of the populations on the breeding grounds, because of the comparatively greater loss from hunting experienced by the juvenile segment of the

Arkansas, table 52. Juvenile mallards are undoubtedly more vulnerable to hunters in Manitoba than to hunters in Illinois, and to hunters in Illinois than to hunters in Arkansas, as shown by seasonal changes in vulnerability ratios, table 44.

Shrinkage in the juvenile segment of mallard populations between the breeding grounds and Illinois is indicated not only by data in table 52 but by rather abstruse calculations employing band recoveries, mortality rates, and juvenile vulnerability rates, as discussed below.

An average annual mortality rate for adult drake mallards in the Mississippi Flyway of about 40 per cent has been derived from band recovery data for drake mallards banded as adults at Lake Chautauqua, Mason County, Illinois, 1939–1944 (Bellrose & Chase 1950:9).

It seems reasonable to assume that hunting accounts for about three-fourths of this average annual mortality and other causes for one-fourth, or an average annual mortality rate of 30 per cent from hunting and 10 per cent from other causes. An analysis of 6,000 indirect (after the year of banding) recoveries of adult drake mallards banded at Lake Chautauqua disclosed that 47.6 per cent or about one-half of the recoveries were from points north of the Illinois River valley. It seems reasonable to assume further that hunting results in approximately a 15 per cent reduction in the numbers of adult mallards before they reach the Illinois River valley from the breeding grounds.

Data in tables 44 and 47 suggest that the juveniles are 2 to 3 times as vulnerable as adults during the early fall season when in migration from Manitoba to Illinois. If we assume that juveniles are 2.5 times as vulnerable as adults, and that hunting takes a toll of 15 of each 100 adults before the flights reach Illinois, then we may say that hunting takes a toll of 2.5 times as many juveniles or 37.5 of each 100 juveniles in the same period.

Fig. 18 shows a scale for converting the age ratios of mallards occurring in wild populations in the Illinois River valley to age ratios which would be comparable for wild populations on the breeding grounds prior to the hunting season. Following is an example showing the method used to determine a point on the scale, fig. 18, representing the probable number of juveniles per adult on the Canadian breeding grounds when 0.6 juvenile per adult has been determined to exist in mallard populations in Illinois; the adults are assumed to have been subjected en route to Illinois to a shooting loss of 15 per 100 and the juveniles to a shooting loss of 37.5 per 100.

When

- A = the number of adults on the breeding grounds per adult in Illinois, with a presumed 1:0.6 ratio of adults to juveniles in Illinois,
 a = the number of adults to 0.6 juvenile in Illinois,
 p = the per cent of the adult population remaining after a 15 per cent loss en route to Illinois,

then

$$A = \frac{a}{p} \text{ or } \frac{1}{0.85} = 1.18,$$

the number of adults on the breeding grounds to 1 adult in Illinois.

When

Y = the number of juveniles per adult on the breeding grounds, with a presumed 1:0.6 ratio of adults to juveniles in Illinois,

y = the number of juveniles to 1 adult in Illinois,

p = the per cent of the juvenile population remaining after a 37.5 per cent loss en route to Illinois,

then

$$Y = \frac{y}{p} \text{ or } \frac{0.6}{0.625} = 0.96,$$

the number of juveniles on the breeding grounds to 0.6 juvenile in Illinois.

Thus, when there is a ratio of 0.6 juvenile per adult in Illinois, the adults have been subjected to a 15 per cent loss en route to Illinois, and the juveniles have been subjected to a shooting loss 2.5 times as great as that of adults, the ratio on the breeding grounds is 0.96 young to 1.18 adult, or 0.81 juvenile to 1 adult.

An average of 0.95 juvenile per adult was calculated for mallard populations in the Mississippi Flyway, principally Illinois, over a 17-year period, 1939-1955, table 58. This average takes into account differences in vulnerability between adults and juveniles. If juveniles suffered a loss of 37.5 per cent en route, the calculated average number of juveniles on the breeding grounds just prior to migration per 0.95 juvenile arriving in Illinois was 1.52 ($0.95 \div 0.625$). If adults suffered a loss of 15 per cent en route, the calculated average number of adults on the breeding grounds just prior to migration per adult arriving in Illinois was 1.18 ($1.0 \div 0.85$). For the 17-year period, the calculated average number of juveniles per adult on the breeding grounds just prior to migration was 1.29 ($1.52 \div 1.18$).

If the average number of juveniles per adult in Illinois (0.95) is to the number of juveniles per hen in Illinois (2.7), table 58, as the number of juveniles per adult on the breeding grounds (1.29) is

Table 59.—Number of juveniles per adult among mallards shot at the Duck Creek Wildlife Area, Puxico, Missouri, 1955–1959.*

YEAR	NUMBER OF DUCKS CHECKED	PER CENT JUVENILES	JUVENILES PER ADULT	APPROXIMATE 95 PER CENT CONFIDENCE LIMITS
1955.....	5,581	66.6	1.99	1.79–2.19
1956.....	2,368	58.5	1.41	1.37–1.45
1957.....	478	54.8	1.21	0.87–1.55
1958.....	581	37.7	0.60	0.47–0.73
1959.....	2,064	32.6	0.48	0.42–0.54

*Data supplied by George Brakhage of the Missouri Conservation Commission.

to the number of juveniles per hen on the breeding grounds (X), the number of young per hen on the breeding grounds can be calculated by solving for X in the following equation:

$$0.95:2.7::1.29:X$$

$$X=3.7$$

Bag data for the Mississippi Flyway, principally Illinois, uncorrected for the greater vulnerability of juveniles to hunters, showed an average of 1.43 juveniles per adult over the period 1939–1955, table 58. This average is greater than the calculated average number of juvenile mallards per adult on the breeding grounds just prior to the hunting seasons (1.29). A higher figure for Illinois than for the breeding grounds may have resulted because the disproportionate loss of juveniles before the mallard populations reached Illinois was more than compensated for by the disproportionate vulnerability of juveniles in Illinois.

Age Ratios as Measures of Production

Many wildlife technicians have assumed that increases in the number of juvenile ducks per adult in hunters' bags reflect increases in production of young during the breeding season immediately preceding, that age ratios can be used as indices of production, and that curves plotted from age ratios may be regarded as production curves.

Year-to-year changes in the age ratios of mallards in the Mississippi Flyway are shown in tables 52, 58, and 59 and fig. 17 for 21 years, 1939–1959. The production curve plotted from the corrected age data follows a pattern somewhat similar

to that plotted from the uncorrected age data, fig. 17. However, because errors of varying magnitude are probably present in the yearly vulnerability factors used in correcting age data, it has been deemed advisable to use uncorrected age data rather than the corrected data as the better indices of year-to-year changes in productivity.

The data (uncorrected) on which the broken line in fig. 17 is based indicate that lows occurred in the production of young mallards in 1941, 1945, 1950, 1953, and 1959; highs occurred in 1939, 1943, 1948, 1951, and 1955. This somewhat rhythmic production trend may be an inherent characteristic of waterfowl populations and may prove to be density dependent in origin.

Significant data for the Mississippi Flyway are lacking on yearly changes in production of species other than the mallard. However, John E. Chatten of the U. S. Fish and Wildlife Service has made available age ratios of pintails trapped at seven banding stations in California, Oregon, and Nevada from 1949 through 1959.

The relatively large number of juveniles among the pintails trapped, particularly in 1951 and 1952, fig. 19, suggests bias in the samples, possibly the result of juveniles entering the traps more readily than adults. Nevertheless, the variations in trap selectivity from year to year are probably not great enough to produce large errors in the indices of production. It is believed that the age ratios obtained from pintails trapped in the Pacific Flyway probably provide a fairly reliable picture of the production trend of the species. A comparison of mallard age ratios in the Mississippi Flyway with pintail age ratios in

the Pacific Flyway for 11 years, 1949–1959, fig. 19, reveals for most years an unexpectedly close agreement between the production trends of the two species.

