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Dr. Charles A. Kofoid, the writer of the accompanying report on the plankton of the Illinois River, was appointed to the staff of the Illinois State Laboratory of Natural History as Superintendent of the Illinois Biological Station, July 1, 1895, and continued in that relation until December 31, 1900. Elected Assistant Professor of Histology and Embryology in the University of California during the summer of the latter year, he received a virtual leave of absence from that University until the beginning of the January following to enable him to complete the collation and tabulation of the data of the Station studies, on which he was then engaged, and these materials were sent to him at Berkeley, California, early in 1901. His paper was thus mainly prepared after his formal connection with the State Laboratory had ceased, and during his residence in a distant state.

Grateful acknowledgements are due to the University of California, and especially to the successive heads of its Department of Zoölogy, Professor Joseph Le Conte and Professor William E. Ritter, for the privileges accorded in this connection. without which this report would necessarily have been prepared, under embarrassing disadvantages, by another hand.

S. A. Forbes,
Director of Laboratory.

Urbana, Ill., October 10, 1903..

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URBANA, ILLINOIS, U. S. A.

VOL. VI. NOVEMBER, 1903 ARTICLE II.

Article I

THE PLANKTON OF THE ILLINOIS RIVER, 1894–1899, WITH INTRODUCTORY NOTES UPON THE HYDROGRAPHY OF THE ILLINOIS RIVER AND ITS BASIN. PART I. QUANTITATIVE INVESTIGATIONS AND GENERAL RESULTS.

BY

C. A. KOFOID, PH.D.

ARTICLE I.—*The Dragon-flies (Odonata) of Illinois, with Descriptions of the Immature Stages. Part I. Petaluridæ, Æschnidæ, and Gomphidæ.* BY JAMES G. NEEDHAM AND CHARLES A. HART.

INTRODUCTION.

The present paper is the combined product of studies made by the authors upon the collections of the Illinois State Laboratory of Natural History, including those of the Biological Station at Havana, and by Professor Needham on his private collection. The state collections comprise the results of many years' work in all parts of Illinois, including five successive years of field observation and collection at the Illinois Biological Station on the Illinois River at Havana; specimens obtained by Professor H. Garman from the Mississippi and related waters at Quincy, Ill. (Garman, '90); a large series from the small lakes of northeastern Illinois; and collections made by Professor Forbes in Yellowstone Park and its vicinity (Forbes, '93) and from lakes Geneva and Delavan, Wis., under the auspices of the U. S. Fish Commission. Professor Needham's private collection used in the preparation of this paper contains many Illinois and New York species, reared by him to the imago, and others contributed by correspondents, particularly by Mr. F. G. Schaupp in Texas, Mr. Adolph Hempel in Florida, and Mr. F. C. Willard in Arizona. The preparation of the introductory matter, biological discussions, and keys to the nymphs has devolved upon Mr. Hart, while the descriptive matter, with a few exceptions, was prepared by Professor Needham.

We are indebted to Mr. C. C. Adams for abundant data on the occurrence of the imagos in Illinois derived from his large private collection, and also for work on the keys to the genera of imagos. We are under special obligation to Dr. P. P. Calvert, of Philadelphia, for aid given Mr. Adams in the revision of keys and in the determination of doubtful species, and for notes on dragon-flies in Illinois made by Mr. Harry Walker at Belvidere, Mr. Shafer at Mt. Pulaski, and Mr. E. J. Kuegeman at Ravenswood and Edgewater. Data relating to collections in Illinois have been furnished us by Mr. Maurice Ricker, of Burlington, Ia., and by W. E. Longley, and others, of the Entomological Society of Chicago.

Of the twenty-eight recognized Illinois species of the families of *Anisoptera* herein treated, we have here described the nymphs of twenty-four (six of them for the first time), representing all our eleven genera. To these have been added by Professor Needham descriptions of ten nymphs of extralimital species. Thirty-four nymphs are thus described in all, fourteen of them for the first time.

Much careful study has been given to the preparation of the keys. In all cases the linear arrangement is according to the principles suggested by Comstock, the more generalized group or species being followed by the divergent ones in the order of the direction and amount of specialization. The descriptions of the nymphs are drawn up from full-grown examples unless otherwise stated. The newly hatched insect quickly takes on the form and structure of the full-grown nymph, and may usually be recognized while still very young by the characteristic sculpture and armament of its species.

ORDER ODONATA.

The common dragon-flies of the suborder *Anisoptera* are familiar to every one, but the damsel-flies, constituting the suborder *Zygoptera*, might not be recognized as also belonging to this order. These damsel-flies are small narrow-winged forms, which, like the butterflies, hold their wings back to back while at rest. The *Odonata* have no quiescent pupal state; the immature stages after the egg are collectively designated as the nymph. The latter is always aquatic. It has highly developed thoracic legs but no abdominal ones. Wing-pads appear at the third or fourth molt. There are no external gill structures except the three terminal appendages of the *Zygoptera*. The abdomen of the nymph is slender among the *Zygoptera*, but in the ordinary dragon-flies (*Anisoptera*) it is rather short and broad. A very distinctive feature is the large and elongate labium, folded beneath the body like an arm, the "hand" of which, ending in a pair of claspers, covers the mouth or the entire face. The nymphs crawl rather slowly, often clumsily, but can dart some distance through the water like the crawfish, being propelled by the sudden ejection of the water in the rectal respiratory cavity.

The *Odonata* and their near relatives the May-flies (*Ephemerida*), isolated remnants of former insect life, in general of primitive character although highly specialized along some lines, are probably among the oldest orders of winged insects. In younger groups the branching of the "family tree" of development may often be traced with some degree of satisfaction by a study of the primitive characters retained by still existing forms; but in the lapse of ages so many of the earlier lines of descent have been obliterated from the earth that in the *Odonata* only the upper parts of a few separated branches are traceable, their points of origin being involved in obscurity. In Illinois the branch nearest the primitive stock is probably that of the "black-wings," or *Calopteryx*, of our smaller streams, representing the *Calopterygidæ*. Another branch (*Agrionidæ*), including the more common damsel-flies, *Agrion*, *Lestes*, etc., has a number of characters in common with the preceding, and the two constitute the suborder *Zygoptera.* In forms related to *Calopteryx* the three tracheated caudal setæ of the May-flies seem to be represented by three shorter and thicker respiratory appendages, the laterals especially being more or less spike-like and triquetral. In the *Agrionidæ* these appendages are vertically flattened thin gill-plates. Quite a different development of the original type is found in the nymphs of the ordinary dragon-flies, the suborder *Anisoptera.* In these respiration is principally performed by internal rectal gills, and the three appendages, very short and subtriangular, are supplemented by two others, the five converging to protect the opening of the respiratory cavity.

The five families constituting the *Anisoptera—Petaluridæ, Æschnidæ, Gomphidæ, Cordulegasteridæ,* and *Libellulidæ*—are variously connected by common characters. It is worth noting that the obscure color, rough sculpture, and general habits of the *Calopteryx* nymph are also found in the more primitive forms of these families. The *Petaluridæ* is probably the oldest of the five. It has not as yet been found in Illinois. In this family and the *Æschnidæ* the ovipositor is well developed and oviposition is endophytic, as in all the *Zygoptera.* The *Petaluridæ,* judging from Mr. Williamson's observations (Williamson, '01), breed in boggy or swampy spots, where the imagos may be found ovipositing. The nymph is remarkably synthetic in its characters and supplies a hitherto missing link in the evolution of the labium, being intermediate in this respect between *Æschnidæ* and *Cordulegasteridæ,* thus indicating a very primitive origin. In its form and antennal structure, on the other hand, it strongly approaches the *Gomphidæ.* In general, however, it is clearly most closely related to the *Æschnidæ.* The nymphs of the *Æschnidæ* are somewhat elongate, and climb on submerged branches, driftwood, roots, and smaller vegetation. The imagos are unusually large and high-flying, the eyes large, the wings much specialized. The nymphs of the third family, *Gom-*

phidæ, nearly all burrow in mud and sand. The imagos are usually of medium size, barred with green or yellow, the apical part of the abdomen often expanded to a greater or less extent. They are usually seen near water, but are not numerous as a rule. The ovipositor is rudimentary or wanting and oviposition is exophytic, as in the remaining families. The eyes are small and widely separated, in which respect the family approaches the *Zygoptera*. The nymphs of the *Æschnidæ* and *Gomphidæ* differ but slightly in the structure of the labium and gizzard, and both these organs are quite similar to the type found in the *Zygoptera*. The next family, *Cordulegasteridæ*, is of special interest. It has but few species, and examples are rarely seen in Illinois. While evidently related to the preceding families in different ways, the nymphs are like those of the *Libellulidæ* in having a spoon-shaped labium and a symmetrically 4-toothed larval gizzard. The last family, *Libellulidæ*, comprises most of the commoner species. They are diversified in structure and habits, and may be grouped in three subfamilies. The first two of these (*Synthemiinæ* and *Corduliinæ*) have a number of common features and have hitherto been classed as one, but the wing structure and nymphal characters of the *Synthemiinæ*, represented in Illinois by *Macromia* and *Didymops*, seem to warrant its separation from the *Corduliinæ*. The greater part of the family belongs to the *Libellulinæ*, which includes three general types, exemplified by *Sympetrum (Diplax)*, *Libellula*, and *Tramea*. The grouping of these is based by Mr. Adams on the extent of development of the ovipositor.

LITERATURE.

A list of the more important papers, to which references are made, is appended to this paper. A brief summary of their contents may be given here.

On the nymphs, the most important papers are by Hagen and Cabot, describing and figuring the nymphs of the Museum of Comparative Zöology, at Cambridge. Cabot's first paper ('72) covered the *Gomphidæ* and *Cordulegasteridæ*, his second ('81) the *Æschnidæ*, and his third ('90) the *Synthemiinæ* and *Cordulinæ* and also *Tramea* and *Pantala*. Hagen ('85) gave a greatly extended revision of the two families previously treated by Cabot ('72). The large and abundant family *Libellulidæ* was not treated by them. Karsch ('93) gives descriptions, figures, and keys to West African nymphs. The characters assigned to the major groups in his keys are, as Dr. Calvert has pointed out, only locally or partially true. Lucas ('97, '97a) has described and figured a few English nymphs, and Roster ('86, '88), a number of Italian *Zygoptera*. Beutenmüller ('90c) has given a bibliography of nymphal descriptions, excepting those in Cabot's '90. Needham ('97a, '99) gives suggestions on collecting and rearing nymphs.

Among the general works, Dr. P. P. Calvert's admirable paper ('93) deserves first mention. It includes a complete and accurate summary of all the more important biological and anatomical details concerning dragon-flies and their nymphs, with generic keys for both. Descriptions are given of the species of the region about Philadelphia, among which are most of our commoner forms. The phylogeny of the dragon-flies in general, with especial reference to the structure of the gizzard, is discussed in a scholarly article by Dr. F. Ris ('97).

The principal monograph of American species is in Hagen's well known "Neuroptera of North America" ('61). A number of monographic papers have been published by Dr. Selys-Longschamps in Belgium. The best catalogue of species is that of Kirby ('90). It contains several surprising changes in nomenclature, one of which—the use of *Æshna* in place of *Gomphus*—is fortunately not well founded. Banks ('92) has listed the American species, and given a key to the genera. From an economic point of view, especially as to their utility as destroyers of obnoxious *Diptera*, dragon-flies are treated in Lamborn's collection of prize essays ('90).

The numerous published lists of *Odonata* in this country contain much valuable information as to the life history of our species, dates of occurrence, and the like, and have been extensively used in the preparation of this paper. Such are those of the late Dr. Kellicott ('95, '96, '97a); of Miss Wadsworth ('90) and Mr. Harvey ('91a) for Maine; of Calvert, Banks, and Van Duzee for New York; of Calvert for Virginia and the vicinity of Philadelphia; of Williamson ('00) for Indiana; and of Elrod for Iowa, and Banks for Kansas. The above localities are not far from our own latitude, and the data given are presumably quite close to the normal for Illinois.

Among Illinois contributions to this subject we may mention the elaborate papers ('62, '63) of our pioneer entomologist, Mr. B. D. Walsh, who listed sixty species occurring about Rock Island, describing a number as new; a list of dragon-flies taken at Kensington, Ill., by Mr. Jas. E. McDade ('92); and the treatment of the *Odonata* in Mr. H. Garman's "Animals of the Waters of the Mississippi Bottoms near Quincy, Ill." ('90). Eight nymphs are listed in the latter paper. The original specimens have been examined and determined as follows: His "4" is *Gomphus externus*; "8, *Epiæschna heros*" is *Nasiæschna pentacantha* of this paper; "9" is *Tramea lacerata*; "10", *Epicordulia princeps*; and "11", *Perithemis domitia*. "12" is immature and not positively determined as yet. The others are correctly identified by him.

LIFE HISTORY.

Dragon-flies hibernate commonly as nymphs, less commonly in the egg stage, and in one species as imago. Nymphs of the *Anisoptera* mostly transform to the imago in the early part of the season, especially from the latter part of May to the first of July in our latitude, the imagos scattering and becoming reduced in numbers by midsummer. Some species, particularly those of the *Gomphidæ*, have a very short period of emergence, large numbers transforming within a few days. *Anax*, and perhaps some species of *Æschna*, has apparently two broods in a year. The adults appear very early in the season, and the young nymphs, feeding voraciously and actively, grow rapidly, and have been known to produce imagos before the close of the same season. *Tramea* also seems to be two-brooded, emerging numerously both in spring and fall. On the other hand, the nymphs of the *Gomphidæ* probably require more than a year in which to mature, emerging in the second or third season after hatching. The one-year life cycle is, however, the rule among the *Libellulidæ*, which contains most of our commoner *Anisoptera*, the eggs laid during midsummer hatching in late summer, and the nymphs maturing in time for the general emergence the following season. In late August there is a surprising number of very small nymphs,—tiny spider-like youngsters,—and even in September and October the preponderance of young nymphs is still manifest. As the period of maximum emergence of their species approaches, usually in early summer, they mostly attain full size, and are at this time most readily seen and captured and apparently more abundant than in the fall, when they were small and easily overlooked. With regard to the *Zygoptera*, it is highly probable that there are a number of broods in a season, the processes of transformation and oviposition beginning as soon as the weather permits and continuing industriously to the close of the season.

In the species whose life cycle is apparently more than a year the nymphs are of two or three distinct sizes, the largest presumably being of the next brood to emerge. In species whose life cycle is completed within a year, the nymphs are fairly uniform in size, but there is, nevertheless, a sufficient extent of variation to cause a considerable number of straggling emergences during the season; and it therefore follows that, in general, nymphs of nearly all species of *Odonata* may be found throughout the entire season. Because of this fact it has not seemed worth while to give dates of the occurrence of nymphs. The accessible data concerning the imago period, on the other hand, is very fully given, thus indicating the limits of the nymphal period also.

Like many other immature aquatic forms, the ground color of the nymphs darkens greatly up to the close of each molting period. Immediately after molting they are very light greenish or grayish and their characteristic color-pattern is beautifully distinct, but they gradually darken and the coloration becomes more and more obscure until, as the time for the next molt approaches, it is almost entirely lost and the nymph becomes uniformly dark and dingy.

When grown, the nymphs seek the shore or some floating object and clamber up a little way on standing vegetation, logs, tree-trunks, sticks, bridge-piling, the sides of boats, or the like, and, fixing their feet firmly, proceed to transform to the imago stage. Transformation mostly takes place very early in the day and is largely over with by nine o'clock, although scattering emergences may occur at any time. The usual process will be fully described under *Tramea lacerata*. The adults scatter considerably, but a large number remain in the original vicinity, busily ovipositing for a new brood of nymphs. A short but undetermined period elapses before egg-laying begins.

Oviposition is of two kinds, endophytic and exophytic. That of the groups with more slender nymphs, *Zygoptera* and *Æschnidæ*, is endophytic. They have an elongated egg, which is inserted by means of an ovipositor into living or dead vegetable substances, either resting in water or at least moist. The female immerses the tip of her abdomen or enters the water completely. She usually succeeds in escaping safely from it, but is sometimes rescued by the male (Todd, '85). The oviposition of the groups with broader nymphs, *Gomphidæ*, *Cordulegasteridæ*, and *Libellulidæ*, is exophytic. Their eggs are shorter and oval, and are extruded in a gelatinous matrix. The female dips her abdomen in the water, usually during flight, releasing at each dip a number of eggs, which sink to the bottom or lodge on the vegetation. Sometimes, when too hotly pursued by males, she will alight on water moss or driftwood and cast her eggs loose there. In the case of *Leucorhinia* this is apparently the usual method of oviposition. In some cases the eggs may be deposited on moist mud (*Diplax*, *Somatochlora*) or affixed to the bank or to water plants. The female of *Celithemis* is usually accompanied by the male, who helps her to escape when menaced by the open mouth of a hungry fish. Several hundred eggs are often laid by a single female.

The period of incubation varies with the season and also independently of it. In midsummer, eggs of some species hatch in from six to ten days, while others, laid in autumn, do not hatch until the following spring. In the same lot of eggs the period of incubation may vary, even in midsummer, from a week to more than a month.

The apparent abundance of nymph and imago is far from corresponding, the difference in some cases being quite surprising. Of the nymph of *Celithemis eponina*, we have secured only a few examples; yet the imago is a familiar sight everywhere about the Station. The species of *Sympetrum* are common and familiar dragon-flies; but we have obtained only a few of the nymphs. This genus probably breeds in swampy places, where the vegetation is so dense, the water so shallow, and the mud so deep as to make collecting very difficult. On the other hand, *Epicordulia princeps* is abundant and widely distributed as a nymph, but the imago is not commonly taken. Nymphs of *Macromia*, *Progomphus*, and *Hagenius* are not at all rare in streams; the imagos are considered very rare or almost unobtainable. In the *Gomphidæ* are numerous similar examples. This discrepancy may be due either to the swift, high, or prolonged flight of the imago, or to the shortness of its life; but in some cases it is almost inconceivable how the imagos can vanish so completely as they do.

Walsh ('63, p. 239) makes some remarkable statements as to the relative proportion of the sexes in *Gomphus*. In some species he found four males to every female, and in another two or three females to each male, and he asserts that this is the case in freshly emerged material. Mr. Needham is of the opinion that in nymphs generally there is no notable excess of either sex, but that in the imago an excess of males may occur because of the destruction of the females by fishes in species the females of which oviposit unattended by the males. It is probable that Walsh's statements were based on insufficient data.

The imagos usually keep near their nymphal home. The *Zygoptera* both fly and alight low, usually over water; the stronger *Æschnidæ* fly high and scatter more; while the other imagos are diversified in these respects, many species being taken both along streams and along borders of roads and fields at some distance from water.

All dragon-flies are most active in hot, quiet, sunshiny weather. They cease flying by sunset, except a few of the *Æschnidæ*, which may be seen in hot pursuit of small *Diptera* during the evening twilight.

The history of the order as a whole in the vicinity of Havana, while under our observation, is interesting but somewhat puzzling. In 1894 there was a great abundance of individuals, in all stages. In 1895 the season's collecting opened up well. Extremely low water prevailed, however, and in June the shallow waters became greatly heated by the sun, their recorded temperatures reaching as high as 96° Fahr. On one occasion, when the heat of the water was especially noticeable, a number of dead nymphs were found floating about, along the west shore of Quiver Lake. Not many nymphs were seen in the usual situations at the close of this season, and from that time on through 1896, they were reduced to insignificant numbers. The low water of 1895, however, encouraged the development of species liking swampy situations, and there was consequently in 1896 an excessive development of *Pachydiplax longipennis* and species of *Sympetrum*. A slight rise took place in the spring of 1896 and the river became very foul. At the close of the year the drouth was broken, with a more extensive rise of the river, and the season of 1897 showed an increase in the number of nymphs. The winter and spring following brought much high water in the river, but the nymphs did not greatly increase in numbers.

Kellicott has noted ('97a ; 97, p. 69) that in Ohio the warm rainy weather of April, 1896, following the drouth of 1894–95, caused emergence earlier than usual, and the number appearing did not seem noticeably reduced by the drouth.

WATERS FROM WHICH COLLECTIONS WERE MADE.

The nymphs in the State Laboratory collections were derived from a large variety of waters: from the broad Mississippi and Ohio, slow and majestic, but flowing more hurriedly at a few points—as at Rock Island and Golconda; from the bottom-land lakes of these streams, muddy and without much vegetation; from the lower course of the Illinois, broad, shallow, slow-flowing, with the bottoms more of mud than sand, the shores often margined with water vegetation; from the broad and shallow bottom-land lakes along this river, some slightly deeper than others, but abounding in floating vegetation,—as Quiver, Thompson's, and Dogfish lakes near Havana,—some shallower and swampy, as the great expanse of Flag Lake, and others changeable and temporary in character, as Phelps Lake; from the smaller affluents of the rivers, usually flowing with an occasional descent over beds of mud, sand, and gravel; from the small lakes which rest in the ancient glacial hollows to the west of Lake Michigan in Illinois and Wisconsin, quite deep in places, permanent in character, usually well supplied with aquatic life of all kinds; from the shallow ponds of similar origin scattered over the state, of all degrees of permanency; and, lastly, from the rapid flowing rocky streams of Yellowstone Park. These waters present a great variety of situations, each with its characteristic forms, and it is interesting to note how each of these situations is occupied by a definite series of nymphs, in accordance with its particular character.

NYMPHS INHABITING THE VARIOUS SITUATIONS.

The nymphs may be roughly grouped in three divisions, according to the kind of situation preferred by them. The first includes groups having the endophytic habit of oviposition, *Zygoptera* and *Æschnidæ*, as well as a few of the more agile members of the other families, such as *Hagenius* among the *Gomphidæ*, and *Mesothemis*, *Celithemis*, and *Tramea* among the *Libellulidæ*. The lighter-colored of these clamber among submerged vegetation, while the dark-colored forms (*Calopteryg-*

idæ, *Hagenius*, and the lower *Æschnidæ*) inhabit driftwood and submerged roots and brush. The second division comprises the heavier nymphs of the *Libellulidæ*, which usually sprawl upon the bottom or climb over fallen rubbish; and the third consists of the remaining *Gomphidæ*, the *Cordulegasteridæ*, and, to some extent, *Libellula* and its relatives, which occupy the mud or sand of the bottom.

The species inhabiting submerged vegetation, constituting the first group, are of course most abundant in the quiet waters of slow streams, lakes, and ponds, where such growths have an opportunity to develop freely. The large and active nymphs of *Tramea* and *Pantala* appear to prefer the more exposed shores of large lakes and rivers. *Mesothemis collocata* is adapted for life in the high temperatures of water from the hot springs of the west. The *Agrionidæ* and *Anax* are common everywhere in bodies of water with vegetation, from the smallest pool to considerable lakes. The other *Æschnidæ* climb on dead sticks and driftwood where there is little vegetation and food is not abundant, as in the bottom-land lakes and sloughs of the larger streams with good current, or (*Boyeria*) in the deeper holes along small streams, where projecting roots catch the floating driftwood. *Hagenius* also lives amongst driftwood and dead leaves in streams. The *Calopterygidæ* thrive in little rapid-flowing sandy rivulets like White Oak Run and Quiver Creek at Havana.

In the second group, those living on the bottom, depth and current are important in determining the particular species likely to be found. *Epicordulia* likes the deeper waters, as of the Illinois River itself or its deeper lakes, or the bottoms of the small lakes of northeastern Illinois, finding there the molluscan diet it enjoys. On the other hand *Sympetrum* and *Leucorhinia* inhabit marshes and reedy shores, as well as shallow weedy ponds and wet meadows. The "Pumpkin Patch" at Havana, the shores of Fourth Lake in northeastern Illinois, and the swampy spots of the upland prairie, are situations of this character. *Pachydiplax* appears to like the deeper swamps and ponds, such as Flag Lake at Havana. In the smaller streams, where the current is often rapid, such as the Mackinaw, the upper Sangamon, and the Little Wabash rivers, a number of very interesting forms find their home, especially the *Synthemiinæ*, *Somatochlora* and other *Corduliinæ*, and the species related to *Libellula*.

Of the third group, which live *in* the mud or sand of the bottom, there may be found in the streams just enumerated other interesting material, especially *Cordulegaster*, *Progomphus* and *Gomphus spiniceps*. In this group the most definite selection of situations prevails. Where rapid currents flow over rocky beds, as in the Mississippi at Rock Island, in the Mackinaw at the "Dells," and in the streams of Yellowstone Park, is the chosen home of *Diastatomma* (*Ophiogomphus*). Where slow currents and a muddy bottom occur, as in many prairie streams and ditches, *Plathemis* and *Libellula*, covered with dirt, trail over the mud along the shores leaving a well-marked track, or lie concealed amongst fallen trash, the dorsally projecting eyes of *Plathemis* enabling it to remain hidden and yet keep a sharp lookout. The nymphs of the *Cordulegasteridæ* conceal themselves in the sand beneath the eddies of streams or under the alluvial deposit in marshes, but do not burrow. Each scratches a hole for itself, and descends into it like a chicken into a dust bath, and, like the chicken, kicks the sand over its back, and does not rest until almost hidden, only the tops of its eyes, the tip of its treacherous labium, and the respiratory aperture at the end of its abdomen reaching the surface. The burrowers of the order are the members of the large and as a whole abundant genus *Gomphus*. These burrow shallowly along in the midst of abundant life, with the tip of the abdomen turned up for respiration. Some are lake or pond species, such as *graslinellus* and *pallidus*. The former is common in prairie ponds and in the small lakes near Chicago ; the latter in similar localities, and in open lakes near Havana, such as Matanzas and Clear lakes. Others choose the larger rivers, being most numerous in quiet corners where fine rubbish and animal life accumulate. Such are *notatus* and *fraternus*; while *spiniceps* prefers swifter flowing waters like Quiver Creek at Havana, or the upper Illinois River at Ottawa.

In some species with which we have had but a limited experience further study may show a wider range of normal situations than that here assigned, but the preceding generalizations should have a value to the student and collector, and may serve as a basis for a more exact account in future.

The Illinois waters which afford the widest range of situations and are most prolific in variety of dragon-fly nymphs are the small lakes of Lake county. Their shores are sometimes exposed, wave-washed, and rocky, and the life here found is remarkably like that of swift running water. Again, they are broad and marshy, and afford a home for *Sympetrum*. Out from shore we may find shallow waters with mats of aquatic vegetation, bare sandy surfaces, or, at great depths, a bottom of soft mud. As to numerical abundance I have seen nothing in Illinois that can compare with the multitudes of dragon-flies that issue in favorable seasons from the broad shallow lakes along the Illinois River.

ODONATA OF THE VARIOUS WATERS IN ILLINOIS.

Taking the subject from a different point of view, we may briefly summarize the odonate life of the Illinois waters as follows.

In the larger rivers, down to the size of the Mackinaw, in places where the water flows with considerable current over a rocky bottom, *Diastatomma* may be looked for; where mud or sand bottom and quieter waters prevail, *Epicordulia* and some species of *Gomphus* may be found. Other species of *Gomphus* occur in the bare muddy or sandy bottoms of the sloughs and bottom-land lakes. In tree-shaded waters, where driftwood and branches have gathered, or along muddy margins, especially amongst exposed roots, the lower *Æschnidæ* may be looked for. In bottom-land lakes where vegetation is abundant, one may find *Anax*, *Agrionidæ*, *Mesothemis*, *Celithemis*, *Tramea*, and *Pantala* amongst the vegetation, the latter two especially on more exposed shores; and *Tetragoneuria, Libellula, Epicordulia*, and *Leucorhinia* on the bottom underneath. If the situation is inclined to be marshy, *Pachydiplax, Perithemis*, and *Celithemis* will be scattered over the bottom; and the shallowest and most temporary waters or wet lands are the especial home of *Sympetrum*.

In the smaller and quicker flowing streams, like the upper Mackinaw and Sangamon, quite a different series occurs: *Hagenius*, clinging to stones and driftwood and amongst dead leaves; *Boyeria* and other dark *Æschnidæ* on submerged branches, roots, and sticks; *Cordulegaster* and the long-legged *Macromia* hidden at the bottom in sheltered eddies; *Somatochlora*; and, finally, *Progomphus, Dromogomphus*, and certain species of *Gomphus* burrowing in the sandy bottom. In the prairie ponds and slow streams and ditches, *Anax, Agrionidæ*, and *Mesothemis* and other *Libellulidæ* occur amongst vegetation, and *Sympetrum* in shallower parts, while *Libellula* and *Plathemis* will be found where there is more mud and less vegetation, as in ditches and tile ponds, resting at the lower ends of well-defined tracks. In streams of rapid flow, but not especially rocky or shaded, the *Calopterygidæ* are most likely to be found, the imagos fluttering along the banks.

In the small northern glacial lakes of Illinois, a remarkably varied odonate life can be found. Among the vegetation and along shore, *Agrionidæ, Anax, Tramea, Leucorhinia, Libellula, Tetragoneuria, Epicordulia*, and *Basiæschna* may be taken. *Sympetrum* has been fonnd along the broader, shallow, reedy margins. On the sparsely grown flats, in somewhat deeper water, *Gomphus graslinellus, spicatus*, and *pallidus* occur, and, especially where it is clayey, the *Synthemiinæ—Didymops* and *Macromia*—have been taken. On the other hand, *Mesothemis, Pachydiplax*, and *Perithemis*, elsewhere abundant, do not appear in our collections from these waters.

As to the imagos, they are most likely to be found along the shores of waters inhabited by their nymphs, though many forms, such as some *Agrionidæ*, most of the *Æschnidæ*, *Libellula*, *Sympetrum*, and *Mesothemis* scatter widely inland. *Sympetrum* will be seen about fields and lawns, and the *Æschnidæ* in the vicinity of houses.

FOOD RELATIONS.

The nymphs are all predatory in habit. Most species remain in ambush, aided by coverings of sand, mud, silt, and algal growths, and by their own protective coloring, until their prey wanders within reach. *Anax junius* and a few others choose their prey. All capture it with a marvellously sudden extension of the labium, bringing it into the grasp of the formidable lateral labial lobes. Almost all kinds of small aquatic animals appear on the bill of fare of the group as a whole. The *Agrionidæ* have a seeming preference for *Entomostraca* and May-fly nymphs. The vegetation-inhabiting species have the most varied diet, including especially back-swimmers (*Notonecta*) and water-boatmen (*Corisa*), small crustaceans, such as *Asellus* and *Allorchestes*, thin-shelled mollusks, like *Physa*, coleopterous and dipterous larvæ, and even the younger or weaker members of their own order. *Anax* takes even the thicker-shelled univalves, like *Amnicola*. The deep-water *Epicordulia* feeds principally on small mollusks, such as *Amnicola* and *Physa*, as well as on other life of the bottom. The *Æschnidæ*, especially *Anax*, are most omnivorous creatures. The larger odonate nymphs eat very young fish, and in some cases appear to have caused a sweeping destruction of large numbers of them.

On the other hand, the nymphs are apparently eaten principally by fishes and by one another; hence their need for hiding places in mud and sand or among matted vegetation. the course of Professor Forbes's studies of the food of ('88a, pp. 485, 524) he found odonate nymphs most a (twenty-five per cent.) in the food of the grass pic *vermiculatus*), and forming ten to thirteen per cent of the crappie (*Pomoxis annularis*), the pirate per *sayanus*), and the common perch (*Perca flavescens*). The latter is an abundant species in the small northeastern lakes of the state.

Belostoma, *Ranatra*, *Notonecta*, and the like, according to Mrs. Aaron (Lamborn, '90, p. 50), prey on young nymphs, and she also mentions a small red mite and a minute dipteron as parasitic on the eggs of *Odonata*. Mr. Needham ('98) has recorded the finding of numbers of nymphs in the stomachs of herons, and he once found the intestine of a nymph parasitized by very large *Gregarinidæ* fully 1 mm. long.

Emerging imagos while limp and pale are the easy prey of even their weakest enemies, and great decimation takes place among them at this time. Ants, spiders, robber-flies, frogs, and birds eat many of them.

The full-fledged dragon-flies devour the small insect life of the air in vast quantities, especially gnats and mosquitoes, most of which probably developed in the waters previously inhabited by the dragon-fly nymphs. These seem to make little or no attack upon the larval stage of the gnats and mosquitoes, as if reserving them for their imago life. Dr. Lamborn, by offers of prizes, started an investigation to determine the practicability of artificially utilizing dragon-flies for the destruction of mosquitoes and flies; but the evidence published (Lamborn '90) indicates that these pests may be dealt with more effectively by direct measures, since the the attack of dragon-flies could not easily be controlled and directed, although in their own way and time they doubtless reduce the numbers of the pests very considerably.

Mature dragon-flies do not usually suffer seriously from natural enemies. They are frequently found infested by small ed mites. Some birds, such as the king-bird, possess sufficient tness to capture them as regular articles of their food. It to be the weaker forms, such as *Agrion*, that suffer thus xtensively (Needham '98). The females while oviposit- netimes captured by fishes.

COLLECTING AND REARING.

sideration of the statements and suggestions in this article as to the various haunts and seasons of the different nymphs and imagos, will give one a pretty good idea what species may be found in the waters near at hand. Nymphs of species inhabiting vegetation may be secured with a dip-net or rake. The dip-net is quite an essential article. The kind most in use at the Biological Station has a D-shaped ring made of heavy wire about a quarter of an inch thick, the two ends joined at the middle of the curve, the last three or four inches of the ends bent outward, welded together, and inserted into the handle, as in a hoe or rake. The net is of bobbinet, with a mesh about like that of mosquito-netting, or finer. It is cut about four or five inches larger than the ring all around and gathered up to form a shallow bag without seams. This bag is edged with a band of strong cloth slightly larger than the ring and then sewed by this edge to the ring with good fine twine.

The nymphs sprawling on the bottom are secured by vigorous movements of the net close to the bottom, the currents produced sweeping them into the net. The burrowers are taken by scraping the surface layer of the bottom into the net or into a sieve, and then sifting or washing out the mud or sand, thus leaving only the nymphs and coarser rubbish. In deep-water collecting a dredge must be used. The swamp-inhabiting nymphs are easiest secured in the early morning as they come up for transformation. A pair of rubber boots is often very useful.

The smaller imagos are easily taken, but the larger ones will often stimulate the activity and alertness of the collector to a considerable degree. If the air net be of light, strong, clean material, like bolting cloth, not too fine-meshed, the possibilities of capture will be greatly increased. The best time to collect dragon-flies is on cool, cloudy, or windy days. On one memorable occasion on the shore of Cedar Lake, just after a light rain, a heavier storm impending, the dragon-flies were found resting on weeds among the trees on the sloping shore, so sluggish that they were picked up by hand in large numbers.

Eggs of the families which oviposit free in the water are easily secured by capturing the ovipositing female and touching her abdomen repeatedly to some water in a small dish, holding her only by the fore wings back to back, while those which oviposit in plants or soft wood may be watched and the stems or wood examined afterward. Experiments indicate that imagos will not voluntarily oviposit while in captivity.

Formalin is not a good preservative for any of the larger insects. The best preservative is strong alcohol carefully heated in a water-bath. The hot alcohol penetrates more rapidly than cold, arresting internal decomposition, and thus retains the beautiful but fugitive colors of the imago. The usual process of sterilizing and fixing the tissues by heating in water in a test-tube to the boiling point before transferring to alcohol is eminently satisfactory for aquatic forms as a rule, but in the *Anisoptera* this expands the air in the rectal gill-chamber and distorts the abdomen somewhat, while in the *Agrionidæ*, as in the *Ephemeridæ*, the flat external gill-plates are badly injured by inflation and gumming together. The slender and brittle abdomen of the imago breaks off very easily, and a bristle or fine non-corrosive wire should therefore be passed lengthwise through the body as far as the tip of the abdomen, but not so far as to project among the terminal appendages. A couple of insect pins, inserted lengthwise, one at each end of the body, are used by some. Specimens for the cabinet may be spread like *Lepidoptera*. For shipment or exchange they are usually inclosed in soft papers folded diagonally.

Rearing the nymphs is not usually difficult. They need plenty of clean water, something to crawl out on, and room to transform in. A pail or tub covered with mosquito-netting answers nicely. It must get plenty of sunshine, but not so much as to overheat the water. If the breeding-cage can be immersed in the water of the stream or lake where the nymphs live, success is almost assured. They may be fed bits of fresh meat or fish, insect larvæ, flies, or the smaller aquatic *Hemiptera*. If meat is fed, it must be kept in motion before them, as they will refuse anything that does not seem to be alive. Mr. Needham has reared *Gomphus* nymphs, which do not feed so readily as others, on earthworms. As they are more or less ready to eat each other, they must not be crowded. *Anax* is especially unprincipled in this respect, and *Gomphus* is fond of libellulids. Recently emerged living imagos should be transferred, each with its cast skin (exuvia), to dry boxes for a short time, till their surfaces and wings gain firmness and their colors are matured. The imago and its exuvia should always be kept together.

If the observer is able to keep a close watch on waters where nymphs occur, about the time of their emergence, and does not mind an early morning visit before breakfast for some larger species, he will be amply rewarded for his enterprise some day by discovering a large number in the midst of the processes of transformation, often of some species rarely taken on the wing and very desirable for exchange purposes.

In all cases and by all means full notes of habits, food, flight, manner of oviposition, and the like, should be carefully recorded.

CHARACTERS USED IN CLASSIFICATION.

The Nymph.—The most important recognition characters in the head of the nymph are derived from the labium, the antennæ, and the form and sculpture of the upper surface. The latter is useful in the separation of species and genera. If the tip of the labium, or mask, which covers the mouth like a hand, be grasped and drawn forward, the labium will straighten out, and may be kept from springing back again. Like the arm, it consists of two joints, the *submentum* and *mentum*, the end of the latter broad, bearing a pair of broad flattened appendages, the *lateral lobes* of the labium. The mentum itself is called the *median lobe*. Each of the lateral lobes bears outwardly, near its tip, a strong *movable hook*. In the *Petaluridæ*, *Æschnidæ*, and *Gomphidæ* the labium is flat, and applied to the lower surface of the head; the lateral lobes are somewhat mandible-like, bearing a row of fine short teeth on the terminal edge in the *Petaluridæ*, and on the inner edge in the other two families mentioned. In the *Cordulegasteridæ* and *Libellulidæ* the labium is spoon-shaped, covering the face, the lobes broad and subtriangular, fitting closely against the median lobe and to each other. The teeth of the opposed terminal margins are, in the former family, large, acute, and interlocking, but in the latter they are rounded crenations, at most not higher than broad. These are tipped with short hairs, however, which when wet make them appear pointed. On the inner surface of each lateral lobe may be a row of several conspicuous setæ, the *lateral setæ*, and a similar row on each side of the middle of the median lobe — the *mental setæ*. The antennæ are usually small and cylindrical, 6- or 7-jointed, but are broad and flattened in the *Petaluridæ* and *Gomphidæ*, and only 4-jointed in the latter family.

The thorax and its appendages are not extensively used in the classification of the nymph. On each side of the prothorax, in the *Æschnidæ*, are a pair of small tubercles, the *supracoxal processes*, best viewed in profile from above. They are fairly constant in form for each species. The *tarsal joints* are usually three in number, but in the *Gomphidæ* there are only two joints in the anterior and middle tarsi. The suture between the first two tarsal joints is oblique, making the basal joint much shorter above than below. The comparative length of these two joints, measured on the dorsal line, is a useful distinction in the *Libellulidæ*. As the suture between them is usually marked in darker color above, it is easily located. The *wing-pads* vary in size with the age of the nymph, being at first entirely wanting. In the adult nymph four or five abdominal segments usually remain exposed behind them.

The two main groups of dragon-flies are quite unlike in the terminal appendages of the nymphal abdomen. In *Zygoptera* it ends in three large leaf-like gills, while in the *Anisoptera* the last segment—the tenth abdominal—bears five small tapering appendages, which converge and form a valve closing the rectal opening. The middle one above is the *superior appendage*, the lower pair are the *inferior appendages*, and on each side of the superior appendage, above the inferiors, are the *lateral append-*

ages. These are of considerable value in classification. The posterior lateral angles of some of the abdominal segments bear the *lateral spines*, sometimes very small but distinct, as in *Libellula*, rarely entirely wanting as in *Mesothemis*. There are also spines or teeth along the median line of the abdomen above, varying greatly in number and form, collectively known as the *dorsal hooks*. These and the lateral spines are extremely useful in separating species and subordinate groups. The dorsal hooks may be viewed in profile from one side, springing the abdomen down away from the wing-pads; but when they are represented merely by teeth projecting backward on the hind margin and not elevated above the general level, as in *Gomphus*, they are of course best viewed from above. The dorsal hooks are always absent on the first one or two abdominal segments, beneath the wing-pads, and as their appearance on the posterior abdominal segments is of especial importance, it has usually been necessary to refer only to those on the exposed segments of the abdomen.

The characters given can usually be applied to nymphs of any age except the very young ones. In case more or less of an antenna or leg is broken off during the life of a nymph, it may be imperfectly replaced, usually with one joint less than before and the relative size of the joints abnormal.

A slight elevation on the under side of the abdomen, if near its base, indicates the male nymph; if towards its tip, the female. This may be easily observed in the common nymphs of *Anax junius*. In the *Æschnidæ*, the male nymph is also distinguished by what seems to be a small median scale resting on the basal part of the superior appendage.

The Imago.—It is unnecessary here to describe in detail the external anatomy of the adult, but for the understanding of the keys a brief statement of the wing venation in the *Anisoptera* is desirable. The fore and hind wings have essentially the same structure, modified to suit the difference in outline especially at the anal angle. The large number of adventitious minor longitudinal veins and cross-veins and cells are extremely variable and unreliable, but the relative positions of the principal veins and cross-veins are constant, and useful as distinguishing characters.

On the front margin of the wing, near its apex, is a conspicuous opaque cell, the *stigma*. The strong vein which runs along its inner side, extending the whole length of the wing, is the *radius*. This is intersected about midway of the wing by a vein (the *nodal sector*) which starts at the margin in a notch of the costa called the *nodus*. Between the costal margin and the basal half of the radius is the *subcosta*, extending as far as the nodal sector. On either side of the subcosta is a row of cells separated by short cross-veins, the *antecubital* cells and cross-veins. On either side of the radius, between the nodal sector and the apex of the wing, are similarly the *postcubital* cells and cross-veins. Behind the base of the radius is a large cell, the *basilar space*, bounded posteriorly by the *cubitus* and outwardly by a conspicuous cross-vein, the *arculus*. Near the middle of the arculus arise, jointly or separately, two longitudinal veins, the upper and lower sectors of the arculus. The upper sector is the main stem of the median vein, the lower is its posterior branch. The bases of the media and the radius form one vein as far as the arculus. The anterior branch of the upper sector is the *principal sector*. It also is intersected by the nodal sector. The next apparent branch of the upper sector, running parallel to and just behind the nodal sector, is really a branch of the radius, and should be called the *radial sector*. Two adventitious longitudinal veins, formed by the stringing together of cross-veins, are the *apical sector*, just behind the tip of the radius, and the *supplementary sector*, behind the radial sector. A little beyond the arculus, the cubitus leads to the inner angle of a conspicuous triangular cell, or group of cells, known as the *triangle*. The elongate cell (sometimes subdivided by minor cross-veins) above the triangle is the *supratriangular space*. The next and last principal longitudinal vein, behind the cubitus, is the *anal vein*. Of the numerous apparent branches that it sends back toward the hind margin of the wing, three principal ones may usually be observed in the hind wing. The *first branch* of the anal vein starts near or at the posterior corner of the triangle, and the other two *branches* are between that and the base of the wing. The first and second branches, in the hind wing, are connected by a strong cross-vein, thus inclosing the *anal loop*. This and the triangle are particularly useful in classification.

The male imago may be recognized by the complex structure on the under side of the abdomen near its base, forming a conspicuous projection. In the families treated in this article the male has the anal angle of the hind wing sharply rectangular, not rounded as in the female. In the *Libellulidæ* it may sometimes be known by the appearance of milky spots on the wings, in addition to the usual black spots, or by a difference in wing-markings. The terminal appendages of the male are unlike those of the female, being usually larger and more irregularly formed.

KEY TO THE NORTH AMERICAN FAMILIES OF ODONATA.

Nymphs.

aa. Last abdominal segment bearing three leaf-like tracheal gills. (Suborder *Zygoptera.*)
  bb. Basal segment of the antennæ extremely elongate. *Calopterygidæ.*
  b. Basal segment of the antennæ short, subrotund. *Agrionidæ.*
a. Last abdominal segment terminating in five converging, short, spine-like appendages. (Suborder *Anisoptera.*)
  cc. Labium flat, not concealing the face, with mandible-like or oblong lateral lobes.
    dd. Antennæ 6- or 7-jointed, superior appendage usually notched at apex.
      ee. Lateral labial lobes toothed on terminal margin, antennæ broad, flattened. *Petaluridæ.*
      e. Lateral labial lobes toothed only on the inner edge, antennæ slender. *Æschnidæ.*

d. Antennæ 4-jointed, broad and flat, superior appendage not notched at apex. *Gomphidæ.*

e. Labium spoon-shaped, covering most of the face, with subtriangular close-fitting lobes.

ff. Teeth on the opposed edges of the lateral labial lobes acute, very large and irregular, interlocking; two stout teeth with a cleft between them at the apex of the median lobe. *Cordulegasteridæ.*

f. Opposed edges of the lateral labial lobes crenate or with rounded teeth; at most but a single median tooth on median lobe. *Libellulidæ.*

Imagos.

aa. Front and hind wings similar, or nearly so, in outline, usually elevated when at rest; males with two inferior abdominal appendages (*Zygoptera*). Head transversely elongated, eyes widely separated. Females with genital valves.

bb. Not less than five antecubital cross-veins in the anterior series. *Calopterygidæ.*

b. Not more than three antecubitals, usually two. *Agrionidæ.*

a. Front and hind wings dissimilar, hind wings usually much broader at the base, horizontal when at rest; males with one inferior appendage, or none. (*Anisoptera.*)

cc. Triangles of front and hind wings of similar shape; antecubitals of first and second series not coincident, except the first and another thick one; second series of postcubitals complete.

dd. Abdomen with lateral carinæ; female with genital valves; head globose, eyes meeting above along the middle line of the head. *Æschnidæ.*

d. Abdomen without lateral carinæ.

ff. Eyes distinctly separated, head transversely elongated.

gg. Median labial lobe bifid; female with genital valves. *Petaluridæ.*

g. Median labial lobe entire; female without genital valves. *Gomphidæ.*

f. Eyes but little separated, or meeting at a single point dorsally; median labial lobe bifid. *Cordulegasteridæ.*

e. Triangle of front wings with its long axis at right angles to the length of the wing; triangle of hind wings with its long axis coincident with that of the wing; antecubitals of the first and second series mostly coincident; second series of postcubitals incomplete at inner end. *Libellulidæ*

FAMILY PETALURIDÆ.

About all we know of the biology of this interesting family is contained in two late papers by Williamson ('00a, '01) on the recently discovered nymph and habits of the adult of our single North American species, *Tachopteryx thoreyi.* This is eastern and southern in its range, and has been found in an adjoining state, Kentucky. While the adult has usually been grouped with the *Gomphidæ*, the nymph is nearest to the *Æschnidæ*, although it approaches nearer to both the *Cordulegasteridæ* and *Gomphidæ* than any other known form, possessing a remarkably synthetic combination of characters. The adults were observed, according to Williamson, ovipositing in boggy ground along a small hill-stream, where a single nymph was found emerging.

FAMILY ÆSCHNIDÆ.

The elongate nymphs of this family have a flat labium very much like that of the *Gomphidæ*, consisting of a long mentum bearing at its extremity a pair of curved appendages (the lateral lobes) like the mandibles of a beetle, more or less toothed on the inner edge and armed outwardly, toward the apex, with a strong movable hook. The apical tooth of these appendages is always present, not terminal and curved inward as in *Gomphidæ*, but rather on the inner side of the squarely truncate or obtusely rounded apex, and directed inwardly. The antennæ are six- or seven-jointed, slender, inconspicuous, and easily broken, quite unlike the heavy, thick, four-jointed antennæ of the *Gomphidæ*. Dorsal hooks are usually absent. The lateral spines are small, but their number is of value in generic separation. The head is widest across the eyes, its hind margin more or less concave. The structure of the hind angles furnishes reliable systematic characters. There is on either side of the prothorax above the front coxa a pair of variously shaped processes, designated in the descriptions which follow as the supracoxal processes. The abdomen is unusually slender and pliant at the base, thence indented as far as the beginning of the very large rectal respiratory chamber. The appendages are rather long and slender, resembling those of the *Cordulegasteridæ*, while the *Gomphidæ* resemble the *Libellulidæ* in the form of these appendages. In the young nymphs the laterals are relatively much shorter than in the full-grown ones, and the superior somewhat so in comparison with the inferiors. This character is therefore applicable only to nymphs about full grown. In the male there is apparently an overlapping scale at the base of the superior appendage.

Like their imagos, these nymphs are among the largest and most powerful in the order. While the *Gomphidæ* burrow and crawl on the bottom, these are great climbers on submerged driftwood, branches, roots, and vegetation of all sorts.

The two extremes of this family are curiously unlike in aspect. Nymphs of the lower genera—which are placed first in the arrangement of the species which follows—climb upon dead sticks and driftwood, and have developed a protective resemblance to these objects. They are rough, blackish, and inactive creatures, seen but rarely. Those of the last genus (*Anax*) clamber actively and abundantly among water vegetation, and are bright green or brownish in color, preying voraciously on the smaller life they find there. Nymphs of this type have paler markings between and behind the eyes and along the sides of the thorax superiorly, three pale rings on each femur and tibia, a pale mid-dorsal abdominal line, and the apical margins and hind angles of abdominal segments and the tips of abdominal appendages also pale.

The imagos are like the *Libellulidæ* in the great development of the eyes, which touch for some distance along the middle of the head, and in the presence of a roughened carina on the sides of the abdominal segments. The nearness of the lowest forms of this family and the *Libellulidæ* in wing venation and nymphal sculpture is evident; but the *Æschnidæ* as a whole are much nearer the primitive stock by reason of several characters, especially the structure of the labium and gizzard, the general form of the nymph, the form of the egg, and the manner of oviposition. The wing triangles are elongate lengthwise of the wing, as in the *Gomphidæ*, usually with several cross-veins; most of the antecubitals not coincident. The female is provided with an ovipositor, by means of which the elongate cylindrical eggs are inserted into various plants and substances in the water instead of being washed off by dipping the abdomen during flight as are the more or less oval eggs of the other *Anisoptera*. Even in the nymphs the developing ovipositor, on the eighth ventral abdominal segment, is well marked and recognizable in all but very young individuals. In the males the corresponding parts are more difficult to see, but this sex possesses a very evident scale-like piece overlying the base of the superior terminal appendage.

Mr. Needham has observed that the eggs are deposited in the stems of plants, in floating timbers, in piers, etc., at or very near the surface of the water, either above or below it, but always in moist tissue. He has floated pieces of decaying wood upon a pond as a means of obtaining æschnid eggs, and these proved very attractive to the ovipositing females.

The usefulness of the imagos, especially *Anax junius*, on account of the enormous quantities of pestiferous gnats and mosquitoes which they destroy, puts them among the particular friends of mankind.

KEY TO THE GENERA OF ÆSCHNIDÆ OF THE UNITED STATES.

Imagos.

AA. Upper part of arculus equal to or longer than its lower part, its upper sector arising near the lower sector and far distant from the median vein above; anal loop evidently 5–7-sided.

aa. Supplementary sector, just back of the usually forked radial (subnodal) sector, nearly straight and subparallel to it, separated from it by one or two (rarely three) rows of cells.

bb. Radial sector forked near the middle of its length; first anal vein leaving the border of the anal loop at its first angulation, border continued by a cross-vein which usually meets an apparent fork of the second anal; bottom of the loop accordingly 3-sided, the part formed by the first anal short, not longer than the remaining distance to the stem of the second anal.

cc. Anal loop sub-oval, much as in *Macromia,* wide but not deep, with a row of, usually, three cells bordering the anal vein, and a second irregular row along the bottom of the loop; triangles 3-celled (rarely 4-celled), inner side not receiving a cross-vein; supratriangular spaces with 2 or 3 cross-veins. I. *Nasiæschna.*

c. Anal loop deep, transversely oblong, with two (rarely three) vertical rows of cells, ending in two or three cells on the anal vein; anterior wings with discoidal triangles 5–7-celled, the inner side receiving a cross-vein, and the supratriangular space with 4 or 5 cross-veins. II. *Epiæschna.*

b. Radial sector not forked; bottom of anal loop normally 2-sided, one of these sides much longer than the other, formed by the base of the first anal, the other by a cross-vein connecting it with the stem of the second anal without an evident intervening fork.

dd. Basilar space (between the arculus and base of wing) crossed by 2–6 cross-veins; supratriangular space with cross-veins; male anal triangle 3–5-celled. III. *Boyeria.*

d. Basilar space free or with a single cross-vein.

ee. Supratriangular space with cross-veins; 2 or 3 rows of cells between the radial sector and the supplementary sector below it; male anal triangle 2-celled. IV. *Basiæschna.*

e. Supratriangular space free from cross-veins, one row of cells between the radial and supplementary sectors, male anal triangle 1- or 2-celled. *Gomphæschna.*

a. Radial sector forked or branched beyond its middle, supplementary sector diverging from it until three or more rows of cells intervene between the supplementary and the basal part of the posterior branch, beyond which the supplementary curves rather rapidly upward toward the branch; anal loop much as in *bb*, the first anal reaching more than half way (usually about two thirds) across the bottom of the loop, and connected with the second anal by a short oblique cross-vein, so that the anal loop appears 4-sided with a truncated inner hind angle; triangles of both wings 4- or 5-celled, inner side almost always receiving a cross-vein. V. *Æschna.*

A. Upper part of arculus much shorter than its lower part, its upper sector arising about midway between the lower sector and the median vein above; radial sector emitting a number of oblique branchlets on its posterior side, but not regularly forked; anal loop apparently 4-sided, the first anal extending nearly across the bottom of the loop, the connecting cross-vein very small and inconspicuous, usually meeting the second anal at about a right angle. VI. *Anax.*

Nymphs.

AA. Four or more pairs of lateral spines (sometimes an imperfect additional pair anterior to those here counted as the first pair); eyes occupying less than two thirds of the side margin of the head; scale of male on base of superior terminal appendage triangular, not emarginate at apex.

aa. Five pairs of fully-developed lateral spines.

bb. Antennæ 6-jointed, the last two segments of the other genera being represented by a single long joint sometimes divided by an indistinct suture in full-grown nymphs; eyes small, occupying only one third the lateral margin of the head; apex of superior appendage truncate or feebly emarginate.

cc. Abdomen carinate posteriorly, forming low dorsal hooks. I. *Nasiæschna.*

c. Abdomen without trace of dorsal hooks. II. *Epiæschna.*

b. Antennæ 7-jointed; eyes occupying about half the lateral head margin; apex of superior appendage deeply emarginate.

dd. Lateral labial lobes scarcely tapering, obtuse or subtruncate at tip, median lobe minutely toothed each side of cleft; superior appendage not less than five sixths as long as the inferiors. III. *Boyeria.*

d. Lateral labial lobes tapering to the incurved apical tooth, median lobe with a chitinous callosity on each side of cleft; superior appendage about three fifths as long as inferiors. IV. *Basiæschna.*

a. Four pairs of lateral spines, the anterior pair much smaller than the others but distinctly spiniform; apex of superior appendage broadly but not very deeply notched; median lobe of labium not toothed. V. *Æschna.*

A. Three pairs of lateral spines, all well-developed; eyes occupying at least two thirds of the side margin of the head; scale of male on base of superior appendage short and broad, emarginate at apex; apical emargination of superior appendage about as in *Æschna*. VI. *Anax*.

I. NASIÆSCHNA Selys.

The single species which follows has until recently remained in the genus *Æschna*, but it is very evidently generically distinct from all other American *Æschnidæ*, and has, in fact, been lately so recognized by Selys-Longchamps and Forster under the name of *Nasiæschna*.* It has been referred by Hagen ('77, p. 37) to *Brachytron* Evans, but it is intermediate between that and *Epiæschna* Hagen. Aside from secondary sexual characters, it is nearer the latter genus. The following characters sufficiently distinguish the imago from related genera:

Face concave; frons narrow, produced above into a shelf-like prominence, with a broad longitudinal superior furrow, and without "T" spot. Radial (subnodal) sector forked midway between the nodus and the middle of the stigma, the branches of the fork diverging all the way to the wing-margin; first and second branches of media (principal and nodal sectors) not approximated beyond the fork of the radial sector; apical sector originating near the anterior end of the stigma; anal loop oval, lying nearly lengthwise of the wing, with about two longitudinal rows of cells, usually one cell between bases of the 2d and 3d anals; supratriangular space with two or three cross-veins, triangles 3- or 4-celled, inner side not receiving a cross-vein. Inferior abdominal appendage of male hardly shorter than superiors.

Epiæschna debilis Karsch (Ent. Nachr., Vol. XVII., p. 286) perhaps belongs to this genus.

The nymph of *Nasiæschna* differs from all other æschnids in the possession of dorsal hooks. Our species represents a distinct and primary step in the evolution of the *Æschnidæ*, and its claim to generic distinction is beyond question.

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*See "Ent. News," Vol. XI., p. 546.

Nasiæschna pentacantha Ramb.

The nymph of this species was doubtfully referred by Garman ('90, p. 178) to *Epiæschna heros.* It differs from all American æschnids hitherto described in the possession of dorsal hooks on the 8th and 9th abdominal segments, having the form of a median carina terminating in a posteriorly projecting tooth. In aspect and habits this interesting nymph is very peculiar. It is rough, blackish, and very sluggish, and clings to dead branches, roots, or driftwood in quiet water. Doubtless it depends, as Mr. Garman suggests, on its obscure color and slow movements for escaping detection. Examples were taken by Mr. Hart in April and May on branches in dead water and along the banks of a slow-flowing stream near Urbana, and also a very young one in August in a muddy remnant of a temporary stream in Perry county, in southern Illinois. Mr. Garman's specimens were from a muddy slough of the Mississippi near Quincy. Outside of Illinois the imago has hitherto been reported only from New York (June), Louisiana, and Texas. Mr. Needham saw one taken at Wellesley, Mass. In Illinois it was taken by Walsh at Rock Island; and we have specimens from Urbana, and also from Cobden in southern Illinois. An imago was found floating May 20 in a narrow passage where nymphs were at the time quite numerous on dead branches lying in the water. From these nymphs adults were obtained up to June 10. Our other imagos were taken June 11 and 16.

In addition to the presence of dorsal hooks, as already stated, the nymph differs further from *E. heros*, as described by Cabot ('81, p. 30, Pl. I., Fig. 3), in the presence of two pairs of tubercles upon the head, in the absence of lateral spines on the 4th abdominal segment, and in that the two processes above each front coxa are of equal length.

The nymph measures 48 mm.: abdomen, 34 mm.; hind femur, 6 mm.; width of abdomen, 8.5 mm., of head, 9 mm.

The median labial lobe is prominent, cleft, without teeth on each side of the cleft. The lateral lobes are squarely truncate, with the outer angle rounded, their sides parallel beyond the base of the hook, the lobes terminating in an internal tooth as long as half their apical width.

The eyes are small but very prominent, about as in *Brachytron*. Behind them the lateral margins of the head extend in a ridge to the rather acute hind angles. Back of the middle of this ridge is a prominent tubercle. There is another pair of tubercles, close together on top of the head. The hind margin is broadly concave.

Abdomen with lateral spines on segments 5 to 9, increasing in length posteriorly, those of 9 about half as long as the 10th segment.

Superior and inferior appendages equal, obtusely pointed, male scale equilaterally triangular, its apex shining black, rounded. Dorsal hooks on segments 8 and 9 and sometimes on 7; represented on the other segments by median ridges.

II. EPIÆSCHNA.

This genus is intermediate in structure between *Nasiæschna* and *Æschna*, the three genera which follow between it and *Æschna* representing a branch line of development. The nymph resembles that of *Nasiæschna* and probably has similar habits, but it is without dorsal hooks. The adult may be recognized by the structure of the anal loop and other details of wing venation. We have but one species in this country.

Epiæschna heros Fabr.

This, the largest of our dragon-flies, is not common in Illinois, though Mr. A. H. Mundt ('82) has recorded the passage of a swarm of them towards the southwest over Fairbury, Livingston county. The air, he says, was literally alive with them; few alighted, and on the following day only a few stragglers remained. *Anax junius* was, and continued to be, the common local æschnid species. *Heros* is found from Quebec to Mexico; thence west to the Mississippi River. The Illinois localities are Rock Island, Quincy, Bloomington, and Urbana, and the extreme dates April 23 and September 1. Williams says it often enters houses before storms, and is commonest in May and early summer, being found along roads, in open woods, or over fields or water—wherever it may capture flying insects.

We have not seen the nymph, but Mr. Needham has compiled from Cabot's description and figure ('81, p. 30, Pl. I., Fig. 3) the following characters.

The nymph is 40 mm. long.

The head is deeply concave behind between the rounded hind angles Of the acute and approximated supracoxal processes, the anterior process is the longer. Median lobe of labium slightly notched at middle, the borders of the notch variable. Lateral lobes truncate on the end, denticulate within. Lateral spines on abdominal segments 5 to 9. Appendages equaling segments 9+10; laterals slightly more than half as long as the inferiors, which are a little longer than the superior. The tip of the latter is blunt.

III. Boyeria McLachl.

In appearance, structure, and habits this is much like the preceding genus. The imagos of the single North American species are not very large. They have a small brown spot at the base of each wing, reddish veins, and a yellow pterostigma.

Boyeria vinosa Say.

Fonscolombia vinosa, Calvert, '93, p. 247.
Neuræschna furcillata, Cabot, '81, p. 29, Pl. II., Fig. 3 (male nymph).
Gomphæschna furcillata, Cabot, '81, p. 28, Pl. II., Fig. 4 (female nymph).

A single exuvia was found by Mr. Needham attached to the under side of a plank, several feet above the water, at McHarry's mill-dam on Quiver Creek, in June. He has collected nymphs since in the rapid streams about Ithaca, N Y. Another nymph was taken by Mr. Hart in April, clinging to floating driftwood in Quiver Creek below the mill-dam. Like *N. pentacantha*, it is dark colored and sluggish, and appears to have similar habits. Kellicott ('96, p. 111) found the imagos quite abundant in Ohio in late summer; his notes on their habits are worth repeating here, as they tend to confirm the preceding statements of the habits of the nymph. "It prefers seclusion, hence should be looked for along ponds and streams with well-wooded banks, where branches overhang the water, and where half-submerged logs and rubbish abound. The males may be seen from early in the forenoon until dark, on warm days, exploring every corner among the obstructions at the water's edge. An interesting habit noted was that it would often fly out and carefully examine a passing skiff. The females, when not ovipositing, are suspended from some overhanging twig." Van Duzee ('97) makes a similar observation. The imago is widely distributed, being reported from Canada and the eastern United States as far south as the Carolinas, and west to Arkansas and Illinois. Professor Frank Smith took examples at Macatawa, Mich., where he says it is fairly common. In Illinois it has been taken only at Havana, Bloomington, and Urbana, a single specimen in each case. The one taken at Havana was flying along the river front. The extreme dates on record are June 20 and October 15, most of the occurrences being in July.

The nymph measures 35 mm.; abdomen, 24 mm.; hind femur, 6 mm.; width of abdomen, 7.5 mm., of head, 7 mm.

Body elongate; eyes large and very prominent, the sides of the head extending backward from the middle of the hind border of the eyes to very prominent slightly elevated hind angles, between which the hind margin is regularly concave.

Labium extending between middle legs. Median lobe prominent, cleft, a conspicuous tooth on each side of cleft, at some distance from it, on front margin.

Lateral lobes truncate apically, with a stout tooth at the inner apical angle and the convex inner margin denticulate. Hook stout, arcuate, and rather sharply incurved at tip.

Prothorax a little narrower than hind margin of head. Abdomen widest across segment 7, wing-cases reaching only the middle of 4, lateral spines well marked on 5, larger and gradually increasing in length on succeeding segments. Inferior abdominal appendages incurved beyond the end of the superior, which is one fourth to one third shorter, in the male narrowly cleft at tip, in the female pointed. Lateral appendages in the male one third, in the female one fifth, the length of the inferiors.

IV. BASIÆSCHNA Selys.

This genus contains but the one species following.

Basiæschna janata Say.

The nymph of this species resembles that of *Æschna*, but may be recognized by the greater number of lateral spines. the deep notch of the superior appendage, and the unusually narrow and pointed lateral lobes of the labium. We have taken the nymphs in Sand Lake, northeastern Illinois, on *Chara* in shallow water, and upon rotten logs along the shore of Delavan Lake, Wisconsin. Mr. Needham has studied the species at Ithaca, and made notes on it as follows: "This is a stream-loving species. It flies from the first of May until midsummer. It is very common in the small turbulent creeks about Ithaca, where I bred a good many in 1897, and collected a large number of nymphs." He has also a large number of specimens, in all stages except the youngest, from Mr. F. G. Schaupp, of Texas.

The imago is on record from several Atlantic states, and is reported by Williamson in Indiana, and by Kellicott as not uncommon May 1 at Columbus, Ohio. It has been taken once in Illinois, at Thatcher's Park, Chicago. The dates given run from the last of April to September. Kellicott ('97) collected it in April, under unusual weather conditions.

The nymph measures 37 mm.; abdomen, 27 mm.; hind femur, 6.5 mm.; width of head, 7 mm., of abdomen, 7 mm.

Generally dark colored, the mid-dorsal pale line on the abdomen often breaking down over the sides in pretty mottlings. The usual three yellow rings on the femora usually very distinct.

The head is evenly narrowed behind the eyes to the sharply angular hind angles.* The labium is abruptly widened in its apical third; its median lobe is without teeth, but with the usual fringe of hairs and closed median cleft. The lateral labial lobe is slender beyond the base of the hook, and is gradually narrowed to a slightly incurved point, with indistinct denticulation along its inner margin.

The abdomen bears distinct lateral spines on segments 5 to 9, those of 6 to 9 hardly increasing in size posteriorly, those of 5 somewhat smaller. The abdominal appendages are a little declined at their sharp and slender apices; the superior is less than two thirds the length of the inferiors, deeply notched at the tip; the laterals are about half as long as the superior.

V. Æschna Fabr.

The nymphs of this genus resemble those of *Anax*, but have four or five pairs of lateral spines instead of three. Their habits are similar to those of *Anax*, but they appear to be more retiring and inactive, being often found clinging to submerged roots and twigs. A single example was found in the Illinois River at Havana upon a submerged branch. It was clearly an *Æschna* nymph, but escaped before it could be further studied. Dr. R. H. Wolcott had under observation a nymph of this genus in Michigan. It liked to cling to the under side of floating objects. It was once seen eating an *Agrion* nymph, but was usually fed on flies, of which it ate two to four a day, coming to the surface for them each morning, and refusing food in the afternoon even when, as an experiment, the morning meal was purposely omitted.

The imagos are of large size, and are dark brown and blue, instead of green as in *Anax*, their wings clear, with black veins. Like *Epiæschna heros* they seem to have a fondness for the vicinity of dwellings.

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*In the younger of Mr. Needham's Texas specimens these angles bear distinct tubercles.

The species are numerous and difficult of separation. The nymphs are not usually abundant, and as few of even the commoner American species have been bred, our knowledge of the immature stages is as yet unusually imperfect. The key which follows indicates the salient characters of the nymphs here treated. In the young nymphs of *Æschna* sp. *b* a tendency to abdominal cross-bands was noted, and the sutures beneath were broadly bordered with paler color, except those between 3 and 4, 6 and 7, and 8 and 9.

KEY TO THE NYMPHS OF ÆSCHNA HERE DESCRIBED.

aa. Lateral spines of sixth abdominal well developed, reaching at least about half way to the hind margin of the segment; those of seventh attaining about to the hind margin; lateral labial lobes squarely truncate at tip.

bb. Fifth abdominal with minute lateral spines, lateral appendages fully two thirds as long as the superior appendage; supracoxal processes sharp, equal. 1. *clepsydra.*

b. Fifth abdominal with at most only a trace of lateral spines; lateral appendages less than two thirds as long as the superior; supracoxal processes less sharp, the posterior larger; abdomen in younger individuals with a medio-dorsal pale line bordered each side with blackish. 2. *constricta.*

a. Lateral spines of sixth abdominal minute, distant from its hind margin by several times their own length, those of seventh reaching about half way to the hind margin.

cc. Apices of lateral labial lobes squarely truncate, contiguous when closed; in younger specimens a pale spot near anterior ocellus and another on clypeus, and a pale median line enlarged on the middle of abdomen into an increasing series of pale spots, the largest and last on segment seven.

dd. Superior appendage sparsely fringed laterally with pale hairs; posterior part of head with some pale markings on the darker ground-color; outer apical angle of lateral labial lobes not rounded.

ee. Hind angles of head prominent; quite young examples (7 mm.) with separate spots at the posterior ocelli, the body not transversely banded. 3. sp. (*a*).

e. Hind angles of head rounded; young examples (10 mm. or less) with a trilobed spot at the back of the head above, the metathorax, a V-shaped spot on the base of the abdomen, and segments 6 and 7, all pale.* 4. sp. (*b*).

d. Superior appendage fringed laterally with blackish hairs; posterior part of head pale, with a dark lateral stripe, a median pair of dark spots, and the posterior margin dark; outer apical angle of lateral labial lobes narrowly rounded; head behind the eyes short. 5. *californica.*

c. Apices of lateral labial lobes exteriorly broadly curving to the acute terminal hook at the inner apical angle, not contiguous when closed; color dark brown, a fine median pale line on labrum, a transverse spot at the anterior ocellus, behind which are two pairs of small spots; a fine median whitish line on thorax and abdomen, vanishing near the middle of the abdomen. 6. *verticalis.*

1. *Æschna clepsydra* Say.

Æschna eremitica Cabot (nymph).

This wide-spread species has been found in the northern part of Europe and Asia, but especially in North America, extending south as far as the Dakotas, Wisconsin, Indiana, northern Ohio, and Maryland. It has not been taken in Illinois. Walsh reported it from Rock Island ('62, p. 397), but Hagen has identified Walsh's specimens as *verticalis*. A number of *clepsydra* imagos were taken, however, by Mr. Hart at the southwest end

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*In the young *Anax junius* the anterior pale transverse band includes the last two thoracic and the first three abdominal segments, and the posterior band covers segment 8, often also 7, and sometimes even the adjacent part of 6.

of Lake Geneva, Wisconsin, within ten miles of the Illinois line, September 2 and 5, about the summer resort cottages and along the lake shore. In New York it has been taken from August 28 to September 22; in Nova Scotia, July 26. Cabot described and figured ('81, p. 23; Pl. II., Fig. 2) a nymph taken at the same time and place as imagos determined as *Æ.* "*eremitica*," and assigned it by supposition to that species. *Eremitica* is an erroneous writing of *eremita*, which is a synonym of *clepsydra*.

The nymph of *clepsydra* differs from all other known *Æschna* nymphs in having recognizable lateral spines on the fifth abdominal. It is otherwise similar to *constricta*, and may be distinguished especially by the following characters given by Cabot ('81, p. 37) from full-grown nymphs of both sexes from Hermit Lake in New Hampshire, mouth of Red River of the North, and Minnesota: "Hind angles of head oblique, processes long, equal, sharp, tips bent a little outwards, inclosing less than a right angle; lateral appendages two thirds the length of the middle one; female valves not quite reaching tip of segment."

2. *Æschna constricta* Say.

This is one of our more common dragon-flies, appearing on the wing in Illinois after midsummer, and disappearing only with the autumnal frosts. It ranges over the entire northern part of the United States, and from Labrador into Siberia, being apparently less common throughout the Mississippi valley than on the north Atlantic and north Pacific slopes. The Illinois specimens are from various localities in the central and northern parts of the state. Van Duzee ('97) found it most abundant along the meanderings of small brooks in hilly country.

Our nymphs were collected in a small ditch at the west end of Lake Geneva, Wisconsin, in August, and from a little streamlet in the Mississippi bluffs near Savanna, Illinois. We also have a half-grown nymph from Pine Lake, near Charlevoix, Michigan, sent by Dr. Henry B. Ward. Mr. Needham has also two quite young nymphs of perhaps the same species sent him by Mr. F. C. Willard from Tombstone, Arizona. These all have labial characters similar to *Epiæschna heros.* The nymph has been described and figured by Cabot ('81, p. 28; Pl. III., Fig. 1), but it does not seem superfluous to present here a detailed description, drawn up from the Lake Geneva specimens and from material bred by Mr. Needham at Ithaca, New York, in 1897. It differs from the remaining species of the genus in the greater size of the lateral spines of the sixth abdominal, as described in the key.

A full-grown male nymph from Montana presents some apparently trivial differences which, under the circumstances, it will perhaps be best to mention. On either side of the open end of the labial cleft is a minute tooth ; the tooth on the inner apical angle of the lateral lobes is less acute than in the typical specimens and not so distinct. The lateral spines of the fifth segment are identical with those of the typical examples, but the others are a trifle longer and more divergent. The notch of the superior appendage is a little deeper. In length this appendage is exactly intermediate between the inferiors and laterals, as in the typical specimens, but the laterals are relatively shorter and the inferiors longer, the laterals being very little more than half the length of the inferiors.

The nymphs measure 40 mm.; abdomen 26 mm.; hind femur 8 mm.; width of abdomen 8 mm., of head 8 mm. Color blackish brown, paler below on legs, on lateral margins of abdomen, and on superior and inferior abdominal appendages. Two black marks upon the costal edge of each wing-case near the base, a pair of black dots near the tip of the basal male enlargement of the superior appendage, and a similar dot near the tip of each lateral.

Head narrowed behind the eyes to the broadly rounded hind angles, one third wider across the eyes than across the hind angles ; hind margin moderately concave, with some coarse pubescence disposed in numerous irregular rows near the hind angles.

The labium extends posteriorly beyond the bases of the second pair of legs. The median lobe is considerably produced, and rather deeply cleft in the middle, the angles each side of the cleft minutely rounded. Lateral lobe squarely truncate on the end, with a minute tooth terminating the inner border, which is finely denticulate. Movable hook long and arcuate. Supracoxal processes of equal length, a little obtuse, pointing in slightly diverging directions, the angle between them about 75 degrees, the posterior a little broader.

Abdomen with lateral spines on segments 5 to 9, increasing in length posteriorly, those of 5 very minute and rudimentary, of 6 somewhat appressed, of 8 and 9 nearly equal, of 9 three fourths as long as the 10th segment at middle. Appendages longer than segments 9 and 10, inferiors longest, slightly incurved at tip; superior four fifths as long as inferiors, exactly intermediate in length between the two pairs, a pair of short spines at its terminal angles, between which the tip is semicircularly notched, sides parallel and fringed with fine hairs, its basal male enlargement elongate, triangular, scale-like, covering its basal three sevenths; laterals three fourths as long as superior, cylindrical, abruptly acuminate apically.

3. *Æschna* sp. (*a*).

A number of small nymphs from Yellowstone Park and Montana, 15 mm. and less in length, appear to be different from any others known to us. The lateral spine on the sixth segment is very small; on the fifth segment there is merely a smooth angulation; the rear angles of the head are very slightly or not at all rounded. The supracoxal processes are exactly equal and similar. The very young individuals (7.5 mm.) are not transversely banded. The nymphs are too young for any comparison of the lengths of the terminal appendages. They were collected July 25 to August 19 from bark and rotten logs in a bayou of Flathead River, near Demersville, Montana, and in Yellowstone Park from the Gibbon River and a lagoon of geyser water near Lewis Lake.

4. *Æschna* sp. (*b*).

This species is represented in our collections by a quantity of young nymphs, 5 mm. to 24 mm. long, all taken from rushes, wood, etc., along the weedy margin of a lake in Yellowstone Park, near Gardiner River, August 30. Unlike the preceding species, which it closely resembles in structure, the hind angles of the head are rounded, and the very young nymphs are banded much as in *Anax junius* but not on quite the same segments.

5. *Æschna californica* Calv.

Æ. californica, Calvert, '95.

This is a species of the far West and the Pacific coast, not found in Illinois. The nymph is here described for the first time. A single one was taken from an irrigation ditch near Tombstone, Arizona, and bred in May, 1897, by Mr. F. C. Willard. The exuvia and imago are now in the Cornell University collection. Through the kindness of Dr. P. P. Calvert, Mr. Needham has examined three young nymphs from the collection of the Academy of Natural Sciences, Philadelphia, which appear to belong to the same species.

The nymph measures 34 mm.; abdomen 20 mm.; hind femur 6 mm.; width of head, 7.5 mm., of abdomen 7.5 mm.

The head is narrowed behind the eyes to the rounded hind angles, between which are two pairs of scars, the smaller pair on each side of the median line. The median lobe of the labium is not prominent; its border is without teeth, its median cleft closed. The lateral lobes are truncate, but their external angle is rounded off slightly. The supracoxal processes are equal and divergent at almost a right angle.

The lateral spines on the 6th abdominal segment are slender and appressed, those on the succeeding segments increasing regularly in length. The inferior abdominal appendages are as long as segments 9 + 10, the laterals one half as long as the inferiors; the superior a little shorter than the latter, roundly notched as usual at the tip, and fringed with a row of stout blackish bristles along either side.

6. *Æschna verticalis* Hag.

Æschna juncea verticalis, Calvert.

This species ranges from Nova Scotia to the District of Columbia, and has also been taken in Ohio, Illinois, and California. At the East it is commoner than *clepsydra*, but not in Illinois, having been taken only at Rock Island. The published dates range from July 16 to October 18. Harvey found it common over meadows, bogs, and rivers in Maine. The nymph has not been described or bred. We have in the Laboratory collections, however, two lots of young specimens taken from the marshy shore of Grass Lake, Ill., which are clearly distinct from the others here treated, especially in the form of the lateral labial lobes, and which may be reasonably assigned to the above species.

VI. Anax Leach.

The abundant and very uniformly distributed nymphs of this genus may be separated from any of the others of this family—which are usually much less common—by the fact that they have only three pairs of lateral spines. In habit they are quite unlike the lower æschnid genera, as they thrive especially—even in small temporary pools and ditches—wherever there is a luxuriant aquatic vegetation, through which they clamber actively, preying on all sorts of water insects.

The imagos are familar objects, large, bright green, the wings with yellowish costal margins, circling about in swarms or singly in search of small insects in the air.

Anax junius Drury.

King of the dragon-flies, powerful and fearless, our great *Anax* is a dominant type of its class; and its worthy offspring, omnipresent and omnivorous in the water world, is equaled only by the large water-tigers (*Cybister*) in strength, activity, and ferocity. It has none of the sluggish obscurity of *Calopteryx*, *Gomphus*, *Boyeria*, or *Epicordulia*. It clings to water weeds, usually nearer the surface than the bottom, in an attitude of alertness, with the head poised low and abdomen slightly elevated. Its locomotion is relatively rapid, accomplished either by walking or by ejecting water from the respiratory chamber. It is notoriously cannibalistic. In the midst of abundant and choice food the larger nymphs will eat the smaller of their own species, and two of equal size may not safely be kept in close quarters. *Anax* nymphs are easily recognized by their having lateral spines on but *three* abdominal segments preceding the last. The young nymphs have wide alternating transverse bands of brownish and white, but become in later life a nearly uniform green or brownish green.

To get a definite idea of the food of the nymph, the stomachs of a considerable number, taken at different dates and in various situations, were examined by Mr. Hart. Thirteen of them contained small quantities of comminuted food, the most unexpected feature of which was the large quantity of remains of univalve *Mollusca*. This was principally *Amnicola*, the lingual ribbons and opercula of which were easily recognized. The molluscan element was estimated as 15 per cent. of the food. Filamentous algæ, in quantities too large to be accidental, constituted 11 per cent. *Crustacea* were also 11 per cent., nearly all a small amphipod species, *Allorchestes dentata*. Of the remainder, 56 per cent. was recognized as the remains of insects, including larvæ of *Chironomus*, of *Stratiomyiidæ*, of *Tipula*, of beetles, of *Agrion*, and of a small caddice-fly (*Rhyacophila*), small *Hemiptera*, and even the moss-bug (*Pelocoris*), the sharp sting of whose beak often temporarily interrupts the routine of station field-work. A nymph was observed by us to attack a crawfish three fourths of an inch long, and devour its abdomen. Young nymphs in a breeding-cage ate *Asellus* eagerly.

In the vegetation-filled waters everywhere about Havana these nymphs developed in great numbers, while in the Mississippi and associated waters about Quincy, in which vegetation is comparatively scanty, Mr. Garman found but few individuals. Our specimens of the nymph were taken from a remarkable variety of waters containing vegetation, and even where other species of nymphs are largely wanting. Lakes, rivers, ponds, swamps, transient pools, small ditches, springs, throughout the state,—all produce a crop of these nymphs. This fact together with their active habits and voracity, would indicate a rapid development. Kellicott states that from an excavation for an artificial lake, which was filled up with water in early May, large numbers of *junius* imagos emerged in late August, indicating the occurrence of two broods in a year. This is confirmed by one of our experiments, half-grown larvæ placed by Mr. Hart in a breeding-cage June 16 reaching the imago stage August 4. A noticeable reduction in the number of large nymphs and an increase of the younger ones about July 1 has been recorded in two different years. Young predominate in our October collections, and those taken early in spring are mostly of large size. The imagos attain greatest abundance in May. On May 19, 1894, the abundance of fresh exuviæ was considered worthy of record.

According to Kellicott this is the first dragon-fly abroad in early spring, remaining until the middle of October. Several pairs were seen by him flying in union March 21, the female ovipositing. In early spring, according to Mr. Needham, the eggs are deposited in the water-soaked stems of reeds, in floating sticks, pieces of board, etc.; while later in the season they are placed in the green and growing stems of aquatic plants. He states that the females are usually held by the males during oviposition, and often descend into the water for this purpose.

The imagos wage a ceaseless warfare on gnats, mosquitoes, and other small winged insects. In August, writes Mr. Needham, I saw a small swarm (more than a score) moving together through an orchard in Cass county, Ill., miles from open water. At the same place a few days later, during three successive days of high wind, *Anax junius* and *Tramea lacerata* could always be seen hovering in the lee of orchard trees, grape arbors, stacks of grain, etc., circling swiftly several rods away from shelter then beating slowly toward it again, head to wind, evidently watching for game. and making short dashes forward betimes, presumably to seize some small insect driven from shelter by the wind.

Mr. Adams and Mr. Hart observed a large swarm which gathered in the lee of the field laboratory boat August 8, at twilight, and after half an hour or more of rapid circling about scattered abruptly at about 7:40. An adult *Anax* was once seen to devour an agrionid imago.

The species covers the continent from Alaska to the West Indies, and is found in eastern Asia.

Cabot ('81, p. 15; Pl. I., Fig. 2) has figured the nymph, and many different reproductions of his figure are current. The following brief description covers the 'more important characters.

The nymph measures 45 mm.; abdomen, 31 mm.; hind femur, 8 mm.; width of abdomen 8 mm., of head 8 mm.

The head is flat and broad, widest across the posterior third of the eyes. Antennæ minute, slender. Eyes broad, laterally prominent, produced well toward the dorsal median line at their posterior internal angles. Labium very long and flat, extending posteriorly beyond bases of middle legs; median lobe with a narrow median cleft. Lateral lobes oblong, denticulate along inner margin, an incurved tooth at tip; hook long, strong. Abdomen widest across segment 7, tapering both ways. No trace of dorsal hooks; short lateral spines on segments 7 to 9. Hind margin of 9 (as seen from above) straight. Superior appendage a trifle longer than segments 9 and 10, notched at tip; inferior appendages a little longer, sharp pointed; lateral appendages half as long.

Young nymphs are more unlike full-grown ones in habitus than are those of most other species. In the earlier stages the abdomen appears more attenuated toward the base. The superior appendage is at first very short and blunt and directed upward, but after a few molts it becomes elongated and notched at the tip, though it remains for a time much shorter than the inferiors. Lateral spines on 7 to 9 appear very early.

Nymphs one third to one half grown are transversely banded with brown across the head, across segments 4, 5, and 6 (sometimes 7), and across 9 and 10. These bands disappear with subsequent molting, and the full-grown nymphs are of nearly a greenish color variously mottled with brown.

FAMILY GOMPHIDÆ.

There is a marked "family resemblance" among the nymphs of each dragon-fly family, and this is quite as true of the present one as of any other. Its nymphs are all evident gomphids, even *Hagenius*, broad and flat as it is. Their most marked characteristic is the pair of thick, rough, four-jointed antennæ. The flat labium is built on the same plan as that of the *Agrionidæ* and *Æschnidæ*—the mentum, nearly truncate in front, bearing a powerful mandible-like pair of grasping arms, carrying on the outer side beyond the middle a large movable hook, the arms usually toothed within and ending in an incurved point. The domain of these nymphs, except *Hagenius*, is the muddy, sandy, or rocky bottom of various kinds of bodies of water, according to species. They live amongst fallen trash and sediment, burrowing shallowly along with the tip of the abdomen turned up so as to reach the water, thus enabling them to breathe while foraging in a stratum of great biological richness. Their colors are similar to the mud and sand in which they dwell, and are often obscured by a coating of mud. The flattened body and stout legs are well adapted for burrowing. The head is broad and more or less wedge-shaped, the antennæ, laid close upon the labrum, forming the point of the wedge. The third antennal joint is much the largest; the fourth, a mere rudiment. The legs are stout, the two anterior pairs directed forward, their tibiæ armed at tip externally with more or less well-developed burrowing hooks. The hind legs are directed backward and used to push the body forward. The anterior and middle tarsi are two-jointed, not three-jointed as in other *Odonata*. The dorsal hooks and lateral spines are rather feebly developed.

When the nymphs are ready to leave the water to transform they cannot ascend very small stems, such as those of reeds, owing to the wide divergence and separation of the legs; but they can readily climb up on a broad surface like the piers and timbers of a bridge or the side of a floating barge, or on large rocks or tangled growths. They do not go far above the water, not more than a few feet at most, and here they may be seen transforming at any hour of the day or night, but most commonly about daybreak, leaving behind them their mud-incrusted shells, which are often seen in great numbers in the situations already mentioned. A study of the different sizes of larvæ indicates that the nymphs require two or three years to attain maturity.

The imago gomphid is in most species a medium-sized clear-winged dragon-fly, the thorax rather prettily striped with green or yellow, the abdomen rather slender in comparison with the thorax but often dilated towards the tip, the eyes not touching as in the *Æschnidæ* and remaining *Anisoptera*, but widely separated as in the *Agrionidæ* and *Petaluridæ*. In wing venation they approach the *Libellulidæ*, the triangles being well differentiated, with few or no cross-veins, but the antecubital cross-veins are mostly non-coincident, as in the other *Anisoptera*. The anal loop is small, inclosing from one to a few cells. As with the *Libellulidæ*, the ovipositor is not developed, and the more or less oval eggs are transferred free to the water by successive taps at its surface with the tip of the abdomen during flight, the females ovipositing alone.* The number of eggs deposited is very large. Copulation takes place while at rest on shore. The females frequent the trees or pathways back of the shore, while the males rest nearer the water. The latter may be quickly recognized by their curious terminal appendages resembling four fingers about to grasp something, while those of the female are short, simple, and inconspicuous. The period of flight usually occurs rather early in the season, vary-

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*The eggs in a *Nymphæa* leaf figured by Lampert, '99, as eggs of *Gomphus* have been demonstrated by our breeding work at Havana to be those of *Agrionidæ*.

ing from a few days to a few weeks according to species. During this season they are little in evidence. Indeed one may not see a living adult, although thousands of fresh exuviæ be scattered along the banks.

The structural characters of the nymph appear early, and the descriptions which follow will apply to all but the very youngest nymphs. The structures latest to develop are perhaps the teeth on the inner margin of the lateral labial lobes, which in some species, at least, increase in number with successive molts. On account of the short life and restricted range of flight of the imagos they are not often taken in ordinary collecting. If the shores, boats, and bridges near the larval haunts are examined early each day in the latter part of June and early in July, the collector may be rewarded some morning by finding large numbers in the act of emerging; and if these are kept alive and uninjured in a roomy box or cage their colors and texture will mature in a few days.

KEY TO THE GENERA OF ADULT GOMPHIDÆ OF THE EASTERN UNITED STATES.

aa. Both triangles with a cross-vein. II. *Progomphus.*

a. Both triangles without a cross-vein, except the discoidal triangle in *Hagenius.*

bb. First and second anal veins distinctly angulated toward each other at the cross-vein of the anal loop, which contains 3 to 5 cells.

cc. Discoidal triangle of usual shape, without cross-vein; 3d femora not reaching base of 2; anal loop 3-celled. IV. *Diastatomma.*

c. Discoidal triangle distinctly 4-sided, with cross-vein; 3d femora very long, reaching base of 3; anal loop with 3 to 5 cells, usually 4. V. *Hagenius.*

b. First and second anal veins nearly parallel, or only the first angulated; anal loop with 1 or 2 cells.

dd. Part of arculus of hind wing above attachment of sectors much shorter than that below them, the lower sector joining it at or above its middle; length of body 40 mm. or less. VI. *Lanthus.*

d. Parts of arculus of hind wing above and below attachment of sectors nearly equal, the lower sector joining it distinctly below the middle.

ee. Hind femora long, reaching base of 3, with 5-7 long spines besides the usual spinules.
VII. *Dromogomphus.*

e. Hind femora usually moderate, with spinules but no long spines. VIII. *Gomphus.*

KEY TO THE GENERA OF THE NORTH AMERICAN NYMPHS OF GOMPHIDÆ.

AA. Tenth (last) abdominal very long and slender, many times longer than broad, nearly half the length of the abdomen. I. *Aphylla.*

A. Tenth abdominal usually broader than long, never more than twice as long as broad.

aa. Middle legs approximated at base; inner pair of wing-cases strongly divergent; ventral longitudinal sutures of abdomen diverging to near apical angles of 8, segment 9 similar to 10; lateral labial lobes entire, their apices rounded; 3d and 4th antennal joints subcylindric, more than twice as long as thick, the latter recurved; five or more pairs of lateral spines; dorsal hooks present but not prominent. II. *Progomphus.*

a. Middle legs at least as far apart as fore legs; ventral longitudinal sutures of abdomen diverging to apical angles of 9, which is unlike 10; 4th antennal joint very short and small; not over 4 pairs of lateral spines, except in *Hagenius.*

bb. Inner pair of wing-cases strongly divergent; 3d antennal joint oblong, at least twice as long as broad; lateral labial lobes dentate, without apical hook; tenth abdominal narrowing posteriorly, following the tapering outline of the apex of the abdomen.
III. *Diastatomma.* IV. *Herpetogomphus.*

b. Inner pair of wing-cases parallel, lying close together or contiguous, except sometimes in exuviæ; sides of 10 subparallel, largely embraced by the lateral spines of the rapidly narrowing 9th segment.

cc. Third antennal joint flat, subcircular or broad oval, less than twice as long as broad.

dd. Body very broad, 3d antennal joint subcircular, abdomen much flattened and subcircular, with distinct dorsal hooks; middle legs more distant at base than fore legs; lateral labial lobes obscurely denticulate, with broadly rounded apices. V. *Hagenius.*

d. Body of the usual form, 3d antennal joint broad oval, dorsal hooks entirely wanting; middle and fore legs about equally distant; lateral labial lobes dentate, with blunt apices. VI. *Lanthus.*

c. Third antennal joint subcylindric, more than twice as long as thick; middle and fore legs about equally distant; lateral labial lobes toothed.

ee. Dorsal hooks with short but acute spiny tips; median labial lobe slightly concave; lateral lobes with prominent apical hook. VII. *Dromogomphus.*

e. Dorsal hooks sometimes present, but obtusely pointed, usually absent except for a median tooth in the hind margin of 9; median labial lobe more or less convex, in some species nearly straight; lateral lobes with a more or less evident apical hook. VIII. *Gomphus.*

I. APHYLLA Selys.

Aphylla producta Selys.

Two curious nymphs from Florida are described by Hagen as probably belonging to this tropical species, common in Cuba. The unusual length of the last segment will at once identify it.

11. Progomphus Selys.

Progomphus obscurus Ramb.

The nymph of this species has divergent wing-pads, like *Diastatomma*, but differs from all our other gomphids in the proximity of the middle legs. It represents an extreme of specialization for life as a burrower in the bed of running streams. It has not been found in the Illinois nor in its adjacent lakes, but seems to be common in the sand of the smaller rivers, such as the Spoon River and upper Sangamon. The State Laboratory has a large number of examples from the latter river, taken in September and October. One specimen was found at the lower edge of a sand-bar in Spoon River, near Havana, in July. The published dates for the nymph are April (Fla.), May, and June. The adults are rare in collections, although the species seems widely distributed. Perhaps the peculiar habits of the nymph may be correlated with a relatively long period of nymphal life and short period of life as an imago. The adult has been taken in Indiana as early as June 26, and in Illinois June 29 and July 13. It is recorded from Massachusetts, Georgia, Ohio, Indiana, Florida, Texas, California, Oregon, and Mexico.

The nymph was described and by supposition connected with this species by Hagen ('85, p. 247), and the supposition was verified by Mr. Needham (97, p. 184).

The nymph measures 31 mm.; abdomen, 20 mm.; hind femur, 4 mm.; width of abdomen, 6 mm., of head 5 mm.

Body depressed anteriorly and tapering posteriorly; lateral margins with long hairs.

Head depressed, sloping anteriorly, cordate, broadly notched behind; hind angles rounded. Antennæ inserted into cylindroid elevations on the front, depressed and incurved so as to almost surround the pilot-shaped labrum; two basal joints very short; third, twice as long as the two basal combined, slightly flattened and upcurved at the tip; fourth joint small, one third to one fifth as long as the third, slender and strongly recurved.

Labium rather small, reaching, when folded, to the bases of the middle legs ; submentum shortened ; mentum narrowed at its proximal end, its median lobe prominent, rounded, fringed with a row of flabellate scales whose bases are overlaid and supported by another series of shorter semicylindrical scales ; beneath this fringe, the margin cut into a series of obscure rectangular teeth ; lateral lobes short, nearly straight, unarmed, rounded at apex ; movable hook stout, moderately incurved, and tapering.

Thorax sloping to the head and to the bases of the legs ; prothorax of unusual dimensions on the dorsal side, its hind margin on a line with the bases of the hind legs, being extended back upon the other thoracic segments, shield shaped, with a short collar close behind the head. Wing-cases strongly divergent. Legs conspicuously fossorial, fore legs approximate to the sides of the head, bearing shields of stiff hairs behind which the middle legs may be brought forward. Middle legs approximated on the venter, rotated downward and extended horizontally close under the fore legs. Hind legs longer, more nearly normal, directed posteriorly. Fore tarsi with soles facing laterally ; middle tarsi rotated on tibiæ so as to point backward ; hind tarsi elongate, the third segment about as long as both basal segments, its claws sharp and long ; claws of fore and middle tarsi short and blunt. Each femur with a distal anterior process which rests against and supports the tibia when moved backward.

Abdomen spindle-shaped, segments about equal, the 9th a little longer than the others; dorsal hooks variable, rudimentary, more or less well represented on segments 2 to 9, smallest on middle segments. Lateral spines on 5 to 9, on 5 rather minute. Appendages slender, tapering; superior and inferiors equal, about one third longer than segment 10, laterals about half as long as the others.

III. DIASTATOMMA Burm.

Ophiogomphus Selys.

IV. HERPETOGOMPHUS Selys.

Diastatomma and *Herpetogomphus* are very closely related, and no good character has yet been found to separate them when in the nymphal stage. They are then similar in form to the common gomphid larvæ of the genera which follow, but may be easily distinguished from them all by the widely diverging wing-pads, the inner margins of which separate at an angle of 60° or more instead of being approximately parallel as in the genera which follow. In exuviæ of the latter forms, however, the wing-pads are often more or less separated. *Herpetogomphus* has not been found east of the Mississippi. *Diastatomma* is widely distributed in North America, but both the nymphs and imagos are quite rare in Illinois, owing probably to the small extent of rocky stream-beds and rapid currents. The rivers near Rock Island and Golconda, in which examples have been found, afford favorable situations of this kind. Three species of the nymphs are in our collections,—one found in Illinois,—readily separable by the number of lateral spines, the length of the lateral appendages, etc., as stated in the key.

Nymph stout, little flattened. Head abruptly sloping forward from the ocelli. Labrum pilot-shaped. Antennæ with the two basal segments globular, third segment twice as long as both basal, much flattened and laid close beside the labrum. Fourth joint a minute rudiment. Median lobe of mentum rounded, with border of short blunt teeth and a double series of fringing scales. Lateral lobes nearly straight, not terminating in an end hook and minutely denticulated within; movable hook short, arcuate.

Legs rather short. Fore and middle tibiæ with external hooks, wing-cases divaricate, strongly sloping downward toward the sides. Dorsal hooks on abdominal segments on 2 or 3 to 9. Tenth segment not inclosed by the 9th but triquetral, exceeding the lateral spines, its own lateral margin forming a part of the margin of the abdomen.

KEY TO THE NYMPHS OF DIASTATOMMA HEREIN DESCRIBED.

Lateral spines on abdominal segments 7–9.

Dorsal hooks distinct, narrowly prominent, ending in a pointed tooth; abdominal granulations fine and much less conspicuous than in the next species; male superior appendage scarcely tubercled, lateral appendages three fourths to four fifths as long. 1. *severus.*

Dorsal hooks represented by a broad elevation, ending posteriorly on each segment in a rounded tooth; abdomen evenly dotted with rather coarse blackish granulations; superior appendage of male notched back of middle, in front of which is a pair of tubercles, laterals about three fifths as long as the superior one. 3. *carolus.*

Lateral spines on abdominal segments 6–9; dorsal hooks as in *carolus* but much more prominent; male superior appendage scarcely tubercled, laterals nine tenths as long as the superior. 4. sp. (*a*).

1. *Diastatomma severus* Hagen.

Ophiogomphus severus Hagen.

The nymphs here described were collected by Dr. Forbes in large numbers from streams in Yellowstone Park, such as the Fire Hole River, Nez Perce Creek, and Gibbon and Goodwin rivers, during the latter half of August. They were found on sand under stones in shallow rapids, and on weedy and grassy bottoms. They answer well to the description given by Hagen ('85, p. 259) for *severus*, which is by far the most abundant gomphid in that region.

The nymph, apparently grown, measures 25 mm.; the abdomen, 16 mm.; hind femur, 5 mm.; width of abdomen 7 mm., of head 5 mm.

Color (alcoholic specimens) fulvous yellowish beneath and on the sutures, and on the legs beyond the middle of the femora. Yellow also on ocelli, in a broad band between the eyes behind the suture, another band on the mid-dorsal line of the prothorax, and sometimes still other bands across the apical half of abdominal segments 7 and 8; also variable spots arranged along the sides of the abdomen. Abdominal appendages yellow, brownish on the margins.

Body but little hairy. Lateral spines on abdominal segments 7–9, all equal. Dorsal hooks on 2 to 9, on 2 slender, on 3–9 subcultriform, on 9 low and directed posteriorly. Otherwise much like nymphs of the other species of *Diastatomma.*

2. *Diastatomma rupinsulensis* Walsh.

This species was first described from Rock Island, Ill. The only other instance known to me of its capture in this state was on June 29 at a point on the Mackinaw River known as Mackinaw Dells, where favorable conditions for the nymph exist. Kellicott says the imago was first taken in Ohio May 5, near Columbus, and was common from the middle of May to the middle of June, flying above the swiftest currents or resting near rapids. It is recorded from Canada, and from a number of the northern states from Maine to Illinois. The nymph is as yet unknown.

3. *Diastatomma carolus* Needh.

Ophiogomphus carolus Needh., '97.

This species flies in May at Ithaca, N. Y., where Mr. Needham bred it by scores in 1897 and picked up hundreds of exuviæ by the banks of streams. Nymphs taken in October emerged in March. In April they were abundant in the trash-filled eddies of the swiftest streams, and after their emergence the banks were in places fairly covered with exuviæ. Notwithstanding all these evidences of abundance, he was able to capture but a single imago there, and saw but two at large, during a whole season of active collecting. It would be very interesting to know what the imagos do with themselves.

The nymph measures 24 mm.; the abdomen, 14 mm.; the hind femur, 4 mm.; width of head 5 mm., of abdomen 7.5 mm.

Body sparsely covered with clavate hairs and minutely pointed blackish granulations; 3d joint of antennæ very flat, oval. Labium short, meeting in front a posteriorly directed fringe of hairs growing under the edge of the labrum. Lateral spines on 7 to 9, those of 9 half as long as segment 10 at middle. Dorsal hooks on 3–9, very low and broad with decurved apices. Lateral abdominal appendages about three fifths as long as the subequal superior and inferiors.

3. *Diastatomma* sp. (*a*).

Nymphs taken by Mr. Hart from gravelly shallows of the Ohio River at Golconda, in southern Illinois, October 27, differ from those of *carolus* in having lateral spines on the 6th segment of the abdomen.

The nymph measures 25 mm.; abdomen, 15.5 mm.; hind femur, 4 mm.; width of abdomen 8 mm., of head 5.2 mm. Color (in alcohol) yellowish with black points at top of thoracic sutures and a pair each side of each dorsal hook ; scars brownish. Body moderately hairy, lateral spines on abdominal segments 6 to 9. Dorsal hooks on 2 to 9, large and subcultriform in front, regularly decreasing to a rudiment on 9 ; superior and inferior abdominal appendages long, laterals very little shorter.

V. Hagenius Selys.

There is but one North American species of this interesting genus, the flat nymph of which is conspicuously unlike that of any other dragon-fly in form, as described below. It is found clinging to the flat surfaces of driftwood and stones or amongst dead leaves. The *Ephemeridæ* inhabiting such surfaces are also conspicuously flattened. They are therefore not easily picked off by fish nor dislodged by a rush of water, and are able to slip away through narrow crevices. Perhaps *Hagenius* has this shape for similar reasons. Its blackish color is evidently protective.

The imago is one of the largest gomphids. It is black, with clear wings and yellow markings, and flies along the small rapid streams which are inhabited by the nymph.

Hagenius brevistylus Selys.

This grotesque nymph looks more like a colossal bedbug than a dragon-fly nymph, being extremely flat and broad, with a disk-shaped subcircular abdomen. It is unique in habits as well as in form. It seems to prefer rapid-flowing streams, and does not burrow as do other gomphid nymphs, but clings to stones or to tethered drift-stuff in the current, or hides among loose drift and dead leaves. Mr. Needham found nymphs of three distinct sizes in a stream near Ithaca. The imagos emerged all at once, and a considerable number of exuviæ were found. This would indicate a three-year life-period, the nymphs not maturing till the third season after the one which brought them into existence. We have examples taken from the upper Sangamon River in Piatt county in September and October, and at Chicago and Quincy. This nymph seems to be quite infrequent in Illinois. The imago occurs all over the country from Maine to Texas and Kansas, and is reported (Kellicott '95) as abundant in Michigan, but I am not aware that it has ever been taken in this state. It flies through June, July, and the greater part of August.

In view of the excellent figures and description by Cabot ('72, p. 9) and the very minute description by Dr. Hagen ('85, p. 279) it will be sufficient here to give only the more prominent characters.

The nymph measures in length 36 to 40 mm.; hind femur, 10 to 12 mm.; abdomen, 22 to 23 mm.; width of abdomen 20 mm., of head 8 mm.; vertical thickness of abdomen about 4 mm.

Body exceedingly flat, ovate in outline, nearly destitute of hairs.

Head cut off squarely behind; eyes a little projecting on the sides, front sloping to base of antennæ. Top of head with a pair of conic tubercles behind the lateral ocelli and a larger pair of flattened ones behind the eyes. Antennæ with the basal joint globular, the second smaller; third joint very flat, nearly circular, but with the inner edge straight. Below the eye a blunt process extends downward and forward to the sides of the labium, obviously for lateral support of that organ.

Labium short and thick; mentum slightly wider than long, contracted at basal fourth; median lobe of mentum occupying hardly a third of its width, slightly rounded, its thickened edge obscurely cut into about ten blunt teeth, and bearing a fringe of flat scales, with a few more elongate and bristle-like at the ends of the fringe; lateral lobes arcuate, broad and strong, with ill-defined blunt denticulation all around the rounded tip and down the inside; movable hook short, feebly arcuate, tapering, with an incurved tip.

Prothoracic dorsum elevated at sides into prominent compressed lateral ridges, between which it is excavated. Femora inclined to be sharp-edged posteriorly and triangular in cross-section.

Abdomen with dorsal hooks beginning on 2, at first narrow and acute, highest on 3, becoming gradually more elongate and blunt, variably reduced on the last three or more segments to low median ridges; lateral spines of 2 acute, those of 3–9 appearing as broad triangular projections of the latero-posterior angle, those of 9 inclosing segment 10. Appendages short and thick, triangular-pyramidal, longer than the very short 10th segment. Superior slightly shorter than the inferiors, laterals one third as long. Longitudinal ventral impressions of abdomen separated by only about one fifth of the width of the abdomen, nearly parallel, becoming strongly divergent on 2 and 9. Young nymphs have the peculiarities of the mature ones even more strongly marked, especially in the form of the abdomen, which is more nearly circular.

VI. Lanthus Needh.

The nymph of the single eastern species for which this genus was established, differs from the ordinary *Gomphus* nymph in several particulars, and is related to *Hagenius* by its antennal structure. It was found burrowing in sandy stream beds.

Lanthus parvulus Selys.

Gomphus parvulus Selys.
Uropetala thoreyi ? Hag. (nymph).

This dainty little gomphid is not yet known to be an Illinois species. The imago has been found only from Nova Scotia to Pennsylvania, but Dr. Hagen ('85, p. 281) has described the nymph from specimens received from Kentucky October 20, doubtfully referring them to *Tachopteryx thoreyi*. Nymphs answering to his careful description were found sparingly by Mr. Needham in the sandy beds of streams about Ithaca, N. Y., where he collected and reared half a dozen. The nymph is notable for its small size and the flat subcircular form of the third antennal joint. It is an active little burrower, and has the habit of feigning death when withdrawn from the water. For these reasons it is more difficult to detect than are other gomphids. Nymphs kept under nearly normal conditions transformed in May. The imagos were not seen by him at large. They have been taken in Maine by Miss Wadsworth June 19 and 25.

The nymph measures 21 mm.; abdomen, 12 mm.; hind femur, 3.5 mm.; width of head 4 mm., of abdomen 6 mm.

Body moderately depressed, a little hairy on sides of thorax and on legs.

Head compact, with obtuse hind angles between which the hind margin is concave. Antennæ with the two basal joints short and thick, the third very flat, broadly oval, almost circular, the fourth very rudimentary.

Labium short; mentum with sides parallel except in the abruptly narrowed basal fourth; median lobe almost straight, with four blunt chitinous teeth and a fringe of long scales; lateral lobes short and stout, rounded off on the outer angle so that the inner border is not arcuate; teeth of the inner border prominent, acute, recurved, somewhat divergent; movable hook short and stout.

Legs somewhat hairy; tibial hooks on the anterior and middle pairs well developed. Wing-cases reaching the middle of the 4th abdominal segment.

Abdomen ovate, widest across the 7th segment and narrowed rather suddenly upon the 9th. No dorsal hooks at all, but a faint impressed median line on the anterior segments; lateral spines on 8 and 9 small, angular; 9th abdominal segment longer than the 8th and three times as long as the 10th. Appendages longer than the 10th segment, stout pyramidal, laterals one half to one third shorter than the others.

VII. Dromogomphus Selys.

One of the three species of this American genus has been found in Illinois. The nymph may be known by the median ridge on the 9th abdominal segment, ending behind in a sharp spine. The imagos resemble those of *Gomphus.*

Dromogomphus spinosus Selys.

Gomphus sp., Hagen, '85, p. 265, No. 19 (nymph).

This appears to be quite rare in Illinois, and we do not know that any one has ever taken the nymph within our boundaries. Walsh records the imago from the Des Plaines River, near Chicago; and Mr. Adams, from Kankakee, July 6. It has been taken in a number of states between Maine and Florida on the east and Texas and Illinois on the west. Kellicott found it common in Michigan July 15 to August 1, and gives the following interesting notes: "The female was several times found ovipositing in a manner similar to *Macromia illinoiensis*, that is, by skimming the water and every few feet or rods touching the water with the abdominal tip, scarcely checking her speed; at other times I have seen them drop down from an overhanging tree and repeatedly tap the water, remaining in one place after the manner of *Libellula*. Pairs were noticed to fly up into tree-tops, and remain in union for a considerable time." The earliest date is June 5, given by Williamson. Miss Wadsworth observed an individual devouring a *Calopteryx maculata*.

The nymph has been bred by Calvert, and imagos, nymphs, and exuviæ were collected by Mr. Needham—all three at the same time and place—near Ithaca, N. Y., in June. Hagen's nymph No. 19, from Michigan, is probably this species.

The nymph measures 34 mm.; abdomen, 22 mm.; width of head 5.5 mm., of abdomen 7 mm.

Body elongate, nearly smooth. Antennæ a little more approximated than in related genera, the 3d segment more upcurved at the tip. Labium moderate, mentum slightly widened all the way to its apex; median lobe a little concave, with minute median tooth and a sparse fringe of flat hairs either side of the tooth; lateral lobes short and stout, the apex incurved in a stout hook which considerably exceeds the 8 truncate teeth of the inner margin. Tibial burrowing hooks strong.

Abdomen cylindric, becoming sharply triquetral in cross-section posteriorly. Dorsal hooks on segments 2 to 9, on 2 rudimentary, but becoming well developed posteriorly, and on 9 straight, almost equaling the lateral spines and confluent anteriorly with the sharp mid-dorsal ridge. Lateral spines on segments 6 to 9 increasing in size posteriorly. Appendages a little longer than the 10th segment, their apices bent a little so as to be divergent; laterals a little shorter than the others.

VIII. Gomphus Leach.

The nymphs of this large and difficult genus represent the typical and most abundant form of the family. The wing-pads are not divergent, as in *Progomphus*, *Herpetogomphus*, and *Diastatomma*, nor the third antennal joint subcircular, as in *Hagenius* and *Lanthus*; nor are the abdominal segments armed with spinose dorsal hooks, as in *Dromogomphus*. Their habits are very similar to those of the rest of the family, with the exception of *Hagenius*, as described fully under the family heading. Observations by Mr. Needham at Ithaca and by Mr. Hart at Havana indicate a nymphal life of more than one year; in the case of *G. villosipes*, of two years. The imagos are all much alike, of medium size, with clear wings, the triangles normally without cross-veins, the thorax with green or yellowish stripes. They disappear rapidly after transformation, and are not usually common.

KEY TO THE KNOWN NORTH AMERICAN NYMPHS OF GOMPHUS.

AAA. Four pairs of lateral spines; lateral labial lobes rather finely toothed, with 6 to 12 teeth; side margin of 9 spinulose or denticulate, 10 (last) wider than long. (*Gomphus* Needh.)

aa. Dorsal hooks represented more or less on 2 or 3 to 9.

bb. Dorsal hooks distinct, each produced at the hinder margin of its segment in a pointed median tooth; side margins of 9 spinulose.

cc. Lateral spines of 9 about as long as segment 10; 9 thrice as long as 10. 1. sp. (*a*).

c. Lateral spines of 9 reaching about half way to the apical angles of 10; 9 twice as long as 10. 2. *graslinellus.*

b. Dorsal hooks feebly elevated, only the last two or three forming median teeth in the hind margin of the segment; side margins of 9 obsoletely denticulate. 3. *descriptus.*

a. Dorsal hooks represented only by median teeth in the posterior margin of 8 and 9; a fine smooth median line on the preceding segments; 9 spinulose laterally, 10 very short.

dd. Lateral spines of 9 distinctly shorter than the distance to the median tooth of the segment; labial apical hook sharp, projecting beyond the teeth.

ee. Lateral spines of 9 broad, scarcely longer than those of 8; length of ventral surface of 9 at middle a little more than one third its basal width; abdomen less than twice as long as broad. 5. *abbreviatus.*

e. Lateral spines of 9 about twice as long as those of 8; length of ventral surface of 9 at middle about one half its basal width; abdomen more than thrice as long as broad. 6. *vastus.*

d. Lateral spines of 9 slender, elongate-acuminate, incurved apically, nearly or quite as long as the distance to the median tooth of the segment; labial apical hook not projecting beyond the teeth. 9. *externus.*

AA. Three pairs of lateral spines, the first pair very small; teeth of lateral labial lobes mostly distinctly separated by rather deep incisions, and obliquely truncate; median lobe rather prominent, a small projecting tooth at middle; side margins of 9 entire, more or less fringed with soft hairs, 10 (except in *spicatus*) as long as, or longer than, wide; only a trace of a median posterior tooth on 9. (*Arigomphus* Needh.)

ff. Last three segments evenly tapering, length of ventral surface of 9 at middle about three fourths of its basal width, 10 wider than long; traces of dorsal hooks; labial apical hook prominent, toothed on its inner side but not appearing bifid. 10. *spicatus.*

f. Last three segments concavely tapering, length of ventral surface of 9 at middle about equaling its basal width, 10 longer than wide; a low scurfy median abdominal ridge.

gg. Labial apical hook as in *spicatus*; lateral spines of 9 not over one fifth as long as the inferior appendages. 11. *australis.*

g. Labial apical hook and outermost tooth united to form a prominent bifid apical tooth.

hh. Lateral spines of 9 not over one fourth as long as posterior appendages. 12. *villosipes.*

h. Lateral spines of 9 about as long as inferior appendages. 13. *pallidus.*

A. Four pairs of lateral spines (minute in *spiniceps*); labial apical hook large and strongly incurved; teeth few, 0–5, usually 2 or 3, broad and subtruncate, separated by deep narrow incisions; side margins of 9 entire, often fringed with soft hairs, as in *AA*, 10 not longer than wide.

ii. Dorsal hooks very small, pointed on 6 to 9; lateral labial lobes 4-toothed. 14. *exilis.*

i. Dorsal hooks wanting, except usually a distinct median tooth in the hind margin of 9; a fine smooth median abdominal line; labial lobes rarely more than 3-toothed.

jj. Length of ventral surface of 9 along median line not more than half its width at base.

kk. Dorsal hooks entirely wanting; lateral spines of 9 as long as segment 10. 16. sp. (*b*).

k. A broad triangular flat dorsal median tooth in the hind margin of 9, as long as segment 10; lateral spines of 9 twice as long as 10. 17. sp. (*c*).

j. Length of ventral surface of 9 more than half its width at base; apical hook of anterior tibiæ very small. (*Stylurus* Needh.)

lll. Ventral surface of 9 distinctly shorter than its basal width; lateral spines of 9 about one third as long as their distance from the median dorsal tooth of the segment; median tooth minute. 18. *amnicola.*

ll. Ventral surface of 9 about as long as its basal width; lateral spines of 9 at least two thirds as long as the distance to the median tooth. 19. *plagiatus.*

l. Ventral surface of 9 twice as long as its basal width. 21. *spiniceps.*

1. *Gomphus* sp. (*a*).

Gomphus sp., Hagen, '85, p. 264, No. 17 (nymph).

This species is known only from a single nymph described by Dr. Hagen from Indiana. It may be distinguished by the following characters:

Length 30 mm. Lateral lobes of labium with a sharp bent apical hook and ten strong teeth; median lobe straight; segment 9 longer than 8, three times as long as 10; lateral spines on 6 to 9, sharp, the last pair as long as 10; lateral margins of 7 to 9 serrate; dorsal hooks well marked on 2 to 9, sharply pointed; appendages as long as last segment.

2. *Gomphus graslinellus* Walsh.

Imagos of this species have been reported from the states of Washington (Hagen '85, p. 264), Indiana, and Ohio. The State Laboratory has a number of the nymphs from the shallows of Cedar and Sand lakes, in northeastern Illinois, taken in June, August, and October, many young occurring in the latter month. It is common in ponded waters near Urbana, but apparently does not occur in the bottom-land lakes and streams about Havana. Mr. Needham studied the species at Purington Lake, near Galesburg, Ill., in 1895, collecting and rearing a large number of nymphs. His notes are as follows: "Very early in the spring I obtained from steep clayey banks in the lake nymphs lacking one and two molts of maturity. Placed in my aquaria these nymphs quickly descended into the mud of the bottom until only the upturned tip of the abdomen remained exposed, then burrowed along parallel to the surface, leaving a shallow groove to mark their course. When out of the mud they crawl stiffly and very slowly, but swim fairly well under compulsion, by expulsions of water in the usual manner. Transformation takes place commonly between daybreak and sunrise. The nymph usually crawls but a few inches from the water, and appears to transform oftenest while lying flat upon the bare earth or upon tangled mats of dwarf club-rush and other semiaquatics. Exuviæ picked up in such places are usually incrusted with mud. The species appears on the wing in Illinois about the 20th of May, and flies for about a month. Imagos were oftenest seen when flushed from the grass or from the bare paths which terraced a steep hillside beside the lake. Females were little in evidence. I took one ovipositing and obtained in a tumbler of water an immense number of eggs."

Other Illinois localities for the imago are Coal Valley Creek (Rock Island county), Des Plaines and Chicago Rivers; Chicago, Bloomington, and Urbana,—the dates ranging from late in May to the early part of July. They were observed emerging numerously at Urbana on May 27.

The nymph was described by Hagen ('85, p. 264) and connected with this species by supposition.

The nymph measures in length 32 mm.; abdomen, 21 mm.; hind femur, 6.5 mm.; width of abdomen 8 mm., of head 6 mm.

Body depressed. Color yellowish brown with darker markings on sides of thorax, on wing-cases, and on median dorsal area of abdomen. Lateral margins of body and appendages fringed with luteous hairs, except on tapering posterior end of abdomen. Scars prominent.

Head compact, notched behind; hind angles broad.

Labium stout, short, not extending posteriorly beyond the bases of the fore legs. Mentum flat, broad, slightly narrowed at base; median lobe very slightly rounded, margined with a dense comb of flat bristling hairs, lateral lobes arcuate, narrowed to an incurved tip within which are about nine teeth on the inner margin. Movable hook long, stout, incurved, and rather bluntly pointed.

Abdomen widest across segment 6, acutely narrowed to the tip; segments 3 to 8 of about equal length, 9 one half longer than 8; 10 cylindric, less than half the length of 9; short lateral spines on 6 to 9, increasing in length posteriorly, those of 9 reaching slightly beyond the middle of 10; small dorsal hooks on segments 3 to 9, best developed on 4 to 6. Superior and inferior abdominal appendages longer than segment 10; laterals shorter than the others.

Younger nymphs lacking two or three molts of maturity do not differ in any essential character. A quite young nymph, 8 mm. long, has dorsal hooks on 8 and 9, well marked only on 9, with merest rudiments on the middle abdominal segments. The four pairs of lateral spines are all present.

3. *Gomphus descriptus* Banks.

G. descriptus Banks, '96.

This was recently described from specimens taken in New York May 15-21. Williamson's statement that it occurs in

Illinois is based on an erroneous determination. The only nymphs of this species known to us were found by Mr. Needham in New York. It abounds in all the streams about Ithaca, transforms in May by thousands, and scatters to the woods. Many imagos were seen by him foraging about the borders of upland woods and going to rest at night among the branches of trees, but he did not observe their breeding habits.

Transformation takes place generally before daylight and within a few inches, or at most a few feet, of the water's edge.

The nymph measures 29 mm.; abdomen, 18 mm.; hind femur, 7 mm.; width of head 5.5 mm., of abdomen 8 mm. Body very flat and hairy; legs and antennæ and lateral margins of head very hairy. Head depressed and wedge shaped.

Labium short; mentum squarish beyond the narrowed basal third; median lobe nearly straight; lateral lobes very arcuate, ending in a distinct hook on the inside of which is a very broadly pyramidal tooth; proximally the lateral lobe bears on its inner side a series of 7 to 9 short, broad, slightly recurved teeth; movable hook long and strong.

Abdomen lancet shaped; scars above and ganglion pockets beneath very plainly marked; segments 2 to 8 about equal in length, 9 one half longer, 10 half as long as 9; dorsal hooks reduced to broad median swellings on segments 2–9, not hooked nor pointed; lateral spines on 6 to 9, those of 9 about one half as long as 10. Superior and inferior appendages one third longer than 10, laterals a little shorter.

4. *Gomphus quadricolor* Walsh.

This imago is seldom captured in Illinois. The nymph is unknown. Walsh's examples were taken at Rock Island. Mr. Adams took the imago at Bloomington June 23. Kellicott made three captures in Ohio, May 20 to June 15; Williamson found one June 26; and it is also on record from Indiana, Michigan, and Massachusetts. It rests, according to Kellicott, on rocks projecting from rapids, or on the banks near by the most rapid parts of large streams.

5. *Gomphus abbreviatus* Hag.

The nymph was collected and bred by Mr. Needham at Ithaca, N. Y., and is here described for the first time. It is not an Illinois species, and seems quite rare and limited in range, imagos being recorded only from Maine, Massachusetts, and (with doubt) Pennsylvania. The only date found recorded for the imago is June 10 (Harvey).

The nymph measures 24 mm.; abdomen, 15 mm.; hind femur, 5.5 mm.; width of head 5.5 mm., of abdomen 8 mm.

Body very flat, very scantily hairy on the margins. Antennæ with the third segment flattened and widened toward the tip. Labium short; mentum narrowed in its basal fourth, beyond which the sides are parallel, median lobe a little convex and with a median marginal tooth in the midst of the fringing flattened hairs; lateral lobes regularly narrowed and incurved to a point which is a little longer than the teeth on the inner border; teeth about eight, quadrant-shaped, pointed at the lower apical angle, successively decreasing in size proximally.

Abdomen flat oval. Conspicuous lateral spines on segments 6 to 9, increasing in stoutness posteriorly, the last about as long as segment 10. Dorsal hooks represented by minute rudiments on 8 and 9; a smooth median line anteriorly to this. Appendages yellow, almost twice the length of the 10th segment, the laterals a little shorter than the others, the superior a little bent upward at the extreme tip.

6. *Gomphus vastus* Walsh.

Walsh found this species emerging in company with *notatus* and *fraternus* "in considerable numbers" at Rock Island, on the Mississippi, and described the imago as a new species ('62, p. 391). Riley (Hagen, '85, p. 265) also reared it from the Mississippi River at Hannibal, Mo. (not "Ill."). The nymph is in Dr. Kofoid's private collection, taken in deep water in Detroit River. The imago is reported from Illinois, Iowa, Indiana, Michigan, Ohio (common in July), Pennsylvania, and several

Atlantic coast states, but seems less abundant in Illinois than some other species. Walsh notes an imago taken June 16 eating one of the larger caddice-flies, *Macronema zebratum*. Kellicott ('96, p. 111) describes the habits of the imago as similar to those of *fraternus*, and says they copulate at rest in trees or shrubs. The time of flight seems to be from the latter part of May through July. Our Illinois imagos are all from the vicinity of the Mississippi along the northwestern border of the state. Williamson says they frequent the larger rivers and lakes, the males being more often found near the water's edge, the females in fields or along roadsides.

The nymph has been described and figured by Cabot ('72, p. 3, Pl. II., Fig. 4) and again by Hagen ('85, p. 265). The following brief description is condensed from that of Dr. Hagen.

The nymph measures 31 mm. in length.

The mentum of the labium is one third longer than broad; the front border of the median lobe is straight, fringed with *long* flat scales; the lateral lobes end in a long sharply incurved point, inside which the toothed inner margin is concave. Abdomen slowly tapering posteriorly, in outline rather bluntly pointed. Ninth abdominal segment three times as long as the 10th, and a little longer than the 8th. Lateral spines on the 6th to the 9th segments, those of the 9th as long as the 10th segment. Dorsal hooks on the 8th and 9th segments. Appendages nearly twice as long as the 10th segment.

7. *Gomphus ventricosus* Walsh.

A widely distributed but rare species in collections. It was originally described from Rock Island, Ill., and has since been listed from Michigan, Massachusetts, and Virginia. The nymph is unknown.

8. *Gomphus fraternus* Say.

This species and the following (*externus*) are closely related but specifically distinct. The nymphs of *fraternus*, if any are in our collections, have not been distinguished from those of *externus*, which is a common species at Havana. Dr. Hagen's

No. 17 ('85, p. 264) which he thought might be *fraternus* is probably not. Walsh states that he found this with other species emerging in considerable numbers on the Mississippi at Rock Island. Kellicott says that it is common in Ohio from May to the first part of July, and flies about the swiftest and most turbulent parts of the river ovipositing in rapids and rough waters. The State Laboratory has a single imago taken near the upper Sangamon, at White Heath, May 18. *Fraternus* is chiefly eastern in its distribution; *externus*, western. In addition to the localities already given, the present species is listed from New York, New Hampshire, and Virginia; Michigan, Indiana, and Arkansas.*

9. *Gomphus externus* Selys.

G. consobrinus Walsh.
G. adelphus (suppos.) Hagen (nymph).

The nymph of *externus* is readily recognized by the breadth, form, and large lateral spines of the ninth segment, and by the entire absence of dorsal elevations or hooks except a rudimentary posterior tooth on the eighth and ninth segments. This species and *G. notatus* are the most abundant gomphids in the field of the Biological Station at Havana. They are usually found in company, burrowing, mole-like, in the soft mud bottom wherever a sufficient current is maintained at all stages of water, and becoming especially numerous in sheltered areas where there is an accumulation of fine trash on the bottom. They are quite common throughout the year in muddy flats about the point where the waters of Quiver Creek become lost in Quiver Lake, and along the line of the channels of the Illinois and Spoon rivers, especially in the narrower part of the Illinois down from the mouth of the Spoon. They are seldom seen at any of the lake stations. *Externus* is also represented in the State Laboratory collections from the vicinity of the Mississippi River at Quincy, where it was common in the muddy side passages and the adjoining narrow slough-lakes; from the

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*The imagos described as *G. fraternus walshii* by Kellicott ('99) have been determined by Calvert ('01) to be *crassus*. See also foot-note on next page.

Rock River, in northern Illinois; from the Sangamon, in the central part of the state: and from the Big Muddy at the south.

Transformation was first observed May 21. Mr. Needham's notes of his observations on this species while at Havana are as follows: "Transformation takes place in the night or very early morning. The nymph crawls but a little distance (one to two feet) out of the water before fixing itself for emergence. I have found exuviæ on bridge piers and on willow stumps, and have taken imagos emerging in such places at about six o'clock on several mornings."

The strong-flying imago was not uncommon at Havana during July, 1896. The males were frequently seen chasing each other over the open river, or sitting at rest on the sand at the bank with the abdomen elevated and the wings declined until their tips touched the sand, in a position of great alertness. The females fly less openly. One female captured in the weeds at the bank, deposited for me in a watch-glass of water in a few minutes' time about 5,200 eggs. This number is an estimate from a partial count.

An observation on the food of the imago was made by Mr. Needham, who found on shore a female *fraternus* engaged in eating a teneral imago of *Mesothemis simplicicollis*.

Examples of the nymphs collected in June were placed in breeding-cages immersed in the water of Quiver Lake beside the field laboratory of the Biological Station. They remained without transforming, and at the close of the season's work, September 28, seventeen nymphs, nearly the original number, were still alive in the cage.

About the middle of July, after a severe rain storm, several dead males of this species were picked up from the guards of cabin-boats along the Havana river-front.

The imago is reported from Illinois, Nebraska, Kansas, Texas, and New Mexico. In Illinois it has been taken in Henderson county, as well as at Havana and Rock Island.*

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*According to Calvert, the imagos described as *externus* by Kellicott ('99) and Williamson ('00) are *G. crassus* Hagen, a species not yet found in Illinois, which is quite unlike *externus* in the form of the terminal appendages of the male.

The nymph measures in length 32 mm.; abdomen, 20 mm.; hind femur, 6 mm.; width of head 5.5 mm., of abdomen 8 mm.

Body stout, only moderately depressed. Lateral margins of body and appendages hairy. Tibial hooks very prominent.

Labium short and stout; mentum a little longer than broad and narrowed at basal third; median lobe very faintly rounded; lateral lobes short, thick, and not strongly arcuate, ending in two teeth which are hardly distinguishable from the five to ten other teeth which extend in a diminishing series down the inner margin; movable hook short, stout, tapering, and regularly curved to its tip.

Abdominal segments 3–8 about equal, 9 one half longer, 10 very short, one third as long as 9; a smooth median dorsal line ending on 7; rudimentary dorsal hooks on 8 and 9; lateral spines on 6 to 9, incurved at tip, those of 9 about twice the length of segment 10. Superior and inferior abdominal appendages twice as long as segment 10, laterals a little shorter than the others.

Younger nymphs dredged from the bed of the stream differ only in size and in the shortness of the wing-cases.

This nymph agrees in every point with the very careful description given by Hagen ('85, p. 262) for "*Gomphus adelphus* (supposition)."

10. *Gomphus spicatus* Selys.

In the collections of the State Laboratory are many examples of a nymph resembling *graslinellus*, all taken from shallow waters in Sand and Cedar lakes, northeastern Illinois, associated with that species, during June, August, and October. Dr. Ward has sent me another of the same species from a lake near Charlevoix, Mich. These nymphs we can properly assign to *spicatus*, imagos of which were collected at the same place, and which is one of the very few Illinois gomphids whose nymphs yet remain unknown.* The nymphs from Cedar Lake

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*Mr. Needham has since verified this supposition by breeding.

referred by Hagen to *pallidus* ('85, p. 267) are of this species. Imagos of *spicatus* were taken by Mr. Hart at Cedar, Sand, and Fox lakes, June 15–22, 1892. This is its first record from Illinois, it having been previously listed only from Canada, Massachusetts, New York, and Ohio. In the latter state it was common in the northern part, flying in June, the latest date, being July 1. Van Duzee found the imago in a swamp. Kellicott found it along wave-washed shores, the males flying out over the water, the females, when not ovipositing, remaining on herbage or trees on shore.

The nymph, not quite fully grown, measures 28 mm.; abdomen, 18 mm.; hind femur, 5 mm.; width of abdomen, 6 mm., of head 5.5 mm.

Body flat, hairy on legs and lateral margins. Color yellowish, eyes black; fuscous mottlings at base of wing-cases and on sides of abdominal segments between the yellow mid-dorsal line and the scars, sometimes forming oblique streaks.

Labium moderate; front border of median lobe nearly straight; lateral lobes short arcuate, with a sharply incurved end hook, on the inner margin 6 to 9 short rectangular backwardly directed teeth.

Wing-cases reach the 5th segment.

Abdomen nearly 3 times as long as wide, lateral spines on segments 7 to 9 increasing in size posteriorly, those of 9 half as long as segment 10. No dorsal hooks; traces of mid-dorsal smooth line apparent on middle segments. Lateral margins of 8 and 9 subentire; segment 10 half as long as 9. Appendages longer than segment 10, the laterals shorter than the others.

11. *Gomphus australis* Needh.

This is a Florida species, described as new by Mr. Needham ('97, p. 184). Nymphs supposed by him to belong to *australis* were collected near Gotha, Fla., in December, 1896, and in January, 1897, by Mr. Adolph Hempel, who took a single male imago at the same place a little later. Morphological characters entirely justify their reference to this species.

The nymph (supposition) measures 30 mm.; abdomen, 20 mm.; hind femur, 5 mm.; width of head 5 mm., of abdomen 5.5 mm. Olivaceous, yellowish below and on sutures.

Body slender, pointed posteriorly, moderately hairy on margins and on all appendages.

Head compact, hind angles prominent, rounded, a pair of small black tubercles on hind margin between these angles and the median line. Antennæ long, considerably exceeding the labrum. Eyes large, black; ocelli yellow.

Labium moderate; mentum narrowed for its posterior two fifths; median lobe very slightly curved, fringe of flat scales short, in the middle of it a single simple or bifid tooth or a double one, which is shorter than the scales; lateral lobes stout, suddenly narrowed and sharply incurved to form the prominent end hook, which bears usually a minute denticle on its inner side. Inside the end hook there are about eight obliquely truncate, short, quadrangular, posteriorly directed teeth.

Hook long, strong, arcuate.

Legs short; tibial hooks of fore and middle legs well developed.

Abdomen somewhat depressed, attenuate posteriorly and upcurved, widest on segment 4 ; segments 3 to 7 and 10 all subequal in length, 8 a little longer, 9 one half longer than the others, margins of 9 yellowish. No dorsal hooks, or on 9 the merest rudiment; lateral spines on 7–9 short, appressed, minute on 7 and 8, on 9 only about one eighth the length of 10. Inferior appendages about as long as segment 10; superior a very little shorter, its basal half thickened; laterals a little shorter than superior and much more sharply pointed

A young nymph one fourth grown differs from the mature ones only in size and in having but 6 or 7 teeth on the lateral lobe of the labium.

12. *Gomphus villosipes* Selys.

This elusive gomphid was bred by Mr. Needham in large numbers at Ithaca, N. Y., in May, 1897. The imago has never been taken in Illinois, but there is a well-marked nymph of this species in the State Laboratory collection from Swan Pond, near the Wabash River in southeastern Illinois. The nymphs were exceedingly abundant at Ithaca. Two distinct sizes were observed, a fact which, taken in connection with the extremely short period of emergence, strongly indicates that the species takes two years to complete its life cycle, the nymph hatching in one season not transforming until the second season thereafter. Two males were all the imagos seen at large, yet exuviæ in countless numbers lined the banks of all streams. The perching habits of these two males were about as described further on for *G. pallidus.* The imago has been taken as far west as Michigan and Ohio. It flies in early summer, the recorded period being May 30 to June 26.

Kellicott says of *villosipes*, *exilis*, and *furcifer* that they "frequent quiet waters of smaller ponds, or even ditches where there are floating algæ or lily-pads on which to rest. The males explore the borders and watch from the muddy shore or floating plants; the females at intervals drop down from their coverts to oviposit among the plants, dipping into the water in a manner similar to that of *Libellula*."

The nymph measures 37 mm.; abdomen, 24 mm.; hind femur, 6 mm.; width of head, 5.5 mm., of abdomen 8 mm.

Form identical with that of *G. pallidus.* Lateral margins of apical segments of abdomen marked rather showily with yellowish, especially beneath. Labium as in *G. pallidus*, but with the fringe of hairs bordering the median lobe shorter, the lateral lobe arcuately incurved at the apex, its extreme point shorter than the first of the six stout posteriorly-directed teeth upon the inner margin. Lateral spines well developed only on the 9th segment. Dorsal hooks almost entirely wanting, even on the 9th segment. Appendages shorter than the 10th segment, the laterals a little shorter than the others.

13. *Gomphus pallidus* Ramb.

Mr. Needham studied this species at Purington Lake, near Galesburg, where it was found in company with *G. graslinellus.*

In his notes he says it corresponds with the latter species in habitat, season of flight, habits of oviposition, and nymphal habits, but is, he observes, a rather more vigorous and active species. Male imagos have a habit of resting flat upon the bare earth of a path or sloping bank at the water's edge and making short sallies forth across the water, whether for prey or for sport or for outlook he was unable to determine. The nymph may be known by its peculiar form and the obtuse ridge along the middle of the abdomen above. Its preference for still water is plainly indicated in the Biological Station field, as it was found only in bare mud and sand on the bottom of Clear Lake and Matanzas Lake. In the latter it was quite common in the level lake-bottom, under about six feet of water. In the Laboratory collections are also specimens from Mississippi River lakes and sloughs near Quincy, and some from the Saline River near Shawneetown. It did not occur in our collections from the Sangamon River. Hagen reports nymphs from Michigan, Massachusetts, South Carolina, and Texas.

Dr. Forbes took an imago, just emerged, at Peoria in June, 1878. At Matanzas Lake, near the Biological Station, fresh exuviæ were noted July 6 on a log near the water, and imagos were taken near by. A single example was taken May 27 at Urbana. The season of flight at Purington Lake was considerably later than that of *graslinellus*, according to Mr. Needham. The first adult was seen May 28; the maximum abundance was attained July 4 and early in August the last ones disappeared—a period of about two months, which is about twice as long as that of the commoner species *graslinellus*. Although the latter imago is fairly common, that of *pallidus* is singularly rare in collections—almost unknown, in fact. It is recorded only from Indiana, Georgia, and Louisiana. The *Odonata* offer several remarkable instances of this kind, which should put us on our guard against wrong judgments of distribution and relative abundance based on the finding of imagos alone.

In view of existing descriptions and figures, (Cabot, '72, p. 2, No. 2, Pl. I., Fig. 3; Hagen, '85, p. 266) it will be necessary here to give only those nymphal characters which are distinctive.

The nymph measures in length 38 mm.; abdomen, 26 mm.; hind femur, 7 mm.; width of abdomen 8 mm., of head 6 mm.

Body flat, elongate, gracefully tapering posteriorly; surface but little hairy.

Labium with median lobe of mentum rather prominent, a median apical tooth on its front margin, in the middle of the usual comb of flat spinous scales; lateral lobe with a blunt-pointed and incurved apical hook, and on the inner margin seven or eight long irregular teeth, widening apically, and obliquely truncate so as to appear to be directed backward.

Abdomen lanceolate, attenuate to apex, slowly tapering for half its length, to the cylindrical 10th segment; a dorsal hook on segment 9, represented on other segments by obtuse ridge-like elevations; lateral spines on segments 7 to 9, on 7 minute, on 8 short, on 9 long, closely appressed, nearly equaling the length of segment 10; superior and inferior appendages subequal, shorter than segment 10, laterals a little shorter than the others.

Half-grown nymphs show clearly all these characters.

14. *Gomphus exilis* Selys.

In the Atlantic coast states from Maine to Maryland this species is often abundant. In Illinois the imago has been taken at Crystal Lake, about 40 miles northwest of Chicago, by Mr. Longley, and at Kensington by Mr. McDade. Williamson records a few examples from Indiana, and according to Kellicott it is common throughout Ohio, especially about canals and ponds. Hagen has described the nymph ('85, p. 263), and doubtfully referred to the same species some examples sent him from Kentucky. Dr. Calvert records it as the first gomphid to appear in spring (May 24), its season of flight lasting until the early part of July. The extreme recorded dates are May 9 (Kellicott) and July 8 (Williamson).

The following brief statement of the characteristic features of the nymph is selected from Dr. Hagen's description.

Length, 19 to 24 mm. Body rather slender; median labial lobe very faintly rounded, lateral lobes ending in a strongly bent and pointed hook, with four strong teeth inside; abdomen tapering slowly after segment 6, segments as far as 8 of equal length, 9 a little longer than 8, 10 half as long as 9, cylindrical; lateral spines on 6 to 9, the last one third as long as 10; dorsal hooks very small, pointed on 6 to 9; appendages as long as last segment; third joint of hind tarsi scarcely longer than second.

15. *Gomphus cornutus* Tough.

G. cornutus Tough, ('00).

This recently published species, readily recognized by the unusual form of the male abdominal appendages, was described from two males from DuPage county, taken May 30 and June 14. The Bolter Collection contains additional male and female examples, but without data.

16. *Gomphus* sp. (*b*).

Gomphus sp., Hagen, '85, p. 262, No. 14 (nymph).

This interesting species, described by Hagen from three nymphs collected by Prof. Forbes at Cairo, Ill., July 26, is quite distinct from any other known to us. The following are the principal distinctions:

Length, 18 to 23 mm. Body flat; lateral labial lobes with only two incisions near the strong and sharp apical hook, median lobe slightly rounded; side margins of abdomen very hairy, segment 9 as long as 8, 10 very short; lateral spines on 6 to 9, the last less sharp, as long as 10; no trace of dorsal hooks; appendages as long as 9, broad; anterior tibial hooks short.

17. *Gomphus* sp. (*c*).

Gomphus sp., Hagen, '85, p. 263, No. 15 (nymph).

A single nymph received from Newport, Ky., by Dr. Hagen is similar to the preceding, but was believed by him to be a distinct species, perhaps *G. minutus*.

Length 23 mm. Body flat; lateral labial lobes with a sharp bent apical hook, and but three strong teeth near tip; abdomen tapering slowly from 7th segment, 9 one third longer than 8, 10 very short, one sixth of 9; lateral spines on 6 to 9, sharp, the last pair twice the length of 10; no dorsal hooks, except that 9 bears a broad, triangular, flat, median apical projection as long as 10; appendages twice as long as 10.

18. *Gomphus amnicola* Walsh.

? *G. olivaceus* (suppos.), Hagen, '85, p. 271, No. 27 (nymph).

This and the remaining species here treated belong to the subgenus *Stylurus*. Williamson has made a thorough study of this troublesome group of species. A copy of his revision of the subgenus (Williamson '01b) has been received from him just as these pages are being set up by the printer, enabling us to incorporate his data concerning the geographical and seasonal distribution of the species, derived from a large number of specimens examined by him.

A single nymph in the State Laboratory collection, taken at Colona, Henry Co., Ill., August 20, is almost identical with that described by Hagen from Utah and connected by supposition with *G. olivaceus*. It stands in about the same relation to *Gomphus notatus* that the imago *amnicola* does, and may be assigned to this species.

Mr. Needham is of the opinion that the affinities of both the present species and *G. scudderi* are with the *dilatatus*, rather than the *plagiatus* (*Stylurus* Needh.), group of species, in which case the nymph here assigned to *amnicola* may be wrongly placed. It is earnestly to be hoped that the nymphs of these species may soon be discovered, as this would doubtless throw much needed light on their specific relationships.

The imago of this species has been taken in Illinois only along the Mississippi in the northwestern part of the state, and by Mr. Longley at Riverside, near Chicago. It was found at Rock Island and described as new by Walsh. Our specimens were captured at Savanna, August 1, by Mr. F. M. McElfresh.

Single examples are also listed from Galena, Ill., and from Iowa (July), Kansas, and New York. It was taken by Mr. Longley in June.

The principal characteristics of the nymph are as follows:

Nymph (supposition) very similar to *G. notatus*; median labial lobe rounded but short, lateral lobes similar to those of *notatus*; abdomen broader, more lance-shaped; 9 a little longer than 8, with a very short apical spine above; lateral spines on 6 to 9, the last one blunt, half as long as 10, which is short, cylindrical; appendages and legs similar to to those of *notatus*.

19. *Gomphus plagiatus* Selys.

G. fluvialis, Walsh (female).
G. notatus, Hagen, '85, p. 270, No. 25 (nymph).
G. plagiatus, Hagen, '85, p. 269, No. 24 (nymph).

This is probably the most abundant gomphid nymph in the larger rivers of Illinois. It may be distinguished from any others herein described by the penultimate (ninth) abdominal segment, with its lateral and basal margins about equal and a rudimentary posterior tooth on the median dorsal line, the other segments being without trace of dorsal hooks or elevations. As already stated under *externus*, it is found about Havana in muddy bottoms where there is current, but not so exclusively in these situations as *externus*. Mr. Garman reported it as the commonest species in waters associated with the Mississippi at Quincy, and states that it does not breed exclusively in running water, presumably basing this statement on the fact that he found it in slough-lakes. These lakes form channels of flow during higher stages of the river, but are more or less completely isolated during low water. Unlike similar waters about Havana, these lakes are but scantily supplied with aquatic vegetation. In our general collection are nymphs from Cairo, Ill., where they are probably common, judging from the number taken; from the Rock River at Colona and Milan; from the Ohio at Golconda; and from the Illinois at Pekin. The species did not appear in extensive collections from the Sangamon in Champaign county. The nymphs were not more common than *spiniceps* or *externus* at the mouth of Quiver Creek, but in the main channel of the Illinois below Spoon River they were the most abundant form. Nymphs have also been taken in Quiver and Matanzas lakes, in the Illinois River at Meredosia, and in Spoon River near Bernadotte, Ill. Examples of this species and *externus* taken in June and placed in breeding-cages immersed in the water along the Quiver Lake shore, remained alive without transformation until the season's work closed at the end of September. This species is very close to *G. notatus*, which is comparatively rare in Illinois, and the nymph of which has not been satisfactorily distinguished from that of *plagiatus*.

The first transforming imago was noted May 21. On July 2, 1894, large quantities of nymphs transformed in the early morning upon the piers of the river bridges. Upon arriving in Havana in the latter part of June, 1897, Mr. Hart found the imagos emerging numerously up to about the end of the month. In 1898 the largest number emerged June 21, and thereafter occasionally up to June 30. Mr. Needham's notes, made while at Havana in July, 1896, are as follows:

"Transformation takes place mostly at night, but not uncommonly late in the afternoon. The nymph crawls a little way (3 to 20 inches) out of the water upon any flat surface. I have found exuviæ sticking to bridge piers and to the sides of barges and fishing boats, to willow stumps, and to bare mud banks. I obtained hundreds of nymphs and exuviæ, and yet during a month spent upon the river collecting I did not see a single imago of this species on the wing. I captured one newly emerged, at dusk, resting in the grass at the bank; no others were obtained except by rearing them. Consequently, no opportunity was found for studying breeding habits and oviposition."

Kellicott also notes the emergence on piling and walls in deep water, and found the imago "resting on coarse grasses during July. None were seen ovipositing, or flying except to escape from danger."

The imagos are reported from Illinois, Texas, Michigan, Ohio, Tennessee, and the Atlantic coast states from New Jersey to Florida, the dates of collection ranging from May 25 to September 30. The period of flight usually ends about August 1, but a single example was taken as late as August 25 at Havana. In Illinois adults have also been listed from Bloomington, Moline, and from Winchester, in Scott county.

The nymph measures in length 35–36 mm.; abdomen, 25 mm.; hind femur, 4.5 mm.; width of abdomen 6–7 mm., of head 5 mm.

Body narrow and elongate, a little hairy on lateral margins and appendages. Head cordate, arcuately notched behind, with broadly rounded but prominent hind angles. External tibial hooks minute.

Labium elongate, mentum one half longer than broad, widened apically; median lobe slightly rounded in front, its comb of scales short and sparse; lateral lobes arcuate and terminating in a sharply incurved hook. Teeth on inner margin varying from none at all to four or five, increasing in size and distinctness proximally. Movable hook long, strong, and regularly incurved.

Abdomen widest on 6, median dorsal smooth line on segments 2 to 7 or 2 to 8; a flattened rudiment of a dorsal hook on 9; segments 3 to 8 of about equal length, 9 one third longer, 10 very short; lateral spines on 6 to 9 appressed, those on 9 half as long as the inferior appendages; appendages about equal and exceeding the length of 10.

20. *Gomphus notatus* Selys.

G. fluvialis Walsh (in part).

The true *notatus* is represented in our Illinois collections by only a single female, taken on the bank of the Mississippi near Savanna August 1. In its wing venation and external sexual structures it seems quite distinct from *plagiatus*. The nymphs described by Hagen as *notatus* and *plagiatus* are probably all *plagiatus*. His description of *notatus* agrees exactly with unquestionable nymphs of *plagiatus*. Walsh apparently included both species in his *fluvialis*, described from specimens collected about Rock Island, but his statements of the habits of *fluvialis*, which are quite unlike those we have recorded for *plagiatus*, very likely apply to *notatus*, and may account for its apparent rarity. He says that while *fraternus* and *vastus* haunt the land and are easy to capture, *fluvialis* "makes long excursions to and fro on the surface of the river, scarcely ever approaching the land except for a second."

Williamson ('01b) lists the species from Illinois, Michigan, Ohio, Tennessee, and Quebec, Canada; June 1 and 21 in Ohio and Michigan, and September 30 in Tennessee.

21. *Gomphus spiniceps* Walsh.

Macrogomphus? spiniceps Walsh, '62, p. 389 (female).
Gomphus spiniceps, Kellicott, '95, p. 209 (male).
Gomphus segregans, Needham, '97, p. 185 (male).

This seems to prefer somewhat rapid currents. Excepting a single example from the Illinois River, the nymphs appear in the Laboratory and Biological Station collections only from Quiver Creek and Quiver Lake near the mouth of the creek.* This creek is a peculiar and beautiful stream, shallow and sandy, fed by springs of soft water flowing out of the sand beds, and hence quite uniform and constant in its flow. At the mouth of this stream *spiniceps* is associated with *externus* and *plagiatus*. The nymph agrees with that of *plagiatus* in having no dorsal elevation or hooks except a single rudimentary posterior tooth on the penultimate segment, but differs from it conspicuously in the form of that segment, which is long and narrow, the lateral margin fully twice the basal width. In this character it resembles *Gomphus pallidus*, but has not the elevated dorsal ridge nor the long tenth segment of that species. As in the case of *plagiatus* and *externus*, nymphs placed in breed-

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*Numerous exuviæ and emerging individuals have since been taken on the rocky walls of the shallow gorge of the Illinois River at Ottawa, July 21 and August 19, the larger number of imagos being secured on the latter date.

ing-cages in June failed to transform, one being still alive on September 28. In 1897 two full-grown nymphs were taken June 22 along shore in the quiet weedy waters of Quiver Lake, not far from the mouth of Quiver Creek. The only imago seen, emerged June 23 from a nymph which we found that day crawling up some blades of bur-reed (*Sparganium eurycarpum*) beside the stream. A number of exuviæ have been observed at various times during June and July on *Sagittaria* stems, brushwood, and the bases of tree trunks along the margin of the creek, from near its mouth to McHarry's Mill, a few miles above.

Cabot ('72, p. 5, Pl. II., Fig. 1) described the nymph from examples taken in Massachusetts July 4, one of them partly transformed, and Hagen ('85, No. 26, p. 270) redescribed it.

Kellicott ('95, p. 209) observed the imagos in Ohio September 4 flying about and ovipositing "in a manner similar to that of the *Libellulas*" in a small brook that was rippling over pebbles, and he later ('96, p. 111) gives the time of flight as August and September. Williamson found the adults transforming abundantly in western Pennsylvania July 4, and also records the species from Tennessee (August) and New York (September). The imago was originally described from Rock Island. Other Illinois localities for the imago are Bloomington and the Mackinaw River at the "Dells."

The nymph measures in length 40 mm.; abdomen, 29 mm.; hind femur, 5 mm.; width of abdomen 7 mm., of head 5 mm.

Body very elongate and posteriorly attenuate, sparsely hairy on lateral margins and on appendages. Tibial hooks minute.

Labium elongate; mentum widened toward the apex; median lobe with a very straight front border; lateral lobes arcuate, with a long-pointed sharply incurved end hook, and on the inner side one to three teeth, though sometimes only the middle one is distinct. These teeth are widened distally, and obliquely truncate so that they appear directed backward. Movable hook long, strong, and more strongly curved toward the tip.

Abdomen very elongate, acuminate toward the end, scarcely depressed; segments slightly increasing in length posteriorly to the 8th; 9 about twice as long as 8, its sides nearly parallel on apical half; 10 very short; smooth mid-dorsal line on 2 to 7, a flattened rudiment of a dorsal hook on apex of 9; short lateral spines on 6 to 9, those of 9 about half as long as the superior appendage; appendages subequal.

Young nymphs in the station collection, dredged from the bed of the creek, some not more than one third grown, show these same characters very clearly marked.

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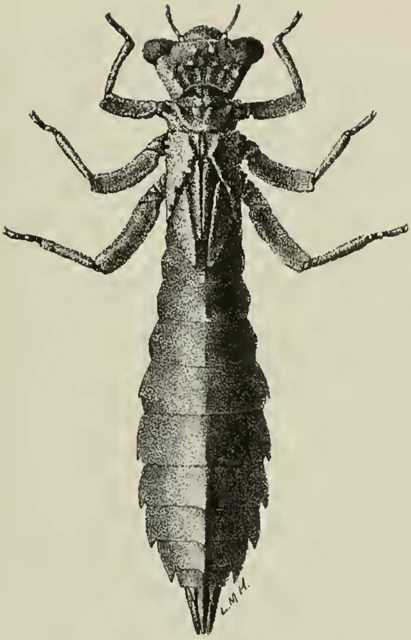
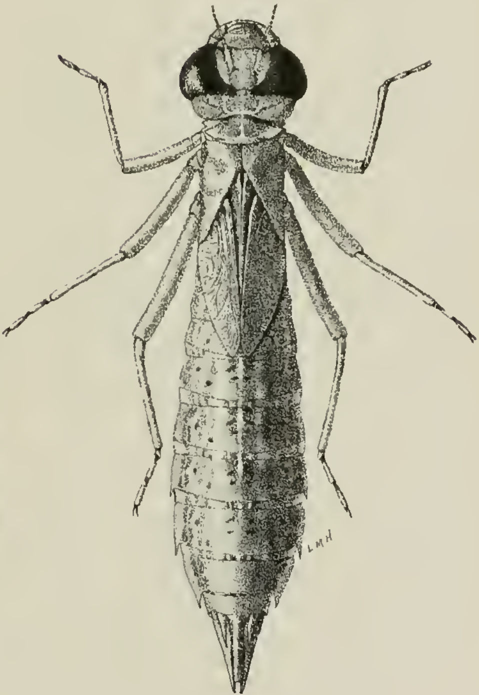
PLATE I.



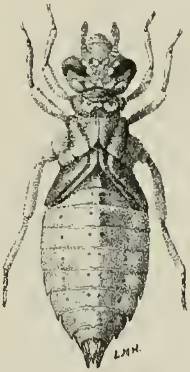
1. *Nasiæschna pentacantha.*

2. *Boyeria vinosa.*



5. *Anax junius.*

3. *Progomphus obscurus.*



4. *Diastatomma carolus.*

NYMPHS.

ARTICLE II.—*Plankton Studies. IV.*[1] *The Plankton of the Illinois River, 1894–1899, with Introductory Notes upon the Hydrography of the Illinois River and its Basin. Part I. Quantitative Investigations and General Results.* BY C. A. KOFOID.

INTRODUCTION.

When the work of the Illinois Biological Station was begun in 1894. it seemed to the Director desirable to determine as far as possible the normal routine of aquatic life as a necessary basis for the detection of problems for investigation and experiment. and as an indispensable background for their adequate solution. Such an investigation demands not only the discovery and specific determination of the biological population, but involves also the study of life histories, seasonal changes, and mutual dependencies of the assembled organisms by quantitative and statistical methods, together with a study of the environment and an analysis of its factors. The plankton presented itself as the most available and concrete assemblage of organisms to which this method of study could be applied, and it afforded, moreover, a problem not only of prime scientific interest. but also of some important practical relation to fishculture. A presentation of the most general results of this investigation of the free microscopic fauna and flora, or plankton, of this typical stream of the Mississippi Valley is the object of the present paper.

Inasmuch as this is the first of a series of reports upon the plankton of the Illinois River system, it has seemed advisable

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[1] The three preceding numbers of this series, all by the present writer, have been published as articles in the Bulletin of the Illinois State Laboratory of Natural History, Volume V., as follows :—

Article I. Plankton Studies. I. Methods and Apparatus in Use in Plankton Investigations at the Biological Experiment Station of the University of Illinois.

Article V. Plankton Studies. II. On *Pleodorina illinoisensis*, a New Species from the Plankton of the Illinois River.

Article IX. Plankton Studies. III. On *Platydorina*, a New Genus of the Family *Volvocidæ*, from the Plankton of the Illinois River.

to treat with considerable detail all those more general features of the environment which pertain to the river as a whole, and which must therefore be considered not only in the discussion of the plankton of the river proper, but also in any investigation of the bottom-land lakes and marshes.

From the vantage-ground of the present development of plankton methods and in the light of the experience gained in the years that have passed, many deficiencies in the work will be evident. To none are they more patent than to the writer. Problems everywhere crowd for solution, and the desirability of additional data and supplementary work will repeatedly appear. In a general survey such as this, many statements of a more or less tentative character must be made which future investigation alone can confirm or invalidate. Indeed, one of the principal values of pioneer exploratory work of this sort lies in the fact that it suggests new fields of endeavor. For the solution of many of these allied problems considerable preliminary work has already been done, but their full discussion falls beyond the scope of the present paper.

The magnitude and complexity of the task have increased with each succeeding year, but it is to be hoped that the conclusions here presented from the data accumulated during this unique opportunity for continuous and systematic observation upon the minute life of a river, will lead to the advancement of the science of limnology.

ACKNOWLEDGMENTS.

For more than a score of years Professor S. A. Forbes has been Director of the State Laboratory of Natural History and State Entomologist of Illinois. The confidence of the public in his good judgment which this service has inspired has been shown by the people, through their legislature, in repeated appropriations for the support of the Illinois Biological Station founded by him in 1894, an institution whose work lies mostly in the field of pure, rather than applied, biological science. To him, then, is due in a very true sense the opportunity of prose-

cuting through a series of years these investigations upon the life of the Illinois River, a problem for whose solution private enterprise and even the usual university facilities are quite inadequate. To him I wish also to make acknowledgment for his valuable directions, suggestions, and encouragement throughout the whole course of the work. To my colleagues of the State Laboratory staff acknowledgments are due for coöperation in manifold ways. The collections of the period preceding July, 1895, were made by Professor Frank Smith or under his direction. He also devised the "oblique-haul" method of collection, and has rendered assistance by the identification of aquatic oligochætes. A portion of the field work in 1894, 1895, and 1896, was performed by Mr. C. A. Hart and Mr. Adolph Hempel. To the former I am indebted for clerical services and for assistance with the aquatic insects and the mollusks; to the latter, for some data concerning the rotifers and the *Protozoa*. During the last seven months of our operations the field work was faithfully attended to by Mr. Wallace Craig. Acknowledgments are also due Mr. Miles Newberry, who from the beginning to the end of our operations served, in summer's heat and winter's cold, as field assistant in the work of collection. His faithfulness and skill in dealing with the frequent difficulties and the occasional dangers of the river situation have added not a little to the success of our work. I am under much obligation to Mr. R. E. Richardson (of the class of 1901, University of Illinois) for most efficient clerical assistance in the laborious task of the counting work and in the compilation and organization of the statistical data resulting therefrom. From Captain J. A. Schulte, Mr. J. M. McHose, and the city authorities of Havana the Station has received many courtesies. Hon. J. M. Ruggles and County Superintendent M. Bollan, of Havana, have also rendered favors by way of information on various points. To many other correspondents I am under obligation for courtesies, and not the least to Mr. G. A. M. Liljencrantz, of the office of U. S. Army Engineer of Chicago, for oft-repeated contributions of hydrographical data.

The Geological and Hydrographic Features of the Illinois River Basin.

These subjects have received elaborate treatment, in connection with the problem of the disposal of the sewage of the city of Chicago, by Cooley ('89 and '91); and by Leverett ('96) in a report to the U. S. Geological Survey upon the "Water Resources of Illinois." The following discussion of those physical features which are more or less directly related to the theme of this paper has been, to a considerable extent, compiled from these papers, with such supplementary data as could be gleaned from the reports of the U. S. Engineers and from the observations and records made by the biological station staff at Havana and at other points along the river.

In many respects the Illinois River may be regarded as a typical stream of the prairie region of the North-Central States; and its basin, in the glaciation of its surface, the level character of the land, the fertility of the soil, the absence of extensive forest areas, the amount of rainfall, the general climatic conditions, and its central position, might well be called a typical one for the central region of the Mississippi Valley. On the other hand, in several very important respects the river presents features and combinations of features that are exceptional and even unique. Foremost among such features is the very large amount of sewage received, an amount largely increased by the opening of the Drainage Canal in December, 1899, by which almost the entire sewage of a metropolis of about two million inhabitants enters the river. This, together with the large amount of organic refuse from the distilleries and cattle-yards along the course of the river, adds immensely to the fertility of its waters, especially when the river is low. Again, the present river is a babe in a giant's bed. The channel and the bottom-lands of the present stream lie in the bed of an ancient outlet of Lake Michigan whose flood-plain constitutes the fertile "second bottom." In this channel of its predecessor the Illinois River is now rapidly building up its flood-plain, the low gradient of the former occupant still persisting. The slight current, the frequent overflows, and the disproportionate extent of water areas in the bottom-lands result from this somewhat unusual ancestry.

LOCATION.

The latitude of the Illinois River is approximately that of the Tagus, the Tiber, the Kezil Irmak, the Oxus, the Yarkand, and the Pei-Ho. Its drainage basin lies between the parallels of 39° and 43° 15′ north latitude and extends from the isotherm of 45° to that of 55°, a belt which, in Europe, includes the areas drained by the Thames, the Seine, the Loire, the Rhine, the Elbe, the Oder, the Vistula, and a considerable portion of the basins of the Black and Caspian seas, and, in Asia, the basin of the Hoang-Ho and that of the Aral Sea. The position of Havana, Ill., near which place our plankton collections have been made, as determined by Mr. G. S. Hawkins, of the U. S. Geological Survey, is 40° 17′ 37″.19 north latitude and 90° 03′ 55″.97 west longitude. The area tributary to the Illinois River at Havana lies between the isotherms of 50° and 55°, and is therefore comparable with the more northerly parts of the regions above enumerated.

GEOLOGICAL FEATURES OF THE ILLINOIS RIVER BASIN.

Illinois is the lowest of the North-Central States, the average elevation being but 632 feet according to Leverett's computations from Rolfe's survey. The range in altitude is from 1,257 feet, at Charles Mound on the Illinois-Wisconsin line, to 268.58 feet, low-water mark at Cairo. Low-water mark at the mouth of the Illinois is 402.56 feet above mean-tide level at the Gulf of Mexico according to the figures given by Cooley ('91, p. 93), 404.7 feet according to Greenleaf ('87), and 402.76 feet according to Rolfe, the different elevations given being based on different surveys. The present bottom-lands from the mouth of the river to La Salle range in elevation from 410 to 440 feet, and bottom-lands slightly higher than these extend for some miles up the Sangamon, and for a short distance along the lower courses of other tributaries in the southern basin The altitude of the river at low water at Havana is given by Rolfe ('94) as 429 feet, and data given by Cooley ('97, p. 60) indicate an elevation of 422.96 feet above mean-tide level at the Gulf of Mexico.* The fertile second bottoms, which are principally on the eastern side of the river, lie from 30 to 75 feet above the first bottoms, while the bluffs range in altitude from 450 to 800 feet, the highest points being reached near Peoria, and near the mouth in Calhoun county. The watersheds bounding the basin range in height from 700 to 1,000 feet, but by far the greater part of the area included has an elevation of 600 to 700 feet, being about the average elevation for the state. The relief of the drainage basin of the Illinois is thus quite insignificant. That part which lies in southeastern Wisconsin is most diversified, while that in the state proper, together with the Kankakee basin in northwestern Indiana, is practically an unbroken plain.

In common with the greater part of the state the basin of the Illinois is covered by glacial drift. West and south of a line drawn through Amboy, Peoria, Shelbyville, and Mattoon, which marks the location of the Shelbyville moraine, this deposit is known as the "older drift," and is from 20 to 150 feet in thickness. The drainage lines are here well developed, the streams in many cases occupying preglacial channels; but to the north and east of this moraine the glacial deposit known as the "newer drift" overlies the older, their combined thickness ranging from 50 to 300 feet. Within this latter region the drainage is not so well developed as it is in the older region to the west and south of the moraine, and the streams, with the exception of the Illinois, do not follow preglacial drainage lines. Aside from a few minor streams between Havana and Peoria, the whole basin of the Illinois above our plankton station lies within the area of this newer drift. It consists of extensive plains of glacial till, separated by glacial ridges or

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*"We seem to be reasonably certain that the elevation of the Illinois at its mouth is 402.76 feet, and that at Beardstown it is 423 feet. We feel somewhat less certain that at Peoria it is 436 feet, and at La Salle 440 feet. Beyond this we can only approximate because the U. S. Engineers and Illinois Canal Commission differ so widely."—PROF. C. W. ROLFE, *in letter*, *Nov. 12, 1901.*

moraines which largely determine the position of tributary streams. Extensive sand deposits are found in the basins of the Kankakee and the Iroquois, and valley drift and alluvium occur along the river and its principal tributaries. These latter deposits along the Illinois River are very extensive, indicating the size of the stream which formerly occupied the valley and connected Lake Michigan with the Mississippi River.

This deposit of valley drift reaches its greatest extent in a strip extending down the river from Pekin a distance of 65 miles. It varies in width from 10 to 20 miles, attaining its maximum a short distance north of Havana. It is a sandy plain, in some localities of which the wind has produced veritable traveling sand-dunes, with characteristic fauna and flora. The drainage basin of Quiver Creek lies mainly in this deposit, while the basins of Kickapoo and Copperas creeks, south of Peoria, lie in the older drift and consist of loess-covered till.

The basin of the Illinois thus lies in a typical prairie region of the Mississippi Valley. To the north and east it is very flat, but to the south and west it presents a more rolling surface. The soil is a rich black loam one to four feet in thickness, underlaid by boulder clay into which the streams have cut their channels. The larger water courses are usually bordered by strips of woodland. A very large part of the area drained by the Illinois is under cultivation. During the last twenty years the natural drainage has been supplemented by tile underdrainage and by the dredging of open channels through large stretches of flat country, the terminal water courses of a very large proportion of the tributaries of the Illinois being thus widened and extended, and the area of tillable land much increased. The extension of these supplemental channels and the removal of the turf by cultivation have undoubtedly a tendency to facilitate the run-off of the rainfall and thus to increase the suddenness and height of floods, and they also favor the introduction of fragments of vegetation and particles of loam and sand, thus increasing the amount of silt carried by the waters of the river at times of flood.

The *length* of the Illinois from its mouth to the place of its formation by the junction of the Des Plaines and the Kankakee is about 270 miles,* and if to this be added the length of the Kankakee, the longest tributary, the total amounts to 505 miles. This is about the length of the Seine, of the Rhone, and of the Oder; of the Des Moines and of the Sacramento; it is about one half the length of the Rhine and of the Yellowstone, one third that of the Danube, and over twice that of the Thames and the Tiber. The distance, in a direct line, from the junction of the Des Plaines and the Kankakee to the mouth of the Illinois is 214 miles. The increase in length due to the windings of the stream is thus 61 miles or 28%, and the ratio of the development of the stream is 1 : 1.28. From the mouth of the main stream to the head waters of the Kankakee, in a direct line, is 315 miles. Upon this basis the increase due to windings is 190 miles or 60%, and the ratio of development is 1 : 1.6. The ratio of development of the Connecticut River is 1 : 1.2, and that of the Mississippi, as a whole, is 1 : 1.5, while from the mouth of the Ohio to the Gulf it is 1 : 2.0. It is evident that the main stream of the Illinois has an exceptionally direct course, though the channel of the Kankakee is not of this character.

The *area* of the basin drained by the Illinois is approximately 29,000 square miles. This is more than twice the area of the Hudson, and also of the Connecticut, and is comparable with that of the Susquehanna, of the Potomac, of the Po, of the Duero, of the Rhone, and of the Loire. It constitutes less than one forty-third of the entire Mississippi basin. According to Greenleaf ('85) the drainage basin of the Illinois comprises an area of 29,013 square miles, 24,726 of which lie within the state, 1,080 in Wisconsin, and 3,207 in Indiana. About three sevenths of the area of the whole state belong to the drainage basin of the Illinois. The following list of tributaries with their respective areas is taken, with slight modification, from Cooley ('89).

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*The statement of the Standard Dictionary (p. 2172) that the length of the Illinois River is 350 miles is manifestly incorrect.

DRAINAGE BASIN OF THE ILLINOIS RIVER AND TRIBUTARIES.

Tributary	Area	Total area	Dist'nce in miles	Bank	Area to:
Des Plaines River	1,392	1,392	00.0	R. B.	Junction
Kankakee River	5,146	6,538	00.0	L. B.	
Aux Sable River	218	6,756	4.7	R. B.	Morris
Mazon River	540	7,296	9.7	L. B.	"
Nettle Creek, etc.	63	7,359	10.0	R. B.	Seneca
Waupecan Cr. and Hog Run	70	7,429	12.1	L. B.	"
Kickapoo Creek	45	7,474	22.7	R. B.	Marseilles
South Kickapoo Creek	24	7,498	23.7	L. B.	"
To Mouth Fox River	16	7,514	33.1	R. B.	Ottawa
To Mouth Fox River	15	7,529	33.1	L. B.	"
Fox River	2,700	10,229	33.1	R. B.	"
Covel Creek	100	10,329	36.4	L. B.	Utica
Clark's Run	36	10,365	42.5	R. B.	"
Vermilion River	1,317	11,682	46.2	L. B.	Peru
Pecumsaugan Cr. L. Verm. R.	165	11,847	47.1	R. B.	"
Spring Creek	56	11,903	52.9	R. B.	
Negro Creek	34	11,937	57.3	R. B.	
All Forks	72	12,009	....	L. B.	Hennepin
Bureau Creek	480	12,489	62.9	R. B.	"
Coffee Creek	24	12,513	65.8	L. B.	
Clear Creek	52	12,565	71.7	L. B.	
Senachewine Creek	77	12,642	73.8	R. B.	Henry
Sandy Creek	147	12,789	75.7	L. B.	"
Crow Creek (west)	88	12,877	81.0	R. B.	
Crow Creek (east)	226	13,103	89.6	L. B.	Chillicothe
Senachewine Creek	132	13,235	90.4	R. B	"
Richland Creek, etc.	198	13,433	93.8	L. B.	Peoria
West Slope	46	13,479	....	R. B.	"
Kickapoo Creek	310	13,789	112.1	R. B.	Pekin
Luck Creek	42	13,831	114.9	L. B.	"
Mackinaw River	1,217	15,048	121.0	L. B.	Copperas Cr. Dam
Tamarish Creek	55	15,103	....	R. B.	Kingston
Copperas Creek	151	15,254	134.0	R. B.	Copperas Cr. Dam
Duck Creek	110	15,364	138.1	R. B.	Havana
Plankton Station	......	**15,364**	**149.7**	......	**Havana**
Quiver Creek	220	15,584	140.9	L. B.	"
Spoon River	1,870	17,454	151.6	R. B.	
Otter and Wilson Creeks	140	17,594	160.7	R. B.	
Sangamon River	5,670	23.264	174.1	L. B.	Beardstown
Sugar Creek	180	23.444	177.7	R. B.	"
Crooked Creek	1,385	24.829	188.3	R. B.	La Grange Dam
Indian Creek	290	25,119	193.4	L. B.	" "
McKees River	472	25.591	205.7	R. B.	Griggsville Landing
Mauvais Terres Creek	275	25,866	209.2	L. B.	" "
West Slope	75	25,941	....	R. B.	Montezuma
Big Sandy, etc.	190	26,131	220.7	L. B.	"
West Slope	75	26,206	....	R. B.	Kampsville Dam
Apple Creek, etc.	525	26.731	235.7	L. B.	" "
W. Slope to Macoupin Cr.	45	26,776	....	R. B.	
Macoupin Creek	985	27,761	248.6	L. B.	
Otter Creek	85	27,846	256.4	L. B.	
West Slope	40	27,886	....	R. B.	Mouth at Camden
East Slope	28	27,914	....	L. B.	

It will be noted that according to these estimates the area is only 27,914 square miles ; also that our plankton station, located about two miles above the mouth of Spoon River and slightly above that of Quiver Creek, is just within the lower half of the basin. The water passing this point is derived from an area of 16,250 square miles (15,363 according to Cooley), or 55% of the total basin, no account being taken of additions to the stream by the pumping works at Bridgeport or by the Drainage Canal.

A glance at the map (Pl. I.) shows that the basin of the Illinois River extends diagonally across the center of the state from the southwest to the northeast as a broad belt one hundred miles in width. The head-water region is spread out in a Y-shaped area which embraces the southwestern portion of Lake Michigan. The northern arm of the Y is formed by the basin of the Des Plaines, which extends northward into Wisconsin for a distance of 50 miles. It is separated from Lake Michigan by a narrow strip of territory 3 to 22 miles in width which is tributary to the Lake. The eastern arm is the more extensive basin of the Kankakee, which extends for a distance of over 90 miles into Indiana.

The river does not take its course through the middle of the basin but lies to the westward, being 60 to 80 miles from the southeastern watershed and but 20 to 40 miles from the northwestern. In the last 50 miles of the course the western watershed is within 10 miles of the stream. Such a deflection of the main stream toward one side of its basin is not infrequent, and has been attributed in many cases to the influence of the rotation of the earth. Russell ('98) says: "Thus, in the northern hemisphere the tendency of the earth's rotation is to cause the streams, no matter what the direction of flow, to corrade their right more than their left banks. * * * There is thus a tendency, due to the earth's rotation, for them to excavate their right more than their left banks, and to migrate to the right of their initial courses. This tendency is slight, but all the time operative." Streams flowing southward in the northern hemisphere thus tend to shift toward the western watersheds of their basins. The position of the Illinois River in its basin seems to afford an illustration of this application of Ferrel's law to the flow of rivers. A reference to the contour maps of the state which Leverett ('96) gives, shows that the bed of the ancient stream which the Illinois River and its bottom-lands now occupy lies toward the western side of the flood-plain of the stream ; in other words, from Hennepin to the Mississippi the second bottoms are of much greater width upon the eastern than upon the western side of the river.

From its origin, fifty miles southwest of Chicago, the Illinois pursues a course almost due west for a distance of sixty miles, to a point a few miles above Hennepin, where it turns abruptly toward the left, and flows southwest by south in quite a direct line for a distance of 165 miles (205, by river) to its union with the Mississippi, 25 miles above St. Louis.

The tributaries of the Illinois River are distributed in a somewhat unusual manner. Dividing the river into three regions, the upper, middle, and lower, terminating respectively at Ottawa, at our plankton station, and at the mouth, we find a very unequal distribution of tributary areas. The upper river, although but 12% of the total length, drains 37% of the basin owing to the fact that it receives three large tributaries,—the Kankakee, the Des Plaines, and the Fox,—besides a considerable number of smaller streams. The middle river, on the other hand, constitutes 43% of the total length but drains only 18% of the basin. This is due to the fact that aside from the Vermilion and the Mackinaw there is no tributary of importance in the 117 miles of its course. These two tributaries have basins of 1,317 and 1,217 square miles respectively and rank in area as seventh and eighth in the list of tributaries. The lower river constitutes about 45% of the total length, and drains a corresponding per cent. of the total basin, since it receives the Spoon and Sangamon rivers and, in addition, a number of creeks of considerable size. The location of the plankton station at the lower end of the middle section of the river is fortunate in that it has enabled us to make collections in water that is typical of the stream as a whole. No large tributary is near enough to disturb the balance, and the greater part of the water of the stream at the place of collection has been moving in the channel for some time. There is, consequently, abundant opportunity for a thorough mingling of the waters derived from the various tributaries and for the breeding of the plankton. The conditions are thus favorable for a uniform distribution and development of the plankton in the river at the place where our collections are made.

THE RIVER BOTTOMS.

As before stated, the present river channel, at least from the bend near Hennepin to its mouth, lies in the bed of a stream which formerly connected Lake Michigan with the Mississippi River. The channel excavated by this ancient water-course is far in excess of the demands of the present river, and it has filled up by alluvial deposits, which constitute the bottom-lands of to-day. This ancient channel varies in width from one and a half to six miles, and borings made near Havana in the bottom-lands of the present river, ten feet above low water, reveal a deposit of alluvial soil twelve to eighteen feet in thickness which lies above alternating beds of sand and fine clay. The depth to which these beds extend is not known. Wells in the bottom-lands are seldom deeper than fifty feet and usually do not exceed twenty feet, water-bearing strata of sand being found at varying levels between these limits. At Cedar Lake, sixteen miles north of Havana, the pipe of a driven well was checked at a depth of fifty-two feet,—forty feet below low water and 389 feet above sea level,—apparently by rock, and the water drawn from this depth is heavily charged with salts of iron, being similar to that from the shales of adjacent coal regions. Alternating beds of sand, gravel, and clay similar to those found beneath the alluvium in the bottom-lands were encountered in a prospect-boring for coal at Mason City, twenty miles south-east of Havana. The elevation at this place is 169 feet greater than at Havana and these complex drift deposits are of correspondingly greater thickness, the underlying rock floor being found at an elevation above the sea of 396 feet, approximately the level of the rock floor at Havana.

The flood-plain of the older river lies from 30 to 50 feet above that of the present stream and varies in width from 3 to 20 miles, reaching its maximum a short distance above Havana, and being widest upon the eastern side of the river. The bluffs rise from 30 to 300 feet above the present flood-plain, the minimum height representing only the first bluff, or that of the present bottoms, the bluff of the second bottoms being found further inland. The greater heights are reached where the first and second bluffs coincide, as is frequently the case upon the western side of the river. The height of the flood-plain of the Illinois River ranges from four to sixteen feet, varying with the local conditions, the highest levels being found where tributary streams cross the bottom-lands. The detritus which they carry is deposited in large quantities in the impounded and quieter waters of the bottoms, and builds up the banks, especially below the region traversed by the tributary streams. This is very apparent at Havana, where the banks of Spoon River rise about sixteen feet above low water. The bottom-lands below this tributary are submerged only at maximum floods, while those above consist in large part of marshy tracts six to eight feet above low-water level.

The total area of the bottom-lands from Utica to the mouth of the river, a distance of 227 miles, is estimated by Cooley ('91, p. 61) to be 704.3 square miles. The average width is 3.1, of which .6 of a mile is estimated to be marsh or water. The middle region, extending 59.5 miles,—from Copperas Creek dam (16.8 miles above Havana) to La Grange dam (42.7 miles below Havana),—has an average width of 4.3 miles and a total area of 256.9 square miles, of which 20.60 are water and 28 marsh. Of the 75 square miles shown in the map of the field of operations of the Biological Station (Pl. II.) 56.5 belong to the bottom-lands, of which about 17 square miles have been cleared of the forests and placed under cultivation, 7 represent river and lakes at low-water stage, 10 are permanent marshes, and the remaining 22.5 are covered by forests, and lie at so low a level as to be subject to frequent overflow. It is difficult to distinguish between marsh and woodland in those areas covered by low growths of willow (*Salix nigra*) or sparsely wooded with willow-trees of considerable size. As their low elevation renders them subject to overflow on slight rises of the river, and as the vegetation is usually of a semiaquatic nature they are on our map in large part included in areas designated as marsh. As the elevation increases, maples (*Acer dasycarpum*) appear among the willows, then the green ashes (*Fraxinus viridis*), while in the higher bottoms the elms (*Ulmus americana*) form the major part of the forest, with maples, box-elders (*Negundo aceroides*), sycamore (*Platanus occidentalis*), pecans (*Carya oliviformis*), oaks (*Quercus palustris*), and clusters of cottonwoods (*Populus monilifera*) interspersed. The marshes and lagoons, especially along the lower part of the river, are often fringed with dense and impassable thickets of button-bush (*Cephalanthus occidentalis*) and buckbrush (*Foresteria acuminata*).

Cooley ('91) gives the average height of the banks of the Illinois above low-water level as 10 feet for the region between Copperas Creek and Havana and 11 feet from Havana to the mouth of the Sangamon River. The range in height for the same distance is 7 to 12 and 9 to 12 feet respectively. The greater height below Havana is doubtless due to the deposits contributed by Spoon River. The dam at La Grange, completed October 10, 1889, has raised the water about two feet at Havana, so that the actual height of the banks above the water at its lowest stage, under present conditions, averages less than 8 feet. The immediate banks are usually higher than the adjacent bottom-lands. This is true of the tributary streams also, and is especially well marked in the case of Spoon River, which carries large amounts of sediment at times of flood. It has built for itself an elevated ridge across the bottom-lands, fifteen feet above the low-water mark, through which it pursues its tortuous course, flowing thirteen miles (See Pl. II.) to reach the Illinois, which is only five miles from the point where the Spoon enters the bottom-lands. The rapidity with which the alluvium is deposited at times is illustrated by the fact that the floods of 1898 left on the banks of the Illinois at the mouth of Spoon River a layer of earth nine inches in thickness. Nevertheless, we find an unusually large area of the bottom-lands occupied by lagoons or bayous, locally known as lakes, by marshes, and by bodies of water of an ephemeral character. Some of these, as, for example, Thompson's Lake (Pl. II.), retain at all times their connection with the river, and receive their water supply wholly or in large part from it. Others, as Quiver and Matanzas lakes, retain their connection with the river, but are fed to a greater or less degree by streams and springs. They respond to changes in the river level and are subject to invasion by the river at times of rising water. During falling or stationary water, except at times of overflow, these lakes are filled with the clear water derived from their drainage basins, which stands in sharp contrast to the turbid waters of the river. Such spring-fed lakes are not uncommon in the bottom-lands along the eastern side of the river from Pekin to its mouth. They derive their water supply from the sand deposits of the second bottoms, at whose margin they usually lie. Other tracts of the bottoms, lying at about the level of low water or losing their connection with the river before low-water mark is reached, become permanent marshes, as in the case of Flag Lake (Pl. II.). In some instances where the body of water left by the overflow lies some distance above low-water level the characteristics of a marsh are not established, owing to the seepage and evaporation of the water and to consequent drying and hardening of the bed, and we have simply an ephemeral lagoon, as in the case of Phelps Lake.

THE RIVER.