The extent of agreement in production trends between the two species is especially remarkable when differences in distribution and habits of the species are considered. The pintails of the Pacific Flyway breed largely in the western part of the northern plains, whereas the mallards of the Mississippi Flyway breed largely in the eastern part of the northern plains. Moreover, mallards are more prone to nest in the Aspen Parklands and the northern mixed Coniferous Forest than are pintails, which are for the most part confined to the grasslands.

Factors responsible for the yearly fluctuations in mallard production appear to have fairly consistent simultaneous effects on pintail production. Discovery of this fact justifies the use of Mississippi Flyway mallard age ratios as criteria for evaluating the accuracy of breeding ground surveys and the effect of environmental conditions on over-all duck production.

Because breeding grounds surveys have been used in the past to provide most of the waterfowl production information on which annual hunting regulations have been based, and will undoubtedly be used for a similar purpose in the future, an appraisal should be made of the validity of these surveys.

Breeding grounds surveys are affected by the vastness of the breeding grounds, shifts in waterfowl populations with changing water conditions, and difficulty in finding and counting broods. Age ratios obtained from ducks bagged on and south of the breeding grounds provide a means for evaluating the validity of waterfowl breeding grounds surveys and in themselves serve as measures of production.

We have attempted to appraise the validity of breeding grounds surveys by comparing the results of surveys on the plains of Manitoba and Saskatchewan with the mallard age ratios obtained through inspection of hunters' bags in the Mississippi Flyway, principally Illinois. Banding of ducks on the breeding grounds has demonstrated that most of the Mississippi Flyway ducks breed in Manitoba and Saskatchewan.

The first comprehensive breeding grounds surveys were made by the U. S. Fish and Wildlife Service in 1947. In that year, although the nesting population was reported "fair" for Saskatchewan as a whole, brood production was not correspondingly high (Lynch 1948:33). In the same year, the duck crop in the pothole country of Manitoba was considered good, but the production in other types of nesting area was "moderate to very poor"

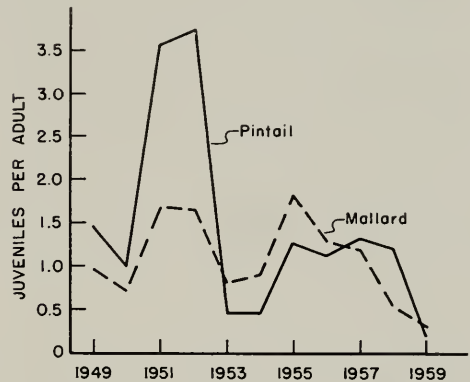


Fig. 19.—Year-to-year changes in the numbers of juveniles per adult in two species, the data derived by two methods in two areas: pintails trapped in the Pacific Flyway and mallards checked in hunters' bags in the Mississippi Flyway, 1949–1959.

(Hawkins 1948:52). Yet, in 1947, mallard age ratios from the Mississippi Flyway showed a pronounced increase in juveniles over the number in 1946, fig. 17. A year later, 1948, "good production" was reported, and "moderate improvement in the waterfowl output for Manitoba" was forecast, by Hawkins & Cooch (1948:97); a small increase in the duck population of Saskatchewan was recorded by Soper (1948:63). Mallard age ratios obtained in the Mississippi Flyway in 1948 showed a further increase in the number of juveniles per adult to a new peak, fig. 17.

In 1949, mallard age ratios from the Mississippi Flyway indicated that a sharp drop had occurred in the relative number of young, fig. 17. From the breeding grounds, Hawkins (1949:64) reported that, in Manitoba, nest success was well below that of 1948. Lynch (1949:52) reported a reduced nesting population in Saskatchewan as a whole, but a successful

hatch in the Aspen Parklands, where mallards from the drought-stricken southwestern part of the province had moved to join the ducks that normally nest in the Parklands.

In 1950, Mississippi Flyway age ratios disclosed a further drop in the number of young mallards per adult, fig. 17. On the breeding grounds, Hawkins (1950:45) concluded "that Manitoba produced considerably fewer ducks in 1950 than in 1949." In Saskatchewan, Colls (1950:40) reported "evidence of a lack of, or an unsuccessful attempt at, first nesting among mallards and pintails," and added that by the end of July there appeared to be no important attempts at second nesting by these two species.

In 1951, mallard age ratios derived from bagged ducks in the flyway indicated a marked increase in the production of young, fig. 17. Hawkins, Gollop, & Wellein (1951:49), reporting on other species as well as the mallard in Manitoba, wrote, "the juvenile crop probably doubled the previous year's." Colls & Lynch (1951:40), after observing the success of the first nesting attempt in Saskatchewan, wrote that "a more than usually successful waterfowl-rearing season" was anticipated for the area.

In 1952, the flyway age ratios indicated a decline in the number of young mallards per adult. From one Canadian province, Hawkins & Wellein (1952:64) reported: "Manitoba's contribution to the fall flight of 1952 should be about one-fifth less than in 1951." From Saskatchewan, Gollop, Lynch, & Hyska (1952:37), following a survey in July, 1952, reported a potential production "almost twice that of last year."

A decrease in the production of young in 1953 was reflected by age ratios for mallards bagged in the Mississippi Flyway and by field observations in the area. Moderate decreases were reported in Manitoba by Hawkins (1954:76) and in Saskatchewan by Lynch & Gollop (1954:49).

Age ratios for mallards bagged in the Mississippi Flyway showed little change from 1953 to 1954, fig. 17. For 1954 on the breeding grounds, predictions made after a summer census were that the fall flight of ducks from southern Manitoba

would be "about the same as last year," but that a "noticeable" reduction would occur in size of flights from northern Manitoba and from both northern and southern Saskatchewan (Crissey 1954:59, 62, 37).

In 1952, John J. Lynch of the U. S. Fish and Wildlife Service developed mathematical formulas for forecasting waterfowl production in Saskatchewan (Gollop, Lynch, & Hyska 1952:37 and charts 1 and 2). From the formulas he

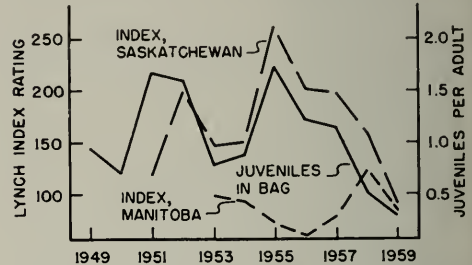


Fig. 20.—Relationship between age ratios of mallards in autumn and the hatch on the breeding grounds in the previous spring, as indicated by number of juvenile mallards per adult in hunters' bags in the Mississippi Flyway, principally Illinois, 1949–1959, and forecast indices of duck production in Canada (Lynch forecast indices, Gollop, Lynch, & Hyska 1952:37), the indices derived from breeding grounds surveys in Manitoba, 1953–1959, and Saskatchewan, 1951–1959.

derived forecast indices, one as of June 1 and another as of August 1. The August index was based upon July data: number of broods per square mile, number (per square mile) of late-nesting pairs and single drakes and hens which supposedly represented late-nesting pairs, number of ponds per square mile, number of ducklings per class III (almost completely feathered) brood, and number of class II (partially feathered) and class III broods per square mile. An index rating of 100 was deemed satisfactory; an index rating of 300 was deemed perfect. Later, some minor modifications were made in the formulas.