As previously stated, the course of the Illinois as compared with that of other streams of the Mississippi basin is remarkably direct. The present stream has not as yet developed in its bottom-lands—the bed of the ancient stream—a meandering course like that of the neighboring Mississippi. The position of its channel in the bottom-lands is often determined largely by the deposits of its tributaries, those made by the streams from the east, as the Mackinaw and the Sangamon, forcing the river towards the western bluff, while those from its western confluents, as Spoon River and Crooked Creek, crowd it against the eastern bluff. The width of the river at low water gradually increases from 536 feet at Peru to 1,040 feet at its entrance to the Mississippi. The expanse in Peoria Lake is over a mile in width, and further down, in Havana Lake, it is about 2,500 feet.

The undeveloped condition of the flood-plain of the Illinois River and the consequent large areas of the marshes, lagoons, and lakes, affect the plankton of the river most fundamentally. In the first place the flood-plain serves, to an unusual extent, as an impounding area in which the flood-waters are stored, the barriers, natural and artificial, in the bottom-lands combining with the low gradient to delay the run-off. This delay is still further prolonged in most years by high water in the Mississippi caused by the run-off from districts of more northerly latitudes and higher altitudes and thus occurring after the spring run-off in the basin of the Illinois. In a few instances the backwaters from the floods of the Mississippi have been known to flow up the Illinois for a distance of one hundred miles, and the slope of the stream is such that the impounding effect might, under suitable conditions, extend even farther. The result of this combination of factors is to increase to a marked degree the volume of water, and to add greatly to the diversity of the environment at the time of the maximum development of spring plankton. It thus profoundly affects both the total product of plankton and its diversification.

In low water stages the flood-plain has less influence upon the *quantity* of plankton present in the river, for the contributions from the lagoons and marshes are at a minimum at that season, constituting but a small part of the total discharge of the river. On the other hand, as the river falls and the flood-plain emerges the local environments of the relict bodies of water become more pronounced, and local developments of the plankton more varied. The great variety of forms found in the summer plankton is doubtless due in large part to the contributions from this diversified environment.

Four dams have been placed in the river for the purpose of aiding navigation, the State of Illinois building those at Henry and Copperas Creek, and the United States Government subsequently erecting the other two. The appended table gives their location, date of construction, length of pool, elevation of water, and the estimated increase in the volume of water in the part of the river included in their respective pools. The data included in the table have been in part compiled from the various reports of Captain Marshall in the Annual Reports of the Chief of Engineers, U. S. A., for 1890–94, and in part furnished through the courtesy of Mr. G. A. M. Liljencrantz, Assistant Engineer at the Chicago office, and Mr. E. J. Ward, of the Illinois and Michigan Canal.

The effect of the dams upon the volume of water in the river is much greater at low stages than when the river is out of its banks, the increase in volume resulting from them ranging from eighty to one hundred and twenty-five per cent. The increase due to the dam at Copperas Creek is less than that from the other dams because of the deep reach of water from Lacon to Chillicothe, and the considerable expanse under normal conditions in Peoria Lake, both above the dam in question. As a part of the biological environment the dams are of great importance, for they check the current, delay the run-off, especially at low water, facilitate the deposition of silt, and double the volume of water at low-water stages. All of these factors tend to increase the production of plankton and are most effective at low-water stages.

Dams in the Illinois River.

Dam	Date of completion	Length of pool (miles)	Elevation of crest of dam above low water	Elevation of crest of dam above low water at head of pool	Per cent. of increase in vol. of water in pools at low-water stage	Remarks
Henry..........	Oct. 19, 1871	To mouth of I. & M. Canal, 26.3	Of 1871, 6.5 ft. Of 1867, 6.1 ft.	Of 1867, 3.4 ft.	Betwe'n banks 100% Including bayous 125%	Length of pools are measured along the thalweg. Increase in vol. of water is a very rough estimate
Copperas Creek	Oct. 21, 1877	To Henry Dam, 58.7	Of 1867, 6.25 ft.	Of 1871, 0.93 ft. Of 1867, 0.57 ft.	Including bayous 80%	Increase in vol. of water is a very rough estimate
LaGrange	Oct. 21, 1889	To Copperas Creek Dam, 59.5 miles	Of 1879, 7.4 ft.	Of 1879, 1.5 to 2 ft.	100%	Increase estimated
Kampsville....	Sept. 30, 1893	To LaGrange Dam, 40 miles	Of 1879, 8.2 ft.	Of 1879, 0 ft.	100%	Increase estimated

From Peoria to Pekin and again from Copperas Creek dam to Havana there are narrower reaches whose average widths fall to 604 and 603 feet respectively. The depth of the river at natural low water varies from .8 of a foot upon some of the bars to more than 14 feet in the deepest channels. The average depth from Copperas Creek to Havana is about 9 feet and the average cross-section 2,801 square feet. Between Havana and the LaGrange dam the river becomes more shoal again, as is usual below the mouths of the larger tributaries.

According to figures given by Cooley the dam at LaGrange raises the level of the river at Havana 2.4 feet. During 1894, a low-water year, no records of the river-gage were kept at Havana, but at the time of the exceptionally low water of 1895 the gage-reading (see Pl. VIII.) repeatedly fell below the level assigned by the engineers to this point in the pool of the dam. From January 12 to February 22 the gage ranged from 2.4 to 2.2, standing the greater part of the time at the latter reading. Again, from June 10 to July 16 it stood below 2.4, reaching the minimum reading 1.7 on June 23. On August 10 and from the 14th to the 23d it stood below 2.4, and so also on September 3 and from October 4 till November 7. During the year the gage read less than 2.4 feet on 111 days; 2.3 on 41 days, 2.2 on 46, 2.1 on 17, and 2.0 to 1.7 on 7 days. During 1896 the gage fell to 2.4 on but a single day, July 19. In 1897 the gage read 2.4, or below, on 84 days—from August 9 till October 31. It stood at 2.4 on 3 days, at 2.3 on 3 days, at 2.2 on 2 days, at 2.1 on 3 days, at 2.0 on 32 days, at 1.9 on 23 days, at 1.6 on 11 days, and at 1.7 on 7 days. In 1898 the lowest point reached was 2.5 The dam at LaGrange is estimated to raise the water 2 feet on the lower gage at Copperas Creek dam, but during 1897 the readings at this place during the period of lowest water very nearly coincided with those at Havana (see Pl. VII. and X.). The coincidence of the readings would indicate that the gages at the two places have not been correlated, since under the conditions the gage at Havana should read somewhat higher than that of Copperas Creek.

The records during periods of low water both at Havana and Copperas Creek thus indicate that the effect of the dam at LaGrange is to raise the water in the upper end of the basin somewhat less than 2 feet—about 1.7 feet at Havana, according to the Havana gage. This gage was established in 1875 by Mr. R. A. Brown, a U. S. Army Engineer, and is based on the low-water record of 1873.

The fall in the Illinois River, owing to the lack of development of the relief of its basin, is but slight. The difference between the elevation of its highest watershed and the low-water level at its mouth is only about 600 feet, or an average fall of 1.2 feet per mile of the total course. The Illinois proper, from the union of the Kankakee and Des Plaines to the mouth, has, according to Cooley ('91, App. I.), a total fall of 81.7 feet, or an average of .267 feet per mile. Of this fall 50.7 feet occur between the mouth of the Kankakee and the head of the pool of the Henry dam at Utica in a distance of 42.6 miles. From Utica to the mouth, a distance of 227 miles, the fall is but 31 feet, or an average of .137 of a foot per mile. According to Rolfe the altitude of the low-water level at LaSalle, three miles below Utica, is 440 feet, while at the mouth of the Illinois it is 402 feet, thus affording a total fall between these places of 38 feet and an average of .167 of a foot per mile. The elevations given by Professor Rolfe are based upon Illinois and Michigan-Canal levels, while those given by Cooley are derived from later surveys. Accepting either figures the fall in the main stream from Utica to the mouth is but slight, exceptionally small, indeed, in comparison with the gradient of other rivers of the Mississippi system. For example, the Mississippi at Cairo has a slope of .666 of a foot per mile, almost five times that of the Illinois, while from Cairo to the Gulf of Mexico, a distance of 1,097 miles by river, it has, according to the most recent surveys, an average slope of .24 of a foot per mile—about twice that of the Illinois from Utica to the mouth.

CURRENT.

The effect of this low gradient is seen in the slight current found in the Illinois, a current so insignificant that Mississippi River steamboat men are wont to refer contemptuously to the Illinois River as a "frog pond." The current is further impeded, especially when the water level is below eight feet, by the presence of the four dams, which at low water convert the river into a series of slack-water pools.

Discharge Observations on Illinois River at LaGrange Lock, 1887-1890.
(Gage referred to low water of 1879; Price current meter used in 1888-89.)

Date	Gage (feet)	Mean velocity (feet) per second	Mean velocity (miles) per hour	Time required (days) to move from Utica to mouth, 227 miles
Low water, 1887*...	0.00	0.600	0.409	23.14
August 1, 1887	0.20	0.600	0.409	23.14
December 21, 1888	1.98	1.329	0.906	10.44
December 20, 1888	2.00	1.277	0.871	10.86
December 31, 1888	2.95	1.539	1.049	9.02
February 4, 1889..	4.33	1.758	1.198	7.90
May 20, 1889......	5.40	1.942	1.324	7.14
April 8, 1889......	5.01	1.852	1.263	7.49
March 30, 1889....	5.85	2.053	1.400	6.76
March 25, 1889....	6.72	2.258	1.540	6.14
May 30, 1889......	†6.98	2.011	1.371	6.90
March 8, 1889.....	7.65	2.554	1.741	5.43
April 22, 1889.....	7.73	2.406	1.640	5.77
March 11, 1889....	8.36	2.572	1.754	5.39
July 15, 1889	8.37	1.857	1.266	7.47
June 9, 1889.......	10.00	2.520	1.718	5.51
July 9, 1889	10.33	2.053	1.400	6.76
January 18, 1890 ..	12.80	2.547	1.737	5.45

*Computed. †Backwater from the Mississippi River.

As shown in the above table, the mean velocity per second of the current at LaGrange, forty-three miles below Havana, has been determined by the U. S. Army Engineers (see Marshall '90, p. 2443) to range from .409 of a mile per hour at low water to 1.754 miles at 12.8 foot stage—1.8 feet above bank height at that point. The velocity, in miles, per hour and the time required to move from Utica to the mouth at this rate are given in the table, having been computed from the data in the second column, quoted from Captain Marshall's Report. It will be noted that in a general way the velocity of the current increases as the river rises. This increase is, however, modified by the relative heights of the water in different parts of the stream; thus backwater from the Mississippi River or from a tributary may cause the river to rise and at the same time check the current above to some extent. Such modifications are often, however, local and temporary, and soon give way to the rush of the current.

Mr. C. A. Abrams, a steamboat man of many years' experience upon the Illinois River, writes me that the current is as much as three miles an hour at high water and on a rising river, while at low water it amounts to "nothing" except on the bars and in the narrower and shoaler parts of the stream such as those near Havana.

Capt. J. A. Schulte, of Havana, Ill., whose experience in steamboating on the Illinois River, especially near Havana, is extensive, has kindly sent me data which indicate that at high water the current from Copperas Creek down to Havana is about 2.5 miles per hour, and at low water about 1.28 miles. He further states that he has observed that the current above Havana is strongest when the river is bank-full and slackens somewhat when the river overflows, while below Havana the current is strongest at times of overflow. It is probable that the elevated bottom-lands above the mouth of Spoon River cause this difference.

A slightly greater rate than the mean quoted from the U. S. Engineers' Report is indicated *in mid-channel* by a few inadequate tests which we have made at the plankton station, near Havana, by means of a vertical float reaching within a foot of the bottom and projecting but a short distance above the surface of the water. A test made September 29, 1897,—when the river had been standing at the lowest levels reached since the dam at LaGrange was built (1.7—2.05 above low-water mark on gage) for forty-eight days and had not fluctuated during the week preceding,—showed a current of .720 of a mile per hour. Steamboat men say that, owing to the proximity of the Spoon River bar, the current is as rapid at low water at this point as at any place on the river. A similar test made June 22, 1898, when the river was at 10.7 feet and was falling at the rate of 0.2 of a foot per day, showed a current of 1.033 miles per hour. At high water (16 feet), tests made about half a mile below the mouth of Spoon River with a steam launch indicate a current at that point of about 3 miles per hour. The figures quoted from the report of the Engineers give the mean velocity for the whole stream at the place of observation, while our tests were made in mid-channel and refer to that point alone. The results of our own tests and those of the Engineers both indicate that the current at low water is but one fourth as rapid as at times of overflow. The current in the bottom-lands at time of overflow is much slower than it is in the channel, being retarded by the vegetation and by the natural and artificial irregularities of the surface, such as the deposits of tributary streams, the embankments of railroads, and the levees about cultivated lands. The bottom-lands thus serve as impounding areas from which the water, except at times of maximum flood, is slowly drawn off through the main channel.

The rate at which the current moves down the stream is not, however, an index of the rate at which the crest of a flood traverses the same distance. For example, the crest of the flood of May, 1892, as shown in the appended table, passed from Morris to the mouth of the river in fifteen days, while the current in the main channel, under these flood conditions, would traverse this distance in four or five days—less than a third of this time.

FLOOD MOVEMENT IN THE ILLINOIS RIVER.

Place	Date	Distance Miles below Morris	Rate Miles per hour
Morris	May 6	.....	....
Copperas Creek	May 10	124.3	1.29
LaGrange	May 16	183.7	0.41
Kampsville	May 19	230.0	0.63
Mouth	May 21*	259.2	0.61

*Estimated.

As stated on a previous page, the current at high water ranges from two to three miles per hour, at which rate, as above shown, water in the main channel would pass from Morris to the mouth of the river in four or five days. This flood was sudden and exceptionally high,—reaching 18.80 feet at Copperas Creek, a height surpassed in recent years only by the flood of 1883 (19.25 feet),—and would thus cause a current at least as rapid as the estimate above given.

This retardation of the flood is due, in part at least, to the overflow of the bottom-lands, and it is much more pronounced in the Illinois River than it is in ordinary streams owing to the imperfect development of its flood-plain and the consequent early inception of overflow stages on a rising river.

The current is an important factor in the environment of the plankton. In the first place it largely determines the amount of silt in suspension in the water, for upon its speed depends not only the amount of material eroded from the banks and carried on by the flood, but also the rate of deposition of the silt delivered to it by the more rapid tributary streams.

The most important relation of the current to the plankton lies in the fact that it is a large factor in determining the length of time in which the plankton can breed, and thus curtails or extends the possible number of generations of the planktonts. The table on page 115 indicates that at the low-water stage over twenty-three days elapse before the water which enters the river at LaSalle, at the upper end of the pool of the Henry dam, joins the Mississippi at Grafton. At the stage of overflow the interval is reduced to less than five and a half days, or about one fourth of the time at low water. It is evident that the possible number of generations increases in arithmetical progression as the current declines, while the number of individuals may increase in geometrical progression. A concrete example will illustrate. A given organism which multiplies by fission and in which a new generation appears each twenty-four hours will, at times of low water, reach the twenty-third generation as it floats from LaSalle to the mouth of the river, and the total possible number of individuals of the last generation would be 8,388,608, while in the more rapid current at the stage of overflow the number of generations could be but five and a half, and the number of individuals only forty-eight. This rate of increase in individuals is theoretically possible only for those organisms which reproduce by fission. In sexual and parthenogenetic reproduction other factors enter to reduce the rate of increase and to render the problem more complex, while life cycles, conditions of the physical environment, competitors, and enemies further modify and limit the increase in numbers. Thus, in every instance the struggle for existence sooner or later so checks the rate of multiplication that the mathematical possibilities of increase are never fully realized. In spite of these various modifying conditions the fact is patent that the current is a very important element in determining not only the amount of the plankton, but also the relative numbers of its constituent organisms.

To a less degree the current curtails the development of the plankton of the backwaters at times of overflow. In general it is not so strong in the overflowed territory as it is in the main channel, though local conditions in these regions sometimes produce quite as rapid a flow in limited areas. The slackened current affording a longer time for breeding, the shallow water, higher temperatures, and the larger amount of organic debris combine to favor the development of the plankton in these impounding areas, which, in turn, drain into the main channel with the run-off of the flood.

The current in the Great-Lake system in many places equals or exceeds that of the Illinois River. For example, the St. Clair River at Port Huron moves at the rate of four miles per hour; the Detroit River, at a rate of one to three miles per hour; and the St. Mary's, at a rate of three quarters of a mile to seven miles per hour. It is well known that currents prevail in the open lakes, but there are no recorded measurements of their flow. Thus, in certain aspects of its current the Illinois River does not markedly differ from the Great Lakes. The impounded backwaters and the main stream at low-water stages have but a slight flow, probably not in excess of that in the open Lakes, while in the main channel at high water the rate in the river does not differ greatly from that in the contracted portions of Great-Lake systems. In the rate of its current the conditions in the Illinois River thus approach those of a lake. In most lakes, however, in which currents may be found whose velocity equals or exceeds that of the Illinois, the movement of the water does not involve to any like degree its replacement by tributary waters. Thus, in the Illinois, even at lowest water, the rate in the channel would necessitate a renewal of the water every twenty-three days—a rapidity of change which few lakes attain. This replacement of the water becomes a most important phenomenon in the environment of the plankton of a river as contrasted with that of a lake, contributing to its fluctuations, complicating the problem of its maintenance, and ever tending to sweep it out of existence.

Biologically considered, the fundamental distinction between fluviatile and lacustrine waters lies in the more rapid replacement and more recent origin, from springs and rain, of the water of the stream as compared with that of the lake.

The attempt has been made by Schroeder ('97) to give to this relation of the plankton to the current a mathematical expression, a formulation which has been called Schroeder's law. As a result of his plankton investigation upon the River Oder and elsewhere the conclusion is reached that the volume of plankton present in any stream is inversely proportional to the rate of the current. It may well be that a comparison of the plankton of certain slow and rapid streams, or of the same stream under different conditions of discharge, will show conformity to this law of Schroeder's, though no such conformity or data for such comparison are as yet at hand. That any extended investigation of the subject will afford the basis for an expression so precise as to be couched in mathematical terms seems improbable in view of the many complex factors environing the plankton. Furthermore, as will be shown later in the discussion of the plankton of tributary streams of the Illinois River, the biological significance of the current as related to the plankton lies primarily in the *length of time afforded for breeding.* The rate of the current is but *one* of the elements determining this time. If this be true, the expression of this relation should take another form, as, for example, the volume of plankton present in any body of fresh water varies with the length of time afforded for breeding.

THE DISCHARGE.

The total annual production of plankton in a given body of water can be estimated only when the total discharge for that time is known. The seasonal fluctuations of the discharge also profoundly affect the local and seasonal distribution of the plankton, and modify alike its quantity and its constituent organisms. For these reasons the consideration of this element in the environment of the plankton is of prime importance. The discussion of the subject naturally falls under two heads, namely, the rainfall and the run-off.

The Rainfall.—The political boundaries of Illinois do not coincide with the watersheds of the Illinois River basin, though almost half the area of the state lies within this basin, which, moreover, extends through more than two thirds the length of the state, and is fairly typical of four fifths of its area. The small portion of the basin (4,287 square miles) which lies outside of the state does not present conditions of rainfall which materially differ from those of parts of the basin within the state. The northern part of Indiana, in which the Kankakee basin lies, has a mean annual rainfall, according to Leverett ('97), of 35.49 inches, which is somewhat less than the average (37.858 in.) for the whole State of Illinois; but since in Illinois as in Indiana the rainfall in the northern part is less than that in the southern part it is not improbable that the precipitation in the Kankakee basin in Indiana is about the same as that in corresponding latitudes of Illinois. Under these circumstances, the statistics of rainfall for the whole State of Illinois may be taken to represent with considerable accuracy the conditions within the basin of the Illinois River.

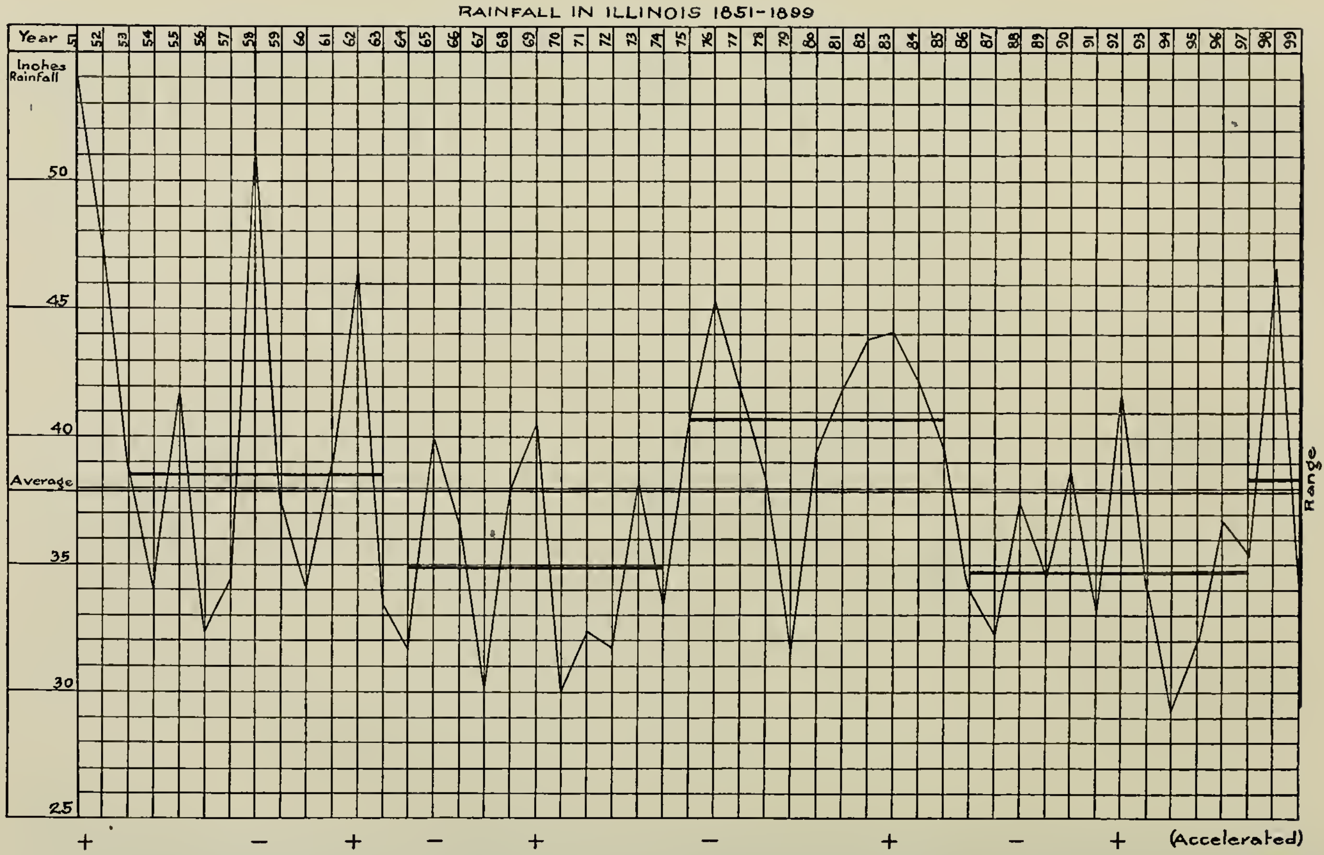

Fig. A. Diagram showing the yearly variations in the average rainfall of Illinois, for 1851–1899. From records of U. S. Weather Bureau. The ordinants represent the depth in inches; the horizontal lines indicate the averages for the years included. The + and — signs indicate the location of the rainfall pulses attendant upon the sun-spot cycle.

The average rainfall for the State of Illinois for a period of forty-nine years, from 1851 to 1899 inclusive, is 37.859 inches. Leverett ('96) gives a tabulation of the records of the U. S. Weather Bureau from stations within the state and on its borders from 1851 to 1895 inclusive. The average for this period of forty-five years, was 37.85 inches per year. The averages for subsequent years, kindly furnished by Mr. M. E. Blystone, of the U. S. Weather Bureau, increase this amount by 0.008 inches.

The above diagram (Fig. A) shows the variations in the rainfall in the period above mentioned. The irregularity in the earlier years of observation may in part be due to the small number of stations from which records are available. In 1895 records were made at ninety-seven points within or adjacent to the state; in 1885, at twenty-seven; in 1875, at twenty; in 1865, at sixteen; and in 1851, at but five. The range of the annual averages is 24.8 inches, ranging from 54.1 inches in 1851 to 29.3 inches in 1894—a year of extreme drouth. Of the forty-nine records twenty-four lie above and twenty-five below the mean.

An examination of this diagram of the rainfall of Illinois shows that the period covered by our plankton collections, 1894 to 1899 inclusive, was predominantly one of minimum rainfall. The average for the six years is 35.5 inches, or 2.3 inches below the general average. It includes one year, 1894, when the rainfall was only 29.3 inches, the lowest on record, while the remaining years with the single exception of 1898 are all more or less below the average. Omitting 1898, a year of excessive rainfall, 46.6 inches, the average for the remaining years is only 33.2 inches, 4.4 inches below the general average. The reduction of overflow stages of the river consequent upon this lowered rainfall doubtless affected the plankton by the restriction of the breeding areas, the concentration of sewage, and the prolongation of the low-water period with its slackened current. Our collections thus, as a whole, are representative of a period of minimum rainfall and its attendant low-water conditions. They are, however, fairly representative of the whole range of rainfall and river conditions, including, as they do, two years (1896 and 1897) which approximate the average rainfall, and a year of minimum (1894) and one of maximum (1898) rainfall.

The periodicity of the rainfall of Illinois and adjoining states was noted by Leverett ('96). There are alternating wet and dry periods of eleven years which correspond somewhat closely in duration to the sun-spot cycle as shown in Plate VI. There is, however, in the sun-spot cycle no recorded alternation of elevation and depression similar to that of the rainfall, the maximum of sun-spot occurrences appearing at intervals of eleven years while those of the rainfall appear in a twenty-two-year cycle. In the diagram this alternation is brought out by the horizontal lines, which represent the average rainfall for periods of the eleven years included. The first wet period within the time covered by the records of the Weather Bureau lies about 1853–1863, the average being 38.5 inches—only 0.59 inch above the general average, though this amount will be considerably increased if the period is shifted back to include one or two preceding years. These earlier records are, however, less reliable owing to the few places of observation. A dry period from 1864 to 1874 falls 2.96 inches below the general average, while the wet period of 1875 to 1885 rises 2.9 inches above it. The following dry period, 1886 to 1896, falls 3.05 inches below the general average, while the few years of the current wet period already yield an average above the general one. The average difference in rainfall between the wet and dry periods is about 6 inches.

Our plankton collections are about equally divided between the closing years of the last dry period and the opening years of the current wet one.

A second cycle or rhythm in the rainfall has been discovered by Sir Norman Lockyer and Dr. W. J. S. Lockyer ('00 and '01) as a result of their study of the temperature changes in the sun, with their accompanying sun-spot phenomena, and the rainfall in the region surrounding the Indian Ocean. They have found that the mean solar temperature is followed by a pulse of rainfall. These mean temperatures occur twice in each sun-spot cycle of eleven years, at intervals varying from four to seven years, and are accompanied by the crossing of the iron and "unknown" lines in the solar spectrum. These solar fluctuations in temperature produce atmospheric conditions, especially over large continental and oceanic areas, which result in rhythmic pulses of rainfall which have been traced by these authors in the rainfall of India and the snow upon the Himalayas, and in the rainfall of Batavia, Cape of Good Hope, Mauritius, and Cordova. They have also correlated them with the floods of the Nile and the famines in India. On Plate VI. is a diagram taken from Lockyer ('01) which shows by curves the fluctuations of sun-spots (which in a general way coincide with solar-temperature changes), and of the iron and "unknown" lines. To this has been added the plot of the rainfall in Illinois and the hydrograph of the Illinois River. As shown in the diagram the mean temperature (crossing of the iron and "unknown" lines) occurs twice in each sun-spot cycle, once on the rise in sun-spots (and temperature) (+ pulse), and once on the fall (— pulse). The location of the rainfall pulses of India and elsewhere accompanying these mean temperatures is indicated upon the diagram.

A close correlation between these pulses of rainfall and the fluctuations in rainfall in Illinois and in the hydrograph of the Illinois River is at once apparent on inspection of the diagram. The + pulses of 1892 and 1883, and the — pulse of 1876–77 are well defined, while that of 1888 is present though not so pronounced.

Similar pulses of rainfall may also be detected at somewhat similar intervals in the rainfall of Illinois in the period not covered by the Lockyers' diagram, 1851–76. Thus + pulses may be located in 1872, 1862, and 1851, and — pulses in 1865 and 1855 or 1858. Another — pulse is probably to be seen in the heavy rainfall of of 1898, though according to the Lockyers' diagram no crossing of the iron and "unknown" lines had occurred though normally to be expected. These unusual solar conditions prevailing in 1897 to 1900 were accompanied by irregularities in the rainfall in India, and may perhaps also be reflected in the somewhat unusual irregularities in the rainfall records and hydrograph in Illinois during this period. The data available for the discussion of the periodicity of rainfall are so limited that only tentative values can be given to any conclusions upon the subject. The striking conformity of the Illinois data to the Lockyers' cycle will perhaps justify this discussion.

As might be expected, the variation in the rainfall for any given point of observation may far exceed that of the average for the whole state. Thus we find a record of 74.5 inches for Muscatine, Iowa, in 1851, while its lowest record is 23.6—a range of 50.9 inches. These extreme records are generally due to local rains of considerable magnitude, which are often the cause of the sudden floods in the tributary streams of the Illinois.

The seasonal distribution of the rainfall for Illinois is shown in the following table taken from Leverett ('96).

	Spring	Summer	Autumn	Winter	Annual	Cubic miles
Inches	10.2	11.2	9.0	7.7	38.1	34.0

The distribution by months, expressed in percentages of the total, is as follows.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
6.2	6.7	7.0	8.2	10.4	12.2	9.9	8.6	9.0	8.5	7.1	6.0

The table shows a minimum in December with a gradual increase to a maximum in June, from which the decline is rapid, with only a slight interruption at the autumnal equinox.

The tables given above apply to the state as a whole. An examination of the individual records shows that the southern part of the state has a somewhat greater rainfall than the northern part. This is due to the greater precipitation during the winter months in the southern part, the rainfall during the remainder of the year being practically the same in all parts of the state.

The Run-off.—Eighty per cent. of the Illinois River watershed lies in two principal basins, each with peculiar climatic and topographical conditions. These basins meet at Havana, and consequently the conditions in the northern one constitute a prominent feature in the environment of the plankton at that point. As the two basins lie in different storm-tracks their rain-floods do not always coincide. The southern basin usually parts with its snow several days sooner in the spring, and more promptly, than the northern, since its latitude is more uniform, and, relatively, its floods are larger. The climatic conditions of the southern basin are manifest at Havana principally in the backwater from floods in the lower river, which check the current and delay the run-off from the northern basin.

The subject of fluctuations in the volume of water in the river is one of fundamental importance in our plankton work. With rising water comes a decided increase in the current and a rapid displacement of the sluggish waters teeming with minute life by a turbid flood to a large extent devoid of life. With the overflow of the bottom-lands the subordinate lagoons, lakes, and marshes are for the time being obliterated from the landscape, and their peculiar fauna and flora mingled, merged, and swept away with the flood. With the decline of the flood, the unusual prolongation of which in the Illinois River has been already alluded to, a great variety of conditions of current, temperature, depth, light, and vegetation are afforded, the most of which favor the development and diversification of the plankton. The large amount of silt—composed of a wide variety of substances, from an impalpable earthy material to coarse sand and the comminuted debris of vegetation—introduced by flood water presents a most perplexing problem in our quantitative plankton work. Aside from the far-reaching effect that the turmoil of flood has upon the quantity and the distribution of the plankton, there are introduced other factors whose influence, though perhaps more subtle, is of no less importance. Such factors are changes in the chemical constituents dissolved in the water, in its temperature, in its transparency, and in the relative proportions of plant and animal life.

The run-off of the rainfall of the catchment-basin of the Illinois is influenced by a variety of conditions, all of which are more or less variable. These are the amount and distribution of the rainfall, the slope, the perfection of drainage lines, the geological structure, the amount of vegetation, and the temperature. As has already been stated, the rainfall, amounting on an average to 37.858 inches, is distributed with considerable uniformity—at least in the northern basin, with which we are most concerned. Purely local excesses and deficiencies of rainfall occurring within this area are rarely of sufficient proportions or duration to affect profoundly the customary regimen of the stream as a whole.

According to Leverett ('96) the slope of the stream beds of the principal tributaries in the northern basin, the Des Plaines, Kankakee, Fox, and Vermilion rivers, is on an average in their lower courses several feet per mile, while in the lower two hundred and twenty-five miles of the Illinois itself the slope is only thirty feet or .13 foot per mile. In much of the state the principal streams have an average slope of about two feet per mile; and the small streams, of five to ten feet, excepting the head waters. In the main, therefore, the slope of the stream beds is such as to favor a very moderate run-off. The slope of the general surface is also very moderate. It ranges from ten to twenty feet per mile, being somewhat greater in the newer drift, where moraines are more abundant, than it is in the older drift of the southern basin. The steeper slopes of the newer drift are, however, counterbalanced by the much inferior development of drainage lines within its area. There are large tracts of land at the head waters of the Vermilion and

Kankakee in which natural drainage channels have not as yet been opened, a fact which has a tendency to further moderate the run-off in the northern basin.

The newer drift which covers the northern basin presents a great variation in its structure and consequent effect upon drainage. In general it is less compact than the older drift and offers greater opportunity for the storage of ground water, especially wherever extensive deposits of sand and gravel occur. Storage in such deposits tends to equalize the run-off throughout the year.

The basins of the several tributaries present marked peculiarities which influence their contributions to the flood waters of the main stream. The basin of the Des Plaines River is largely underlaid by impermeable rock upon which the drift is twenty to one hundred feet in thickness. The lower end of the watershed alone contains deposits capable of affording considerable ground storage, while the upper end abounds in lakes, bogs, and swamps, which also have a tendency to retard and equalize the flow of the run-off. In spite of these equalizing factors the floods of the Des Plaines assume large proportions and, owing to the extent in latitude of the basin, they are often prolonged. A considerable portion of the flood water, under conditions prior to the construction of the drainage canal, escaped over the Ogden dam and through the Ogden-Wentworth ditch and the Chicago River to Lake Michigan, following what seems to have been a former channel of the Des Plaines. Cooley ('89) estimates that the discharge of the normal extreme flood at the junction of the river with the Kankakee is 12,000 cubic feet per second, and that this would be increased to 20,000 if all the water from the basin sought this outlet. This latter estimate is equivalent to the bank-full capacity of the Illinois River at Copperas Creek dam, seventeen miles above Havana. High-water level at the junction is 15.7 feet above low water. The flow at low water is insignificant, amounting in 1887 to less than 16⅔ cubic feet per second for a period of five months. The variations in the Des Plaines thus constitute a very important element in the fluctuations of the main stream, and its contributions of detritus are extensive.

The basin of the Kankakee, occupying 5,146 square miles, lies in a single belt of latitude, extending 216 miles in an east and west direction. About 700 square miles of the lower part of the basin have a slope sufficient to afford a rapid run-off, and of the remainder fully one half is swamp and marsh, the other half being flat or slightly rolling, but capable of cultivation. The drift, except in the lower portion, is of considerable depth, and in much of the marshy region extensive deposits of sand are found. The lower stream is also bordered by extensive sand deposits, and these afford a storage basin for the waters derived from the adjacent slopes. Cooley ('89) estimates the mean of the extreme flood-discharges of the Kankakee at its junction with the Des Plaines at 31,200 cubic feet per second, and the mean of the extreme low-water discharges at 500 cubic feet per second. Flood water at the mouth of the Kankakee has been known to reach sixteen feet above low-water level. Aside from the uniformity in latitude, the physical features of the Kankakee basin, under present conditions, favor a gradual run-off, with floods which rise slowly to a moderate height and continue for a considerable period. Owing to the storage facilities of the basin the stream maintains a relatively large flow even in periods of prolonged drouth. The Kankakee is thus an important factor in moderating the extremes of high and low water in the Illinois. Its contributions of silt are but slight.

The northern part of the basin of the Fox River is similar to that of the Des Plaines, and acts as a storage reservoir; but the southern part, which is of greater extent, has steep slopes, and the rapidity of the run-off is thereby heightened. Leverett ('96) states that its flood waters reach a level of fifteen feet above the normal, and that the discharge, presumably at low water, is 526 cubic feet per second. Cooley ('91) gives the discharge of the Fox in the flood of February, 1887, as 13,680 cubic feet per second. The conditions of its basin are such as to aggravate the fluctuations and to increase the amount of silt in the Illinois.

The Vermilion and Mackinaw rivers present common features of drainage. They both drain till plains of compact drift and have a comparatively rapid descent. The run-off is rapid, and floods are sudden and of extreme proportions. Owing to the absence of head-water marshes the flow in the period of low water is very slight. The steep slope, the rapid run-off, and the cultivation of practically the whole of their drainage basins render the amount of sediment carried by their flood waters very large.

The minor streams, such as Bureau, Clear, Copperas, and Quiver creeks, and the rivulets which course down the bluffs from the adjacent uplands, differ from the streams last described only in the greater steepness of their slopes. This, added to their proximity to the main stream, makes their run-off very rapid. The clearing away of the forests and the cultivation of the hillsides also add to the debris which they carry.

The varying contributions of these tributary streams combine to produce the fluctuations manifested in the main stream at the point where the plankton work of the Biological Station has been done. There are also other factors influencing the stage of the river at this point, notably the fluctuations of the larger tributaries below, as Spoon River and the Sangamon. Owing to the slight fall from Havana to the mouth of the river —only 20.4 feet*—the stage of the Mississippi River may materially affect the gage-reading at Havana. High water in this latter streams prolongs the floods in the Illinois, or even turns the current up stream, as in 1844, when, as I am informed by Hon. J. M. Ruggles, of Havana, the up-stream current came within five miles of that place.

The Volume Discharged.—Streams in fertile regions of the north-temperate zone usually discharge but little more than one cubic foot per second per square mile of watershed. Thus the mean discharge of the Great Lakes is about 1⅛ cubic feet

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*Based on Cooley's figures in " Lake and Gulf Waterway," Appendix I. Rolfe's survey makes it 29 feet (Rolfe, '94, p. 133), though other data in his possession make it 26.24 feet.

per square mile, while for some of the reservoir tributaries of the upper Mississippi, which include regions of less rainfall, it is estimated at about 0.75 cubic foot per mile.

There have been as yet no adequate measurements of the flow of the Illinois River at its mouth, and no extended gagings at any point on its course aside from the observations made by the U. S. Army Engineers at LaGrange, and a few isolated records and estimates at other points.

The *average flow* of the river has been estimated by Cooley ('97) to be under rather than over one cubic foot per second per square mile of watershed. Upon this basis it would be somewhat less than 29,000 cubic feet feet per second, or 915,170,400,000 cubic feet or 6.2 cubic miles per year.

Measurements made in 1882 at Hannibal and at Grafton in the Mississippi River above and below the mouth of the Illinois indicate that the discharge of the Illinois River ranges from 11,000 to 80,000 cubic feet per second, with an average of 30,000 cubic feet. This is equivalent to a maximum run-off of nearly 3 second-feet per square mile, a minimum of 0.4, and an average of 1.1. In 1882, one of the wet-year series, the river was out of its banks during the greater part of the year owing to the heavy rainfall which, throughout the state as a whole, was 18 per cent. in excess of the average. A reduction of 18 per cent. from the average flow of 1882 leaves 24,600 cubic feet per second, or 0.902 of a second-foot per square mile, as an estimate of the mean annual flow of the Illinois River. Cooley's estimate ('97) of the average run-off of the upper 15,250 square miles of the basin, based upon the gage-readings at Copperas Creek for eleven years (1879–1889), is 10,500 cubic feet per second, or 0.688 second-foot per square mile. This is 25 per cent. below the above-given estimate, based on Greenleaf's measurements at the mouth of the stream. Accepting these two estimates as approximately the average, and adopting the calculation for the river at Copperas Creek as applicable to Havana, eighteen miles below, we have the average run-off at our plankton station approximately 0.688 second-foot per square mile, or 10,570 cubic feet per second—a total, for the year, of 333,563,832,000 cubic feet, or 2.27 cubic miles. The run-off in an ordinary year is equivalent to a trifle over eight inches of rainfall in the whole watershed, or 21% of the total rainfall for the year. Greenleaf ('85) states that the area of the entire catchment-basin of the Mississippi is 1,240,039 square miles, and that the average discharge per second is 675,000 cubic feet, or only .54 cubic foot per second per square mile. The Illinois, with one forty-third of the catchment-basin, thus contributes one twenty-third of the discharge. Greenleaf's estimate of the discharge of the Illinois, even when reduced to 0.908 second-foot per square mile, places the stream in the category of the St. Lawrence River, whose discharge is slightly in excess of one second-foot, rather than with the Mississippi River, whose total discharge is but about half that amount. The average discharge from the Illinois is thus somewhat less than that of the Connecticut, of the Hudson, or of the Seine ; is about the same as that of the Delaware and of the Elbe ; but is much less than that of the Loire and of the Po, and relatively less than that of many European streams.

The *maximum flood discharge* of the Illinois has been variously estimated. On the basis of normal basin ratios for streams of like climatic conditions it should be equal to the two-thirds power of the area ($A^{2/3}$), which would be about 123,000 cubic feet per second. The exceptional flood of May, 1892, the crest of which at Kampsville had a height of 22.8 feet above low water, was reported by the engineers of the Chicago Drainage Commission to have discharged only 94,760 cubic feet per second at the mouth of the river. Cooley ('97), basing his estimate upon the discharge curves of the Mississippi at Hannibal and at Grafton, states that the maximum discharge seldom exceeds 70,000 to 80,000 cubic feet per second, and that a flood of 16 feet —a height which ordinary floods rarely exceed—would approximate only 55,000 cubic feet per second. The maximum discharge is thus considerably below what is to be expected, and the explanation lies in the delay in the run-off due to the impounding action of the bottom-lands, a phenomenon which will be discussed later. This discharge occurs most often in March or April, or in June, and rarely, if ever, in the late summer or fall, from July to December.

The *minimum discharge* of the Illinois is, for a stream of its size, extremely small, indicating the impermeability of the strata of its basin and the slight contribution of ground water to its volume. According to Cooley ('91) the discharge over the dam at Copperas Creek for a period of low water continuing for twenty days was less than 500 cubic feet per second, or 200 cubic feet less than the amount sent through the Illinois and Michigan Canal by the operations of the Bridgeport pumping works. In conclusion Cooley says: "It is probable that since the Bridgeport pumps were erected, in 1883, over half the minimum discharge above Havana has come from Lake Michigan, and one third of the minimum below the Sangamon. For the purposes of calculation, the normal low-water volume is taken at 600 cubic feet per second for the upper section of the river and at 1,200 cubic feet for the lower section." The minimum discharge occurs most frequently in the late summer and early fall,—in August, September, and October,—and occasionally in the early winter months.

THE REGIMEN OF THE ILLINOIS RIVER.

Leverett ('96) gives the following as the usual regimen of an Illinois stream:

"During the winter, when the ground is frozen and precipitation is comparatively light, the streams are low. In early spring the thawing of the ground and the greater precipitation lead to a spring freshet, when the streams are often bank-full, or even overflowing. This freshet usually occurs in March or early in April. For a few weeks after this freshet the streams are at a moderate stage, slightly above the normal. This is followed by the 'June rise,' occasioned by the great rainfall which occurs in that month, when the streams often reach as high a stage as in the spring freshet. After the June rise the streams usually drop to a low stage and remain low through the heated term, evaporation and absorption being so great as to dispose of nearly all the rainfall. In the autumn, about the autumnal equinox or a little later, heavy rains occur, which cause the streams to become swollen for a few days, or even weeks, but which seldom cause them to overflow their banks. In some years these seasonal variations are slight, and the streams show but little change in volume, but such years are exceptional. The rainfall is seldom sufficient to cause freshets to last more than a few days. The moderate and low stages are estimated to generally cover ten months of the year, and occasionally eleven months."

In the Annual Reports of the Chief of Engineers of the U. S. Army for the years 1890 and following, Captain Marshall has published the readings of the river gages located at the government dams in the Illinois River. The readings at Copperas Creek, 16.8 miles above Havana, begin in 1879, and those at LaGrange, 42.7 miles below, in 1883. The dam at Copperas Creek was completed in 1877 and the one at LaGrange in 1889. On Plate VII. will be found hydrographs plotted from the daily readings at the gages below these dams from 1879 and 1883, respectively, to 1900. The heavy sinuous lines represent the fluctuations of the river, referred in the plot to the low-water level of 1879. The mean annual curve was plotted from the mean monthly readings at the above-named localities from 1879 and 1883, respectively, to 1900. Deficiencies in the records at the two points named have been supplied, by estimate, from records at nearest point of observation, in a few cases from our Havana records.

A comparison of the hydrographs of the gages at Copperas Creek, Havana, and LaGrange reveals a close correspondence in the fluctuations, and suggests that these main movements are due to general rains or spring thaws coincident in the greater part of the drainage basin. The differences are of a minor character, and many of them are consequent upon local conditions of rainfall. On closer inspection the records at Copperas Creek and LaGrange exhibit certain general differences which are not thus explained, but result from some more widely operative cause. As a rule the extremes of high and low water are more pronounced at LaGrange than at Copperas Creek. This is apparent in the hydrographs of 1883, 1893, and 1896–98. It is also expressed in the tabulation (Tables I. and II.) of the extremes of high and low water at Copperas Creek for twenty-one years (1879–1899) and at LaGrange for seventeen years (1883–1899). The average range between highest and lowest water at Copperas Creek is 13.14 feet, at LaGrange 14.68 feet—an increase of 1.54 feet or 11.5%. In like manner the average of the total + and – movements per year of the river level at the upper dam is 50.5 feet to 59.15 feet at the lower one—an increase of 17.1% in the fluctuations of the stream at that point.

The greater fluctuations probably result from the fact that in the lower basin, within which the lower dam lies, the rainfall is greater, the drainage lines better developed, and the run-off more rapid. The reservoir action of the Des Plaines, the Kankakee, and the pumps at Bridgeport are also less effective in regulating the flow of the stream at this point, owing to their distance and to the reduction in their relative contributions.

The distance, by river, from Copperas Creek to Havana is 16.8 miles; from Havana to LaGrange is 42.7 miles—a total of 59.5 miles. The fall between the two dams is given by Cooley ('91) as 8.5 feet at natural low water. Our plankton station thus lies in the upper and more evenly regulated portion of the LaGrange pool, and probably in the most stable portion of the river between Utica and its mouth. The dam at LaGrange is estimated by the engineers to raise the water 8 feet at LaGrange, 2.4 feet at Havana, and 2 feet at Copperas Creek. As has been stated on page 113, prolonged low water will lower the level at Havana to 2 feet or even less. At such times the river between the two dams is practically a slack-water pool, which responds quickly to flood water from any source. Two principal tributaries, Spoon River and the Sangamon, enter this pool from opposite sides of the river, the former ½ mile above

Havana and the latter 22 miles below. During the summer season, when local rains occur, it sometimes happens that a storm is confined to the basin of a single tributary, especially as the Sangamon and Spoon rivers lie, according to Cooley ('91), in different storm-tracks. In such cases the effect may be very evident at one gage, but be dissipated in large part before it reaches the other.

The progress down stream of floods which originate in the upper valley varies with the abruptness and extent of the rise and with the stage of water in the lower Illinois. As stated on page 117, it took 15 days for the crest of a flood to pass from Morris to the mouth of the Illinois, a distance of 259.2 miles. Comparisons of the gage-readings at Copperas Creek and LaGrange show that the progress of the crest of the flood between the two dams is subject to great variations in duration. In some instances the culmination is reached upon the same day at both dams; in rare instances it is reached at LaGrange several days before it is at Copperas Creek, probably as a result of excessive flood water from the Sangamon. In the majority of cases, however, the maximum height is reached at the upper dam in from 2 to 3, or even as high as 7, days before it is at the lower dam. This delay is due to a variety of causes, of which one of the principal ones is the impounding action of the bottom-lands.

FLOODS AND THE IMPOUNDING ACTION OF THE BOTTOM-LANDS.

Owing to the slight development of its flood-plain, overflows occur at early stages of the rising river. The appended table, adapted from Cooley ('91), gives data pertaining to bank height and bank-full capacity of the river at various points along its course.

It will be noted that the bank-full capacity at Kampsville is 40,000 second-feet, only one third more than Greenleaf's ('85) estimate of the average discharge at that point. At Copperas Creek, on the other hand, the more moderate estimates of Cooley ('91) place the average discharge at 10,500 cubic feet per second, while the bank-full capacity is estimated at double this amount. In either case complete overflow stages appear more readily than they do in the majority of streams.

The impounding action of the bottom-lands, on the other hand, begins with every rise of the river, for as the water rises large amounts are drawn off from the main stream by the adjacent lakes and bayous, many of which retain their connection with the river even at the lowest stage. In the vicinity of Havana, for example (see Plate II.), Quiver, Thompson's, and Matanzas lakes respond at all times to fluctuations in the river. Flag Lake is invaded at about the stage of 3 feet, and at 5 to 6 feet the water begins to overflow the bottom-lands between Flag and Thompson's lakes. It is not, however, until the river has reached a stage of 8 to 9 feet that the water enters Phelps Lake. The wooded bottom-lands to the east of Flag Lake are not entirely submerged until the gage reads 12 feet, while those below Spoon River and adjacent to the main stream do not disappear until the water has reached 16 feet. Thus the impounding action of the bottoms is at its greatest as soon as the water reaches the condition of complete overflow, though it begins at the first stages of a rise above low water.

BANK-FULL CAPACITY OF LOWER ILLINOIS RIVER.

Locality	Distance from Utica (miles)	Bank Height (feet)		Cubic feet per second	Remarks
		Av.	Range		
Peru	6.2	10.4	8—13	18,000—22,000	Measured in 1889. Variation according as river is rising or falling
Henry.. ...	33.2	9.4	9—11	20,000—22,000	Very tentative estimates from dam and prison
Copperas Creek	92.7	13.7	12—15	18,000—20,000	Very tentative estimates from dam and prison
Havana	109.5	10	7—16		
LaGrange ..	152.2	11.5	8—15	30,000	Measured in 1889
Kampsville..	197.8	11.8	8—15	40,000	Estimated from measurements in 1889

In his discussion of this subject Cooley ('91), speaking of the inadequacy of the stream for the prompt removal of flood waters, says: "This lack of capacity, while it explains the wide and deep overflows, by no means implies that any large proportion of the volume moves down the valley for considerable distances except in the river bed. The dense timber and the vegetation in summer, the higher ground leading across from the bluffs along every tributary, the occasional approach of bluff, terrace, or ridge, the frequently returning sloughs from interior ponds and lakes, all forbid this. The bottoms are really storage grounds to impound the flood waters that arrive faster than the channel can carry them away, and they prolong the floods in some inverse ratio to the reduction of volume."

Observations made in the course of field work during the floods of 1896 to 1900 at Havana, lead me to suggest that there may often be developed a fair current outside of the channel of the main stream in such localities as Thompson's, Flag, Quiver, and Phelps lakes (Plate II.), where a considerable reach of open territory lies in the general direction of the main current. Even in the wooded districts the current may not be wholly absent, though it is often very slight.

The duration of the overflow in various parts of the valley illustrates the reservoir action of the bottom-lands. In the period from 1883 to 1889 the river was out of its banks at Morris 60 days, or 8.5 days per year; at Copperas Creek, for 444 days, or 63.5 days per year; at LaGrange, 526 days, or 75 days per year. I quote from Cooley ('91) the following discussion of this subject: "A better appreciation of the reservoir action, or equalizing effect, of overflows may be obtained by a consideration of the impounding area of the bottoms. An area of 704 square miles submerged to a uniform depth of four feet—this is a flood height of sixteen feet and not an unusual occurrence—represents 1.21 inches of water running off the entire watershed, and will supply the river at the rate of 110,000 cubic feet at the mouth for 8.26 days, or at half this volume, which is an approximation to the true maximum discharge, for 16.52 days. An overflow of eight feet, or a flood of twenty feet, which is an extraordinary occurrence, represents 2.42 inches of water running off the entire watershed, and will supply the river at the rate of 110,000 cubic feet for 16.52 days, or at half the volume for 33.04 days. * * * During flood stages the valley is a great lake of, say, 700 square miles, into which flood waters from above and from tributaries are precipitated, and from the lower end of which they run out more at leisure and in reduced and equalized volume."

When we remember that even in the average year over 21%, or more than 8 inches, of rainfall escapes by way of the river, that the greater portion of this run-off takes place at times of flood, and that the overflows are greatly prolonged in the lower river by the inadequacy of the channel to carry off the excess of water and by the imperfect development of the flood-plain consequent upon the past history of the valley, we realize how important, and at the same time how unique, a factor is the retardation of the run-off in relation to our plankton operations.

The past decade has witnessed the completion of a vast amount of surface and under-drainage throughout large areas in the watershed of the Illinois River. Extensive open ditches have been dredged through localities where the slope or other conditions do not favor the establishment and maintenance of natural channels. These have been supplemented by miles upon miles of tile drains, thus bringing under constant cultivation hundreds of square miles of territory occupied in former years by pond, marsh, or meadow of the original prairie. Even in the rolling prairie the thousands of little ponds and marshes which formed the head waters of the various tributaries of the river have been blotted from the landscape by the tile drain. In addition to this the natural lines of drainage have been supplemented in a great many cases by under-drainage, in order to facilitate the run-off of the rainfall and the ground water, and thus bring the soil as soon as possible into condition for cultivation. This work of drainage is to a great extent completed throughout a large part of the catchment area. The principal exception is the basin of the Kankakee River, but the drainage of even this has already been projected.

The outcome of this wide-spread interference with the established condition of natural drainage has given ground for the almost universal testimony that streams which in former years held a continuous flow throughout the summer no longer run in the dry season. The reservoirs at their head waters are emptied and the supply of ground water is early exhausted by the artificial drainage in their basin. There is also a considerable concurrence of opinion that, in the smaller streams at least, the floods come more suddenly and rise to greater heights than they did in former years. The "wash" along the banks and consequently the amount of silt carried in suspension by the flood waters are thus increased.

The presence of under-drainage undoubtedly facilitates the discharge of such water as reaches the drains, but this impetus is in large part counteracted by the greatly increased power of absorption of the soil when thus drained. Heavy rains upon a soil already surcharged with moisture may lead to even a greater run-off than the same rainfall upon the same territory rendered porous and capable of absorbing and retaining, for a short time at least, a large amount of moisture.

From many points of view the subject of the effect of drainage of the catchment-basin upon the flow of streams is one of interest and importance. For its adequate discussion records of a long series of years of the stages of tributary streams and the river both before and after the installation of the drainage system are needed. With a view to throwing some light upon the possible effect of drainage upon the floods in the main river, and consequently upon the plankton, I have tabulated the fluctuations (in excess of .25 foot in 24 hours) in the river level at the lower gage at Copperas Creek for an earlier and a recent period, each of five years. The earliest authentic records which I have been able to secure begin with 1879. This antedates the completion of a considerable portion of the artificial drainage of the river basin. I have accordingly chosen the records of 1879–1883 inclusive for comparison with those of 1892–1896 inclusive. This choice is unfortunate in one respect, for the earlier series lies in a period of heavy rainfall and the later includes two years of unusual drouth. The fact that the earlier period is in a series of wet years and the later in one of dry years will, it seems, tend to obliterate whatever contrast may exist in the rate of the fluctuations. Thus the extent of the fluctuations is much greater in the earlier period and the duration of high water is longer. The river was above the six-foot level during 1,028 days in the first period, as against 709 in the second; and it was above ten feet, that is at a stage of overflow, 645 days in the earlier period, and only 297 in the later one. The dam at LaGrange, completed in 1889, raises the water 2 feet on the lower gage at Copperas Creek at the low-water stage. Its effect at the stages above cited is not, however, according to Cooley, perceptible at the upper end of the pool.

The results of the tabulation do not reveal any alarming changes in the flood habits of the river. There is, however, a well-defined increase in the *rate* of movement in the later period as compared with the earlier. The average daily movement (above .25 foot) is in the first period .416 foot, in the second period .492 foot,—an increase of 18%. The difference is still more marked when the comparison is made in the rate of rise alone. In the earlier period the rate of movement (in excess of .25 foot) was .4848 foot per day; in the later period it was .592 foot; an increase of 22%. The distribution of this increase through the year is somewhat irregular, and, owing to the insufficiency of the original data, is probably of slight significance. The greatest increase occurs, however, in the months of May, December, September, and March, all months in which floods prevail, or at least occur occasionally.

As shown on previous pages the conformation of the valley is such as to induce a prolongation of the floods. The records and the hydrographs show that the decline from a rise is in most cases much less rapid than the approach of the flood. We find accordingly in the above table that the number of days of decline (at a rate exceeding .25 foot per day) is considerably less than those of rising waters, and that the rate of fall is also less than the rate of rise, being only .3185 and .337 foot, respectively, per day, in the two periods. The increase in the rate of

Table of Fluctuations in Illinois River at Copperas Creek Dam, lower gage, for 1879–83 and 1892–96, inclusive.
(Only fluctuations amounting to .25 ft. or more are tabulated.)

Year		Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Total	
		Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet	Days	Mvt. in feet
1879		2	+ .71	6	+ 2.15	11	+5.70	0	+0	0	+0	0	+0	6	+4.37	0	+0	1	+ .33	1	+ .35	2	+ .95	2	+ .75	31	+15.21
		0	−0	1	− .33	1	− .28	1	− .25	15	−4.86	0	−0	7	−1.90	1	− .28	0	−0	0	−0	0	−0	1	− .27	27	− 8.17
1880		11	+4.69	0	+ 0	3	+ .97	7	+2.93	4	+1.55	0	+0	0	+0	3	+1.36	3	+ .95	1	+ .35	0	+0	0	+ 0	32	+12.80
		0	−0	0	− 0	2	− .50	0	−0	0	−0	0	−0	8	−3.17	2	− .50	0	−0	1	− .60	0	−0	0	− 0	13	− 4.77
1881		0	+0	10	+ 8.58	9	+3.00	1	+ .40	0	+0	10	+4.78	2	+ .96	0	+0	0	+0	11	+4.48	9	+5.78	7	+ 2.55	59	+30.53
		0	−0	0	− 0	1	− .33	0	−0	7	−1.93	5	−1.95	17	−6.46	0	−0	1	− .26	0	−0	1	− .33	0	− 0	31	−11.26
1882		0	+0	6	+ 2.03	6	+2.07	0	+0	6	+1.77	7	+2.34	1	+ .25	0	+0	2	+ .65	0	+0	0	+0	11	+ 4.46	39	+13.57
		8	−2.37	0	− 0	0	−0	0	−0	1	− .30	3	− .75	15	−4.15	7	−1.96	0	−0	0	−0	0	−0	0	− 0	34	− 9.53
1883		0	+0	15	+15.00	0	+0	5	+1.65	3	+ .83	0	+0	2	+ .57	0	+0	1	+ .58	1	+ .28	10	+4.50	0	+ 0	37	+23.91
		0	−0	1	− .27	18	−5.28	0	−0	0	−0	0	−0	0	−0	14	−4.78	0	−0	0	−0	0	−0	2	− .52	35	−10.85
Average per year	+......	2.6	+1.08	7.4	+ 5.55	5.8	+2.35	2.6	+1.00	2.6	+ .83	3.4	+1.42	2.2	+1.23	.6	+ .27	1.4	+ .50	2.8	+1.09	4.2	+2.25	4.0	+ 1.65	39.6	+19.20
	−.....	1.6	− .47	.4	− .12	4.4	−1.28	.2	− .05	4.6	−1.42	1.6	− .54	9.4	−3.24	4.8	−1.50	.2	− .05	.2	− .12	.2	− ,07	.6	− .16	28.0	− 8.92
	Total	4.2	1.55	7.8	5.67	10.2	3.63	2.8	1.05	7.2	2.25	5.0	1.96	11.6	4.47	5.4	1.77	1.6	.55	3.0	1.21	4.4	2.32	4.6	1.81	67.6	28.12
Average movement per day	+......		+ .41		+ .75		+ .41		+ .39		+ .32		+ .42		+ .56		+ .45		+ .36		+ .39		+ .54		+ .41		+ .4848
	−.....		− .29		− .30		− .29		− .25		− .31		− .34		− .34		− .31		− .26		− .60		− .33		− .26		− .3185
	Total		.37		.73		.36		.37		.31		.39		.39		.33		.36		.40		.53		.39		.4160
1892		0	+0	0	+ 0	0	+0	10	+4.43	6	+7.13	6	+2.52	0	+0	0	+0	0	+0	0	+0	0	+0	1	+ .30	23	+14.38
		0	−0	0	− 0	0	−0	0	−0	1	− .26	5	−1.74	6	−1.85	10	−3.18	1	− .27	0	−0	0	−0	0	− 0	23	− 7.30
1893		0	+0	10	+ 7.90	8	+4.27	9	+3.20	0	+0	0	+0	0	+0	0	+0	0	+0	0	+0	0	+0	3	+ 1.30	30	+16.67
		0	−0	0	− 0	5	−1.74	5	−1.54	0	−0	1	− .25	7	−2.41	0	−0	0	−0	0	−0	0	−0	0	− 0	18	− 5.94
1894		*0	+0	*0	+ 0	8	+3.90	0	+0	0	+0	0	+0	0	+0	1	+ .50	5	+2.40	1	+ .47	0	+0	1	+ .60	16	+ 7.87
		*0	−0	*0	− 0	0	−0	1	− .80	0	−0	0	−0	0	−0	0	−0	2	− .70	0	−0	0	−0	0	− 0	3	− 1.50
1895		0	+0	5	+ 4.08	0	+0	2	+ .56	0	+0	2	+ .54	6	+4.46	1	+ .40	3	+3.83	1	+ 60	0	+0	10	+10.00	30	+24,47
		0	−0	0	− 0	1	− .35	1	− .30	0	−0	2	− .73	5	−1.77	4	−1.56	7	−2.37	2	− .97	0	−0	0	− 0	22	− 8.05
1896		0	+0	1	+ .27	0	+0	1	+ .27	6	+3.00	0	+0	10	+4.55	3	+1.07	1	+ .27	6	+2.37	0	+0	0	+ 0	28	+11.80
		4	−1.30	0	− 0	0	−0	2	− .24	3	− .97	3	− .83	3	−1.21	0	−0	0	−0	1	− .27	0	−0	0	− 0	16	− 4.81
Average per year	+ ...	0	+0	3.2	+ 2.45	3.2	+1.63	4.4	+1.69	2.4	+2.02	1.6	+ .61	3.2	+1.80	1.0	+ .39	1.8	+1.30	1.6	+ .69	0	+0	2.8	+ 2.44	25.4	+15.04
	−	.8	− .26	0	− 0	1.2	− .42	1.8	− .78	.8	− .25	2.2	− .71	4.2	−1.45	2.8	− .95	2.0	− .67	.6	− .25	0	−0	0	− 0	16.4	− 5.52
	Total	.8	.26	3.2	2.45	4.4	2.05	6.2	2.47	3.2	2.27	3.8	1.32	7.4	3.25	3.8	1.34	3.8	1.97	2.2	.94	0	0	2.8	2,44	41.8	20.56
Average movement per day	+ ..		+0		+ .77		+ .57		+ .38		+ .84		+ .38		+ .56		+ .39		+ .72		+ .43		+0		+ .87		+ .592
	−		− .33		− 0		− .35		− .43		− .31		− .32		− .35		− .34		− .34		− .42		−0		− 0		− .337
	Total		.33		.77		.47		.40		.71		.35		.44		.35		.52		.43		0		.87		.492

*Estimated from LaGrange record.

fall is thus less than 6%. So far, then, as the table goes, it indicates that there has been a moderate increase in the rapidity with which floods rise and a slight increase in the rate of their fall, as compared with the rate of their movements in a corresponding period thirteen years ago.

It is impossible from data at hand to determine whether or not the general drainage of the basin has shortened the period of high water and extended that of low water with a considerable diminution of volume at low-water stage. The decade prior to 1896 seems to have witnessed such a change, as hydrographs on Plate VII. show. This diminution is the more marked when allowance is made *at low-water stages* for the 2 feet which the dam at LaGrange (completed October 12, 1889) is estimated to raise the water on the lower gage at Copperas Creek. The fact that the rainfall was deficient during this decade doubtless

MONTHLY MEANS OF GAGE-READINGS (IN FEET) BELOW COPPERAS CREEK DAM 1879–1899.

(Basis of reference, low water of 1873 and 1879.)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly mean
1879...	2.76	6.20	8.66	10.80	5.52	2.66	4.53	2.09	.30	1.03	2.19	5.24	4.33
1880...	9.88	9.83	9.65	10.15	12.39	9.90	7.48	2.83	2.90	2.32	1.69	1.58	6.72
1881...	1.48	7.88	14.69	14.72	11.41	9.01	4.89	2.04	1.22	4.74	10.69	13.88	8.05
1882...	12.47	9.61	13.87	12.43	12.91	14.65	11.64	6.10	4.06	3.29	4.22	5.08	9.19
1883...	6.58	10.01	14.95	12.60	11.85	11.57	9.43	5.83	1.94	2.91	8.48	9.63	8.82
1884...	6.58	12.23	13.54	13.55	10.57	7.57	6.41	3.49	2.82	7.89	6.22	6.91	8.15
1885...	13.12	10.31	12.33	13.69	11.12	7.34	4.90	5.04	6.06	6.68	10.30	9.07	9.16
1886...	12.28	12.67	13.24	12.85	12.37	8.87	2.85	1.78	2.24	3.13	2.91	2.67	7.32
1887...	4.29	13.05	12.48	7.77	3.86	2.40	1.62	1.40	1.83	2.38	2.09	3.49	4.72
1888...	6.48	7.47	12.87	11.75	7.81	10.18	8.31	4.05	1.86	1.91	2.85	2.59	6.51
1889...	4.52	3.84	7.18	6.24	3.88	8.81	8.80	4.44	1.30	2.47	4.10	6.03	5.30
1890...	9.56	9.31	8.98	11.24	10.07	10.46	7.86	3.17	2.66	3.16	3.32	3.52	6.92
1891...	3.67	4.08	8.00	11.94	9.23	6.85	4.73	3.13	2.41	1.93	2.47	4.24	5.22
1892...	4.58	5.53	6.88	11.44	16.46	14.52	13.41	7.14	3.31	2.83	2.90	3.77	7.74
1893...	3.87	7.69	14.90	12.60	13.74	10.37	4.93	1.73	1.67	2.42	2.54	3.33	6.63
1894...	3.92	4.29	9.24	7.40	7.29	4.63	2.32	1.99	4.43	2.96	2.97	3.41	4.63
1895...	3.30	3.51	6.28	5.41	3.68	1.88	3.17	2.43	3.42	1.93	2.20	6.16	3.61
1896...	10.65	9.23	9.79	7.66	7.35	7.73	4.38	7.70	4.66	6.37	6.10	5.64	7.26
1897...	11.39	11.04	14.09	13.34	9.52	5.71	6.19	2.36	1.81	1.76	2.42	3.06	6.86
1898...	5.10	9.31	13.25	14.69	11.49	11.49	5.50	3.52	4.29	4.28	7.79	6.92	8.11
1899...	8.47	7.28	13.07	11.24	7.86	7.58	4.05	2.71	2.24	2.54	3.64	4.56	6.27
Means for 21 years	6.90	8.29	11.34	11.11	9.59	8.29	6.06	3.57	2.82	3.27	4.38	5.27	6.74

MONTHLY MEANS OF GAGE-READINGS (IN FEET) BELOW LAGRANGE DAM
1883-1899.

(Basis of reference, low water of 1879.)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly mean
1883...	7.41	11.36	16.71	12.77	12.18	13.04	10.34	5.62	1.67	2.52	6.89	8.81	9.11
1884...	6.09	13.04	14.17	14.92	11.22	8.66	6.42	4.04	2.74	7.62	6.01	6.70	8.47
1885...	14.17	12.06	13.84	14.20	12.48	7.99	6.40	4.72	5.18	5.69	9.32	8.15	9.52
1886...	12.83	13.77	14.24	13.79	12.77	9.31	2.79	1.54	1.68	2.53	2.12	2.32	7.47
1887...	3.70	12.71	13.64	7.36	3.75	1.70	0.72	0.23	0.24	0.79	0.83	2.21	3.99
1888...	6.25	7.62	9.87	12.01	9.02	10.78	8.61	3.93	1.21	0.95	1.79	2.05	6.17
1889*..	4.33	3.59	7.27	5.78	3.72	9.48	9.05	4.00	2.45	0.92	3.75	5.43	4.98
1890...	10.22	9.41	8.92	10.43	9.39	8.82	6.83	1.39	1.11	1.58	1.86	1.92	5.96
1891...	2.21	2.67	6.06	10.13	9.00	5.18	3.56	2.16	0.92	0.32	1.23	2.83	3.86
1892...	3.42	4.84	6.69	12.70	17.16	15.97	14.39	5.84	2.13	1.29	1.69	2.94	7.42
1893...	2.46	8.31	15.44	13.74	15.87	12.00	4.24	0.68	0.34	1.28	1.09	2.24	6.45
1894...	2.70	4.19	7.38	6.28	5.80	3.24	1.26	0.57	2.96	1.56	1.73	2.12	3.30
1895...	1.96	2.70	4.98	4.05	2.32	0.73	1.96	1.55	2.74	0.86	1.02	4.99	2.49
1896...	10.06	8.64	8.92	6.61	5.90	7.09	4.77	7.59	4.32	5.28	5.20	4.85	6.60
1897. :	11.50	10.95	14.50	15.49	10.28	4.99	5.65	1.80	0.98	0.86	1.43	1.93	6.67
1898...	4.55	9.09	13.15	16.33	12.74	12.85	5.44	3.29	3.96	3.57	6.75	6.40	8.14
1899...	7.87	7.87	13.79	11.58	8.92	8.93	3.94	2.28	1.08	1.23	2.45	3.19	8.09
Means for 17 years.	6.57	8.40	11.15	11.07	9.56	8.28	5.67	3.01	2.11	2.28	3.25	4.07	6.40

*Dam practically completed in November of this year.

accounts for much of this change. Records during a period of abundant rainfall are necessary for an adequate discussion of the problem.

The foregoing tables give the monthly means and monthly and yearly averages at the two dams for the period above named.

In Tables I. and II. are to be found tabulations of the extremes of low and high water, the range of movement, and the total of the + and – movements for each month in the periods covered by the records at the two dams. The appended table also gives some data pertaining to the major fluctuations at Copperas Creek. The rainfall statistics refer to the state as a whole and are taken from Leverett ('96).

From the data presented in the hydrographs and these tabulations the variations and the average condition of the Illinois River may be determined, and some estimate made of the normal regimen of the stream. In general terms this is as follows: There is in each year a period of high water—that is,

FLUCTUATIONS AT COPPERAS CREEK.

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Per cent. of rainfall	6.2	6.7	7.0	8.2	10.5	12.2	9.9	8.6	9.0	8.5	7.1	6.0	
Number of rises exceeding 3 feet in range	8	6	10	5	4	7	2	3	2	3	3	3	56
Number of culminations of floods exceeding 10 feet above low water	4	3	5	9	3	6	0	0	0	0	1	3	34
Occurrences of minimum stages for the year	0	0	0	0	0	1	3	6	8	5	1	1	25*
Occurrences of maximum stage for the year	3	3	5	6	2	1	0	0	0	0	0	1	21
Average number of days when water was more than 8 feet above low water	11.1	15.8	24.8	23.9	20.1	16.8	7.9	1.7	0	1.0	4.0	5.1	132.2
Average number of days when water was less than 4 feet above low water	10.0	3.8	0	0	3.6	4.8	8.9	20.8	23.2	25.0	19.0	15.0	134.1

*Minimum levels reached in two different months in 1887 and in 1892, and in three in 1897.

more than 8 feet above low water—whose duration has averaged 132 days, ranging from 11 days in 1895 to 230 in 1883. The average seasonal position of this period is from February to June, inclusive, though portions of it have occurred in every month of the year but September. In some cases it begins with the autumnal rains in October or November and continues throughout the winter, as in 1881 and 1889, though in some instances this early autumnal rise is followed by a sharp and considerable decline. The rise of the flood may occur in any of the succeeding months up to and including April. There is a predominance of flood movement in January as compared with February, there being more instances in the former month of movements exceeding 3 feet and culminations of floods exceeding 10 feet than there are in the latter. What is popularly known as a "January thaw" is probably the occasion of this predominance. The rise of the flood is often very rapid, as, for example, in 1881, 1883, and 1895, the rise in 1883 being over 11 feet in 8 days. These rapid rises often occur after heavy precipitation in winter months when the conditions favor a very rapid run-off. The initial stages of the flood are usually less precipitous, as are also the final stages preceding the culmination, especially at overflow stages, when the flood capacity is greatly increased by the impounding action of the flood-plain. The flood curve is rarely an even one, such as that of 1887, since fluctuations of more or less importance occur, as a rule, during both the rise and fall. A well-defined culmination is, however, present, except in a few instances, such as in 1890, when three about equal maxima appear.

The maximum of the flood occurs most frequently in the latter part of March or the first part of April, though it may appear as early as December, as in 1895, or as late as June, as in 1889. Of the twenty-one maxima six have been in April, five in March, three each in January and February, two in May, and one each in December and June. The highest point reached at Copperas Creek in 21 years was 19.25 feet in 1885. The rises in excess of 10 feet above low water in the 21 years have appeared nine times in April, six in June, five in March, four in January, three each in December, February, and May, and but once in November, while no flood has reached this limit in the remaining four months. The decline of the flood is much less rapid than its rise, and is often marked by secondary rises which more or less delay the return of the low-water period.

The "June rise," caused by the heavy rainfall of that month, is masked by the averaging process in the mean hydrograph, but appears occasionally (nine times in twenty-one years) in the annual ones as a well-defined flood. In the majority of years, however, it appears as a slight interruption in the decline of the earlier spring flood. In a few cases these fluctuations occur late in May or early in July. The fact that this June rise is so little felt in the Illinois, while it is so prominent in other streams of the state, is explained by the fact that it often occurs within the period of overflow, when large accessions of water produce relatively slight rises of river levels. A comparison of the hydrographs of 1889 and 1892 will illustrate the points in question, the June rise of the latter year appearing as a slight fluctuation in the declining flood, while in the former year it stands out as a well-marked rise, owing simply to the previous low water.

As compared with Leverett's normal regimen for an Illinois stream, we find in the case of the Illinois River that the high-water period exhibits a considerable range; that it extends over a much longer time; and that the phenomenon of the June rise is less pronounced,—all of which deviations may be explained by the impounding action of the slightly developed flood-plain of the Illinois.

Following the period of high water comes an equally pronounced period of low water, extending through the summer months until the late autumnal or winter rise. As shown by the averages, this low-water period (below four feet) extends from August to November, inclusive. It varies, however, with the high-water period, appearing even in May, as it did in 1895, and frequently continuing through the fall and winter till late in February, as it did in 1891, 1893, and 1894. The average time during which the water was below 4 feet for the 21 years at Copperas Creek is 134.1 days, two days more than the high-water period. This low-water stage is quite variable in its duration, ranging from 260 days in 1895 to 5 in 1885. The low-water period, which Leverett estimates as continuing at least ten months in normal Illinois streams, is thus much shortened in the Illinois River. The lowest levels of the year are reached usually in September, the occurrence of minimum levels being distributed among the months as follows: In the records at Copperas Creek, eight occur in September, six in August, five in October, three in July, and one each in November, December, and June. The lowest level was recorded at Copperas Creek in 1879, when the low-water mark was established. It has not again been reached, owing since 1889 to the dam at LaGrange.

The low-water period is often one of marked stability as contrasted with other parts of the year, the total movement of river levels falling to 0.10 foot per month in November, 1893, and frequently amounting to less than one foot in September, October, and November, while even this movement is probably caused to a considerable extent by the operation of the locks and by changes in the direction or force of the wind. The stage of extreme low water is followed by a gradual but very slight rise during the fall months, which cannot be attributed entirely to rainfall since, as shown in the table on page 126, these are months of lessened precipitation. This increase is well shown in the hydrographs of 1893 and 1897. It seems more probable that with the falling temperatures the loss by evaporation, both from the river and its tributaries, is sufficiently lessened to account for this slight rise in levels, amounting in most cases to about one foot.

This low-water period is frequently interrupted by minor fluctuations, some of which appear at or subsequent to the autumnal equinox. These fluctuations are due to heavy summer rains, and usually appear suddenly and decline with almost equal abruptness. They rarely rise to eight feet and are usually below five; they thus do not cause overflows, and affect only those bayous and lakes which maintain connections with the river at low-water levels. Their duration is short also, being but a week or ten days, rarely a fortnight. In 1896 there was a repetition of such rises of more than usual prominence and duration, giving a unique character to the hydrograph of that year. The equinoctial period, marked by the slightly increased rainfall of September, is not marked in the average hydrograph by any increase. Indeed, the average level for this month at Copperas Creek is only 2.82 feet, the lowest average for the year. The rises attending this period appear but twelve times in twenty-one years, are usually insignificant, and are often less than two feet, owing doubtless to the greater capacity of the soil for absorption at this season of the year.

The time not included in the high- and low-water periods as here defined amounts on the average to 96 days, a relatively short time for the transition between these two extreme conditions. This abruptness of the transition stages is to some extent apparent in the hydrographs.

On Tables I. and II. will be found tabulations of the total movement, both + and —, of the river levels in each month in the period covered by the records at the two dams. The monthly and yearly averages of these data are also given. The figures are to a certain extent an index of the relative stability, both monthly and annual, of the river. The averaging process has to some degree masked the differences in the several months, as will be seen on a comparison of the mean monthly movements with those for any single year, the latter exhibiting at some times of the year much greater contrasts than the means. Thus the greatest and least movements in 1897 are respectively 10.37 feet in January and 0.40 in October, while the corresponding limits in the means are 4.18 feet in July and 2.78 in November. The means indicate two periods; one of considerable movement, corresponding to that of high water, and one of less movement, representing the low-water stages. The greatest movements occur in February and July, indicating the rise and decline of the flood. The least movement is found in November, a period of low water and freedom from sudden and heavy rainfall. The several years exhibit quite a range in the total amount of change in levels, the extremes in Copperas Creek in twenty-one years being 68.70 feet in 1881 and 32.92 in 1894; at La Grange, in seventeen years, 85.36 feet in 1898 and 40.41 in 1887. The movement is thus somewhat greater and more variable at the lower dam. In general there is some correlation between the average heights of the water for the year and the total movement of levels, though this correlation is by no means continuous or uniform, as will be seen, for example, on comparison of the average heights and movements for 1895 and 1896 (3.61 and 7.26 feet; and 51.89 and 53.16 feet). The abnormally low water in 1895 was followed by an unusually early rise in December. Had this rise occurred ten days later the correlation of average heights and total movements would have been more apparent in these years.

The range in movement of river levels between the highest and lowest water of the year as shown in the tables varies at Copperas Creek between 9.00 feet in 1889 and 17.70 in 1883, and at LaGrange between 8.75 in 1894 and 20.52 in 1883, while the extreme range for the period of record at each dam is 19.27 and 22.92 feet respectively. Somewhat greater fluctuations thus occur at the lower dam.

The preceding discussion of the fluctuations in river levels affords evidence for the extreme instability of the environment of the plankton with which we are to deal. Indeed the only really constant feature seems to be this very instability. The mere presentation of the statistics of the fluctuations can give but little life or color to the great modifications which these changes produce in the physical conditions environing all the aquatic life of the river. The great increase in area and volume (not far from one hundredfold) which occurs at high water (Plate III.) affords an opportunity for a grêat increase in the total production of the plankton, especially when the flood period extends into the spring and early summer months, when the maximum development of the plankton sometimes occurs. The submerged flood-plain also affords the greatest variety of conditions of depth, current, vegetation, bottom, light and shade, temperature, and sewage, thus favoring the diversification of the plankton locally produced but carried away to some extent into the channel by the receding floods.

A trip by boat across the submerged bottom-lands from the Quiver shore to the western bluff (Pl. II. and III.) in the latter part of May would be far more enlightening than any description that might be given. As we leave the sandy shore of Quiver we traverse the clear, cold, and spring-fed water along the eastern bank with its rapidly growing carpet of *Ceratophyllum,* and in a few rods note the increasing turbidity, rising temperature, and richer plankton of the water which has moved down from the more or less open and slightly submerged bottom to the north (Pl. II.). As we cross the muddy bank of Quiver ridge and enter the main channel of the river we find rougher water, caused by the wind which usually sweeps up or down the stream with considerable force between the bordering forests. The water also appears much more turbid by reason of silt and plankton, and no trace of vegetation is to be seen save occasional masses of floating *Ceratophyllum* or isolated plants of *Lemna*, *Wolffia*, or *Spirodela.* Huge masses of cattle-yard refuse, veritable floating-gardens, may also at times be seen moving down the channel or stranded in some eddy along shore. As we plunge into the willow thicket on the western shore we have to pick our way through the accumulated drift lodged in the shoals or caught by the trunks of the trees or the submerged underbrush. The surface of the water is one mat of logs, brush, sticks, bark, and fragments of floating vegetation, with its interstices filled with *Lemnaceæ* dotted with the black statoblasts of *Plumatella.* From this dark labyrinth we emerge to the muddy but quiet waters of Seeb's Lake with its treacherous bottom of soft black ooze. We next enter a wider stretch of more open territory with scattered willows and maples and a rank growth of semiaquatic vegetation, principally *Polygonums.* The water is clearer and of a brownish tinge (from the diatoms), while mats of algæ adhere to the leaves and stems of the emerging plants. A flock of startled water-fowl leave their feeding grounds as we pass into the wide expanse of Flag Lake. We push our way through patches of lily-pads and beds of lotus, past the submerged domes of muskrat houses built of last year's rushes, and thread our way, through devious channels, among the fresh green flags and rushes just emerging from the water. Open patches of water here and there mark the areas occupied by the "moss" or *Ceratophyllum*, as yet at some depth below the surface. The *Lemnaceæ* are everywhere lodged in mats and windrows, and, amidst their green, one occasionally catches sight of a bright cluster of *Azolla*. The water is clear and brownish save where our movements stir the treacherous and mobile bottom. We now enter a second time the partially wooded country, and cross the submerged ridge to the sandy eastern shore of Thompson's Lake. This ridge is covered by submerged vegetation which has as yet attained but little growth. The "breaks" of the startled fish show that we have invaded favorite feeding grounds. The waters are evidently moving towards the river, and they bear the rich plankton of Thompson's Lake, while their turbidity is doubtless increased by the movements of the fish. Schools of young fry can be seen feeding upon the plankton in the warm and quiet waters. Thompson's Lake, the largest expanse of water in the neighborhood, is wont to be rough in windy weather, but if the day be still we can see the rich aquatic vegetation which fringes its margin and lies in scattered masses toward its southern end. Its waters seem somewhat turbid, but more from plankton than from silt, though the deep soft mud which forms much of its bottom is easily stirred. The slender transparent limnetic young of the gizzard-shad may be seen swimming near the surface. There is a perceptible drift to the south in the open lake, though this current is deflected by the elevated banks of Spoon River (Pl. II.) towards the Illinois River, crossing the lower bottom-lands above this region. If we push on through the fringing willows at the south we find a series of open places locally known as "ponds". The warm still waters are turbid in places from the movements of fish, and at times we see the compact schools of young dogfish (*Amia calva*) and, if we are late enough in the season, the myriads of young black, tadpole-like catfish (*Ameiurus*), likewise in schools, while young carp (*Cyprinus carpio*) are everywhere. The new vegetation is already springing from the decaying and matted stems of the preceding summer. Turning back towards the river we pass through the heavy timber where the still brown water, cool and clear, overlies the decaying leaves and vegetation of last season's growth, now coated with the flood deposits of the winter. Emerging again upon the river channel we may find a turbid yellow flood pouring out from Spoon River, bringing down its load of drift and earth, and marking its course down the stream as far as the eye can see.

From an environment even more varied than this come the different contributions to the plankton of the river in the flood seasons. Every change in level modifies this environment by connecting or cutting off backwaters, shifting or checking currents, disturbing vegetation and temperature in a manner the very complexity of which beggars description.

Contrast with the extent and variety of conditions at flood the limitations placed upon the stream at low water (Pl. IV. and V.). Instead of an unbroken expanse of four or more miles we find now a stream only 500 feet in width (at Station E), while the adjacent territory is dry land save where the sloughs, marshes, and lakes remain as reservoirs. Quiver Lake is now much reduced in width, and it may be choked with vegetation except in a narrow channel where the clear water shows little or no current. A half mile below we find the river water rushing in a narrow "cut-off" across the ridge of black alluvium into the lower end of the lake. The wooded banks which separate the river from Quiver and Seeb's lakes are now crowded with a rank growth of weeds and vines. The latter "lake" is reduced to a shallow stagnant arm of the river, whose warm turbid waters are foul with dead mollusks, and whose reeking mudflats beneath the August sun shine green and red with a scum of *Euglena*. As we pick our way through the tangle of rank vegetation we come upon Flag Lake, now a sea of rushes. The discharge from this marsh to the river ceased in the early summer, and its margins are even now dry, with gaping cracks. Beyond the marsh we pass to the shore of Thompson's Lake to find its southern end choked with vegetation, though the greater part to the north is open water. The woodland and open ground to the south are now pastures and fields of waving corn The only outlet to this large body of water, now somewhat reduced in area but warm, turbid, and rich in plankton, is a tortuous slough six miles to the north. The discharge, however, is in any case but slight, the lake being, indeed, not infrequently the recipient of river water. Spoon River still pours a sluggish but constant stream into the river, but save for a water-bloom of livid green (*Euglena*) its waters yield but little plankton. Thus, of all the wide area contributing to the plankton of the channel at high water there now remain only Thompson's and Quiver lakes and Spoon River, each much diminished in volume, but all diversified in character.

Returning now to the river itself we find a gently sloping bank of black mud, baked and cracked by the sun's heat, extending towards the softer deposit at the water's margin. A low growth of grasses, sedges, and weeds springs up as the water recedes. The river margin does not often have much aquatic vegetation. In low-water years, such as 1894 and 1895, a considerable fringe is formed along the shore, but this is quickly cleaned out on the seining grounds, which occupy a large part of the shore, as soon as the fishing season opens in July. In years of normal high-water the vegetation rarely gets much of a foothold along the shores, even at low-water stages. Save for the few sandy banks where springs abound, such as those below Havana along the eastern bluff, there is little, at least in the LaGrange pool, to vary this monotony of mud banks and fringing willows. The backwaters have been reduced to the lakes, sloughs, bayous, and marshes (Pl. II.) which abound everywhere in the bottom-lands. Many of these, as, for example, Phelps and Flag lakes, have ceased in their reduced condition to contribute to the river. Others, like Thompson's Lake, maintain a connection with the river by means of a long and tortuous bayou or slough through which the current flows in or out as the relative levels of the two fluctuate.

This lake receives but little water from a few springs and creeks along the bluffs, and like many others in the bottom-lands serves only as a reservoir from which the water is slowly drawn off as the river falls, but when once the lower stages are reached its contributions cease. Still others, like Quiver and Matanzas, maintain direct and open connection with the river, and since they receive tributary streams they continue to feed the river, but in reduced volume. Though the number of tributary areas is thus much reduced at low-water stages, the individual peculiarities of the tributary waters in the bottom-lands become more pronounced. As each one loses its connection with the general flood it becomes a separate unit of environment, with its local differences in those factors which determine the character of the plankton developing in its waters. The resulting contributions may thus differ greatly in amount and component organisms, and accordingly tend to diversify the river plankton of low water to a degree even more marked than that of high water.

With the confinement of the river waters to the channel goes a marked condensation of the sewage, which, under conditions of uninterrupted low water, leads at times to an excessive development of the plankton, or, if the river is closed by ice, to stagnation conditions. But few years, however, offer such opportunities; for, as a rule, in most low-water periods sudden and heavy rains are wont to occur which flush the stream, wash away the sewage and plankton-laden waters, and store anew the reservoir lakes without causing any considerable overflow. After each catastrophe of this sort the decline of the flood affords a new and favorable opportunity for the development of the plankton.

In this instability lies the great distinction between the river and the lake as a unit of environment—for I believe we are justified in applying this phrase to the conditions of fluviatile life, though it must be admitted that the "fluviatile unit" is an exceedingly complex one. As the discussion of the river fluctuations indicated, there is a seasonal routine which the cycle of seasonal fluctuations more or less approximates year after year, and not a few of the important environing factors are operative in much the same way upon by far the larger part of the biological area. There is thus a common basis upon which the other less constant factors produce their effect. The best justification, however, for the use of the term lies in the results of our work, which show a biological assemblage adapted to this complex environment, and exhibiting in some of its phases at least as much uniformity as the more stable factors of its surroundings.

During 1894 and the early part of 1895 readings were recorded only at occasional intervals owing to the fact that the Station was occupied but part of the time, its work being as yet in the preliminary stage. From August to October, 1895, bi-daily readings were made by Mr. Newberry at a gage located by us at our field headquarters and based upon the government gage on the protection at the wagon-bridge at Havana. From October, 1895, to January, 1896, the readings were taken by Mr. Hempel at the government gage, and since that time bi-daily or daily readings have been taken under the direction of the city authorities of Havana. These readings are given in the tables which follow.

READINGS OF RIVER GAGE AT HAVANA, 1895.

(Plane of reference, low water of 1873.)

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	......	......	......	......	......	......	2.10	......	2.50	2.75	2.25	.....
2	......	......	......	4.75	......	......	......	......	2.42	2.55	2.30	3.15
3	......	......	......	4.85	4.00	2.80	......	......	2.32	2.42	......	3.20
4	......	......	......	......	3.90	......	......	......	5.12	2.37	2.30	2.20
5	......	......	......	......	4.00	.. ..	......	......	5.75	2.30	......	3.35
6	......	......	......	......	......	......	......	......	5.87	2.27	2.37	3.35
7	......	......	......	......	......	......	......	......	5.80	2.22	2.45	3.35
8	......	......	......	4.85	......	......	......	2.57	5.52	2.20	2.55	.....
9	......	......	......	4.85	......	......	......	2.40	5.00	2.20	2.65	3.35
10	......	......	......	4.95	......	......	......	2.30	4.50	2.20	......	3.35
11	......	......	......	5.00	......	......	2.40	2.37	4.10	......	2.67	3.05
12	......	......	......	5.20	......	......	2.35	2.45	3.77	2.20	2.70	3.00
13	......	......	......	5.35	......	......	......	2.42	3.55	... ..	2.70	2.92
14	......	......	......	......	......	......	......	2.35	3.27	2.20	2.70	2.85
15	......	......	......	......	......	......	......	2.32	3.00	......	2.70	.....
16	......	......	......	......	......	......	......	2.25	3.47	2.25	2.70	2.70
17	......	......	......	5.80	......	......	......	2.20	3.62	2.37	......	.....
18	......	......	5.60	......	3.40	......	......	2.17	3.52	2.45	2.70	2.85
19	......	......	......	......	......	2.00	......	2.12	3.35	2.37	2.75	5.20
20	......	......	......	5.85	......	2.10	......	2.00	3.12	......	2.77	7.60
21	......	......	......	......	3.25	2.00	......	2.10	2.92	2.40	2.75	7.75
22	......	......	......	......	3.00	1.85	......	2.20	2.82	2.35	2.70	8.45
23	......	......	5.30	......	......	......	......	2.22	2.72	2.35	2.75	8.82
24	......	......	......	......	......	1.80	......	2.57	2.67	2.35	......	9.55
25	......	......	......	......	......	1.70	......	2.70	2.62	2.30	2.80	10.30
26	......	......	......	......	......	2.10	......	2.85	2.72	2.40	2.90	11.00
27	......	......	5.10	5.10	......	......	......	2.72	3.90	......	2.85	11.50
28	......	......	.... :	......	......	......	......	2.60	2.90	2.32	......	11.92
29	......	......	......	......	......	......	......	2.65	......	2.30	2.85	12.25
30	......	......	5.10	4.55	......	......	......	2.65	......	2.25	2.90	12.50
31	......	......	......	......	2.70	......	......	2.65	......	2.25	......	12.60

Readings of River Gage at Havana, 1896.

(Plane of reference, low water of 1873.)

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	12.6	8.4	10.0	7.8	7.1	8.4	5.2	7.9	5.6	4.4	5.1	6.2
2	12.6	8.5	10.1	7.7	7.1	8.5	5.0	8.3	5.5	4.8	5.0	6.1
3	12.5	8.5	10.1	7.7	7.0	8.5	4.9	8.5	5.4	5.4	5.0	6.0
4	12.4	8.5	10.2	7.6	6.9	8.5	4.8	8.6	5.2	5.8	5.1	6.0
5	12.2	8.6	10.2	7.6	6.8	8.4	4.7	8.6	5.1	6.0	5.3	5.9
6	12.2	8.6	10.2	7.5	6.7	8.3	4.6	8.6	4.9	6.2	5.3	5.9
7	12.0	8.7	10.2	7.4	6.6	8.3	4.5	8.5	4.7	6.5	5.3	5.9
8	11.8	8.8	10.2	7.3	6.4	8.3	4.4	8.4	4.5	6.7	5.3	5.9
9	11.6	8.8	10.2	7.3	6.2	8.2	4.1	8.3	4.3	6.7	5.3	5.9
10	11.4	8.9	10.1	7.4	6.0	8.1	4.0	8.2	4.2	6.9	5.4	5.9
11	11.1	9.0	10.0	7.5	5.8	8.0	3.9	8.1	4.1	6.9	5.6	5.8
12	10.9	9.0	9.9	7.5	5.6	7.9	3.7	7.9	4.0	6.9	5.7	5.8
13	10.7	9.1	9.9	7.5	5.4	7.8	3.5	7.7	4.1	6.9	5.7	5.8
14	10.5	9.1	9.9	7.5	5.2	7.7	3.3	7.6	4.3	6.9	5.9	5.7
15	10.3	9.1	9.8	7.4	5.0	7.6	3.1	7.4	4.1	6.9	6.0	5.7
16	10.1	9.0	9.7	7.4	4.9	7.6	2.9	7.4	4.2	6.8	6.2	5.7
17	10.0	8.8	9.6	7.3	4.9	7.5	2.7	7.5	4.4	6.7	6.3	5.6
18	9.9	6.8	9.5	7.1	5.0	7.5	2.5	7.5	4.7	6.6	6.4	5.6
19	9.7	8.5	9.4	7.1	5.9	7.4	3.2	7.3	4.8	6.4	6.5	5.5
20	9.4	8.5	9.3	7.0	6.4	7.2	4.1	7.2	4.9	6.3	6.5	5.5
21	9.2	8.3	9.1	7.0	6.7	7.0	4.3	7.1	4.9	6.2	6.5	5.4
22	9.0	8.1	9.0	6.9	7.0	6.9	4.2	6.9	4.9	6.0	6.5	5.3
23	8.8	8.0	8.9	6.9	7.2	6.7	4.2	6.8	4.8	5.9	6.5	5.2
24	8.7	8.6	8.7	6.9	7.4	6.5	4.8	6.7	4.7	5.7	6.5	5.1
25	8.5	9.1	8.6	6.9	7.5	6.3	5.3	6.6	4.6	5.6	6.4	5.0
26	8.4	9.4	8.4	7.0	7.5	6.1	5.7	6.5	4.5	5.4	6.4	4.8
27	8.2	9.7	8.3	7.0	7.6	5.9	6.1	6.3	4.4	5.3	6.4	4.6
28	8.2	9.8	8.2	7.0	7.8	5.7	6.4	6.2	4.4	5.2	6.3	4.5
29	8.1	9.9	8.1	7.1	8.0	5.5	6.8	6.0	4.3	5.1	6.3	4.5
30	8.1	...	8.1	7.1	8.1	3.5	7.0	5.9	4.3	5.0	6.2	4.5
31	8.2	...	7.9	...	8.3	...	7.3	5.8	...	5.1	...	4.5
Mean	10.24	8.83	9.41	7.28	6.58	7.38	4.55	7.42	4.62	6.04	5.89	5.48
Grand Average												6.975

Readings of River Gage at Havana, 1897.

(Plane of reference, low water of 1873.)

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.5	11.8	11.9	15.7	11.2	6.8	7.4	4.0	1.7	1.9	2.5	3.3
2	5.0	11.7	11.9	15.8	11.1	6.6	7.4	3.8	1.7	1.9	2.5	3.2
3	7.0	11.6	11.8	15.8	11.0	6.5	7.3	3.6	1.7	1.9	2.5	3.0
4	8.0	11.5	11.8	15.7	11.0	6.4	7.2	3.5	1.7	1.9	2.4	3.0
5	8.6	11.4	12.0	15.6	10.9	6.2	7.5	3.3	1.7	1.9	2.4	3.0
6	9.5	11.3	12.2	15.4	10.9	6.0	7.4	3.2	1.8	1.9	2.4	3.0
7	10.3	11.2	12.3	15.1	10.8	5.8	7.3	2.8	1.8	1.9	2.6	3.0
8	10.8	11.2	12.3	14.9	10.6	5.6	7.2	2.5	1.9	1.9	2.6	3.0
9	11.2	11.1	12.4	14.6	10.5	5.4	7.0	2.3	2.0	1.19	2.6	3.1
10	11.6	11.0	12.5	14.4	10.4	5.2	6.9	2.3	2.0	1.9	2.8	3.1
11	12.0	10.9	12.7	14.1	10.3	5.0	7.2	2.3	2.0	1.9	3.0	3.3
12	12.2	10.7	12.9	13.9	10.2	5.0	7.0	2.0	2.0	1.9	2.9	3.4
13	12.4	10.6	13.2	13.7	10.1	4.8	6.6	2.0	2.0	1.9	2.8	3.5
14	12.5	10.4	13.4	13.5	9.9	4.6	6.3	1.9	2.0	1.9	2.8	3.4
15	12.6	10.4	13.6	13.2	9.8	4.4	6.0	1.9	2.0	1.9	2.8	3.4
16	12.6	10.4	13.8	13.1	9.6	4.2	5.9	1.9	2.0	2.0	2.8	3.4
17	12.6	10.5	14.0	12.9	9.5	4.1	5.7	1.9	2.1	2.0	2.8	3.4
18	12.7	10.7	14.2	12.7	9.3	4.0	5.5	1.9	2.1	2.0	2.9	3.3
19	12.7	10.8	14.4	12.5	9.2	4.2	5.4	1.9	2.1	2.0	2.9	3.3
20	12.9	10.9	14.7	12.3	8.9	4.3	5.3	1.9	2.1	2.0	2.9	3.3
21	12.9	11.0	14.9	12.1	8.7	4.7	5.2	1.9	2.0	2.0	2.8	3.2
22	12.9	11.1	15.2	11.9	8.6	5.1	5.1	1.9	2.0	2.0	2.8	3.2
23	12.9	11.3	15.6	11.9	8.4	5.3	5.0	1.8	2.0	2.0	2.8	3.2
24	12.6	11.4	15.8	11.9	8.2	5.7	5.1	1.8	2.0	2.0	2.8	3.2
25	12.6	11.6	15.9	11.8	8.0	6.0	5.3	1.8	2.0	2.1	2.9	3.2
26	12.6	11.7	16.0	11.7	7.9	6.4	5.1	1.8	2.0	2.1	3.2	3.2
27	12.5	11.6	16.0	11.6	7.7	6.7	5.0	1.8	2.0	2.2	3.4	3.2
28	12.4	11.7	16.0	11.5	7.5	6.9	4.8	1.8	2.0	2.2	3.5	3.2
29	12.2	....	15.9	11.4	7.3	7.1	4.5	1.8	2.0	2.3	3.4	3.2
30	12.1	....	15.8	11.3	7.2	7.2	4.6	1.8	2.0	2.4	3.2	3.2
31	12.0	....	15.7	....	7.0	...	4.4	1.8	...	2.4	...	3.2
Mean	11.28	11.13	13.89	13.40	9.41	5.54	6.05	2.29	2.01	2.01	2.82	3.22
Grand Average												6.903

READINGS OF RIVER GAGE AT HAVANA, 1898.
(Plane of reference, low water of 1873.)

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.2	7.3	11.4	17.9	11.3	13.6	9.4	2.6	3.6	4.3	6.3	8.2
2	3.2	7.3	11.4	18.0	11.2	13.5	9.3	2.7	3.6	4.2	6.5	8.0
3	3.2	7.4	11.3	17.8	11.3	13.3	9.1	2.8	3.5	4.1	6.5	7.9
4	3.2	7.5	11.3	17.6	11.0	13.1	8.9	2.8	3.5	4.0	6.5	7.7
5	3.2	7.5	11.2	17.3	10.9	12.8	8.7	2.8	4.0	3.9	6.7	7.5
6	3.2	7.4	11.1	16.9	10.8	12.7	8.5	2.7	4.7	3.9	6.7	7.2
7	3.2	7.3	11.1	16.5	10.7	12.5	8.3	2.8	5.1	3.9	6.7	6.9
8	3.2	7.1	11.0	16.2	10.5	12.3	8.1	3.0	5.1	3.8	6.7	6.7
9	3.5	7.0	10.8	15.8	10.4	12.1	7.8	3.2	4.9	3.7	6.7	6.5
10	3.6	7.1	11.0	15.5	10.3	12.0	7.6	3.0	4.7	3.8	6.7	6.5
11	3.7	7.5	11.1	15.1	10.1	12.0	7.2	2.8	4.5	3.9	6.7	6.9
12	4.3	8.1	11.4	14.8	10.0	11.9	7.0	2.7	4.4	3.9	6.8	6.8
13	5.4	8.3	11.6	14.5	9.9	11.9	6.7	2.7	4.2	3.8	6.9	6.7
14	5.7	8.6	11.9	14.3	9.8	11.9	6.2	2.9	4.7	3.8	6.9	6.7
15	5.8	9.0	12.1	14.0	9.7	11.6	5.8	3.3	5.0	3.6	7.0	6.6
16	5.6	9.0	12.4	13.8	9.9	11.5	5.5	3.7	4.8	3.6	7.2	6.5
17	5.4	9.3	12.9	13.6	10.1	11.4	5.2	4.7	4.6	3.7	7.1	6.3
18	5.2	9.6	12.9	13.4	10.2	11.2	5.0	5.5	4.3	3.8	7.9	6.2
19	5.2	9.9	13.2	13.1	10.7	11.1	4.7	5.7	4.4	3.9	8.0	6.0
20	5.4	10.2	13.5	12.9	11.4	10.9	4.2	5.3	4.2	3.9	8.2	5.9
21	5.8	10.3	13.7	12.9	12.1	10.8	4.0	4.8	4.0	4.0	8.3	5.9
22	6.3	10.7	14.1	12.7	12.9	10.6	3.8	4.1	4.1	4.1	8.5	5.8
23	6.4	10.8	14.3	12.5	13.3	10.5	3.6	4.2	4.3	4.1	8.5	5.8
24	6.2	11.0	14.5	12.4	13.6	10.4	3.3	4.0	4.6	4.2	6.6	5.9
25	6.8	11.1	14.6	12.2	13.8	10.4	3.1	3.8	4.8	4.3	8.7	5.9
26	6.7	11.3	14.7	12.0	13.8	10.8	2.9	4.1	4.9	4.8	8.6	6.1
27	6.6	11.3	15.1	11.8	13.8	10.2	2.7	4.4	4.9	5.4	8.5	6.1
28	6.9	11.4	15.8	11.6	13.8	10.0	2.5	4.3	4.7	5.6	8.3	6.2
29	7.0	....	16.5	11.5	13.8	9.8	2.5	4.1	4.6	5.9	8.3	6.2
30	7.0	....	17.2	11.4	13.8	9.6	2.6	3.9	4.5	6.1	8.2	6.3
31	7.2	....	17.7	....	13.6	....	2.6	3.7	...	6.2	...	6.4
Mean	5.08	8.94	12.99	14.00	11.55	11.53	5.70	3.66	4.44	4.26	7.44	6.59
Grand Average												8.015

READINGS OF RIVER GAGE AT HAVANA, 1899.

(Plane of reference, low water of 1873.)

Day	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.5	8.0	10.9	12.8	9.1	8.7	4.0	3.8	2.2	2.6	3.5	4.1
2	6.7	7.9	11.3	12.6	9.8	8.8	4.0	3.8	2.2	2.6	3.6	4.1
3	6.8	7.8	11.9	12.5	9.4	8.9	3.9	3.7	2.3	2.6	3.6	4.0
4	6.9	7.7	12.2	12.3	8.8	9.1	4.0	3.7	2.3	2.6	3.6	4.0
5	7.1	7.5	12.6	12.1	8.5	9.3	4.7	3.7	2.3	2.6	3.5	4.0
6	7.2	7.4	12.9	12.0	8.3	9.3	4.3	3.8	2.3	2.6	3.5	4.9
7	7.4	7.3	12.9	12.0	8.2	9.3	4.3	3.8	2.3	2.6	3.5	4.9
8	7.6	7.2	12.9	12.0	8.0	9.3	4.3	3.9	2.4	2.6	3.4	4.8
9	7.8	7.3	12.9	11.9	7.9	9.2	4.3	4.0	2.4	2.6	3.4	4.8
10	7.9	7.1	13.1	11.8	7.8	9.2	4.2	3.9	2.4	2.7	3.4	4.9
11	8.0	6.9	13.1	11.7	7.7	9.1	4.1	3.8	2.5	2.7	3.4	4.9
12	8.1	6.8	13.0	11.6	7.5	9.0	4.1	3.7	2.5	2.7	3.5	4.0
13	8.2	6.7	13.3	11.5	7.4	8.8	4.2	3.5	2.5	2.8	3.6	4.1
14	8.2	6.6	13.1	11.4	7.4	8.5	4.2	3.4	2.4	3.0	3.7	4.2
15	8.1	6.5	13.1	11.4	7.4	8.6	4.1	3.3	2.4	3.1	3.8	4.2
16	8.1	6.4	13.1	11.3	7.2	8.5	4.0	3.1	2.4	3.1	3.9	4.3
17	8.2	6.3	13.0	11.2	7.1	8.2	4.3	3.0	2.4	3.2	4.0	4.4
18	8.3	6.1	13.1	11.0	7.1	8.0	4.6	3.0	2.4	3.2	4.1	4.6
19	8.4	5.9	13.3	11.0	7.0	7.7	4.9	3.0	3.6	3.1	4.1	4.7
20	8.5	5.7	13.4	10.9	7.1	7.5	4.9	3.0	3.4	3.1	4.2	4.8
21	8.5	5.5	13.7	10.7	7.3	7.2	4.9	2.9	3.2	3.1	4.3	4.9
22	8.7	5.5	13.8	10.5	7.6	7.0	5.0	2.9	3.2	3.1	4.3	5.0
23	8.9	6.1	13.6	10.4	7.9	6.7	5.0	2.8	3.1	3.1	4.4	5.0
24	8.9	6.3	13.5	10.3	8.0	6.3	4.7	2.8	3.0	3.2	4.4	5.1
25	8.9	6.6	13.4	10.0	8.0	6.0	4.8	2.7	3.0	3.2	4.4	5.2
26	8.8	8.0	13.3	9.9	8.2	5.7	4.6	2.8	2.9	3.3	4.4	5.3
27	8.5	9.3	13.1	9.7	8.3	5.4	4.5	2.4	2.8	3.5	4.4	5.4
28	8.3	10.2	13.5	9.6	8.6	5.2	4.4	2.3	2.7	3.5	4.3	5.5
29	8.2	....	14.2	9.4	8.7	4.9	4.2	2.3	2.7	3.5	4.2	5.6
30	8.0	....	14.0	9.2	8.7	4.6	4.1	2.2	2.6	3.5	4.1	5.6
31	8 0	....	14.0	...	8.7	...	4.0	2.2	...	3.5	...	5.7
Mean	7.99	7.02	13.05	11.15	8.02	7.8	4.38	3.20	2.63	2.99	3.88	4.74
Grand Average..............												6.401

These gage-readings at Havana have been plotted in the hydrographs of Plates VIII. to XIII. on a scale large enough to show the minor fluctuations, and at the same time to serve as a basis for the graphic representation of temperatures of the water and the results of the quantitative study of the plankton. The hydrographs for 1894 and 1895 are based upon the records at Copperas Creek with such supplementary data as our incomplete records at Havana provide. For convenience in comparing the seasons in the several years the following tables have been prepared from the same data, to show the monthly and yearly means, extremes, range, and total movement.

MONTHLY AND YEARLY AVERAGES OF READINGS OF RIVER GAGE AT HAVANA, 1894–1899.

(Plane of reference, low water of 1873.)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Av.
1894.......	3.92	4.29	9.24	7.40	7.29	4.63	2.32	1.99	4.43	2.96	2.97	3.41	4.63
1895.......	3.30	3.51	6.28	5.41	3.68	1.88	3.17	2.43	3.42	1.93	2.20	6.16	3 61
1896.......	10.24	8.83	9.41	7.28	6.58	7.38	4.55	7.42	4.62	6.04	5.89	5.48	6.98
1897.......	11.28	11.13	13.89	13.40	9.41	5.54	6.05	2.29	2.01	2.01	2.82	3.22	6.90
1898.......	5.08	5.94	12.99	14.00	11.55	11.53	5.70	3.66	4.44	4.86	7.44	6.59	8.02
1899.......	7.99	7.02	13.05	11.15	8.02	7.80	4.38	3.20	2.63	2.99	3.88	4.74	6.40

HIGHEST AND LOWEST WATER, RANGE, AND TOTAL MOVEMENT, BY MONTHS, OF RIVER LEVELS FROM GAGE-READINGS AT COPPERAS CREEK, 1894–95, AND AT HAVANA, 1896–1899.

(Plane of reference, low water of 1873.)

	January				February				March				April				May				June				July			
Year	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1894	4.4	3 5	0.9	2.0	4.8	3.8	1.0	1.5	10.4	4.5	5.9	7.2	9.0	6.9	2.1	2.4	7.9	6.4	1.5	2.7	6.3	3 8	2.5	3.4	3.8	1.9	1.9	2.1
1895	3.8	2.8	1 0	1.0	7.5	2.9	4.6	4.6	7.6	5.0	2.6	2.9	6.2	4.6	1.6	3.1	4.4	2.7	1.7	2.1	2.7	0.9	1.8	2.7	5.4	1.5	3.9	7.3
1896	12.6	8.1	4.5	4.6	9.9	8.0	1.9	3.9	10.2	7.9	2.3	2.6	7.8	6.9	0.9	1.6	8.3	5.0	3.3	5.6	8.5	5.3	3.2	3.4	7.3	2.5	4.8	7.8
1897	12.9	4.5	8.4	9.3	11.8	10.4	1.4	3.1	16.0	11.8	4.2	4.8	15.8	11.3	4.5	4.6	11.2	7.0	4.2	4.3	6.9	4.0	2.9	6.3	7.5	4.4	3.1	5.2
1898	7.2	3.2	4.0	6.0	11.4	7.0	4.4	5.2	17.7	10.8	6.9	7.8	18.0	11.4	6.6	6.8	13.8	9.7	4.1	6.0	13.6	9.6	4.0	4.0	9.4	2.5	6.9	7.4
1899	8.9	6.5	2.4	3.6	10.2	5.5	4.7	6.4	14.0	10.9	3.1	6.0	12.8	9.2	3.6	4.8	9.8	7.0	2.8	5.1	9.3	4.6	4.7	5.5	5.0	3.9	1.1	4.4

	August				September				October				November				December				Extremes		Totals	
Year	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1894	2.9	1.5	1.4	2.6	5.8	3.0	2.8	4.7	4.7	2.7	2.0	3.1	3.0	2.8	0.2	0.4	13.8	3.0	0 8	0.8	10.4	1.5	8.9	32.9
1895	4.3	1 8	2.5	3.5	5.8	2.2	3.6	8.8	2.6	1.2	1.4	2.7	2.6	1.9	0.7	1.6	13.1	2.5	10.6	11.5	13.1	0.9	12.2	51.9
1896	8.6	5.8	2.8	4.3	5.6	4.0	1.6	3.7	6.9	4.4	2.5	4.6	6.5	5.0	1.5	1.9	6.2	4.5	1.7	1.7	12.6	2.5	10.1	45.7
1897	4.0	1.8	2.2	2.6	2.1	1.7	0.4	0.6	2 4	1.9	0.5	0.6	3.5	2.4	1.1	2.2	3 5	3.0	0.5	1.2	16.0	1.7	14.3	44.8
1898	5.7	2.6	3.1	7.5	5.1	3.5	1.6	6.2	6.2	3.6	2.6	3.9	8.7	6.3	2.4	2.6	8.2	5.8	2.4	3.8	18.0	2.5	15.5	67.2
1899	4.0	2.2	1.8	2.4	3.6	2.2	1.4	2 6	3.5	2.6	0.9	1.1	4.4	3.4	1.0	1.6	5.7	4.0	1.7	3.8	14.0	2.2	11.8	47.3

It is evident that the changes from year to year in the conditions of the river environment are such that they must be taken into consideration in any study of the fluctuations of the plankton. A glance at the general hydrograph (Pl. VII.) shows that the years of our plankton work at Havana practically include the extremes of conditions in the river; no two years present the same fluctuations, and both typical and aberrant hydrographs are found. In the discussion which follows, the average or "normal" conditions and figures pertaining thereto are based upon the twenty-one years of record at Copperas Creek, eighteen miles above Havana.

The year 1894 (Pl. VIII.) is typical in that the high- and low-water periods are normally located as to season and also in the presence of a March, June, and September rise. Both the extreme and average heights for the year, 10.4 and 4.63 feet respectively, are, however, much below the general average (13.8 and 6.74 feet). The high-water period (above 8 feet) is shortened to three weeks, and the overflow stage is thus almost eliminated. The concentration of the sewage in the narrow limits of the channel during the early summer favors the greater development of the plankton. With the exception of the September rise the extreme low water continued without interruption for a period of eight months—till the last of February, 1895. These are conditions which cause the drying up of extensive backwater areas, and also the development of a large amount of aquatic vegetation in those lakes and marshes which remain—a circumstance which reduces their plankton, and their contribution, if there be any, to the river. The autonomy of the river plankton is thus emphasized in such a year as this, which may be briefly characterized as one of predominant low water and unusually stable conditions.

In 1895 (Plate IX.), another low-water year, we find, on the other hand, little that approaches the normal. There is, to be sure, a diminutive March rise and a sharp but very brief equinoctial one, with very low water in the autumnal period. The abnormal features are the failure of overflow, the long low stages,—almost ten months, with unusually low water in February and June,—the July rise, and the December overflow. The extreme low water of the year is apparent in the average, 3.61 feet, the lowest on record in twenty-one years. The low water in the winter combined with ice produced a stagnation fatal to the plankton, while the June minimum favored an unusually large development for that season. The July, September, and December rises flushed out the river. The low water of this year, following that of the previous year and combined with the absence of overflows with rise and current sufficient to lift and carry away the vegetation, resulted in a very unusual growth of the aquatic flora in the lakes and even along the river margins. The conditions prevailing throughout the greater part of the year thus continued to favor the autonomy of the main stream noted in the previous year. In brief, the year may be characterized as one of extreme low water, with some minor and unusual fluctuations. The contrast with 1894 is best seen on comparison of the total movements of the two years, viz., 39.98 and 51.75 feet respectively.

The year 1896 (Pl. X.) is one of still more unusual character, since it presents a series of bimonthly rises culminating in step-like succession throughout the year. In none of these, however, save the initial one, is more than a very moderate stage of water reached. This results (Pl. VII.) in a reduction of the normal March flood, the isolation of the June flood in the hydrograph, and the submergence of the September rise between the abnormal rises of August and October. The general result of such a series of rises is to bring the average level for the year up to 6.98 feet (7.26 at Copperas Creek), 0.71 feet above the general average, though the rainfall for the year is slightly below normal. The increased average height does not, however, in this case carry with it the usual extension of the flood period. The river was above ten feet for less than a month and above eight feet only three months. The overflow stage was thus slight, and in addition it occurred in the first months of the year, during the winter minimum of the plankton, while during the spring months, when the normal overflow occurs, the river was practically confined to its banks. The succession of minor floods and the slight increase in the average level does, however, greatly extend the reservoir action of the permanent backwaters. The repeated floods also had the effect of clearing out the vegetation in the river and lakes where some current develops, as, for, example, in Quiver Lake. This reduction in the amount of vegetation in the reservoir waters is accompanied by a considerable increase in their plankton. This fact, combined with the increase in the volume of their contributions due to higher levels, augments the relative importance of their share in the formation of the river plankton, tending to increase its quantity and variety. On the other hand, the repetition of floods, no less than eight of which may be found in the hydrograph, flushes the river so often that no concentration of sewage and marked maximum of plankton occur. The unusual extent of these movements is apparent when the total movement for the year, 50.7 feet, is compared with the totals of other years having about the same average height. For example, 1890 and 1897, with an average height of 6.9 feet, have a total movement of only 44.2 and 36.56 feet respectively. In brief, the year was one without extended overflow, with lower water than usual at the normal flood season, with prolonged bank-full river and reservoir action of the permanent backwaters, and with more than the usual turmoil.

In 1897 we find a hydrograph (Pl. XI.) which approaches the mean closely in its main features, and exhibits all the expected movements excepting the equinoctial rise. The average height for the year, 6.90 (6.86 at Copperas Creek), is also near the general average (6.74). The year thus approximates the normal. The high-water period is of 141 days' duration, almost exactly the average (140), but it occurs somewhat earlier in the year and attains 16 feet—a little more than the usual height. The earlier decline renders more prominent the June rise, and gives an early start to the extreme and uninterrupted low water of the remaining five months of the year. The low-water period (155 days) is normally located but is somewhat in excess of the average (147), and it is also unusual in the fact that the extreme low-water level (1.7 feet since the completion of the dam at LaGrange) continued almost unchanged from the middle of August till the first of November. This was followed by the usual slight increase in water in the closing months of the year. The total movement of the year (43.1 feet) is considerable in view of the average height (6.9 feet), but this was less disastrous to the plankton than usual since it was in the main due to the spring flood and not to minor changes when the stream was within its banks. This freedom from minor interruptions during the low-water period is somewhat unusual, and resulted in a concentration of sewage approaching stagnation and in a marked increase in the fall plankton. The overflow period, in which the reservoir action of the bottom-lands as a whole was operative, prevailed during the first five months; the change to low water, during which the reservoir action of the more permanent and diversified waters was in force, took place very rapidly; while the low-water stages, during which it is a minimum, were both pronounced and prolonged. These circumstances combine to emphasize in this year both the unity and the autonomy of the river. In brief, 1897 was a year of normally located but pronounced high and low water, of marked freedom from interruptions, and of unusually favorable conditions for the unity and autonomy of the plankton of the river and for the full development of its normal seasonal cycle.

In 1898 (Pl. XII.) we find another year whose hydrograph approaches the normal in its main features. There is a well-defined period of high water followed by one of much interrupted low stage. The spring flood is normally located, continues (above 8 feet) for 164 days, and culminates at 18 feet on April second. The extension of the flood period for 24 days beyond the normal is due largely to the "June" rise of unusual proportions, which culminated in the last of May at 13.8 feet, and covered a period of five or six weeks. The impounding action of the bottom-lands as a whole is thus shifted forward into the late spring and early summer, while the concentration of the overflow into the channel occurs in the early part of May and again in June, and the conditions of rainfall, season, and overflow combine to favor the production of a relatively large amount of plankton at these times. The decline is rapid in July to low-water stage, which continues but three weeks, the lowest record being 2.5 feet. This is followed by a series of minor rises, which flush the river at short intervals during August and September, and a rise to bank height in November —fluctuations which favor the reservoir action of the permanent backwaters, and at the same time introduce much silt and interrupt and diversify the plankton cycle. Of all the years of our operations at Havana this was the one of highest average level—8.02 feet (8.11 at Copperas Creek)—and greatest movement (66.2 feet). The dilution of the sewage, the increased current and silt, and the flushings incident to such hydrographical conditions tend under most circumstances to decrease the *relative* amount of the plankton, though doubtless they also tend to increase the total production of the stream. In brief, the year was a typical one of high water with much delayed run-off and interrupted low-water period.

In 1899 (Pl. XIII.) we find another year conforming very closely to the normal hydrograph in its main outlines. We are concerned only with the first three months, at the close of which occurs the maximum (14 feet) of the spring flood. The greater part of the rise occurs in a brief period at the close of February, and the declining waters or more stable conditions at other times reduce considerably the flushing and silt attending most winter floods, such, for example, as that of the preceding year. The decline in February also afforded a good opportunity for the reservoir action of the permanent backwaters under midwinter conditions. Our collections of 1899 thus cover a period of winter flood of more than usual stability.

The wide range of hydrographical conditions during the six years of our plankton work at Havana have afforded a unique and, up to this time, unexampled opportunity to follow the effect of flood and drouth, of changing season, and of yearly fluctuations upon the life in the waters of a stream, and to give to the conclusions here reached the confirmation which repetition alone can bring.

TEMPERATURES.

The fluctuation in the temperature of the river water constitutes for the plankton one of the most marked evidences of the climatic changes of the recurring seasons. This factor in the environment of the plankton is thus an ever changing one, but at the same time it runs an annual cycle of the same general character year after year with ever present minor variations of a seasonal or local origin. The extremes of temperature in bodies of water in this latitude are so divergent that they afford the basis for marked seasonal changes in both the constitution and the quantity of the plankton. Adaptations on the part of the organisms of the plankton to definite temperature limits thus occur.

Records of the temperature of the air and of the surface and the bottom water have been taken regularly at all stations where quantitative plankton collections were made. These are recorded in Table I. The temperatures were taken with a Negretti-Zambra self-recording thermometer from 1894 till May 24, 1898, after which time a Hick's self-recording maximum-minimum thermometer was used. Under stable conditions no appreciable variation was noted in the reading of the thermometers, but at the times of sudden change, as in the mingling waters of a rising flood, readings would sometimes vary as much as four or five degrees at one location and level.

The temperature of the river water is influenced by a variety of causes in addition to the immediate action of solar heat. The most prominent of these are the access of the tributary water from streams, springs, and impounding backwaters. The temperature of tributary streams, such as the Spoon River (Table IV.), is often, though not always, warmer in winter and colder in summer by several degrees than that of the main stream, as a result probably of the greater proportion of spring water and the greater nearness of the same to its subterranean source. A good illustration of this was to be seen along the eastern shore of Quiver Lake, where at low-water stages springs near the water's margin kept up a continuous flow. The temperature of the water in summer was 54°, while in winter it fell only to 51°. The smaller tributary waters also respond more quickly to fluctuations of temperature than does the river itself. In like manner the backwaters, which are usually much shoaler than the river, are subject to greater changes, exhibiting in warm days greater extremes of heat, as high, for example, as 96° having been found in the margins of bottom-land ponds. On the other hand, the flood waters in the forests and marshes, where the vegetation protects the water from the direct rays of the sun, remain at lower temperatures than those of more open tracts. The lakes and bayous with aquatic vegetation also remain cooler in their deeper waters, as, for example, Thompson's Lake, where, among the *Ceratophyllum*, the temperature at the surface on the fifteenth day of July was 88.2°, while only six inches below, in the vegetation, it was 80°, the difference being due to the protection from sun and wind which the vegetation afforded.

Another factor tending to modify the temperature is the earth temperature, which in the very shallow waters of our environment becomes relatively important in both summer and winter. In the low temperature of winter this is heightened by the fact that most of the bottom of the backwaters is strewn with a mass of vegetation whose decay must produce some heat. This probably accounts for the higher bottom temperatures sometimes observed in winter (cf. Tables III. and VIII.) in Flag Lake, where such detritus was more abundant than in the river, where but little is found. For example, on February 26, 1897, the bottom temperature in Flag Lake was 36°, while in the river, with about the same surface temperature (32°) and greater depth, it was only 32.5°. This difference may also be due to the effect of the current in the river in mingling more quickly the surface and bottom waters and thus equalizing their temperatures more rapidly.

The temperatures recorded in the Illinois River, Spoon River, and in Thompson's, Quiver, Dogfish, Flag, and Phelps lakes are to be found in Tables III.–IX. respectively, and they appear on the plates with the hydrographs and plankton data of the respective years and stations. The extreme range of temperature observed by us in the river and its adjacent waters at Havana was 32°–96°. The highest temperature recorded in the river was 89°, on the afternoon of August 3, 1897, and again, at the same time of day, July 26, 1898.

The diurnal range in temperature is considerable at times, depending naturally upon that of the air. On August 3–5, 1898, in connection with a test of the diurnal movements of the plankton and accompanying analysis of the gases dissolved in the water, the temperatures recorded indicate in the surface waters a range of 5.5°, with a maximum of 79.5° at 5:00 p. m. and a minimum of 74° at 2:00 a. m. The bottom water (depth 2.44 meters) showed a range of but 2°, from 74° at 8:00 a. m. to 76° at 11:00 a. m. The air temperatures on the days in question ranged from 83° at 5:00 p. m. to 58° at 5:00 a. m. A diurnal variation of 5.5° in surface waters and 2° in bottom waters is thus indicated at this time. Other conditions will probably show a slightly greater range.

MONTHLY AND YEARLY AVERAGES OF SURFACE TEMPERATURES, 1894–1899, ILLINOIS RIVER.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Av.
1894....	.....	.....	.....	.....	.....	80.25	82.25	83.5	77.5	58	41	39	......
1895....	.....	32	.....	58	....	80	79	80.51	78.87	54.26	42.5	37.5	......
1896....	32.75	33.7	39.52	64.54	72.7	74.7	80.7	82	65.75	56	44	33.6	56.66
1897....	.....	32.25	43.8	60	66.3	75	81.02	80.9	77.07	65.1	45.7	33.02	......
1898....	32.7	32.12	43.3	53.32	65.8	78.8	82.87	80.56	71.87	54.37	41.42	32.98	55.84
1899....	32.9	32.6	35.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
Monthly average	32.78	32.73	40.45	60.46	68.27	77.75	81.03	81.49	74.21	57.55	43.00	35.22	57.08*

*Average of monthly averages.

The temperature records are too isolated to plot complete thermographs of the river and its backwaters, though they do give a very fair idea of the seasonal fluctuations, especially in the later years, when they were more evenly distributed, and in the midsummer, when they were more numerous. They were usually taken between 7:00 a. m. and 5:00 p. m., and may be regarded as day temperatures. A comparison of the records in Table III., the plottings (Pl. VIII.–XIII.), and the above table, giving the monthly averages of surface temperatures of our records, shows the following seasonal routine in the river:

During the months of January and February there is a period of minimum temperature approaching 32°, averaging 32.75°, and rarely exceeding 34°. The constancy of the temperature at this season is probably due in large part to the equalizing effect of the ice which normally covers the stream, and especially its backwaters, at this season of the year. During the early part of March the temperature rises, but the rate becomes more rapid in the last part of the month. The upward movement reaches 40° or 50°, in early springs, such as 1898, attaining the latter temperature. The average for the month rises to 40.45° and the fluctuations increase in extent. The rapid rise continues through April, attaining 60°–70°, and averaging 60.46°. The records for this month are somewhat meager for any comparisons. In May the season of maximum temperature is approached and occasionally reached, as in 1896, the average temperature from somewhat scanty records being then 68.27°. This month is one not only of marked rise but also of considerable fluctuation. The period of maximum temperature is in full swing in June, and continues through July and August and well over into September. The average rises from 77.75° in June to 81.49° in August, and falls to 74.21° in September owing to the decline which begins in the latter part of this month. This period of maximum summer heat is fairly well defined in the thermograph and continues at or near 80° approximately three months, from the middle of June to the middle or latter part of September. It is a time of considerable fluctuation, most of the movements being within 10°, though the range for August in the five years of record was from 74.3° to 89°. These fluctuations combined with the diurnal changes and the wind are effective in producing a considerable vertical circulation of the water.

Following the summer maximum comes the fall decline, which begins late in September and is practically completed in November. The greater part of the change takes place in October, the average decline in that month being 16.76°, while that in November is 14.55°. In some years, as 1897, the decline is a gradual one; in others, as 1895 and 1898, it is subject to some irregularities. With December the winter minimum returns, but with less persistence than in the months which follow, flood waters at this season bringing their higher temperatures.

The annual temperature cycle thus falls into four periods: one of minimum and quite constant temperatures, including December, January, and February, and a varying portion of March ; one of maximum and more fluctuating temperature, approaching 80° and extending, with some interruptions, from the early part of June till about the middle of September; and, separating these, the two shorter intervals of change. The period of increase in temperature, which is also one of rapid change and increase of the plankton, includes the latter part of March and the months of April and May. The period of decline, which is sometimes more abrupt than the spring rise, as in 1895, 1897, and 1898, extends from the latter part of September until the end of November. This is also a period of change and of frequent but not universal diminution in the plankton. The average temperature for the years, as expressed approximately in the table, is 57.08°. This point is passed about the middle of April and again about the middle of October with considerable regularity. Since, however, these dates both lie in periods of rapid change, the average temperatures are of much less duration than the more extreme ones. The existence of these well-defined periods of maximum, minimum, increase, and decline of temperatures affords the basis for corresponding seasonal changes in the minute life of the water as fundamental and extensive as those which affect the plant and animal life of terrestrial and aerial environment. This subject of the relation between temperature and organisms of the plankton will be fully discussed in connection with the statistical study of their seasonal distribution.

A comparison of the thermographs (Pl, VIII.–XIII.) of the different years and an inspection of the table on page 171, reveal but few significant annual differences. The spring rise in temperature was somewhat delayed in 1896 and again in 1899, and the summer maximum was less pronounced in 1895 and 1897, though in compensation the summer heat was prolonged into September in these years. The spring rise in 1896 and the autumn declines in 1895 and 1898 are rather more abrupt than usual. These annual differences extend and curtail the plankton periods characteristic of the seasons, or render their changes more abrupt.

The difference between surface and bottom temperatures is, as a rule, but slight. It is perforce usually lacking during the period of decline in the autumn, and at other seasons varies in amount with the air temperature, the wind, and other attendant circumstances. So long as the temperature is above the point of maximum density of water, 39.2°, the surface waters are the warmer by an amount ranging from a fraction of a degree to 5°, the latter occurring on still, hot days. With air temperature falling below that of the water the surface and bottom quickly come to have the same degree of heat. Below 39.2° the colder waters are at the surface, though at this season of the year there is usually much less contrast at different levels than in the warmer months.

Temperature fluctuations, following those of the season and the day, occur in the waters of this region to a degree not realized in the typical lake, whose deeper waters respond but slowly to the surface changes, and thus exercise an equalizing effect. Examples of this quick response are found in the unusually high temperature (82.3°) in both top and bottom waters of the river on May 13, 1896, while temperatures of five days later showed a drop to 71.2° in both regions. A decrease equal in suddenness and extent occurred in September, 1898. The surface layers of water, quickly affected by temperature changes, form relatively a very large part of the volume of the river and its backwaters, and thus instability of temperature becomes an important feature of the environment of the plankton of the river as contrasted with that of the lake. Changes of the extent above noted must affect considerably both the movements and the multiplication of the plankton organisms.

The temperature conditions here described are those assigned by Whipple ('98) to lakes of the temperate type and third order, those whose bottom temperatures are seldom very far from their surface temperatures, and in which there is considerable vertical circulation at all seasons when the surface is not frozen. At no place in the region examined by us has a depth been found sufficient to permit the occurrence of a stratum of cold water at the bottom unaffected by the vertical circulation and warming process in the surface regions, such, for example, as has been found by Birge ('97) in Wisconsin lakes. This absence in the river environment of the "thermocline" and of summer and winter periods of stagnation in lower levels, marks another point of contrast between the river and some lakes as units of environment.

The temperature conditions in the bodies of water adjacent to the river do not differ to any considerable degree from those here discussed. The limited extent, greater amount of vegetation, shallower waters, or greater access of spring water in some of these will cause slight variations from the conditions found in the river.

The ice conditions attending the winter minimum are of profound biological significance, since they produce important alterations in the winter routine. As a result of the presence of an ice sheet on a body of water, the temperatures become more constant, the mingling of waters due to winds ceases, the usual processes of aeration are interrupted, and the proportions and amounts of the gases dissolved in the water may be very much altered, the degree of the change depending upon conditions such as the completeness with which the surface is sealed by the ice, the amount of sewage, the relative abundance of plant and animal life, the duration of the ice, and the existence of currents. So far as our observations go at Havana, the stage of stagnation attended by the destruction of the animal life which is sometimes found in small lakes is rarely realized in this environment. Several reasons may be assigned, the principal one being being the instability of river levels in the winter season, which prevents the culmination of stagnation conditions. Again many of the backwaters are rich in vegetation, and some of them are spring fed at the margins which thus remain open even in the coldest weather. The river itself rarely closes over entirely, air-holes remaining where the current is rapid. Thus, below the mouth of Spoon River (Pl. II.) a large area was usually free from ice even when the river was closed above this point. The currents due to tributary waters, as in Quiver Lake, and to changes in level, as in all impounding waters, also tend to prevent stagnation conditions. In spite, however, of these favoring circumstances one catastrophe of this nature did occur in the years of our work at Havana. In the winter of 1894–95 prolonged low water and heavy ice upon the river and lakes combined to render the conditions unfavorable to life in the river, and to some extent in Quiver Lake. Conditions in other localities at this time were not observed. The practical extinction of the plankton and the death of large numbers of fish attended this period of stagnation.

The duration of the ice at the various stations in the several years is indicated at the bottom of the diagrams which give the hydrographs and plankton data of the several stations by black lines of a thickness proportional to the ice. The occurrence of ice in the different years at Havana has varied considerably. No records were made in 1894–95, but from other sources, river stages and weather reports, it seems probable that the river closed in the last days of December, and that the ice continued until the rise of February 25, a period of almost 60 days. In the winter of 1895–96 there was but little ice, the river and backwaters being partially closed only for the first fortnight in January. In 1896–97 the river did not close until after the rise in the early part of January, the ice remaining about one month, going out with the rise of February. The lakes, on the other hand, were closed to a large extent throughout December, and again, to varying extents, during January and a part of February, the current due to high water keeping portions free from ice at times.

In 1897–98 the lakes closed the last days of November and opened again on December 12, freezing again December 17, and not clearing entirely until February 14. Rising water continued from January 10, so that stagnation conditions did not ensue. The river also closed partially early in December, opening and closing again with the lakes. The first ice went out with the rise on January 11. The river closed again January 27, and the ice went out February 9 and 10. Again on February 21 ice was present, and for several days following.

In 1898–99 ice again formed early in December and partially closed the river during the month, going out about the 27th and reappearing on the 30th. This went out gradually January 17–24, and the river froze over again on the 26th and remained closed for a month. Thin ice formed March 5, remaining only three days. The lakes closed early in December, the ice never entirely disappearing until the middle of March. Partial breaking up occurred at the times of breaking up of the river ice. These partial openings and the changes in level were sufficient to prevent a period of stagnation.

OTHER METEOROLOGICAL FACTORS.

As indicated in Tables III.–IX., at each plankton collection observations of the direction and force of the wind, with its effect upon surface conditions and on the state of the sky, were recorded. The relation of these factors to the plankton may not seem intimate or apparent. They have more bearing on the subject of vertical movements of the plankton, data upon which will be found in the study of the surface and bottom collections made with each of the vertical collections which form the basis of the present paper. The surface waters affected by the intensity of the sunlight and the movements caused by the wind form relatively so large a part of the environment of the river plankton that these factors are much more widely operative here than in the lakes, where the surface stratum thus affected is relatively small.

The wind conditions on the river and the lakes adjacent to it—which are generally elongated in the direction of the main stream (Pl. II.)—are somewhat peculiar. Owing, it may be, to the configuration of the river valley, or perhaps still more to the bordering forest of the contiguous bottom-lands, the prevailing direction of the wind is either up or down the river or lake, especially during the summer season. The effect of an up-stream wind is greatly to increase the disturbance of the surface when wind and current are thus opposed. These winds, when prolonged and violent, decidedly affect the levels of the different parts of the lakes, and, for example, in Thompson's Lake (Pl. II.) determine at low-water levels whether the lake shall discharge its waters into the river or itself receive an access of river water. Owing to the mobile condition of the abundant bottom deposits, at low stages the winds also add very much to the silt in suspension in the water, and thus hinder the penetration of light.

The effect of varying sky conditions lies primarily in their relation to the temperature of the water, but is due in a less degree to the influence of light upon the multiplication of chlorophyll-bearing organisms—the primal food supply of the plankton—and upon the movements of these and other plankton organisms. The abundant silt in suspension in waters of the river and most of the adjacent lakes doubtless hinders the penetration of the sunlight, but modifies to a much slighter extent its effect upon temperatures. Wind and sky conditions combine to favor or prevent the appearance of the "water-bloom." This is a characteristic green scum which coats the surface of the river, and occasionally of the lakes, on still, warm days in midsummer. On cloudy or windy days the minute organisms (*Euglena*, *Chlamydomonus*, etc.) which form the bloom do not rise to the surface. The conditions of wind and sky are thus important factors in the economy of limnetic life and, by reason of their relatively greater effectiveness in the river and its adjacent waters as contrasted with the typical lake, add to the elements of instability in the fluviatile environment.

TURBIDITY.

Records of the turbidity were made (Tables III.–IX.) in general descriptive terms during the first two years of our work at Havana. After April 29, 1896, the turbidity was tested by means of a white plate of semi-porcelain, 10 cm. square. The depth at which this square disappeared from view was recorded in centimeters as a measurement of turbidity. Although the method is somewhat primitive and subject to some variations with the conditions of sky and daylight, it is still sufficiently accurate for the purposes of the present paper. The disc method has not as yet been correlated with the platinum-wire method, the diaphanometer method, or the silica-standard method of Whipple and Jackson ('00), and comparisons with these are consequently excluded.

As might be expected in the river environment, when floods occur the turbidity is often extreme, and is exceedingly variable according to the locality and the river levels. (Cf. Tables III.–IX.) The extreme range of our records extends from 1.3 cm., in a Spoon River flood, to 260 cm., in Quiver Lake, under the ice.

In the river (Table III.) the great majority, about two thirds, of the records lie between 20 and 50 cm., while the extreme range is from 2 cm., in the flood of May, 1897, to 115 cm., in the declining waters of July, 1896. The clearer waters appear, as a rule, with declining floods and stable low stages, especially under the ice. With the inception of floods the most turbid water is found, which gradually clears even while the rise continues. The river varies in clearness according to the instability of the river levels, as will be seen on comparison of the turbidity in 1896 and 1897, the latter year being more stable and having relatively fewer records of a marked turbidity.

The turbidity of the river is due to both plankton and silt, the latter being as varied as the character of its tributaries, with the added contamination from the cities along its banks.

In Spoon River (Table IV.) the extremes are even more marked than in the main stream, varying from 1.3 cm., in flood conditions, to 165 cm. at low water under the ice. The turbidity here is almost entirely due to silt, that at flood being largely composed of earth and clay, giving a black or yellow tinge to the water. The amount of comminuted vegetable debris found in the waters is considerable.

In Thompson's Lake (Table VIII.) the turbidity is not so frequently marked by the extremes seen in the other bodies of water examined, the range being from 115 cm. in the declining waters of May, 1896, to 6 cm. in invading floods, and again in the late autumn of 1897, when high winds roiled the shallow waters. As a general rule the turbidity of this lake is somewhat less than that of the river, but as great or greater than that of other backwaters. This turbidity is often due in part to the heavy planktons occurring here, and also to the flocculent debris loosened from vegetation and stirred up from the mobile bottom by fish and the waves. Very little silt enters the lake except at times of inundation, especially with backwater from Spoon River. Owing to its origin the silt in this locality is usually of finer, more flocculent material than that found elsewhere.

In Quiver Lake (Table V.) the extremes are much more marked than in any other locality, ranging from 3.5 cm., in flood water from the river, to 260 cm. on June 5, 1896, in clear impounded water. In winter, under the ice, the bottom was visible on December 3, 1896, in 260 cm. of water. A great deal of variation in turbidity occurs in this lake. In years of low water, as 1894 and 1895, when vegetation is abundant, the turbidity is very slight, the bottom being visible much of the time. In the three succeeding years the lake was free from vegetation, and the turbidity was considerably increased as a result largely of the increase in the plankton. The sources of the silt in this body of water are varied; occasional freshets in Quiver Creek, which enters the upper end of the lake (Pl. II.), invading floods from the river, and debris from vegetation and the bottom put in suspension by the wind, current, or movements of fish,—all contribute their share to the pollution of the otherwise clear water of this lake.

In Dogfish Lake (Table VI.) the conditions are essentially those of Quiver Lake, of which it is an arm. The principal difference lies in the fact that flood water entering Quiver Lake at low stages never moves as far up as our station in Dogfish Lake (Pl. II.). Floods from Quiver Creek also merely back up the clear water in Dogfish Lake without themselves invading that territory. The only flood silt entering this region is, consequently, that which comes with general inundations.

In Flag Lake (Table VII.) the conditions at inundation are similar to those of other impounding backwaters. The great amount of vegetation found here adds to both the vegetable and the flocculent debris which roil the water whenever this is disturbed by waves or the movements of fish. Turbidity is but rarely caused by plankton here, with the exception of the few instances when diatoms or *Oscillaria* became very abundant. The water is thus usually clear, the bottom being commonly visible in the small spaces left free of vegetation, even at a depth of 215 cm.

In Phelps Lake (Table IX.) the silt conditions are peculiar. The high level at which the lake lies and the intervening stretch of bottom-lands (Pl. II.) combine to keep out all silt-laden flood-waters except those that enter by a now abandoned channel from Spoon River or from the main stream at times of their maximum floods. At other times the silt consists principally of particles of bark and dust from the adjacent forests, or of fragments of loam from the bottom, which is here unusually stable. The comparative freedom from vegetation removes a large element common in the silt of the other lakes. The turbidity, however, is very marked in this lake, falling in many cases below 20 cm., and in the majority of instances is largely due to the very abundant plankton characteristic of its waters during the greater part of the summer. Movements of fish and water-fowl add considerably to the silt in suspension in this lake at some seasons of the year.

The color of the water has not been made a subject of special inquiry. In general the turbidity gives it a grayish cast that varies to yellowish or blackish tints with silt of clay or loam origin. When diatoms are abundant a brownish tinge is very evident, and with *Oscillaria* rising in quantity, as it does in some semi-stagnant waters in late summer, a blackish tint becomes pronounced. In midsummer and early fall, when water-blooms rise, we find varying tints of green according to the kind and quantity of chlorophyll-bearing organisms present.

The turbidity, as above suggested, is due to a great variety of factors, one of the most important of which is the plankton itself. Indeed, under some conditions turbidity becomes a token by which the relative abundance of the plankton may be estimated. The presence in our plankton of vast numbers of the most minute planktonts, such as the flagellates, renders this relation of plankton and turbidity more prominent in our waters than it is in waters where such organisms are less abundant.

The turbidity otherwise is due to non-living solid matter in suspension. This is brought in by tributary streams, and is torn loose from the shores and bottom by the current of the river, the movements of fish, the wash from steamboats, and the constant sweeping of the river channel by fishermen's seines during the open season at stages when seining is possible in this place. The dust from prairies and forests brought by winds; the waste from factories, distilleries, glucose-works, and cattle-yards; and the sewage of a score of cities along the banks, —all make additions to the burden of the water.

Microscopical examination of the plankton has revealed the diverse character and origin of the silt which accompanies it. Fine fragments of quartz, bits of mollusk shells, small pieces of coal or ashes, minute particles of loam or clay, and the fecal pellets of aquatic organisms—especially of mollusks and of insect larvæ—constitute the heavier element of the silt. To this is added a variable but ever considerable quantity of exceedingly fine sediment of earthy or clayey origin, some of which remains long in suspension. The coarser and lighter silt consists largely of comminuted vegetation, both terrestrial and aquatic, minute bits of leaves, stems, bark, and wood, with the characteristic grain refuse from distilleries and glucose-works and the offal from the cattle-yards at Pekin and Peoria. At all seasons of the year and in all waters the scales of *Lepidoptera* and the pollen of coniferous trees are of common occurrence. Mingled with this material, especially when aquatic vegetation is present, is a very light flocculent material consisting, in part at least, of the zoöglœæ of bacteria. It is in the midst of debris of this varied composition that the plankton lives, and it is in collections consisting to a greater or less extent of silt material that the river plankton must be studied, its species determined, and its individuals enumerated.

In collections made with the silk net the greater part of the fine silt passes through the meshes with the water. In filter-paper catches some of it adheres to the paper, and the finer flood silts will even pass through hard-pressed filter paper in small quantities. With silt of so varied a character it is practically impossible to establish and continue any standard of measurement or estimate which affords a satisfactory basis for the determination of the relative amounts of silt and plankton present in the collections. After considerable experience in the examination of our collections I have endeavored to estimate the amount of silt present in them as they appear in the Rafter counting-cell. The distribution of the material in the cell and the conditions of examination are such as to favor a uniform standard of estimation. On the other hand, the estimates are purely personal, without any volumetric check, and are thus only comparable with each other. This method seems to be the only solution at present available for this perplexing problem. These estimates are given in Tables III.–IX., together with computations, based thereon, of the amount of both plankton and silt per cubic meter. These figures form the basis of the diagrams in Plates VIII.–XIII. and XXII.–XLII. As will be seen in the tables, the per cent. of silt varies from a mere trace to almost the entire catch, changing with the river conditions as previously stated.

A still more accurate determination of the total amount of solids in suspension in the river, both silt and plankton, is afforded by the catches made by the Berkefeld army filter, data concerning which will be found in Table XV. This filter removes all of the suspended solids and permits their complete removal from its surface, but adds a small portion of its own substance to the catch. After the first few catches with this filter the wear becomes somewhat uniform and is thus distributed. On computing the loss from the filtering surface by wear, and quadrupling this volume to allow for its less compact condition, we find that it constitutes less than five per cent. of the catches washed from its surface. The true amount of solids is thus about five per cent. less than the figures cited in the tables and in the following discussion.

The amount of water strained in making these catches was usually 5 liters, while the tables give the computed amount per cubic meter.

The amount of solids was measured by our usual method of measuring plankton, that is, by condensation in a centrifuge. In this treatment it usually attains the consistency of soft mud. For the river the amount ranges from 148 cu. cm. (per cubic meter), in declining water under the ice in December, to 5,416 cu. cm., in the incipient stages of the winter flood of February 28, 1899. The average amount of the weekly catches for 1898 is 592.2 cu. cm. per cubic meter, which for an average flow of 24,600 cubic feet of water per second (see page 132) means a discharge of 14.57 cu. ft. of solids per second, or, 459,794,232 cubic feet (1,301,990 cubic meters) per year, or 16,472 cu. ft. (46.64 cu. meters) per square mile of the catchment-basin of the river.

The average amount, per cubic meter of water, of solids taken at fortnightly intervals in 1898 in Quiver Lake was only 378 cu. cm., a fair index of the greater clearness of its waters. In Thompson's Lake similar collections average 557 cu. cm., indicating waters somewhat clearer than the river. In Phelps Lake the average amount is large, 1,572 cu. cm., due in no small degree to the very abundant and minute plankton organisms. In Spoon River the average of the monthly collections is 1.746 cu. cm., three times as much as the main stream carries. The heavy floods and rapid current of this tributary are responsible for this large amount of earthy solids in suspension.

In this matter of silt and turbidity the river as a unit of environment stands in sharp contrast to the lake. Deposition of solids and clear water are normal to the environment of the lake, while solids in suspension and marked turbidity are the rule with river waters. Owing to their varied occurrence these elements, silt and turbidity, also add to the instability of fluviatile, as contrasted with lacustrine, conditions.

Silt and turbidity are usually attendant upon floods, so that their unmodified effect upon the plankton is not easily determined. Some inferences and observations regarding the relation of these factors to the economy of the plankton may, however, be made. The silt affects the plankton indirectly by hastening the solution of nutrient substances from the organic detritus that forms a considerable portion of the unstable deposits which accumulate in shoal and in sheltered parts of the stream. It hinders the penetration of light, thus checking the development of the chlorophyll-bearing organisms while favoring the multiplication of bacteria and hastening the decay of organic matter in suspension. It also seems probable that it produces a deleterious effect upon the *Entomostraca* by adhering to the hairs which clothe their various appendages, thus hampering their movements and causing them to sink to the bottom. Accessions of flood water are frequently followed by an increase in the relative number of moribund and dead *Entomostraca*, especially of the *Copepoda*.

CHEMICAL CONDITIONS.

The food supply is the most fundamental feature in the environment of the plankton. Its abundance or scarcity determines to a large degree the growth and reproduction of organisms, and its fluctuations are important factors in determining the seasonal and local production of plankton. The primary source of the food of the plankton lies in the water and in the gases and inorganic salts dissolved therein, the oxygen, the carbon dioxid, the nitrates, and the phosphates being usually regarded as of prime importance to the growth of chlorophyll-bearing organisms. The phytoplankton, which utilizes these inorganic materials, then becomes itself the food for the zoöplankton. These inorganic substances, the primary food supply, are thus indices of the capacity of the water for the production of plankton.

With the inauguration of the work of the Biological Station at Havana arrangements were made whereby collections of water taken by the Station staff from the river and some of the adjacent lakes were sent to the Chemical Department of the University of Illinois, at Urbana, for analysis. In 1895 the Chemical Survey of the waters of the state was established at the University under the direction of Prof. A. W. Palmer, and in September of that year regular shipments for analysis from the Illinois River and from Quiver Lake were made at intervals of one week, and in January of the following year Spoon River was added to the collection points. These collections were continued throughout the period of our operations at Havana. In September, 1897, collections were instituted in Thompson's Lake, and from that time on the samples for chemical analysis were taken at the same time and place as the plankton and, like that, by the plankton pump. After the date above named a fortnightly interval corresponding to the plankton interval was made between collections in Quiver Lake, though the weekly interval was continued in Illinois and Spoon rivers. August 16, 1896, a disastrous fire in the chemistry building of the University destroyed many of the records, and this fact accounts for the absence of data of the analyses in the months of the year prior to the fire and for some other gaps in the record. Special collections were made during the last twenty months of our operations for the determination of the oxygen and carbon dioxid dissolved in surface and bottom waters, but determinations of these dissolved gases made by Professor Palmer immediately upon collection in the field, yielded results which throw some doubt upon the value of those made on samples which were shipped for analysis at the laboratory of the Chemical Survey. Twenty-four to forty-eight hours elapsed between the time of collection and that of analysis, and during this time changes no doubt took place in the gases dissolved in the samples, so that the results of the analyses give no trustworthy basis for a statement of the amount of dissolved oxygen and carbon dioxid in the water at the time of collection.

I am indebted to Professor Palmer not only for the data of the chemical analyses which he has furnished me from the records of the Chemical Survey, but also for many other courtesies in connection with this subject.

COMPARISON OF CHEMICAL CONDITIONS AND PLANKTON AT THE DIFFERENT STATIONS.

In Tables X.–XIII. will be found data from the chemical analyses of the waters of Illinois and Spoon rivers and Quiver and Thompson's lakes, together with plankton data of the same or contiguous dates. The most important of the determinations, those of chlorine, oxygen consumed, free and albuminoid ammonia, organic nitrogen, nitrates and nitrites, as well as the plankton, are graphically shown in Plates XLIII.–L.

CHEMICAL ANALYSES OF WATER FROM PLANKTON STATIONS. AVERAGES OF ALL ANALYSES. PARTS PER MILLION.

Locality	Number of Analyses	Residue on Evaporation					Chlorine	Oxygen consumed	Nitrogen as Ammonia		Total Organic Nitrogen	Nitrites	Nitrates	Plankton* per m.³, in cm.³	Silt* per m.³, in cm.³
					Loss on Ignition										
		Total	Dissolved	Suspended	Total	Dissolved			Free	Albuminoid					
Illinois River	188	367.5	304.1	61.4	32.8	25.1	21.6	10.4	.86	.46	1.03	.147	1.58	1.91	2.00
Spoon River	137	522.3	167.1	274.3	41.9	24.4	3.8	14.1	.245	.604	1.292	.039	1.01	.388	.969
Quiver Lake ..	50	268.9	248.2	25.1	27.5	25.6	4.8	5.9	.165	.251	.61	.023	.66	1.62	.62
Thompson's Lake	40	326.4	282.9	44.6	36.5	28.3	16.3	11.9	.422	.546	1.05	.048	.64	6.68	1.00

* Plankton and silt averages are for collections coincident with or contiguous to collections of water samples.

The foregoing table gives the number of samples analyzed from each locality and the averages of the different substances determined for each. Since the samples were collected at intervals throughout the year, the averages may be regarded as presenting in succinct form the chemical characteristics of the stations examined, and they may therefore serve as a basis for a comparison of the relative fertility of the localities.

The *residue upon evaporation,* which comprises the solid matters left upon evaporating the water and drying the residue, includes both organic and inorganic substances. The inorganic constituents are salts, and comprise mainly compounds of lime, magnesia, soda, potash, iron and alumina with chlorine and with carbonic, sulphuric, nitric, and silicic acids. In this residue lie both the mineral constituents of the food of the phytoplankton and the undecayed organic matter found in the water. Not all of the constituents of the residue are equally utilized as food by the phytoplankton, so that the quantity of the residue gives a basis only for a very rough estimate of the fertility of the different waters. Some significance, however, attaches to the marked differences shown in the table.

The differences in total residue in Illinois and Spoon rivers (367.5 and 522.3) and Quiver and Thompson's lakes (268.9 and 326.4) show no particular correlation with those of the average plankton production of these waters for corresponding periods (1.91, 0.384, 1.62, and 6.68 cm.^{3} per m.^{3}, as shown in Tables X.–XIII.). The amounts and relative proportions of the dissolved and suspended residue in these localities show some relation to the plankton production. The residue in suspension is not, in its present form at least, available for plant food. Its occurrence in the four localities is almost directly correlated with the relative turbidity of the water Spoon River has from four to eleven times as much suspended matter (274.3) as the other localities, and this consists largely of clayey material with considerable fine quartz, neither of which contributes any considerable source of nutrition to the phytoplankton. The suspended material in the other locations at times of flood partakes of the character of that in Spoon River. At other times it contains a considerable proportion of debris of plant or animal origin including the plankton itself. The current of the river is doubtless responsible for the excess (61.4) which its waters carry above that in the lakes (25.1 and 44.6). The greater amount in Thompson's Lake (44.6) may be due to two sources, its greater dependence on the river for its water supply and the greater disturbances in its waters due to fish and to waves. The fact that the total catches of the plankton net (3.91, 1.35, 2.24, and 7.68) do not on the average more nearly approximate in their ratios to each other the ratios of the chemical residues (61.4, 274.3, 25.1, and 44.6) is due to the great leakage of the finer suspended particles through the silk, especially in Spoon and Illinois river waters.

The *residue in solution* contains the available supply of mineral salts for the phytoplankton as well as some organic materials which become sources of plant food, and its distribution in the four localities is correlated with the plankton production in the direction of the differences, though not in their quantity. Thus Spoon River with the least dissolved residue (167.1) has the least plankton production (.384), and Quiver Lake has likewise less residue (248.2) and less plankton (1.62) than Thompson's Lake (282.9 and 6.68). The Illinois River exceeds all of the localities in its dissolved residue (304.1), which may be attributed to the fact that the water is "older," affording greater time for solution, and that it is the recipient of considerable sewage and industrial wastes which add to its burden of substances in solution. The small amount in Spoon River may be attributed to the fact that it is largely uncontaminated surface water of recent origin. The greater amounts in the two lakes (248.2 and 282.9) are due in part at least to their dependence upon the river, which in the case of Quiver Lake is slight during the summer season. In so far as the total residue held in solution is an index of fertility, the data indicate that the river itself carries the greatest store of food (304.1); Thompson's Lake, somewhat less (282.9); Quiver Lake, still less (248.2); and Spoon River, least of all (167.1). On this basis and in the light of the production of Thompson's Lake it would seem that the river water might under more favorable conditions develop a more abundant plankton. These favorable conditions are to be found in the quiet backwaters of river-fed lakes, where time for breeding is afforded.

The loss which the residues of total solids suffer upon ignition (heating to redness) includes the organic matters which are burned away and such constituents of the mineral matters as are volatile or are decomposed by heat into volatile substances. In stream waters the suspended portion of this material may be a rough index of the quantity of plankton and silt of organic origin, all of which on decay add to the water substances available for plant food. From the data in the table it may be ascertained that the four localities yield respectively, in the order of the the table, 7.7, 17.5, 1.9, and 8.2 parts per million of such material. The excess in Spoon River (17.7) is doubtless due to silt of organic origin, while the plankton presumably forms a larger proportion in Thompson's Lake and in the Illinois River. The poverty alike of plankton and of silt in Quiver Lake is reflected in the small amount (1.9) lost on ignition in its waters. The loss, on ignition, of substances held in solution shows no differences at all commensurate with the relative production of plankton, though the *trend* of the differences is similar in three instances of the four.

The *chlorine* is contained in surface waters in combination with various basic elements, but chiefly in the form of common salt. Its principal source is animal matter, sewage, or drainage from refuse animal matter. In our river and lake waters it is largely an index of their relative contamination with sewage from cities within the drainage basin. Since its combinations are not utilized by plants as food in any considerable quantity, at least as compared with other constituents of the sewage, such as the nitrates, the chlorine becomes the best criterion of the amount of sewage and thus of the principal adventitious fertilizer which the waters examined by us contain. The differences in the four localities are striking and significant. The average chlorine in the Illinois River (21.6) is more than five times as great as that in Spoon River (3.8), while that in Thompson's Lake is more than three times the amount in Quiver Lake. The large amount of chlorine in the Illinois and in Thompson's Lake—which draws its water supply mainly from the river—is due to contamination by the sewage of Chicago, Peoria, and other cities within the drainage basin. Quiver Lake receives water from the river only during flood periods, when the sewage is diluted, and at other seasons it contains more nearly the chlorine of the uncontaminated prairie stream. Its chlorine thus averages low (3.8). That of Spoon River runs higher (4.8), in part because of backwater from the main stream to the point of collection. The sewage systems discharging into this stream are few and but slightly developed, and its chlorine is correspondingly low. While it is true that the chlorine is not a precise measure of the amount of sewage or of the adventitious fertilizing material received by a stream, it is nevertheless significant that ratios of chlorine and plankton production not only trend in the same direction but are quantitatively somewhat similar when lake is compared with lake and stream with stream. Thus in Quiver and Thompson's lakes the ratio of their chlorine content is 1 to 3.4 while that of the plankton production is 1 to 4.2. The corresponding ratios in Spoon and Illinois rivers are 1 to 5.7 and 1 to 5. An increase in chlorine due to sewage or animal wastes seems thus to be accompanied by a proportionate increase in the plankton produced. It is safe to infer that it is one of the factors producing the increase, but, as shown elsewhere in this paper, other factors, such as vegetation and current, are also potent in producing the contrasts in plankton production above noted.

The *oxygen consumed* in oxidizing the organic matters affords an additional index of the quantity of these substances present in the water, but since all kinds of organic matter are not oxidized in the analysis it does not yield a criterion of the *total* quantity of organic matter. A comparison of the oxygen consumed in the four localities yields results very similar to those obtained by a comparison of loss on ignition, except in the case of Quiver Lake, where the oxygen consumed (5.9) is proportionately very much lower than the loss on ignition (27.5). The amount of oxygen consumed is greatest in Spoon River (14.1), and may be attributed largely to the detritus of organic origin which the stream carries, or to the products of its decay held in solution. It may also be due in part to the organic material of the water-bloom (*Euglena*) which escapes the silk of the plankton net. There is, however, no increase in the oxygen consumed in the season of the water-bloom which can be considered commensurate with its development.

Nitrogen is an essential constituent of protoplasm and of many of its products. It is taken up by plants in the form of nitrates and free ammonia, and there is increasing evidence that it may be utilized, especially by the lower plants, in more complex combinations, such as the amido-compounds. Since the other principal constituents of protoplasm—carbon, hydrogen, and oxygen—are present in inexhaustible quantity in the air, water, and carbon dioxid, and since the nitrogen available for plant food is practically limited to that contained in the above-named compounds, the nitrogen in combination in any given body of water becomes *par excellence* an index of its fertility. These compounds exist in living plants and animals, in their wastes, and in the products of their decay. They enter stream and lake waters in various ways: in the debris of vegetable and animal origin washed into the stream, especially by flood waters; in leachings from such matters drawn from the soil in seepage and spring waters; and, especially (in the Illinois River) in the sewage and industrial wastes of Chicago, Peoria, and other cities within the drainage basin. In the lake and stream waters these nitrogenous compounds are found in solution in the water, in the sediment and debris of organic origin in suspension, in the zoö- and phytoplankton, and in the macroscopic aquatic plants and in the larger animals—such as fish, mollusks, insects, and crustaceans. The chemical analyses show only those nitrogenous compounds in solution, in silt, and in plankton, while that stored in the larger plants and animals is not determined. Since the silt is undergoing decay, and since the individuals of the plankton are short-lived and rapidly release their nitrogenous compounds into the water by waste and decay, the determinations of nitrogen in its various forms in the analyses represent both the present fertility and that in immediate prospect. The contributions from the macroscopic plants and animals not included in the samples analyzed constitute an undetermined element in the sum total of the nitrogenous matter available for the sustenance of the phytoplankton. The relative amounts of nitrogen in the several stages of decomposition are shown in the determinations of total organic nitrogen, of nitrogen as albuminoid and free ammonia, and of nitrites and nitrates.

The *total organic nitrogen* includes all nitrogen that is in combination with carbon (together with other elements) in the tissues of living plants and animals and in many of the waste products of the latter. It is also present in organic matter in the early stages of decay, and is accordingly found in organic debris and sewage of stream and lake waters. It is accordingly an index of the quantity of organic matter which in its present form is not available for plant food (with the possible exception of certain amido-compounds) but is destined to become available by decay. It thus indicates the potential fertility of the water. The differences in the amount of total organic nitrogen present in the four localities are not in each case correlated with the actual plankton production. Spoon River, which contains the least plankton, has the greatest amount (1.292) of organic nitrogen. The absence of any excessive contamination by sewage in this stream combined with the paucity in plankton, makes it apparent that this matter is probably in the organic detritus of the silt, which is present in an unusual amount in this stream. The close resemblance of the Illinois River and Thompson's Lake in the matter of total organic nitrogen (1.03 and and 1.05) is explained by the dependence of the latter upon the river for its water supply, and by the excess of sewage in the former and of plankton in the latter. The small amount in Quiver Lake is attributable to its greater independence of the river, to the paucity of its plankton, and to the sandy nature of its drainage basin and consequent share of spring water in its water supply. It is noticeable that the large amount of submerged vegetation in this lake does not contribute any great amount of organic nitrogen to the water at any season of the year.

The nitrogen as *albuminoid ammonia* is included in the total organic nitrogen, and exhibits almost identical relative amounts in the four localities, though actual quantities are only half as great. It represents the nitrogenous materials which have not undergone decomposition.

The nitrogen as "*free*" *ammonia* represents the ammonia contained in the water in free or saline condition. It is a product of the decomposition of organic matter in the first stages of oxidation, and its quantity is an indication of the amount of such matter present in the water in a partially decomposed state. It is abundant where sewage occurs, and together with the chlorine affords evidence of the degree of contamination. The occurrences of free ammonia in the four localities (.86, .245, .165, and .422) are not in most instances in the same ratios as those of the chlorine (21.6, 3.8, 4.8, and 16.3) or of the plankton (1.91, .384, 1.62, and 6.68). The excess (two to five times as much) of decaying organic matter in the river as compared with the other situations is apparent, and is doubtless due to the concentration of sewage in its channel and to the more recent access of the sewage there as compared with that in the reservoir backwaters, as, for example, in Thompson's Lake. The early stages of decay are in consequence more active in the river. The free ammonia is high in both the river (.86) and Thompson's Lake (.422) but lower in Spoon River (.245), where the organic material in suspension is considerable, as indicated by the loss on ignition, the albuminoid ammonia, and the organic nitrogen and oxygen consumed. The decay of this matter and the accompanying release of free ammonia has not been attained as yet in a part at least of the silt in Spoon River to the same degree that it has in the older river and lake waters. Its burden of silt thus adds to the sources of fertility of the main stream and of the reservoir backwaters at times of flood. The small amount of free ammonia in Quiver Lake (.165) is correlated with the small amounts of the substances above named in its waters and the sandy nature of its drainage basin. The differences in the two streams in the quantity of free ammonia (.86 and .245) have the same trend as the differences in plankton production (1.91 and .384), but they are not commensurate quantitatively, owing apparently to the more recent origin of the water in Spoon River. In the lakes the free ammonia (.165 and .422) and plankton (1.62 and 6.68) exhibit a similar trend and a like absence of quantitative differences in the plankton commensurate with the free ammonia available for support of the plankton. The effect of the relative food supply is thus apparent in the trend of the differences, and the operation of other factors is suggested by the quantitative contrast. The factors in Quiver Lake tending to reduce the plankton below the amount that the food supply would make possible are to be found in the passage of tributary waters through the lake and in the excessive aquatic vegetation. It is noticeable that the considerable amount of submerged vegetation in Quiver Lake does not seem to effect any appreciable increase in the free ammonia. The abundance of free ammonia in the Illinois River would seem to afford a basis for a greater development of the phytoplankton than it attains under the conditions in that stream. The time for breeding which is afforded in the backwaters is one factor involved in this contrast.

The *nitrites* constitute a second intermediate stage in the oxidation of nitrogenous substances into inorganic products. Their presence indicates organic matter in the final stages of decay, and that decompositions due to the vital processes of living organisms are under way. The nitrites exhibit a distribution in the four localities which in the trend of the differences is similar to that of the free ammonia. The ratio of the free ammonia in Spoon River to that in the Illinois is 1 to 3.4, while that of the nitrite content of the two streams is 1 to 3.7. The ratios in the two lakes, Quiver and Thompson's, are 1 to 2.6 and 1 to 2.1 respectively. Spoon River and Quiver Lake are thus poorer in nitrites than Illinois River and Thompson's Lake. The same contrasts are to be found in their production of plankton, though the differences in the amounts produced are greater than those in this source of fertility. The amount of nitrites (.048) in Thompson's Lake is quite low when the large plankton production in this lake (6.68) is contrasted with the much smaller amounts (1.91, .384, and 1.62) in the other localities, where the nitrites are but a little less or even greater (.147, .039, and .023). Either the nitrites are an inadequate measure of the potential fertility of the water, or the other waters named might, in the environment of Thompson's Lake, support a more abundant plankton.

The *nitrates* are the final products of the oxidation of nitrogenous matters, in which the nitrogen returns to inorganic compounds and is once more in a form most available for utilization as food for the phytoplankton or other aquatic plants. The quantity of these compounds is a prime index of the immediate fertility of the water, and becomes a basis for future growth of the phytoplankton and other aquatic plants. The amounts of nitrates present in the waters of the four localities are very different, and at first glance exhibit little correlation either with the other forms of nitrogen present in the water or with the quantity of plankton produced. It should be noted in this connection that the nitrates, more completely perhaps than any other form of nitrogen, are utilized by the chlorophyll-bearing organisms as food, and if taken up by the phytoplankton the nitrogen appears in the subsequent analysis as organic nitrogen. If, however, the phytoplankton or the zoöplankton feeding upon it is utilized by some macroscopic animal, —as, for example, by *Polyodon*, or by the *Unionidæ* which cover the river bottom in places,—it is removed from the field of analysis, excepting only in such animal wastes as are returned to the water by the feeding organism. If it is utilized by the grosser forms of submerged aquatic vegetation, it is likewise effectually removed from the field of analysis until again released by the decomposition of this vegetation. The nitrogen as ammonia in organic compounds, or as nitrites, is either entirely unavailable for plants or, with the probable exception of the free ammonia and the amido-compounds, is less available than the nitrates. These other forms consequently more fully represent the potential fertility of the water than the nitrates do, for the latter indicate mainly the *unutilized* portion of the nitrogenous plant food immediately available. In the light of the foregoing conditions more significance attaches to the distribution of nitrates and plankton in the four localities. The excess in the river (1.58) over that in the tributary waters of Spoon River (1.01) and Quiver Lake (.66) may be due in part to the greater age of the waters of the main stream and the opportunity thus afforded for the completion of the processes of decomposition of organic substances delivered to the main stream by tributaries above the point of examination. When the quantity of nitrates in the river is compared with the organic nitrogen, free ammonia, nitrites, and nitrates in Spoon River or Quiver Lake, it becomes apparent that the tributary waters of this stream still act as a diluent of the river water. The source of this excess in the main stream is to be found in the sewage and industrial wastes of Chicago and Peoria. The unutilized nitrates are two and a half times as great in the river (1.58) as in Thompson's Lake (.64). In so far as the nitrates are concerned, both Spoon River and the Illinois might support a much more abundant plankton than they now produce (1.91 and .384) if the conditions permitted. Thompson's Lake, drawing its water from these sources, does maintain a greater production (6.68) and exhibits a great reduction in the amount of nitrates (.64), the unutilized residium being less in this lake than in any of the other localities. The increase in the amount of plankton in Thompson's Lake over that in the river (3.5 times as much) is roughly proportional to the decrease in nitrates in the lake as compared with the river (.4 as much).

The similarity of the residual nitrates in the two lakes is striking (.66 and .64), and it bears no apparent relation to their plankton production (1.62 and 6.68). The excess of other forms of nitrogen in Thompson's Lake (roughly twice that in Quiver) would seem to indicate either that the decomposing nitrogenous substances are utilized before they reach the form of nitrates, or that they are abstracted from the water so promptly that they do not accumulate above a certain residual minimum which is apparent during the growing period of the phytoplankton and of the coarser forms of aquatic vegetation. (See Plates XLIX. and L.) It is evident that the nitrates in the two lakes (.66 and .64) cannot adequately represent the nitrogenous resources of the two bodies of water; neither can they furnish any reliable clue to their actual productiveness in plankton. Other factors of the environment are equally or even more potent. The number of analyses and of plankton catches is so great (188 and 156 from Illinois River and 40 of each from Thompson's Lake), and they are so distributed through the year, that the inference is justified that the nitrates shown by chemical analysis in the water of a lake or stream, especially during the growing period of vegetation, afford no reliable basis for judgment as to its plankton production.

The *sewage* received by the Illinois River bears an important relation to the chemical condition of its water and thus to the plankton which it produces. No measurements are made by boards of public works of the amount of sewage which municipal systems discharge into the various streams which unite to form the Illinois River. Two sources of information are, however, available which throw some light on the extent of sewage pollution arising from these sources. They are the population of the cities in question and the pumpage of their water-works. Municipal engineers are accustomed to estimate the sewage discharged from a city with well-established sewage and water systems as approximately equivalent to the pumpage of the latter. I have accordingly prepared a table which includes practically all of the cities provided with these works in 1897, and states the pumpage in gallons per day, the population, and pertinent data concerning the systems in discussion. The population is that reported by the census of 1890, and the figures for 1897 would show a considerable increase owing to the rapid growth of the urban population in the vicinity of Chicago during the past decade. The second part of the table includes the smaller cities with water-works but without developed sewage systems. These do not contribute to the stream

POPULATION AND PUMPAGE IN CITIES WITH SEWAGE SYSTEMS.

City	Population in 1890	Daily Pumpage in gal.	Remarks.
Illinois			
Aurora	19,688	1,338,570	Combined sewage system
Chicago	849,850	520,275,109	Population 1,099,850, from which 250,000 was deducted for area of City draining directly into Lake Michigan. Pumpage is that at Bridgeport.
Elgin	17,823	1,143,488	Combined sewage system
Hinsdale	1,584	124,000	
Joliet	23,264	2,500,000	Part separate, part combined systems.
Kankakee	9,025	1,200,000	
LaGrange	2,314	223,609	Combined sewage system
La Salle	9,855	1,503,835	
Lemont	——	600,000	Population not given in 1890 apart from that of township.
Mendota	3,542	205,479	Separate sewage system.
Ottawa	9,985	511,000	Sewage system incompl't.
Pekin	6,347	750,000	" " "
Peoria	41,024	5,000,000	
Peru	5,550	216,183	Sewage system incompl't.
Pontiac	2,784	750,000	Pumpage estimate reduced from 2,000,000 gal.
Streator	11,414	2,000,000	
Utica	1,094	720,000	Water supply from artesian wells.
Watseka	2,017	150,000	Pumpage estimated.
Wheaton	1,622	70,000	Sewage system incompl't.
Wisconsin			
Waukesha	6,321	500,000	Separate sewage system.
Indiana			
La Porte	7,126	747,788	
Total	1,032,229	540,529,061	Total pumpage, 442.17 cu. ft. per sec.

waters a volume of sewage equal to the pumpage, though their imperfectly developed systems of drainage, combined with the surface run-off, carry some sewage to the stream.

POPULATION AND PUMPAGE IN CITIES WITHOUT SEWAGE SYSTEMS.

City	Population in 1890	Daily Pumpage in gal.	Remarks.
Illinois			
Batavia	3,543	2,500	1,500— 3,500 gallons.
Braidwood	4,641	5,500	1,000—10,000 “
Chenoa	1,226	20,000	
Delavan	1,176	50,000	
Dundee	2,073	70,000	
Earlville	1,058	25,500	
Elmwood	1,548	19,000	7,000—31,000 gallons,
El Paso	1,353	27,500	25,000—30,000 “
Fairbury	2,324	71,500	53,000—90,000 “
Forrest	1,021	8,442	
Geneva	1,692	40,000	Pumpage estimated.
Lacon	1,649	15,000	
Lexington	1,187	60,000	
Lockport	2,449	44,500	
Minonk	2,316	109,689	
Momence	1,635	250,000	
Morris	3,653	54,795	
Plano	1,825	31,500	
Princeton	3,396	650,000	
Spring Valley	3,837	55,000	
Washington	1,301	100,000	
Wenona	1,053	23,000	21,000—25,000 gallons.
West Chicago	1,506	20,000	
Total	47,562	1,753,426	Total pumpage, 2.8 cu. ft. per sec.

The principal sources of the sewage contributed to the Illinois River above Havana are Chicago, Peoria, and the smaller cities within the drainage basin. The amounts contributed by each are approximately 520,275,109, 5,000,000, and 16,007,378 gallons respectively per day. The total amount of 542,282,487 gallons per day or 838.7 cubic feet per second is about 8 per cent. of the average flow of the river at Havana and exceeds by 40 per cent. the estimated low-water flow at Copperas Creek dam, eighteen miles above our plankton station. In 1890 the population of the two larger cities and the total of the remaining smaller ones was respectively 849,850, 41,024, and 188,817, a total of 1,079,691, 250,000 having been deducted from the population of Chicago, as before stated, because of the fact that the drainage of certain districts did not enter the Illinois River. It is apparent that Chicago, with a population four times and a pumpage twenty-five times as great as that of the remaining territory, is the principal source of sewage, overshadowing all others by its magnitude.

The sewage of Chicago during the period of our operations was mainly discharged into Chicago River, a tributary of Lake Michigan. An area of 50.63 square miles lying within the city limits and having in 1897, according to estimates kindly furnished us by the engineering department of the Sanitary District, a population of 250,000 to 300,000, drains directly into Lake Michigan. The water supply of Chicago is drawn directly from the lake, and to decrease its pollution by sewage, pumping works were established at Bridgeport which raised the fouled water of Chicago River into the Illinois and Michigan Canal, which empties into the Illinois River at La Salle. At low-water stages the pumpage of Bridgeport prevented the discharge of a considerable amount of the sewage into the lake, reversing at times the direction of the current in the river. During floods the pumps were powerless to prevent the discharge of large amounts of sewage into the lake. Under the conditions prevailing during the years of our operations a considerable portion of the sewage of Chicago thus found its way into the Illinois River. This sewage included a large amount of industrial wastes, especially from the Union stock-yards and slaughter-houses connected therewith. The average daily pumpage of the city water-works in 1897 in Chicago was 265,530,910 gallons—an amount 50 per cent. less than the pumpage at Bridgeport. The amount discharged into the Illinois and Michigan Canal thus represents a somewhat diluted sewage as compared with that from other sources. Chemical examinations of the canal water indicate (see Palmer, '97) that the maximum period of decomposition of the sewage passed before the water entered the river. The location of the crest of this wave varied with the temperature, ranging from Lockport to Morris. Bacteriological determinations (see Jordan '00) also indicate a somewhat similar wave of bacterial development, which is to be correlated with the wave of nitrification detected by the chemical analyses. By the time the sewage of Chicago entered the Illinois River at La Salle it was thus already in the advanced stages of decay and available for the support of the phytoplankton or other vegetation, if, indeed, it was not already used to some extent by these agencies. The progressive nitrification of the sewage in the canal is shown by the average nitrates found by Palmer ('96) at Lockport (.84), Morris (1.44), and La Salle (2.51 parts per million). The average at Havana, about one hundred miles below La Salle, in the same year, was only 2.34 with the added amount from Peoria's contribution. At Kampsville, about 190 miles from La Salle, the amount falls to 1.39.

The sewage of Chicago under conditions prior to the opening of the drainage canal in 1899 thus enters largely into the sources of fertility of the river water. It reaches the maximum of decomposition before mingling with the channel waters at La Salle, and is reinforced by the sewage and wastes of Peoria. The products of decomposition (nitrates) continue in diminishing quantity, diluted by tributary streams—as, for example, by Spoon River, where the average amount of nitrates (1.01) is somewhat less than that of the river at that point (1.58, for 1894–99)—and utilized by the developing phytoplankton and other aquatic vegetation. Entering practically at the headwaters of the Illinois, it becomes one of the most potent factors in the maintenance of the abundant plankton found in the river and its backwaters.

The sewage of Peoria, as represented by the pumpage of the water-works, is but a small fraction of the total amount received, being less than one per cent. if industrial waters are included. For two reasons its effect upon the plankton in the river at Havana is proportionally much greater than the figures indicate. The first is the proximity of Peoria, it being 55.7 miles above Havana. The maximum stages of decomposition are usually passed, even in the coldest weather, before the sewage reaches our plankton station, so that its fertilizing effect upon the water has been operative for some time. The second reason lies in the fact that large industrial plants with private water supplies—such as the distilleries and cattle-feeding yards connected therewith and the glucose factory—discharge immense amounts of organic wastes directly into the river. As many as thirty thousand head of cattle are often on hand at one time in these feeding-yards, and the refuse from the feeding-pens is flushed into the stream or piled at the river's edge till a rising flood carries it away in huge floating islands. The contributions from these sources at Peoria and Pekin are considerable. The comminuted vegetable debris of the silt owes its origin to this source in some degree, and it shares also in producing a wave of bacterial development (Jordan, '00), of putrefaction (Palmer, '97), and of the rapidly developing plankton organisms whose crest lies between Peoria and Havana.

The contributions of sewage from the smaller cities in the drainage basin above Havana are relatively so small, so scattered, and so mingled with tributary waters in many cases before they enter the river, that no localized effect upon the plankton of the stream can be traced.

The direct conveyance into drainage channels of so large an amount of animal wastes as occurs in sewage diverts from the soil and adds to the water an unusual, and, owing to the narrow confines of our streams, a proportionately great, source of fertility. In these particulars, together with its unusual extent of impounding backwaters, its low gradient, and its immediate access to markets, the Illinois River offers a magnificent field for the development of a scientific aquiculture.

CHEMICAL CONDITIONS AND PLANKTON PRODUCTION.

A summary of the chemical conditions as related to the production of plankton in the four localities, Illinois and Spoon rivers and Quiver and Thompson's lakes, yields some evidence of correlation, and also some points of difference which indicate the operation of other factors than nutrition in determining the production of plankton. The following table—giving the sum total of the averages of the nitrogenous matters (free ammonia, organic nitrogen, nitrites, and nitrates) and also the average plankton production—sets forth in brief the relative fertility and production of the four localities.

Locality.	Sum of averages of nitrogenous matters —parts per million.	Average plankton— cm.^{3} per m.^{3}
Illinois River........	3.617	1.91
Spoon River.........	2.586	.384
Quiver Lake.........	1.456	1.62
Thompson's Lake....	2.160	6.68

There is more nitrogenous matter in the streams than in the lakes, but also less plankton. Nutrition for the plankton is present, but time for breeding, owing to the more recent origin of stream waters, has not been afforded there, while in the lakes, which have somewhat of a reservoir function, there is time for growth of the plankton, and the store of food is depleted as compared with that in the river. It is also evident that there are unutilized stores of food in the rivers affording a basis for further development of the plankton.

The Illinois River exhibits the greatest fertility (total nitrogenous matters 3,617), owing largely to sewage and industrial wastes. These matters cause the high chlorine (21.6) and the large amount of free ammonia (.86) and organic nitrogen (1.03), while the abundant solids in solution (304.1) and the nitrites (.147) and nitrates (1.58) show how large a part has reached the last stage of decomposition. The unutilized products of decomposition are without exception in the data here discussed greater in the waters of the channel than in the tributary or impounded reservoir waters.