A mimeographed report, "Waterfowl Breeding Ground Survey Report, 1958," compiled by Arthur S. Hawkins for the U. S. Fish and Wildlife Service, provides a comparison of late season forecast indices for Saskatchewan, 1951–1958, and for Manitoba, 1953–1958. A similar re-

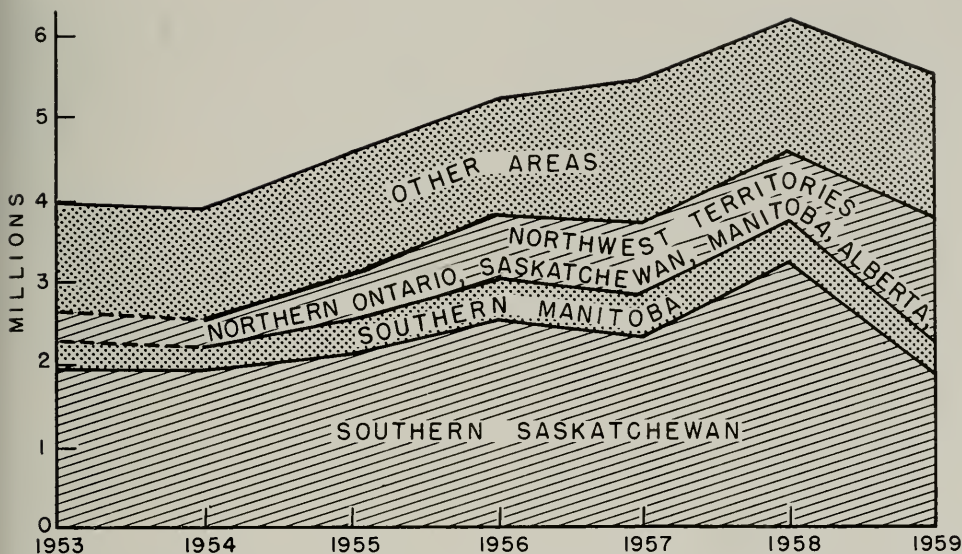


Fig. 21.—Estimated numbers of mallards in various parts of the Canadian breeding grounds in May, 1953–1959.

port compiled by Hawkins in 1959 provides data on breeding grounds forecasts for that year. The production forecast indices for Saskatchewan and Manitoba may be compared with the number of juvenile mallards per adult as checked in the bags of Mississippi Flyway hunters, fig. 20.

For the period 1952–1959, the population curve plotted from the forecast indices of waterfowl production in Saskatchewan was similar to the curve plotted from the Mississippi Flyway age ratios for mallards, fig. 20. However, for the years 1955 through 1958, and especially for 1958, the forecast indices showed considerably higher production than was shown by the age ratios, fig. 20.

Manitoba forecast indices showed very little correlation with mallard age ratios from the Mississippi Flyway, fig. 20. For example, in 1957 and 1958, Manitoba forecast indices pointed to an increasing production of young; yet the mallard age ratios from the Mississippi Flyway pointed to a decreasing production of young. That there is only slight correlation may be ascribed to Manitoba's relatively small contribution of mallards to Illinois and adjoining states. Aerial surveys made on the breeding grounds in May indicate that about six times as many mallards nest in

the plains and parklands of southern Saskatchewan as in the plains and parklands of southern Manitoba, fig. 21; the Saskatchewan contribution to the Mississippi Flyway kill is larger than that of Manitoba, even though much larger numbers of Saskatchewan mallards than of Manitoba mallards are killed in the Central and Pacific flyways (Cartwright 1956:14–5, 17–8, 20–1).

For 8 years, beginning with 1952, Saskatchewan breeding grounds indices showed production trends similar to those derived from mallards shot by hunters in the Mississippi Flyway, fig. 20. Information on breeding grounds success of ducks in Saskatchewan in 1951 was somewhat contradictory. The report by Colls & Lynch (1951:40) indicated "a more than usually successful waterfowl-rearing season." The forecast index for 1951, although above 100 and therefore "satisfactory," indicated a production that was low compared to that of most other years of the period 1949–1959. We are inclined to believe that some mechanical error was made in calculating the 1951 forecast index for Saskatchewan.

During the period 1949–1954, duck production as determined from breeding grounds surveys in Manitoba showed a fairly close relationship to production as

determined from age ratios of mallards shot in the Mississippi Flyway, principally Illinois. However, production as determined by the forecast index in Manitoba showed no positive correlation with production as indicated by age ratios of ducks shot in the Mississippi Flyway; diametrically opposite production trends were indicated for 1954, 1955, 1957, and 1958, fig. 20. The mallard flight reaching Illinois from Manitoba, compared to that from Saskatchewan, may have been so small as to have had little influence on age ratio figures obtained from mallards inspected in hunters' bags in the Mississippi Flyway.

One item apparently responsible for bias in the forecast index, especially in Manitoba, has been the production factor associated with late-nesting ducks. This factor was included in the index formula to measure the anticipated brood production represented by pairs, lone hens, and lone drakes (believed to be mates of incubating hens) found on the last survey flights, usually conducted in mid-July. The production from ducks that are actually breeders may be lower than anticipated, and many ducks that are classed as breeders may be through breeding. Charles D. Evans of the U. S. Fish and Wildlife Service and Ralph Hancox of the Manitoba Game Branch recognized the latter possibility in Manitoba in 1958 (unpublished report), when they found abnormally high numbers of molters and premolters on breeding areas. In spite of diligent effort to classify breeders and nonbreeders correctly, Evans and Hancox believed that they included many nonbreeders in their late-nesting index.

It is apparent from age ratio data from the Mississippi Flyway that in those years in which there was a major population shift from the Canadian Grasslands north to the lakes and marshes of the Aspen Parklands and Mixed Coniferous Forest production of young declined more than had been anticipated.

No doubt some of the differences between production data based on age ratios obtained from bagged ducks in the Mississippi Flyway and similar data based on breeding grounds surveys stem from differences in production between the Grasslands, the Parklands, and the Coniferous

Forest region. Because of difficulty of access, difficulty in making observations, and a low density of breeding ducks, only cursory duck surveys have been made in the Coniferous Forest region. Hence, the production of mallards from this region is largely unknown but may be larger than suspected. Although the population density of mallards there may be low, this region is so vast that it may well contain a sizable breeding population.

Other differences between production data from the Mississippi Flyway and data from the breeding grounds surveys may result because the Mississippi Flyway data include only mallards, whereas data from breeding grounds surveys include all species of ducks. Mallards usually make up over half of the breeding population, but diving ducks and late-nesting species, such as the baldpate and the gadwall, which may show yearly production trends different from those of the mallard, may influence the production data from the breeding grounds.

Production and Environment

It is difficult to evaluate the effect of environment on waterfowl production because of the vastness of the breeding grounds and the variations in water and weather conditions. Seldom, if ever, are water or weather conditions similar over the entire breeding range. Moreover, an area that is favorable for waterfowl in one year may be unfavorable the next. Nevertheless, a general review of water and weather conditions in Manitoba and Saskatchewan, the principal breeding range of the mallard of the Mississippi Flyway, has been made for the years 1939-1946 from *The Duckological*, a news sheet published at irregular intervals by Ducks Unlimited (Canada), with headquarters at Winnipeg, and for the years 1947-1959 from published and unpublished reports of breeding grounds surveys by the U. S. Fish and Wildlife Service and the Canadian Wildlife Service. In the following paragraphs the water and weather conditions on the breeding grounds for each of the 21 years in the period 1939-1959 are summarized in relation to mallard production as indicated by the number (uncorrected) of juveniles per adult inspected in hunters' bags in the Mississippi Flyway

—Illinois and Arkansas, table 58, and Missouri, table 59.

Water conditions on the Canadian plains in the spring of 1939 were much improved over those of 1938. Conditions for breeding ducks were good in Saskatchewan and poor in Manitoba. Most water areas persisted until broods were on the wing. These conditions resulted in a production per breeding mallard (uncorrected number of juveniles per adult) which was about equal to the average of such production data for 17 years, 1939–1955, table 58.

In 1940, spring water conditions in Manitoba were the worst in the history of that province and in Saskatchewan were poor as far west as the central part. Water conditions were good in western Saskatchewan. Good rains in June improved many water areas. Mallard production in this year, as in 1939, was close to the average for the 17-year period, table 58.

In the spring of 1941, water conditions, although greatly improved over conditions in 1940, were considered fair in Manitoba and ranged from poor to good in Saskatchewan. Water areas rapidly dried up when such summer rains as fell failed to maintain them. Heavy losses among ducklings occurred as a result of drought. A drop in the number of young per adult bagged in the Mississippi Flyway revealed a sizable decline in mallard production, table 58.