In Spoon River the solids in suspension are highest (274.3) and those in solution least (167.1), a condition due to the recent origin of its water and to the large amount of silt which it carries. The organic origin of some of this silt is shown by the large loss on ignition (41.9), the oxygen consumed (14.1), the albuminoid ammonia (.604), and the total organic nitrogen

(1.292), all of which are in excess in its waters. The freedom from sewage is evidenced by the low chlorine (3.8), while the considerable amounts of free ammonia (.245), nitrites (.039), and nitrates (1.01), indicate organic decomposition in progress or completed. In the absence of any considerable contamination by sewage it seems probable that these substances have their origin in the organic silt and the soil waters of the very fertile catchment-basin of the stream. The water of Spoon River, in so far as the nitrogenous substances (2.586) are concerned, could support a much more abundant plankton than it produces (.384). As in the case of the main stream, the explanation of the slight production lies in the recent origin of the tributary water. Impound Spoon River water in Thompson's Lake, and it produces an abundant plankton.

In food resources Quiver Lake is the poorest locality of the four (1.456, total of nitrogenous substances), having 40 per cent. of the amount of the nitrogenous substances in the Illinois, 56 per cent. of that in Spoon River, and 67 per cent. of that in Thompson's Lake. The suspended solids (268.9), the loss on ignition (27.5), and the oxygen consumed (5.9), are least here as a result of slight access of silt-laden waters. The chlorine is low (4.8), and would be much lower if contaminations from river water at overflow could be eliminated; and corroborative evidence of the slight contamination of the waters of this lake by sewage is seen in the amounts of free (.165) and albuminoid (.251) ammonia, of organic nitrogen (.61) and nitrites (.023), all of which exhibit minimum averages in this lake. Organic matter in decay is less abundant here than in the other localities, being, for example, about 50 per cent. less than in Thompson's Lake. The final products of decay, the nitrates, are greater (.66) than the amounts of organic matter would lead us to expect, and are probably due in large part to soil waters from the drainage basin. In the light of the production of Thompson's Lake (6.68) the small amount of plankton produced in Quiver Lake (1.62) finds no adequate explanation in a reduction of 33 per cent. in the total nitrogenous substances. Flushing by tributary water and abundance of submerged non-rooted vegetation are the more potent factors in the failure of the plankton development in Quiver Lake.

In most particulars the averages of the analyses of water from Thompson's Lake approach those of the river water, from which it draws its main supply. There are less solids in suspension (282.9) than in the river as a result of sedimentation, and less in solution (44.6)—probably the effect of the small amount of creek water, or of the utilization by the plankton and vegetation of substances held in solution. The loss on ignition (36.5), oxygen consumed (11.9), albuminoid ammonia (.546), and organic nitrogen (1.05), all run higher than in the river as a result of the greater amount of plankton. The decreased amounts of free ammonia (.422) and of nitrites (.048) as compared with those in the river (.86 and .147) would seem to indicate less decomposition here, while the small amount of nitrates (.64)—the least of all the averages—suggests utilization of these matters by the plankton, which here reaches a greater development than in any of the other localities under present consideration.

SEASONAL CHANGES IN CHEMICAL CONDITIONS AND PLANKTON.

The data concerning these changes are given in Tables X–XIII., and they are presented graphically in Plates XLIII.–L. They afford evidence for the following general conclusions:

There is a major seasonal movement in the chemical conditions which can be traced in the analyses for each year and each locality. There are, in addition to this wide-spread and recurrent cycle of changes, many abrupt and often considerable fluctuations due to floods, while others are of minor importance and apparently of local origin. The various nitrogenous substances to a considerable extent fluctuate together. The quantitative fluctuations in the plankton show no intimate and immediate correlation with those of any substance determined in the analyses. Certain relations of the plankton to the quantity of nitrogenous substances are however indicated, but precise quantitative correlations cannot be established. The operation of other factors is evident, chemical conditions alone offering no satisfactory clue to causes of many of the fluctuations in the amount of plankton.

The cycle of seasonal fluctuations in chemical conditions is best seen in years of more normal hydrograph, such as that of 1898, and it is more regular in the backwaters, such as Quiver and Thompson's lakes, than it is in tributaries such as Spoon River, or in the Illinois itself. In the streams the floods produce irregularities which either do not enter the reservoir backwaters or reach them only in diminished volume. The varying degree of contamination by sewage in the different localities and in different seasons in the same locality adds another element which diversifies the seasonal changes and makes it more difficult to detect the common features which the fluctuations exhibit in all the localities.

The cycle of seasonal fluctuations (see Pl. XLIII.–L.) in the chemical conditions is, in the most general terms, an increase in the nitrogenous compounds during the colder months and a decrease during the warmer ones. The maximum period usually appears in October and continues until the following summer, declining in May and June to the summer minimum, which in the following October and November rises again to the winter maximum. This fluctuation is somewhat similar to that found in soil waters. This coincidence suggests the operation of fundamentally similar causes back of the common phenomenon.

These maximum and minimum pulses in the Illinois River in 1896 (Pl. XLIII.) are most evident in the nitrates and free ammonia, though traces of their influence can be detected in the curve of the albuminoid ammonia. The suppression of this spring flood and the recurrence of four minor but unusual floods during the summer and fall are probably the cause of the nonconformity of some of the substances to these pulses and of the irregularity which they all exhibit in this year.

In 1897 (Pl. XLIV.) the curve of the nitrates again exhibits these pulses, but they are not apparent elsewhere unless it be in the free ammonia. The prolonged and unbroken low water from August to the end of the year, and the consequent concentration of the sewage in the river and the marked development of the water-bloom during this period, seem to have obliterated the minimum pulse in all but the nitrates. The marked rise in chlorine and free ammonia gives some idea of the unusual degree of concentration of the sewage.

In 1898 and the first three months of 1899 (Pl. XLV.) these pulses are much more evident, being traceable in the nitrates, albuminoid ammonia, organic nitrogen, and oxygen consumed. The marked depression of the free ammonia during the flood season in a measure modifies its conformity to these pulses.

A relation of these maximum and minimum pulses to the growth of the plankton is suggested by the chronology of the chemical (especially that of nitrates) and the plankton curves. The spring maximum of plankton production, which normally occurs in the last of April and the first of May, comes toward the close of a long period of high content of nitrogenous matters. It is followed by or is coincident with the decline in these substances. With the decline in plankton production in late autumn the nitrogenous substances again increase (Pl. XLIII.-XLV.). During the low water of 1897, when the midsummer minimum of nitrogenous substances was overshadowed by the concentration of the sewage, we also find a marked increase in plankton production as contrasted with that of corresponding seasons of 1896 and 1898. The warm season is presumably one of more rapid nitrification, the heat favoring the more rapid decomposition of the organic matter in water, but excepting instances of great sewage concentration, as in the late summer of 1897, we do not find an increase or an accumulation of the products of such decay in the water during the warm season. Indeed, the opposite seems to be the tendency. The explanation of this phenomenon lies, it seems, in the *rapid utilization* of the nitrogenous products of decay by the nitrogen-consuming organisms of the water. In open water these are the chlorophyll-bearing organisms of the plankton. In lakes rich in vegetation the grosser forms of aquatic vegetation draw heavily upon these resources. The accumulations of decay in winter and the increased products of decomposition in summer are all largely and promptly transformed again into organized matter, leaving only an unutilized residual minimum which represents an equilibrium of the processes of growth and decay in progress in summer waters. The seasonal distribution of floods may also enter as a determining factor in the problem.

The coincidence of the spring plankton maximum and the decline of nitrogenous matters in the river water has its parallel in the decline of nitrates in soil waters with the pulse of spring vegetation. In both cases the decline in nitrogenous matters seems to be due to utilization by growing vegetation, by chlorophyll-bearing organisms.

These maximum and minimum pulses of nitrogenous matters may also be traced in the analyses of samples from Spoon River. In 1896–97 (Pl. XLVI.) the nitrates exhibit most clearly the fluctuations in question. Traces of their presence can be detected in the plottings of the organic nitrogen, albuminoid and free ammonia, and oxygen consumed, though in all these cases the effect of flood waters is also evident and cannot be eliminated from the problem. Invasion of Illinois River water is also apparent in October of the low-water period of 1897, being shown especially by the chlorine curve.

In 1898 and the first three months of 1899 both the cold weather maxima and the warm weather minimum are more sharply defined and appear in all the substances above enumerated.

The plankton of Spoon River, with the exception of that of the low-water period of 1897, is too insignificant to make much of a showing even when plotted upon a scale tenfold that used for other stations (see explanation of Pl. XLVI.); nevertheless we still find here the same midsummer reduction in nitrogenous substances which has just been explained as the result of the utilization of such matters by the phytoplankton.

In spite of this seeming contradiction, I believe the explanation still holds in the case of Spoon River. The minimum period occurs during the time of low water, when the principal source of the flow in the stream is ground water which has already been robbed of its nitrates to some extent by terrestrial vegetation. Again, the plankton production of Spoon River, judging from the development of the water-bloom (*Euglena*), consists largely of chlorophyll-bearing organisms, which also rob the water of its nitrogenous substances. The period of development of the water-bloom covers the months of summer and early autumn, thus coinciding with the period of depressed nitrates. It is quite certain that the collections of the silk net fail completely to represent the quantity of those minute organisms which compose the water-bloom, and thus give no adequate clue to the amount of nitrogen-consuming organisms present in these or other waters. The reduction in nitrates in this stream during summer months is not, however, as great in quantity as it is in the Illinois River (cf. Pl. XLV. and XLVII.). The excess of sewage in the latter creates a greater winter maximum, thus permitting a greater range in reduction to the residual minimum of midsummer, which is about the same in both streams. But little correlation between the chemical conditions of Spoon River and its plankton production can be established beyond the reduction in nitrates in the plankton maximum of the autumn of 1897 at a time of abnormal low-water. Under normal conditions the plankton curve (silk-net catches) exhibits no movement correlated with or commensurate with the changes in chemical conditions. Flood and current afford here no time sufficient for the expression of the chemical factors.

In Quiver Lake the maximum and minimum periods appear with distinctness and affect all of the substances in question. This is partly the result of the diminished effect of floods in this reservoir area, and also of the delimitation of the lake as a separate unit of environment with the cessation of overflow. During the flood period (see Pl. III. and hydrographs on Pl. XLVIII. and XLIX.) the lake receives in addition to the drainage of its own catchment-basin some access of flood waters from the bottom-lands above and from the adjacent river. The water along the eastern shore, even in flood conditions, is "lake" rather than river water, as a comparison of the plottings of the analyses of water from the two sources clearly demonstrates. Our collections of plankton and water samples were taken within or near this belt of lake water, in which contamination by flood waters was not usually noticeable. Compare in this connection the chlorine curve of the river and lake (Pl. XLV. and XLIX.). To some slight extent, then, the analyses pertain to two sources: to the waters of overflow, largely belonging to the colder months and period of the maximum of nitrogenous substances; and to the waters of a spring-fed lake, delimited during the period of low water and of the minimum of nitrogenous substances. The data at hand do not cover low-water conditions during a "maximum" period, which might give evidence of a seasonal cycle in chemical conditions in this lake independent of the river overflow. From conditions elsewhere it seems probable that such a cycle does occur here also, though the overflow and probable contamination may serve here to heighten somewhat the contrast between the maximum and minimum periods of the seasonal cycle.

In the autumn months of 1896 and 1897 covered by the analyses, the rise in nitrates only is indicated (Pl. XLVIII.), the summer minimum continuing through the low-water period of autumn.

In 1898 and the first three months of 1899 (Pl. XLIX.) the period of maximum, November to May, is well distinguished from that of the minimum, May to November, and not only in the nitrates but to some extent also in all of the other substances, appearing most clearly in the free and albuminoid ammonia and the organic nitrogen.

As in the Illinois River, so here also the spring maximum of the plankton (Pl. XLIX.) comes at the close of the period of maximum of nitrogenous substances in the water and is followed by a period of depression in these substances, and in this case by a much more marked fall in the amount of plankton, which does not again rise until the return of the nitrogenous substances in the autumn. The unutilized minimum of nitrates during the summer season is but a trifle less than that in the river (cf. Pl. XLV. and XLIX.), but the fact that all the other forms of nitrogenous matters are not only low but are lower than in the river throws some light on the slight development of the plankton here as compared with that in the river during this period of the summer minimum of nitrogenous substances. While the small amount of plankton seems inadequate to explain the marked reduction in the various nitrogenous substances, it may be that the more permanent vegetation, the submerged aquatic flora of this lake, is an important factor in the reducing process. In its seasonal production the plankton of Quiver Lake shows a general correlation with the movement of the chemical changes, though all of its fluctuations are not commensurate with the fluctuations of the nitrogenous materials. The operation of other factors—such as the submerged aquatic flora and replacement by tributary waters—must be called in to throw light on all the plankton changes in this lake.

In Thompson's Lake the seasonal cycle of periods of maximum and minimum amounts of nitrogenous matters is almost as well defined as it is in Quiver Lake. The plottings of the analyses (Pl. L.) from September, 1897, to March, 1899, include two periods of winter maximum and one of summer minimum, all of which are well defined, and affect not only the nitrates but also the organic nitrogen, the albuminoid and free ammonia, and the oxygen consumed. The diminished effect of floods and of unusual flushes of sewage in this reservoir backwater is evident in the greater regularity of its seasonal curves of nitrogenous substances as contrasted with those of the river. Its close dependence upon the river for its water supply is shown by the similarity of its chlorine curve to that of the river. The rise in chlorine during the minimum period, July to November, indicates the entrance into this lake of sewage-laden waters of the river during this period, but it brings with it no corresponding increase in the residual nitrogenous substances. The depression of the nitrates, and possibly of the other forms of nitrogen, may be referred here as elsewhere to their utilization by the phytoplankton and submerged vegetation of the lake during their period of growth. As in the Illinois River and Quiver Lake, the spring maximum of the plankton appears at the close of the maximum of nitrogenous substances and is followed by their minimum period. The autumn maximum appears, at least in 1897, somewhat before any marked increase in the residual nitrates, though in both this year and the following one it extends into the period of rising nitrates. A general correlation thus exists between the seasonal production of plankton and the seasonal fluctuations of nitrogenous substances.

The *seasonal fluctuation of the several nitrogenous substances* exhibits some interrelations with the changes in the plankton, and especially with the accession of flood waters, and some variations from the general maximum-minimum cycle above discussed which call for brief notice.

The *nitrates*, the final products of decomposition, exhibit the maximum-minimum cycle most clearly, as, for example, in Pl. XLV., XLIX., and L. The fluctuations which affect the other substances appear here in diminished prominence, as may best be seen by comparing the plottings of Spoon River (Pl. XLVI. and XLVII.) with those of Thompson's Lake (Pl. L.). The close of the maximum period of nitrates is usually later than that of the free ammonia (Pl. L.), and extends for a varying distance into the period of growth of vegetation. This growth in our latitude becomes marked in the last days of April and the first of May, and continues, in some plants at least, until the frosts of October. The nitrates do not reach minimum levels, however, (see Pl. XLV.–L.) until late in June. In like manner the close of the minimum period is frequently delayed beyond the limits of the growing period of vegetation into November or even December. This seeming inertia in the seasonal movement of the nitrates seems to be due on the one hand to the gradual utilization of the accumulations of the winter and contributions of the spring floods by the spring plankton ; and on the other, to the slow accumulations of the autumn and to utilization by the autumn plankton, which, as in Thompson's Lake in 1897, often attains a considerable development.

A somewhat intimate connection between the nitrates and the plankton maxima can be detected in many instances in the diagrams. When the plankton increases, the nitrates often exhibit a depression, the extent of which, however, is not always proportionate to the change in the plankton. This absence of any constant ratio between the apparent changes in these two factors indicates the operation of other factors, one doubtless due to defects in the quantitative plankton method, and another due to changes in the component organisms of the plankton.

In the Illinois River in 1895–96 (Pl. XLIII.) the plankton maxima of April and October are accompanied by a marked fall in nitrates; on the other hand, those of November, June, and August appear with rising nitrates, the last two accompanying floods. The depressions in nitrates in October, December, February, June, July, and September are not in any case associated with a rise in the plankton, though often with the initial stages of the flood. In 1897 (Pl. XLIV.) the April-May, July, September, and October maxima are all associated with depressions of the nitrates. The February and March depressions of nitrates occur with floods, while in November and December no correlation is apparent. In 1898–99 (Pl. XLV.) the effect of the May, June, and July maxima can scarcely be detected in the nitrate curve, while those of December and March produce corresponding depressions. In this diagram neither plankton nor nitrates show marked changes after July.

In Spoon River the development of plankton is apparently so slight and the nitrates are relatively so abundant that no correlation between the respective fluctuations is apparent in the data except in the fall of 1897, when an unusual minimum of nitrates appeared in conjunction with an unusual development of plankton (Pl. XLVI.). Decrease in nitrates often attends the initial stages of flood independently of plankton development, as in December, 1896 (Pl. XLVI.). Some nitrate increases, as in the autumn of 1896 (Pl. XLVI.), appear with the crests of floods, especially those of the gradual type. Other fluctuations in the nitrates—and they are often considerable—show no correlation with available data

In Quiver Lake in 1898–99 (Pl. XLIX.) the plankton maxima of April-May, June, and December all occur when nitrates decrease. The tendency of nitrates to increase and then fall again with the crest of the flood is apparent in January, March, May, November, January, and March.

In Thompson's Lake in 1897–99 (Pl. L.) practically all of the maxima are attended by a greater or less diminution of the nitrates. This appears in October, November, December, April-May, June, July, August, and December. The effect of floods in decreasing the nitrates in their initial stages and subsequently increasing them is slightly indicated in January, February, November, and February.

The *nitrites* exhibit a tendency in the Illinois River to excess during the low-water period of midsummer (Pl. XLIII.–XLV.), averaging about .3 to .4 parts per million to .1 during the remainder of the year. This excess was prolonged into November in 1897 with the low-water period of that year. It seems thus to attend the concentration of sewage in the river. No constant correlation of movement between the nitrites and plankton can be detected. In a few instances, however, plankton maxima coincide with marked decrease in nitrites, as, for example, in the river in September and October, 1897 (Pl. XLIV.), and the spring maximum precedes the rise in nitrites in each year. The changes in the nitrites show no constant correlation with those of other forms of nitrogen, though at times they exhibit indications of a common movement with the nitrates or the free ammonia.

In Spoon River (Pl. XLVI. and XLVII.) the summer rise in nitrites is not apparent except in the low water of 1897. The decay of organic matter is thus less active during this season in tributary water than it is in the main stream. In contrast with the summer, the winter exhibits somewhat more nitrites, but these are not markedly different in amount from those in the main stream at that season. The only correlation between the nitrites and the plankton of this stream appears in 1897 from May to December, when plankton maxima are uniformly attended by decrease in nitrites. As elsewhere, they present no constant relation to the fluctuations of other forms of nitrogen.

In Quiver Lake (Pl. XLVIII. and XLIX.) the nitrites have their maximum during the colder months and the flood period. A marked depression of nitrites appears with the May maximum of the plankton in 1898 (Pl. XLVIII.).

In Thompson's Lake (Pl. L.) the changes in the nitrites are slight, irregular, and without apparent correlation either with other nitrogenous substances or with the plankton. Like the nitrates, the nitrites are not greatly and immediately affected by the accession of flood waters, and they run lower in the reservoir backwaters than in the main stream.

The *albuminoid ammonia* and the *total organic nitrogen* fluctuate together so closely (see Pl. XLIX.) that it seems unnecessary to distinguish between them in this discussion. The seasonal fluctuations in these substances in the Illinois River (Pl. XLIII.–XLV.) are not marked, as a result apparently of the somewhat uniform accession of sewage. The dilution of the sewage consequent upon overflow is to some extent offset by the large accessions of these substances, which as silt and leachings accompany flood waters. A slight increase attends concentration in the low water of 1897 (Pl. XLIV.), and a slight decrease comes with the period of overflow of the same year. Similar movements are less evident in the other years

(Pl. XLIII. and XLV.). The effect of sudden floods, presumably those of tributaries but a short distance above Havana, appears in February, 1896 (Pl. XLIII.), and in 1899 (Pl. XLV.) as a twelve- and two-fold increase respectively, which is remarkably abrupt and is followed in both cases by a quick but somewhat more gradual return to the previous condition.

Owing to the complexity alike of the substances included in these items of the analysis and of the plankton itself, no uniform correlation of these factors can be discovered. Two different and in a certain sense opposite tendencies can be detected in the relationship of the movements of the plankton to those of the substances under discussion. During the winter season and the period of excess of nitrates, plankton pulses are attended by *increase* in the albuminoid ammonia and organic nitrogen. This appears in the Illinois with the pulses of April, 1896 (Pl. XLIII.), and December, 1898 (Pl. XLV.). During the warmer months, when most of the plankton pulses occur, the opposite tendency is seen in the movement of these substances. They tend to *decrease* at times of plankton pulses, as may be seen in August and October, 1896 (Pl. XLIII), in May, July, September, and October, 1897 (Pl. XLIV.), and in June, 1898 (Pl. XLV.). With the pulses of December, 1895 (Pl. XLIII.), and May, 1898 (Pl. XLV.), no marked effect in either direction is apparent.

In Spoon River any seasonal movement of the albuminoid ammonia and organic nitrogen is quite thoroughly masked by the disturbances due to floods. In 1898 (Pl. XLVII.) these substances are a trifle lower in the warmer months than in the colder, a condition which may result from the prevalence of floods in the latter season. In 1897 (Pl. XLVI.) they increase during the warm season and period of low water attending a development of the plankton unusual in the water of this stream.

The effect of flood upon the quantity of these substances in the water of this stream is well defined, and seems to throw light upon the relation which flood waters bear to the plankton of the main stream. Not all of the floods which flush this tributary appear with corresponding prominence in the hydrograph of the main river, which is the one plotted upon all the diagrams pertaining to Spoon River. In many instances they coincide. All instances in the chemical diagrams (Pl. XLVI. and XLVII.) of abrupt, steeple-like eminences in the curves of albuminoid ammonia and organic nitrogen (and also of oxygen consumed) are due to sudden floods, and appear most prominently when the date of collection of the water sample coincides with the initial stages of the flood. This is well shown in September, 1898 (Pl. XLVII.). Not all of the samples from flood waters were collected at times which afford evidence for the enriching effect of the initial stages of these tributary flushes. The relative amount of these and other forms of nitrogen which floods bring to the river is well shown in this flood of September, 1898 (Table XI. and Pl. XLVII.). On August 30 the amounts of albuminoid ammonia (.32) and organic nitrogen (.6) are normal for that season of the year. With the flood of the first week of September these amounts increase more than tenfold (being 3.6 and 8.32 respectively), falling again a week later to the normal (.2 and .48). A large part of this matter is in suspension. For example, in the flood of May, 1898 (Pl. XLVII.), about 86 per cent. of the albuminoid ammonia (2.32) and 90 per cent. of the organic nitrogen (5.46) was in suspension.

It is not plankton, neither is it to any large extent sewage, which the tributary floods of Spoon River bring to the Illinois as organic nitrogen, but largely organic debris not yet decayed. The sewage-laden river habitually carries much less of these substances than these tributary flood waters laden with this organic debris from fertile prairies. The latter thus become very important agents in maintaining the fertility of the river water. The effect of these periodic additions of nitrogenous substances by tributary floods upon the plankton of the river will be discussed in another connection.

A decrease in these nitrogenous substances attends the two plankton pulses of 1897 (Pl. XLVI.) in the warm months of May and September, but the increases noted with the pulses of plankton in the winter in the Illinois River are not apparent in the case of the pulses of February and December in this stream, though no decrease appears as in the summer months.

In Quiver Lake in 1898–99 (Pl. XLVIII.) a seasonal movement in the albuminoid ammonia and the organic nitrogen is evident, though it seems to accompany the access of sewage-contaminated waters of overflow, as appears on comparison with the chlorine curve. This seasonal movement is evident as a depression of the curves during the warm and low-water months, and as an elevation during the colder months of the flood period. As in Illinois and Spoon rivers, the plankton pulses in Quiver Lake of the warm period, in May and June, are attended by a temporary decrease in these nitrogenous substances. A still more marked *decrease* in both albuminoid ammonia and organic nitrogen attends the winter pulse of plankton in February, 1899, while that of the preceding December appears with an upward movement of the organic nitrogen and a downward one in the albuminoid ammonia. The correlation between the movement of albuminoid ammonia and organic nitrogen and of the plankton is thus in this instance (predominantly, at least) similar to that noted elsewhere in the warmer months. The very slight ripples in the plankton curve in July, August, and September attend minor *increases* in these nitrogenous substances, a feature noted elsewhere in colder months.

In Thompson's Lake (Pl. L.) the albuminoid ammonia, the organic nitrogen, and the plankton are all more abundant and exhibit greater fluctuations than they do in Quiver Lake. These conform in a general way to the tendencies noted in other localities. The amounts present during the colder months, October to May, are a trifle greater than in the intervening warmer period. There is also a temporary *decrease* in those nitrogenous matters attending plankton pulses in the *warm* months. This appears with the pulses of June, July, and

August-September, 1898. A temporary *increase* appears with plankton pulses in *cold* months, as in December-January and February, 1899. Some exceptions to these general tendencies appear here as in Quiver Lake; such, for example, as that in the low water of the autumn of 1897, when the great plankton pulse of October-November attends an unusual wave of both the albuminoid ammonia and the total organic nitrogen. Temporary decrease in the former appears with the crest of this plankton pulse, and again in the pulse of December, along with an *increase* in organic nitrogen. The spring maximum of April-May, 1898, comes with a rising wave of both substances, whose crest coincides with the fall in the plankton.

It is evident from the data here presented that the fluctuations in the volume of the plankton, as determined by the methods employed by us, show some intricate correlations with the changes in the quantity of albuminoid ammonia and organic nitrogen. The massing together of all organic matters, both living and dead, indigenous and adventitious, in the determination of these two substances, and the composite nature of the plankton itself, including both the synthetic phytoplanktonts, and the analytic zoöplanktonts, alike combine to conceal the relationship which exists between the succession of living forms in the plankton and the flux of nitrogenous matters in suspension and solution therein. Furthermore, the plankton is not the only assemblage of organisms concerned in this flux of matter; the bottom fauna, the fishes and other aquatic vertebrates, and aquatic fauna of the grosser sort, all share in effecting the changes here manifest.

We lack a common unit of measurement in terms of which we can express the values alike of the chemical analyses and of the volumetric and the statistical determinations of the plankton. Precise comparisons, for example, of the changes in the organic nitrogen with the cubic centimeters of plankton and the number of diatoms cannot be made. The *direction* of the changes in these several elements can, however, be noted, and its interpretation, in many cases at least, becomes probable, if not, indeed, certain.

In the first place it may be noted that the fluctuations of the plankton are not paralleled by proportionately great movements in the total nitrogenous substances in the water which enter largely into their composition. For example, the spring maximum of the plankton is accompanied by no such wave in these substances. Indeed, a slight ripple of depression seems to be the only concomitant fluctuation. Even granting a large margin because of the absence of a common unit of measurement, it remains apparent that the fluctuations of the substances in question and of the plankton are not *proportional*. A single illustration, found in the spring maximum in Quiver Lake in 1898 (Pl. XLIX.), will suffice to make this point clear. The following table, drawn from Table XIII., gives the amounts of plankton and of the several forms of nitrogen present before (April 19), during (May 3), and after (May 11) the plankton wave, and the extent of the change, in per cent., of the amount present on the 19th which each exhibits. The plankton rises from 1.03 cm.^{3} per m.^{3} to 42.14, falling subsequently to 4.70 and 1.97. This is an increase of 3991 per cent. No one of the nitrogenous substances in the table exhibits a change exceeding 100 per cent., and the average change is only 45 per cent. In this case the change in plankton is eighty-eight times as great as that in the average of all forms of nitrogen, assuming, of course, that the units of measurement are comparable.

QUIVER LAKE.

Date 1898	Free Ammonia	Albuminoid Ammonia	Organic Nitrogen	Nitrites	Nitrates	Plankton
April 19......	.046	.44	1.01	.033	.65	1.03
May 3.........	.092	.32	.82	.022	.35	42.14
May 11.......	.05	.48	.98	.015	.4	4.7
Per cent. of Change.						
April 19 to May 3......	+100	−27	−19	−33⅓	−46	+3991

Three causes may be assigned in explanation of the absence of proportional correlation in the flux of these nitrogenous substances and of the plankton, all of which are operative, but in varying effectiveness at different times and under different conditions.

In the first place, the plankton itself constitutes but a part of the total organic nitrogen; how small a one the data at hand do not determine. Barring out error arising from the death of the plankton and from the solution of the products of its decay which might take place during the interval between the collection and analysis of the sample, we find in the relative amounts of albuminoid ammonia and total organic nitrogen in solution and in suspension respectively some evidence as to the possible limits of the proportionate amount which the plankton and silt together form of the total nitrogenous substances. The average amount (Table X.) of albuminoid ammonia in solution and in suspension from July 6, 1897, to March 28, 1899, is .355 and .131 parts per million respectively. Plankton and silt together thus constitute about one third of the total albuminoid ammonia in the Illinois River. The relative amounts of dissolved and suspended albuminoid ammonia at the weekly intervals of analysis fluctuate according to access of flood waters and increase in the plankton. The former is the more potent factor. Usually the amount in suspension is from one third to one half that in solution, rarely equaling or surpassing it, as in the flood of February, 1898, when it rose to .4 as compared with .28 in solution. The plankton pulse of April-May, 1898, accompanies a rise in total albuminoid ammonia from .4 to .6—an increase of 50 per cent. The increase lies almost entirely in the suspended form, which rises from a previous level of .04 to .08, to .08 to .20, that is, it is more than doubled. The volumetric increase in the plankton is, however, over thirty-five-fold. Thus, under the most favorable conditions, receding flood, little silt, and plankton maximum, the increase in suspended albuminoid ammonia attending a thirty-five-fold increase in the plankton constitutes but 33 per cent. of the total amount present. During the long-extended periods of plankton minimum it is apparent that the plankton must constitute a very much smaller part of the total amount of albuminoid ammonia in the water.

That much of the albuminoid ammonia may be in the silt is shown especially in the table (Table XI.) and diagrams (Pl. XLVI. and XLVII.) of Spoon River at times of flood. In such waters there is practically no plankton—as will be shown else where from the examination of our plankton collections in that stream—although the amount of albuminoid ammonia is often very great.

The average amounts of total organic nitrogen (Table X.) in solution and in suspension during this same period are .69 and .34 parts per million respectively. The latter (.34), which represents plankton and silt, thus constitutes about one third of the total amount (1.03) of organic nitrogen in the water. The proportion of this fraction which the plankton may constitute under the most favorable conditions may be inferred from the increase in the suspended organic nitrogen which attends the spring pulse of 1898 (Pl. XL.). This rises from a previous level of .12–.16 parts per million to .24–.64, the latter with the decline of the plankton, and at its maximum (.64) it constitutes 46 per cent. of the total amount of organic nitrogen in the water. On May 3, when the plankton is at its maximum, the suspended organic nitrogen is but .24, or .25 per cent. of the total. During the periods of plankton minimum the proportion which the plankton forms of the total organic nitrogen must be very much less than at times of plankton maximum, since the amount in suspension shows no decrease at all proportional to the fall in the amount of plankton. Here also floods are quite as potent as plankton in causing marked increase in the amount of total organic nitrogen in suspension, as will be seen on comparison of the curves of this matter with the hydrographs on Plates XLIII.–L.

It is thus evident that the plankton does not form, even under most favorable conditions, any large part of the total organic nitrogen—certainly less than 50 per cent. and on the average much less than 33 per cent., which figures represent the total organic nitrogen, both plankton and silt, in suspension. The fluctuations of the organic nitrogen contained in the plankton are thus masked by the predominance of the dissolved form, and by the undetermined quantity of nitrogen-containing silt.

A second cause for the lack of proportional correlation between the movement in these nitrogenous substances and the plankton may lie in the utilization by the plankton itself of some forms of nitrogen included within the range of substances reported in the analyses as albuminoid ammonia and total organic nitrogen. For example, some organisms of the phytoplankton may utilize as food such forms of organic nitrogen in solution in the water as the amido-compounds and the humus acids. It may be that some of the animal wastes are turned into the more highly organized nitrogen of the phytoplankton without passing through complete oxidation and a return to the inorganic nitric acid and nitrates. If this be the case the flux of nitrogenous matters may lie quite within the range of substances here discussed, and the movements in nitrogen incident to these changes will consequently produce no pulses in the common curves of these substances. When, however, the inorganic nitrogen enters largely into the ebb and flow of the nitrogen of the plankton, the possibility of a correlated movement of plankton and organic nitrogen becomes apparent, though proportionate pulses in the two remain improbable so long as the organic but non-living nitrogen contributes also to the flux of matter involved in the plankton changes.

That the phytoplankton, as other low forms of vegetation, may thus utilize organic nitrogen in some of its forms as food, has been rendered probable by the experimental work of Loew ('96), Bokorny ('97), Maxwell ('96), and Zumstein ('99). The work of the latter is especially in point in this connection, since his experiments deal directly with a genus, *Euglena*, which furnishes a large part of our phytoplankton of midsummer and the bulk of the water-bloom. The experiments of this author have shown conclusively that this chlorophyll-bearing organism is usually autotrophic (holophytic) in the light and in the absence of abundant organic nitrogenous matters in solution, and under these conditions its chromatophores are a bright green. When organic nitrogenous matters in solution are abundant the organism becomes mixotrophic (half saprophytic) even in the light, and its chromatophores may become paler. In the dark it becomes colorless, and depends entirely (saprophytic) upon the dissolved *organic* nitrogen for its growth and multiplication.

The waters of the Illinois River and its backwaters are unusually turbid, thus excluding more than the usual amount of light. The plankton of this environment is rich in species and individuals of flagellates, algæ, and diatoms, many of which exhibit this tendency to become paler. This I have noticed repeatedly in the examination of the living plankton, and to some extent in material preserved in formalin-alcohol. It has occurred in the several species of *Euglena*, viz., *viridis*, *sanguinea*, *deses*, *acus*, *spirogyra*, and *gracilis*. I have noted it also to a very marked degree in *Chlamydomonas*, *Carteria*, *Trachelomonas*, and *Lepocinclis*. It has been less pronounced in the *Peridinidæ*, in *Mallomonas*, and *Dinobryon*. Among the diatoms the most striking instances occur among the typical limnetic forms, such as *Synedra*, *Melosira*, and *Asterionella*. In the light of Zumstein's results, and in view of the chemical data exhibiting an absence of proportional correlation between the movements of the organic nitrogen and the fluctuations in the volume of the plankton, and of the frequent occurrence in our waters of colorless individuals of chlorophyll-bearing species, it seems that we are justified in assuming that the flux of nitrogenous matter involved in the plankton changes lies to some appreciable and as yet undetermined extent within the range of substances included within the dissolved and suspended nitrogenous matter of the water.

A third reason for the absence of proportional correlation between the movements of the organic nitrogen and the fluctuations of the plankton lies in the cumulative nature of the latter as contrasted with the non-cumulative character of changes in the chemical substances at whose expense it increases. Growth and reproduction of organisms is fundamental in the plankton pulses, and there is nothing comparable to either of these in the chemical changes of non-living matter.

It remains only to discuss the correlations that do appear between the albuminoid ammonia and total organic nitrogen, on the one hand, and the plankton, on the other. The two diverse tendencies noted in the preceding pages, the one for the plankton pulses of warm months to coincide with a decrease in these nitrogenous matters, and the other for the pulses of cold months to coincide with an increase in these substances, or at least in the organic nitrogen, will be fully accounted for only when the changes in the different elements included under these common designations, the dissolved portion, the silt, and the plankton, shall be differentiated, and when the changes in the different kinds of organic nitrogen shall be separately unraveled, and, furthermore, when the fluctuations of the synthetic (phytoplankton) and analytic (zoöplankton) portions of the plankton can be separately expressed in terms of a common unit. It is evident that the available chemical analyses and volumetric and statistical determinations of the plankton do not afford such comprehensive data. The incomplete data at hand throw some light, however, upon the nature of the correlation, and suggest the probable explanation for the two divergent tendencies noted and the numerous exceptions thereto.

As has been previously shown, plankton pulses are usually coincident, or nearly so, with an upward or a downward movement in the nitrogenous substances, organic and inorganic. The upward movements of the albuminoid ammonia and organic nitrogen and the downward movement in the nitrates occur most frequently when the diatoms are most rapidly multiplying. As will be shown later, these seasons occur in the colder months, and often precede the summer pulses of plankton whose crests are predominantly of the animal plankton. The upward movement of the organic nitrogen and the downward movement of nitrates is thus due in large part to the synthetic action of these organisms. The major plankton pulses, which are as a rule predominantly animal in their composition, usually occur in the warmer months With their culmination there is always a great decrease in their food supply (the phytoplankton) and analytic processes thus predominate, and the decay of the products of animal metabolism results in a decrease in the total organic nitrogen and leads to a recovery of the nitrates. This interplay of the synthetic and analytic processes of the phyto- and zoöplankton, is, I believe, the basis of the coincidence in the fluctuations of the plankton and of the nitrogenous contents of the water. Further reference will be made to the subject, and data illustrating it will be cited in connection with the discussion of the seasonal changes of the plankton.

The seasonal changes in *free ammonia* seem to be due to the effect of floods and temperature upon the processes of decay, and reveal but minor correlations with plankton changes. A marked increase with rising flood waters is apparent in Spoon River (Pl. XLVI. and XLVII.) and occasionally in the Illinois, as, for example, in February, 1896 (Pl. XLIII.). Prolonged high water, on the other hand, tends to lower the free ammonia (Pl. XLIV.). The stagnation in the sewage-laden river when it is covered with ice at low-water stages appears in the elevenfold increase in free ammonia under the ice in December, 1897 (Pl. XLIV.). The fluctuations are also much more marked in the rivers (Pl. XLIII.–XLVII.) than in the lakes (Pl. XLVIII.–L.), owing to the diminished and equalized effects of flood and sewage in the reservoir backwaters. There are repeated instances where the plankton pulses coincide with decreases in the free ammonia followed by a recovery upon the decline of the plankton. Illustrations of this may be seen in the April-May pulse in Thompson's Lake (Pl. L.), where a decline of fifty per cent. accompanies a ninefold increase in the plankton. The April pulse of 1896 in the Illinois (Pl. XLIII.) coincides with a still more pronounced decline in the free ammonia. Upward movement of both plankton and free ammonia appears occasionally, as in the Illinois in September, 1897 (Pl. XLIV.), though a downward movement of the free ammonia attends the plankton pulse of the subsequent month. The free ammonia thus exhibits some evidence that it enters into the flux of nitrogenous matter involved in the rise and fall of the plankton. It decreases when the synthetic activities predominate in the plankton, and some, at least, of its increases coincide with periods of predominantly animal (analytic) plankton.

The changes in the *oxygen consumed* coincide very nearly with those in the organic nitrogen and albuminoid ammonia both in direction and amount, and thus bear much the same relation to the plankton changes.

The changes in the *chlorine* are of especial interest, not because of their direct relation to the plankton, but on account of the fact that they indicate, perhaps better than any other element in the analysis, the relative contamination by and concentration of the sewage in the different localities at different seasons of the year.

In the Illinois River (Pl. XLIII.–XLV.) the chlorine usually fluctuates in a direction opposite to that of the hydrograph, running low during high water and rising with the return of low water. Some exceptions appear, as in the rising flood of December, 1895, and the declining flood of June, 1896, the former apparently due to the flushing of sewers by initial flood water, and the latter to an irregularity for which no natural cause appears. The marked irregularity of the chlorine in the Illinois, indicating a corresponding instability in access of sewage, with its additions of matter helpful or deleterious to the plankton, adds to the environment of the potamoplankton a further factor of uncertainty not present, to a like degree at least, in the reservoir waters of the lake.

That natural waters in this locality are not subject to the presence of chlorine (sewage) in such excess or in such fluctuating amounts appears on contrast of the chlorine curves of Spoon River (Pl. XLVI. and XLVII.) with those of the Illinois (Pl. XLIII.–XLV.). In the former, barring a few instances of apparent contamination by river water (October, 1897, January and February, 1899), the chlorine runs uniformly low throughout the year, dropping but a trifle with rising floods.

In Quiver Lake (Pl. XLVIII. and XLIX.) the chlorine similarly runs low during the period of individuality of the lake, that is, of low water. The increase in chlorine comes only at times of invasion of flood water from the river or the bottom-lands above, as, for example, in November and December, 1898 (Pl. XLIX.). The periods of fertilization of this lake by sewage thus depend upon floods, and occur at times of greatest dilution.

In Thompson's Lake (Pl. L.) the chlorine (sewage) content exhibits the same general tendencies found in the river, from which its water supply is derived. The chlorine content runs high during low water and drops with the rise of the flood. The abrupt and numerous fluctuations of the chlorine of the river do not, however, appear in the lake, being diminished and equalized by its greater permanency. Even under these favorable conditions it is difficult to find any constant or well-defined correlation between the chlorine pulses and those of the plankton. It may be that the fertilizing elements of the sewage which the chlorine is regarded as representing have already been exhausted, so that the chlorine curve no longer represents a commensurate fluctuation in the fertility. In a few cases, as, for example, in December, 1897, and in January and September, 1898 (Pl. L.), a slight correlation in the chlorine and plankton curves appears, though the only relation between the two may lie in the effect of changing river levels upon both, a declining flood (as in September) concentrating the sewage and at the same time favoring the development of the plankton.

That the sewage of Chicago is quite thoroughly rotted out before it enters the Illinois at La Salle, and that the contributions from Peoria are also well advanced in decay before they reach Havana have been demonstrated by the chemical and bacteriological examinations made at the instigation of the Sanitary District of Chicago *apropos* to the opening of the drainage canal. The full results of this work have not as yet been published, but from the data published by Prof. A. W. Palmer ('97) from the analyses of the Chemical Survey and from the preliminary report of Jordan ('00) upon the bacteriological examination it is evident that the nitrogenous matters of the Chicago sewage were in process of rapid oxidation in the upper reaches of the Illinois and Michigan canal near Lockport; that this process was largely completed before the canal waters entered the river at La Salle; and that the Peoria pulse of sewage is, during the summer months at least, well decayed before it reaches Havana, though in colder weather, when decay is less rapid, the sewage is not so well oxidized and the bacteria are more abundant than during the summer at this point. The following table, which has been made up from the averages in Palmer, '97, exhibits to some extent these facts in tabular form. The increase in nitrates and decrease in free ammonia unite in indicating the extent to which decay has progressed.

Station.	Miles below Chicago.	Total residue on evaporation.	Total loss on ignition	Chlorine	Free Ammonia	Albuminoid Ammonia.	Total Organic Nitrogen	Nitrites	Nitrates
Lockport	29	438.6	20.5	24.	.092	.417	.84	.019	.95
Morris.	57	359.4	23.4	29.7	3.55	.709	1.44	.149	1.72
La Salle.	95	372.3	23.03	19.6	.971	.612	1.26	.255	2.51
Peoria.	158	376.7	21.	41.8	.252	.516	1.06	.209	2.59
Havana.	199	355.3	21.2	15.4	.63	.455	1.06	.135	2.35
Kampsville*	288	352.1	22.4	13.4	.261	.508	1.17	.062	1.39

*Average July 23—Dec. 29, 1896.

The influence of the sewage of Peoria upon conditions at Havana, owing to temperature changes, is not uniform throughout the year, and it may be that some of the seasonal fluctuations in the chemical substances which have been discussed in the preceding pages, and some of those in the plankton also, depend in some measure upon this changing effect of temperature upon the sewage.

The following table, taken from Jordan ('00), gives the seasonal changes in numbers of colonies of bacteria from May 30, 1899, till the end of the year at Havana, and at Pekin, thirty-two miles above. The decline from the larger numbers in June to a fairly well-maintained minimum during midsummer at Havana is very evident, as is also the rise as the temperature lowers in the autumn. Both the period of time and the

BACTERIOLOGICAL EXAMINATION OF ILLINOIS RIVER AT HAVANA.

Date 1899	Chlorine (pts. per million)	Stage of river, in feet	Temperature of water, C.	No. of colonies per cm^3.	
				Havana	Pekin
May 30......	13.6	8.7	21	4,500	542,000
June 6......	13.	9.3	26	18,450	129,000
13......	13.5	8.8	25	15,900	205,000
20......	12.1	7.5	26	2,500	225,000 (1)
28......	14.9	5.2	25	4,500	2,030,000 (2)
July 5......	14.7	4.7	26	2,400	52,000 (3)
12......	23.	4.1	26	7,300	1,435,000
19......	36.	4.9	27	5,700	470,000 (4)
26......	31.	4.8	30	850	980,000 (5)
Aug. 9......	27.5	4.1	26	1,550	985,000 (6)
23......	34.	3.	26	900	10,000 (7)
30......	39.	2.2	29	9,800	30,000 (8)
Sept. 6......	40.	2.4	29	1,900	650,000 (9)
14......	46.	2.5	22	1,500	310,000 (10)
20......	35.	3.5	14	3,400	240,000 (11)
27......	49.	3.	16	3,700	120,000 (12)
Oct. 4......	52.	3.	14.5	2,500	500,000 (13)
11......	59.	3.2	16.	6,600	430,000 (14)
18......	58.	3.2	17.	8,800	———
25......	60.5	3.	12.	3,900	30,000 (15)
Nov. 1......	63.	3.5	9.	7,000	150,000 (16)
15......	51.	3.7	10.	3,300	30,000
22......	47.5	4.4	11.	128,000	1,650,000
29......	43.	4.	6.	41,600	380,000 (17)
Dec. 6......	35.	3.1	2.	85,000	140,000 (18)
20......	35	4.8	1.	66,800	5,000

(1) June 21. (2) June 27. (3) July 6. (4) July 18. (5) July 25. (6) Aug. 8. (7) Aug. 22. (8) Aug. 29. (9) Sept. 5. (10) Sept. 12. (11) Sept. 18. (12) Sept. 26. (13) Oct. 3. (14) Oct. 10. (15) Oct. 31. (16) Nov. 7. (17) Nov. 30. (18) Dec. 5.

reach of the river in which the bacterial action and attendant decay of the sewage ensues, are lengthened as the temperature falls, and we find in consequence an increase in the bacteria in the river water passing Havana which approximates fortyfold. The pulse in bacteria due to the sewage of Peoria which is found at Pekin during the summer, reaches Havana also, thirty-two miles below, as temperatures fall in the autumn.

The averages of the number of colonies of bacteria found in the canal and river water at points from Bridgeport to Grafton during the period of analyses given in the first table are to be found in the following table, also taken from Jordan ('00).

CHLORINE AND BACTERIA—DES PLAINES AND ILLINOIS RIVERS, BRIDGEPORT TO GRAFTON.

Collecting Stations	Distance from Bridgeport, in miles	Chlorine (pts. per million)	Number of colonies per $cm.^8$
Bridgeport	0	119.2	1,245,000
Lockport	29	117.4	650,000
Joliet	33	104.8	486,000
Morris	57	68.1	439,000
Ottawa	81	58.5	27,400
La Salle	95	46.1	16,300
Henry	123	44.2	11,200
Averyville	159	40.9	3,660
Wesley City	165	40.9	758,000
Pekin	175	38.4	492,600
Havana	199	36.2	16,800
Beardstown	231	29.3	14,000
Kampsville	288	22.9	4,800
Grafton	319	18.3	10,200

The chlorine content at the several points also appears in the table, and exhibits a steady decline from Chicago to the Mississippi River with a brief pause at Peoria. This decline expresses approximately the dilution which on an average the sewage undergoes during the low-water period. The flood season of the spring was not included in the period of analysis. From Ottawa to the mouth of the Illinois, as indicated by the chlorine, this dilution is about one third.

The decrease in number of bacteria, while it may not coincide strictly with the completion of processes of decay still gives in general a suggestive index to the extent to which oxidation of the sewage has proceeded.

When the facts of both tables are taken into consideration it becomes evident that the sewage of Chicago has been thoroughly decayed, and its fertilizing capacity presumably to some considerable extent utilized in the development of the plankton, before the water reaches Havana. The sewage of Peoria likewise, during the summer months, is well oxidized by the time the sluggish current of low water brings it to Havana, thus adding new resources for the increase or rehabilitation of the plankton. During the colder months the process of decay is not so fully completed owing to the lowering of the temperature and the increased current attending the higher water which often prevails at that season. In the winter the initial effect of the sewage upon the plankton may be witnessed, partially at least, at Havana. At all seasons the plankton of the channel waters passing Havana is the resultant of two succeeding pulses of fertilizing additions to the normal constituents of stream waters. It represents during the warmer months predominantly the later phases of the cycles of organisms, which multiply and succeed each other with considerable rapidity after the enrichment of the water. In this important particular the plankton at this point in the stream differs from that of the lake, where the whole sequence of changes may be accomplished in one locality. The fact that a relatively small proportion of the tributary waters enters the stream between La Salle and Havana makes it possible for these chemical changes to take place, and for the plankton cycles to run their courses with less interruption and disturbance than in other parts of the stream.

The enrichment of the Illinois River and its backwaters by the sewage of Chicago and Peoria has been utilized thus to some considerable extent before the waters reach Havana. The chemical products of its oxidation have been converted into aquatic vegetation and phytoplankton, and some of the latter in turn into zoöplankton. The development of new cycles of limnetic organisms at this middle reach of the river comes accordingly to depend to a great extent, not upon the primary contributions of the sewage, but upon secondary or even later conversions of the nitrogenous matters originally contributed. The decay of the vegetation of the backwaters and bottom-lands, and the wastes and decay of the plankton itself and of the other organisms dependent upon it, come to be to a greater extent the immediate sources of support of the locally developed plankton.

COMPLETE MINERAL ANALYSES.

Three complete mineral analyses of the water of the Illinois River have been made by the Chemical Survey under the direction of Professor Palmer, the samples for which were collected by us at Havana. These appear in the accompanying table.

ANALYSES OF MINERAL MATTERS CONTAINED IN SAMPLES COLLECTED FROM ILLINOIS RIVER AT HAVANA, ILLINOIS. PARTS PER MILLION.

		Nov. 1 and 2, 1897	Oct. 31 and Nov. 1, 1898	June 15, 1900
Lithia		0.0	trace	0.0
Potassium phosphate	K_3PO_4	0.0	2.4	0.0
Potassium nitrate	KNO_3	5.05	2.4	6.
Potassium nitrite	KNO_2	6.06	0.0	0.0
Potassium chloride	KCl	3.72	4.4	2.2
Sodium chloride	$NaCl$	100.85	44.2	21.4
Sodium sulphate	Na_2SO_4	17.72	27.5	20.1
Ammonium sulphate	$(NH_4)_2SO_4$	6.21	10.2	2.2
Magnesium sulphate	$MgSO_4$	31.02	33.4	35.5
Magnesium carbonate	$MgCO_3$	74.01	77.3	69.7
Calcium carbonate	$CaCO_3$	137.79	150.3	267.5
Iron carbonate	$FeCO_3$	3.2	.3	6.6
Alumina	Al_2O_3	8.95	1.7	7.
Manganese oxide	MnO_2	0.0	0.0	0.7
Silica	SiO_2	26.07	31.6	27.6
Total		420.65	385.7	466.5

The analysis in 1897 was made in a period of prolonged low water, the effect of which appears in the large amount of sodium chloride, indicating the concentration of sewage, while the presence of potassium nitrite suggests the active decay of sewage or the products of animal metabolism, such as might occur with the abundant plankton of that autumn (Pl. XII.). The analysis of 1898 was made toward the close of a considerable rise, and it shows the effects of dilution of sewage in the lessened sodium chloride. The analysis of 1900 was made in a high-water period, and exhibits even a greater dilution of sewage, as shown in the chlorine and ammonia salts. These analyses indicate an abundance of all the salts upon which plant life depends for its growth, and complete the demonstration of a chemical basis for the development in abundant phytoplankton.

COMPARISONS WITH OTHER STREAMS.

So far as I am aware this is the only instance in which opportunity has been offered for a comparison of the chemical conditions in stream waters and the plankton fluctuations coincident with them. Steuer ('01), who worked upon the plankton of the Danube, near Vienna, in 1898–99, cites averages of chemical analyses made in 1878. These analyses indicate that the Danube at that time was barren in comparison with the Illinois River. The average organic matter in solution as shown by the oxygen consumed was only 5.6 parts per million in the Danube to 43.4 (in 1898) in the Illinois River, while the chlorine was but 2.4 to 12.40. The conditions of analysis differ, so that the nitrogen content of the two streams cannot be compared, though the indications are that the nitrogen compounds are low in the Danube as compared with the Illinois River. The silica and carbonates are also lower in the former than in the latter stream. The poverty of the plankton of the Danube which Steuer describes, seems thus to be correlated with a deficient food supply, and the rich plankton of the Illinois with a more abundant one.

In general terms, a chemical analysis of stream and lake waters throws some light on the productive *capacity* of the water. This appears in a comparison of the chemical conditions and plankton production of Quiver and Thompson's lakes.

With less nitrogen we may expect to find less plankton. The contrast of Illinois and Spoon rivers shows the same tendency, though the difference in the chemical conditions in the streams is less than that in the lakes, while the contrast in plankton production is much greater. Likewise in seasonal changes, the greatest developments of the plankton—the spring maxima—appear at the close of a period of high nitrogen content.

On the other hand, precise comparisons and correlations cannot be maintained, in part because of the operation of other factors,—such as temperature and vegetation,—and in part because of the fundamental difference between chemical and biological phenomena. The fertility of a body of water must be judged, not by chemical analyses only, but in conjunction with other phenomena which condition growth and reproduction. It is also evident that isolated chemical analyses throw as little light upon the fertility of a body of water as isolated plankton examinations do upon its productiveness. The routine of seasonal changes must be discovered in both before trustworthy data for estimation of fertility can be obtained.

VEGETATION.

The aquatic environment at Havana impresses the visiting biologist who for the first time traverses its river, lakes, and marshes, as one of exceedingly abundant vegetation, indeed almost tropic in its luxuriance. The aquatic flora of the ponds, lakes, and streams of New England, of the Middle States, and of the north central region is, as a rule, but sparse in comparison with that which here constantly meets his eyes. He will note the entire absence of beds of *Chara* and patches of *Nitella*, and will find the *Potamogetons* fewer both in species and numbers. The shore-loving *Juncaceæ*, *Cyperaceæ*, and *Equisetums* are also less in evidence, for here the shore itself is a shifting region, lacking the permanence which these plants demand. On the other hand he will find acres upon acres of "moss," as the fishermen call it—a dense mat of mingled *Ceratophyllum* and *Elodea* choking many of the lakes from shore to shore, and rendering travel by boat a tedious and laborious process. Beds of lotus (*Nelumbo lutea*) and patches of *Azolla* will suggest warmer climes, while the fields of rushes (*Scirpus fluviatilis*), and patches of water-lilies (*Nymphæa reniformis*), arrowleaf (*Sagittaria variabilis*), and pickerel-weed (*Pontederia cordata*) will recall familiar scenes in northern waters. The carpets of *Lemnaceæ* will be surprising, and the gigantic growths of the semiaquatic *Polygonums* will furnish evidence of the fertility of their environment.

Both the nature and the quantity of the vegetation varies in the different localities whose plankton has been the subject of investigation by us, and in the same locality the conditions may change at different seasons and from year to year, low water in the early summer favoring its growth, and summer floods and fishermen's seines uprooting and sweeping it away.

The following list includes only the most common and most important members of the aquatic flora, with brief notes on their habitat and frequency.

Ranunculus multifidus Pursh. Found occasionally in quiet waters in shoal regions with soft alluvial bottom.

Caltha palustris L. Rare, along springy shores.

Nelumbo lutea Pers. Forming large patches in the more open vegetation in the permanent backwaters on very soft alluvial bottom. Usually at some distance from shore and in quiet waters.

Nymphæa reniformis D. C. Common in the more open regions of the permanent backwaters in quiet regions, and along channels on alluvial bottom.

Cardamine rhomboidea D. C. Rare, along springy margins.

Cardamine hirsuta L. Occasional, along alluvial margins.

Nasturtium sessiliflorum Nutt. Rare, along wet sandy margins.

Nasturtium palustre D. C. Common, in shallow water along alluvial shores.

Proserpinaca palustris L. Rare, along shady shores permanently fed by springs.

Angelica atropurpurea L. Occasional, along margins.

Sium cicutæfolium Gmelin. Occasional, in swamp margins near bluffs on alluvial bottoms.

Cicuta maculata L. Common, in places with the preceding.

Cicuta bulbifera L. Occasional in margins of swamps.

Utricularia vulgaris L. Rare in quiet backwaters, in the more open places with alluvial ooze and underlying sand and springs.

Polygonum amphibium L. Common in shoal water, in places, in the flooded bottoms and along margins of permanent backwaters. Habitat usually dry at low water. Stems often attaining a length of fifteen to twenty feet.

Ceratophyllum demersum L. Abundant everywhere in shoal and deeper waters, often above low-water levels, and at times even encroaching upon channels where currents are maintained. It grows in patches and dense masses, sometimes choking the smaller lakes from shore to shore. It occurs usually on bottom of soft alluvium, which in some places forms but a thin film above the hard sand beneath. It reaches the surface in early summer, and grows throughout the warm season unless swept away by floods or seines. These agencies, combined with wind and decay, remove much of the summer's growth in the autumn. Large areas of bottom growth survive the accidents of the colder season and, together with the detached terminal buds, provide for the rapid recovery of the water meadows of *Ceratophyllum* in the following spring. Though essentially an immersed floating plant, this species has its lower stems fixed in the soft ooze of the bottom upon which they rest, and it thus becomes almost as firmly "rooted" as do the *Potamogetons* and similar plants. This species constitutes the greater mass of the aquatic vegetation of the larger impounding and permanent backwaters. It is known in local parlance as "moss," though this designation is not always confined to this plant. No true aquatic mosses have been found in this bottom-land region. This *Ceratophyllum* forms by far the greater part of the aquatic vegetation in this locality.

Elodea canadensis Michx. Common on alluvial bottom with *Ceratophyllum*, especially in quiet waters, but not reaching the surface so generally. It is widely distributed and is next in abundance to the preceding species, though forming a very much smaller proportion of the total vegetation.

Vallisneria spiralis L. Rare; found only in channels with currents, as at the mouth of Quiver Creek.

Pontederia cordata L. Common along open places, such as the channels at the head of Quiver Lake and the outlet of Flag Lake, on both alluvial and sandy bottoms.

Heteranthera graminea Vahl. Creeping along margins of lakes and the river, usually on alluvium.

Juncus acuminatus Michx. Common in shoal water along sandy shores.

Typha latifolia L. Occasional patches found in the swamps and sloughs of the permanent backwaters.

Sparganium eurycarpum Engelm. Frequent in the margins of lakes and sloughs along channels on sandy and alluvial bottoms.

Spirodela polyrrhiza Schleid. Everywhere in quiet waters, forming in places dense mats upon the surface. Often drifted by wind or current in great windrows along shore. Very common in open water, usually but not always on the surface. Often taken in the plankton with other species of the family.

Lemna trisulca L. Locally abundant in the more open vegetation of the backwaters in quiet bays and nooks in both surface and deeper waters. Not generally distributed, and less abundant than other members of the family.

Lemna minor L. Associated with *Spirodela* but much less abundant.

Wolffia columbiana Karsten. In surface and deeper waters in both river and backwaters among vegetation and in open water. Frequently taken in the plankton.

Wolffia braziliensis Weddell. With the preceding but less abundant.*

Sagittaria variabilis Engelm. Abundant in shallow water along margins of lakes and swamps and in protected nooks along the river. On both alluvial and sandy bottoms, and often forming well-defined belts of vegetation.

Triglochin palustris L. Occasionally found in marshes on alluvium.

Potamogeton natans L. Widely distributed along margins of lakes, sloughs, and the river, in both quiet and flowing water, often occupying the open spaces in the littoral vegetation and among *Ceratophyllum* and *Elodea.*

Potamogeton pusillus L. Rare, in open water of larger lakes.

Potamogeton pectinatus L. Rare, in lakes and in river near channels where there is considerable current.

Naias flexilis var. *robusta* Morong. Frequent along shores of lakes and river in shallow water on alluvium.

Dulichium spathaceum Pers. Occasionally found along alluvial shores of quiet backwaters.

Eleocharis palustris R. Br. Very common, forming patches of considerable extent along low sandy shores and in the margins of swamps.

Eleocharis intermedia Schultes. Occasional in the margins of lakes and swamps.

Eleocharis tenuis Schultes. In shallow water in margins of swamps. Not common.

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*According to some criteria all of our representatives of the *Lemnaceæ* might be considered as part of the plankton. This is especially true of *Wolffia*, which is found in open water at all levels. Wind and current have much to do with its distribution, but, it has, nevertheless, a limnetic habit, comparable with that of many organisms of the plankton. Its general distribution and its small size afford further reason for regarding it as a part of the plankton of our locality. It was therefore not removed before measurement of the plankton. There are but few instances in our collections where it becomes a disturbing factor by reason of its predominance. The other members of the family are much larger and are more irregular in their distribution, and thus tend to distort the quantitative relations of the more typical plankton. For these practical reasons it seemed best to remove all specimens of these species from our catches before measurement.

Eleocharis acicularis R. Br. Common in shallow water on alluvial and sandy bottoms.

Scirpus pungens Vahl. Common along sandy margins.

Scirpus lacustris L. Lake and swamp margins; common on both sandy and alluvial bottom.

Scirpus smithii Gray. Occasional along sandy shores.

Scirpus fluviatilis Gray. Very abundant in bottom-land swamps on alluvial bottom. Forming great tracts, to the exclusion of other plants, and contributing largely to the decaying vegetation of the backwaters.

Scirpus atrovirens Muhl. Common, in marshy borders.

Rhynchospora alba Vahl. Rare, along sandy margins of backwaters in shallow water.

Zizania aquatica L. Forming meadows of considerable extent in margins of lakes and more open swamps in the backwaters.

Equisetum limosum L. Sparingly present along springy margins of sandy shores.

Azolla caroliniana Willd. This brilliant little cryptogam is locally abundant in warm sheltered regions of the backwaters in early summer. It is found principally in the dense mats of drifted *Spirodela*, where it forms bright red rosettes, the clusters sometimes forming an area several square feet in extent.

The filamentous algæ, principally *Spirogyra* and *Zygnema*, becomes very abundant in shallow waters in spring and early summer as the bottom-lands emerge from the receding flood. As the shores of the more permanent bodies of water are left bare, there remains upon them, half supported by the semi-aquatic vegetation, a thick felted mat of fading green, the strength and consistency of which are sufficient to justify the local name of "blanket moss." Its rapid decay in warm shallow water contributes immediately to the support of the plankton.

VEGETATION AT THE SEVERAL STATIONS.

Illinois River (Station E).—The following statements concerning the vegetation of the river are based upon many observations about Havana, and upon the conditions observed during a trip made in May, 1899, by the courtesy of the Illinois State Fish Commission, upon the steamer "Reindeer," from the mouth, at Grafton, to Hennepin, 211 miles above. As a rule, the river is quite free from vegetation. There is, to be sure, in the upper part of Peoria Lake, which is merely an expanse of the river (Pl. I.), an extensive area which is permanently occupied by aquatic plants. A similar expansion known as Havana Lake (Pl. II.) is also at times abundantly supplied with vegetation in its shoaler and quieter portions. There are also springy shores, usually of gravel or sand, located where the channel encroaches upon a bluff upon which a permanent littoral vegetation is maintained regardless of river levels. Generally, however, the water reaches the steep or sloping bank of black alluvium without any fringe of green. There are scattered *Lemnaceæ*—principally *Spirodela polyrrhiza* and *Lemna minor*, with *Wolffia braziliensis* and *columbiana*—floating with the current from spring till late in the fall. Patches of "moss" consisting of *Ceratophyllum demersum* are also floated into the channel from flooded backwaters, or loosened by fishermen's seines and then carried by the current from backwaters or the shores of the river into the channel. On some protected shores where the current is slight the arrowleaf (*Sagittaria variabilis*) maintains a foothold—as on the east shore, just above the "towhead" (Pl. II.). A small patch of *Potamogeton pectinatus* also remains year after year in the river in the rapid currents that rush through Quiver cut-off (Pl. II.). Such instances of permanent vegetation are, however, of rare occurrence, and form but insignificant factors in the immediate environment of the river plankton.

A temporary fringe of vegetation has appeared along the river margins when relatively low-water stages prevailed in the spring and were maintained without marked floods until summer, as in 1894 and 1895. This littoral growth is not composed, however, of the permanent littoral flora, such as the arrowleaf, the *Polygonums*, and the rushes, but is like that found in deeper and more permanent backwaters. It consists, in the main, of *Ceratophyllum* with some *Naias* and *Elodea*. Scattered sprays of *Potamogeton natans* lie in the more open places, and the *Lemnaceæ* multiply in the more sheltered nooks, while the yellow-flowered *Heteranthera* abounds at the water's edge and creeps out upon the black mud at the margin. This fringe of vegetation continues until it is stranded on the shore by the recession of the water, washed away by sudden floods which lift it from its slight foothold upon the unstable bottom, or pulled out upon shore or floated down stream by fishermen's seines. Thus, of the heavy fringe present in June, 1895, only a trace was left by September of that year. In the four years following, the river levels were such that no vegetation of consequence appeared along the shores of the river at any season of the year.

Even at the time of its maximum development this littoral belt of vegetation did not often exceed ten meters in width. It is thus a relatively small, as well as an inconstant, factor in the environment of the plankton of the river itself. The current carries the plankton-laden water through its tangled growth, and sessile animals, such as *Hydra* and the *Bryozoa*, find in it an abundant food supply. These and other organisms which find a retreat in the shelter of the vegetation are from time to time carried into the channel by the current and serve to diversify the plankton. On still, warm days *Hydra* habitually abandons its sessile mode of life and adopts a limnetic habit, often attaching itself to the surface film of water.

Owing to the changes in levels and to other reasons above cited the vegetation of the river, where it occurs, does not continue until autumn, and is absent during the ice blockade of the winter. In this respect the river environment is in strong contrast with that of most of the backwaters, in which the vegetation, though reduced, persists throughout this period. This absence of winter vegetation in the river is one of the conditions favoring the stagnation which sometimes occurs, as in 1895, in the Illinois.

Spoon River (Station M).—Spoon River, throughout the bottom-land region at least, is free from vegetation—a condition which prevails throughout the greater part of our prairie streams.

Quiver Lake (Station C). Pl. XV.–XVII.—The vegetation is a very important and much more constant factor in the environment of Quiver Lake than it is in that of the river. In its maximum development reached in the summers of 1894 and 1895 it fills (Pl. XV.) the lake from shore to shore with a closely matted growth, the only open places being an interrupted and tortuous channel through which the waters of Quiver Creek (Pl. II.) make their way to the river. The vegetation in the body of the lake consists in the main of *Ceratophyllum*, with an admixture of *Elodea* and *Potamogeton* toward the margins. Along the eastern shore, and toward the upper end of the lake where springy shores and sandy bottom are to be found, the vegetation partakes more of the permanent littoral character. Here rushes, sedges, arrowleaf, and the aquatic *Cruciferæ* and *Umbelliferæ* appear among the *Potamogetons* and other floating plants. In the northern area, especially along its western shore, where more alluvium is found, water-lilies, pickerel-weed, and the lotus abound, and the *Potamogetons* are more abundant (Pl. XVII). The "wild celery" (*Vallisneria spiralis*) is sparingly present in the channel of the eastern arm of the lake, while in the tributary bottom-lands above are aquatic meadows of wild rice and other water-loving grasses, rushes, and sedges.

In years of higher water (Pl. XVI.), such as the four following 1895, the vegetation differs from that of low-water years more in quantity than in kind. The main body of the lake and a considerable portion of both arms are freed to a greater or less extent from their vegetation, a border of varying width remaining near the shores, and scattered clumps dotting the lake here and there in the broad stretches of open water.

Dogfish Lake (Station L). Pl. XVIII.—This lake shares the flora of Quiver Lake, of which it is but the northwestern arm. Its vegetation is somewhat denser, having no channels traversing its matted growth. A fringe of marsh flora along its northeastern border and the encroachments of the semiaquatic bottom-land plants but slightly vary the uniformity of the vegetation, which at low-water stages fills the greater part of the lake.

In such lakes as Dogfish and Quiver the vegetation by reason of its predominance exerts a profound influence upon the quantity and the constitution of the plankton. Its fluctuations in quantity with the change of the seasons and the invasion of flood water are attended by marked readjustments of the plankton.

Phelps Lake (Station F). Pl. XXI.—Phelps Lake was practically free from vegetation throughout the period of our plankton collections. The drying up of the lake in 1894 and its cultivation in 1895 destroyed whatever foothold the aquatic vegetation had obtained. In the following years the ingress of the aquatic flora become increasingly evident, though the alluvium in the bed of the lake, hardened by the drouth, gave but scant foothold to marsh-loving plants, especially to the perennial species or to those with well-developed roots. Each spring saw here a remarkable development of "blanket moss," a mat of algæ, principally *Spirogyra*, *Zygnema*, and *Cladophora*. In the period of midsummer stagnation a dark green film of *Oscillaria* coated the bottom or rose to the surface in scattered masses. The fringe of button-bush (*Cephalanthus occidentalis*) and willows (*Salix nigra* and *S. longifolia*) at the edge of the surrounding forest gave shelter to a few semiaquatic *Compositæ* and rushes, and beyond these there were scattered clumps of *Potamogeton natans* and *Nais flexilis* var. *robusta*, which found a place even in the first year in which the water reentered the lake. In 1899 the margin occupied by these plants had increased in width, and arrowleaf and lotus were represented by a few isolated plants, while the ubiquitous *Ceratophyllum* had made its first appearance in the lake. Aside from the algæ, the aquatic flora formed but a small part of the environment of the plankton in this body of water.

Thompson's Lake (Station G). Pl. XX.—This lake combines in one area almost the whole range in the development of the aquatic flora characteristic of the backwaters of the Illinois River bottoms. The regions occupied by aquatic vegetation (Pl. II.) are of considerable extent even at low-water stages, and increase rapidly in area at higher river levels. The diversity of the aquatic flora is most pronounced at the moderate stages of water (3 to 6 feet above low water) which often prevail after the decline of the spring flood during early summer.

A characteristic littoral flora is found along the firm sandy margin of the eastern side, and on a few points of similar soil which project from the western bluffs to the lake. *Juncaceæ* and the shore-loving grasses and sedges abound here, and as the shores emerge the bottom-land *Compositæ* and *Polygonums* encroach upon their domain. In other regions the slope is more gradual and the shore line, as the water recedes, moves over wide stretches of alluvial soil, often of slight consistency, to a considerable depth. Here the vegetation is more luxuriant, and *Polygonum amphibium*, the arrowleaf, and the water-lily vie with the big river rush (*Scirpus fluviatilis*) for a foothold in these regions, exposed only at lowest levels and never baked hard by the midsummer's drouth.

At higher levels is found a varied mixture of semiaquatic and upland genera, such as *Lippia*, *Bidens*, and *Polygonum*, with coarse grasses and sedges. Inside of this varied littoral zone is found a permanent flora of almost equal diversity. Along sandy shores we find a belt of more or less open vegetation consisting largely of *Potamogeton natans*, *Elodea*, *Nais*, and a few *Juncaceæ*, with scattered lilies and lotus. At the southern end of the lake there is an area over a mile in length occupied mainly by *Scirpus lacustris*, great beds of lotus and water-lily, and mats of *Lemnaceæ*. A narrow belt with less of the *Scirpus* is found along the alluvial margins of the western shore, and scattered patches occupy the shoals that connect the northern end of the lake with the swamps that lie to the northward.

In the deeper waters *Ceratophyllum* takes possession in some regions to the practical exclusion of all other species save a few *Potamogetons* and some scattered *Elodea*. The region in which this species prevails lies in the southern third of the lake and along its sides for a distance of several hundred feet from shore, and again at the northern end for a distance of three quarters of a mile from the outlet. During low-water years scattered clumps of *Ceratophyllum* and *Potamogeton* were found as far north as the middle of the lake. Thus, at all seasons about half of the lake—often two thirds of it—is open water with scarcely a trace of fixed vegetation.

The seasonal changes in the vegetation of this lake are very marked. In midwinter, during the ice blockade, which continues much longer upon the lakes than upon the river, the vegetation is not much in evidence. At low stages dead rushes rise above the ice in a few places, but give little hint of the great mass of broken and more or less comminuted vegetable debris which covers the bottom in those portions with vegetation of a semi-littoral character. This debris is of great extent, and in the absence of current and buoyancy is not carried away, but remains to enrich the waters and the unstable ooze upon which it lies. Most of the vegetation in this belt is dormant at this period, little trace of green appearing on the half-buried root-stalks and rhizomes of the perennial species belonging to this zone. In the deeper water, on the other hand, a considerable quantity of *Ceratophyllum*, with some *Elodea*, remains upon the bottom throughout the winter, keeping its foliage beneath the ice. This is an important factor in preserving the equilibrium in the gaseous contents of the water, and thus in the maintenance of the winter plankton.

With the rise in temperature in spring the vegetation starts into growth which the spring floods to a large degree conceal. This growth and the decline in river levels combine to make its appearance at the surface or its emergence above it somewhat sudden. The greatest growth takes place during the months of May and June, and is in large part attained by the close of the latter month. The changes subsequent to this period which are incident to growth are but slight, and have but little effect upon the "waterscape."

Late summer and early autumn see the decay of much of the more succulent vegetation, such as the water-lilies and lotus, the arrowleaf, the *Potamogetons*, and some of the *Elodea* and *Ceratophyllum*, while the emergent and more resistant rushes, sedges, and grasses yield more slowly and later to the accidents of flood and ice, and do not reach the late stages of decay until the following spring.

The vegetation of Thompson's Lake is subject to considerable fluctuations, due to other than seasonal changes. These are variations in river level, the seining of fishermen, and the movements caused by flood, wind, and ice. The changes in level, owing to the very gentle slope of most of the shore of this lake, greatly contract the littoral zone as the spring flood recedes, and restore more or less of it with each recurrent rise—changes which facilitate the decay of whatever vegetation of the submerged type develops in this zone. The location of the lake with its long axis in the direction (S. W. to N. E.) of the prevailing winds, gives a force to the waves sufficient at times to tear isolated patches of "moss" from their slight hold on the unstable bottom and drive them toward the northern end of the lake. This is an important factor in keeping the greater part of the lake free from vegetation.

The vegetation of Thompson's Lake is thus a considerable factor in the environment of the plankton. It furnishes a considerable quantity of decaying organic matter in fall and spring, both being periods of marked plankton development. At high and moderate stages of water, when a gentle current passes through the lake, its influence must be generally diffused. At low-water stages, when the current is cut off, its effect is much more local. At such times no open channel is maintained through the vegetation at the northern end of the lake (Pl. II.) to the outlet, as in the case of Quiver Lake. The movements in the lake attending change in level tend to mingle the plankton of regions full of vegetation with that of the open lake or vice versa, thus tending to diversification. There still remains at all times a large tract of open water in which for considerable periods of time the vegetation forms no appreciable part of the environment of the plankton. It was in this region that the most of our collections were made, and they may therefore be regarded as in the main typical of vegetation-free waters of our locality.

Flag Lake (Station K). Pl. XIX.—In vegetation this is the richest by far of all the bodies of water examined by us. It is the type of a permanent marsh, filled from shore to shore by a rank growth of plants (Pl. XIX.), with little or no development of channels or current, and a bottom of ooze with great quantities of decaying vegetation. The wide expanse of this marsh (over 1,200 acres) and the varied character of its borders afford opportunity for great diversity in its vegetation. Its margins are not sharply defined, and the vegetation in such regions varies greatly according to the locality, and in the same locality according to the present and previous stages of water. Thus in the autumn of low-water years the *Compositæ*, *Polygonums*, and grasses of the dry and higher bottoms attain a rapid and rank growth in regions where *Sagittaria* and *Lemna* held sway in the spring. A greater part of this marsh is occupied by a dense growth of the river rush (*Scirpus fluviatilis*) to the exclusion of almost all other aquatic species of any size. Here and there irregular areas of considerable extent are filled with scattered *Scirpus*, water-lilies, and the lotus, together with great quantities of the *Lemnaceæ* (Pl. XIX.). Near the center of the marsh there existed throughout the years of our examination two irregular spaces of open water of several acres in extent, more or less encroached upon by a surrounding belt of *Ceratophyllum*. Whenever access was possible our collections were made in these open places.

The vegetation of this marsh, by reason of its omnipresence, its great volume, and its periods of growth and decay, is a factor of great importance in the environment of its plankton. The nourishment taken up by the submerged and more succulent vegetation is released again by decay in the autumn, and thus favors the development of the autumnal plankton. The emergent vegetation, which reaches a great development here, adds its contributions to the enrichment of the marsh waters with the return of flood conditions and temperatures facilitating decay—conditions prevailing in the spring at the time of plankton maximum. The growth of vegetation in the spring, and the choking up of the lake which attends its transformation into a marsh seem, on the other hand, to introduce conditions of nutrition and light inimical to the development of the plankton.

PLANT ZONES.

The classification of the aquatic vegetation of our locality and its divisions into definite zones or belts is made difficult by the fluctuating character of the environment. The average range in river level is almost fourteen feet, and with the changes in level go advance, recession, or even obliteration of the shore-line in a large part of the territory included in our field of operations. Drouth and untimely flood also bring widespread catastrophe to the aquatic vegetation. The depth, even if it was constant, is insufficient to provide for any extreme differentiation of plant zones, while its inconstancy obliterates any which may gain a partial development. The greatest depths, 7–8 meters, occur temporarily in maximum floods in Spoon and Illinois rivers. The depth at such times over areas of vegetation in the backwaters rarely exceeds 5–6 meters, while during the period of spring growth it is usually less than 3–4 meters and in large areas less than one. The whole area of vegetation thus lies within the depth assigned by Magnin ('93) to the littoral zone. Under these conditions the origin and maintenance of permanent zones of vegetation is far less possible in this fluviatile environment than it is in the more stable conditions of the typical lake.

An attempt to classify our water meadows according to the scheme adopted by Magnin ('93) for lakes in the Jura, and by Pieters ('94) for Lake St. Clair cannot succeed in our fluviatile environment. The zone of deep and colder water characterized by *Chara*—called the Characetum—is entirely absent in our locality. The zone characterized by pond weeds—Potamogetonetum—may perhaps be found in the great areas of immersed vegetation, principally *Ceratophyllum*, which occur in Quiver and Thompson's lakes. The few *Potamogetons* found in our locality occur in this zone, though they are not confined to it. The depths in which this zone is here found are much less than in Lake St. Clair, in the lacustrine environment. The "Nupharetum" may be represented in the lotus beds of Quiver, Thompson's, and Flag lakes; but these do not show a zonal arrangement, and merge variously with littoral and *Ceratophyllum* regions. The littoral zone, which, according to the authors above quoted, extends from the shore line to a depth of 3 meters, is confined in our waters to a much shoaler region, and, as elsewhere, is characterized by *Scirpus*, the sedges, *Polygonum amphibium*, *Nymphæa*, and *Potamogeton natans*. Almost all of Flag Lake, the northern and southern ends of Thompson's Lake, and the northern and eastern margins of Quiver Lake belong to this zone.

A classification more applicable to our locality is that of Pieters ('01), who recognizes in Lake Erie two regions,—one including all submerged forms and those with floating leaves, the other all the remaining species with emersed leaves and growing with roots and parts of the stem in the water." These regions of immersed and emergent flora are often recognizable in our locality. To the latter belong the greater part of Flag Lake, a considerable portion of Quiver Lake along the eastern and northern shore, and the two ends and the margin of Thompson's Lake; to the former, the body of Quiver and Dogfish lakes, a small area in Flag, and a large area at either end of Thompson's Lake. It is this zone which constitutes the great plant factor in the environment of the plankton of our waters, and it consists almost entirely of *Ceratophyllum*. The effect of vegetation upon the production will be discussed in another connection.

It is evident that our investigations afford a unique opportunity for examining the effect which vegetation (the word is used in the sense of the coarse aquatic growth as distinguished from the microscopic phytoplankton) has upon the quantity and kind of plankton in bodies of water the remaining factors of whose environment are for the greater part common.

QUANTITATIVE INVESTIGATION OF THE PLANKTON.

GENERAL CONSIDERATIONS.

The purpose of this investigation was the determination, by measurement, of the quantity of minute organisms developing in the water at intervals throughout the year, and by this means to trace the seasonal fluctuations in production, and the relation of quantitative changes to constant and fluctuating factors of the environment, to flood and drouth, to chemical conditions, to the ice blockade, and to vegetation; and to contrast production in waters of the main and tributary streams, in impounding backwaters and the channel, and in bottom-land lakes and the main stream.

METHOD OF COLLECTION.

The method used in determining the quantity of plankton was based upon that devised by Hensen ('87) and modified by Apstein ('96) for use in fresh water. The changes and modifications which were made to adapt the method to use in our situation and to correct some of its errors have been described in detail by me elsewhere ('97); I shall, therefore, only briefly refer to a few phases of the subject of special pertinence or interest in this connection.

The changes in method during the progress of the work are indicated in Tables III.-IX. From June, 1894, to May 20, 1896, the plankton was collected by means of the silk net, made after Apstein's smaller model (see Apstein '96) of No. 20 silk bolting-cloth of Keller's manufacture. This net was drawn through the water at a uniform rate of one half meter per second for a distance of thirty meters. As shown in the tables referred to, most of the hauls were made by the oblique-haul method devised by Prof. Frank Smith, in which the net was drawn along an oblique rope from bottom to surface across channel in the river, and across the current, where current existed, at our other stations of collection, except in a few instances when conditions of ice or vegetation necessitated a temporary modification of the direction.

Collections subsequent to May 20, 1896, were made by means of the plankton pump, a known volume of water being strained through the silk net. The water strained was taken in such a way as to represent a vertical column of equal dimensions from bottom to top. This was accomplished by lowering the inlet of the hose from the intake of the pump to the bottom, or as near it as we could go without fouling the water by disturbing the unstable deposits, and raising it to the surface during the progress of the pumping. To secure a perfect column it is necessary to begin raising the hose with the first strokes that deliver water to the net, and to arrive at the surface long enough before the required amount is pumped to allow surface water to reach the net. With a fixed hose length and a known capacity of pump, this is easily determined by experiment. The volume strained varied with the contents of the water. As a rule, one fourth of a cubic meter was strained. When plankton was scanty and silt light the quantity was doubled, and occasionally in excessive plankton or unusual silt but half this volume was strained. Variations of minor importance in the methods here noted will be mentioned in connection with the discussion of the plankton at the several stations. These variations are such as were necessitated by difficulty of access with collecting apparatus, or by the exigencies of flood, ice, and current

PRESERVATION AND MEASUREMENT.

During the first three years the plankton was killed and preserved in strong alcohol. In subsequent years 70 per cent. alcohol to which formalin had been added to the grade of 2 per cent. was used, and proved to be a better preservative than the strong alcohol.

The quantity of plankton present in the catch was determined by compression in a Purdy centrifuge for two minutes at the rate of 1,000 revolutions per minute, resulting in an application of 1,420,484 dynes. All records and discussions in this paper are based upon this method of measurement. It brings about a considerable reduction in the volume of plankton as compared with that recorded by the usual method of allowing the plankton to settle in the Eggert color-tubes for twenty-four or forty-eight hours and condense by gravity only. I have determined the amount of this reduction in measurement of all planktons collected by us up to June 6, 1896. There are two hundred and forty-three of these catches, and they represent the full seasonal and local range in quantity and quality, covering, as they do, a period of two years and all the localities with which we have dealt. The actual quantity of plankton handled in these tests ranges from .025 to 10.25 cubic centimeters (centrifuge measurement), and 143 of the 243 catches lie between .25 and 2. cubic centimeters.

The average decrease in volume when determined by the centrifuge as compared with that by the gravity method in these 243 cases was 49.5 per cent. As shown in the following table, the decrease ranges from 8 per cent. to 76 per cent. In 21 cases it is just 50 per cent., in 111 cases it is below this, and in 111 above.

TABLE SHOWING DISTRIBUTION ACCORDING TO PERCENTAGE OF DECREASE OF 243 CATCHES MEASURED BY GRAVITY AND CENTRIFUGE METHODS.

Per cent. lost	No. of catches	Per cent. lost	No. of catches	Per cent. lost	No. of catches	Per cent. lost	No. of catches	Per cent. lost	No. of catches
76	1	62	4	52	4	42	3	32	3
75	1	61	5	51	5	41	2	31	1
74	2	60	5	50	21	40	4	29	5
71	1	59	9	49	8	39	1	27	1
69	1	58	9	48	11	38	7	26	1
67	4	57	10	47	10	37	5	25	1
66	4	56	5	46	7	36	4	22	1
65	3	55	12	45	9	35	4	21	1
64	5	54	7	44	6	34	4	13	1
63	3	53	11	43	9	33	1	8	1

The factors determining the decrease are the proportions of silt and plankton and the character of each. When flocculent debris is abundant, or when filamentous diatoms or algæ, *Copepoda*, or the *Cladocera* with long antennæ are present in numbers, the decrease upon centrifuging is greater. When the silt is earthy or contains considerable quartz, and when the plankton consists of *Protozoa* such as *Synura*, or *Rotifera* such as *Synchæta*, or *Cladocera* such as *Chydorus* or *Bosmina* the decrease is less. The amount of plankton placed in the tubes of the centrifuge also slightly affects the ratio of decrease in volume. For example, one of our largest planktons, measuring 11.15 cm.^{3} by the gravity method, fell but 8 per cent. when centrifuged in a single tube. When divided among three tubes the decrease became 14 per cent. This was a plankton largely composed of *Chydorus* and *Bosmina*. Another large plankton, measuring 11.85 cm.^{3} by the gravity method, fell to 7.6 cm. upon centrifuging in a single tube—a loss of 36 per cent. This consisted very largely of *Synura*. As other large catches decreased as much as 50, or even 60, per cent., it is clear that large volumes do not necessarily yield only slight decreases.

The instances in which the decrease exceeded 70 per cent. are 5 in number. Of these, 3 contained *Melosira* or *Fragillaria*, 1 was rich in *Oscillaria*, and 2 contained considerable flocculent debris from aquatic vegetation. All of the 12 whose decrease was less than 30 per cent. occur in April and May, when *Chydorus* and *Bosmina* are at their maximum and constitute a large, if not the greater, part of the plankton. In a few instances these catches which showed slight reduction in volume contained *Hydra*, insect larvæ, and other adventitious forms from surrounding vegetation.

Both extremes contain numerous instances in which the plankton catch is made up of typical plankton organisms, and consequently the range in the decreases here recorded *is normal for the range in planktons occurring in our waters* throughout the year. It is therefore reasonable to assume that the *centrifuged volumes here reported for plankton in the Illinois must, on the average,* *be doubled for comparison with volumes reported in similar regions elsewhere and measured by the gravity method.*

The silt in our catches and the predominance of rotifers at times will tend, I believe, to render the decrease on centrifuging somewhat less in the case of our planktons, on the average, than that found in lake planktons where filamentous diatoms and *Copepoda* abound more generally. Ward and Graybill ('00) find that the decrease ranges from 60 per cent. to 70 per cent. and averages slightly less than two thirds. Juday ('97) finds that the decrease amounts on the average to 80 per cent. Both of these records deal only with a small number of midsummer planktons, while our records cover the whole round of seasonal changes. This may be an element which tends to increase the range of the decrease shown in our results. The gravity work in our experiments was done in tubes identical in pattern with those used by Ward and Graybill ('00), and the time for settling was the same. Juday ('97) gives no account of his gravity method.

The centrifuges which we have severally used are only approximately of the same pattern, and they have not been used in exactly the same way by any two of us.

We may compute the specific pressure in dynes per square centimeter at a given distance from the axis of rotation according to the formula $\delta \omega \left(\frac{r^2 - r_1^2}{2}\right)$: in which δ is the density of the contents of the tube; ω, the angular velocity in radians per second; r the distance in centimeters from the axis of rotation to the bottom of the tube; and r_1, the distance from the axis to the top of the fluid. For density I have used the specific gravity of water, since the extractions from the plankton considerably increase the specific gravity the alcohol in varying degrees in which the plankton was preserved.

The formula for ω is $\frac{2 \pi n}{60}$, in which n is the number of revolutions per minute.

On this basis the pressure in dynes in our use of the centrifuge, where there were 1,000 revolutions per minute with distances of 16.7, and 4.5 cm. to bottom of tube and top of liquid respectively, was 1,420,484. Professor Ward writes me that these distances r and r_1 in the Bausch & Lomb machine he used were 14 and 5 cm. respectively, which with a density of 1 and 80 turns of the crank, equaling 1,840 rotations of the axis (on the manufacturer's authority that the machine is geared to give 23 rotations of the axis to one of the crank), gives 2,774,-897 dynes. Mr. Juday ('97) states that the pressure in his centrifuge was 391,680 dynes, but he writes me that the density used was the difference between that of alcohol and dried plankton, amounting to only .2 and .25. Reducing his calculations to our basis in so far only as the matter of density is concerned, we find the dynes to be from 1,958,400 to 1,566,720. A further difference between our methods lies in the fact that in our use the pressure was exerted *two* minutes, and but *one* minute in that of the other investigators.

The practical differences may not really be so great as the figures indicate because of the asymptotic character of the curve of reducing volume as the pressure continues or is increased. It it desirable that some standard unit of measurement be agreed upon for purposes of comparison.

The use of the centrifuge in the many measurements here recorded has only confirmed the views expressed by me ('97) regarding its utility, greater accuracy, and convenience for volumetric plankton work. Material which has been properly preserved has not suffered in the compression. All of the enumeration work to be reported in the second part of this paper has been done upon plankton which has been centrifuged at least once and in some cases six times. I have not detected any mutilation or distortion of the constituent organisms unless it be of *Leptodora hyalina*, an elongated and delicate cladoceran, and several other organisms of great delicacy of organization. These are often crumpled as a result either of the compression or manipulation of the plankton, but the crumpling rarely interferes with identification of the species or determination of sex or breeding condition.

The statement made by me ('97, p. 20) that "this is, I believe, the first application of the centrifugal machine to quantitative plankton work" requires modification. In Kraemer's account of Samoan plankton ('97) he describes a traveler's centrifuge for use on shipboard for measurement of plankton, and I infer from his text that this machine was in use by him in 1893–95 in Samoan waters, though I find no explicit statement to that effect. If this be true, his use antedates ours, which did not pass the experimental stage until January, 1896. In any case the measurements he publishes ('97) were made by the centrifuge. The following statement made by Ward and Graybill ('00), — "Juday ('97) was apparently the first to publish an account of the use of the centrifuge for this purpose. Both Dr. Kofoid and I had, however, experimented independently for more than a year before that, and had written to various investigators regarding the advantage of such an instrument,"—requires notice in this connection, since the question has been raised by these writers as to the priority in publication of the use of the centrifuge for plankton measurement, and the facts are incorrectly given. The date of Juday's paper is subsequent to May 28, 1897,* for the volume containing the paper contains the records of the field meeting of the Indiana Academy held on that date. The date of publication of my account of the centrifuge was March 10, 1897, and it was also mentioned by Professor Forbes ('96) in the biennial report of our Station operations. This report was again issued January 24, 1897, in separate form, and distributed to plankton investigators generally. The date of publication of Kraemer's work is "Ende Januar oder Anfang Februar 1897; genauer können wir das Datum leider nicht angeben," according to information received by me from the publishers Lipsius and Tischer, of Kiel, Germany. The empty honor of first publication thus probably belongs to us, and certainly not to Juday as Ward

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*In a letter Mr. Juday informs me that his paper was published in August, 1897.

and Graybill state. The real credit for first centrifuging plankton belongs evidently to Kraemer. In view of the statement above quoted it may be well to add that our experimental use of the centrifuge was begun in the autumn of 1896. It was at once adopted, and our plankton thus far collected was measured by it at that time. The measurements made are those used in the present paper. Our experiments with and adoption of the centrifuge were independent of and without knowledge of similar work elsewhere.

SILT ESTIMATION

In Tables III.–IX. the amount of the actual catch of the plankton net will be found, and in subsequent columns the estimated percentage of silt, and computed volumes of silt, plankton, and total catch are given in cubic centimeters per cubic meter of water. In all our discussions of the plankton the amounts used are those of plankton only, unless otherwise stated, that is, of the total catch *less the estimated amount of silt*, and they are always quoted in terms of cubic centimeters per cubic meter of water.

The determination of the amount of silt has been of necessity a matter of personal estimation, and involves a source of error of uncertain extent. The estimates have been made largely by myself, with some aid from Mr. R. E. Richardson, and no effort has been spared to maintain a uniform standard of estimation so as to distribute, as far as possible, the error incident to the process. Accordingly the estimates were revised and correlated after the qualitative and numerical analysis of the collections at Station E, and they consequently rest upon a comparative basis upon the examination of the catch as it appears in the Rafter cell.* In the case of the collections from the Illinois River only, they have been controlled in some degree by the results of the numerical analysis. The estimates of silt were made

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*Closer study of the quantitative and qualitative data since the above was written leads me to suspect that in some cases the silt estimates are too high, especially where there is much light flocculent debris, which occupies considerable space in the Rafter cell but may be compressed considerably in the centrifuge.

without reference to, and in most cases prior to, the preparation of tables and plots of seasonal distribution. Estimates made by others, not accustomed to judging the plankton, reveal a wide divergence in percentages, and independent estimates which I have made of the same material on different occasions show some divergence, though, as a rule, quite within the probable error of plankton method. The silt estimation does not, I believe, essentially vitiate any of the conclusions drawn in this discussion of quantitative results, and in no way enters into the qualitative analysis.

THE CLOGGING OF THE NET.

The collections made with the silk net drawn from the bottom to the surface of the water in vertical or oblique hauls are all diminished in volume to some extent by the resistance of the silk to the rapid passage of the water. As a result of this, the net pushes aside some of the water in the column which it is supposed to traverse. As its meshes clog with the accumulating catch the amount pushed aside is increased progressively during the haul. The actual catch of the net is therefore only a portion of the total contents of the column of water, whose length is that of the haul and diameter that of the mouth of the net. The volume of plankton actually present in this column can be computed if we can determine the factor of correction. Hensen ('87 and '95) has sought by experiment with filtered water to determine the mathematical formula which will give this correction for a net of known silk and dimensions drawn at given velocities. This factor he calls the "coefficient of the net." Reighard ('94) attempted to determine the coefficient of his net by using a miniature model in water in which *Lobelia* seeds had been placed, but ultimately adopted the formula of Hensen.

It was necessary that in our final computation of the volume of plankton we should make some correction in all catches of the drawn net for this loss due to the pushing aside of the water. Since our net was constructed after the Hensen-Apstein model it was possible to apply the mathematical method of

Hensen ('95). This coefficient—computed for us by Instructor W. C. Brenke, of the University of Illinois—is 1.320 or 1.303, according to the area of the silk in the bucket of the net, for the velocity of one-half meter per second, which we uniformly employed. Our net has an area of 81.72 square centimeters in the opening; of 1,847.5 and 22.66 square centimeters respectively in filtering cone and windows of the bucket; and its coefficient is 1.32. With a disk of silk clamped to the lower end of the net,—a method used prior to the adoption of my detachable bucket,—the area of the silk of the bucket falls to 15.2 and the coefficient is accordingly reduced to 1.303. A second net frame which we used, with an opening two millimeters less in diameter, has a coefficient of 1.318. Apstein's ('96) net has an opening of 92 square centimeters, a filtering cone of 1,730, and the silk of the bucket measures 62 square centimeters. The coefficient of his net is computed to be 1.39.

Observations on the operation of the net in the field through the seasonal changes of the plankton led me to believe that a uniform coefficient, and, moreover, one founded on the operation of the net in filtered water, would not adequately correct the error, since it takes no account of the seasonal changes in the quantity and kind of plankton, and does not recognize the effect of the progressive clogging of the net by the catch, or the change of the net with use.

Upon the adoption of the pumping method of collection a number of tests were made for the comparison of the amount of plankton taken by the drawn net and that by the pump and filtering net along parallel courses of thirty meters—our usual haul. The results amply justified my belief that the coefficient fluctuates with the conditions above named as well as with the condition of the net. We therefore sought by this empirical method to determine the coefficient under a variety of conditions representative of our environment. These tests were not carried beyond this point, since we had adopted the pumping method for the later and major part of our work.

TABLE OF DETERMINATIONS OF COEFFICIENTS OF NETS BY EMPIRICAL METHOD.

Date	Locality, etc.	Length of haul	Net	Haul	Gravity Method—24 hrs.			Centrifuge			Enumeration—1 m.^{3} water			Plankton.
					Net	Pump	Coefficient	Net	Pump	Coefficient	Net	Pump	Coefficient	
1895 Oct. 11	Illinois River	30 m.	2	1	.175	.475	**2.717**	.075	.215	**2.868**	37,771	57,931	**1.533**	Some silt. *Synura* and *Copepoda*.
Dec. 30	Illinois River	30 m.	2	1	.160	.760	**4.750**	.080	.350	**4.375**	119,150	243,181	**2.041**	Much silt. *Synura*, *Synchæta*, and *Copepoda*.
1896 June 16	Quiver Lake	30 m.	4	1	.325	.850	2.615	.140	.285	2.143	141,490	458,057	3.468	Small amount of flocculent debris. Polymixic plankton. Many nauplii. *Entomostraca*, *Rhizopoda*, *Rotifera*, diatoms, and *Protophyta* present.
			4	2	.235	.900	3.617	.090	.310	3.333	84,160	535,507	5.819	
			4	av.	.280	....	**3.036**	.115	....	**2.609**	112,830	....	**4.340**	
			5	3	.625	.750	1.360	.280	.255	1.071	195,990	439,054	2.448	
			5	4	.410	.900	2.073	.180	.350	1.667	164,840	566,216	2.971	
			5	av.	.520	.850	**1.635**	.230	.300	**1.304**	180,410	489,708	**2.604**	
July 9	Matanzas Lake	30 m.	4	1	.365	1.300	**3.562**	.180	.540	**3.000**	96,891	421,175	**4.347**	Small amount of debris. Polymixic plankton. *Entomostraca*, *Rotifera*, *Rhizopoda*, *Protophyta*.
July 11	Thompson's Lake	30 m.	4	1	.550	1.225	**2.227**	.200	.420	**2.100**	117,898	239,744	**2.034**	Polymixic plankton. *Rotifera*, *Entomostraca*, *Protozoa*, and *Protophyta*.
			5	2	1.275	....	**.961**	.495	....	**.848**	261,961	....	**.915**	
July 21	Thompson's Lake	30 m.	4	1	.675	1.125	**1.667**	.180	.400	**2.222**	133,559	438,108	**3.280**	*Entomostraca* somewhat more abundant than in the preceding test. Plankton polymixic.
			5	2	1.750	....	**.642**	.700	....	**.591**	237,643	....	**1.844**	
Aug. 28	Illinois River	30 m.	4	1	.200	.235	1.175	.100	.110	1.100	43,480	183,595	4.223	Much silt and debris. Polymixic plankton. *Entomostraca*, *Synchæta*, *Protophyta*.
			4	2	.200	....	1.175	.080	....	1.375	45,199	....	4.062	
			4	av.	.200	....	**1.175**	.090	....	**1.222**	44,339	....	**4.144**	
			5	3	.280		**.839**	.120	....	**.917**	50,992	....	**3.600**	
Oct. 14	Thompson's Lake	30 m.	5	1	.275	.250	.909	.085	.085	1.000	160,932	310,470	1.929	Very little debris. Polymixic plankton. *Rotifera*, especially *Synchæta*, *Protozoa*, *Entomostraca*, *Protophyta*, and diatoms. Largely small forms.
			5	3	.250	....	1.000	.075	....	1.133	157,749	....	1.968	
			5	5	.170	....	1.471	.095	....	.789	148,519	....	2.090	
			5	7	.260	....	.962	.110	....	.682	153,193	....	2.025	
			5	av.	.239	....	**1.047**	.091	....	**.934**	155,203	....	**2.000**	
		15 m.	5	2	.400	$\frac{250}{2}$	.312	.150	$\frac{085}{2}$	.283	146,418	....	2.120	
			5	4	.110	.....	1.136	.055	....	.773	213,388	....	1.455	
			5	6	.200	.....	.625	.100	....	.425	187,924	....	1.720	
			5	8	.180	.....	.694	.075	....	.567	166,917	....	1.860	
			5	av.	.163	.....	**.767**	.077	....	**.552**	179,630	....	**1.738**	
Oct. 14	Dogfish Lake, 20 cm. below surface	30 m.	5	1	1.375	3.200	**2.327**	.800	2.100	**2.625**	2,071,384	7,755,061	**3.740**	Monotonic plankton. Principally *Synchæta*, a few *Synura*, nauplii, *Brachionus*, and *Codonella*.
		15 m.	5	2	1.800	$\frac{3.200}{2}$	**.889**	.700	$\frac{2.100}{2}$	**1.500**	1,830,862	$\frac{7755061}{2}$	**2.118**	
	Dogfish Lake, 40 cm. below surface	30 m.	5	3	1.050	....	......	.420	....	......	1,563,763	.....	......	
		15 m.	5	4	.900	....	......	.400	....	......	1,387,151	.....	......	
1897 July 27	Thompson's Lake	5 m.	5	2	.425	....	.804	.105	....	1.468	593,311	.....	1.706	Small amount of flocculent debris. Polymixic plankton. *Leptodora*, *Cyclops*, nauplii, *Difflugia*, and *Flagellata*.
			5	3	.350	....	.976	.100	....	1.542	364,135	.....	2.780	
			5	av.	.388	....	**.881**	.103	....	**1.503**	478,723	.....	**2.114**	
		10 m.	5	5	.550	....	1.242	.135	....	2.284	392,146	.....	2.581	
			5	6	.680	....	1.005	.130	....	2.372	415,063	.....	2.439	
			5	av.	.615	....	**1.111**	.133	....	**2.327**	403,605	.....	**2.508**	
		15 m.	5	8	.630	....	1.627	.180	....	2.569	275,011	.....	3.696	
			5	9	.800	....	1.281	.165	....	2.803	345,462	.....	2.930	
			5	av.	.715	....	**1.434**	.173	....	**2.681**	310,236	.....	**3.299**	
		20 m.	5	11	1.000	....	1.367	.240	....	2.569	253,367	.....	3.995	
			5	12	.650	....	2.103	.210	....	2.936	294,670	.....	3.746	
			5	av.	.825	....	**1.656**	.225	....	**2.740**	274,019	.....	**3.867**	
		25 m.	5	14	.720	....	2.373	.195	....	3.952	223,065	.....	4.538	
			5	15	.550	....	3.107	.135	....	5.710	166,025	.....	6.096	
			5	av.	.635	....	**2.690**	.165	....	**4.672**	194,545	.....	**5.203**	
		30 m.	5	1	.725	2.050	2.828	.230	.925	4.022	224,932	1,012,194	4.500	
			5	4	1.050	....	1.952	.260	....	3.558	198,195	.....	5.107	
			5	7	.950	....	2.158	.235	....	3.936	209,654	.....	4.868	
			5	10	.950	....	2.158	.275	....	3.364	196,497	.....	5.151	
			5	13	.720	....	2.847	.250	....	3.700	189,282	.....	5.343	
			5	av.	.879	....	**2.332**	.250	....	**3.700**	203,712	.....	**4.969**	

Date	Locality, et		
1895 Oct. 11	Illinois Rive		
Dec. 30	Illinois Rive		oda.
1896 June 16	Quiver Lak		olymixic ca, *Rhi-* present.
July 9	Matanzas La		lankton. *otophyta.*
July 11	Thompson's L		*nostraca,*
July 21	Thompson's L		than in
Aug. 28	Illinois Riv		ton. *En-*
Oct. 14	Thompson's L		*Rotifera,* *nostraca,* forms.
Oct. 14	Dogfish Lake	20 cm. bel surface	*hæta,* a
		40 cm. bel surface	*pdonella.*
1897 July 27	Thompson's L		lymixic *ifflugia,*

In this method the question of coefficient is entirely eliminated.

The results of these tests are given in the preceding table.

The variation in the coefficient with different seasons, localities, and planktons is apparent upon the first glance at the table. The greater straining capacity of a new net as compared with one which had been used for some time may be seen in the tests made June 16, and July 9, 11, and 21, 1896. The new net—the silk in which had been shrunken by washing and pressing several times prior to use—catches at least 50 per cent. more than the old one which had done service since February 25.

The rise in the coefficient as the net progressively clogs by plankton is demonstrated by the tests of October 14, 1899, and July 27, 1897. The latter test is graphically presented in the accompanying figure.

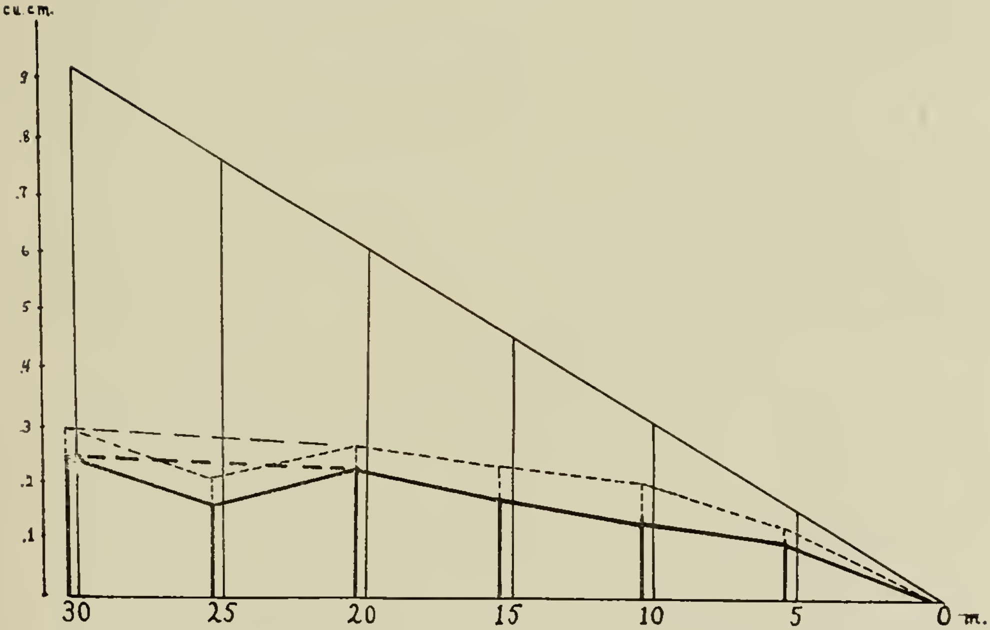

Fig. B.—Catches of plankton made on 30-meter haul by drawn net and pump The upper, continuous line represents the pump catch; the middle, dotted line the catch of the net measured by the settling method; the lower, heavy line the same measured by the centrifuge.

The coefficient has been computed in each case on the basis of measurements by the gravity method, by the centrifuge, and by enumeration of all the larger and quantitatively more important constituents of the catch. An examination of the table will indicate that the relation and direction of the differences of the various coefficients do not materially differ by the three methods. The results by the enumeration method give the largest coefficient—probably as a result of the elimination of the silt factor in some instances, and possibly by reason of the large margin of error involved in the method.

It is evident from the table that an average of a number of catches, not only by the net but also with the pump, should be used if empirical coefficients are to be established with accuracy. It is probable that the low coefficients seen in a few instances result from insufficient pump catches, or from some error in paralleling the catches. Since the coefficient problem was eliminated in our later work by the use of the pump, further efforts to establish empirical coefficients were abandoned for lack of time to carrv on more elaborate tests.

Three alternatives were thus before us. First, to adopt the coefficient computed according to Hensen's formula, and use this one factor, 1.32, for all catches irrespective of the age of the net and of seasonal, local, quantitative, and qualitative differences in the catch. This method Apstein ('96) and other European planktologists have adopted. Reighard ('94), Ward ('95), and Juday ('97) have also followed this plan, but in each case they were dealing only with catches taken in midsummer from the same or similar bodies of water, and the resulting error thus introduced was much less than would result from the adoption of a uniform coefficient for our varied catches. Furthermore, we had the evidence of the probable extent of this errror which the pumping method afforded.

A second alternative was to ignore the coefficient question entirely; but this involves even greater distortion of the probable seasonal and local fluctuations in the plankton.

A third method, and the one finally adopted, was that of assigning an empirical coefficient to each catch. This coefficient was decided upon after analysis or inspection of the plankton, and in view of its quantity and constituent organisms, the amount and nature of the silt, and the age of the net. the basis of estimation in each case being the coefficient test by the pumping method whose conditions most nearly approached those of the catch in question. These coefficients were decided upon without knowledge of or reference to the effect which they might have upon the theoretical questions arising from the analysis of the quantitative results, and prior to the organization and analysis of the volumetric data.

Obviously this latter method involves both possible and probable error in estimation of similarities and differences in the catches examined and in maintaining throughout a uniform standard. Nevertheless, for plankton catches as varied as those with which we deal, it is probable that this method involves less distortion of volumetric results than the omission of the coefficient factor or the adoption of a uniform factor for all catches irrespective of the fluctuations in this factor as revealed by our field tests. Accordingly all of the volumes of catches by the drawn net, of plankton, silt, and total catch per cubic meter recorded prior to May 20, 1896, in Tables III.-IX. have been computed with this coefficient as one of the factors, the actual factor employed being given in the tables in each case.

The results of my efforts (see Kofoid, '97a) to find an adequate correction for the loss by leakage through the silk by the use of hard-pressed filter paper and the Berkefeld army filter will be discussed in another connection.

The volumetric data of the plankton at the seven stations (see Pl. II.) at which periodical collections were made, namely, the river channel (E), Spoon River (M), Quiver Lake (C), Dogfish Lake (L), Flag Lake (K), Thompson's Lake (G), and Phelps Lake (F) will now be discussed, and the general questions arising from the investigation as a whole will then be treated.

The chronological series of collections at these seven stations included in this discussion number in all 643, distributed as follows: Illinois River 235, Spoon River 36, Quiver Lake 115, Dogfish Lake 48, Flag Lake 44, Thompson's Lake 99, and Phelps Lake 67.

ILLINOIS RIVER CHANNEL, STATION E.

(Table III.; Pl. I., V., VII.—XIII.)

DESCRIPTION OF LOCALITY OF COLLECTION.

The collections were made two and a quarter miles above the city of Havana, a short distance above the outlet of Quiver Lake (Pl. II.), at a point where the river was about 500 feet in width at low water and about 600 feet from crest to crest of the banks, which are here fringed by willows (*Salix nigra* and *S. longifolia*) on both sides. The eastern shore is a narrow spit, 6 to 8 feet above low water, separating the river from Quiver Lake. The western bank is higher, 8 to 10 feet, and is covered by bottom-land forest. This is also a spit or "towhead" between the river and Seeb's Lake. At low water (Pl. IV.) the eastern bank is exposed as a gentle declivity of 25 to 40 feet, while the western one is much wider—a belt, 50 to 75 feet in width, of soft black mud with gaping cracks (Pl. V.). A short distance from the low-water shore-line the bank shelves somewhat abruptly to the bottom, which with the exception of a slight ridge near the center of the channel extends in an unbroken level from side to side of the stream. The depth at low water for a width of over 400 feet is 8 to 9 feet. To the northward the river deepens slightly, while towards the mouth of Spoon River it shoals to 6 feet, and below it to less than 5 feet. The banks are of black alluvium, hardened in the upper levels by exposure at low water, but always soft and treacherous near the low-water line. The bottom in the channel is firm, being a compact bed of heavy bluish mud mingled with sand and the shells of *Unionidæ*, which form in many places continuous beds of large area.

A slight curve in the river above our plankton station shifts the current at that point towards the eastern shore, but at the point of collection the run of driftwood in the stream exhibited no marked difference in current in the channel for an extent of fully 400 feet. Approximately uniform conditions thus prevail over a considerable extent of the river channel at this point. At high water (Pl. III.) the banks are submerged, but aside from increased rapidity and some lateral extension there is no noticeable difference in the conditions of the current.

MODIFICATIONS OF METHODS AT THIS STATION.

Collections made by the oblique-haul method were always taken on the western side of the stream, across the current from a point in deep water, the surface end of the haul being completed in shoaler water. At times of high water it was necessary, both on account of the strength of the current and the depth, to shift the apparatus still more towards the shore, and, finally, in the flood of December, 1895, to abandon the method and substitute temporarily a series of four to six vertical hauls, amounting to about 30 meters—the usual distance of the oblique haul. These were made in midstream from a floating or anchored boat, and were continued from December 27, 1895, to May 20, 1896. After the adoption of the pumping method on the latter date the boat or launch was at first allowed to drift with the current while the collection was made. Owing to frequent difficulty caused by the drifting of the boat into shallow water by the wind before the catch was completed, we finally adopted the plan of anchoring the boat or launch in or near the mid-channel while the collections were being made.

During the winter season, owing to air-holes and weak places caused by the irregular melting of the ice upon the lower surface, the ice on the river channel was rarely firm enough to permit safe transit of our plankton outfit, whose total weight was over 800 pounds. Steel runners were placed upon the bottom of the boat, and by the aid of ice hooks it was possible to run over or to break one's way through thin or rotten ice to the mid-channel station, where open stretches of water were not infrequently found. In a few instances, owing to roughness and rottenness of the ice, it was not possible to reach the point up-stream where the collections were usually made, and in such instances the catch was taken nearer Havana but always above the mouth of Spoon River (Pl. I.). Even when the ice was running at the time of break-up, it was possible by floating in rifts of the floes to secure a catch of the channel plankton. Thus in all seasons our catches at this station are typical of the channel plankton.

CHRONOLOGY OF COLLECTIONS.

As shown in Table III., the collections at this station cover the period from June 12, 1894, to March 28, 1899, in which time catches were made on 235 different days, 10, 50, 76, 34, 52, and 13, respectively, for the several years included. The interval between collections in 1894 (Pl. VIII.) ranges from 14 to 34 days. In the first half of 1895 (Pl. IX.) they were few and irregular, but four being taken, while in the second half of that year 46 were taken at intervals of one to twelve days, the interval varying with flood conditions, since an attempt was made to follow closely the effect of changing river levels upon the quantity of plankton. The December flood of this year was followed at intervals not exceeding five days until February 10 of the following year (Pl. X.). From this time till April 24 the intervals average about seven days, in no case, however, exceeding eleven. From this date till the end of August, 49 collections were made at intervals of one to seven days, following thus closely the fluctuations attendant upon the two recurrent floods of that season (Pl. X.). The field station at Havana was then closed, and until it was reopened in the following July fortnightly or monthly trips were made to Havana for collections (Pl. XI.). From this time until the suspension of operations March 28, 1899, the collections—with the exception of a few extras and two delays due to sickness—were made at regular weekly intervals (Pl. XII., XIII.). Thus, in one or another of the years in question all months but October, November, February, March, and April have been covered by collections at intervals of five days or less, and from July 14, 1897, to March 28, 1899, a period of nearly twenty-one months, the series of regular weekly collections is almost unbroken. The following table gives the distribution of the collections by months in the several years.

DISTRIBUTION OF COLLECTIONS BY MONTHS.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1894						2	2	1	2	1	1	1	10
1895		1		2		1	4	10	15	5	4	8	50
1896	9	4	5	5	9	8	15	14	2	2	1	2	76
1897		2	1	1	1	1	5	5	4	5	5	4	34
1898	3	4	5	4	5	4	4	5	4	4	5	5	52
1899	5	4	4										13
Total	17	15	15	12	15	16	30	35	27	17	16	20	235

The distribution by months is such that a fair basis is formed for the determination of the seasonal fluctuations, since every month is represented by a considerable number of collections. The larger numbers in the summer months result from the fact that the field station was always open during this season. The total number, 235, is more than twice that made at any other station in our field of operations, and affords the most complete and longest series in our collections. It is fitting that in this our most variable station the interval between collections should be least. The total period covered by our collections here is a little over fifty-seven months, and the average interval between collections 7.4 days. I know of no series of quantitative plankton collections, in any waters, of equal range or time, variety of season, and brevity of interval.

THE LOCAL DISTRIBUTION OF THE PLANKTON AND ITS RELATION TO THE LIMIT OF ERROR IN THE METHOD.

The investigator of plankton problems is constantly confronted by the question of the extent of the error resulting from the assumption that a collection at a single place is representative of a larger area—an assumption necessary if any wide significance is to attach to the analysis of plankton data. It has been a matter of observation that the quantities of plankton taken at different places in a body of water, or even within very narrow limits, are not equal in volume under similar methods of collection. Thus, Apstein ('96) in eighty catches in German lakes finds the average deviation from the means to be 5.52 per cent. when the plankton is computed per square meter of surface. Of the eighty catches 68 or 85 per cent. exhibit a departure of less than 10 per cent. from the mean, and only four have a departure in excess of 15 per cent. These departures are derived from averages of comparable collections on various dates and in several different lakes *in groups of only two to five*, evidently from mid-lake waters, and hardly afford sufficient data for an analysis of the conditions of distribution in any given lake or in a typical lake, since on account of their small number they do not throw any light on the effect of shore, tributary waters, vegetation, currents, or other factors of the environment. They indicate, however, the probable error of ±5.52 per cent. in mid-lake collections, and seem hardly sufficient to substantiate fully the more general conclusion that "das Plankton sehr gleichmässig in einern Seebecken vertheilt ist." Reighard ('94) finds in the case of twenty-nine hauls that his results "agree very well with that of Apstein." Of his twenty-nine hauls, 26, or 90 per cent., have a "percentage of difference from the average" which is less than 20. These percentages yield, I find, an average of 9.7 per cent. to Apstein's 5.52 per cent. Reighard does not, however, compute his "percentage of difference from the average" in the same manner as Apstein determines the "Abweichung von Mittel," the former using the volume of each catch as the basis for the determination of the percentage of difference from the average, while the latter employs the average of the two or more catches for this base. Obviously this slightly increases one half of Reighard's percentages and decreases the other half, though it does not materially affect the average of all of them. Apstein's method of stating the ± error in terms of departure from the mean is, it seems to me, to be preferred to the "percentages of difference" which Reighard uses.

In all instances but one Reighard averages but two collections, made at some *one* of fourteen points of collection in Lake St. Clair. His percentages of difference, therefore, refer only to these individual points of collection and *not to the lake as a whole.* His collections were all made within an interval of ten days, and it is probable that the results can be used to determine the departure from the mean in the lake as a whole. This he has not done, though he concludes from these percentages of differences of the *pairs of collections* that "*the plankton is distributed over Lake St. Clair with great uniformity.*" In the case of Apstein's data the sets of collections are scattered over several seasons and represent a number of lakes, and range in number from two to five in each test.

It is obvious that conclusions as to the uniformity of distribution of the plankton in the lake *as a whole* should be based upon a comparison of all catches with their average, and are best expressed in terms of departure from their mean, employing the mean as a base and expressing the deviation in percentages whose average will constitute the mathematical expression of the variation in distribution or the ± error of the method. For reasons above stated, this method cannot be applied to Apstein's data as a whole, though it is the one he uses for individual lakes or tests.

Applying this method to the data of Reighard's ('94, p. 33) table, as in the accompanying tabulation, I find that the average departure from the mean is ±31.8 per cent., with a range of +111.5 to −57.5,—a total of 169 per cent,—on the basis of the amount of plankton per square meter of surface; and ±28.8 with a range of +91.3 to −55.4,—a total of 146.7 per cent.,—on a basis of plankton per cubic meter of water—a deviation much greater than that expressed by Reighard's method. This deviation is much greater than that found by Apstein ('96), and it results in large part, doubtless, from the greater number of catches averaged, and from the fact that they represent a number of more widely separated points in a larger body of water, in which currents, vegetation, shore, and bottom are important factors environing its plankton.

DISTRIBUTION OF PLANKTON IN LAKE ST. CLAIR.

Haul No.	Depth in meters	Plankton per sq. m. of surface		Plankton per m.^{3} of water	
		Volume in cm.^{3}	Departure from mean in per ct.	Volume in cm.^{3}	Departure from mean in per ct.
IIQ	5.00	7.19	−29.4	1.44	−55.4
II	5.00	13.38	+31.3	2.68	−17.0
IIIQ	5.54	15.27	+49.9	2.76	−14.6
III	5.54	21.55	+111.5	3.89	+20.4
IVQ	2.50	5.02	−50.7	2.01	−37.8
IV	2.50	5.02	−50.7	2.01	−37.8
VQ	5.26	14.40	+41.2	2.74	−15.2
V	5.26	19.04	+86.8	3.62	+12.1
VIQ	4.70	10.93	+7.2	2.29	−29.1
VI	4.70	14.69	+44.2	3.08	−4.7
VIIQ	1.17	4.32	−57.5	3.69	+14.2
VII	1.17	4.32	−57.5	3.69	+14.2
VIIIQ	4.44	11.99	+17.1	2.70	−16.4
VIII	4.44	13.36	+31.1	3.01	−6.8
IXQ	4.28	10.88	+6.8	2.54	−21.3
IX	4.28	10.22	+0.3	2.39	−26.0
XQ	1.50	6.23	−38.8	4.15	+28.5
X	1.50	6.23	−38.8	4.15	+28.5
XIIIQ	2.21	10.59	+3.9	4.79	+48.3
XIII	2.21	8.76	−14.0	3.97	+22.9
XIVQ	2.89	10.41	+2.2	3.60	+11.4
XIV	2.89	9.56	−6.2	3.31	+2.5
XVQ	5.17	9.29	−8.8	1.80	−44.2
XV	5.17	12.50	+22.6	2.42	−25.1
XVIQ	4.55	8.65	−15.1	1.90	−41.2
XVI	4.55	10.61	+4.1	2.33	−27.8
XVIIIQ	1.27	7.09	−30.4	5.58	+72.8
XVIIIQ$_a$	1.27	6.13	−39.8	4.83	+49.5
XVIII	1.27	7.85	−22.9	6.18	+91.3
Av.		10.19	±31.8	3.23	±28.8
Range			+111.5 to −57.5		+91.3 to −55.4

This large variation in the distribution of the plankton in lakes naturally raises the question whether there is in the channel of a running stream, for example the Illinois River, a plankton whose uniformity of distribution is such that a collection made at a given place and time may be considered as a fair sample of the contents of the water in contiguous parts of the stream, or of the plankton present in the water passing a given point of the stream for any considerable length of time. Will not the conditions pertaining to fluviatile life cause such local variations in the plankton and such changes in it from day to day that chronological series of isolated collections will reveal only erratic and meaningless fluctuations, without significance for the analysis of the factors of the environment and incapable of revealing an orderly regimen of aquatic life? In other words, is the river a unit of environment sufficiently compact to yield, by the plankton method, data of scientific value comparable with those derived from other bodies of water, types of which we find in the sea and the lakes?

As contrasted with the lake, the river as a unit of environment presents a constant and excessive predominance of the longitudinal over the transverse axis. This feature, combined with the fact that in a river the relative shore development is much greater than it is in the lake, makes it necessary to discuss the longitudinal and transverse distribution of the plankton in the stream separately.

LONGITUDINAL DISTRIBUTION.

With a view to testing this question of the local longitudinal distribution of the plankton in the Illinois River, I made a series of ten catches in immediate succession from a boat anchored at our usual station in mid-channel on October 29, 1896. This was at a time of a considerable autumnal development of *Synura* and *Synchæta*, and the quantity of plankton present (see Table III.) was sufficient (Pl. X.) to allow room for considerable fluctuation and to minimize the error attributable to measurement.

In the following table the volume of the centrifuged plankton per m.^{3} and the deviations from the mean in volume and in percentages of the mean are given.

The similarity in the amounts of these successive catches is shown in the fact that the average departure from the mean catch is only ±3.58 per cent. and the total range of the limits of departure only 14.1 per cent. I know of no test of similar extent elsewhere with which this may be compared, but its range is well within the limits of the records of repeated catches in

TEN CONSECUTIVE CATCHES FROM ANCHORED BOAT.

No.	Vol. of catch in $cm.^3$ per $m.^3$	Departure from average	
		In volume	In percentage
1	3.20	+ .07	+2.2
2	3.24	+ .11	+3.4
3	3.04	− .09	−2.9
4	3.40	+ .27	+8.6
5	3.06	− .07	−2.3
6	3.20	+ .07	+2.2
7	2.94	− .19	−5.5
8	3.20	+ .07	+2.2
9	2.94	− .19	−5.5
10	3.10	− .03	−1.
Average	3.13	+ .112	+3.58
Greatest +		+ .27	+8.6
Greatest −		− .19	−5.5

DEPARTURES FROM MEAN CATCH COMPUTED FROM HAULS FROM EQUAL DEPTH IN GERMAN LAKES BY APSTEIN ('96, pp. 56–57).

Apstein's No.	No. of hauls	Average catch in $cm.^3$	Average departure from mean in per cent.	Limits of departures of percentages.	Total range of departure
23 b-d	3	4.66	2.2	− 3.4 to + 3	6.4
26 a-c	3	5.5	6.1	− 9.1 " + 9.1	18.2
27 a-e	5	4.1	7.8	−14.6 " +15.9	30.5
28 a,b	2	4.5	11.1	−11.1 " +11.1	22.2
30 a,b	2	9.12	1.3	− 1.3 " + 1.3	2.6
32 a-c	3	13.2	4.3	− 5.3 " + 6.1	11.4
33 a,b	2	26.3	6.4	− 6.7 " + 6.7	13.3
33 d,e	2	15.5	3.2	− 3.2 " + 3.2	6.4
34 a,b	2	17.	8.8	− 8.8 " + 8.8	17.6
37 a-c	3	2.43	8.6	− 7.4 " +13.2	20.6
41 a,b	2	1.5	13.3	−13.3 " +13.3	26.7
43 a-c	3	1.93	19.5	− 17.1 " −29.5	46.6
46 a,b	2	2.	0.	0.	0.
65 a,e	2	3.3	7.7	− 7.7 " + 7.7	15.4
73 a,b	2	2.5	0.	0.	0.
45 a,b	2	1.2	8.3	− 8.3 " + 8.3	16.7
47 b,c	2	1.1	0.	0.	0.
63 a,g	2	1.23	2.5	− 2.5 " + 2.5	5.
68 a,b	2	0.1	0.	0.	0.
69 a,b	2	−0.1	0.	0.	0.
70 a,b	2	0.16	0.	0.	0.
24 a-c	3	1.	0.	0.	0.
83 a-c	3	1.13	3.8	− 2.7 " + 6.1	8.8

smaller number in waters of European lakes. For example, Apstein ('96) records 23 instances of hauls on the same date from equal depths and evidently in every case within distances between catches *less* than that represented in the extremes of our test. The number of hauls did not, however, in any of his tests exceed four. I have compiled or computed from Apstein's table (pp. 56–57) the average and limits of departure from the mean in these 23 cases. In 12 of the 23 the average departure exceeds ±3.58 per cent.—the average departure in our test, in which there were from two and a half to five times the number of hauls. In 10 of the 11 instances in which the departure from the mean in Apstein's records falls below ±3.58, only two hauls were averaged. The total range of the limits of departure also exceeds that found in our test in 8 of the 23 cases.

In the light of Apstein's results and considering the larger number of catches averaged in our test, and also the considerable length of the channel that it covers, it seems beyond reasonable doubt that single catches of the plankton in the channel of the Illinois at our station of collection afford as trustworthy a basis for the analysis of plankton problems as do similar catches made in a lake. The margin of error thus introduced is no greater, if indeed so great, as that appearing in investigations in such waters.

Since these catches were made from an anchored boat, the water from which the plankton was taken was distributed over a considerable length of the stream. The test was made between 7:30 and 9:30 a. m. The river stood at 5.1 ft. above low water and was falling rapidly, so that the current was noted at the time as unusually swift, probably approaching two miles an hour in mid-channel at this point. At this rate the collections represent plankton taken at ten intervals from a body of water about three miles in length. This areal distribution is comparable with, if it does not exceed, the limits of widest distribution of catches in Apstein's tests, but it is much less than that of Reighard's, which lay within an area of about ten by thirty miles.

A series of ten consecutive hauls made on the afternoon of August 21, 1896, from a floating boat between the bend in the river above the plankton station and the towhead below it (Pl. II.) throws some light on the questions of local distribution and of variation in catches from a limited area. Owing to the wind it was not possible to float with the current, and the apparatus also served to impede the boat. The river stood at 7.1 ft. above low water and was falling slowly, so that the current was not so strong as when the ten were made from the anchored boat. The test occupied about eighty minutes, and the boat drifted about a mile, so that the body of water actually passing it, from which the plankton was taken, was less than half a mile in length. Considerable dislodged vegetation and some cattle-yard debris were floating at the time, causing more than the usual inequality in the distribution of the silt which these elements introduce into the plankton. The catches ranged in centrifuged volume from .4 to .575 cm.^{3}, averaging .48, and showing an average of divergence of ±11.2 per cent. from the mean, with limits of +19.9 and −16.6—a total of 36.5 per cent. The divergence in this test is greater than that from the anchored boat, owing in part to the floating debris, and in part, probably, to the fact that the wind drifted the boat across fully three quarters of the channel.

These divergences, both in average and limits, fall within the figures of parallel catches in lake waters quoted above from Apstein ('96) and computed from Reighard ('94). The fact that the range of variation on the whole is greater than the average run of Apstein's results is doubtless due in part to the larger number of catches included in my test.

These two tests thus indicate that the plankton of the main channel waters of the Illinois at the point where our collections are made, is distributed quite as evenly as that in lakes thus far examined from this point of view, and in consequence single collections may be utilized for the study of plankton problems with no greater error for the potamoplankton than for the limnoplankton. The divergence from the mean will upon the average, in all probability, fall within ±10 per cent.

Our chronological series of collections affords a few instances of catches under somewhat stable conditions of river levels and temperature, and at intervals so short that they may be utilized as tests of local distribution within certain larger limits of error, since the utilization of such data introduces the errors resulting from changes of chemical conditions due to rotting of sewage, and from growth, reproduction, and destruction of the plankton in the interim between collections. The following tabulated instances (p. 278) from Table III. and Plates X. and XI. may be cited as throwing light on this question of local distribution along the length of the stream.

The fourteen groups of collections were selected with reference to stability of conditions, therefore in falling or low water and in periods of relatively even temperatures. Inspection of the tables and plates above referred to will show that the selection has not been made so as to eliminate wide variations, and it may therefore be regarded as fairly typical. The periods included, range from 2 to 15 days in extent, and upon estimated rates of current the several tests include planktons taken at intervals in reaches of channel water from 24 to 252 miles in length. The average departures from the mean, range from ±0 to ±29.8, and yield a grand average of ±14.1. In view of greater number of catches averaged and extended time element involved, these results compare very favorably with those derived from Reighard's data and Apstein's results. The probable error resulting from variations in the longitudinal distribution under stable conditions seems to be less than ±15 per cent.

An inspection of Table III. and Plates X.–XIII. will show that in the case of invading flood waters the departures from the mean of catches at similar intervals would be considerably greater than the averages above computed. Also, that in case of plankton pulses in stable conditions—for example in September and October, 1897—collections at weekly intervals may exhibit departures in excess of ±50 per cent. It is evident, how-

LOCAL DISTRIBUTION OF PLANKTON IN RIVER AS SHOWN BY CHRONOLOGICAL CATCHES.

No. of group	Estimated rate of current	Estimated range in miles	Date	Temp. (F.) at bott'm	Stage of river	Catch per m.^{3}	Departure from mean in per cent	Av. depart. in per ct. of mean	T'l r'ge of limit in per ct. of mean
1	.75	54	1895 July 29	75.5	5.38	.47	+22.3	±22.3	44.6
			Aug. 1	77.8	4.20	.74	−22.3		
2	.5	36	Aug. 5	79.	3.13	.95	0	0	0
			" 8	78.	2.63	.95	0		
3	.5	36	Aug. 12	82.5	2.40	5.94	−1.2	± 1.2	2.4
			" 15	83.2	2.35	6.08	+1.2		
4	.5	84	Aug. 24	78.5	2.35	7.87	+48.5	±24.3	74.5
			" 26	79.	2.78	4.32	−18.5		
			" 29	80.	2.58	3.92	−26.		
			" 31	77.5	2.65	5.08	4.1		
5	.75	108	Sept. 5	72.5	5.70	1.48	+22.3	±17.6	51.2
			" 6	72.	6.85	1.16	+ 4.1		
			" 7	72.	5.88	.86	−28.9		
			" 9	72.5	5.38	1.48	+22.3		
			" 11	77.	4.25	1.06	−12.4		
6	.6	115	Sept. 12	78.	3.90	2.92	+27	±29.8	91.3
			" 14	75.5	3.38	3.49	+43		
			" 16	74.5	3.20	1.91	−17		
			" 18	75.5	3.58	1.19	−48.3		
			" 20	78.	3.20	1.98	−13.9		
7	.25	24	Sept. 23	76.5	2.75	1.37	+15.1	±10.4	26.9
			" 25	72.5	2.63	1.05	−11.8		
			" 27	72.	3.23	1.14	− 4.2		
8	2.5	252	1896 Jan. 6	32.2	12.20	.51	−42.7	±25	78.7
			" 8	32.1	11.90	1.21	+36		
			" 10	32.3	11.40	1.02	+14.6		
			" 13	32.4	10.80	.83	− 6.7		
9	2	720	Jan. 15	32.1	10.40	1.84	−10.2	±10.8	26.8
			" 20	32.6	9.50	1.81	−11.7		
			" 25	33.	8.60	2.36	+15.1		
			" 30	34.3	8.10	2.18	+ 6.3		
10	2	720	Mar. 9	37.1	10.20	4.96	− 6.1	±6.6	15.9
			" 17	35.8	9.70	5.08	− 3.8		
			" 24	40.7	8.80	5.80	+ 9.8		
11	1	24	Apr. 24	71.8	6.90	17.07	+ 0.5	±0.5	1.
			" 25	67.5	6.90	16.91	− 0.5		
12	1	48	Apr. 29	70.	7.10	9.03	+28.1	±28.1	56.2
			May 1	68.8	7.10	5.06	−28.1		
13	.75	108	Aug. 15	78.	7.40	2.32	+ 1.1	±12.8	38.4
			" 18	78.	7.50	2.72	+18.8		
			" 21	78.	7.10	1.84	−19.6		
14	.6	43.4	Aug. 26	77.	6.50	1.44	− 7.7	±7.7	15.4
			" 29	74.	6.00	1.68	+ 7.7		
Av.								±14.1	37.4

ever, that in all tests extending over many days other factors than variation in local distribution come in to modify the results.

LONGITUDINAL DISTRIBUTION FROM THE MOUTH TO HENNEPIN.

By courtesy of the Illinois State Fish Commission I made on May 18–21, 1899, a trip on their steamer "Reindeer" from the mouth of the Illinois to Hennepin, about 205 miles from the mouth, making ichthyological collections for the State Survey. Incidentally plankton collections were also taken continuously from a short distance above the mouth to Hennepin—in all, 21 collections. Of these, 19 will be utilized in the following comparison, the first being omitted because of uncertainty as to the distance, and one other because of loss of the collection. The catch was made by means of a 1½ in. iron pipe carried from the guards of the boat to a depth of 18 in. below the surface of the water. The intake was reduced to ¾ in. and turned toward the prow of the vessel, so that, while moving, a continuous stream of water was discharged into the plankton net, immersed in a barrel on deck. In this fashion a continuous stream from the level of the intake was filtered. The contents of the net were removed approximately every ten miles of transit, and its clogging to the point of resistance prevented by shaking it down whenever necessary, thus minimizing, in part at least, this source of error. The following table gives the data concerning these catches and the measurements and silt estimations,* together with my computations of the departures of the total catches from their mean and of the estimated planktons.

The distances between points of collection were not determined with great accuracy, since we had no log, and maps give no clue to the not infrequently tortuous steamboat channels. The distances are therefore approximations based on the experience of the pilot and engineer in charge of the boat.

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*By the generous permission of Professor Forbes, centrifuge measurements and silt estimations have been kindly furnished to me by Mr. R. E. Richardson, who is preparing for publication in this Bulletin a detailed report upon these collections.

No.	Location	Time	Disc	Water temp. F.	Silt per cent.	Vol. in cm.³ of catch			Departure from mean in per cent.	
						Pl'nkton	Silt	Total	Total catch	Plankton
1	1 m. above Hardin	5:45-6:45 p. m.	.10	72	60	.18	.26	.44	− 85	− 75
2	Kampsville Dam	6:45-7:45p. m.	.08	71	80	.23	.91	1.14	− 61	− 68
3	1 m. above C. A. bridge	4:30-5:45 a. m.	.08	69	90	lost				
4	Florence	6:00-7:05 a. m.	.03	68	99	.02	2.32	2.34	− 21	− 97
5	Mauvaise Terres Cr'k	7:10-8:10 a. m.	.04	68	98	.05	2.36	2.41	− 18	− 93
6	Meredosia	8:10-9:15 a. m.	.04	69	95	.11	2.15	2.26	− 23	− 85
7	La Grange	10:00-11:00 a. m.	.04		97	.07	2.21	2.28	− 24	− 90
8	Beardstown	11:00-12:00 a. m.	.04		88	.22	1.61	1.83	− 38	− 69
9	Browning	2:45-3:45 p. m.	.05		95	.11	2.15	2.26	− 23	− 85
10	Holmes Landing	3:45-4:45 p. m.	.05		10	1.80	.20	2.00	− 32	+153
11	Havana	6:15-7:30 p. m.	.05		80	.53	2.13	2.66	− 10	− 25
12	Liverpool.	4:20-5:20 a. m.	.04	67.5	50	2.12	2.12	4.24	+ 44	+199
13	2 m. above Copperas Creek	5:25-6:30 a. m.	.04	68	80	1.32	5.29	6.61	+125	+ 86
14	Mackinaw Creek	7:10-8:20 a. m.	.05	67	70	1.47	3.42	4.89	+ 66	+107
15	6 m. above Pekin	8:40-9:45 a. m,	.06	67	90	.95	8.59	9.54	+224	+ 34
16	7 m. above Peoria	9:50-10:10 a. m. 12-12:40 p. m.	.08	67	60	2.19	3.29	5.48	+ 86	+209
17	Chillicothe Park	12:50-1:50 p. m.	.12	66	15	.92	.16	1.08	− 63	+ 30
18	1 m. below Lacon	2:30-3:40 p. m.	.15	66	20	.88	.22	1.10	− 62	+ 27
19	Henry	4:00-4:55 p. m.	.20	66	88	.12	.90	1.02	− 61	− 83
20	Hennepin	5:20-6:30 p. m.	.20	66	95	.12	2.20	2.32	− 21	− 83
	Average					.71	2.23	2.94	±57	±89

An inspection of the data of this table at first gives little comfort to one desiring to establish even an approximate uniformity in the distribution of the plankton along the length of the stream. The average departure from the mean is ±57 per cent. in the case of the total catch and ±89 per cent. in the estimated plankton, with ranges respectively from −85 to +224, a total of 309 per cent., and from −97 to +209, a total of 306 per cent. This is greatly in excess of the figures above given from the work of Reighard and of Apstein, and *as a whole* the data are so aberrant as apparently to disqualify them for scientific use.

If, however, we take into consideration the conditions under which the collections were made, the aberrancy of this series loses its force. In addition to the errors introduced by the slight clogging of the net and the uncertainty as to the precise distance, there is an error of undetermined proportions caused by the vertical movement of the planktonts and consequent possibility of uneven distribution at the 18-in. level between 4:30 a. m. and 7:45 p. m.—the extremes of our time of collection.

Furthermore, an examination of the planktographs in the river and its backwaters for 1896 and 1898 (Pl. X., XII., XXVII., XXIX., XXXI., XXXIII.) —in which years the collections were sufficiently frequent to trace the movement in plankton production—shows that this season of the year is wont to be a period of rapid change in plankton content. Thus, in the river in 1896 on May 13–18 the plankton fell from 3.56 to .86, or 76 per cent., in stable hydrographic conditions. A similar phenomenon may be involved in the fluctuations in plankton content found in this transit of the river. The time intervening between the first and last collections was a little over two days. To this must be added the consideration that the collections represent a strip more than 200 miles in length, since we were traveling against the current, and, furthermore, that we have to deal with the volumetric changes in plankton content, as it passes down stream, due to growth and decay.

All of these influences are apparently but slight in comparison with the effect of certain environmental factors which are locally dominant within certain sections of the river. We can distinguish *on the days of collection* four sections or minor units of environment dominated by different factors. The first three collections made in the lower river lie in a region of comparatively clear water free from flood invasion. Unfortunately the third collection was lost, but the remaining two exhibit a departure in the case of the estimated plankton of ±12 per cent. and of ±44 per cent. in the total catches. The next six collections, covering a stretch of 60 miles, from Florence to Browning, were all taken in a section of the river invaded by flood water of recent origin and poor in plankton, as was evident from the increased turbidity, the large amount of drift floating, and the discharge from tributary streams—principally on the right bank. In such conditions the amount of plankton (estimated) is small, and its variations form proportionately large percentages of its mean, the average departure being ±51 per cent., with a range from −79 to +127—a total of 206 per cent. If, however, simply the total catch is taken, the average departure is ±5 per cent., with a range of −18 to +8—a total of 26 per cent. In view of the extent of the river included in this section—60 miles—and the uneven distribution of the flood contributions, it is not surprising that we should find such irregularity in the (estimated) plankton.

We now come to the section of the river dominated by the Peoria-Pekin pulse of sewage, including 70 miles of channel—from Holmes Landing to Peoria. The flood waters are still in evidence, but in reduced volume, and there is marked increase in the plankton content. The average departure from the mean plankton is ±32 per cent., with a range of −64 to +48—a total of 112 per cent. In the case of the total catches the average departure from the mean is ±36 per cent., with a range of −60 and +89—a total of 149 per cent.

The upper section of the river, above Peoria, a stretch of 40 miles, was less disturbed by flood conditions, there being only slight local invasions. This region is within the sphere of influence of Chicago sewage, and not receiving any large tributaries, we might expect but do not find conditions somewhat equalized here. The average departure from the mean plankton is ±76, with a range of −76 to +80 per cent.—a total of 156 per cent. The average departure of the total catch is ±34 per cent., with a range of—27 to +66 per cent.—a total of 93 per cent. These departures will be much reduced if we break this section into an upper and lower region of two collections each, the percentages falling from ±34 to ±2 and ±0 for plankton, and to ±1 and ±39 per cent. for the total catch for the two sections, each of which represents 20 miles approximately.

The average departures from the mean plankton in the four sections are respectively ±12, ±51, ±32, and ±76 per cent., yielding a grand average of —43 per cent.; while the corresponding average departures for the total catches are ±44, ±5, ±36, and ±34, with a grand average of ±29.7 per cent. These four subordinate units of environment represent longitudinal extensions of 20, 60, 70, and 40 miles. The area included in Reighard's Lake St. Clair collections has a length of 32 miles and a maximum width of 5½, and the average departure from their mean (computed by similar methods for all localities) is ± 28.8 per cent. Similar methods of computation thus yield for Lake St. Clair and these sections of the Illinois River almost an identical ± error of distribution.

In the light of these volumetric data the conclusion is patent that plankton data from fluviatile environment contain on the average a distribution error which approximates that in plankton data from limnetic areas of similar extent selected with reference to unity of environment as determined by local factors.

It should be noted in this connection that the conditions prevailing when this plankton traverse of the Illinois River was made, were most adverse to an equalized plankton in the following particulars. It was at a time of rapid seasonal change in plankton during the decline of the vernal pulse, and it was at a time of intercalation of flood water of local and recent origin, whose poverty in plankton is brought into contrast with the larger content of the run-off of impounded backwaters elsewhere. Finally, the river stage, which was 9 feet at Kampsville and 6.9 at La Grange, was such that the equalizing effect of general overflow on plankton content in impounded backwaters had ceased and local differences were emphasized, while at the same time their discharge continued in considerable volume. All of these factors, the last two of which are more important in the river than in the lake, tend to diversify the plankton content in the river at this season. It is reasonable to suppose that under other conditions—such as general overflow, the more stable features which attend falling levels above or below 9–7 feet, or in prolonged low water—we should find the uniformity of distribution of the plankton more pronounced than it was on May 18–21, 1899, barring, however, the effect caused by sewage contamination, which at all stages and seasons is the most potent factor in the environment of the plankton of the Illinois River.

TRANSVERSE DISTRIBUTION AND RELATION OF SHORE TO PLANKTON.

The shore is a factor of great importance in the aquatic environment. It is here that land and water come into most intimate relation; seepage and drainage waters enter here; vegetation gains its foothold, affects the gaseous contents of the water, and contributes by its decay to the nutrition of aquatic organisms; rise and fall of temperature are more profound here in shoal surface waters; light pervades more completely; and currents are less rapid. It is in many respects a less stable region than the central waters which it bounds, and it may, indeed, be regarded as a separate unit of environment, in contrast with mid-lake or channel waters.

The effect of the shore-line upon the distribution of the plankton in the lake has not entered into the data referred to in the previous section, for in the investigations of both Apstein ('96) and Reighard ('94) along-shore collections were not made, and, moreover, the shore-line is less important relatively in the lake as compared with the stream. For example, the absolute development of the shore-line in Lake St. Clair—determined by the method of Seligo ('90) (=shore-line divided by square root of area) is given by Reighard ('94) as 9.23. In the Illinois River at high water, from Utica to the mouth it is approximately 17.1, and at low water 78.3, omitting all the connecting lakes and bayous, computing the area on the basis of the average of the low-water widths given on page 110, and ignoring sinuosities exceeding that of the channel. The relative development (absolute development divided by absolute development in a circle in which $r=1$) in Lake St. Clair is 2.607, in the Illinois River at highest water, 4.83, and at low water, 22.1. These figures serve to show in a general way the exceeding importance of the shore-line in the environment of the potamoplankton. Owing to the great sinuosities of the shore-line as rising waters invade the bottom-land, these figures are probably very much smaller than actual measurement would make them. It is probable that the relative shore development in the Illinois is ten times that of Lake St. Clair, and fifteen times that of most lakes.

Added to the diversifying action and predominance of the shore-line in the river, there is the tendency of its tributary waters, especially of the smaller lateral feeders, to follow their shore for some distance. The absence of great sinuosity in the

Illinois as compared with other streams, as shown by the slight ratio of development of the stream (see p. 102), tends to prevent the rapid mingling of channel and marginal waters, and thus gives cumulative effect to their differential characters.

In order to trace the quantitative effect of the shore and determine the variation in transverse distribution, I made two series of ten collections each along a transverse line, the first at our usual plankton station and the second below the mouth of Spoon River (see Pl. II.). The results of the first-named test, made August 26, 1896, are given in the following table, together with conditions of distance from shore, depth, temperatures, and turbidity. The river at this time stood at 6.5 feet above low water, and had a width at the station of 150 meters.

PLANKTON IN CROSS-SECTION OF RIVER AT STATION E.

No. of collection	Distance from east shore, in m.	Depth, in m.	Temperature (F.)		Turbidity depth (in m.) disc visible	Centrifuge method		Enumeration method		Omitting Nos. 1, 9, 10		Omitting Nos. 1, 8, 9, 10	
										Per m.³		Under 1 sq. m.	
			Surface	Bottom		Plankton in cm.³ per m.³	Departure from mean in ±	No. of planktonts per m.³	Departure from mean in ± per ct	Volume	Departure in ± per ct	Volume	Departure in ± per ct.
1	10	1.68	82	77	.33	2.00	+27.5	143,800	+31.8			[3.36]	
2	37.5	3.96	78	77	.33	1.34	−14.5	110,000	+ 0.8	1.34	−22.1	5.31	−25.2
3	75	4.88	77.5	77	.45	1.34	−14.5	95,600	−12.4	1.34	−22.1	6.54	− 7.9
4	85	4.88	77.5	77	.45	1.52	− 3.2	110,200	+ 1.0	1.52	−11.6	7.42	+ 4.5
5	95	4.27	77.5	77	.45	1.44	− 8.6	109,600	+ 0.5	1.44	−16.3	6.15	+13.4
6	105	4.04	77.5	77	.42	2.36	+50.5	93,100	−14.7	2.36	+37.2	9.53	+34.2
7	115	3.18	77.5	77.1	.40	2.40	+53.1	112,500	+ 3.1	2.40	+39.5	7.63	÷ 7.5
8	125	1.68	77.5	77.5	.40	1.64	+ 4.8	110,300	+ 1.1	1.64	− 4.7	[2.76]	
9	135	1.22	77.75	77.5	.38	1.04	−33.9	109,900	+ 0.7			[1.27]	
10	146	0.56	77.75	77.6	.30	.60	−61.7	96,200	−11.8			[.34]	
Average						1.57	± 27.2	109,120	±7.8	1.72	±21.9	7.10	±15.4

The collections were made with the pump, one fourth of a cubic meter of water taken from bottom to surface being strained in each catch.

The variation in the catches is much greater in the cross-section than in limited longitudinal tests, in accord with the greater contrast in environmental conditions. The marked decline near the western shore may be due to the marginal belt of vegetation then present along that side of the river, and the increase in the initial collection at the east shore is caused in part by the greater abundance of *Wolffia* drifted there by the prevailing wind. It is obvious that for comparison with lake collections these shore catches should be excluded, for the former are rarely taken so near shore. Furthermore, all our chronological series on which this paper is based were taken in mid-channel, far from the shore belt, and in excluding those marginal collections but one sixth to one third of the total width of the stream is removed from the test. After all allowances are made, it is obvious that quantitative differences in the plankton are much greater in a single transverse traverse of the stream than they were found to be in a longitudinal test extending over approximately thirty times the width of the stream. Indeed, it is to be expected that differences arising from the effect of the shores and of tributary waters would be carried by the current far down the stream. On the basis of volume per m.^{3} the probable error of distribution is ±27.23, with a range of —61.7 to +53.1, and a total between limits of 114.89—all within these limits of variation in Reighard's data from Lake St. Clair, but exceeding somewhat the more limited data of Apstein. If we omit the three inshore collections, Nos. 1, 9, and 10, the probable error of distribution falls still lower,— to ±21.9 per cent., with a range of —22.1 to +39.5, a total of 61.6 per cent. between limits.

If we take the amount of plankton under one square meter as the basis of comparison the results will be much more divergent, owing to the greater relative difference in depth in my locations and to the introduction of variation due to vertical distribution of the plankton. In Apstein's tests the greatest departure from the mean depth in no case exceeds 10 per cent., and with but four exceptions his 31 tests are in water from 15 to 45 meters in depth, where differences in depth are of less importance than in shoaler water. In Reighard's series the greatest departure from the mean depth is 66.9 per cent., the range being from 1.17 to 5.54 meters. In my test the range is from .56 to 4.88 m., the greatest departure being 81.5 per cent., and my inshore collections were all probably very much nearer the shore than any of his were made. It is therefore legitimate to omit these inshore collections in comparisons based on amounts under one square meter. Accordingly, if we omit Nos. 1, 8, 9, and 10, the probable error of distribution becomes ±15.4 per cent., with a range of —25.2 to +34.2, a total of 59.4 per cent. between limits. This is far within the limits of error which Reighard's St. Clair data yield. Since his catches include two at depths of 1.17 m., we may include all of my catches except No. 10, in which case the probable error of distribution rises to ±38 per cent., with a range of —77.1 to +71.7, a total of 148.8 per cent., Reighard's data yielding on this same basis of computation ±31.8 per cent., —57.5 to +111.5, and 169 per cent. The greater average ± error of distribution in my river test when these lateral collections are included is manifestly an expression of the effect of shore—an element not so pronounced in Reighard's tests. On this basis the limits and total range still remain less in the river test than in the lake.

From the data of transverse distribution in the Illinois River it is apparently demonstrated that, on the whole, the distribution is no more variable than it is in Lake St. Clair; and if we eliminate marginal collections and consider only channel waters, that is the middle two-thirds beyond 20 meters from shore, the variation falls considerably within the margin of error found in the lake, being in the six centrally located collections ±15.4 per cent. on computations per square meter of surface, and ±24 per cent. for the same on the basis of plankton per cubic meter.

The variation was also tested by counting the planktonts in the catch, with the resulting error in distribution of ±7.8 per cent. *for all ten catches*, with limits of —14.7 and +31.8—a total of 46.5 per cent.

The cross-section made below the mouth of Spoon River September 30, 1897, contains ten collections made at equal distances, about 12 meters apart, and the first and last this same distance from the east and west shores respectively. As will be seen in Plate XI., this was made after nine weeks of uninterrupted low water, when the river had been standing at 2 ft. for some time. The catches were made between 2 and 4 o'clock p. m. There was no vegetation in the river at this point in this season, though both Havana Lake and Quiver Chute, to the north (Pl. II.), contained a small amount. The discharge from Quiver Creek and Lake makes its way along the eastern margin of the river, while that of Spoon River under these hydrographic conditions hugs the western shore. The effect is seen in the turbidity records, the clearer water being on the eastern side and the more turbid on the western.

The following table gives the data of collection. There was almost no silt in the catch, and the silt estimates are therefore omitted.

PLANKTON IN CROSS-SECTION OF ILLINOIS RIVER BELOW MOUTH OF SPOON RIVER.

Number of collection.	Temperature (F.)		Depth in m.	Turbidity depth (in m.) disc visible	Plankton per m.^{3}, in cm.^{3}		Plankton under 1 sq. meter		Departure from mean in per cent. (omitting Nos. 1 and 2)	
	Surface	Bottom			Volume	Departure from mean in per cent.	Volume	Departure from mean in per cent.	Per m.^{3}	Under 1 sq. m.
1	71.5	70	.66	.35	2.40	−60	1.58	−83		
2	71.5	70	1.06	.33	3.88	−35	4.11	−57		
3	70.5	70	1.42	.35	5.40	−10	7.67	−20	−20	−32
4	70.5	70	1.58	.30	6.32	+ 5	9.99	+ 4	− 6	−12
5	70.3	70	1.58	.31	5.60	− 7	8.85	− 8	−17	−22
6	70.5	70	1.68	.25	7.64	+27	12.84	+34	+14	+14
7	70.5	70	1.83	.25	8.20	+37	15.00	+56	+22	+33
8	70.5	70	1.88	.22	7.40	+23	13.91	+45	+10	+23
9	71	70.5	1.83	.20	6.84	+14	12.52	+30	+ 2	+11
10	71.2	71	1.72	.15	6.28	+ 5	9.55	− 1	− 6	−15
Average					6.00	±22.3	9.60	±33.8	±12.1	±20.2

The results of this test are confirmatory of the thesis here maintained, namely, that the distribution of the plankton in a stream does not differ in the main from that thus far observed in lakes in the matter of variations in the plankton content (volumetric) in different localities. The average ± departures from the mean volume, computed per m.^{3} and under 1 sq. m., in these ten catches are 22.3 and 33.8 respectively, as compared with 31.8 and 28.8 for Lake St. Clair and 5.52 for the German lakes examined by Apstein.

The hydrographic conditions and the location of the test in the stream are responsible for a large percentage of this variation. Though the low-water levels cut off and reduce the diversifying action of impounding backwaters, the slight current minimizes the equalization due to mingling by the flow of the water in the channel, and, most of all, the location of the test just below the outlets of Quiver Lake and Spoon River (Pl. II.) involves the full effect of the diluent action of their relatively poorer waters. In Spoon River, on the day of the test, 3.12 cm.^{3} of plankton per m.^{3} of water was found (Table IV.), while in Quiver Lake on October 1 there was only .07 cm.^{3} per m.^{3} (Table V.). The discharge from Quiver Lake is reinforced by the seepage from springs along the eastern shore, and these diluents are probably the cause, to some extent, of the low plankton content in the two collections nearest the eastern shore—2.4 and 3.88 cm.^{3} to an average of 6. for the ten collections. The effect of Spoon River is seen in the much smaller decline in the inshore collection on that side of the river. Combined with the diluent action of these plankton-poor tributaries may also be the effect of shoal water and the horizontal stratification of the plankton.

If we eliminate from the test the two collections made in the marginal belt of spring-fed waters, 24 meters wide along the eastern shore, the ±departures from the mean fall from ±22.3 and ±33.8 to ±12.1 and ±20.2. These latter figures more truthfully represent the variation in distribution of plankton in channel waters including four fifths of the width of the stream—a lateral extension far beyond the range in that direction of the mid-channel collections of our chronological series which form the basis of the conclusions of the present paper.

The data concerning the local distribution of the plankton in the Illinois River in longitudinal and transverse directions presented in the preceding pages may be summarized as follows: The average ± departure from the mean longitudinal distribution in consecutive catches at the same point in the stream is 3.58 per cent; from a floating boat, 11.2 per cent.; at intervals of 1—7 days for periods of 2 to 5 days in the more stable hydrographic conditions, 14.1 per cent.; and in the stream as a whole for 200 miles of its course, 57 (total catch) or 89 per cent. (plankton estimated). If, however, we break up the 200 miles into four sections representing subordinate units of environment, each dominated by some local factor, the ± departures from the mean are 12, 51, 32, and 76 per cent. respectively for estimated plankton (i. e. after silt deduction), or 44, 5, 36, and 34 per cent. for the total catches, the averages for the two methods being ± 43 and ± 29.7 per cent.

The average departure from the mean catch in two transverse series of 10 catches each is ± 27.2 or ± 22.3 on the basis of plankton content per $m.^3$ If we eliminate the shallow-water shore collections, the departures fall to ± 21.9 and ±12.1, or on the basis of volumes under 1 sq. m., to ± 15.4 and ± 20.2. The departure from the mean number of planktonts is only ± 7.8 for the whole cross-section.

These results are in the main within the ± error of distribution of the plankton in lakes arrived at by similar methods of computation. *The plankton method may therefore be applied to the quantitative investigation of the life of a stream as legitimately as to that of a lake. The laws of the horizontal distribution of the plankton are in this respect essentially the same in both types of aquatic environment.*

Whether or not a fundamental source of error as large as this—probably the greatest of all the errors in the method as we have used it—vitiates the utilization of such data for scientific conclusions must be to some extent a matter of opinion. The extent to which it renders conclusions tentative must depend upon the distribution of the error, the extent of the data, and the method of their utilization. Personally I may say that close study of the at first sight aberrant data upon which this paper is founded, has led me to attach less significance to this source of error than I was at first inclined to do. Readers of the paper will, I believe, find that in the main the conclusions arrived at rest on a body of confirmatory data so large as to counterbalance to some extent the probability of vitiating error from this source. The distribution of the error is, moreover, continuous throughout the whole series of data, with, however, some probability of variation with the stability of the hydrographic conditions. Finally, the conclusions to be drawn in subsequent pages rest upon data which to a large extent rise above the level of the error resulting from the irregularity of distribution.

PLANKTON PRODUCTION.

1894

(Table III., Pl. VIII.)

Ten collections were made by the oblique-haul method in this year between June 12 and December 15. The volumes of plankton, silt, and total catch per cubic meter average 2.49, .28, and 2.77 cm.^{3} respectively. The maximum catch, 10.18 cm.^{3} per m.^{3} (plankton, 9.67; silt, .51) was taken Aug. 15, and the minimum, .25 cm.^{3} (plankton, .10; silt, .15), on Nov. 11. The series of ten catches form a somewhat regular curve, rising during July and August, and declining, most rapidly in September, to a minimum in October–December.

A comparison of the record of 1894 (Pl. VIII.) with that of other years (Pl. IX.–XII.). as shown in the accompanying table of averages (p. 292), and with the conditions of temperature and hydrograph, will serve to throw light on the significance of the plankton volumes of this first year of our collections.

As shown on pages 163 and 164, this was a year of normally located high and low water, with March, May, and September rises all so reduced as almost to eliminate overflow stages and to prolong low-water stages, resulting in the low average height of 4.63 ft. above low water. Our collections all fall in the stable period, broken only by the September rise. They therefore afford no data on the spring maximum of plankton production,

MONTHLY PRODUCTION OF PLANKTON IN ILLINOIS RIVER—SILT DEDUCTED—1894-1899.

	Jan.		Feb.		March		April		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Summary		
Year	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per. m.^{3}	No. coll.	Av. vol. pl. per m.^{3}	No. coll.	Av. vol. pl. per m^3. for the year.*	Av. vol. pl. per m^3. for the year.†	Total No. collections.
'94											0.74	2	5.12	2	9.67	1	1.36	2	0.61	1	0.10	1	0.10	1	2.53	2.49	10
'95			0.01	1			3.18	2			30.42	1	9.33	4	4.03	10	1.52	15	0.57	5	3.02	4	1.14	8	5.91	3.22	50
'96	0.01	9	0.02	4	0.07	5	5.67	5	1.30	9	0.72	8	1.44	15	1.12	14	0.38	2	1.11	2	0.02	1	0.76	2	1.05	1.16	76
'97			0.04	2	0.38	1	5.11	1	5.62	1	0.27	1	4.69	5	3.65	5	8.83	4	5.95	5	1.00	5	0.56	4	3.27	3.69	34
'98	0.45	3	0.27	4	0.33	5	4.40	4	11.30	5	3.96	4	0.58	4	0.91	5	0.69	4	0.24	4	0.25	5	0.99	5	2.03	2.13	52
'99	0.18	5	0.81	4	0.28	4																					13
Av.*	0.213		0.23		0.27		4.59		6.08		7.22		4.23		3.88		2.56		1.70		0.88		0.71		2.71		235
Av.†																										2.19	

*Of monthly averages.
†Of all collections.

revealing only a single midsummer pulse, culminating in the August maximum in a period of maximum heat and lowest water.

In the light of collections of later years in this and other localities it seems probable that collections at more frequent intervals would have yielded a curve of greater irregularity, with other fluctuations than the single one apparent in the present record.

It seems probable from the records of 1896 (Pl. X.) and 1898 (Pl. XII.) that the small average (0.74) in June is due to the fact that the dates of collection fall in a period of decline from an April-May pulse, hastened by the rise in May and perhaps reduced in volume by the relatively small contributions of impounded backwaters resulting from the depression of the spring flood. It may also be that the collection of June 29 exhibits the flushing, depleting effect of the rise of the preceding ten days. It will be noted that the collection of June 12 lies about four weeks after the crest of the May rise—a location which is attended in 1896, 1897, and 1898 (Pl. X.—XII.) by a decline to a minimum after a pulse of plankton development.

The hydrographic conditions of July in 1894—decline of flood to low-water levels—are approximately realized with varying stages of river and rates of decline in all the other years but 1895 (Pl. IX.-XII.). In 1894 they attend a tenfold increase in the plankton during this month. The movement of production is in the same direction approximately in July in 1896, 1897, and 1898, though its development is less in 1896 and 1898, and data are lacking for its progress in 1897. In 1894, and to a varying extent in other years, this rise attends among other factors the restriction of contributions from impounding backwaters and the differentiation of what might be called channel plankton proper. The July production in 1894 averages 5.12 cm.^{3} per m.^{3}—the largest, with the exception of that for 1895, of any year, and a fact to be correlated with the unusually stable conditions then prevalent.

In August of this year the single collection forms the apex of the season's production, reaching 9.67 cm.^{3} per m.^{3}—an amount not surpassed for this month in any subsequent year. It may also be correlated with the continuance of stable conditions. The nearest approach to this amount is found in 1897 (9.45 cm.^{3}, Table III.), likewise in stable conditions. It is not impossible that there is more than one culmination in the months of June and July, collections being at too great intervals to suggest the direction of the movement in production.

The flood of September attends a decline of the plankton to a minimum of .34 on the 17th in the fluctuations in level on the crest of the flood (Pl. VIII.). Similar direction of movement in production may be traced in 1895, 1896, and 1898. This decline in production attends the beginning of the autumnal decline in temperature, 10°–15° of which occur within this month.

The hydrographic conditions during the remainder of the year are exceedingly stable, there being a gradual rise of only .5 ft. from the middle of October until the middle of December. Beyond the insignificant rise in the October catch no movement in production is evident. A comparison of these scanty data with the curves of production in these months in 1895 and 1897, both with low-water autumns, makes it evident that collections in 1894 were too infrequent to serve as a basis for any conclusions as to the average autumnal production in this year, and raises the query as to whether considerable fluctuations of pulse-like character might not have run their course in the intervals between our collections. The higher averages in October–December in other years supports this suggestion. It is evident that the monthly interval of plankton collection is too infrequent to afford usable or significant data.

The average of the ten collections in 1894 is 2.49 cm.^{3}, and that of the seven monthly averages 2.53 cm.^{3} This is larger than the averages for a similar period in 1896 and 1898 (.99 and 1.09 respectively), both years of disturbed autumnal hydrograph. It is much less than that of the last seven months of 1895 (7.15). If, however, the exceptionally large collections of June–July be omitted in this year, its average (of monthly means) falls to 2.05. In the main, the hydrographic conditions in 1894 and

1895 in the last five months are somewhat alike, and their plankton production is somewhat similar (cf. Pl. VIII. and X.). In 1897, however, the uninterrupted and prolonged low water yields a much larger production of plankton (3.56 for the last seven months).

Though incomplete, the evidence in a general way indicates that 1894, in the period included in the collections, was a year of abundant plankton production, approximating 2.5 cm.^{3} per m.^{3} of water.

1895.

(Table III.; Pl. IX., XLIII., LI.)

Of the 50 collections of this year but 4 were made in the first six months. This was particularly unfortunate, for the spring was one of exceptionally low water, and the collections are so infrequent as to give only the faintest clue to the curve of plankton production in this important period. All of the collections were made by the oblique-haul or repeated vertical-haul method. Omitting the very unusual catch of June 19, the mean volumes of plankton, silt, and total catch per cubic meter are respectively 2.12, 1.88, and 4.01 cm.^{3} As an average, the proportion of silt in the catches is thus quite low—a fact explained by the absence of considerable floods during the period of most frequent collections.

As is shown on pages 164 and 165, this was a year of unusually low water, the mean annual stage of the river being 3.61 ft. The spring rise did not bring the river to much more than minimum bank height, and there was no June rise. Aside from a few minor meteoric rises to less than 6 ft. in July and September the low-water period was unbroken until the December flood culminating at 12.6 ft. at the close of the year A glance at Plate IX. will indicate that the collections suffice to trace the production during the last six months,—a low-water period with minor rises,—and to follow somewhat closely the effect of these hydrographic changes upon the volume of the plankton.

The isolated collection of Feb. 23, made beneath 37 cm. of ice at the close of a period (Pl. IX.) of ice blockade of approximately two months' duration, reveals an almost complete extermination of the plankton, the amount given in the table,. 01 cm.^{3}, being only an expression for an amount beyond the reach of our methods of measurement. As shown in Plates VIII. and IX., there was prolonged and quite stable low water from Oct. 15, 1894, till the flood of the last week of February of the following year which carried away the ice. The concentration of sewage under such conditions was shown by the stench of the water, by the departure of fish into tributary backwaters, and by the death of many not escaping. Unfortunately no chemical analyses of river water at this season are now available, and the chemical conditions can only be inferred from those in later years at times of briefer ice blockade, higher water, and presumably less contamination. For example, in January, 1898, following the low water of 1897, we find under ice of three weeks' duration (Pl. XI., XII., and XLIV., XLV.) great excess of free ammonia and chlorine, and high albuminoid ammonia, organic nitrogen, and oxygen consumed—all, indices of contamination. The ice sheet upon a contaminated stream must also profoundly affect the equilibrium of oxygen and carbon dioxide dissolved in the water, and thus directly influence the life of all constituents of the plankton. It is therefore not surprising that these unusual conditions should exterminate all but the most resistant members of the plankton. The catch consisted almost entirely of flocculent debris (zoglœæ?) with a few minute filaments of bluish green alga of uncertain affinities, while the usual plankton was represented by only 43 individuals, representing 14 + species, as follows.

Protozoa:

Difflugia sp. (deformed?)..........	1
Epistylis sp., heads...............	3
Carchesium lachmanni, head.......	1
Ciliate, indeterminate............	1
Heliozoan	1

Rotifera:	
Brachionus dorcas, female	1
Rotifer tardus, female	9
Polyarthra platyptera, female	2
Polyarthra platyptera, female with 1 egg	1
Indeterminate rotifer sp.	1
Entomostraca:	
Cyclops bicuspidatus, female, young, dead or moribund	1
Cyclops, young	2
Cyclops, nauplii	4
Canthocamptus, nauplii	4
Chydorus globosus	1
Miscellaneous:	
Rhabdocœl	1
Dero vaga	2
Indeterminate	7
Total	43

In towings made at the time of the quantitative collections Mr. Hempel found an individual each of *Pterodina patina* and *Notholca acuminata*.

The list includes representatives of the prominent winter planktonts excluding algæ and diatoms. The effect of the sewage contamination is observed in the reduced numbers both of individuals and species, in the moribund condition of *Difflugia*, *Carchesium*, *Epistylis*, *Brachionus*, and *Cyclops*, and in the fact that apparently the only breeding forms, with the exception of the *Cyclops*, were the ubiquitous and perennial *Polyarthra* and the muck-loving *Canthocamptus*, and possibly the slime-dwelling *Rotifer tardus*.

This incident affords a striking illustration of the catastrophic effect of the ice blockade upon the life of sewage-fed streams in whose waters the products of decay are concentrated by the exclusion of the air by the ice sheet.

The absence of collections in March prevents any tracing of the initial stages of the rise in vernal production indicated in later years, especially in 1896 and 1898.

The two April collections average 3.18 $cm.^3$—about 37 per cent. below the mean for this month in the three subsequent years. An inspection of the vernal plankton curves for this and subsequent years at this and other stations (Pl. IX.-XII., XXVI.-XXXIV., XXXVI.-XLII.) reveals the presence of a vernal volumetric pulse* of plankton, which, as a rule, marks the maximum period of production in the year, and follows immediately upon the vernal rise in temperature.

In 1895 our collections were too infrequent to detect the location and extent of this vernal pulse. In other years, as seen in the plates to which reference is made above, the best-defined vernal pulses appear in the closing days of April and the first week of May. From the character of the best delineated vernal pulses—e. g. those of 1896 and 1898 (Pl. X. and XII.)—it is probable that the apex or crest of the pulse is narrow, that is, the maximum development lasts but a few days. If this be the case, our two collections in April may miss entirely the period of culmination. The second collection, upon the 29th, would appear to be located at the probable season (temperature?) to detect the maximum development. If this be the case the vernal development of 1895 is much reduced, and might be correlated with the suppression of overflow stages and consequent reduction of contributions from the impounded backwaters. Two facts lead me to think that two well-developed vernal maxima may have been present in 1895. First, a comparison of the vernal pulses of 1896 (Pl. X.) and 1898 (Pl. XII.) indicates that the pulse of the former year culminates about

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*I use the term plankton "pulse" to designate the phenomenon of a periodic increase of the plankton volumetrically, as a whole, from a minimum to a maximum, followed by a decline to another minimum, the rise and fall being more or less gradual, and the data forming when plotted a more or less symmetrical curve, resembling that known as the "probability of error" curve. A typical example of this phenomenon and resulting curve is seen in the case of the April-May plankton of 1898 (Pl. XII.).

The term may also be applied to a periodic increase in individual members of the plankton similar in its graphic delineation to that of volumetric changes. The pulses will be designated by the months in which the major part of their course is run.

April 24 and that of the latter about May 3. The temperature curves of 1896 pass 60° about sixteen days before they reach that point in 1898. This may be the cause of the earlier culmination of the vernal pulse in 1896. Now in 1895 there is a suggestion in the temperature curve of an early spring, and the suggestion is borne out by the records of the U. S. Weather Bureau for central Illinois. The normal mean temperature for Illinois as a whole in April is 51.8°. In 1896 it was 54.8°. In this case we might expect to find an earlier vernal pulse culminating, as in 1896, before the end of April, so that our collection of the 29th would fall upon its decline rather than upon its apex. I use the term vernal maxima advisedly, for I am inclined to the view that the period from April 29 to June 19 witnessed a remarkable development of the plankton. The reasons for this view are found, first, in the fact that the catch of June 19 contains many *Moina micrura*, numerous males and epphippial females being among them, whose presence suggests the close of a period of rapid multiplication by parthenogenesis. The catch of June 19, though large, may thus represent the decline of a still larger population. In the second place, the qualitative collections made with a tow-net in the river in the interim between the quantitative collections of April 29 and June 19 indicate an exceedingly abundant plankton rich in *Moina*.

From the available data in 1895 and the course of the vernal production in other years it may be inferred with some degree of possibility, if not indeed of probability, that the vernal production in this year was accelerated by the early spring, and that a pulse appeared prior to April 29, and that this was followed in May-June by another pulse of much larger proportions and longer duration, a part of which (probably the decline) is detected in catches of June 19 and July 6. Of the occurrence of this latter and larger pulse there is little doubt, though the data are not available for its location and delineation.

The unusual and prolonged low water of these spring months thus seems to result in a marked increase in the plankton content. The causes which lead to this are not far to seek.

The decreased volume of water causes a relative concentration of the sewage and consequent increase in fertility of the channel water over that of the usual high water of this season. Lower levels insure more rapid rise in temperature, and the slackened current affords more time for the breeding of the plankton. The occurrence of *Moina micrura*, a lover of foul water, is in itself an index of the character of the stream in this low-water spring. The contributions of the impounded backwaters to the stream during this April–June period (see Pl. IX.), owing to the small areas submerged, are reduced in volume so that both the relative and actual share which they have in the formation of the channel plankton is probably less than in years of normal spring flood. Nevertheless, as seen in Plate XXXVI., such waters as Thompson's Lake tend by their run-off to enrich and increase the channel plankton.

The month of July (Pl. IX.) witnesses the rapid decline of the second vernal pulse from 29.68 cm.^{3} on the 6th to 6.8 on the 23d and .33 on the 29th—a fall of 98 per cent. in 23 days. The last stages in this decline were hastened by the rise of 3 ft. in the third week of July, the flushing and destructive action of the flood waters continuing until the close of the month.

In this and subsequent years I shall call attention—whenever the interval between collections is brief enough to afford adequate data—to the phenomenon of recurrent pulses of plankton production. I am led to make this emphasis by observing in the numerical analysis of these catches recurrent pulses in most if not all of the more abundant species, pulses, moreover, which exhibit a degree of concurrence in many species which I believe to be expressed in the faintly traceable volumetric pulses which run like waves, erratic in amplitude but more regular in interval, through the seeming vagaries of the volumetric data. I shall therefore treat the volumetric data from this point of view, endeavoring to discover evidence of cyclic production wherever it exists, and seeking to correlate this phenomenon with the more patent factors of the environment.

Considering, then, the data from July to the end of the year in 1895 (Pl. IX.), we find that the month closes at a minimum of .33 cm.^{3}—the end of a pulse of uncertain limits and the beginning of the next, which culminates in the third week of August. This August pulse is followed by one of less amplitude and duration, culminating about three weeks later, by one of slight amplitude in October, culminating at an interval of about four weeks, by one of greater amplitude in November, after an interval of about five weeks, and by one in December, also of considerable amplitude, at an interval of about four weeks.

The fluctuations of some of the component groups of organisms are shown in Plate LI., and considerable correspondence in the volumetric and statistical pulses will be apparent on comparison.

The *August pulse* has a duration of 39 days,—from July 29 to Sept. 9,—and a maximum amplitude of 7.63 cm.^{3} on August 24. The mean of the pulse,* that is the line upon which the center of gravity of the polygon formed by connecting the ordinants lies, falls upon August 22. This pulse occurs in a period of somewhat stable low water, and its decline from the maximum of 7.63 reaches 2.07 on Sept. 4 and occurs without the assistance of flood waters. On Sept. 5 a sudden minor flood, due to local rains, flushes the stream and completes the depletion of the plankton to .69 on the 7th. The August average for 1895, 4.03 cm.^{3}, is higher than that of any other year excepting 1894, in which but a single collection was taken, which may not be representative of the whole month. Freedom from rising flood waters in 1895 is doubtless one cause conducing to this high average of production. The enriching effect of the minor flood which culminated in the closing days of July may also contribute to this end. The absence of rises in May and June would also tend to increase the contributions of organic material to the stream by this July flood as compared with

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*The mean was computed by multiplying the volume of each catch in the pulse (ordinant) by the number of days from preceding minimum to date of collection (abscissa) and dividing the sums of the products by the sum of the catches in the pulse, the quotient being the abscissa of the mean.

floods which followed normal spring rises. The correspondence of the August pulse of plankton with a heat wave of 10° amplitude is well shown in Plate IX. Similar correspondences may be detected in some instances elsewhere in the plankton and temperature curves, but neither the completeness of our temperature data nor the corroborative evidence is sufficient to lend much support to a causal nexus between the phenomena.

The *September pulse* has a duration of 25 days,—from Sept. 7 to Oct. 2,—and a maximum amplitude of 3.25 cm.^{3} on the 14th. Its mean falls on the 17th, 26 days after that of the August pulse. This is a month of considerable hydrographic disturbance, the rises of the 6th, 17th, and 27th causing almost twice as much movement (8.75 ft.) in river levels (see Table I.) as is found in other years of our operations. These accessions of flood water in each instance attend a fall in temperature of 5° to 8°, though that on the 27th is combined with normal autumnal decline. None of the three is sufficient to cause overflow; and each is of but few days' duration. Their effect upon plankton production is, however, considerable. In the first place, the immediate result of the invasion of flood water is an instant decline in the plankton, as shown by the change from 2.07 on the 4th to .69 on the 7th, the flood in this case accelerating and perhaps continuing the normal decline of the August pulse. So also the little rise of the 17th checks the rising curve of production, the fall being from 3.25 cm.^{3} on the 14th to .89 cm.^{3} on the 18th. The rise of the 27th evidently occurs towards the minimum of a declining plankton pulse, and the fall from 1.03 cm.^{3} on the 25th to .37 cm.^{3} on Oct. 2 is of less extent. The location of these floods in the pulse is such that if my conjectures as to their reducing effect be true they cause a shifting of the apex of the curve and of the location of the mean to the left of their probable position had not the floods occurred. In technical phraseology the mode of the curve of this pulse exhibits left-handed skewness. In the second place, the general effect of these recurrent rises is a reduction in total production the extent of which can only be conjectured. It seems probable that the rise of the 17th is responsible for the suppression of a rising pulse whose culmination had not yet been reached. The slight recovery in the following week is indicative of the upward tendency in production thus interrupted. That continued low water in this month may attend great plankton production is seen in the records of 1897, when the monthly average (see table on page 292) is 8.83 cm.^{3} to 1.52 cm.^{3} in 1895. On the other hand, in 1896 and 1898 the disturbed conditions, with higher water and more current, are accompanied by much reduced production, averaging only .38 and .69 cm.^{3}

The last week in September witnesses the first stages of marked decline in temperature from the well-sustained summer heat of 75°–85°. The decline reaches 68° at the end of the month. This phenomenon combined with the last flood to accelerate and complete the decline of the September pulse which had already appeared prior to the last flood.

The *October pulse* has a duration of 29 days,—from the 2d to the 30th,—and a maximum amplitude of .76 cm.^{3} on the 11th and 15th, following a rise in nitrates and attending increased sewage contamination (Pl. XLIII.). Its mean falls on the 18th, 31 days after that of the preceding pulse. This is a month of stable low water approaching minimum levels, the total movement in the pulse period at Havana being only 1.03 ft. The temperature in this period falls from 61° to 45°, and this taken in connection with the fall of 11.5° in the preceding week brings to bear upon the plankton production of this month the cumulative effect of a decline of 27.5° and the results of the low temperature of 45°. The consequence is that the summer planktonts are killed off or reduced in numbers, and the winter planktonts have not as yet had time or temperature to reach any considerable development. The plankton production is therefore low; so low, indeed, that its pulse-like character is largely a matter of conjecture in the volumetric data (cf. statistical data on Pl. LI.). Phenomena of like character are to be detected at corresponding periods of autumnal decline in temperature in September-October, 1896; in October-November, 1897; and in October, 1898. The effect of this autumnal decline of temperature may also be traced in monthly averages of production in the table on page 292. Rapid decline in temperature is thus immediately followed by rapid decline in production in the channel plankton. Such correlation in decline of temperature and plankton cannot, however, be found as a general phenomenon in the bottom-land lakes (cf. Pl. XXX.–XLII.) and a causal nexus between the two declines must therefore be of limited operation and at the best highly conjectural. The operation of other factors than that of direct temperature is probable.

The monthly mean of production for October in 1895 is .57 cm.^{3}, approaching that of 1894 (.61) and 1898 (.24). In 1896 and 1897 it is much higher (1.11 and 5.95 respectively), an earlier decline of temperature in 1896 (Pl. X.) and a later one in 1897 seeming to shift accordingly the attending decline in plankton, so that the September (.38) and November (1.) averages respectively more nearly represent the October averages of 1895.