In the spring of 1942, water conditions were fair to good in Manitoba; they were bad, fair, or good, depending on the locality, in that part of Saskatchewan where most of the ducks are produced. Heavy spring rains prevailed over most of the plains, and these continued into the summer. The number of young per adult in the Mississippi Flyway, table 58, indicated a moderate increase in mallard production.

Spring water conditions in 1943 throughout the Canadian plains were the best in many years, being rated fair over northern Saskatchewan and northern Manitoba and good to excellent almost everywhere in the southern parts of these provinces. In that year, age ratios in the Mississippi Flyway, table 58, indicated a pronounced increase in mallard production.

In 1944, there was "lots of water" in northern Saskatchewan and Manitoba, but in the southern parts of these provinces, where most of the ducks are produced, water levels were largely "dangerously low" to fair. A larger than usual proportion of the breeding waterfowl population moved through the Grasslands northward into the Aspen Parklands and Mixed Coniferous Forest. Rains in June removed danger of heavy loss of ducklings through drought. Mallard production declined markedly to a point below average, table 58.

In 1945, spring water conditions were good in Manitoba and all of Saskatchewan but the southwestern part, where few Mississippi Flyway mallards breed. Water conditions in Manitoba remained good for ducks, but southern prairies of Saskatchewan dried up. Subnormal temperatures occurred through much of April and May, and, in the northern portions of Manitoba and Saskatchewan, ice was still present on marshes and lakes on May 24. Age ratios of ducks bagged on the flyway indicated that mallard production had declined to the lowest point since the study started in 1939, table 58.

In 1946, water conditions were excellent in Manitoba and through a belt 100 miles wide in eastern Saskatchewan. June rains improved water conditions in Alberta and Saskatchewan. May was excessively cold, and heavy frosts occurred. Age ratios from the Mississippi Flyway indicated that mallard production rose considerably but remained below the 17-year average, table 58.

More detailed information on breeding grounds conditions became available in 1947, when extensive surveys were inaugurated by the U. S. Fish and Wildlife Service. Salient facts from these surveys have been condensed in tables 60 and 61 and are shown graphically in figs. 22 and 23. These tables and figures, as well as tables 58 and 59, should be referred to in connection with the following paragraphs on duck production and breeding grounds conditions.

In 1947, a year in which fair to good water conditions prevailed and slight to moderate water loss occurred during the breeding season in Manitoba and Saskatchewan, the number of juveniles per adult

Table 60.—Environmental conditions on breeding grounds in southern Manitoba, 1947–1953, and mallard production as indicated by number of juveniles per adult checked in hunters' bags in the Mississippi Flyway.

YEAR	WATER CONDITIONS	BREEDING POPULATION OF ALL DUCKS PER SQUARE MILE	WATER LOSS	SPRING TEMPERATURE	FARMING ACTIVITIES	NUMBER OF MALLARD JUVENILES PER ADULT*	AUTHORITY FOR ENVIRONMENTAL CONDITIONS AND BREEDING POPULATION
1947.....	Fair	11.8	Slight	Subnormal	Average	2.36	Hawkins (1948, 1950)
1948.....	Good	13.4	Slight	Subnormal	Favorable	3.18	Hawkins & Cooch (1948), Hawkins (1950)
1949.....	Good	32.2	Moderate	Above normal	Adverse	0.97	Hawkins (1949, 1950)
1950.....	Excellent	37.5	Slight	Extremely subnormal	Favorable	0.73	Hawkins (1950)
1951.....	Fair	41.0†	High	Normal	Adverse	1.71	Hawkins, Gollop, & Wellein (1951), Hawkins (1954)
1952.....	Poor	28.3†	High	Above normal	Adverse	1.65	Hawkins & Wellein (1952), Hawkins (1954)
1953.....	Fair to good	28.1†	None	Extremely subnormal	Favorable	0.82	Williams (1953), Hawkins (1954)

*Data from table 58.

†Calculated from data in table IV, Hawkins 1954:79, for area of 135.75 square miles ("No. per Sq. Mi.," in table IV should undoubtedly be "Number of Square Miles"); figures for 1951 and 1952, with data from one additional transect included, are shown in table I, Hawkins & Wellein 1952:64.

Table 61.—Environmental conditions on breeding grounds in southern Saskatchewan, 1947–1953, and mallard production as indicated by number of juveniles per adult checked in hunters' bags in the Mississippi Flyway.

YEAR	WATER CONDITIONS	BREEDING POPULATION OF ALL DUCKS PER SQUARE MILE	WATER LOSS	SPRING TEMPERATURE	FARMING ACTIVITIES	NUMBER OF MALLARD JUVENILES PER ADULT*	AUTHORITY FOR ENVIRONMENTAL CONDITIONS AND BREEDING POPULATION
1947.....	Good	.....	Moderate	Subnormal	Adverse	2.36	Lynch (1948), Smith (1948)
1948.....	Good	17.3	Moderate-high	Subnormal	?	3.18	Soper (1948), Colls & Lynch (1951)
1949.....	Poor	10.7	Slight	Above normal	Very adverse	0.97	Lynch (1949), Colls & Lynch (1951)
1950.....	Excellent	16.3	Slight	Extremely subnormal	Favorable	0.73	Colls (1950), Colls & Lynch (1951)
1951.....	Good	15.8	Slight	Normal	?	1.71	Colls & Lynch (1951)
1952.....	Good	38.5	Slight	Normal	?	1.65	Gollop, Lynch, & Hyska (1952)
1953.....	Excellent	40.2	Slight	Subnormal	Favorable	0.82	Williams (1953), Lynch & Gollop (1954)

*Data from table 58.

in the bags of Illinois hunters revealed a spectacular rise in production by the mallard; the rise occurred even though spring temperatures were below normal. The spectacular increase in production continued in 1948, as water conditions in Canada improved. In 1949, water conditions in Saskatchewan were poor, and mallard production dropped drastically.

In 1950, water conditions were excellent in both Manitoba and Saskatchewan. May of 1950, however, was unusually cold and wet. Mallard production, as indicated by age ratios of ducks bagged in the Mississippi Flyway, declined. In 1951, water conditions were good through the breeding season in Saskatchewan and fair in Manitoba; a major water loss occurred in Manitoba. In that year, mallard production increased considerably. The two provinces differed materially in water conditions in 1952. In Manitoba, rapid disappearance of water areas began in April and continued through the summer; by August waterfowl conditions were the worst known since breeding grounds ob-

servations were started. In Saskatchewan, water conditions were favorable throughout the breeding season. Mallard production in 1952 declined very little, if at all, age ratios of bagged ducks indicated. In 1953, water conditions were excellent in Saskatchewan and fair to good in Manitoba. There was no water loss during the season in Manitoba and only a slight loss in Saskatchewan. Despite these favorable water conditions, age ratios of bagged ducks revealed a decline in the production of mallards in 1953.

Although small water areas in Saskatchewan and Manitoba were almost at maximum numbers in 1954, age ratios indicated only a slight increase in mallard production, fig. 22. In 1955, with a further increase in number of ponds in Saskatchewan, but with a sizable decrease in the number in Manitoba, mallard production increased materially.