The *November pulse* has a duration of 35 days,—from Oct. 30 to Dec. 4,—with a maximum amplitude of 4.37 cm.^{3} on Nov. 27. Its mean falls on the 22d, 36 days after that of the preceding pulse. This is also a month of continued stable low water, with a slight rise of .75 ft., due to the checking of evaporation and to autumnal rains. The total movement is only .99 ft. at Havana. Temperatures during the first three weeks are somewhat stable for this season of the year, exhibiting a range of only 5.3°—from 48.5° to 43.2°. The last week, however, exhibits a fall of 10.2°, to minimum winter temperatures and the beginning of the ice blockade. Under these stable conditions the plankton production in November rises to a level approaching that of midsummer of the current year, its apex (4.37) falling 44 per cent. short of the August apex (7.63), and its average (3.02) 25 per cent. short of the August average (4.03). Both volumetric (Pl. IX.) and statistical data (Pl. LI.) demonstrate the rapid multiplication of the plankton in these stable conditions, and the result is a pulse of considerable amplitude, moreover, one not attained in any other year in channel plankton; a fact whose significance is apparent when we find (Pl. VIII.—XII.) that no other year combines to the same extent stability of hydrographic and thermal factors. The relative production in different years (see table on p. 292) bears upon the point in question, the monthly mean (3.02) being from 150 to 3 times as great as that reported for other years. The chemical conditions attending this remarkable plankton production (Pl. XLIII.) are those following increased sewage contamination, namely, a rise in nitrates, free ammonia, and chlorine.

The *December pulse* has a duration of 21 days,—from December 4 to 25,—the limits being taken from the statistical data (Pl. LI.), which are based only on catches at intervals of 5 to 7 days. Its maximum amplitude (2.60) occurs on the 20th, and its mean falls on the 16th, 24 days after that of the preceding pulse. The first 18 days of the month are relatively stable, with a movement in levels of only 1.05 ft. and stable minimum temperatures under the ice sheet. During this period a slightly developed pulse begins its course (cf. also Pl. LI.), but its apex does not rise much above the level of previous production. It is noteworthy that this takes place beneath the ice sheet which covered the upper river during the fortnight preceding the flood. It is in this month that the contamination noted in November reaches its maximum (Pl. XLIII.), at least as shown by nitrates and free ammonia. The chemical conditions thus favor a continuance of the productive activity of the previous month. On the 19th heavy general rains started a flood of unusual magnitude which continued to rise, culminating at 12.6 ft. at the end of the month. This raised the temperature about 9°, brought in an immense load of silt, flushed out the plankton, and increased the rate of the current so as to greatly reduce the time for breeding. The first two days of rising water did not materially change the quantity of plankton per m.^{3}, indicating a considerable rise in production had not the flood occurred. By the 25th, however, the flood waters had swept away all but a vestige of the rich plankton of the earlier weeks. The amount remaining was so small that its quantitative changes were swamped in the errors of the volumetric method and silt estimation. The large amount of silt carried in this and subsequent floods of the winter is due to the fact that bottom-lands and fields covered with a rich vegetation were now submerged for the first time in two years (Pl. VII.), and vast quantities of debris from this region and tributary streams now entered channel waters.

In comparison with other years December in 1895 is, in spite of its fortnight of flood, the most productive December recorded (see table on p. 292), averaging 1.14 cm^3 to .76 in 1896, .56 in 1897, and .99 in 1898. It shares the large development of the preceding month, and with it presents the most marked late autumnal development in channel waters, though falling far below the production of some of the permanent backwaters in this and other years in this season. The unusually stable hydrographic conditions in the river doubtless contribute in large measure to this exceptional development. That low temperatures alone do not prevent the development of a large winter plankton is apparent from this December development of 2.6 $cm.^3$ per $m.^3$ and 11.1 $cm.^3$ per square meter at temperatures but little above 32°.

The year 1895 as a whole may be summed up as one of midwinter stagnation followed by excessive spring and early summer development of the channel plankton, of midsummer and equinoctial floods, which check development at that season, of stable autumnal conditions and exceptional production in late autumn, and of catastrophic reduction by flood to a minimum. As a whole the year was one of exceptionally heavy production when expressed in terms of plankton per cubic meter. This is seen in the high average—3.22 $cm.^3$ of all catches, 5.31 $cm.^3$ of monthly averages. When *total production* is considered it may be that the decreased volume of water at the time of the maximum in the low water of June will at least counterbalance the excess per cubic meter, and that the *total production* will not exceed, if indeed equal, that of years of more normal hydrograph.

1896.

(Tables III., X. ; Pl. X., LI.)

There were 76 collections made in this year, of which 69 are prior to Sept. 1 and are, moreover, at intervals brief enough to enable us to trace the curve of plankton production with some degree of accuracy. In the last four months the fortnightly interval is too great to permit more than conjecture as to the probable course of the plankton curve.

The collections prior to May 22 were all the result of combining 4 to 9 repeated vertical hauls of the net. Subsequent to that date they were made with the plankton pump. This, as is shown on page 165, was a year marked by recurrent floods, which bring the average height for the year up to 6.98 ft. in a year of less than average rainfall. This is almost twice the average height (3.61) of the preceding year. Since the flood did not in most cases reach bank height, the overflows were not extensive and did not occur during periods of large plankton production (Pl. X.). The distribution of the collections with reference to the floods is such that we have again in this year the opportunity to test the effect of the access of flood water upon the curve of plankton production at all seasons of the year but the autumn months. In this year the vernal rise in temperature occurred abruptly in the middle of April, and the autumn decline began quite early but progressed slowly. Summer temperatures were also lowered somewhat by access of flood water.

The *plankton of January, February, and March* (Pl. X.) forms so small a portion of the total catches that its quantitative changes are swamped by the probable error of silt estimation, and are apparently of such slight extent that their significance cannot be detected. The amount of silt carried is very large, doubling or trebling in quantity on rising floods, and reaching a maximum of 14.77 cm.^{3} per m.^{3} on the crest of the March freshet. No recurrent pulses appear in the volumetric data, though the statistical data (Pl. LI.) indicate the recurrence of three such pulses in this period.

The volumetric production is very small throughout this whole period, rising above an estimated amount of .01 cm.^{3} per m.^{3} in only 7 of the 18 catches, and not exceeding .13 in any of them. This results in monthly averages of .01, .02, and .07 respectively for the three months (see table on p. 292). These are lower than those of any other years excepting only that afforded by the single collection of February, 1895. The cause of this slight production is, I believe, the high water and increased current resulting therefrom, which does not afford to the channel plankton the time requisite for breeding a more abundant plankton. Some corroboration of this view may be found in the fact that the February collections in the high water of 1897 (Pl. XI.) likewise yielded minute quantities of plankton (average .04 cm.^{3} per m.^{3}), while the channel waters of 1898 (Pl. XII.) in January and the early part of February, and of January–March, 1899 (Pl. XIII.), produced at stages below that of overflow (8 ft.) a more abundant plankton—.07 to 1.15 cm.^{3} per m.^{3} of water. High water with accompanying rapid current is thus deleterious to plankton production in channel waters, in midwinter at least. It is noteworthy that this minimum production occurs in the presence of nitrates in great excess, in fact in quantities larger than those recorded at any other period of our records. (cf. Pl. XLIII.–XLV.). It is not therefore for lack of nitrates and other products of decay that the plankton fails to develop.

The data of the collections in the latter part of March indicate a rising production as levels fall and temperature rises. The direction of movement is upward, though the quantity attained in this month is not great.

The interval of collections and the quantities of plankton obtained from March to September enable us to trace with some probability the course of the recurrent plankton pulses of this season.

The *April pulse* has a duration of 32 days,—from March 30 to May 1,—with a maximum amplitude of 9.39 cm.^{3} on the 24th.

Its mean falls on the 23d. This is the vernal pulse, often the largest of the year, this distinction being attained in 1896. It rises in 25 days from a minimum of .13 cm.^{3} on March 30 to a maximum of 9.39 on the 24th—an average daily increase of .37 cm.^{3} This pulse, as elsewhere, follows immediately upon the vernal rise in temperature, which in this spring reaches 72° on the day of the maximum of the pulse and passes from 46° to 66° a week prior to it. The maximum thus lies a fortnight after the most rapid vernal rise in temperature begins. It attends a sharp decline in nitrates and free ammonia, and its maximum coincides (Pl. XLIII.) with that in the organic nitrogen. It also occurs in a period of apparently stable hydrographic conditions, the total movement in April in this year being only 1.4 ft. less than in any other year. This stability is more apparent than real. The decline of the March flood (Pl. X.) was checked, and slight rises resulted from spring rains which brought large quantities of silt into the stream, so that movement in river levels is not in this instance a sufficient index of hydrographic stability. The result was apparently the suppression to some extent of the vernal pulse (cf. on this point 1896 and 1898, Pl. X. and XII.). The amplitude of this vernal pulse (9.39) is less than that of 1898 (35.68)—the only other year in which our collections are frequent enough to locate and delineate this pulse with sufficient accuracy. This may be due to the operation of one or more of the following factors. First, to the spring rains above referred to, at the time of the apparent maximum of the pulse, which flush it out and dilute it, and to some extent destroy the plankton. In the second place, there was no general overflow at this season, and plankton bred in the less current-swept, impounded backwaters is not entering the channel to the usual extent at this period of the year (cf. Pl. X. and XII.). Again, the periods of standstills in levels and those of rise check the outflow from impounding areas or turn channel water into the bottom-lands, conditions which obtained in 19 of the 30 days in April. Lastly, there is some possibility that the days of maximum production were not touched in our collections. The meteoric character of the vernal pulse of 1898 in channel waters (Pl. XII.) is indicative of such a possibility. If a greater production than that recorded did occur, it probably fell between the 17th and 24th—a period of non-interference by flood and of rising production.

The location of the apparent maximum in this year is significant. This was an early spring, the average of the surface temperatures in April in 1896 (see p. 171) being from 4° to° 11° higher than that in any other April represented in our records. The temperature of 70° degrees is attained almost a full month earlier in 1896 than in 1898 (cf. Pl. X. and XII.). The maximum production was recorded in 1898 on May 3; in 1896, on April 24, nine days earlier, and it may have antedated even this. Early spring thus affects the life in water much as it does that upon land. Vegetation bursts into leaf and insects multiply in field and forest in proportion to vernal rise in temperature; so in lakes and streams, in like response, the algæ multiply with meteoric rapidity, and the animal planktonts dependent on them follow in their wake. In 1896 the early vernal rise in temperature deflects the maximum of the vernal pulse to an earlier date by virtue of this response on the part of aquatic life to the environing factor.

The average production in April in 1896 (5.67) exceeds that in any other year of our records, in large part, it seems, because of the early spring and the deflection into that month of the maximum production, which in other years passed undetected or fell in the following month in consequence of later vernal rise in temperature, as in 1898.

The *May pulse* has a duration of 31 days,—from the 1st to June 1,—with a maximum amplitude of 3.56 cm.^{3} on the 13th. Its mean falls on the 15th, 22 days after that of the preceding pulse. There is in this month considerable hydrographic disturbance—a total movement of 7.5 ft., consisting of a fall of 3.1 ft. followed by a rise of 4.4. The maximum production oc- c urs during the decline in the earlier weeks, which is practically the run-off of the April rains which checked the fall of the March flood (Pl. X.). This is also a period of rising temperature, a rise of 12° (to 82°) attending the decline of river levels and the rising plankton production. The rising plankton pulse is, however, flushed out by the entrance of flood waters in the closing fortnight of the month. The plankton falls at once from 3.56 cm.^{3} on the 13th to .86 on the 18th with the first stages of the flood, and the fluctuations during the period of rise are erratic, suggestions of recovery and decline appearing in the data. These vagaries may be due to the distribution of local storms, which contributed largely to this somewhat slow rise in river levels. The general effect of the flood seems to be to depress the production and thus to deflect the apex or node and the mean of the curve of production to the left, that is, to an earlier date. The flushing effect of the floods of May, 1896, is apparently greater than that in 1898, as shown by the plankton production. The flood of 1896 did not exceed bank height. Its diluent action is thus concentrated in channel waters. In 1898 the floods occur in overflow stages and are thus diffused over a large area.

The chemical conditions show but little relation to plankton movement in this month. The maximum production follows immediately upon a rise in nitrates, nitrites, and free ammonia, and coincides with a slight decline in the two first named. The decline in production during the rising flood takes place along with considerable increase in nitrates and nitrites.

The average production in May, 1896 (1.30 cm.^{3}), is less than that of the following years (see table on p. 292), since it does not contain the vernal maximum, and also because it is reduced by flood action.

The *June pulse* is not well differentiated in the volumetric data, and its delimitation here becomes largely a matter of conjecture though it stands out more clearly in the statistical results (Pl. LI.). If we follow the latter the pulse terminates, at least so far as the chlorophyll-bearing organisms are concerned, in the last week of June. If, on the other hand, we delimit the pulse here as heretofore by minimum volumes, we shall find its later limit to be July 6, giving it a total duration from June 1, of 35 days. Its greatest amplitude, 1.68 cm.^{3}, occurs on the 11th, and its mean on the 14th—29 days after that of the preceding pulse. With the exception of the first three days this was a month of continuously falling river levels. The large proportion of silt in the catches and the fluctuations in the temperatures in the first ten days of the month suggest flood water of recent origin. Nevertheless, the maximum production of the pulse appears at the close of this disturbed period, a slight decline with little subsequent fluctuation in production marking the remainder of the pulse.

The average production in June, 1896 (.72 cm.^{3}) is low in comparison with that of 1898 (3.96), the only other year in which the June production is sufficiently represented in our records. In both of these years there was rapid and prolonged decline from previous flood, but in 1896 the proportion of contributions from impounded backwaters was much less than in 1898. Greater time for breeding plankton is thus afforded as a whole in 1898, and greater production follows. The maximum production coincides with the maximum of nitrates (Pl. XLIII.), though it attends a depression in nitrites and free ammonia. The general low production of this month occurs in the presence of an unusual quantity of nitrates, so that one at least of the important elements for production was not lacking.

The *July pulse* has a duration of 19 days,—from the 6th to the 25th,—with a maximum amplitude of 2.24 cm^3. on the 20th. Its mean also falls on the 20th—36 days after that of the preceding pulse. This is a month of considerable hydrographic disturbance, the total movement in levels being 7.7 ft.—a fall from 5.2 to 2.5 followed by an interrupted rise to 7.3. The pulse lies in the middle of this period and falls under the influence of both fall and rise. During the period of decline the recovery of the plankton from its minimum of .26 on July 6 progresses irregularly to a slight maximum of 2.24 on the 20th during a very rapid rise caused by a Spoon River flood (Pl. II.) which, while not invading the stream above its mouth to any great extent, held back the water from the upper river. The greater part of the rise in the latter part of the month was due to the access of water below the plankton station or in remote headwaters, and is thus a reflection of the rise in the lower river or distant tributaries. The freedom from silt apparent in the catches bears testimony to this fact. The pulse reaches its culmination and declines in this rising flood.

The average production for July in 1896 (1.44 cm.^{3}) is less than that in any other year save 1898, and that, too, in what seem to be favorable hydrographic conditions. The sharp decline in nitrates (Pl. XLIII.) from 2.8 to .4 parts per million may be a factor in the small production.

The *August pulse* has a duration of 27 days,—from July 25 to August 21,— with a maximum amplitude of 3.90 cm.^{3} on July 30. Its mean falls on the 5th, 16 days after that of the preceding pulse. This was predominantly a month of falling levels. The culmination of the rise at 8.6 in the first six days is followed by a steady decline reaching 5.8 on the 31st, broken only by the slight interruption in the middle of the month. The total movement is 3.7 ft., and the total at Copperas Creek (4.60) is somewhat above the average (4.06). The disastrous effect of the local floods at the culmination of the rise which flushed out the rising plankton pulse is apparent in the decline from 3.90 cm.^{3} on July 30 to .40 on Aug. 1, and in the introduction and continuance of a considerable volume of silt. The rapid recovery of the plankton is seen in the rise from a minimum of .26, .48, and .32 on Aug. 3–5, to 1.08, 2.40, and 2.60 on Aug. 6–8. These data suggest the intercalation of barren flood waters of recent and local origin in the course of channel waters bearing a much more abundant plankton, and the apparent result is a cleft in the otherwise somewhat symmetrical curve of production of this August pulse. It also results in an apparent shifting of the node and means of the curve to the left, giving a left-handed skewness to the curve. Aside from this depression due to flood there is a general decline in production as levels fall, the pulse closing on the 21st with a minimum of .28 cm.^{3} This decline in production is attended by a steady rise in nitrates, organic nitrogen, and free ammonia (Pl. XLIII.), and thus in the presence of increasing nutriment, as well as growing hydrographic stability—that is lower river levels. The two summits of production in this pulse coincide with temperature pulses. The plankton and temperature pulses are alike set off by flood waters, and the causal nexus may lie between plankton and flood rather than between plankton and temperature. The location of the flood also has the effect of lowering the average production of the month to 1.12 cm.^{3}—the lowest average on record, excepting only 1898 (.91), also a year of much disturbance.

From this point the remaining collections of 1896 are too infrequent to delineate or even to suggest recurrent volumetric pulses. They are also insufficient to adequately trace the results of hydrographic changes. Diminished production at the time of rapid decline of temperature is apparent late in September. Increased production follows declining flood and stable temperatures and a downward movement of nitrates (Pl. XLIII.) in October, and the phenomenon is apparently again repeated in December, though the volumes do not equal those of the preceding year.

As a whole, 1896 was a year of but slight plankton production, averaging only 1.16 (average of all catches) or 1.05 (average of monthly averages) cm.^{3} per m.^{3} This is only a half or a third that of other years in our records (see table on p. 292). The silt, on the other hand, is more abundant than in any other year, averaging 2.55 cm.^{3} per m.^{3} to .28, .72, 1.91, and 2.11 respectively for 1894, 1895, 1897, and 1898. The total movement in levels for this year at Copperas Creek is 53.16 ft., an excess of that in all other years but 1898 of 4 to over 40 per cent. (Table I.). From this fact, and from the evidence accumulated in the detailed discussion, it is apparent that the oft-recurrent floods of this year are responsible in large degree not only for the increased silt but also for the reduced production of plankton. The floods of this year were not only more numerous, but they were also more effective as reducing factors, since they rarely reached stages of considerable overflow, So long as the flood does not exceed bank height its flushing action is concentrated in channel waters, and impounded backwaters do not contribute so largely to channel plankton, nor are they so immediately connected with the channel on account of the bank development along the stream. The floods of 1896 were of such a character that they continually flushed the channel without at any time, except midwinter, forming any large body of impounded water in which the plankton had time to reach any marked development. Although there was a plankton in the backwaters—e. g. Thompson's and Phelps lakes—which was more abundant than that in the channel (see Pl. XXXVII. and XL.), contributions from such areas to the channel plankton are relatively small owing to their slight connection with the stream in this year.

As shown in Table X., the average amount of nitrates in 1896 is 2.34 parts per million; in 1897, 1.66; and in 1898, only.81. The smallest production of plankton observed in the years covered by our data has thus taken place in water richest in nitrates. Other forms of nitrogen than the nitrates vary in the same general direction with these. It seems probable that nitrates, or available nitrogen generally if not, indeed, nutrition as a whole, are less dominant in determining plankton production in our waters than other environing factors, as, for example, in this instance, hydrographic conditions, or, more specifically, current in its relation to time for breeding.

1897.

(Tables III., X. ; Pl. XI., XLIV., LII.)

There were 34 collections in this year, of which 6 were made at intervals of about a month from February to July, and the remainder at approximately weekly intervals, or less, during the remainder of the year. All of the collections were made with the plankton pump. This was a year of high winter floods, a normal March rise, a belated June rise, but prolonged low water throughout late summer and autumn. The collections afford a good opportunity to observe the result of prolonged low water and a late autumn.

From February to July the collections are too infrequent to enable us to trace the curve of plankton production or detect any cyclic movement. Of the two collections in February the first was made under the ice sheet and yielded little plankton or silt. The second, made while the ice was going out, contained much more silt—the result of the rising flood. Both were very poor in plankton (.03 and .05 respectively), but neither showed the least evidence of stagnation conditions such as obtained in 1895. This was due to the larger volume of water and the swifter current and greater dilution of sewage, as well as to the briefer ice blockade and the direct connection of channel waters with the vegetation-rich bottom-land lakes and forests when the ice was full of air-holes, so that the equilibrium of gases in the water did not undergo so violent a disturbance as in 1895.

In the March collection there is evidence of the increasing production as vernal temperatures approach. The collections of April and May were both made on the decline of the March flood, and both lie at temperatures between 60° and 70°. This spring presented ideal conditions for a very large plankton production, namely, uninterrupted decline, with run-off of impounded backwaters in which the plankton had had abundant time to breed. Neither of our vernal collections shows any large production, though that of April lies in the period in which the vernal maximum may be expected. It is not improbable that a maximum occurred but was not detected. The June collection lies in the midst of turbulent flood waters, as the great proportion of silt (26.33 $cm.^3$ per $m.^3$) indicates.

From this point until the close of our operations in March, 1899, the weekly interval of collection was adopted, and the data accordingly afford opportunity to trace the cyclic movement in production in this period.

The *July pulse* has a duration of 32 days,—from June 28 to July 30,—with a maximum amplitude of 8.16 $cm.^3$ per $m.^3$ on the 14th. Its mean falls on the 20th. This was a month of falling river levels with slight interruptions by local rains, of rising temperature and of falling nitrates, but of increasing sewage contamination (Pl. XLIV.) as shown by the rising chlorine and oxygen consumed. The pulse presents a very sudden drop in production from 6.40 $cm.^3$ on the 16th to .92 $cm.^3$ on the 21st, followed by an immediate recovery to 6.91 on the 23d. I am at a loss for a satisfactory explanation of this fluctuation. There is no change in levels at Havana (see page 160) which suggests flood, though there is a slight increase in turbidity (Table III.) and was a rise of .1 ft. at Copperas Creek on the 20th which does not appear in the Havana gage readings. The chemical analysis of the sample taken on the 21st (Table X. and Pl. XLIV.) contains evidence of some disturbance in conditions. There is a sharp decline in nitrates, nitrites, and oxygen consumed, with a check in the rising chlorine, while free and albuminoid ammonia and total organic nitrogen move upwards. Had the oxygen consumed risen and the free ammonia fallen, all indices would point toward access of recent storm water carrying silt into the stream and locally diluting the plankton, though not materially affecting the hydrograph. In any event the fluctuation in production is correlated with a localized disturbance in chemical conditions suggesting in some particulars restricted access of recent storm waters.

The average production for this month (4.69) is higher than in any other year excepting 1894 and 1895, due it seems to the somewhat stable conditions of continued decline in levels, with slight overflow sufficiently prolonged (3 weeks at 6 ft.) to afford time for breeding plankton in the waters of overflow, though apparently similar floods in 1896 resulted in much lighter production (Pl. X.). The main difference in hydrographic conditions between the summer floods of 1896 and those of 1897 lies in the fact that in the latter year a great spring flood preceded the summer floods. This, it seems, might occasion the difference in summer production apparent on comparison of these two years. The slowly receding spring overflow of 1897 seeded the submerged territory with cysts, spores, and resting stages of the planktonts which afford the basis for rapid production upon the next flood invasion. In 1896 the summer floods follow a period of two years in which there had been no prolonged overflow in a period of marked plankton production. The overflowed lands were thus not recently seeded, and production was longer in gaining headway in 1896 and did not attain the same amplitude.

It is to be noted that this pulse arises in declining nitrates and falls away as the temperature rises.

The *August pulse* does not reveal itself plainly in the volumetric data, though it stands out more clearly in the statistical curves (Pl. LII.). Adopting these as a clue to its limits, the pulse has a duration of 25 days—from the 30th of July to Aug. 24. The volumetric data would apparently terminate it on the 17th and limit it to 18 days. Its greatest amplitude is 2.02 cm.^{3} per m.^{3}, attained on both the 3d and 10th. Accepting the shorter interval, the mean falls on the 10th, 21 days after that of the former pulse, while with the longer interval it is on the 14th—24 days after the preceding mean. This is a month of remarkably uniform production, the departure from the mean in no case exceeding 26 per cent. It is accompanied by stable hydrographic conditions, the total movement being 2.2 ft., most of which occurred in the first week. After a heat pulse in the first week the temperature conditions were also stable, while in the chemical conditions there is but slight change. The chlorine increases as the sewage contamination rises with decline in levels. The absence of any marked maximum in this month is evidently due to the fact that the animal plankton which forms the greater part of the volumetric pulses has not greatly fluctuated as a whole. The occasion for this may be detected in the slight wave of the chlorophyll-bearing organisms (Pl. LII.), which in comparison with the wave of July and September is indeed diminutive. There is, however, nothing in the chemical data to explain this suppression of the pulse of the chlorophyll-bearing organisms.

The average production for this month as a whole, 3.65 cm.^{3}, is large, though not so great as that of 1894 (9.67) or 1895 (4.03), both, like 1897, with stable conditions. It is, however, greatly in excess of the production in 1896 (1.12) and 1898 (.91), when August floods flushed out the stream.

The *September pulse*, on the other hand, is very well defined. It has a duration of 35 (28) days,—from Aug. 17 (24?) to Sept. 21,—and a maximum amplitude of 19.80 cm.^{3} per m.^{3} on the 14th. Its mean falls on the 9th (10th), 30 (27) days after that of the preceding pulse. As a whole, this is a month of great stability. The total movement of the hydrograph is only .4 ft.—the smallest monthly movement recorded at Havana during the years of our operations, and but rarely surpassed in many years at Copperas Creek (Table I.). Most of this movement—Sept. 3–10—was due to the flash-boards placed upon the LaGrange dam. The chemical conditions also are in the main remarkably uniform, the only aberrant movement being the constant upward tendency of the chlorine (Pl. LII.)—an index of the increasing proportion of sewage in the stream. There is, however, no proportional increase in the various forms of nitrogen, though they all exhibit a slight upward movement. The temperature is sustained at summer heat (80°+) till the middle of the month, dropping 10° in the third week.

The plankton, however, exhibits considerable fluctuation, rising to a maximum of 19.80 cm^3. per m.^{3} on the 14th, and falling again to 3. on the 21st, at the rate of 2.4 cm.^{3} per day. This is the maximum record for this year, though, it may be, not equaling the undetected vernal maximum. It is also the largest volume recorded in any year after the first week in July. Contributing causes for this exceptional development are to be found in the stable conditions and concentration of fertilizing materials attending low water. This is the month of greatest production in 1897, and also the one of lowest unutilized nitrates, the latter not exceeding 1 part per million during the month. It is in the rising chlorine (Pl. XLIV.) that we have a suggestion of the degree to which sewage has made contribution to the stream. The unutilized nitrates do not of course afford a measure of its quantity.

The *October pulse* has a duration of 42 days,—from Sept. 21 to Nov. 2,—with a maximum amplitude of 12.92 cm.^{3} per m.^{3} on the 5th. Its mean also falls on the 5th, 26 (25) days after that of the preceding pulse. This extended volumetric pulse is found to include within its limits two of the pulses of chlorophyll-bearing organisms (cf. Pl. LII.), one culminating Sept. 29 and the other Oct. 19. The month was one of continued hydrographic stability. The total movement in levels was only .5 ft., due mainly to the check in evaporation resulting from decline in temperatures. The temperatures in this month average about 64.5°, which is 6° to 8° higher than the average in other years of our records. The difference between the extremes is only 17° as compared with 23° in 1896 and 27° in 1898. The autumnal decline in this year has come later and progressed less rapidly, at least till the last ten days of the month (Pl. XI.), than is usually the case. The curve of the October, as well as that of the September, pulse is delimited on either side by declines in temperature.

The chemical conditions in this month (Pl. XLIV.) are less stable than in September. The nitrates and nitrites move inversely with the plankton, and both chlorine and free ammonia ascend rapidly to unusual heights, suggesting the presence of sewage in which decay had not yet progressed as far as was wont during warmer weather. This is doubtless the result of the Peoria sewage pulse, which as winter approaches extends down stream toward Havana, and under the stable low-water conditions of 1897 appears in exaggerated form.

In view of the stable conditions, excessive fertilization by sewage, and abnormally high temperatures, it is not surprising that the production in this year exhibits a monthly average (5.95 cm.^{3}) 5 to 25 times (see table on p. 292) that found in the same month in other years.

The decline at the close of this pulse to .06 cm.^{3} on Nov. 2 reaches the lowest point recorded after the midwinter-flood conditions of the previous February. This decline is abrupt and complete, and is followed by a recovery in production of apparently normal proportions. The prime cause may lie in the cyclic growth and reproduction of the planktonts in which an "internal" factor may be dominant, or it may be due to the operation of one or more external factors in the environment or to the combined action of internal and external factors. What external factors can be cited to "explain" this abrupt decline in production in the midst of these apparently stable conditions? In the first place, the minimum record (.06 cm.^{3}) was made when the autumnal decline had reached 54° (a little below the yearly average), and after a decline of 25°+ from the summer heat of 80°+. The cumulative effect of this change in temperature is suggested, and similar declines in production during or towards the close of the autumnal decline in temperature in other years may be cited in corroboration of this conjecture. The recovery in production in this year in the face of the cumulative effect of further decline may not weaken the force of this conjecture, since it occurs at a time of change in the constituent organisms of the plankton. This minimum of production is, then, a period of readjustment between summer and winter conditions. Again, in the chemical conditions the pulse of the nitrites (Pl. XLIV.) and chlorine, and the steady rise in free ammonia may indicate conditions which compelled a readjustment of the fluviatile population and resulted in a temporary decline in production. It is not, however, a simple matter to find corroborative instances in the records. It may be that we have in this marked decline at the close of this pulse an instance of combination of the internal (cyclic) factor on the part of the constituent organisms and several depressing agencies in the environment, whose united effect is this almost complete but temporary suppression in production.

The *November pulse* has a duration of 21 days,—from Nov. 2 to 23,—with a maximum amplitude of 1.86 cm.^{3} per m.^{3} on the 15th. Its mean falls on the 16th, 42 days after that of the preceding pulse. The limit between this and the December pulse is not well defined in the volumetric data, and any treatment from the cyclic standpoint seems arbitrary. The end of the pulse might as well be regarded as Dec. 7, in which case its duration is 35 days and its mean falls on the 21st, 47 days after the preceding one. The conditions during this month are not so stable as during September and October. The autumn rains, though slight, cause a movement in levels of 2.1 ft. and introduce considerable silt into the stream. These are insufficient to flush out the river or to materially reduce the sewage contamination. There is some decline in chlorine (Pl. XLIV.) and considerable in nitrites, but the free ammonia continues to rise rapidly, indicating much organic material in process of decay. The nitrates also show much increase. The temperature decline to the winter minimum is completed. The production rises, however, in these conditions from .06 to 1.86, and continues at a fair volume for this time of the year throughout the last half of the month, bringing the monthly average up to 1. cm.^{3} per m.^{3}—an amount surpassed only by the heavy production of 1895 (3.02 cm.^{3} See table on p. 292). This is also a year of stable November hydrograph. It may be noted that the maximum accompanies a pulse of nitrates and a check in the falling temperature , and that the decline on Dec. 7 attends a drop to the minimum beneath the forming ice.

The *December pulse* has a duration of 21 days,—from the 7th to the 28th,—with its greatest amplitude of 1.22 cm.^{3} per m.^{3} on the 14th, and its mean on the 16th—30 (25) days after that of the preceding one. This is likewise a month of stable hydrographic conditions, the total movement in levels being only 1.1 ft. The ice-sheet covered the river during most of the month (Pl. XI.), with a slight break with rising levels in the second week. This closing of the river conduced to stagnation, as is shown by the chemical conditions (Pl. XLIV.). The free ammonia rose from a normal of less than 1 part per million in October to 5.6 on the 28th—the maximum record for all the analyses (Table X.). This is attended by slight increase in the oxygen consumed and the albuminoid ammonia as well as in the total organic nitrogen, all of which betoken the approach of stagnation. This is reflected in the fall of the plankton production to .03 cm.^{3} per m.^{3} on the 28th. The extermination of the plankton did not approach that of Feb. 23, 1895, though there was a marked decrease in the number of planktonts excepting only in stagnation ciliates. Temperatures during this month were at the winter minimum of approximately 32°, with only a slight increase to 36° with the rise of the second week. The plankton of this December in average production (.56 cm.^{3}) falls below that of all other years with the exception of the inadequately represented 1894. This relative falling off results, it seems, from the near approach of stagnation, due to sewage which the stable low water permitted under the ice-sheet.

As a whole, 1897 was a year of heavy plankton production when measurements are stated in plankton per cubic meter (3.69 cm.^{3} if all collections are averaged; 3.27 cm^3., mean of monthly averages). If, however, we consider the slackened current and reduced volume of the discharge of the stream, it is evident that the *total* production may not be greatly, if at all, increased during the low-water period of high plankton content. The vernal production, judging from results in similar conditions in 1898, was possibly very large. It is evident on comparison, that our isolated vernal catches do not adequately represent the vernal production, and, furthermore, that the vernal maximum may have exceeded that of the low-water period in plankton content. Fuller representation in this period would doubtless have raised the yearly average. The high water, rapid current, and large discharge at this period combine to make the production in these conditions relatively very great, as compared, for example, with that of 1896, when the impounding action of the reservoir backwaters was slight, current and discharge reduced, and plankton content below the normal. The effect of prolonged low water, with its attendant stability, is shown in increased plankton content, and in the increased contamination by sewage, which under the ice results ultimately in stagnation and great reduction of production.

1898.

(Tables III., X.; Pl. XLV., LII.)

As shown on page 167, this is a year of normally located spring floods of considerable amplitude followed by a disturbed summer and a considerable autumnal rise. It accordingly affords our best opportunity for tracing the vernal movement of production in flood conditions, and also another chance to note the effect of floods at times of reduced flow of the stream. Both vernal and autumnal changes in temperature came on gradually, and chemical conditions were free from catastrophic fluctuations. The collections of this year number 52, all at weekly intervals excepting only in January, when the regular interval is slightly varied. They are without exception pump collections. The interval between collections is so brief that the cyclic movement can be traced, as a rule, and this point of view will continue to control the discussion, though in this year the suppression of production by floods increases the element of conjecture in this method of treatment.

The *January pulse* has a duration of 28 days,—from Dec. 28 to Jan. 25,—with a maximum amplitude of .81 cm.^{3} per m.^{3} on the 21st. Its mean falls on the 22d, 37 days after that of the preceding pulse, This is a period of stagnation followed by a small flood which carried off the ice-sheet. A fall in temperature immediately closed the river again, and levels fell only to continue again an interrupted rise during the last fortnight, carrying the imperfect ice-sheet with it, but not breaking it up and carrying it out (Pl. XI. and XII.). This second rise removed the stagnation conditions in the third week, producing a sharp decline in chlorine and free ammonia (Pl. XLV.) toward a normal status. There is also a fall in the several forms of organic nitrogen and a rise in nitrates and in the oxygen consumed,resulting from the introduction of storm waters and silt. The temperatures remain at or near the winter minimum, rising slightly with access of storm water. The total movement in levels is 6 ft., but the rise is so gradual that a considerable development of the winter plankton appears. This brings the monthly average up to .45 cm.^{3} per m.^{3}, an amount over twice that recorded in 1899 and forty-five-fold greater than that in the flood of 1896. The occasion for the greater production in this year is, it seems, the greater enrichment of the waters (though not in nitrates), the lower levels, and the slighter current, the latter affording time for breeding even upon the slowly rising flood. The same or even less rate of rise at higher levels—e. g. 1899—would be attended by a more rapid current with lessened time for production.

The *February pulse* has a duration of 35 days.—from Jan. 25 to March 1,—with a maximum amplitude of .67 cm.^{3} per m.^{3} on the 3d. Its mean lies on the 7th, 16 days after that of the preceding pulse. This is a month of almost continual rise, there being only a slight cessation in the first week. The total movement in levels is 5.1 ft., of which the greater part is above bank height, and leads to extensive overflow. The large amounts of silt carried (Pl. XII.) testify to the extent of the overflow and the access of flood waters of recent origin. These result in a continued reduction in free ammonia and chlorine, both of which reach approximately normal levels at the close of the month. Nitrates rise with access of flood waters, and the nitrites continue to decline, while the oxygen consumed and organic nitrogen rise with the increase of silt. Temperatures remain at the winter minimum throughout the month, and an imperfect and disintegrating ice-sheet covers the stream during a part of the month. The effect of the rising levels, access of recent flood waters, increased current and great volume of silt is seen in the falling off of the plankton content to a minimum of .02 cm^3. per m.^{3} on March 1. The incipient pulse of production of an amplitude exceptional for this season is thus washed out, and the apex and mean of the pulse are shifted to the left. Flood conditions thus check the winter production and reduce the monthly average to .27 cm.^{3} per m.^{3} This occurs in the presence of an increasing abundance of nitrates (Pl. XLV.). This monthly average is much higher than that of 1896 (.02) under somewhat similar conditions. The levels and amount of movement are about the same in both years (cf. Pl. X. and XII.), but antecedent conditions differ. In 1896 there is six weeks of flood before February, but in 1898 the flood begins but a fortnight before. The cumulative effect of its flushing action is thus less developed in 1898, and production is greater under similar immediate conditions. It is, however, but one third as great as that of February, 1899, a month of falling levels.

The *March pulse* has a duration of 28 (42) days,—from the 1st to the 29th (or Apr. 12),—with a maximum amplitude of .77 cm.^{3} per m.^{3} on the 22d. Its mean falls on the 22d (or 26th), 43 (or 47) days after that of the preceding pulse, Levels decline in the first week of March, but thereafter rise rapidly and continuously to a maximum of 18 ft. on Apr. 2—a point not surpassed during our operations. The total movement in March is 7.5 ft., and the result is complete overflow following the introduction of vast amounts of flood water of recent origin. As a result of this, chlorine and free ammonia reach a flood minimum, and the nitrates decline, the excess since previous heavy rains having been leached out from the water-shed. Other forms of nitrogen decline or remain stable, and the oxygen consumed falls as silt declines. Owing to the great expanse of the stream, tributary waters enter more into impounding backwaters and drop their burden of silt there, so that channel waters are now much freer from it than in the earlier stages of the rise. Temperatures begin the vernal ascent, passing from the winter minimum to 50°. In keeping with this and in the presence of rising flood and rapid current the plankton production begins its vernal increase, attaining an average of only .33 cm.^{3} per m.^{3}—about the same level of production as that in

1897 (.38) and 1899 (.28), and much more than that in the more stable conditions but lower levels of 1896. Our collections in 1896 and 1898 (cf. Pl. X. and XII.) are frequent enough to afford a basis of comparison of the two years. The very small production in the former year (.07) as compared with the five-fold greater product (.33) of the latter may find its explanation in the earlier rise in temperature in 1898. In this year the average temperature of surface water is 43.3° ; in 1896, only 39.5°. In 1898, 40° is passed on the 10th; and in 1896, on the 23d.

The two summits on March 22 (.77) and Apr. 5 (.53) are due to the separation by a fortnight of the rotiferan and entomostracan maxima. The later limit, Apr. 12, may therefore be regarded as the probable end of this volumetric pulse, and it might therefore be designated as the March-April pulse. It is noticeable that the decline in this pulse follows, at a week's interval, upon a check in the rising temperature (Pl. XII.). On April 22 the temperature (see Table III.) is 51° ; a week and a fortnight later it is respectively 49.5° and 48.3°. It rises to 52° on the week following. The plankton production declines from .77 cm.^{3} on March 22 to .43, .53, and .13 respectively in the three weeks following. The fluctuations in production during the month seem to show a very close interrelation between production and temperature at this degree of heat and season of the year.

The *April-May pulse* has a duration of 49 days,—from Apr. 12 to May 31,—with a maximum amplitude of 35.68 cm.^{3} per m.^{3} on May 3. Its mean falls on May 5, 44 (40) days after that of the preceding pulse. The months of April and May are both months of very high water, the level falling below 4 ft. on but four days in the latter month. This stage of the river, exceeding bank height, results in wide-spread overflow and fullest communication between channel and backwaters. The total movement in April and May was 6.7 and 5.9 ft. respectively. The month of April, with the exception of the first day only (see page 161), witnessing a rapid and unbroken decline from 18 to 11.4 ft., the decline continuing till May 15, when an early

"June rise" set in, which culminated at 13.8 in the last week of May. The high levels, the rapid fall, and the subsequent rise are all associated with strong current and rapid replacement in channel waters. The early vernal rise in temperature noted in March did not continue with like rapidity. The rise from 33° to 51° occurred in 21 days, while that from 49.5° to 73° takes 49 days. In 1898, 70° is attained on May 19, while in 1896 it is reached 27 days earlier. The result of this delay in the vernal rise is seen in the shifting of the vernal maximum from April into May in 1898.

The chemical conditions throughout this period are remarkably uniform. The great plankton wave of the 3d is accompanied by but the slightest ripple in the nitrogenous matter in the stream, a slight drop in the nitrates and rise in the free ammonia being the only attendant phenomenon (Pl. XLV.).

The average production in April, 4.4 cm.^{3} per m.^{3}, is slightly below that of the two years preceding (5.67 and 5.11) as a result of the delay in the vernal rise and consequent shifting in the vernal maximum, and the May average (11.30) is for the same reasons much in excess of that in these earlier years (1.30 and 5.62).

The maximum of this vernal pulse (35.68 cm.^{3}) is the largest plankton content noted by us in channel waters. The conditions which environ this pulse are therefore of more than passing interest, since they must be potent factors in determining production. Since the cyclic character of plankton production is apparent throughout the greater part of our records, we are not here concerned with those factors which operate to produce this *series* of recurring waves of production, but only with those whose influence is potent in bringing about the unusual amplitude of this vernal pulse.

In general we may group the important environing factors under the heads of chemical, thermal, and hydrographic conditions. From all that has been said in previous pages regarding chemical conditions it is not probable that they are immediately the occasion of this great development. An analysis of the conditions prevalent during this pulse (Pl. XLV.) does not reveal anything peculiar to this season. The nitrogenous substances are neither greater nor less than at other times when production was at a minimum. It is only evident that there is an overplus of these substances in which all correlation between chemical and plankton contents of the stream is lost. The slight quantitative rise in nitrates (.75 to 1.1 parts per million) a week prior to the culmination of the plankton pulse (Pl. XLV.) may contribute to the increase, but similar rises in nitrates elsewhere are not followed by like results. We may therefore dismiss chemical factors—in so far as our data reveal them—as affording only the basis of nutrition, but neither revealing nor explaining their meteoric utilization in this remarkable pulse of growth and reproduction of the plankton organisms.

The thermal factor peculiar to this season of the vernal pulse is the vernal rise in temperature. This pulse in production follows immediately upon it, rising with it and culminating shortly before summer heat is reached. The vigor and rapidity with which growth and reproduction ensue in the aquatic world is comparable with that which we see in field and wood at this same season of the year. On the very days in which this plankton pulse culminates, the bursting buds are releasing leaf and flower in growth unsurpassed for rapidity during the whole year. The animal world, notably the insects, also begin their rapid multiplication at this period. The same fundamental causes, whatever these may be, underlie these responses of organisms to the vernal rise in temperature both on land and in the water. The prolongation and gradual ascent of the vernal pulse in 1898 may have made its cumulative effect much greater, and thus increased the amplitude of the vernal pulse beyond that of years of more sudden approach of spring.

The hydrographic conditions in 1898 thus conduce to the presence in channel waters of an unusually abundant plankton at this season. Reference to Plates, XXIX., XXXIX., and XLII. will show that the backwaters have a greater plankton content than the channel, Quiver, Thompson's, and Phelp's lakes showing respectively 42.14, 51.39, and 76.17 cm.^{3} per m.^{3} of plankton. The first two collections were taken on the same day as that in the channel; the last, two weeks later. On May 3 the river was 11.1 ft. above low water, and thus above bank height in almost all localities. Flood water had invaded the bottom-lands in the middle of February, two and a half months before, and the invasion had continued for a month and a half before the run-off of the impounded flood commenced. Time for breeding a plankton had thus elapsed, and hundreds of pools, ponds, lakes, and swamps which had dried up in the drouth of the previous fall afforded a prolific seed-bed of resting stages of plankton organisms to populate the impounded and submerging waters. The slight current, shoal and warm waters, and abundance of organic debris in these impounding regions contribute also to the great development of plankton which the rapid decline in levels draws off into the channel to mingle with and enrich the plankton content of its waters. The proportion of impounded water entering the channel at times of such rapid decline from the high levels of April, 1898, is a very large part of the run-off, and predominates over waters of tributary streams which contain but little plankton (see Pl. XXIV.).

The conjunction of the vernal rise in temperature and the run-off of the impounded flood from reservoir backwaters in which the plankton has had time to breed are thus dominant factors in determining the amplitude of this unusual vernal pulse of plankton in channel waters.

The effect of the flood of the last part of May upon plankton production is apparently slight. The decline from the maximum of 35.68 cm.^{3} on the 3d was well under way, reaching 10.31 on the 10th, and 5.22 on the 17th with the first entrance of flood waters. The remainder of the decline forms a very regular curve in which no break due to flood waters—such, for example, as that of August, 1896 (Pl. X.)—can be traced. This is not due to the presence of an abundant plankton in the waters of tributary streams such as Spoon River, the paucity of whose plankton content (.023 cm.^{3}) may be seen in Table IV. and Plate XXIV. It is the result of the relatively greater volume of impounded backwaters into which, by reason of the ease of entrance in overflow stages, the flood waters of tributaries in part make their way. Their diluent action is thus less than at lower levels, and owing to river levels their contributions go into backwaters quite as much as into the channel. Thus, at such levels Spoon River flood water invades the Thompson's Lake region to the north and rushes southward through the bottoms about Phelps Lake (Pl. II.). At levels only a trifle below that of this flood all of the storm waters are carried within the banks of Spoon River and enter the channel directly. Conditions such as these at the mouths of tributaries tend to render floods which occur during overflow stages less destructive to the channel plankton.

The *June pulse* has a duration of 35 days,—from May 31 to July 5,—with a maximum amplitude of 6.99 cm.^{3} per m.^{3} on June 14. The mean also falls on the 14th, 40 days after that of the preceding pulse. This is a month of falling levels, the "June rise" (p. 161) declining from 13.6 to 9.6 ft. above low water —a total movement of 4 ft. The decline was checked thrice by silt-bearing flood waters of slight proportions, the results of which are seen in the increased silt content of the catches. The chemical conditions are relatively stable, the only marked changes being the usual summer rise in nitrites and chlorine (Pl. XLV.). The nitrates fall somewhat, while the other forms of nitrogen remain somewhat uniform, exhibiting no movement in correlation with, or proportionate to, that in the plankton production. Temperatures exhibit an upward pulse whose apex coincides with that of plankton production. Flood waters may contribute to the depressions which delimit this heat wave. The average production for this month (see table on p. 292) 3.96 cm.^{3} per m.^{3} is larger than that found in any other year save 1895, when abnormally low water prevailed. It exceeds that of 1896, our year of fullest observation, by over fivefold. These two years are much alike in that both (cf. Pl. X. andXII.) have continuously falling levels from a "June rise" just culminated, with similar rates of decline and much the same flood duration. They differ in the fact that the level of 1898 is on the average 4.2 feet above that of 1896. Higher levels with increased reservoir action of backwaters thus seem to conduce to greater production in this instance.

The contrast in the amplitude of the April-May and the June pulses (Pl. XII.) is very striking, the former being fivefold greater than the latter. Both occur on declining floods at almost identical levels (11.1 and 11.9 ft.). The principal differences in environmental conditions lie, first in the higher temperatures (by 20°) in June, and, again, in the duration of the flood on whose decline the pulse appears. The April-May pulse appears at a level which had been exceeded by ten weeks of overflow, while that of the June pulse had been exceeded by only four. Greater time for breeding is thus afforded in the first instance. I am inclined to think that the main factor in this decreased production is to be found in the fundamental midsummer decrease apparent in most years and localities in our quantitative catches by the silk net. To this decrease summer heat may be one of the contributing factors.

From this point onward in our records the variations in amplitude of the fluctuations in plankton production are but slight, and it may seem from the volumetric point of view of little importance. Since, however, they may continue to illustrate what I have called the cyclic movement in plankton production I shall endeavor to trace the recurrent pulses wherever they can be found in the data.

The *July pulse* has a duration of 21 days,—from the 5th to the 26th,—with a maximum amplitude of .88 cm.^{3} per m.^{3} on the 19th. Its mean falls on the 18th, 34 days after that of the preceding pulse. This is a month of most pronounced fall in river levels. The distance between the extremes (9.4 and 2.5 ft.) and the rate of decline (.25 ft. per day) are unequaled in any other month of our plankton operations. It is a decline from overflow exceeding bank height to the midsummer minimum within four weeks. This sweeping change in river levels involves great hydrographic modifications and accompanying disturbance in the equilibrium between the plankton and its movement. It brings about a reduction of the reservoir action of the backwaters to a minimum. Such waters as Phelps and Flag lakes (Pl. II.) speedily lose all connection with the river, and the greatly reduced contributions enter from those which maintain permanent connection with the stream, for example, from Thompson's Lake. The inflow of water from tributary streams thus comes to form more and more the principal source of channel waters as levels decline. These tributary waters are mostly of recent origin, from rains or springs, and have not had time as yet to breed a plankton of much volume. I believe this growing preponderance of tributary waters to be one of the factors responsible for the slight amplitude of this July pulse.

Along with this there comes also a further decline in nitrates (Pl. XLV.) and a slight increase in free ammonia and chlorine indicating a greater proportion of sewage. The heat pulse of the last fortnight in July is not attended by any similar movement in plankton production.

The *August pulse* has a duration of 28 days,—from July 26 to Aug. 23,—with a maximum amplitude of 1.62 $cm.^3$ per $m.^3$ on the 2d. Its mean falls on the 9th, 22 days after that of the preceding pulse. In this month there begins a series of small rises in the river which flush the stream repeatedly at intervals of one to two weeks until October. Two of these fall within the period of this pulse, result in its suppression, and shift its apex and mean to the left. The total movement in levels in this month is 8.2 ft.—a distance not equaled in any other August of our records. The result is seen in the low average of production (.91 $cm.^3$), which is but one fourth to one tenth that in other years save only 1896 (1.12)—also a year of much hydrographic disturbance.

The nitrates are at a minimum (Pl. XLV.) during this month, and the sewage contamination is shown by the high nitrites and increase in chlorine and free ammonia. The movement in these substances is correlated with that in the river levels rather than that of the plankton. The maximum amplitude of this pulse follows at an interval not exceeding a week the heat pulse of the last part of July, and its slight decline coincides with a period of lowered temperatures.

The *September pulse* has a duration of 42 days,—from Aug. 23 to Oct. 4,—with a maximum amplitude of .95 cm.^{3} per m.^{3} on the 20th. Its mean falls on the 12th, 34 days after that of the preceding pulse. The movement in levels in the month of September is 5.9 ft., and no less than five small rises appear in the records during this pulse (see page 161). The result is a considerable fluctuation in nitrites, chlorine, and free ammonia,—all of which tend to run high at this season,—and a depression of the plankton to a continued low level of production, .69 cm.^{3} per m.^{3} being the monthly average. The production in other and more stable years is from two- to thirteen-fold greater. In 1896 alone, a year of even greater September disturbances, does the production fall below that of 1898. The net decline in temperature is about ten degrees, and the production at the decline of this pulse is lower than that in other instances, save one, since the preceding April. The cold wave in the middle of the month (Pl. XII.) with a temporary decline of 20° coincides with a slight decline in production.

The *October pulse* has a duration of 35 days,—from October 4 to Nov. 8,—with a maximum amplitude of .42 cm.^{3} per m.^{3} on the 18th. The mean falls on the 20th, 38 days after that of the preceding pulse. This was a month of more stable hydrographic conditions, though the flood at its close brings up the total movement to 3.7 ft. Considerable movement in chemical conditions also occurs, as this is the beginning of the period of readjustment to lowered temperatures. The nitrates rise slowly, the nitrites fall to the winter minimum, and the chlorine and free ammonia fall and rise with river levels. It is in this month that the greater part of the autumnal decline in temperature occurs, the total reduction being 27°, at the rate of about 1° per day. This, with the other environmental changes above noted, necessitates considerable readjustment on the part of the plankton to the new conditions. We find here as in corresponding conditions in other years a decline to a minimum production, which in 1898 lowers the monthly average to .24 cm.^{3} per m.^{3}, the least recorded for this month in any year (see table on p. 292). The average temperature of surface waters in October, 1898, is about 56.4°—about the average, and 8° less than in 1897, when production was much higher (5.95 cm.^{3}). It is 2° higher than in 1895, when production was double (.57) that in 1898. I attribute this least production in 1898 in part to the unstable conditions in the month prior, and in part to the cumulative effect of the *rapid decline in temperatures*, which exceeds by 30 per cent., or more, that in other years of our records. The rapidity even more than the extent of the change seems to be the potent factor in depressing production. It is significant that this most complete suppression of plankton production occurs at this season of greatest change in environmental conditions.

The *November pulse* has a duration of 35 days,—from Nov. 8 to Dec. 13,—with a maximum production of 1.26 cm.^{3} on Dec. 6. Its mean falls on Dec. 2, 43 days after that of the preceding pulse. This was a month of continued rise to a maximum of 8.7 ft. on the 25th, after which the river fell. The total movement was 3.1 ft. This autumn flood brought with it from bottom-lands and prairies a load of silt composed largely of the summer's growth of vegetation, as well as the accumulated refuse from industrial establishments on the banks of the stream above our location. The silt thus reaches the unusual amount of 22.18 cm.^{3} per m.^{3} on Nov. 22. The chlorine and free ammonia decline with the dilution of the sewage caused by flood, the nitrates continue their autumnal rise, and other forms of nitrogen remain rather constant. The net temperature decline is only 10°, reaching, however, almost the winter minimum. There is no rapid decline in temperature, and the hydrographic changes are also relatively gradual with the exception only of the rise on the 17th. There is under these conditions a gradual, though slight, rise in production, which with the establishment of winter temperatures and decline in levels culminates at 1.26 cm.^{3} on Dec. 6. Increase in stability even in winter conditions thus tends to increase production.

This November pulse drops suddenly in the silt-laden waters of the slight rise in river level on Dec. 11 to a minimum of .01 on the 13th. The completeness of this decline is doubtless due to the fact that this collection was made in storm waters of recent local origin due to local rains. Flood waters of slight extent were thus intercalated in the stream, and if there was a normal decline in production accelerated it to this extent ; or it may be that the flood is solely responsible for the separation of the November and December pulses. The cyclic movement elsewhere renders this also a matter of conjecture.

The *December pulse* has a duration of 28 days,—from Dec. 13 to Jan. 10,—with a maximum of 1.98 cm.^{3} per m.^{3} on Dec. 20. Its mean falls on the 22d, 20 days after that of the preceding pulse. This is a month of falling river levels with the exception of the rise of .4 ft. on the 11th. The total movement is 3.4 ft. Since, however, all but 0.4 ft. of this is downward movement, the environmental stability is greater than the extent of the movement indicates. Temperatures under the thin ice-sheet that formed in the first week change less than 2°, and throughout the period of the pulse the several forms of nitrogen (Pl. XLV.) vary but little. The chlorine, free ammonia, and oxygen consumed, however, rise steadily as levels fall, to fall again as the river levels rise at the close of the month. This increase is again an index of the approach of stagnation under the cover of the ice-sheet and with the advance of the Peoria sewage pulse down stream as winter comes on. Stagnation is not reached, however, and in the relatively stable conditions of this period of the plankton reaches a level of production (1.98) not before attained since the close of the June pulse (Pl. XII.). It may be significant that the nitrates fall during this period of increased production (Table X.) to half the content in November. The average production in this month (.99) is in excess of that in all previous years excepting 1895, when stable conditions of longer prior duration were prevalent. The relation of stability in environmental conditions to increase in plankton production is thus confirmed by the data of this month.

As a whole, 1898 was a year of relatively light plankton production, averaging 2.13 cm.^{3} per m.^{3} (mean of all collections), or 2.03 (mean of monthly averages). This is all the more apparent when we note (Pl. XII.) that production falls below 2 cm.^{3} in all but eight weeks of the year and below 1 in all but fourteen. The only large production is found in April–June, and the unusual extent of this brings up the yearly average. The well-defined vernal pulse under peculiarly favorable hydrographic conditions, and the suppression of production by the flushing effect of repeated floods are the prominent features of the year's record. The effect of stability of environmental factors in increasing production, and of instability in suppressing it is apparent. The cyclic movement of production is also to be traced throughout the year.

1899.

(Tables III., X.; Pl. XIII., XLV., LII.)

Collections at weekly intervals were made in this year through the month of March. The 13 collections afford an opportunity of tracing the effect of the interrupted ice blockade which continued during the first two months in semi-flood conditions, and of noting the effect of the early maximum spring rise upon production.

The *January pulse* has a duration of 21 days,—from the 10th to the 31st,— with a maximum amplitude of .5 cm.^{3} per m.^{3} on the 17th. Its mean falls on the 18th, 27 days after that of the preceding pulse. This is a month of gradual though considerable change in levels, the total movement being 3.5 ft. The gradual character of the rise permits the development of a slight pulse of production which, however, declines with the culmination of the rise and increase in current attendant thereon. The nitrites rise again (Pl. XLV.) to twofold the quantity present in December, when plankton production was fourfold as great as in the present month. The movement of free ammonia and oxygen consumed suggests varying degrees of sewage decay, while the chlorine falls with flood dilution. The ice blockade continues till the close of the month, but gives way with rising temperatures and the culmination of the flood on the 24th. The average production for the month (.18 cm.^{3}) is much less than that of January, 1898 (.45), when the direction and extent of movement in levels were very similar, but the levels lower by 2.5 ft. on the average, and hence the current less rapid. Less time for breeding is thus afforded in 1899, and production is less than in 1898.

The *February pulse* has a duration of 28 days,—from Jan. 31 to Feb. 28,—with a maximum amplitude of 1.92 cm.^{3} per m.^{3} on the 21st. Its mean falls on the 20th, 33 days after that of the preceding pulse. During the first three weeks of this month there is a steady decline in levels under an ice-sheet of unusual thickness (31 cm.), which was carried out by the sudden rise from a level of 5.5 ft. to one of 10.2 ft. in the last week. The temperature beneath the ice remains at the winter minimum of 32°+ with a variation of less than 1°. Chemical conditions (Pl. XLV.) are subject to abrupt and great change with the rising flood of the last week. This is due in large part to the sudden increase in industrial refuse from the accumulations on the banks above previous water levels at Peoria and Pekin. These are carried into the stream by the flood and cause the fivefold increase in oxygen consumed and the rise in albuminoid ammonia and organic nitrogen. Prior to this flood there had been a rise in nitrates, and on the 21st the chlorine, nitrites, organic nitrogen, and free ammonia all exhibit a very marked upward movement suggestive of the approach of stagnation conditions. Stagnation is not reached, however, owing to the higher levels, to the break in the ice in the blockade late in January, and to the repeated flushing of the stream in the preceding autumn. The plankton was not therefore diminished by the change in chemical conditions which had progressed up to the time of the sudden rise on the 23d. The average production for the month (.81 cm.^{3}) is the largest recorded in any year. Production reaches on the 21st the unparalleled midwinter level of 1.92 cm.^{3}—an amount in excess of any production in July–November of the preceding year. This is due, it seems, to the stable conditions attending the decline of the January rise, to the high levels which permitted some access of plankton from backwater breeding grounds, and to the freedom from stagnation. The near approach of this condition is, however, revealed by the direction of the changes in chemical conditions, but its arrival was prevented by the almost equally catastrophic invasion of the sudden flood of the 23d, which reduced the plankton content to a minimum of .07 cm.^{3} on the 28th. Plankton production of this volume at approximately freezing point, equaling that at the summer maximum in July, is a striking instance of the adaptation of the plankton to the extremes of temperature.

The *March pulse* has a duration of 28+ days,—from Feb. 28 to Mar. 28+,—with a maximum amplitude of, 54 cm.^{3} per m.^{3} on the 7th. Its mean falls on the 12th, 20 days after that of the preceding pulse. In the first week the rise of the last of February ceased at 13 ft., affording overflow of all but the highest bottoms. Levels continued to fluctuate between 13 and 14 ft. during the remainder of the month, so that we have here a month of sustained overflow with repeated additions of storm water. The sewage and organic materials carried into the stream with the first access of flood waters decline rapidly during the month, as is seen (Pl. XLV.) in the rapid and considerable decline of chlorine, oxygen consumed, free ammonia, and organic nitrogen. Temperatures rise but 5° during the month, and the average for the month is from 5° to 10° lower than that in other years. The reduction in production with the initial flood and the thrice-repeated influx of storm water, combined with late spring and high levels with rapid current, result in but slight plankton production in channel waters. The pulse is barely perceptible, and its amplitude is very slight. The monthly average is but .28 cm.^{3}, a production somewhat less than that in 1898 (.33) and 1897 (.38), though exceeding that of 1896 (.07).

In comparison with other seasons these three months of 1899 exhibit a greater production, reaching even tenfold, and this result is correlated with the freedom from stagnation and the gradual change in river levels in the first two months.

COMPARISON WITH TRIBUTARIES AND BACKWATERS.

STATION M, SPOON RIVER.

(Tables IV., XI., XIV.; Pl. I., II., XIV., XXII., XXIV., XLVI., XLVII.)

ENVIRONMENTAL CONDITIONS.

This is a tributary on the right bank, draining 1,870 square miles of fertile prairie, and entering the Illinois about a mile and a half below our plankton station (Pl. I. and II.). No large cities lie in its water-shed, so that its pollution by sewage is not excessive. Its waters therefore represent the normal run-off of the central water-shed, and are typical of the tributary waters received by the Illinois below La Salle. A study of plankton content and chemical conditions will accordingly throw light upon the relations existing between channel and normal tributary streams in general in the matter of plankton production.

Our station at which collections were made in Spoon River was located immediately below the abandoned trestle of the Chicago, Peoria, and St. Louis Railroad (Pl. XIV.), less than forty rods from the mouth of the stream. A blockade formed by a raft of driftwood prevented further progress up stream during a part of the time, and in the winter the ice which formed and continued in the tributary when at times the main stream was open, made approach, even to the bridge, difficult.

Owing, however, to the current, our collections, with one or two possible exceptions, were all made in tributary water, though the chosen location could not always be reached. These exceptions were at times of backwater from the Illinois.

Spoon River has near its mouth a width of 75-100 ft., and a depth below low-water mark in the Illinois of 10-14 ft. It runs between almost vertical banks of alluvium (Pl. XIV.), and has a hard gravelly bottom full of sunken logs which form treacherous snags at low water. The current at the point of collection at low water may be scarcely perceptible, while at times of sudden flood, due to local storms in its water-shed, it is so strong that a boat enters it with difficulty. At such times its load of silt and drift is very great. During the heated term, and especially when the heat pulses occur and there is little wind to ruffle the surface, the green water-bloom on this stream is remarkable, exceeding—possibly because of protection from wind—that of the main stream in lividness and density.

The turbidity of this stream (see Table IV. and p. 179) is greater than in any other locality and serves as a general index of its silt content. It is, for example, in 1898, 31 cm. (average of disc readings), while in the Illinois River in that year the average is 40 cm.

COLLECTIONS.

All collections were made with the plankton pump. Examination of the plankton of this stream was begun in August, 1896, and continued at a fortnightly interval until December of that year, and thereafter until the close of operations in March, 1899, at approximately a monthly interval. From the character of the curves of plankton production in the Illinois River we may infer that collections at this long interval in Spoon River will fail to give us any adequate or accurate delineation of the *movement* in production in this stream. Furthermore, in the summer season at least, the plankton of Spoon River is composed largely of those small planktonts—such, for example, as *Euglena* and *Trachelomonas*—which almost wholly escape through the meshes of the silk net. A comparison of the plankton of the two streams on volumetric data derived from the catches of the silk net is to some extent misleading, owing to the relatively greater proportion which the escaping planktonts form of the production in the tributary stream. Another factor which prevents an equally accurate volumetric determination of the plankton of the two streams is the presence in Spoon River of a much greater proportion of silt. For example, in 1896 and 1898 the estimated ratios of silt and plankton in the average of the catches (Table IV.) is .007 to .349 and .029 to .796. In 1897, when low water and slight current and some probable invasion of channel waters increased the plankton production, the ratios are 1.257 to 1.173. The ratios of the first-named years are more nearly normal for this tributary, and in such ratios it is quite probable that the error in silt estimation to some undetermined degree tends to prevent any precise determination of the actual plankton production. Nevertheless, after a very wide margin is allowed for probable error in the data, the comparison of production in the two streams is instructive and significant, for it is the *direction* of change or contrast in production which is of greatest consequence, and this may be found even in the presence of a large but distributed error.

It should be noted that the plankton ordinants in the Spoon River plates (XXII.—XXIV.) are plotted on a scale ten times that of all other stations in order to give an appreciable height to the plankton portion of the entry.

PLANKTON PRODUCTION.

1896.

(Table IV.; Pl. XXII., XLVI.)

For purposes of comparison I introduce at this point a table which gives in terms of monthly averages of plankton in cm.^{3} per m.^{3} the relative production in the seven localities examined by us. The number of collections entering into each average is stated, and the grand average of all collections and of the monthly averages are given for each station.

In 1896, nine collections were made in Spoon River in August–December, the average being only .007 cm.^{3} per m.^{3}

COMPARATIVE EXHIBIT OF PLANKTON PRODUCTION IN ILLINOIS RIVER AND IN ITS TRIBUTARY WATERS AND BACKWATERS, 1894–1899.

Mo.	Year	Illinois River		Spoon River		Quiver Lake		Dogfish Lake		Flag Lake		Thompson's L.		Phelps Lake	
		Average plankton	No. catches	Average plankton	No. catches	Average plankton	No. catches.	Average plankton	No. catches	Average plankton	No. catches	Average plankton	No. catches	Average planktoo	No. catches
January	'94	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'95	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'96	0.01	9	......	0	0.03	1	0.53	1	0.29	1	2.51	1	1.89	2
	'97	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'98	0.45	3	0.017	1	0.02	2	......	0	......	0	7.22	1	......	0
	'99	0.18	5	0.005	1	0.77	3	......	0	......	0	1.64	3	4.69	2
	Av...	0.213		0.011		0.27		0.53		0.29		3.79		3.29	
February	'94	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'95	0.01	1	......	0	0.03	1	......	0	......	0	......	0	......	0
	'96	0.02	4	......	0	1.75	1	2.04	1	3.06	1	2.58	1	12.14	1
	'97	0.04	2	0.047	2	0.19	2	0.15	2	0.07	2	0.27	2	0.19	2
	'98	0.27	4	0.016	1	0.31	2	......	0	......	0	0.64	2	......	0
	'99	0.81	4	0.001	1	1.05	2	......	0	......	0	1.59	2	4.70	2
	Av...	0.23		0.021		0.67		1.10		1.57		1.27		5.68	
March	'94	......	0	......	0	....	0	......	0	......	0	......	0	......	0
	'95	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'96	0.07	5	......	0	1.85	1	3.43	1	1.02	1	10.26	1	19.20	1
	'97	0.38	1	0.007	1	0.34	1	0.48	1	0.83	1	0.65	1	1.44	1
	'98	0.33	5	0.124	1	0.74	2	......	0	......	0	0.70	2	0.25	3
	'99	0.28	4	0.026	1	0.15	2	......	0	......	0	0.21	2	1.82	2
	Av...	0.27		0.052		0.77		1.96		0.93		2.96		5.68	
April	'94	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'95	3.18	2	......	0	3.00	2	8.20	1	......	0	28.20	1	......	0
	'96	5.67	5	......	0	12.12	3	15.11	3	17.72	3	16.94	3	25.44	4
	'97	5.11	1	0.048	1	13.38	1	8.18	1	8.55	1	10.38	1	4.26	1
	'98	4.40	4	......	0	0.53	2	......	0	......	0	2.44	2	5.60	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	4.59		0.048		7.26		10.50		13.14		14.49		11.77	
May	'94	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	'95	......	0	......	0	......	0	......	0	......	0	61.44	1	......	0
	'96	1.30	9	......	0	2.99	5	9.63	5	51.93	5	23.11	5	12.96	4
	'97	5.62	1	0.440	1	1.29	1	1.94	1	10.61	1	7.88	1	22.58	1
	'98	11.30	5	0.023	1	16.27	3	......	0	......	0	25.94	3	40.44	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	6.08		0.232		6.85		5.79		31.27		29.59		25.33	
June	'94	0.74	2	......	0	0.23	2	......	0	......	0	24.92	1	24.17	1
	'95	30.42	1	......	0	......	0	0.12	1	......	0	9.42	1	......	0
	'96	0.72	8	......	0	1.26	4	2.64	4	2.13	3	4.92	4	2.90	4
	'97	0.27	1	0.250	1	1.26	1	2.48	1	4.87	1	3.59	1	0.42	1
	'98	3.96	4	0.096	1	2.23	2	......	0	......	0	10.43	2	27.67	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	7.22		0.173		1.25		1.75		3.50		10.66		13.79	
July	'94	5.12	2	......	0	2.20	2	......	0	......	0	10.74	1	......	0
	'95	9 33	4	......	0	0.37	2	2.99	2	......	0	4.83	2	......	0
	'96	1.44	15	......	0	0.30	4	0.91	4	3.33	3	2.73	3	9.03	5
	'97	4.69	5	......	0	0.89	3	......	0	7.13	1	3.31	2	9.49	1
	'98	0.58	4	0.036	1	0.16	2	......	0	0.36	4	2.08	2	6.97	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	4.23		0.036		0.78		1.95		3.61		4.74		8.50	
August	'94	9.67	1	......	0	0.74	4	......	0	......	0	1.08	1	......	0
	'95	4.03	10	......	0	0.21	2	1.11	2	......	0	3.09	3	......	0
	'96	1.12	14	0.018	2	2.46	5	3.91	5	3.74	3	4.74	3	8.80	4
	'97	3.65	5	0.652	2	0.21	5	......	0	......	0	19.40	2	25.70	2
	'98	0.91	5	0.002	1	0.22	3	......	0	0.03	1	2.63	3	139.85	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	3.88		0.224		0.77		2.51		1.89		6.19		58.12	
September	'94	1.36	2	......	0	2.12	3	......	0	......	0	6.40	1	......	0
	'95	1.52	15	......	0	0.94	2	3.15	2	......	0	3.58	2	......	0
	'96	0.38	2	0.005	2	0.31	2	1.63	2	2.09	2	4.20	2	......	0
	'97	8.83	4	5.130	1	0.16	3	......	0	......	0	10.01	2	......	0
	'98	0.69	4	0.002	1	0.33	2	......	0	15.54	1	2.66	2	47.25	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	2.56		1.712		0.77		2.39		8.82		5.37		47.25	
October	'94	0.61	1	......	0	0.95	1	......	0	......	0	......	0	......	0
	'95	0.57	5	......	0	0.13	1	.52	1	57.76	1	3.15	1	......	0
	'96	1.11	2	0.005	2	2.10	2	5.58	2	5.67	2	2.81	2	23.04	3
	'97	5.95	5	......	0	0.04	2	......	0	......	0	35.35	1	......	0
	'98	0.24	4	0.001	1	0.23	2	......	0	......	0	1.25	2	32.31	2
	'99	......	0	......	0	.....	0	......	0	......	0	......	0	......	0
	Av...	1.70		0.003		c.69		3.05		31.72		10.64.		27.68	
November	'94	0.10	1	......	0	0.02	1	......	0	......	0	......	0	......	0
	'95	3.02	4	......	0	0.05	1	5.01	1	14.40	1	5.07	1	......	0
	'96	0.02	1	0.005	1	0.24	1	0.26	1	4.37	1	2.66	1	32.00	1
	'97	1.00	5	1.671	2	0.09	3	......	0	......	0	16.67	3	......	0
	'98	0.25	5	0.001	1	0.73	2	......	0	......	0	1.17	2	51.14	3
	'99	......	0	......	0	.....	0	......	0	......	0	......	0	......	0
	Av...	0.88		0.559		0.23		2.64		9.39		6.39		41.57	
December	'94	0.10	1	......	0	0.03	1	......	0	......	0	1.29	1	......	0
	'95	1.14	8	......	0	0.46	2	5.32	2	4.82	2	1.00	2	......	0
	'96	0.76	2	0.002	2	0.92	2	2.20	1	4.40	2	2.56	1	......	0
	'97	0.56	4	0.599	1	0.007	2	......	0	......	0	6.98	2	......	0
	'98	0.99	5	0.001	1	1.74	2	.....	0	.....	0	3.58	2	21.96	2
	'99	......	0	......	0	......	0	......	0	......	0	......	0	......	0
	Av...	0.71		0.201		0.63		3.76		4.61		3.08		21.96	
Gr'nd av. of collections		2.19	235	.465	35	1.70	115	4.22	48	11.46	44	7.94	96	19.65	67
Av. of monthly averages		2.71	...	.256	...	1.75	...	3.16	...	9.23	...	8.26	...	22.55	...

(Table IV.), with a maximum of .032 on August 25. The amounts reported are all very small, and the significance of their differences is questionable. The following correlations with environmental conditions may be noted. There is little plankton (.004) in the turbid (3 cm.) flood water of August 18; there is more (.032) in the clearer water (30 cm.) of August 25. The production following the rapid decline of temperature in September falls to a minimum (.002) as it does in the channel waters (.53 and .23), and like the latter rises again (.008) late in October, after a month of somewhat stable temperatures (Pl. XXII.). The December production (.002 and .001), however, shows no rise corresponding to that in the main stream.

The average production in Spoon River for the five months in 1896 in which collections were made there is only .007 cm. per m.^{3}, while that in the main stream is 97 times as great, the production there exceeding that in the tributary from 4-fold to 380-fold in each month (see table between pp. 342 and 343). Spoon River water is thus throughout this season a diluent of the channel plankton.

The chemical conditions during this period reveal unutilized nitrates averaging 1.2 parts per million in Spoon River to 1.15 in the Illinois. Other forms of nitrogen are somewhat more abundant in the main stream. There is, however, plenty of food for the plankton in the tributary, and other causes than poverty of nutrition must be cited to explain its paucity of plankton.

1897.

(Tables IV., XI.; Pl. XXVIII., XLVI.)

There are 13 collections in this year, at intervals of two to six weeks. They average 1.257 cm.^{3} per m.^{3}, and have a maximum of 7.296 on September 11. The conditions attending the unusual plankton production in Illinois River channel waters in this year affect Spoon River also in much the same manner. The vernal overflow mingled impounded backwaters to some extent with the channel water of Spoon River, and the prolonged drouth of the autumn cut down the run-off and reduced the stream to a series of slack-water pools, in which, owing to the reduction in current, there was time enough for an abundant plankton to develop.

The explanation of the contrast between the plankton content of this stream on February 3 (.002) and 26 (.092) is to be found in the hydrographic conditions. The tributary shares the rise in production seen in channel waters (.03 to .05). The rising flood of the 26th forces the impounded backwaters away from the channel, and in their downward movement some of them get into Spoon River channel in the overflowed bottomlands above the point at which our collection was made. Thompson's Lake waters contained considerable plankton (.39) at this season, and it seems probable that some of its richer waters may have entered and (Pl. II.) enriched Spoon River channel plankton at this stage of river. Under such circumstances we find the tributary with a richer plankton (.092) than the storm-filled channel (.05)—an exceptional occurrence in the history of the two streams. The very slight production (.007) on March 22 is due to the fact that Spoon River itself at this time was rising rapidly, turbid (2 cm.) with silt, and invading rather than receiving contributions from the impounded backwaters through which it rushed to the channel. The collection of April 27 was also in flood waters (turbidity 5 cm., silt 4.75 cm.^{3}), which are in part responsible for the check in the flood decline at that time (Pl. XXIII.). This held back contributions from connecting and impounded backwaters, and the plankton content is low (.048), while that in the main stream (5.11) shows no such flood reduction. In the collection of May 25 (.44) we find the tributary waters as well as the main channel exhibiting a vernal rise in production, though its amplitude is 13-fold greater in the latter. The lower river level (8 ft.) then prevalent precludes the possibility of any considerable contributions from impounding areas, though accessions in small volume are not improbable. On June 28 the silt-laden storm-water in the Illinois River channel (turbidity, 2 cm., silt, 26.33 cm.^{3}) contains but .27 cm.^{3} per m.^{3} of plankton, but the vernal production in the tributary does not suffer so marked a decline, remaining at .25 cm.^{3}, so that its diluent action on this occasion was slight. As in the main stream, so also in the tributary there is a drop in production in August (.056) to about a fourth that in June-July.

From this time throughout the remainder of the year the production in Spoon River is considerable, exceeding that in the main stream, however, only in the last two months of the year. The production rises on Aug. 26 to 1.248 and on Sept. 11 to the unprecedented record of 7.296 cm.^{3}, while that in the main stream is only 2.77 on Aug. 24, and on Sept. 7 and 14 is 8.47 and 19.80 respectively, On the 21st and 29th of September production in the Illinois falls again to 3.00 and 4.04 cm.^{3} respectively, while in Spoon River on the 30th it is only 2.96, production in the tributary thus remaining below that in the channel throughout this period. The low chlorine in Spoon River at this time (3 to 4 parts per million. See Table XI.) as compared with the main stream (21-50 parts) indicates that the Spoon River water is not contaminated by channel water, and that we are dealing with an indigenous plankton. None of our collections falls in the period in October (Pl. XLVI.) in which chlorine in Spoon River rises temporarily. The three collections of November-December, 1.351, 1.99, and .599 cm.^{3}, are respectively 22.5, 1.6, and 20 times as great as the production in the main stream at the same time. The monthly averages for this period are 1. and .56 for the Illinois, and 1.671 and .599 cm.^{3} for Spoon River, so that the excess in the latter is apparently not more than 50 per cent. Under these conditions the tributary stream enriches the plankton of the channel instead of diluting it, but its discharge is slight.

Hydrographic, thermal, and ice conditions are similar in the two streams, and we find the main difference in the chemical conditions. Aside from evidences of sewage contamination in the last weeks of October, the Spoon River records

(Pl. XLVI., Table XI.) show somewhat uniform conditions in strong contrast with the instability in these particulars in the Illinois. With greater stability Spoon River apparently produces a more abundant plankton in this low-water autumn.

The exceptional production in this autumn stands in strong contrast with the poverty of this tributary in the same months in 1896 and 1898. As seen in the table between pp. 342 and 343, the maximum monthly production in the low water of 1897, as recorded in monthly averages, is from 285 to to 5,130 times greater than that in any month in this season in the other two years. A comparison of the data in Table XI. for the three years in question and of their plottings on Plates XLVI. and XLVII. will show the great similarity in the chemical conditions which accompanies this remarkable inequality in production. The accompanying table summarizes the data concerning nitrogenous contents of the water and the plankton.

NITROGENOUS SUBSTANCES AND PLANKTON, 1896–1898.

MONTHLY AVERAGES—PARTS PER MILLION.

Year	November					December				
	Free Ammonia	Organic Nitrogen	Nitrites	Nitrates	Plankton	Free Ammonia	Organic Nitrogen	Nitrites	Nitrates	Plankton
1896	.065	.84	.013	1.6	.005	.01	.52	.008	1.3	.002
1897	.052	.76	.008	.56	1.671	.022	.68	.005	.63	.599
1898	.026	.37	.009	.58	.001	.084	.89	.015	.33	.001

Other factors than these chemical conditions are thus responsible for the great differences in production in these three years. Low water, slight or imperceptible current, and consequent time for breeding in the latter part of 1897 are the most probable factors in causing the high production of that season, while in other years the recent origin of the tributary water, from rains or springs, precludes any considerable production in water otherwise capable of supporting an abundant plankton, as is shown by the production in 1897.

As a whole, Spoon River plankton in 1897 reflects the same relation to environmental factors that was found in the case of the Illinois. This is seen in the increased winter production, in the vernal rise, in the decline after the vernal pulse, and in the unusual autumnal development. The tributary stream, with but four exceptions, was acting as a diluent of channel plankton at each examination of its plankton content. These four exceptions—on Feb. 26, Nov. 2 and 30, and Dec. 28—are due in the first instance to channel flood, and in the last three cases to exceptionally low water in the tributary and less stable chemical conditions in the channel. In the four years in which Spoon River was examined they are the only exceptions to the general rule that these tributary waters are diluents of the channel plankton. The average production for 1897 (1.257 cm.^{3}) is 180 times that recorded in the last half of 1896, and 43 times that for 1898—as a result of the low-water conditions discussed above.

1898–1899.

(Tables IV., XI.; Pl. XXIV., XLVII.)

There are 14 collections at intervals of four or five weeks in the 15 months included in this period, and they fairly represent the contributions of this tributary in a year of considerable flood and repeated access of storm water. In 1898 there is but a trace of plankton in the January (.017) and February (.016) collections, while that in the March collection (.124) is the maximum for the year. At this time the spring flood is nearly at its height (16.5 ft.), and the waters of Spoon River are in quite free connection with the general overflow that spreads over the surrounding bottom-lands. On the day of the Spoon River collection there was .43 cm.^{3} of plankton in the Illinois and .79 the week prior in Thompson's Lake, three miles above Spoon River (Pl. II.). There is thus three and a half times as much plankton in the main stream and six times as much in Thompson's Lake. With its maximum burden of plankton, the tributary is still a diluent, and its plankton content at this time is probably in large part derived from the run-off of the contiguous impounding backwaters. No Spoon River collection falls in the week of the vernal maximum (see Pl. XII.), but the collections of May (.023), June (.096), and July (.036), all exhibit a considerable rise above the usual level of production, and all, moreover, were made during the run-off of the spring flood and receive slight contributions from impounded waters. It is in the *direction* of the movement in production that the tributary and main stream are alike at this season. In the *amplitude* of the curve of production the difference is very great, production being respectively 491-, 41-, and 16-fold greater in the latter in the three months named.

Throughout the remainder of the year 1898 plankton production in Spoon River is at a minimum, there being but the merest trace of living organisms in the catch. None of these catches was taken in rising flood water (Pl. XXIV.), though they all show the results of the flushing action of the frequent floods which wash out with rapid current whatever plankton may have developed in the tributary, and at the same time afford little opportunity for its replenishment. The relative absence of backwater feeders in the tributary stream at this stage of river levels serves also to emphasize the poverty in production of the tributary.

The average for 1898 (.029 $cm.^3$ per $m.^3$) is exceeded over 73-fold by the yearly average of the Illinois (2.13). The tributary waters are at all times—at least in so far as the data go—diluents of the channel plankton, reaching their lowest ratio, .124 to .38, in March, when they share most in impounded backwaters of the main stream, and at the same time are at the maximum of their own reservoir action.

This meager production occurs in waters almost as rich in nitrates (av., .67 parts per million) as the main stream (.809), and, save on rising floods (Pl. XLVII.), in normal chemical conditions. The potent environmental factor is rather to be found in the recent origin of the tributary waters than in any available chemical data.

In the three months' collections of 1899 we find that the low level of production continues under the ice, which remains on the stream for about three months (Pl. XXIV.). There is considerable fluctuation (Pl. XLVII.) in the organic nitrogen, free ammonia, and oxygen consumed, most if not all of which are traceable to the access of storm waters rather than to any considerable degree of stagnation. The catches are all full of silt, though the turbidity of the stream is not great under the ice in January and February. The silt at such times is mainly comminuted vegetation brought in by the storm waters. There is a slight rise in the plankton production in March (.026), when the river stands at 12.9 ft. and the plankton-rich waters of Thompson's Lake (see Table V.) are brought into connection slightly with Spoon River by overflow.

During these three months the production in the tributary is but a small fraction—never more than a tenth—of that in the main stream. It continues to be a diluent of the channel plankton.

SUMMARY.

The average plankton in all of the Spoon River collections is .465 cm.^{3} per m.^{3} of water. In the Illinois it is 2.19, or over 4.7 times as much. If we omit the low-water period, Aug. 26 to the end of 1897, and compare only the remaining collections between Aug. 18, 1896, and the close of operations, the ratio of production in the two streams becomes .044 to 2.19, or 1 to 50. As has been repeatedly pointed out in the preceding discussion, this contrast in production is not explainable on any difference in available chemical data. The tributary waters are fertile enough to yield a large production. The explanation is rather to be sought in the hydrographic conditions, in the recent origin, from rains or springs, of the tributary water, and in the more rapid current, and consequently the less time for breeding a plankton in the tributary environment. That this is the probable explanation is borne out by the large production in the only period of prolonged low water in the tributary in the fall of 1897, when time for the growth of the plankton was afforded in the slack waters of the tributary.

The immediate effect of the access of the tributary waters of the stream is as a whole diluent upon the plankton content of the Illinois. A mixture of equal volumes of each would result in a reduction in the Illinois to 1.33 cm.^{3} per m.^{3} from 2.19 —a falling off of 39 per cent., or even of 49 per cent. if we omit the low-water period of 1897. If we consider the areas of the drainage basins as an index of the relative volumes of water carried by the two streams, and determine the effect of Spoon River contributions, we find the net result, based on the averages of our collections, to be a decline in plankton content in the Illinois from 2.19 cm.^{3} per m.^{3} to 2.00—a decline of 9 per cent. If the low-water period of 1897 is omitted, the decline is even greater, namely, from 2.19 to 1.96—a fall of 11 per cent. in the plankton content as an immediate result of the contributions of this tributary. Spoon River thus exerts in the economy of the Illinois an immediate diluent function upon its production, which, qualitatively, is approximately 10 per cent.

STATION C, QUIVER LAKE.

(Tables V., XII. ; Pl. II., IV., XV.-XVII., XXV.-XXIX., XLVIII., XLIX.)

ENVIRONMENTAL CONDITIONS.

This lake lies on the right bank of the Illinois (Pl. II.), extending parallel to the river for a distance of three miles, including Quiver Chute. This is the lower end of the lake, which is separated from the Illinois River only by a low mud bank submerged at levels of 4 ft. and crossed just below our plankton station in the main stream by two "cut-offs" which bring a varying volume of river water into the chute, the amount depending upon the relative levels on the two sides of the spit. The close connection of the lake and river makes the former responsive to all changes in level in the latter at all stages of water. This lower spit extends northward as a low bank 5 to 40 rods in width and generally less than 6 to 8 feet above low-water mark, lying between the lake and river. This is covered with low willows and, to the northward, with heavy forest (Pl.

IV., XV., XVI.). The northern end of the lake is Y-shaped, and the western arm is known locally as Dogfish Lake.

The lake from Quiver Creek to its mouth near Spoon River is about 3 miles long, and does not exceed a quarter of a mile in width at any point. The lake proper, that is, above the chutes and excluding the western arm, contains at low water about 230 acres (93 hectares), but approaches 500 acres if these contiguous bodies of water be included. As levels rise, its area increases rapidly, and at 6 to 8 ft. the demarcation between river and lake is obliterated, and extensive areas to the northward (Pl. II.) come into connection with it, while at higher levels it quite loses its identity as a separate area (Pl. III.) except as the tree tops and its clearer waters serve to differentiate it from contiguous channel waters. Its depth at low water (river levels about 2 ft. above low water of 1873) is throughout most of its area less than 2 ft., and in the deepest parts, at the narrows above the chutes, it does not exceed 4 ft.

The bottom is of hard sand and bluish clay covered generally by a soft alluvial ooze of 1 to 2 or more feet in depth. Its eastern bank is a sloping sandy bluff (Pl. XV.), which abounds in clear springs of cold water, occurring the whole length of the lake and contributing not a little to its water supply. The western bank is of black alluvium, and the ooze along its margin of considerable depth. The eastern arm of the lake receives Quiver Creek, a tributary draining 220 sq. miles of sandy upland and "second bottom."

The vegetation, described on page 244, in low-water conditions frequently chokes the channel, which extends from the mouth of Quiver Creek in a tortuous course through the vegetation along the western shore of the eastern arm towards the point between this and Dogfish Lake, and thence in an equally crooked and shifting course towards the mouth.

It was in this channel in low water, and in its neighborhood at times of high water, that our plankton station was located (Pl. II). It is simply a shifting path through the vegetation, and is not generally marked by deeper waters than adjacent regions. It was only a few meters in width, and in 1894 and 1895 it was frequently necessary to clear it of encroaching vegetation in order to make feasible the 30-meter oblique haul. In high water and generally in years subsequent to 1895 it was only necessary to avoid with drawn net or pump the clumps of *Ceratophyllum* which still dotted the bottom in this neighborhood. The point of collection thus lay at all seasons towards the narrowing end of the lake and in the path of the current maintained by Quiver Creek and the marginal springs. At times of high water it was in the direct path of the downward current of impounded backwaters thrust towards the channel by the encroaching eastern bluff (Pl. II.).

At times of flood the invading river waters extend for some distance, even to the middle of the lake, crowding the clearer lake waters to the eastern side. When the western bank was not submerged the backwaters entering by way of the chutes sometimes reached the plankton station. Our collections were always made in evident lake water unless otherwise stated (Table V.).

The access of creek and spring water, the extensive areas of dense vegetation, and the shoal waters, which at all levels form the greater part of the area of this lake, all combine to make the temperature conditions subject to great local variation, and to diversify the fauna and flora indigenous or adventitious in the plankton of this body of water.

COLLECTIONS.

Our chronological series in this lake includes 115 collections, extending from June 6, 1894, to March 28, 1899. The collections in the several years number 14, 13, 31, 24, 26, and 7 respectively. Their distribution by months is shown in the table between pages 342 and 343. In the earlier years the interval of collection was somewhat irregular, though with 6 exceptions every month is represented. From July, 1897, collections were made at least every fortnight and on the same day as at the other stations. The oblique-haul method was used—with a few exceptions of repeated vertical hauls (Table V.) in the winter flood of 1895-96—from the beginning till May 22, 1896. After this date all collections were made with the pump.

This lake is a type of some other bottom-land waters, spring-fed and rich in vegetation, and our collections suffice to show the relation which these bear to production in the adjacent channel waters. They also serve for comparison of production with that in other backwaters less rich in vegetation, and since the quantity of vegetation in Quiver Lake varied from year to year they also throw some light on the effect of vegetation upon plankton production in a single area.

PLANKTON PRODUCTION.

1894.

(Table V., Pl. XXV.)

The 14 collections in this year average 1.08 cm.^{3} per m.^{3} to 2.49 cm.^{3} in the Illinois. The maximum (3.50) falls on September 6. There is a striking resemblance in the planktograph of Quiver Lake for this year (Pl. XXV.) and that of the adjacent channel (Pl. VIII). The amplitude is generally less in the former, but the direction of movement is the same in both. The June production (monthly average) is low in both Quiver Lake (.23) and the Illinois (.74); it rises in July (2.20 and 5.12); and it declines in September (2.12 and 1.36) to a minimum of .80 and .34, from which it recovers slightly in October (.95 and .61) to fall again in November (.02 and .10) and December (.03 and .10). The only exception to this parallelism in the movement in production is seen in August, when in Quiver Lake production drops to .74 but attains a seasonal maximum of 9.67 in the river. Aside from the fact that this is the season of greatest predominance of vegetation in the lake, owing both to growth and to low river levels, there seems to be nothing in the environmental conditions to be correlated with this contrast.