Ponds were down in number in Saskatchewan in 1956, but they increased in number in Manitoba, fig. 22. In that year, age ratios of bagged ducks indicated a

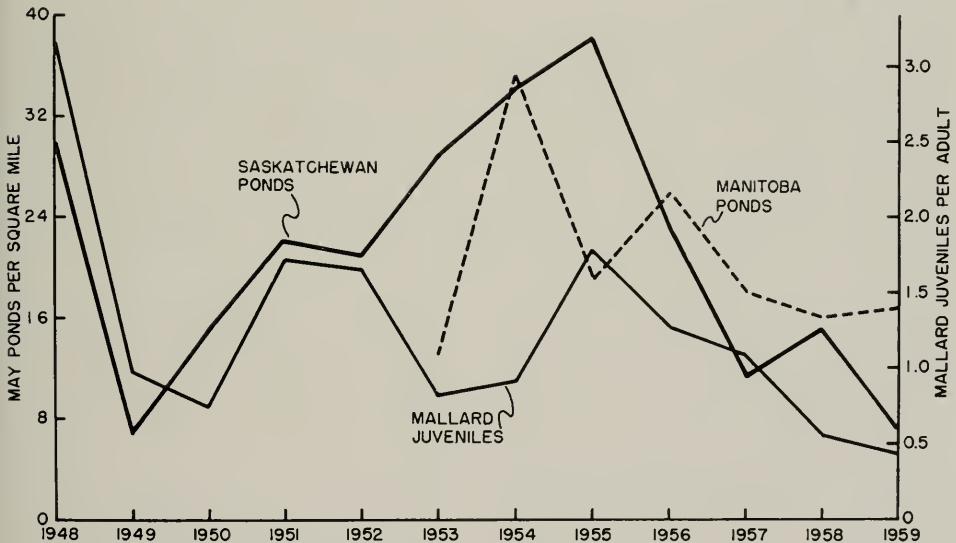


Fig. 22.—Relationship between water conditions on the Canadian breeding grounds and mallard production, as indicated by the number of ponds per square mile in southern Saskatchewan and southern Manitoba in May of certain years, and by the number of juveniles per adult checked in hunters' bags in the Mississippi Flyway. Points on the graph representing number of juveniles per adult for 1948–1955 are based principally on data from Illinois, table 58; points for 1956–1959 are based on data from Missouri, table 59. Because data for 1955 showed the number of juveniles per adult among Illinois mallards to be about 10 per cent less than the number among Missouri mallards, each point on the graph for the years 1956–1959 represents a figure that is 10 per cent less than the corresponding figure in table 59. Data for the breeding grounds are from the U. S. Fish and Wildlife Service and the Canadian Wildlife Service.

drop in mallard production. In 1957, ponds were down in number in both provinces, and mallard production declined. In the following year, 1958, water areas continued down in number in Manitoba but increased in Saskatchewan; mallard production showed a further decline.

In 1959, water conditions in Manitoba remained about the same as the year before, but the number of ponds in Saskatchewan declined sharply. For the fourth consecutive year mallard production de-

clined (one mile in May) followed similar trends in most years of the period 1948–1959, fig. 22. Mallard production and water abundance followed divergent trends in 1950, 1953, and 1958. In 1954, mallard production showed no decisive trend, while water abundance rose markedly. In Manitoba, mallard production tended to parallel water abundance in the years 1956–1959 but not in the 3 years previous.

In 1945, 1950, and 1953, when water conditions on the breeding grounds were

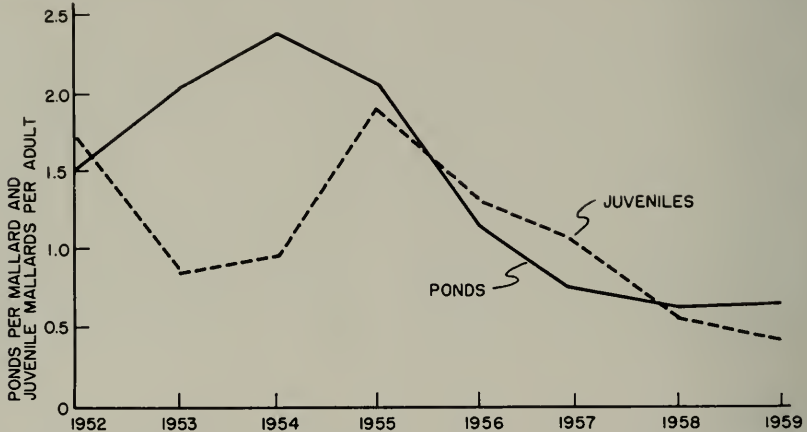


Fig. 23.—Relationship between the density of the adult mallard population on the Canadian breeding grounds in spring and the production of young, 1952–1959, as indicated by the number of ponds per mallard in southern Manitoba and southern Saskatchewan in May and by the number of juveniles per adult checked in hunters' bags in the Mississippi Flyway the autumn following. Data for the breeding grounds in 1952 represent Saskatchewan only. Points on the graph representing number of juveniles per adult for 1952–1955 are based principally on data from Illinois, table 58; points for 1956–1959 are based on data from Missouri, table 59, as explained in the legend for fig. 22. Data for the breeding grounds are from the U. S. Fish and Wildlife Service and the Canadian Wildlife Service.

clined; the number of juveniles per adult in the Mississippi Flyway, as represented by data from Missouri, was at a 21-year low, tables 58 and 59.

No completely objective correlation can be made between waterfowl production and conditions on the breeding grounds. Much of the information from the breeding grounds is not of an objective nature; it is not subject to convenient or exact measurement, and the effects of the many environmental variables are not well understood.

In Saskatchewan, mallard production (as determined by the number of juveniles per adult among birds bagged in Illinois) and water abundance (as measured by the number of ponds per square

fair to excellent and mallard production was down, temperatures below normal and other unseasonable weather conditions, including blizzards, occurred as late as mid-May, disrupting the nesting activities of the mallard, pintail, and other early nesters. In 1947, when water conditions were fair to good, and subnormal temperatures were experienced early in the nesting period, mallard age ratios indicated substantially better than average production.

Concerning weather and water conditions in Manitoba in 1950, Hawkins (1950:42) reported as follows:

If abundant water were the only requirement of nesting waterfowl, ducks nesting in Manitoba would have had a "banner" year;

they did not, however, in spite of the greatest spread of surface water in many years.

Sub-normal temperatures continued throughout the nesting and brooding season. May was particularly cold and wet, possibly a factor in the poor hatch. From July 12 to 15, when many broods were only a few days old, temperatures dipped almost to the freezing point, perhaps another factor affecting success.

Colls (1950:36-7) reported that unseasonably cold weather prevailed all over Saskatchewan for most of the summer and that the more northerly lake country remained ice-bound in some cases as late as the end of May; however, he stated "that weather and water conditions over southern Saskatchewan were exceptionally favourable for the 1950 waterfowl population."

Hawkins (1954:75) reported that on April 15, 1953, the worst spring blizzard in many years combined with several days of freezing temperatures to adversely affect waterfowl production in Manitoba. Another record-breaking blizzard occurred on May 11, and smaller snowstorms on April 24 and May 14 resulted in snowdrifts which could have buried large numbers of nests. Indeed, a few nests that had been buried were found after the snow disappeared. Furthermore, temperatures accompanying the blizzards were sufficiently low to freeze unprotected eggs.

In Saskatchewan, Lynch & Gollop (1954:45) reported that May, 1953, was very cold, with much snow prior to the middle of the month. Stoudt & Buller (1954:55) reported that the weather was "wet, cold and miserable for the most part" during the nesting and brooding season, but concluded: "We have always heard of the dire effects of wet, cold weather on newly hatched ducklings but such ill effects were *not* noted during the 1953 brooding season."

A late breakup of ice occurred in Manitoba lakes in 1954 (Evans 1955:72), with freezing temperatures and snow extending into early May. May and early June were generally cool and wet.

Saskatchewan experienced a record-breaking cold wave in late April and early May of 1954 that substantially delayed nesting by mallards and pintails (Gollop & Lynch 1955:46-7). As late

as mid-May, many lakes were still frozen over.

As a result of adverse weather in the spring of 1954, Stoudt & Stinnett (1955:60) found an extremely high nest loss among mallards as well as other ducks on a small study area in southeastern Saskatchewan. They attributed the loss in the first nesting effort of mallards to a blizzard and zero temperature on May 1. Most of May and June was characterized by cold, very wet weather, retarding the development of good nesting cover. The paucity of nest cover and the lack of stable food for predators resulted in greatly increased predation upon duck nests. Flooding destroyed many nests missed by predators.

Decreased production by the mallard on the plains of Canada in years of very plentiful water and of cold weather, snow, and heavy rains at nesting time suggests that cold and excessively wet springs may be as unfavorable to duck production as dry and warm springs.

It is quite evident that water and weather conditions on the breeding grounds during the nesting and rearing period were major factors contributing to the gross changes in mallard production in 1939-1959. Yet there was another factor in mallard production, population density, that seems to have operated in most years within the broad limits of the environment, and, indeed, that may well have been the dominant regulating factor in production in those few years in which there was a poor correlation between environment and age ratios. In 2 years having similar water conditions but breeding populations of different sizes, the number of juveniles produced per breeder may be lower in the year with the larger population than in the year with the smaller.

Several years ago, an inverse relationship between population density and production of young was reported for the muskrat by Errington (1943:877), who stated: "the data indicate that rates of increase tend to vary with particular habitats and inversely with the density of the breeding stock."

That an inverse relationship between population density and production could be detected in upland game was noted by several writers (Baskett 1947:25-7;

Bump *et al.* 1947:540; Errington 1945:13).

Production in the mallard and possibly other duck species may bear, within certain undetermined limits, an inverse relationship to population densities, or a direct relationship to number of ponds per duck. (Increased density in a duck population on the breeding grounds may be brought about by a decrease in the number of water areas as well as by an increase in the number of ducks.)

With the exception of 1953 and 1954, years in which cold temperatures and snow reduced production of the mallard, there was a good correlation between number of ponds per breeding mallard and production of young on the Canadian breeding grounds. As the number of ponds per breeding mallard decreased from 2.0 to 0.6 in the Grasslands and Aspen Parklands of Manitoba and Saskatchewan, production declined from 1.78 juveniles to 0.54 juvenile per adult, fig. 23.

A change in the density of the mallard population on the breeding grounds may affect production in two ways: (1) alter the rate of nest destruction and desertion; (2) alter the relative number of ducks that can be accommodated by prime breeding habitat.

Sowls (1955:74) found that most mallards nest within 100 yards of pond, slough, or lake margins rather than at greater distances from water. The area of nest concentration adjacent to a body of water has been called the nesting zone. As ponds and other small water areas decline in number, greater concentrations of mallard nests occur in the nesting zones of the bodies of water that remain. It is probable that, as nest density increases, the rate of nest loss rises. Although data on the relationship between nest density and nest loss are lacking for waterfowl, Stokes (1954:36) found that in pheasants nest abandonment increased with breeding density.

Unpublished field studies by Alex Dzubin (letter March 5, 1960) of the Canadian Wildlife Service suggest that space requirement also may be related to mallard production. Dzubin believes that, through interactions involving both aggressive and sexual behavior, pairs of mallards space themselves over the breeding

grounds. Adequate spacing is most evident in the Aspen Parklands region, with its abundance of water areas; it is less evident in the Grasslands region, which may have a scarcity of water areas. Space behavior of ducks around waiting areas tends to place a limit on the number of pairs any one area can accommodate.

The role of space in regulating the size of breeding populations of waterfowl is apparent in an analysis made by Schroeder (1959:4-5) of water areas and numbers of breeding ducks in North Dakota. Schroeder found that the numbers of breeding ducks and water areas tended to fluctuate up and down together. For example, in 1950, water areas numbered 11.4 and breeding ducks 24.6 per square mile, whereas, in 1959, water areas had declined to 2.1 per square mile and ducks to 8.4 per square mile.

Evans & Black (1956:52) found a direct relationship between water areas and breeding ducks on an 11.25-square-mile prairie pothole area in South Dakota. Their study showed that as the number of potholes with water on May 10 increased and then decreased from 1950 through 1953 so did the number of breeding pairs of ducks.

Stoudt (1959:103) reported a direct relationship "up to a certain point" between numbers of breeding ducks and numbers of water areas on a study area 40 miles long and one-eighth mile wide near Redvers, in southeastern Saskatchewan. He did not find this direct relationship in "extremely wet years and extremely dry years."

From 1953 through 1958, there were only small variations in the number of water areas each year on May 1 in a Lousana, Alberta, study area, but the number of breeding pairs of mallards on this small area rose from 103 to 338 during that period (Smith 1959:3, 8). The number of ponds on May 1 decreased from 198 in 1958 to 131 in 1959 and the number of breeding pairs from 338 to 241.

The smaller a study area, the less likely it is to show direct relationships between the numbers of breeding pairs and the numbers of water areas. Local variations in mortality rates, homing, and population saturation levels that grossly affect the data for small areas may have no appreci-

able effect upon the data for extensive areas, because the many local variations in the extensive areas tend to cancel each other.

Because the space behavior of ducks limits the number of breeding pairs that a given waterfowl habitat can accommodate, when an increase occurs in the breeding population of an area that has reached the limit of its carrying capacity, or when a decrease occurs in the number of ponds on the area, some of the ducks associated with the area must do one of two things: (1) move to other areas not occupied to the saturation level or (2) fail to reproduce.

The areas to which the ducks move may be of poorer quality for the production of young than the areas occupied to the saturation level. Biologists have long been aware of the tendency of bird populations to make maximum use of the best available habitat before occupying less favorable habitat. On a Saskatchewan study area, Stoudt (1952:55) found that breeding pairs of ducks tended to make maximum use of the small water areas (1 acre or less) and shift to less favorable habitat when the prime areas were occupied to the limit of their carrying capacity.

Under conditions associated with population or habitat changes, ducks may move from a region of basically good habitat to a region of inferior habitat. In 1959, there was an increase in the number of mallards found during May in the marshes of the Coniferous Forest in northern Alberta and other northern parts of Canada and a decrease in the number found in southern Saskatchewan. The Coniferous Forest lacks the quality habitat for nesting mallards supplied primarily by the Grasslands and secondarily by the Aspen Parklands.

Biologists have noted that under severe crowding many ducks do not breed and that some ducks that make attempts at nesting do not make further attempts if the first attempts fail. Arthur S. Hawkins and Gerald Paspichal in an unpublished report of the U. S. Fish and Wildlife Service on the 1959 breeding season in the pothole country of western Manitoba noted that many ducks in that area were individuals that had been displaced from other areas. They found indications that

some ducks did not attempt to nest and that others did not make the usual re-nesting attempts after having lost nests. Stoudt (1959:104) observed that many pairs of ducks in southeastern Saskatchewan in 1959, a year of very low water levels, "did not seem to nest at all."

Fig. 17 may be interpreted as showing that when the Grasslands and Aspen Parklands have reached the limit of their carrying capacity as a result of population increases and/or habitat deterioration, the production of juveniles per adult mallard declines for 2 to 4 years, until the breeding population has declined to a point where population density is no longer a limiting factor. Then, when a decrease in population or an increase in water areas results in more space per breeding pair, the production of young per breeder increases for 1 to 3 years, until population density again becomes a limiting factor.

The highs and lows in a breeding population of mallards may lag 1 or 2 years behind the highs and lows in the production of young per breeder. The first year a high breeding population produces a smaller number of young per breeder, the over-all population will probably continue to increase because of the large number of breeders still present to produce young. The over-all population may continue to increase even into the second year of lower production. When the breeding population is at a low point, the over-all population will probably continue to decline for a year after an increase in production, as the increased number of young per breeder may fail to result in as many young as are needed to replace the ducks lost through hunting and natural mortality the previous year.

The foregoing analysis of the effect of environment on production of mallards and other ducks points up the importance of water areas that are available to breeding pairs. Also, it points to abnormally low temperatures and associated weather conditions in April and May as factors of major importance in production. Abnormally low temperature conditions do not occur on the breeding grounds as frequently as abnormally low water conditions. Within the framework of acceptable nesting environment, and within certain undetermined population limits,

Table 62.—Number of juveniles per adult hen (the number corrected for the greater vulnerability of juveniles to hunting) in each of 12 species of ducks checked in hunters' bags in the Mississippi Flyway, principally Illinois, 1946–1949.

SPECIES	NUMBER OF ADULT HENS	NUMBER OF JUVENILES	NUMBER OF JUVENILES PER ADULT HEN	JUVENILE VULNERABILITY FACTOR*	CORRECTED NUMBER OF JUVENILES PER ADULT HEN
Mallard.....	3,631	19,860	5.47	1.3	4.2
Black duck.....	402	2,858	7.11	1.8	4.0
Gadwall.....	201	1,335	6.64	2.4	2.8
Baldpate.....	210	2,280	10.86	2.9	3.7
Pintail.....	445	2,669	6.00	1.9	3.2
Green-winged teal..	226	1,427	6.31	1.7	3.7
Blue-winged teal...	370	1,901	5.14	1.7	3.0
Shoveler.....	119	836	7.03	1.7	4.1
Redhead.....	190	1,882	9.91	3.5	2.8
Ring-necked duck..	123	1,043	8.48	2.0	4.2
Canvasback.....	208	2,745	13.20	2.9	4.6
Lesser scaup.....	297	1,525	5.14	2.0	2.6

*Correcting factors for most species are from tables 42, 43, and 45, ratio of adult to juvenile vulnerability. The correcting factor for the green-winged teal and the shoveler is assumed to be the same as that for the blue-winged teal, and the correcting factor for the ring-necked duck the same as that for the lesser scaup.

production of mallards, and possibly all species of waterfowl, seems to be inversely related to population density.

Production in Different Species

Age ratios of ducks checked in hunters' bags in the Mississippi Flyway for the period 1946–1949 provide indices of production for the various species, table 62. At least a partial correction for the greater vulnerability of juveniles than of adults has been made by using banding data from Illinois for the black duck and blue-winged teal, tables 42 and 43, and banding data from Canada for the mallard, gadwall, baldpate, pintail, redhead, canvasback, and lesser scaup, table 45. It has been assumed that the ratio of adult to juvenile vulnerability in the green-winged teal and shoveler is similar to that in the blue-winged teal and that the ratio of adult to juvenile vulnerability in the ring-necked duck is similar to that in the lesser scaup. Even though the calculations representing the "corrected number of juveniles per adult hen," table 62, were derived from arbitrarily selected vulnerability ratios, it is believed that they are so close to the actual juveniles-per-hen figures that some useful generalizations can be made.

The differences among the species are not so great in the "corrected number of juveniles per adult hen" as in the actual

number of juveniles per adult hen in hunters' bags, table 62. The vulnerability differential between adults and juveniles offers an explanation for the excessively high ratios of 10 to 13 juveniles per adult hen that have been found in checks of hunters' bags.

Several species of ducks appear to have about equally high production rates, table 62: mallard, black duck, shoveler, ring-necked duck, and canvasback. The baldpate and green-winged teal seem to be intermediate in production. The gadwall, pintail, blue-winged teal, redhead, and lesser scaup appear to be species with comparatively low production rates.

The fact of survival in a duck species indicates that the species is adapted to maintain its place in the total duck population. The production of each species must compensate for the losses suffered through mortality, or the species declines. With possibly a few exceptions, notably the redhead and the wood duck, no duck species has been known to undergo more than a temporary major decline in population status in recent times.

Age Ratios in Population Management

One aim of waterfowl management is the establishment of hunting regulations that will permit the greatest possible har-

vest of birds without undue depletion of populations. Age ratios obtained through inspection of ducks in hunters' bags offer valuable assistance in determining the well-being of populations and in evaluating the extent to which production may be expected to replace annual losses.

An average annual production of 2.7 young of flying age per adult hen has been estimated for mallards of the Mississippi Flyway in the period 1939-1955, table 58. Although this average figure and other production figures shown in table 58 are for the mallard only, they are of value in making over-all hunting regulations because mallards comprise about half of the duck population.

Major year-to-year changes in production of the mallard, changes that probably are present in other species also, require flexibility in regulations governing the duck kill.

Production data from age ratios need to be supplemented by information from the breeding grounds in the northern part of the Mississippi Flyway. More information is needed on the effect of different combinations of regulations on mortality in the mallard and other species of ducks. Bellrose & Chase (1950:22) found evidence that natural losses plus hunting losses occurring under the regulations in force in the years 1939-1947 resulted in an annual mortality rate of about 48 per cent in male mallards; the annual mortality rate of the entire population was somewhat higher.

The extent to which increased production in ducks can compensate for increased mortality is at present pure speculation. The ability of animals to compensate for annual variations in mortality rates by flexibility in production is widely recognized. More than 80 years ago, Forbes (1880:9) wrote: "The fact of survival is . . . usually sufficient evidence of a fairly complete adjustment of the rate of reproduction to the drains upon the species." A few years ago, Allen (1943:113-4) cited the resilience of the fox squirrel in compensating for severe losses in number. Bump *et al.* (1947:539-40) reported for the ruffed grouse (*Bonasa umbellus*) in New York "a distinct tendency for greater relative increases to be associated with lower breeding popula-

tions." Diem (1959:30+5), in reporting on duck production in an Alberta study area, stated that some years "having low breeding populations have witnessed bumper crops of young."

The probability that ducks have some degree of elasticity in their capacity to reproduce is shown by differences in production among various species. It is shown further by differences in production between the ducks of different flyways. Although age ratios for Nebraska mallards have tended to follow the same general trend from year to year as those in Illinois, they have consistently reflected lower numbers of juveniles per adult, fig. 16. There is good evidence from banding and from the percentage of birds carrying shot wounds that shooting pressure is lighter in the Central Flyway (and, therefore, that the mallard undoubtedly has a lower mortality rate in that flyway) than in the Mississippi Flyway. Perhaps the apparently lower reproduction rate of mallards in the Central Flyway is the result of the lower mortality rate there.

More data are needed on production and mortality rates in various species of ducks in each of the four flyways. By comparing production and mortality rates in various species of ducks in each of the four flyways, it would be possible to learn a great deal more than is now known about an apparent inverse relationship between mortality and production and the operation of other population mechanisms of waterfowl.

Waterfowl population research requires a more concerted effort to appraise production and to relate this to habitat conditions. We recommend that state and federal biologists, working through the four flyway councils, make detailed and uniform appraisals of conditions on the breeding grounds and that, by use of age ratios obtained from bagged ducks, they determine yearly production for the important species.

The most feasible approach to the problem of obtaining data on age ratios appears to entail the establishment of stations where large samples of particular species could be obtained. Some samples should be taken where there is evidence that a cross section of the migrating population can be obtained or where the win-

tering populations exhibit a minimum of regional bias. In some areas, a station might be established at which the age ratios for only one species of duck are taken. For example, in the Mississippi Flyway, the best station for sampling the mallard might be Stuttgart, Arkansas; the best for the gadwall, Mobile Delta, Alabama; the best for the pintail and the green-winged teal, the coastal marshes of Louisiana; the best for the ring-necked duck, Reelfoot Lake, Tennessee; the best for the redhead and the canvasback, Lake St. Clair and the Detroit River, Michigan.

SUMMARY

1. The present study is an evaluation of sex and age ratios in North American duck populations and the ways in which, in waterfowl management, these ratios can be used to measure productivity. (Page 391.)
2. Determination of sex composition in duck populations presented a difficult sampling problem complicated by differences in species, seasons, and places, and by inadequate sampling techniques. (Page 393.)
3. In the study reported here, most trapped or bagged ducks that could not be readily sexed by plumage differences were sexed by cloacal characters. (Page 396.)
4. Four methods of sampling waterfowl populations for sex ratios were used: (1) examination of trapped ducks, (2) inspection of ducks taken by hunters, (3) observation of ducks in the field, and (4) examination of disease victims. Biases evident in each method were recognized, and corrections were made whenever possible. (Page 396.)
5. Baited, funnel-type traps tended to take disproportionate numbers of drakes, while gate-type traps placed on shore tended to catch a predominant number of hens. (Pages 397, 400.)
6. Inspection of ducks in hunters' bags made possible the separation of drakes and hens in molting adults and in juveniles. (Page 400.)
7. Most sex ratios derived from inspection of hunters' bags showed little bias, usually in favor of drakes. (Page 400.)
8. Banding records indicated that mallard drakes were 1.05 times as likely to be shot by hunters as were hens, the differential probably a result of hunter preference for drakes. (Page 401.)
9. A few field observations on living ducks in spring were used to provide sex data on samples of several species; however, because it is almost impossible to make a sufficient number of random observations to insure an adequate sampling of the population of a flyway or other large area, field observations were not more extensively used. (Pages 401-2.)
10. The validity of sex ratios obtained from examination of ducks that were victims of disease was found to need further study. (Page 402.)
11. Analysis of available data showed no significant departure from an evenly balanced sex ratio in ducks at fertilization or at hatching. (Pages 402-3.)
12. Data obtained from examining juvenile ducks trapped during the breeding season or taken by hunters during the fall indicated that the ratio between the sexes from the time of hatching to adulthood was close to 50:50; local variations appeared to result from differences in seasonal movements. (Pages 403-5.)
13. Although sex ratios of adults usually favored drakes, there were numerous exceptions. (Pages 405-6.)
14. Sex ratios of many species of ducks varied from week to week in any given area as the composition of the local population changed with the arrival and departure of flocks containing varying numbers of drakes and hens. (Page 408.)
15. In most species of ducks for which data were available, drakes made up a smaller proportion of the hunters' kill in Manitoba than in three states to the south (North Dakota, Illinois, and Tennessee), indicating that more drakes than hens left Manitoba in advance of the hunting season. Among adult mallards bagged in Illinois, there was a steady increase in the drake segment through the third week in November, followed by a period of stabilized sex ratios, and then further increase in the drake segment of the wintering population, usually present in Illinois after the first week in December. In Utah, sex ratios of adult mallards bagged by hunters were relatively stable throughout fall. In only a few species did there appear to be differences in seasonal movements between

drakes and hens in the juvenile class. (Pages 408-9.)

16. Periodic counts of ducks in late winter and early spring revealed differences in the sequence of northward migration of drakes and hens of the same species. (Pages 411-16.)

17. The first spring flights arriving in Manitoba showed, with minor exceptions, a closer approach to a balance between sexes than did subsequent populations. (Pages 416-9.)

18. Sex ratios in ducks were found to vary with migration routes and various areas of their wintering grounds. (Pages 419-20.)

19. Information collected on the principal mortality factors affecting the North American duck population indicates that hunters and disease take relatively more drakes than hens. This information is not sufficient to permit appraisal of the influence of predation on sex ratios; however, appreciable losses among hens during the breeding season, most of these losses apparently attributable to predation, agricultural operations, and stress, may account for the predominance of drakes in the adult class. (Page 426.)

20. Data showed that, the more productive a species of waterfowl, the greater is apt to be the proportion of juveniles in its population at the opening of the hunting season; the greater the proportion of juveniles in a population, the more nearly balanced is its sex ratio. (Page 426.)

21. Drakes occurred in relatively greater numbers among diving ducks than among dabblers; however, examination of the available knowledge on the reproductive biology characterizing these two subfamilies revealed nothing which suggests that extra drakes may be more important to the maintenance of populations of diving ducks than of dabblers. (Page 427.)

22. The study suggested that the value of extra drakes needs investigation through an experimental procedure designed to reduce the number of drakes in a subpopulation of a species having a large drake segment. (Page 428.)

23. Sex ratios that were derived from inspection of mallards in hunters' bags in Illinois provide a fair index to production but not so good an index as age ratios; sex ratios obtained from observations on

the breeding grounds in Canada do not appear to provide a more reliable index to production than sex ratios calculated from bag inspections in Illinois. (Page 429.)

24. Age ratios alone, this study assumed, are seldom true indices of waterfowl production, but they offer a promising basis for measuring it. (Page 430.)

25. In this study, age ratios were obtained by examination of ducks trapped for banding, shot by hunters, or killed by disease. (Page 431.)

26. Although most traps were selective for adults, ducks taken in traps were found to provide a rough index to yearly changes in age ratios. (Pages 431-5.)

27. Juveniles were found to be more vulnerable to hunting than adults; the vulnerability differential varied with place, time of hunting season, year, and species. (Pages 435-9.)

28. Age ratios obtained from bagged ducks and corrected for the greater vulnerability of juveniles offered the best means of determining the adult-juvenile composition of duck populations. (Page 439.)

29. Age ratios derived from waterfowl lost to severe outbreaks of disease were considered unreliable because of the irregular occurrence and site limitations of such outbreaks. (Pages 439-40.)

30. Because juveniles and adults do not follow identical migration schedules or routes, age ratios showed seasonal and regional variations. (Pages 440-9.)

31. Age ratios were found to be useful for appraising the production of ducks if the data on which they are based have been carefully evaluated as to the effect of seasonal, regional, and shooting biases. (Page 449.)

32. A production curve (page 449) that was plotted from corrected age data for mallards in hunters' bags in the Mississippi Flyway for 17 years, 1939-1955, follows a pattern somewhat similar to that plotted from uncorrected data and shows a somewhat rhythmic production trend that may be inherently characteristic of waterfowl populations and prove to be density dependent in origin. (Page 454.)

33. A comparison of mallard age ratios in the Mississippi Flyway with pintail age ratios in the Pacific Flyway for 11 years, 1949-1959, revealed for most years an unexpectedly close agreement between pro-

duction trends of the two species involved. (Pages 454-5.)

34. For the period 1952-1959, the population curve plotted from forecast indices of waterfowl production in Saskatchewan was similar to the curve plotted from the Mississippi Flyway age ratios for mallards. Manitoba forecast indices showed very little correlation with mallard age ratios from the Mississippi Flyway, possibly because, as aerial surveys indicated, about six times as many mallards nest in the plains and parklands of Saskatchewan as in the plains and parklands of Manitoba, and because the Saskatchewan contribution to the Mississippi Flyway kill of mallards is larger than that of Manitoba. (Page 457.)

35. An attempt was made to correlate water conditions on the breeding grounds with mallard production. In Saskatchewan, mallard production (as determined by the number of juveniles per adult among birds bagged in Illinois) and water abundance (as measured by the number of ponds per square mile in May) followed similar trends in most years of the period 1948-1959. In Manitoba, mallard production tended to parallel water abundance in the years 1956-1959 but not in the 3 years previous. (Page 462.)

36. Decreased production by the mallard on the plains of Canada in years of very plentiful water and of cold weather, snow, and heavy rains at nesting time suggests that cold, excessively wet springs may be as unfavorable to duck production as dry, warm springs. (Page 463.)

37. Population density, as well as water and weather conditions on the breeding grounds, seems to have contributed to gross changes in mallard production in 1939-1959; it may well have been the dominant factor regulating production during those years in which there was poor correlation between age ratios and conditions on the breeding grounds. (Page 463.)

38. Age ratios of ducks checked in hunters' bags in the Mississippi Flyway for the period 1946-1949 provided indices of production for the various species. Several species appear to have had about equally high production rates: mallard, black duck, shoveler, ring-necked duck, and canvasback. The baldpate and green-winged teal seem to have been intermediate in production. The gadwall, pintail, blue-winged teal, redhead, and lesser scaup appear to have had production rates lower than those of the other species. (Page 466.)

39. Age ratios obtained through inspection of ducks in hunters' bags were found to be of value in establishing hunting regulations, for they provide a basis for evaluating the well-being of the population and the extent to which production may be expected to replace annual losses. (Pages 466-7.)

40. Further progress in waterfowl population management, the study concluded, requires a more concerted effort to obtain age ratio data by design and to relate these data to conditions on the breeding grounds. (Page 467.)

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INDEX

The following index covers Articles 1, 2, 3, 4, 5, and 6 of Volume 27 of the ILLINOIS NATURAL HISTORY SURVEY BULLETIN. Indexing has been limited for the most part to the names of birds, fish, insects, mammals, and plants mentioned in the articles. In most cases, the singular form of the word has been used in the index, even though the plural form has been used in the text, as *mouse* for both *micc* and *mouse*. Place names have not been indexed.

Of necessity, variation occurs in some of the terms. For example, *peach* in the index may refer to either the fruit or the tree.

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