While as a whole for this year the contributions of Quiver Lake (1.08 cm.^{3} per m.^{3}), as shown by our data, only result in an immediate dilution of the channel plankton of the Illinois, there is a season when its plankton content exceeds that of the river. The average of the collections in September–November in Quiver Lake exceed by 70 per cent. the average of those in the Illinois. This is the season when some autumnal decay of vegetation takes place, and this vegetation-rich lake has a larger plankton production than the river waters which it thus enriches.

1895.

(Table V.; Pl. XXVI., XLVIII.)

There are 13 collections in this year, with an average of .78 cm.^{3} per m.^{3} as compared with 3.22 in the Illinois. The maximum of 4.57 occurs on April 29, being but 1.26, or 22 per cent. less than the corresponding vernal maximum in the adjacent, but—owing to river levels in this season—non-contiguous, river.

The similarity in the movement of production between this lake and the river noted in the previous year can be traced in 1895 in but two instances,—in the rise to the vernal maximum and in the increased production in December (cf. Pl. XXVI. and IX.). Outside of these periods there is no resemblance between the planktographs of the two waters. From July to November inclusive the low level of production is broken only by two pulses, both of which attend a rise in river levels with increase in the impounding function of the lake. These changes in level shift the loosely attached vegetation, and are often followed by death and decay of masses of aquatic growths. The slight rise in the last week in August (Pl. XXVI.) caused an invasion of muddy river water into the lower end of the lake. Decay of the vegetation and death of many fish, clams, and other animals ensued in the invaded area. The flood early in September (Pl. XXVI.) came largely from up-river rainfall, and the lake waters, enriched by invasion, were impounded with resulting increase in the plankton. It was not apparent that either of the large collections were made in invading waters, and I infer that the plankton was indigenous and not adventitious, though the invasion resulted in the enrichment of the lake by the decay of vegetation and dead animals. It may also have "seeded" the lake with organisms whose subsequent multiplication caused these temporary increases in production. These same floods are attended by depressions in production in the main stream, so that these two pulses in Quiver Lake lie in these depressions, intercalated between summits of the curve of production in channel water (cf. Pl. IX. and XXVI.). The inference is suggested that the run-off of this plankton-breeding impounded water of Quiver Lake and similar reservoirs elsewhere may have contributed to the increased production in channel waters following the flood.

The plankton content of Quiver Lake water on July 26 (.71) and Sept. 6 (1.57) thus exceeds that in the river on July 23 and Sept. 6 (.68 and .99), and its contributions to the stream, if any were made, serve to enrich the channel plankton. In three other cases the lake production exceeds that of the river; on Feb. 23 (lake, .03, river, .01), April 9 (1.42 and .52), and Dec. 28 (.29 and .01). In the first instance there was stagnation under the long continued ice-sheet in both river and lake, as was shown by the great mortality of fish in the latter. The plankton, however, did not reach the degree of extermination in lake water that it did in the channel, since there was less sewage, more vegetation, and access of spring water. In the April instance the silt burden of the channel waters (4.67 cm.^{3}, Pl. IX.) is much greater than that in the lake (1.43), and suggests the intercalation of storm water in the former, resulting in the slight rise in levels (Pl. IX.) and the lessened plankton content of the channel waters as compared with those of the less disturbed lake. The great contrast on December 28 is also due to the flushing action of the great winter flood which depleted the channel plankton but increased the impounding function, and therefore breeding capacity and productivity, of the lake. Each of the three instances of greater production in lake than in river waters occurs with rising river levels, when the rising river checks the relative outflow from the lake or otherwise increases its impounding function. Whatever run-off from lake to channel occurs under such conditions will result in a slight enrichment of the plankton content of the channel waters with which the tributary mingles. At all other seasons of this year our collections indicate that the immediate result of the access of Quiver Lake waters to the river is a reduction in plankton content of the main stream, on an average for the year for equal volumes of tributary and channel waters, of 38 per cent.; or if the relative volumes of each based on areas of drainage basins are considered, the plankton content of the channel is reduced to 3.19 cm.^{3} per m.^{3}—a decline of about 1 per cent.

This was a year of maximum development of vegetation in Quiver Lake. The low water of this and the preceding year and the absence of floods adequate to flush the lake of its loosely attached vegetation permitted an unusual and enormous growth of *Ceratophyllum* and other aquatic plants, which choked the lake from shore to shore and from Quiver Creek far down the chute towards its mouth (Pl. XV.). The very slight plankton production in its waters during the summer is due, I believe, to this predominance of vegetation. The rise in production when river levels rose in July and September (Pl. XXVI.) attends, among other factors favorable to production already discussed, a reduction in the relative abundance of vegetation.

1896.

(Table V., Pl. XXVII.)

There are 31 collections in this year, with an average of 2.59 cm.^{3} per m.^{3} as compared with 1.16 in the Illinois. The maximum of 16.76 cm.^{3} occurs on April 24, exceeding by 7.37 cm.^{3}, or 78 per cent., the production in the adjacent river on that day.

The similarity in the movement of plankton production in Quiver Lake and the Illinois noted as generally present in 1894 and but slightly so in 1895 is quite apparent throughout this year, as will be seen on a comparison of Plates X. and XXVII. With a few exceptions which will be noted in the subsequent discussion, the trend of the production is similar in the two bodies of water to a most striking degree month by month throughout the year.

With rising temperatures in February-March, production in the lake attains the unusual level of 1.75–1.85 cm.^{3} per m.^{3}, an amount not equaled at this season in this lake in any other year, and exceeding by 88- and 26-fold the production in the adjacent flood-swept stream (see table between pp. 342 and 343). This greater production in the lake is due, it seems, to the fact that Quiver Lake collections in these months represent the impounded backwaters of the eastern bottom-lands forced through the lake by the configuration of the eastern bluff (Pl. II.). Slight current and time for breeding permit in them a production not possible in the silt-laden rapidly flowing channel waters with which at our plankton station (Pl. II.) they are contiguous during prevalent levels. The larger production in this year may be attributed to the enrichment of the water by the great mass of organic debris accumulated on the now submerged bottom-lands during the two preceding years of low water.

The vernal pulses in the two waters coincide in the position of their limits and maxima though not in amplitude at any time, as will be seen on comparing Tables III. and V. and Plates X. and XXVII. The vernal development in the lake proceeds more rapidly, appears earlier, and attains a greater amplitude than it does in the river. Thus, on April 10 and 17 there is present in Quiver Lake 3.29 and 16.32 cm.^{3} of plankton per m.^{3} to 1.68 and 4.45 in the river. The rate of increase is 4.7 times as rapid in the lake, and attains on the 17th a volume 3.7 times as great as that in the river. The maximum (16.76) is almost twice that in the river (9.39). The large development (16.32) on the 17th indicates that the true maximum probably occurred a few days earlier in the lake than in the river. A partial explanation of this phenomenon, and also of the earlier and more rapid rise in production, may be found in the somewhat higher temperatures in the shoaler and clearer impounded waters which are drained off through Quiver Lake. The temperatures of surface waters in the lake from February up to the time of the maximum are from 1° to 15° higher than in the river, as will be seen on comparison of the thermographs on Plates X. and XXVII.

The May pulse in Quiver Lake attains 8.14 cm.^{3},—more than twice the amplitude of that in the river, 3.56,—while the average production for the month in the lake (2.99) exhibits a similar ratio to that of the river (1.30). The very sudden decline from 8.14 on the 8th to .51 on the 16th attends a decline of about 2 ft. in river levels at a stage which cuts off the lake from large impounding areas to the north, and also, at this season of the year, brings the submerged flora to the surface. These two factors combine in effecting this sudden drop in production in the lake before it appears in the stream (cf. Pl. X. and XXVII.).

The flood which wipes out the rising June pulse in the river (Pl. X.) increases the impounding area and relative occupation of the lake water by vegetation and permits a pulse of some amplitude (2.60) to develop in the lake, while only a belated and slight development appears in the contiguous river. As levels fall in July and impounding areas are again cut off and vegetation anew occupies a relatively larger proportion of the lake, production declines to so slight an amplitude that a July pulse can hardly be traced (Pl. XXVII.), and the average monthly production in the lake falls to a fifth of that in the stream, whose plankton content it had in previous months of the year exceeded.

With the rise of the August flood, production again assumes a pulse-like character, lagging throughout its development a few days behind that in the adjacent stream (cf. Pl. X. and XXVII.), and lacking in the lake the cleft in the apex of the curve caused in the river production by the flushing action of local floods.

The seven collections during the remainder of the year exhibit a similar direction of movement in production in every instance but two, Oct. 14 and 29. In the first of these, silt-laden flood waters in the river, but not in the lake, interrupt the parallelism. In the second instance the production of the lake declines and that of the river rises—again as a result of the prior flood conditions, as will appear on a comparison of the sequelæ of the June and August floods in the two bodies of water. In these, as also in the October flood, there are indications that the rising plankton pulse common to both is temporarily suppressed in the river and continues undisturbed and reaches an earlier culmination in the lake, but only a delayed one of slight amplitude in the stream.

The average production in the lake in the last four months of the year exceeds that in the river by 52 per cent. and in five of the seven collections.

The comparison of production in Quiver Lake and the Illinois River in 1896 is very instructive in several important particulars. In the first place, both the relative and absolute productivity of the lake has increased, rising from 1.08 and .78 cm.^{3} in 1894 and 1895 to 2.59, an increase of two- to three-fold. The ratio of productivity in the lake to that in the river in 1894 was 1 to 2.3; in 1895, 1 to 4.1; while in 1896 it falls to 1 to .45. The low average in the river is, as has been shown, the result of the repeated flushing by storm waters. The increase in the lake is due to the higher levels and increased impounding function, and to the actual and relative decrease in its vegetation. The combined result of the operation of these factors is that in this year the lake waters cease to be diluents of the channel plankton and become sources of enrichment. Considering the areas of their respective drainage basins, and basing calculations on the yearly averages, the net result of the contributions of Quiver Lake is a rise in the plankton content of channel waters from 1.16 cm.^{3} per m.^{3} to 1.18—an increase of a little less than 2 per cent.

Not only was the average production in the lake (2.59) greater than that in the stream (1.16), but individual collections upon coincident or approximate dates exhibit the same relation in 22 out of 31 instances, and 4 of the 9 exceptions fall in the period of low water in July, during predominance of vegetation in the lake. The monthly averages in the lake also exceed those in the stream in all months but July and September. Higher levels, increased impounding function, and decrease in vegetation thus favor plankton production in Quiver Lake, and tend to raise it from a diluent to a source of immediate enrichment.

In this connection it should be noted that the increased production of this year (2.59) still falls below that of the river in 1894 and 1897, and, as seen in the table on p. 292, below the general average of the river production (2.71); and also that the higher river levels of this year tend to lower the proportion which the tributary spring and creek waters form of the total volume of Quiver Lake.

A second significant fact brought out by the comparison is rendered patent by the frequency in this year of the collections in Quiver Lake. The weekly interval from April to September (Table V.) makes it possible to trace somewhat fully the movement of production, and *demonstrates in Quiver Lake a pulse-like movement in production similar to that previously described in the Illinois River, and one, moreover, which exhibits a very striking coincidence of developmental succession.* A superposition of Plate XXVII. upon Plate X. will make this demonstration apparent. There are exceptions, but these, as shown in the preceding discussion, are in most, if not all, instances to be correlated with local environmental factors confined to one or the other body of water. The return to parallelism with the cessation of the peculiar factor incident to the interruption serves still further to emphasize the significance of this similarity. The key to the parallelism must lie in fundamental factors common to the plankton of both areas or to their environment.

1897.

(Tables V., XIII.; Pl. XXVIII., XLVIII.)

There are 24 collections in this year, with an average of 0.88 cm.^{3} per m.^{3} as compared with 3.69 in the river, and a maximum of 13.38 on April 27—more than twofold the production in the river (5.11) on that day.

The collections of the first six months of this year are so infrequent that the course of production is but slightly indicated. In February the production in the impounded waters of the winter flood in Quiver Lake (.19) is nearly fivefold that in the current-swept channel (.04), while in March there is little difference (.34 and .38) in their plankton content. The collection of April 27 probably falls near the presumably common vernal maximum and in the midst of the decline of the spring flood. Since Quiver Lake at the stage of river (11.6 ft.) then prevalent contains the run-off of the impounded backwaters to the north. it is not surprising that its plankton content (13.38) is more than double that of the river (5.11). The similarity in the movement of production thus far seen in this year is interrupted on May 25 by the decline in the lake to 1.29, while the river rises to 5.62. The decline in the lake may be attributed to the great reduction in impounding area due to the decline in levels to 8 ft., and to the gain in proportion in the lake of the contributions of creek and spring water and of the area occupied by the now rapidly appearing vegetation. The silt-bearing flood of June in the river yields less (.27) than the lake waters (1.26) impounded by the rise of the river.

In the last six months of the year the collections are of sufficient frequency to enable us to trace somewhat the movement in production. This period is marked by a great depression in plankton content as compared with that of the same season in the previous year, the average for each being 1.06 and .23. The parallelism in the movement of production can still be traced in the slight tendency in Quiver Lake to increased production in July, September, and November at times of pulses in the channel plankton. The amplitude attained in the lake is, however, but slight.

The explanation of this marked decrease in production in this year as compared with that of 1896 lies, I believe, in the hydrographic conditions of the two years. In 1896 (Pl. XXVII.) the average height of the river for the period August–December is 5.89 ft., while in 1897 it is only 2.47 ft. The impounding action of the lake was at its minimum, and there was present in it in these months of 1897 only about a third the quantity of water that it contained in the corresponding season of 1896, and this consequently gave to vegetation in 1897 a relatively greater predominance in the lake, and also made possible a more frequent renewal of lake water by the contributions from the creek and tributary springs, thus cutting down the time for breeding. Both of these factors tend to limit plankton production. We find, accordingly, that the lake produces on an average from August to December but .1 cm.^{3} per m.^{3} to 4.0 in the adjacent river, that is, only a fortieth of the plankton content of the stream. The contrast between the lake and the river in this year is heightened by the fact that owing to low water and increased fertilization by sewage the production in the river is much greater than usual.

A comparison of Plates XI. and XXVIII. will reveal the fact that in only 5 instances out of 24 in 1897 does Quiver Lake contain more plankton than the river. These instances in February and April attend impounding action of the lake when it is not differentiated from overflowed bottom-lands as a separate unit of environment, while those of June 28 and July 21 are caused by the flushing of channel waters by floods from which the lake is exempt.

As a whole for this year, the net result of the contributions from Quiver Lake is a dilution of the channel plankton with which it mingles. Basing calculations upon the yearly averages and areas of the drainage basins, the quantitative effect would be a decline in the plankton content of channel waters from 3.69 to 3.65, or a loss of 1.1 per cent.

The lake waters in October–December contain (Table XIII., Pl. XLVIII.) but a fraction—from a third to a tenth—of the nitrogenous matter that is found in the channel. This is an index of the relative poverty of Quiver Lake waters when isolated as a separate unit of environment and dependent upon creek and spring waters, mainly of seepage origin, for its supply. This relative poverty, combined with the factors before discussed, lies at the basis of the relatively small plankton production in this body of water in this year.

1898.

(Tables V., XIII.; Pl. XXIX., XLIX.)

There are 26 collections in this year at fortnightly intervals, with an average of 2.44 cm.^{3} as compared with 2.13 in the river, and a maximum of 42.14 on May 3 coincidently with the vernal maximum in the channel (Pl. XII.), which, however, falls 6.46 cm.^{3}, or 15 per cent., short of that in the lake.

The parallelism in the movement of production noted to a varying extent in prior years may be traced also in 1898. The most striking coincidence is the agreement in the location and relative development of the vernal pulse, and further resemblance may be seen in the June pulse and the December rise in production. The small quantities of plankton in the lake at other seasons and the fortnightly interval of collection render the correspondences less obvious though perhaps not less significant.

During the low water of January and in the subsequent flood (Pl. XXIX.) there is little plankton in the lake (.02) as compared with the river (.45—see table between pp. 342 and 343), though an increase with a rise in levels and development of the reservoir function of the lake might have been expected. There is, therefore, no January-February rise in the lake corresponding to that in the river unless the increase from .003 Jan. 11 to .04 Jan. 25 be held to be significant. The February flood, which depletes the plankton of the channel, is accompanied by a rise to .58 on the 22d in the lake coincidently with a slight but not equal rise (.10) in channel production. The March pulse in the river, with a maximum amplitude of .77 on the 22d, is attended by almost equal production in the lake (.67).

The vernal pulse rises with like abruptness at both stations, increasing from April 1 to May 3 from 1.03 to 42.14 in the lake, and from 1.12 to 35.68 in the river. The decline of this pulse is much more abrupt in the lake, falling from 42.14 on the 3d to 4.7 on the 11th—a decrease of 89 per cent. in 8 days, while the decline in the stream is from 35.68 to 10.31, or 71 per cent., in 7 days. The more abrupt change in the lake plankton is due to the fact that the decline in levels of 1. ft. in the interim between the two collections compared, is at the critical point approaching bank height, when the bottom-lands to the north of Quiver Lake are beginning to emerge and cut off and divert some of the run-off of the impounded backwaters which at higher levels make their way to the channel through Quiver Lake (Pl. II.).

There is a very slight July pulse in the lake on the 19th coincident with the July maximum in the river. In the early part of August there is another maximum in the river, but no parallel developement in the lake, owing possibly to the low water then attained and the resulting dominance of vegetation and tributary waters—conditions not incident to these levels in like degree in channel waters. The rise at the close of August and again in September, and the low level and slight change in production in October found in channel waters are all to be traced coincidently, or approximately so, in the less complete records of the lake production.

The silt-laden flood waters which cause rising levels in November deplete the channel plankton (.25), increase the impounding function of the lake, and lead to greater production (.73) in the latter. There are coincident culminations in river and lake on Dec. 6, but the interval of collection in the lake does not permit comparison in case of the river maximum of Dec. 20. The large December production (1.74), six to eleven times that of July (.16), August (.22), September (.33), or October (.23) is noteworthy.

There is thus a striking similarity in production in the river and lake in 1898, not only in the larger movements, such as the vernal pulse, the low level of midsummer, and the December rise, but also in the minor details which differentiate movements at shorter intervals, suggesting in some cases, and demonstrating in others, the presence of coincident recurrent pulses of production with approximately similar locations but, it may often be, with more widely differing amplitudes.

A part of this similarity is doubtless due to the fact that in 1898 for fully five months of the year, when the river was at 8 ft. or above, the lake was not, superficially at least, differentiated from the general bottom-land environment, and therefore shares more extensively the course of production elsewhere than it does when its emerging boundaries delimit it as a separate unit of environment. The similarity is not, however, confined to this period of aquatic continuity, but appears also in the season of delimitation, when local factors are relatively more potent. It is also true that even in the period of continuity the environmental factors peculiar to the lake continue, though submerged or invaded,—as, for example, the chemical conditions, which even in flood periods exhibit a certain autonomy in the lake, as will be seen on comparison of Plates XLV. and XLIX.,—to exercise some differentiating influence, which, in the presence of the apparent tendency towards similarity of movement in production, still produces modifications sufficient to stamp the seasonal planktograph with a characteristic facies, thus differentiating it from other localities.

The average production for the year is 2.44 cm.^{3} per m.^{3} as compared with 2.13 in the river, so that as a whole in this year the outflow from this lake enriches the channel plankton. On the basis of yearly averages and drainage areas the net result is an increase from 2.13 to 2.14, a rise of less than .5 per cent. A more detailed analysis of the data reveals the fact that in 7 of the 12 months, in January, April, and June–October, the river exceeds the lake in production. As will be seen on Pl. XXIX., the remaining months are those of high river levels, when the impounding action of the lake is most operative and its localization least pronounced. The largest production, in May and June, occurs when on declining flood the flow of impounded bottom-land waters from the north is greatest through the lake.

If we omit from both records the months of May and June, we find that the averages of the remaining monthly averages (see table between pp. 342 and 343) are .91 and .50 respectively for the river and the lake. Thus for ten months of the year the plankton content of the latter is but five ninths of that of channel waters, and during this period the immediate result of the access of the run-off from Quiver Lake will be a dilution and diminution of the plankton content of channel waters, due, it seems, to the relatively more recent origin, from storm and seepage waters, of these tributary contributions, and to the greater prevalence of vegetation in the lake. Another factor operative in the diminished production of the lake is relative poverty in nitrogenous substances. For example, the average nitrates (cf. Tables X. and XIII.) for the year in river and lake are respectively .809 and .68; the nitrites, .121 and .029; the organic nitrogen, .92 and .569; the albuminoid ammonia, .431 and .275; and the free ammonia, .95 and .138. The unutilized nitrogenous substances in the lake are, however, of sufficient proportions to indicate the possibility of the support of a larger volume of plankton if greater time for breeding were allowed.

1899.

(Tables V., XII.; Pl. XXIX., XLIX.)

The 7 collections in January–March average .67 cm.^{3} per m.^{3} as compared with .41 in the river. As in the previous year, the direction of movement in production is similar in the two regions. For example, the January pulse in both culminates on the 17th and that of February on the 14th and the 21st, while the March production is at low levels in both, and the apex of the pulse is not apparent in the lake records. The invasion of some channel flood water with the March rise and its speedy elimination may be traced in the chemical records (Pl. XLIX.)

The production in the lake during this period is greater than that in the river at all times of coincident examination excepting March 14 (.14 and .35). The average production in the lake (.67 cm.^{3}) is 63 per cent. greater than that in the river (.41 cm.^{3}). This percentage of increased production is a measure, or an index, of the impounding or reservoir action of the lake under the hydrographic conditions of these months. The immediate result of the access of Quiver Lake waters to the channel will be a rise in its plankton content from .41 cm.^{3} per m.^{3} to .414—an increase of 1 per cent.

The summary of the interrelations of production in this lake and the river will be made in conjunction with that of Dogfish Lake, which is only an arm of Quiver Lake.

DOGFISH LAKE.

(Table VI.; Pl. XVIII., XXX., XXXII.)

ENVIRONMENTAL CONDITIONS.

This so-called lake is only the western arm of Quiver Lake (Pl. II.), separated from the eastern by Quiver Point, a low marshy spit covered with rushes and willows and lying but a few feet above low-water mark. It is of elliptical form, about three quarters of a mile long and one third of a mile wide, contains about 150 acres at low water, and as levels rise it extends northward and eastward over the low bottoms towards Mud Lake and Cartwright Slough, but it is only at highest levels that very much of a current makes its way down through this lake. As levels rise above 8 ft. the intervening ridge separating this lake from the river is gradually submerged, and channel waters invade more or less of the lake. It affords the natural channel for the run-off of the backwaters impounded in several square miles of bottom-land marsh and forest through the swale (Pl. II.) which extends towards Mud Lake.

Its shores are everywhere low and marshy, of black alluvium, and a soft black ooze of similar origin covers the bottom of the entire lake. In only a limited area towards the eastern side can a substratum of harder sandy clay be reached beneath two or more feet of this deposit. With the exception of a narrow fringe along the eastern side, the vegetation lacks the lilies, rushes, sedges, and other emergent plants which characterize the eastern shore and northern end of Quiver Lake proper (Pl. XVII.). It consists (Pl. XVIII.) almost exclusively of *Ceratophyllum*, *Elodea*, and *Potamogetons*, which, in the low water of 1895, represented in the plate, filled the lake from center to periphery. Irregular openings in this dense growth appear occasionally in the area, and are modified by the shifting of the lightly attached vegetation, by wind, and by flood water.

Except at high water and during the rapid run-off of impounded backwaters no appreciable current traverses this area. It receives no immediate contributions of spring or creek water along its margins, but depends entirely upon backwater from Quiver Lake or flood invasions for its supply.

The examination of the plankton content of its waters accordingly affords an opportunity to test the effect of this impounding factor, and also serves to throw some further light on the effect of vegetation on plankton development in impounded waters.

COLLECTIONS.

The collections in this lake cover a period of two years—from April 29, 1895, to June 28, 1897 (Table VI.). They number 48, and are distributed in much the same manner as those in Quiver Lake in the same period. The collections of 1895 and those of 1896 through May 8 were all made by the oblique-haul method with the single exception of that in the flood of Feb. 27, which was one of repeated vertical hauls. The collection of May 19, 1896, was made in the midst of rapidly growing vegetation by dipping from surface waters, which then afforded no area suitable for an oblique haul. The oblique hauls were made for the most part near the center of the lake in a channel freed from vegetation a day prior to the collection. From May 21, 1897, all collections were made by the plankton pump in open stretches of water amid the vegetation.

In 1895 the lake was choked with vegetation which the winter flood largely removed and the recurrent floods of the following year reduced somewhat in extent, while higher levels lowered its relative occupation of lake waters.

PLANKTON PRODUCTION.

1895.

(Table VI., Pl. XXX.)

There were 12 collections in this year, from April to December, averaging 3.25 cm.^{3} per m.^{3} The average of the monthly averages (see table between pp. 342 and 343) is 3.3 cm.^{3} to .74 and 6.65—similar averages for the same period in Quiver Lake and the Illinois River. The maximum collection was made Dec. 19—a very unusual date for such production.

A superposition of the planktographs of the river and Quiver and Dogfish lakes for this year brings out some instructive similarities and differences in the movement of production. The vernal pulse of April 29, in so far as the data reveal it, is quite similar in all three localities, reaching its greatest development in Dogfish Lake (8.20), where impounding action is greatest, and being greater in the river (5.83) than in Quiver Lake (4.57), where, owing to low levels, the proportion of water of recent creek or spring origin is greater than in the channel of the adjacent river.

The June-July pulse may be found in all three localities, but it is belated and much smaller in the lake waters. This pulse in Dogfish Lake (4.59 cm.^{3} per m.^{3}) is less than a sixth of that in the river (30.42), where, in the semi-stagnant sewage-polluted channel waters of unusually low levels, *Moina* and other *Cladocera* caused the unusual production. Between the April and June-July pulses the river levels fell 2 ft., to minimum stages (Pl. XXX.), so that the proportion of creek and spring water in Quiver Lake is probably more than doubled at the later date. This may account in large part for the very low production in Quiver Lake (.02) on July 8, while on July 5 the contiguous but impounded and current-free waters of Dogfish Lake contain 229 times as much plankton.

The increased production following the September flood is apparent in all three localities, but reaches its highest level (4.65) in Dogfish Lake, the region where the impounding factor is greatest, while the least increase and quickest decline is in Quiver Lake, where tributary waters of recent origin are in greatest proportion. The low production in October is common to the three localities, reaching a slightly lower level in the lakes (.13 and .52) than in the river (.57). The considerable increase in production in November-December attains the highest level in Dogfish Lake (5.01 and 10.57), exceeding by 100- and 17-fold that in Quiver Lake (.05 and .63), and that in the river (4.37 and 2.60) by 1.2- and 4-fold. Here also the effect of the quieter impounding waters of Dogfish Lake is apparent in this relatively greater development. The large plankton content on Dec. 19 (10.57) seems to be due to a combination of several favoring environmental factors. This collection was made after a steady but slight rise lasting for over five weeks, followed by ten days of gentle decline in levels and contracting margins of the lake. The steady rise to levels which introduced no run-off currents through the lake established the impounding function to its fullest, and invaded a considerable stretch of margins rich in dead and decaying vegetation. There is also at this season of the year less growth and more decay of the *Elodea* and *Ceratophyllum* which abound in the lake. The collection was taken when the December flood had just begun to rise (about 2.6 feet) and with the combined action of wind and waves which attended the storm then raging had torn loose the vegetation and dislodged many of the smaller *Crustacea* and insect larvæ which find shelter in it. There were at the time 572 *Allorchestes* per m.^{3} adventitious in the plankton. A part of this large production is thus adventitious owing to disturbed hydrographic conditions. Nevertheless, there still remains after such contributions are deducted a considerable plankton of normal constitution (mainly *Cladocera*), in amount certainly much in excess of the production at that time in Quiver Lake (.63) or the river (1.74). This large production in this locality is then, it seems, to be attributed to impounding and decaying vegetation combined with accession of adventitious planktonts.

The average monthly production (3.3) in this lake is on the whole less than half that in the river (6.65) for the same period, and it exceeds by over fourfold that in Quiver Lake (.74), through which all its run-off passes to reach the river. Since the comparison of the two lakes is based on coincident collections, these amounts may serve as a quantitative statement of the effect of the environmental differences. As vegetation is much the same in both lakes the difference in production must be attributed to some other factor presenting a difference which may be correlated with that in production. Such a factor is found in the impounding action, which is at a maximum in Dogfish Lake and is relatively much less in Quiver Lake at the point of our collections, where creek and spring water of recent origin cause a more rapid displacement of the contents of the lake and carry away the products of decay of vegetation before the plankton can reach the degree of development that it does in the more stable waters of Dogfish Lake.

The run-off from this lake in this year would thus tend to enrich Quiver Lake, though not on an average of sufficient production to enrich the river even if it could reach it without mingling with that of Quiver Lake. However, owing to the fact that this lake receives no tributary creek or spring water, and except at high levels has no bottom-land current through it, we must infer that its run-off is confined—excepting only at stages of general overflow—almost wholly to stages of falling water. During rising levels and in fairly stable conditions its contributions to Quiver Lake, and thus to the river, are practically *nil.*

1896.

(Table VI., Pl. XXXI.)

There are 30 collections in this year, with a distribution similar to that of the collections in Quiver Lake for this year, the only exception to the coincidence of collections, actual or approximate, being on December 29, when on account of rottenness of the ice it was not possible to get the collecting outfit to the station.

The maximum production occurs in the vernal pulse in the last fortnight of April, culminating at 20.35 cm.^{3} per m.^{3} on the 17th, though production is also large on the 24th (19.5). In Quiver Lake this maximum is on the 24th (16.76), though production is also large on the 17th (16.32). The maximum in channel waters (9.39) is also on the 24th. These differences in the time of the maxima may, I believe, be correlated directly with the thermal factor. For example, in both Quiver and Dogfish lakes the production is large and almost equal on the 17th and 24th, but is greater in Dogfish Lake on the 17th and in Quiver Lake on the 24th. This lag in the maximum is correlated with the fact that surface temperatures in Quiver Lake on the 17th and 24th are respectively 3° and .8° lower than they are in Dogfish Lake. On the 17th the latter is 8° warmer than the river. After all allowances are made for the time of day at which temperature records are taken, it is still evident that the shallower waters of Dogfish Lake would warm up more quickly than the spring-fed waters of Quiver Lake or the deeper channel waters, and we have found that the thermal increase favors the earlier rise in plankton production.

The coincidence of the dates of collection makes possible a precise comparison of the production in the two lakes, and facilitates the comparison with that of the river. A superposition of the planktographs of Dogfish and Quiver lakes and the river (Pl. XXXI., XXVII., and X.) for this year emphasizes far better than any description the most striking similarity at the three stations of the movement of plankton production as shown by the direction of the differences in plankton content in successive collections. The correlation between production in Quiver Lake and the river in this year—discussed in detail on pages 357–360—is paralleled in every important detail by the sequence of the changes in Dogfish Lake. Indeed, the correlation is, if anything, even closer, since the amplitude of the plankton pulses is greater in Dogfish Lake than in Quiver Lake, and the changes are here—as, for example, in August—the more readily followed and compared with those of the river. Since I have already compared in detail the production in Quiver Lake and the river I shall not repeat the comparison of these similar data from Dogfish, for the correlations are essentially the same in both cases, and it will suffice simply to emphasize the similarity of the course of production in the three localities.

The similarity between the production in the two lakes is, however, even greater than that between either of them and the river. This results from the greater similarity of the environmental factors in the two lakes, with which the river contrasts in matters of sewage and current. The similarity of environmental factors lies in the amount and kind of vegetation, the depth, the character of bottom and shores—excepting the eastern margin of Quiver, the impounding function (modified, however, in the case of Quiver Lake by the access of creek and spring water), and the freedom from sewage. Under these circumstances it is not surprising that the details of the course of production as well as its *ensemble* are so strikingly alike in the two lakes.

To be specific, the similarity in details of the course of production in Quiver and Dogfish lakes lies in the fact that in the 31 coincident collections in these waters the plankton content rises or falls in both at the same time in 23 out of the total number. The *amplitude* of the change is rarely equivalent, but its *direction* is identical—referring, of course, to the fact of its being an increase or decrease, and not to the particular angle which the lines forming a planktograph might take. The 8 exceptions to this similarity in the direction of movement in production are shown in the following table, and may without exception be correlated with *differences* in the environment.

In this table the plankton contents of the two adjacent collections determining the direction of the change in production are given under the date of the later collection, and the position of the entries also indicates the direction of the change.

VARIATIONS IN THE MOVEMENT OF PRODUCTION IN DOGFISH AND QUIVER LAKES, 1896.

	Apr. 24	May 8	May 16-19	May 21-22	July 3	Aug. 15	Aug. 29	Sept. 16
Dogfish Lake	20.35 to 19.50	13.39 to 13.06	18.40 13.06 to	18.40 to .36	1.58 1.14 to	11.25 3.88 to	1.18 .75 to	3.06 1.18 to
Quiver Lake	16.76 16.32 to	8.14 4.24 to	8.14 to .51	.99 .51 to	.68 to .49	4.36 to 3.42	1.60 to .72	.72 to .55

In almost every case these exceptions to the precise similarity of movement in production in the two lakes can be correlated directly with some disturbing environmental factor potent in one and not equally so in the other, that is, to *local* disturbance in the environmental similarity, as follows: The exception on April 24 is due to the earlier appearance of the summit of the vernal pulse of production in Dogfish Lake, and this in turn is correlated with the greater proportion of shoal waters in Dogfish and the greater access of spring water in Quiver, both factors favoring the more rapid and complete warming up of Dogfish waters. As has been repeatedly pointed out, the thermal rise deflects towards itself the vernal rise in production.

Conditions on May 8, when Quiver Lake production doubles and that in Dogfish Lake falls slightly, are to be explained by the different effect which the hydrographic changes have at the two stations. At stages existing at the first of the month (7 ft.) there is not sufficient overflow to carry any considerable current of warm backwaters to the southward down through the lake to the river. The content is largely of local impounding. The slight rise at that time (Pl. XXXI.) would therefore tend to increase the local reservoir action, and creek and spring waters would most naturally be impounded along the usual line of their run-off, in which our Quiver Lake station lies (Pl. II.), while the plankton-rich backwaters of Dogfish Lake are held back, hence the low production in Quiver Lake on the 2d (4.24) and the larger one in Dogfish (13.39). On the 8th conditions are changed; the decline in levels (.6 ft.) has increased the run-off, and the recent contributions of tributary water have brought down into Quiver Lake an increased proportion of plankton-rich impounded backwaters which increase the content at that point to 8.14 cm.^{3}, this being, however, still below that of contributing and declining Dogfish Lake (13.39 to 13.06).

On May 16–19 the collections were not quite coincident, but, such as they are, they form another exception to the similarity of movement in the two lakes. In Quiver on the 16th the decline of levels brings the proportion of tributary waters at that point into greater prominence, while on the 19th in Dogfish the impounding function is greatly increased by the inter vening rise in levels (1 ft.). Examination of the collections also shows that the maximum of 18.4 cm.^{3} in Dogfish Lake on the 19th is caused primarily by an extraordinary pulse, or possibly a local "swarm", of *Melosira* with some *Cladocera*, whose apex and location the date of collection approximates.

On the 21st the plankton content in the same locality fell to .36 cm.^{3}—a decline of 98 per cent. in 2 days. On the 21st and 22d a quantitative survey of the local distribution of the plankton in the whole area of Quiver and Dogfish lakes was made, with the result that no development commensurate with that on the 19th at this point was anywhere detected. Since a similar sudden decline is to be seen in Flag Lake in this same week, I am inclined to the view that we are dealing here with a complex biological phenonenon in which the reproductive cycles of the organisms as well as external factors—such as possible temporary decline of food supply, or encroachment of emerging vegetation—are involved. This sudden decline is earlier and less marked in Quiver Lake than in Dogfish, possibly because of increasing differential environment, and thus occasions this temporary dislocation of the similarity in the movement of production on May 16–19, and again on May 21–22.

On July 3 we again find lower levels reached and accompanying decline in production in Quiver Lake when tributary waters rise in proportion. The readjustment which this necessitates so modifies production that its movement differs, though the difference is slight and consequently the less significant.

On Aug. 15 and 29 we deal again with a phenomenon similar to that of May 21, namely, a pulse of large production in Dogfish Lake with an accompanying one of lesser amplitude in Quiver. The pulse in Dogfish was again later, apparently, in reaching its culmination (on the 15th) than that in Quiver (on the 7th), and its decline (93 per cent.) on the 22d more complete than that which Quiver attains (63 per cent.) on that date from its maximum (4.36) on the 7th. The conditions in Quiver Lake are further complicated by the fact that on the 15th river water was just beginning a temporary invasion at the point of collection (see hydrograph, Pl. XXXI.). Save for this invasion the similarity of movement might perhaps have been preserved on the 15th. The abrupt and extreme decline in Dogfish Lake on the 22d, however, with the resulting interruption of the similarity of movement on the 29th, is in some way related to the excessive development of the 15th, which may bring into operation again the factors above suggested in connection with the like phenomenon in May. It seems not improbable that the sharper localization in Dogfish Lake due to absence of current and tributary waters and the presence of these factors in Quiver tends to intensify environmental influences or inherent tendencies of the plankton in the one area, and to minimize some if not all of them in the other, and that this differentiating influence of these purely local factors is fundamentally the cause of the dislocations and disturbances of the otherwise similar movement in production in the two lakes. These exceptions seem, however, to emphasize the essential similarity in the production in the two areas, a similarity founded on the common factors of the environment shared equally by both, and on the identity, in the main, of the constituent organisms of the plankton.

The general hydrographic conditions of this year affect profoundly the plankton production in this lake and in Quiver also. Although the average height for this year (6.975 ft.) is almost the same as in 1897 (6.903 ft.), the distribution of high water is such that the impounding function is exercised not only during the winter months, when production is low, but, owing to the recurrent floods, it is in operation to an unusual extent during the period from June to October, when production is wont, as a rule, to run low in these waters. Thus levels (Pl. XXXI.) are above 6 ft. fully half of this time and are at all times above 4 ft. with the exception of 10 days in July. Not only does this increase the impounding function of these waters, but it decreases the relative occupation by vegetation in addition to reducing its actual extent by uprooting and removal. It also decreases the proportion which creek and spring waters form of the total content of the area, or impounds them long enough for the plankton to breed therein.

The *distribution of high water* is such in this year that it affords an opportunity for increased production in the lake. In comparison with 1895, when production averaged 3.25 cm.^{3} per m.^{3} from April to the end of the year, we have 5.01 in 1896 for the year as a whole. The average height of the river in 1895 was 3.61 ft. (p. 163), in 1896, 6.98—an increase of 3.37 ft., or the equivalent of almost doubling the volume of water in the lake. So not only is the amount per cubic meter greatly increased, but the total run-off of plankton into the channel is multiplied by some undetermined factor.

The net result of the hydrographic conditions of 1896 in Dogfish Lake is therefore an increase in its impounding function at a time of large production (5.01), and its discharge tends to raise the plankton content alike of Quiver Lake (2.59) and the river (1.16), but data are lacking which might enable us to compute its quantitative effect upon the plankton content of either.

Not only is the *average* production of Dogfish Lake greater than that of Quiver, but individual collections here exceed *coincident ones* there with the exceptions only of those on May 21 and 22 and Aug. 15, when phenomenal declines appeared in Dogfish lake. In a similar way its production exceeds that in the river in every case but one, that of May 21. Thus production is prevalently higher here than in Quiver Lake and the river, to which it contributes its run-off, as a result of the impounding factor and, in this year, of the relative absence of vegetation also. The impounding permits the growth of the plankton to utilize the nutriment derived from decay of vegetation and other sources before it is carried out of the lake.

1897.

(Table VI., Pl. XXXII.)

There are but 6 collections here in 1897, in the first six months of the year, at approximately a monthly interval. The average production for this period is 2.23 $cm.^3$ per $m.^3$, with a maximum of 8.18 on Apr. 27. Since the collections are coincident in the river, Quiver Lake, and this lake, a comparison of production is facilitated. The similarity noted in the previous year may be traced here also, and the relationship of the three areas remains in the main unchanged during this half of 1897. Briefly, there is low production in all three under the ice in midwinter, with a slight increase in all in March, a vernal pulse in April followed by a decline in production in May in the lakes but not in the river, while in June the flood reduces the plankton content in the river but changes that in the lakes but little. The collections throughout the period show greater production in the lakes (Dogfish, 2.23, Quiver, 2.77) than in the river (average, 1.91) with the exception of the May collection (Dogfish, 1.94, Quiver, 1.29, river, 5.62). This drop in plankton content in the lakes below that of the stream occurs at the time of greatest increase in vegetation and rapid drop in levels, which increases the relative occupation by vegetation—a factor from which the river is relatively free. The flood of June, flushing the stream, obscures the relationships of production at that season. In all collections but those of May and Feb. 26 Dogfish Lake contains a more abundant plankton that Quiver by from 25 to 100 per cent. This is apparently due to the preponderance of the impounding factor in the former.

Thus in this season also the similarity in the movement of production noted in the previous year can be traced, and the excess of production in Dogfish over Quiver continues in the main. Its run-off therefore serves in this period to enrich the plankton alike of Quiver Lake and the river. This is correlated with the high levels and consequent increase in the impounding factor and the relative diminution of vegetation in this area.

GENERAL SUMMARY.

RELATIONS OF PRODUCTION IN DOGFISH AND QUIVER LAKES TO THAT IN THE ILLINOIS RIVER.

The analysis of the data of production in these two lakes leads to the following conclusions.

Plankton production is in a large degree a function of the time allowed for the breeding of the plankton. Thus at times of high water, when both lakes are filled principally with the impounded backwaters of overflow, production is greater, other things being equal, than at low water, when a greater proportion of water of the lake (Quiver) is of recent origin from tributary creeks and springs. So, also, areas such as Dogfish Lake, in which by reason of absence of tributaries and springy shores the impounding function is greater, show a greater plankton content than similar areas (Quiver) where by reason of access of tributary water the impounding function is decreased.

Vegetation of the character of that found in these lakes seems to exercise an inimical effect upon plankton production. Thus the season of dominant vegetation is generally one of low production in these lakes. Also during this period, as levels fall and occupation of the lake by vegetation becomes relatively greater, production generally declines, and, conversely, production rises when levels rise. Years of greater dominance of vegetation, other things being equal, are wont to exhibit a decline in production, and, conversely, with lessened vegetation production rises.

These factors, combined with changes in production in the river, vary the relation which these lakes bear to production in channel waters. In general, in times of low water and dominance of vegetation the outflow from these lakes is a diluent of channel plankton, but during the run-off of impounded backwaters or in years of higher levels and less vegetation it serves to enrich channel waters.

The river and the two lakes exhibit in common a very marked similarity in the seasonal movement in production. The recurrent pulses, which may be traced whenever collections are of sufficient frequency, coincide closely in their location but exhibit considerable local differences in their amplitude. This similarity is greatest when local environmental factors, such as vegetation and tributary waters in the lakes and sewage contamination and recent flood water in the river, are least operative, and is diminished or obscured as these factors come more into action. The diversity, as shown in the differing amplitudes of the pulses of production and in the divergences and interruptions in their rise and decline, can generally be traced to the preponderance of some local factor or factors above named.

The similarity in the seasonal movement of production is all the more marked when the striking differences of the three localities in question are considered and the general instability of the whole environment is borne in mind. The changes in the plankton content of the river,—turbid and fouled by sewage, traversed continuously by a considerable current, and scoured repeatedly by flood,—of Quiver Lake,—with gentle current,clear spring-fed waters, and greater or less, but always considerable, vegetation,—and of Dogfish Lake,—with tranquil, almost currentless waters, without access of tributary contributions, and also with considerable vegetation,—all exhibit a harmony that compels us to admit the potency of those general factors of the environment common to all—their climatic and geographical surroundings, which determine the amount and distribution of the light and heat, and the chemical constituents of the medium in which the plankton grows. The similarity in the movement of production must also be correlated with the fact that these common environmental factors are responded to in the three localities by a plankton composed of identical or closely related species in varying proportions. It is in the main the result of the response of similar organisms to the common factors of an environment, factors, moreover, of fundamental significance.

FLAG LAKE.

(Table VII.; Pl. XIX., XXXIII., XXXIV.)

ENVIRONMENTAL CONDITIONS.

This is the local name for a marsh in the western bottomlands opposite the location of our plankton station in the river (Pl. II.). Together with its outlet, Flag Lake Slough, it extends parallel to the river from north to south a distance of about 4½ miles, and is generally less than ¾ of a mile in width. It has no precise boundaries, since the fringe of willows which borders it, save for 2 miles along its northwestern margin where it joins Thompson's Lake, merges gradually with the marsh on the one hand and the bottom-land forest on the other. It contains about 2¼ square miles of permanent marsh, of which but a small area toward the lower end was free from vegetation. The depth depends upon the stage of the river or the extent of the run-off of the impounded water. Its bottom, if we may dignify the treacherous ooze from which the vegetation springs by this name, is generally, if not entirely, several feet above low-water mark in the river. In the autumn of 1897, during the prolonged low water of that season, the lake dried up and a road was opened across it to Thompson's Lake. Generally, however, it retains sufficient water to tide over ordinary periods of low levels.

The hydrographic conditions are such as to make this marsh exempt from all current save at times of most general overflow. Owing to the somewhat elevated banks along Flag

Lake Slough and along the west bank of the river, no access of river water is possible from the north or east until bank height is exceeded by the flood. At all levels below this, water enters the lake by the slough, which forms its outlet, or backs in from Seeb's Lake (Pl. II.). Another line of access is the low margin to the northwest between it and Thompson's Lake. The rank growth of living or dead vegetation which at all times fills this region, effectually blocks any localized current here, and no channel has opened in this region. Probably much of the water, as indicated by the distribution of drift, enters the lake from its southern end. The same reasons which prevent access of water from the north also tend to restrict the flow through this area at times of general overflow, and the fact that Thompson's Lake (Pl. II.) affords for backwaters impounded to the north a channel where resistance is much less than in the shoal, forest-begirt, and rush-filled Flag Lake, tends also to divert the moving backwaters to that region. Consequently, Flag Lake is in the main an impounding area whence the impounded water is drawn off as levels decline, but which is not generally traversed by the waters of general overflow as are Quiver and Thompson's lakes. It is thus one of the most strongly localized of all plankton stations, and the unity of its environment is more continuously maintained than that of any of the localities thus far examined.

Its vegetation has been described on pages 249–250, and it will suffice in this connection to call attention to the predominance of the emergent and succulent types in its waters, and to the fact that little, if any, of it is ever carried away by flood or currents as it is from Quiver and Dogfish Lakes. This is a large factor in maintaining the local fertility of this area.

This is a favorite haunt of migrating water-fowl in fall and spring, and contains breeding grounds of the few summer residents. It is also much resorted to by the German carp, now one of the most abundant fish in the Illinois. Fish enter the lake in numbers when levels rise, but leave again before low water in the slough (Pl. II,) prevents their departure. Evidences of the destructive work of the carp are seen in their activity in uprooting great patches of *Sagittaria*. Such conditions were prevalent shortly after the August flood of 1896 (Pl. XXXIII.), when the combined action of the change in levels and the invasion of fish destroyed not a little of the vegetation.

COLLECTIONS.

Systematic examination of the plankton in this area was begun Oct. 17, 1895, and continued until Aug. 16, 1897. Six summer collections were made in 1898 for the purpose of detecting *Trochosphæra*.

Owing to the surroundings of this region access to it except during high water was a matter of much time and considerable difficulty. Absence of roads and bridges made approach by conveyance impracticable, and save at maximum overflow the elevation of the surrounding bottoms or the abundant vegetation prevented the entrance of the steam launch. The drift in the slough (Pl. II.) and the matted, and in many places impenetrable, growth of *Scirpus fluviatilis* rendered access to the small areas of open water an arduous task. At low stages the only means of obtaining a collection was to wade out through the morass to a suitable place. The difficulties of approach in winter were even greater, when ice and the emergent vegetation combined to interfere with rapid transit of any considerable load. For these reasons this station, though one of much local biological interest, was early dropped from our list.

These same difficulties have enforced some variation in the methods of collection (Table VII.) and in the locality at which collections were made. In the autumn of 1895 they were made by dipping water in scattered areas in the vegetation and in advance of the roiling of the water caused by wading. On Feb. 28, 1896, a measured quantity of water from successive levels was taken amid the standing but submerged vegetation with a pump. Other collections prior to May 23, 1895, were made by the oblique-haul method and thereafter by the plankton pump.

In the autumn of 1895 collections were made in the northern arm of the area marked as open water on Plate II., and occupied at that time by a considerable amount of submerged and floating vegetation, largely of *Nymphæa.* During high water, when landmarks were submerged, this location was approximated as nearly as possible, but in the following spring the location of the plankton station was shifted to the lower arm of this open area (Pl. II.), and as the vegetation emerged and blocked access the station was moved to the head of the slough in effluent waters. These changes in method and location impair somewhat the value of this series of collections for comparisons *inter se*, but they still serve to throw important and significant light upon the relationship of such marshes and of their vegetation to plankton production in their own confines and in the channel waters to which they may contribute.

There are 38 collections, extending continuously over 22 months in 1895–1897, with an interval of collection in the greater part of 1896 sufficiently short to enable us to follow the course of production. The scattered collections of the remainder of the period and the six additional collections in 1898 throw but little light upon the movement in production, though they are of interest for comparison with other localities.

PLANKTON PRODUCTION.

1895.

(Table VII., Pl. XXXIII.)

There are but four collections in this year, in October–December, averaging 20.45 cm.^{3} per m.^{3} and having a maximum of 57.76 on Oct. 17, and declining to 6.38 on Dec. 19. This period was one of no marked changes in the hydrographic conditions. The lowered temperature and autumn rains had checked evaporation and brought about a slight increase in the volume of water, as shown by the increase in depth from .25 to .45 m. The lake was choked with decaying vegetation, the product of two season's growth without a flood exceeding 7 ft. Even the rise to 5.2 ft. Dec. 19 was only beginning to affect the conditions within the lake. In October the succulent vegetation, such as *Nymphæa*, *Nelumbo*, and *Sagittaria*, was undergoing rapid decay, which was checked by falling temperatures, and we find plankton production declining (from 57.76 to 6.38), and the decline accelerated on Dec. 28 (3.26) with the invasion of flood waters. This large production, unsurpassed at any other station (cf. Pl. XXXIII. with Pl. IX., XXVI., XXX., and XXXVI.), is to be correlated with the excess of decaying vegetation in this locality resulting both from the abundance and character of the vegetation and its freedom from flushing by current due to access of tributary waters. The maximum in October is due almost wholly to *Synura ubella*, which declines in the later collections in which the *Cladocera* and later the *Copepoda* appear in increasing numbers. Throughout this period there was no run-off until flood levels were reached late in December, and even then, owing to reasons above cited, the run-off from the area is relatively slight. There was consequently no direct enrichment of the channel waters from this area. Unfortunately, no chemical analyses of water from this area are available, and the chemical basis for an estimate of the relative fertility of this marsh is lacking. The data of production illustrate the great fertility of waters impounded where decaying organic matter abounds. Both the impounding factor and the local enrichment factor are apparently at a maximum potency here at this season, and production is correspondingly great.

1896.

(Table VII., Pl. XXXIII.)

There are 27 collections in this year, with an average of 13.83 cm.^{3} per m.^{3}, and a maximum of 203.52 on May 2. The weekly interval of collection in April–June enables us to follow the course of production with some detail, but the fortnightly, or longer, interval prevalent during the most of the remainder of the year reduces greatly the value of the data for such purposes or for comparison with other localities.

The hydrographic conditions are such in 1896 that this lake maintains, throughout, a connection with the river. This is owing to the relative absence and brief duration of low levels, the run-off not being completed before a new invasion occurs as a result of a recurrent flood. Since falling levels prevail during more than two thirds of the year, a run-off from the lake continues during this portion of the time at least. The lake is therefore in this year a factor in the determination of production in channel waters, whose continuity is broken only when levels are such that no waters are draining off from the lake or passing through it during general overflow—which is the case in less than one fourth of the time. The average production in the lake for 1896 (13.83) is almost twelvefold greater than that in the stream (1.16), and the monthly averages also (see table between pp. 342 and 343) are from 2½ to 218 times greater, while individual collections in the lake in all but three instances exceed coincident or approximate ones in the river. The exception on July 30 occurred, when the invasion of flood water was followed, as is usually the case in midsummer in vegetation-rich backwaters, by a semi-stagnation with great development of *Oscillaria*, and the formation of considerable gas with a strong odor of H_2S beneath the felt of *Oscillaria* which covers the bottom. Under these presumably abnormal conditions the plankton content reached a lower level in the lake (1.62) than in the river (3.90), and this was at a time of influx rather than outflow of water. With the above exceptions the lake at all observed seasons contains a richer plankton than the channel, which its run-off directly enters, and under similar hydrographic conditions we are justified in predicting at other times a similar relationship, though the exact ratio of production would probably vary according as the vegetation by its growth or decay affected the fertility of the water.

In the absence of any satisfactory basis for determining the amount of the run-off from this lake, a quantitative expression of its effect in increasing the plankton of the channel cannot be given. Similar marshy regions are found, along the course of the river elsewhere, especially above higher bottoms which have been built up across the flood-plain by tributaries such as Spoon River, and such areas presumably share with Flag Lake this contributory function in the maintenance of channel plankton.

In the discussion of production in Quiver and Dogfish lakes I have called attention to the similarity in the movement in production, these two lakes and in the river. In Flag Lake, we are dealing with a very different environment; bottom, shores, vegetation, hydrographic relations, especially in the matter of tributary waters, are all diverse. Indeed, the lake itself includes several distinct types of environment. It is interesting to note that in so distinct a unit of environment as this marsh we find so large a degree of similarity in the movement of production as can be traced between its seasonal planktograph and that of the river and of the lakes thus far examined. It should, however, be stated that the similarity is less precise here and is more evident in 1896 than in other years, though this is probably in part due to the absence of sufficiently frequent collections.

The degree of similarity may be seen in the following comparisons. In 17 of the 27 possible comparisons between production in Quiver and Flag lakes (Pl. XXVII. and XXXIII.) the direction of the change in production coincides. Most of the 10 exceptions are due to slight differences in the location of apices of pulses, or occur at times of lowest water, that is, of most pronounced local differentiation—as, for example, at the drop in levels in May and again in July. The same number of exceptions similarly located occurs when production in Dogfish Lake (Pl. XXXI.) is compared with that in Flag Lake (Pl. XXXIII.), and there are 11 exceptions in the possible 27 in the case of the river (cf. Pl. X. and XXXIII.).

In general terms, the similarity consists in the rise in production, probably obscured in Flag Lake by an overestimation of silt on March 30—with increase in temperatures in January–April, culminating in a vernal pulse in April-May, which in Flag Lake reaches a much higher level (203.52) than elsewhere, culminates later by 7 to 14 days and is not divided into two apices as in the other three localities, but in duration covers the period of two pulses elsewhere. It is further seen in the May-June and August pulses and in the fairly well sustained correspondence in direction of the changes in the September–December period. The most marked disagreement appears with the declines in stage of the river in May and July, when local environmental factors are most potent, and when, also, vegetation is at the height of its relative occupancy of the lakes in question.

One of the most striking features in the production of this lake, and one not without parallels elsewhere in our records (Pl. XXIX., XXXI.), is the very sudden decline in plankton content after the vernal pulse, namely, from 203.52 cm.^{3} per m. on May 2 to 47.7 on the 9th—a decline of 77 per cent. in 7 days. On the 15th it reached the low level of .72, a decline of 98 per cent. in 6 days or of 99.6 in 13 days. The attendant hydrographic conditions are not without significance. This pulse (Pl. XXXIII.) attains its growth between March 30 (1.02) and May 2 (203.52), in which period the net drop in levels in channel waters is only from 8.1 to 6.9 ft. and the total movement only 1.7 ft., while in this protected backwater the fluctuations are probably somewhat lessened, as will be seen in the fact that the depth in the lake changes only .5 ft. to 1.2 ft. in the channel. The pulse thus rises in *stable* conditions.

The decline of the pulse takes place between May 2 and 23 from 203.52 cm.^{3} per m.^{3} to .12. In this time levels fall from 7.1 to 4.9 (see p. 159) on the 17th and rise again to 7.2 on the 23d. The decline in production from the 15th (.72) to the 23d (.12) is so small a part of the total that its significance in the present connection is slight, and the rise in levels has probably not had time to materially affect the lake. The hydrographic influences potent in the decline in production have been operative prior to this rise, and consist in a fall of 2.2 ft. in channel waters though the depth at the station of collection changes only 1.6 ft.—equivalent to a reduction in volume of 25 per cent. at the point of collection and 30–40 per cent. in the lake as a whole. It thus involves a considerable and rapid run-off of the rich plankton developed in these impounded waters. This factor alone is, however, quite insufficient to account for the total loss in plankton content in this period. Another factor which is correlated with this reduction in the plankton content is the increasing occupancy of the lake by vegetation. The decline in levels hastens the emergence of the emergent forms and increases the relative occupancy by submerged and floating species, while the vernal growth in all during these three weeks in May, more than any other factor, transforms the broad expanse of open water into a vegetation-clogged marsh in which but few stretches of open water are visible. This phase of the growth of the grosser forms of the aquatic flora robs the water of some of its store of nutriment and cuts off the free access of light—both of which might interfere with the growth of the competing phytoplankton. Limnetic diatoms such as *Asterionlla* and *Melosira* are the principal synthetic organisms building up this remarkable pulse, and the *Cladocera*, principally *Bosmina* and *Chydorus*, appear in numbers with its culmination. The composition of the plankton favors the inference that a temporary exhaustion of the food of the phytoplankton and zoöplankton alike contributes to the sudden reduction in plankton content, while the additional and perhaps related factor of reproductive cycles may also have a large causal relation to the phenomenon.

1897.

(Table VII., Pl. XXXIV.)

There are but 7 collections in this year, at approximately monthly intervals in January–July. Collections were suspended on July 16, when decline in levels made access even to the foot of the lake by boat impossible. With the further decline (Pl. XI.) in river levels the run-off from the lake soon ceased, and by the middle of September the water had practically disappeared within its boundaries.

The 7 collections average 4.59 cm.^{3} per m.^{3}—about double the average production in the adjacent river, and in Quiver, and Dogfish lakes on coincident dates. Individual collections also exhibit in every case a greater plankton content in the lake than in the river. This area in this season thus contributes to the enrichment of the channel waters, which its run-off enters, and its contributions exceed those of the lakes on the eastern side of the river. This higher production in this locality is, I believe, a corollary of the greater impounding function of Flag Lake, resulting from its freedom from tributary waters of recent origin, from its somewhat sheltered location—which checks the downward movement through its area of the general currents of overflow, and from the enrichment of its impounded waters during this period by the decay of the abundant vegetation of the previous season, which, for the reasons just mentioned, is not extensively carried away by flood waters.

The fact that production appears to be so much less in 1897 (4.59 cm.^{3} per m.^{3}) than in the corresponding months of 1896 (11.21) may be due to several factors ; to the greater dilution in the greater volume of overflow (cf. Pl. XXXIII. and XXXIV.) in the winter and spring floods of the latter year, to the greater abundance in 1896 of decaying organic matter accumulated by the vegetation of two preceding low-water seasons, and, possibly, in a measure, to the infrequency of collections in 1897 and the probable omission of the maxima of pulses of production which would tend to raise the average.

The similarity in the movement of production in this and other localities will appear at once on comparison of Pl. XXXIV. with Pl. XI., XXVIII., and XXXII. The coincidence in the direction of the changes is precise in all of the 7 instances in the case of the river, in all but one for Quiver Lake, and in all but two in the case of Dogfish Lake. This is a period of maximum overflow, when the individuality of these several localities is submerged by the flood. It will be noted that the exceptions lie at the close of this period, when low water brings local factors into prominence. It is at this time also that the differences in the amplitude of production are most in evidence.

1898.

(Table VII., Pl. XXXIV.)

Six collections made at the outlet of Flag Lake in this year in July–September for the purpose of detecting *Trochosphæra* are introduced into Table VII., since they throw some additional light on production here. The four collections in July exhibit a very low level of plankton content, the highest being .62 cm.^{3} per m.^{3}; and the level is not raised in the single August collection. However, with the run-off of the slight rises of August and September we find a rise to 15.54. At this time water of overflow was making its way from across the bottoms at the southern end of Thompson's Lake through the marshy swale into the foot of Flag, and thence out to the river.

The similarity in the movement of production here and in other stations is seen in the general low level of production in July and the slight rise towards the end of the month. A decline early in August can also be traced, followed by a rise in the next month (cf. Pl. XXXIV., XII. and XXIX.).

With the exception of the collection on September 6, the collections of this year indicate that the effluent of Flag Lake is a diluent of channel plankton. This may result from the low levels and consequent dominance of the vegetation in the lake at this time of low production there.

SUMMARY.

The data discussed in the preceding pages lead to the following conclusions concerning Flag Lake.

The average production of plankton in this lake, or, more properly speaking, marsh (11.46 cm.^{3} per m.^{3}, or 9.23 on the basis of monthly averages), exceeds that in the river (2.19 or 2.71). This greater fertility appears not only in the averages but in general throughout most of the seasonal changes. Its run-off therefore serves generally to enrich the channel waters.

The greater production is due to the decay of the abundant vegetation which the lake contains, to the absence of tributary water of recent origin, to the relative freedom from the general current of overflow which largely takes the line of less resistance through Thompson's Lake (Pl. II.), and, consequently, to the greater time afforded for breeding an abundant plankton in this impounding area.

The dominance of the abundant vegetation is inimical to large plankton production. Other things being equal, plankton production is greater when the relative occupancy of the water by vegetation is decreased.

The movement in plankton production in this area is in the main similar to that in the river and in Quiver and Dogfish lakes. Pulses of production tend to coincide, though their amplitude may differ widely in the several localities. This similarity is least when local environmental factors such as vegetation, stagnation, or local exhaustion of the food supply are most potent. It is greatest when these are least, that is, during high water.

STATION G, THOMPSON'S LAKE.

(Table VIII., Pl. II., XX., XXXV.—XXXIX., L.)

ENVIRONMENTAL CONDITIONS.

This body of water lies in the bottom-lands on the right bank of the Illinois, above Spoon River, midway between the bluff and the main stream. It trends in a northerly and then a northeasterly direction, following somewhat the curve of the Illinois. It is about five miles in length at low water, with a width in three fourths of the distance of about two thirds of a mile, while the northern end is less than one third of a mile in width. At this stage it contains about 1,400 acres. As levels rise, its margins spread rapidly—owing to the slight gradient of the shores—northward to Grass and Slim Lakes, westward, through Mud Lake, towards the bluff, to the south, towards

Spoon River, while its connection with Flag Lake is early established over the low sandy bank which lies between them. At stages above six feet the "cut road" (Pl. II.) and the marshy swale above it fill, and connection with Flag Lake at its lower end and with the river is established. Its area is about doubled by the time the river reaches bank height and general overflow ensues.

The lake is of somewhat uniform depth in the middle half, but shoals toward either end. In prolonged low water, when the slough at the northern end is practically cut off from the lake, extensive mud-flats are exposed in the northern area, and a portion of the southern end for about half a mile is also left bare except when prolonged and heavy winds drive the water towards one or the other end of the lake. The depth at lowest river levels in the central region, which includes about two thirds of the total area, is 3 ft. Laterally the water does not shoal until within 10 rods of the shore. There is thus a large area (about two square miles) of water with uniform conditions in this particular.

With slight exception the bottom is of the softest alluvial mud, several feet in depth, overlying a sandy blue clay. The shores along the southern, western, northern, and northeastern margins are also of soft alluvium and of a marshy character. The eastern shore, for most of its extent, and limited stretches along the western one, together with the spit which makes out into the lake on that side, are of sand and of a firmer consistency.

All of the shores are bordered by a belt of vegetation, which has been described on page 246.

This lake is the largest of the reservoir backwaters examined by us, and is one of the permanent type, resembling in all important particulars except that of submergence in times of general overflow and its reservoir relation to the river a typical lake of an alluvial prairie country. Its position in the bottom-lands brings it into intimate connection with the river, the source of most of its water supply, while at times of flood its position is such that the backwaters from the bottom-lands up-stream sweep through it and out to the river through the "cut road," being deflected by the alluvial deposits of Spoon River (Pl. II.). Its relation to the river is a peculiar one in that its outlet, or slough, lies at its up-stream end. At stages above six feet the current enters through this slough, and the run-off takes place at the lower end through the cut road. Below this level all the run-off must take place through the slough. The direction of the movement in the run-off of the lake is thus reversed as river levels pass this stage. There are no tributary waters of consequence which enter the lake, though a small rill and a few springs enter along the western margin. The main supply is drawn directly from channel waters through the slough, and when levels are stationary there is no interchange in either direction. The current sets in or out, at stages below 6 ft., according as the river rises or falls. The result of this condition is that during the higher levels backwaters of overflow and the river water entering by the slough are impounded and drawn off slowly at the lower end of the lake. At stages below 6 ft. a run-off occurs only in the falling stages and in relatively smaller volume through the narrow and tortuous slough. The impounding function is accordingly more highly developed at lower levels, while at lowest levels all interchange ceases.

This close and intimate dependence of this lake upon the river for its water supply in so far destroys the unity and independence of the lake as a separate unit of environment, and tends to eliminate the differences in plankton production between it and channel waters. This tendency is counterbalanced to a considerable degree by the large size of the lake and consequent increase in the time occupied in transit during overflow, and by the impounding, at lower levels, of entering river water at the upper end of the lake, where it deposits its silt and soon permits the development of the lake plankton in its area. Here, as elsewhere, local factors are most potent at lower levels.

The effect of the greater size of this lake is thus to equalize environmental fluctuations and to obviate their catastrophic results, which may be seen in their maximum violence in channel waters, and in a lesser degree in the lakes thus far examined.

COLLECTIONS.

This station was opened June 7, 1894, and collections were continued until the close of operations on March 28, 1899. In all, 99 collections were taken, distributed in the several years as follows: 5, 14, 27, 18, 25, and 7, with but few exceptions at approximately a monthly or fortnightly interval. It was only in the spring and summer of 1896, when an interval of 7–10 days was adopted, that the interval is brief enough to enable us to trace the movement in production with any degree of fullness. At other seasons the data are suggestive, but not conclusive, of its course. The relatively smaller number of collections made at this important station is due to its distance from our center of operations, the round trip from Havana to the lower station in low-water conditions exceeding 25 miles. The difficulties of access were greatly increased when at low water it was necessary to make the trip from the outlet of the slough by rowboat, and to drag or push this over the soft mud and through the dense vegetation at the upper end of the lake, and when, in winter, at low water, the boat and outfit had to be dragged across the frozen bottom-lands.

The locations at which collections have been made are principally the two marked on the map (Pl. II.). The lower one was used exclusively in 1894 and 1895, and thereafter when access to the lake was had through the cut road. The location off Sand Point, at the upper end, was used when the lake was entered by way of the slough. Both were in the open central region, well out in the vegetation-free area, though in 1895 and 1896 the lower station was encroached upon somewhat by shifting masses of *Ceratophyllum*. In a few instances, owing to high southwest winds and the dragging of the waves in the shallow lake, it was not possible to maintain an anchorage in the unstable bottom, and refuge was had under the lee shore, but still in usual depths and open water. In several instances in overflow stages, when the ice was too heavy to break and too light to carry our load, it was necessary to make the collection near the margin of the lake in effluent waters. These variations in the location of the point of collection introduce no error of consequence into the series, judging by the results of an examination of the local distribution of the plankton in this lake, the details of which cannot be given in the present paper.

With the exception of the single pump collection on February 28, 1896, all collections prior to May 20 of that year were made by the oblique-haul method, and thereafter by the plankton pump.

This lake is a type of the larger reservoir backwaters, such as Meredosia Lake, Clear Lake, and others found in the bottomlands of the Illinois and maintaining a constant connection with that stream. An examination of its plankton content will therefore serve to throw light on the relation which lakes of this type bear to plankton production in channel waters.

PLANKTON PRODUCTION.

1894.

(Table VIII., Pl. XXXV.)

There are but 5 collections in this year, from June to December, at an interval of a month or more, with an average production of 8.89 cm.^{3} per m.^{3} and a maximum of 24.92 on June 7.

An inspection of the hydrograph (Pl. XXXV.) of this year reveals the fact that only the first two collections were taken under conditions which permitted any run-off from the lake to the river, and both of them at times—that is, in falling levels below 6 ft.—when the run-off was largely, if not wholly, through the tortuous slough at the up-stream end of the lake. The production in the lake (24.92 and 10.74) at these times was 33- to

4-fold that in the river (.74 and 2.39), so that the run-off at this season enriches channel plankton. With the exception of the August collection the plankton content in the other three collections in the lake exceeds that in the stream. The low content in August (1.08) occurs at a time of lowest water, when vegetation by reason both of river stage and the season is at its maximum occupancy of the lake. At other times the effect of the reservoir function of the lake is seen in the relatively greater production in its waters.

The scattered data of this year are insufficient as a basis for any conclusions as to the correspondence in the movement of production in this and other waters.

1895.

(Table VIII., Pl. XXXVI.)

There are 14 collections in this year, between April 10 and the end of the year, averaging 9.67 cm.^{3} per m.^{3}, and with a maximum of 61.44 on May 1—an amplitude nearly 11-fold that of this pulse in the channel.

The average production (9.67) is 3-fold greater than that of the river in this year (3.22), and the monthly averages (see table between pp. 342 and 343) are in 5 of the 9 months from 1.6- to 12-fold greater in the lake than in the river. In the remaining four months, June, July, August, and December, the ratios are respectively 30.42, 9.33, 4.03, and 1.14 (river), to 9.42, 4.83, 3.09, and 1.00. The lower production in June–August occurs at a time when, with the exception of three weeks, levels were low and vegetation at its maximum occupancy of the lake, and when, moreover, the current was greatly slackened in the river, and channel plankton in the richly fertilized waters had more than the usual time to breed, while the less production in the lake in December is, owing to the distribution of collections, more apparent than real.

In the matter of individual collections on coincident or approximate dates the lake shows a greater plankton content in 9 out of the 14 instances, and of the 9 there are 5 in which hydrographic conditions favor a run-off of this richer plankton of the lake into channel waters. There are two instances in which run-off occurs when lake waters are poorer than the channel, but they are both at low levels and during slow decline, so that the discharge and resulting diluent effect is but slight. Considering the average production, the times when run-off occurred, and the hydrographic conditions when the lake waters contained less than the channel, it is probable that even in this year Thompson's Lake, owing to its reservoir function, served predominantly to enrich the channel plankton. Though this relation predominated, the total contribution of the lake to the stream in this year was but slight owing to the hydrographic conditions. In the April–December period covered by our collections, the stage of river never exceeded 6 ft. until the December flood. There was, therefore, never any general current of overflow passing through the lake and carrying the impounded waters out from the southern end (Pl. II.) into the river and thus discharging a considerable volume of plankton-rich water into the channel—a condition possible in both rising and falling levels above 6 ft. At the levels below this point which prevailed throughout this period, influx and efflux both can take place only through the slough at the northern end, so that contributions to the stream from the lake occur only during falling levels, and, moreover, owing to the tortuous course and clogged condition of the outlet, the volume discharged at these lower levels is very much less than at higher ones, across the broad outlet at the other end of the lake. Falling levels occurred in less than one half of the time in April–December, so that the contributions of the lake to the river were not only slight in volume but limited in duration and discontinuous.

Collections were too infrequent to trace the movement in production with fullness or certainty. There are, however, a few suggestions of a similarity in the course of production here and elsewhere. The direction of the changes in the course of production in this lake and in the river in coincident or approximate collections is the same in 9 out of the possible 13 instances (cf. Pl. IX. and XXXVI.); in the case of Quiver Lake the agreements number 7 out of a possible 12 (cf. Pl. XXVI. and XXXVI.); in the production in Dogfish Lake the correspondence is found in 9 out of a possible 12 (cf. Pl. XXX. and XXXVI.); while in Flag Lake there are 2 out of 3 (cf. Pl. XXXIII. and XXXVI.).

The agreement is lessened in this year, it seems, by the hydrographic conditions. The low water affords less opportunity for a mingling of the waters of the stream and its backwaters, and also serves to bring out the local environments at each of the stations. Thus Thompson's Lake has but little connection with other backwaters at any time during the year, and ingress or egress of channel waters was but very slight during six months of the twelve in this year. Vegetation also gained more extended possession of this lake in this year than in other seasons of our operations. Low water also tends to make the channel plankton more directly affected by its peculiar factors, such as sewage. It is noticeable that the agreement in production is most marked between Thompson's and Dogfish lakes, both backwaters of somewhat similar character in respect to tributary waters, relation to the channel, and vegetation.

The most marked differences between production in this lake and the channel appear in the respective amplitudes of the pulses of production in April-May and June-July. In the lake the rising vernal pulse attains the exceptional volume of 28.2 on April 10 to .52 in the river on the 9th, a difference which may in part be due to the earlier warming up of the shoaler lake waters. The maximum (61.44) in the lake is 12- fold that observed in the stream. The June-July production in the river, on the other hand, is 3- to 5- fold that in the lake, the contrast being due on the one hand, it seems, to the temporary exhaustion either of the chemical substances utilized by the plankton or of the reproductive capacities of the planktonts of the lake waters, and, on the other, to the increased sewage contamination in the stream as a result of low levels. The *direction of the changes in production*, however, remains the same in both localities (cf. Pl. IX. and XXXVI.) in the face of these contrasts in amplitude.

1896.

(Table VIII., Pl. XXXVII.)

There were 27 collections in this year, at monthly intervals until April, and then every 5–11 days until the end of August, and thereafter every fortnight. The average production in this year is 9 cm.^{3} per m.^{3}, with a maximum at the vernal pulse on May 2 of 48.99 cm.^{3}

The hydrographic conditions of this year are such as to bring Thompson's Lake into intimate connection with channel waters. The average height of the river for the year, 6.98 ft., is sufficient to maintain a run-off from the southern end of the lake to the river, submerging the bottom-lands between to the depth of a foot. Indeed a run-off of varying depths was maintained for 241 days, in which stages exceeded 6 ft. This was due to the recurrence of 6 floods, so distributed as to keep the lake discharging through the southern outlet for 241 days with only 5 interruptions between May and December. Of the 125 days in which water did not flow through the lake from the northern to the southern end, there were 29 of rising water in which no discharge to the river occurred, 28 of stationary levels in which the movement of the water, if any, was declining, and 68 of falling water, in which the lake discharged through the slough at the northern end. Thus, during 309 days of the year this lake was discharging to the channel, waters which had been impounded for a varying length of time within its boundaries. The importance of this impounding area is best shown by rough calculations which show that the run-off of a single foot from the lake proper, not including the expanding areas which join it with every rise in levels, will fill the channel of the river at Havana to a depth of 8 ft. (low-water stage) for about *three* miles. In 1896 the total depth of the run-off for the year computed on a *single* discharge after each rise is 26.9 feet—sufficient to fill the channel for 81 miles. When we add to this the consideration that at levels above 6 ft. water is continually passing through the lake with brief impounding, the length of channel filled by the run-off of this area must be considerably extended.

The relationship of plankton production in this lake to the plankton content in channel waters in this year may be inferred from the yearly averages. Thompson's Lake contained 9 cm.^{3} per m.^{3} to 1.16 cm.^{3} in the river. The net result would therefore be an enrichment of the channel plankton in a ratio dependent upon the relative volumes of the mingling waters. No quantitative statement of this ratio is possible in the absence of data as to the run-off of Thompson's Lake. Not only is the net result an increase in the channel plankton, but the monthly averages (see table between pp. 342 and 343) and the coincident or approximate individual collections (Tables III. and VIII.) *in every instance* exhibit a higher plankton content in this lake than in channel waters. The monthly averages range from 2 to 251 times greater in Thompson's Lake than in the river—ratios within which most, if not all, of those of individual collections fall. The data all indicate that this impounded water of the lake breeds a plankton whose run-off, without exception throughout this year, enriched channel waters.

The effect of invading and plankton-poor river waters upon the plankton content of the lake is not conclusively apparent in the data, since we have also to deal with the phenomenon of pulse-like changes in plankton content which are combined with other factors in affecting the movements in production. It may be significant of the diluent action of invading river water that plankton content falls in the lake with the first entrance of the May-June, the July-August, the October, and the November floods (Pl. XXXVII.). The recovery in production follows promptly in each case with the impounding of the entering waters. Since, however, declines in content, as in June, July, and August, occur also when flood waters are not entering, we cannot conclude that the decline upon this entrance is due solely and unequivocally to the diluent action of the invading waters, though their share in the phenomenon seems probable.

I have previously called attention to the similarity in the movement in production in the several localities wherever collections were of frequency sufficient to permit the tracing of the fluctuations in production. The course of production in Thompson's Lake in 1896 forms no exception to this similarity, though the parallelism is less precise than it is in some other instances. Thus the plankton content rises or falls together in Thompson's Lake and the Illinois River in 18 out of 26 instances of coincident or approximate collections; in Thompson's and Dogfish lakes in 18 out of 26 instances; in Thompson's and Flag lakes in 16 out of 25 cases; and in Thompson's and Quiver lakes in 12 out of 25. The *direction of the change* thus agrees in a total of 64 out of 104 possible instances in the data. This is a somewhat greater proportion of instances in agreement than chance would demand, and its significance is enhanced by the fact that the agreement with Thompson's Lake is greatest (64 and 69 per cent.) in the case of Flag and Dogfish lakes—impounding bodies similar to Thompson's Lake—and of the river (also 64 per cent.), which is in a measure and especially in this year a summation of impounded backwaters. Quiver Lake, on the other hand, where tributary waters increase the local differentiation, has an agreement in only 12 out of 25 instances. In like manner months of high water, such as August, when local differences are to some extent submerged, exhibit greater agreement than months of low water, when they are emphasized. Thus in August (average river gage, 7.42 ft.) 92 per cent. of the changes in production are in agreement, while in July (average river gage, 4.55 ft.) only 58 per cent. exhibit this relation. Again, since the above comparisons are based on *coincidence* of changes in production it results that slight chronological dislocations of otherwise similar movements in production indicate a greater disagreement than really exists. This is especially true of the vernal pulses of April–June, where as a whole only 58 per cent. of the coincident or approximate collections show this agreement. A comparison of Plates X., XXVII., and XXXI. with XXXVII., will show that much of this disagreement is due to slight variations in the positions of the apices of the several pulses in the different localities. In each locality we can trace three diminishing pulses in this period, pulses, moreover, which have much in common, barring variations in amplitude and time of culmination. Their similarity is greater than the 58 per cent. of agreement would seem to indicate.

The most marked difference between the production in the river and in Thompson's Lake, as has been shown, lies in the amplitude of the pulses, which in the river never attain the height that they do in the lake. A part of this contrast is due to the fact that pulses of production are sometimes flushed out by floods in the channel while they continue to a normal culmination in lake waters, as, for example, the vernal pulse which culminates in the lake May 2. Similarly, in the flood of the last of May and July the plankton content is suddenly depleted in the channel waters, while the rising pulse continues to a later and much higher culmination in the lake.

1897.

(Table VIII., XIII.; Pl. XXXVIII., L.)

There are 18 collections in this year, at monthly intervals till July, and thereafter approximately every fortnight. The average annual production this year, 10.43 cm.^{3} per m.^{3} is the largest recorded for this body of water, and is due to the excessive development in the low-water period, August–November, which reached an amplitude (35.35) over threefold that detected in the vernal pulse (10.38). (Pl. XXXVIII.)

The hydrographic conditions are very different from those of the previous year, and change profoundly the relationship of the lake and river. As will be seen on Plate XXXVIII., the river levels were above 6 ft. from the beginning of the year until June 6, and thereafter from the 25th until July 15, a total of 175 days in which the lake received water through the slough at the northern end, impounded it for some time, and maintained a run-off at the southern end (Pl. II.) of its plankton-rich waters. There are in addition 35 days in June, July, and August in which falling levels below 6 ft. afforded an opportunity for a run-off through the slough at the northern end. Of the remaining 155 days, 10 are of rising levels below 6 ft., when the lake receives water from the river but does not discharge any into it, and 145 belong to the low-water period of the last 5 months, in which there was little interchange between lake and river though the run-off continued in diminishing volume for a few days after stable levels were reached, early in August. About August 16 the channel discharge was so slight as not to float a rowboat in the narrow channel at the northern end of the lake, and connection with the river was not reestablished as the river rose in October–November until the level of 2.8 ft. was reached, Nov. 10. The slight fluctuations during the remainder of the year practically amount only to the reception of .4 ft. of water by the lake. For the last five months of the year—months of heavy plankton production in lake waters—there was no run-off to the river.

On the average the lake produced this year 10.43 cm.^{3} per m.^{3}, about 3-fold that in channel waters (3.69 cm.^{3}) and the net result of the run-off would be, it seems, an enrichment of channel waters. The actual enrichment is, however, much less than these averages indicate. An examination of the monthly averages (see table between pp. 342 and 343) reveals the fact that the excessive production in the lake, when the plankton content rises to 5- to 16-fold that in the channel, appears in the low-water period when no run-off occurs. During the first 7 months, in which there is an almost continual run-off, the production in lake waters is but 1.5- to 2-fold that in the channel except in February and June, when flood waters in the latter increase the ratio to 1 to 7 and 13 respectively. The insufficiency of the collections in this period leaves in doubt the amplitude of the vernal pulse. The April and May collections indicate only a low level of production as compared with that in other years, and this also tends to lower the relative productiveness in the lake. It is evident that the seasonal distribution of the period of flood waters and the resulting impounding function of the lake affect greatly its contributions to channel plankton. In this year flood waters are largely confined to the colder and less productive season, when the run-off contains little plankton and its contributions are small, while in 1897 recurrent floods throughout the year afforded a run-off in seasons of larger production, and this tended to greatly increase the enrichment of channel waters in that year as compared with 1897.

Plankton content in 1897 in Thompson's Lake was in excess of that in the river in the case of coincident or approximate collections in 16 of the 18 instances, the two exceptions appearing in July and September, when pulses in channel plankton rise above the recorded production in the lake as a result of some undetermined factor.

The similarity in the course of plankton production here and elsewhere is most marked in the first part of the year, and decreases in the time of low water. Thus, on comparison of the planktographs of Thompson's Lake (Pl. XXXVIII.) and the Illinois River (Pl. XI.) we find 14 out of 18 changes in the course of production coincident in the two regions, the four exceptions occurring in May (1), July (2), and September (1). The environmental differences between Thompson's Lake and the river are much less than between this lake and Quiver, and we find a corresponding disagreement in their planktographs, only 10 out of 18 changes being in the same direction, and six of the ten are in the period of high water, when local differences are submerged. In the cases of Flag and Dogfish lakes collections extend only to July, with agreement in 5 cases in each out of a possible 7 and 6 respectively. In the year as a whole and including all the above localities we find 34 agreements to 15 exceptions, in January–June the ratio being 3 to 21 for 4 localities, and in July–December, in low water conditions, 12 to 13 for from 2 to 3 localities. The effect of the common elements of the environment which high water introduces, in unifying the course of plankton production in their several areas, and of low water in diversifying it, is well demonstrated by these comparisons.

In the planktographs of Thompson's Lake and the Illinois River there is a striking general agreement in the low vernal production and the increased and unusual autumnal production. There are also some indications of a pulse-like character of the planktograph in the lake, though the collections are too infrequent to demonstrate it.

1898.

(Table VIII., XII.; Pl. XXXIX., L.)

There were 25 collections in this year, at fortnightly intervals, with an average of 5.71 cm.^{3} per m.^{3} to 2.13 cm.^{3} in channel waters. The net result of the run-off from Thompson's lake in this year is thus an enrichment of the plankton of channel waters. This is true for all of the monthly averages (see table between pp. 342 and 343) with the exception of April, and this exception is due solely to the distribution of collections on the rising vernal pulse, and is more apparent than real (cf. Pl. XII. and XXXIX.). The relative plankton content in the two areas, as will be seen on a comparison of the planktographs, is not subject to great variations in this year aside from January, when the ratio of the lake to the river is 1 to 17, and, as above noted, in April, when the ratio apparently falls to 1 to .6. With these exceptions, it ranges in the first six months from 1 to 2–3 and in the last six from 1 to 3–5. These figures express quantitatively the striking similarity in the planktographs of the two areas, which may also be recognized at once in the plates (XII. and XXXIX.) in the low winter production, in the meteoric vernal pulse followed by a minor one in June, and in a low level of production during the remainder of the year with fluctuations within rather narrow limits.

The cause of this close resemblance lies in the hydrographic conditions, which throughout this year favor constant interchange between lake and river. The average height for this year is 8.02 ft., the highest during our years of record. From Jan. 22 to July 15 river levels were above 6 ft., and a constant inflow of impounded water from bottom-lands above the lake, or through the slough when overflow ceased, continued with impounding in the lake and subsequent discharge from its southern end to the channel. The same conditions again prevailed from Oct. 30 till the end of the year, with an interruption of 6 days in December. During the remaining parts of the year there was a constant wavering in levels which favored frequent—in fact, no less than 21—reversals in the direction of flow in the slough connecting the lake with the river. During the 134 days of low water there were 56 of falling levels in which the lake was discharging its plankton-laden water through the slough to the river, making a total of 287 in which it contributes to channel plankton to 78 in which, owing to low levels, it merely receives an inflow from the river. Moreover, the periods of greatest plankton production in the lake, during the vernal pulse, occur at times when the run-off from the lake is at its height, so that in this year all the hydrographic factors combine with the distribution of the plankton production to render this reservoir lake a feeder of the channel plankton. Though the differences in the plankton content are such that the actual enrichment per cubic meter may be less than in other years, the total run-off of plankton into the channel must compare favorably with that in any other year of our operations.

The comparison of coincident collections shows in all cases but three, a greater plankton content in the lake than in river. The first of these is on April 5, at the height of the spring flood, when a considerable current sweeps through Thompson's Lake and shortens the period of impounding, and thus reduces the time for the development of the plankton. The second instance is on June 21, on the decline of the accessory vernal pulse, which reaches a lower level in the lake (2.47) than in the river (2.88). This is one phase of a not uncommon phenomenon in the plankton pulses of the backwaters.

They have greater amplitudes, but are frequently followed by more sudden and complete declines. Thus, in this case the apex of the pulse is at 18.39 and 6.99 cm.^{3} respectively in the lake and river on June 7 and 14, while the decline has reached 2.47 and 2.88 on the 21st in the two localities—a fall of 86 and 59 per cent. respectively. The third instance occurs on Aug. 16 (lake, .45, river, .61), when a large silt content in Thompson's Lake, due to roiling of the water by heavy wind, obscures the actual quantity of the plankton.

The similarity in the direction of the changes in plankton content in Thompson's Lake and the other localities continues in this year even to a greater degree than formerly, owing in part at least to the hydrographic conditions above noted and to the more complete and uniform records. In the case of Thompson's Lake and the river there are 21 agreements in the direction of the changes to 4 exceptions, and in the records of Quiver Lake 22 to 3 in the possible 25. This is so far in excess of the degree of agreement demanded by chance that we may look with confidence for an efficient cause in the common factors of the environment, in the similar reproductive cycles of the constituents of the plankton found in common in the several localities, and in the uniformity in the reactions of at least a predominant portion of the total plankton assemblage to the factors of the environment.

The river levels average 8.01 ft. for the year and stood above 6 ft. for 8 months of the 12. The high water increases the area of the "open water," and causes a retreat of the shore-line and bottom, and a decrease in the relative occupancy of the bodies of water in question by the spheres of influence of the immediate environment. Thus the local differentiating characters of the several environments are in general progressively less potent as the open water increases in extent. The locations of the 7 exceptions to the similarity in the direction of the movement in production are significant. All of them lie in the last five months, in the period of low water, and 2 in the lowest water in August, when local influences are more potent.

1899.

(Table VIII., XII.; Pl. XXXIX., L.)

There are 7 collections at fortnightly intervals in the first 3 months of the year, with an average of 1.21 cm.^{3} per m.^{3} to .41 in channel waters. With the exception of four days in February, river levels were above 6 ft. throughout the period, and consequently the lake was continually receiving water at the northern end and discharging at the southern, and contributing throughout the whole time, in this way or through the slough, to channel waters. The average result is an enrichment of the plankton of channel waters. The monthly averages (see table between pp. 342 and 343) in January and February in the lake exceed those in the channel by 9- and 2-fold respectively, while those of March, in highest flood waters, are respectively .28 and .21 cm.^{3}, owing, as will be seen on a comparison of Plates XIII. and XXXIX., to the distribution of the dates rather than to an actual smaller production. A comparison of all coincident collections in lake and river exhibits likewise a larger plankton content in every instance in lake waters. The lake thus tends continually during this period to enrich by its run-off the plankton content of channel waters.

The similarity in the movement in production noted in 1898 is interrupted in these winter months by dislocations of the apices of the slight pulses of production, due in part to the flushing action of sudden floods and its unequal distribution in channel and backwaters. Of 7 possible agreements in the direction of movement in production there are but 3 realized in the case of both the river and Quiver Lake. A comparison of the three plates (XIII., XXIX., and XXXIX.) will, however, show that all, in common, exhibit evidences of a January and a February pulse and a common March decline.

SUMMARY.

The grand average of all the Thompson's Lake collections shows a plankton content of 7.94 cm.^{3} per m.^{3} in comparison with

2.19 cm.^{3} for channel waters. The relative fertility of each is perhaps better expressed by the average of the monthly averages, 8.26 and 2.71 respectively. The run-off of the impounded lake waters would thus tend to enrich the plankton content of the channel in some ratio dependent upon the relative volumes and plankton contents of the mingling waters. We have also seen that the enriching function of the contributions of this lake is continuous throughout a large part of the year, with a few interruptions dependent upon cessation of run-off in rising levels in low-water periods, and, rarely, to a lower plankton content in lake waters, due generally to increase of plankton in channel waters as the current slackens in low river stages.

The following comparison of the averages of the monthly averages for the years of our operations, taken from the table between pages 342 and 343, is instructive in indicating the varying relation of production in lake and channel waters.

COMPARISON OF MONTHLY PRODUCTION IN THOMPSON'S LAKE AND ILLINOIS RIVER.

	January	February	March	April	May	June	July	August	September	October	November	December	Grand average
Illinois River..	.213	.23	.27	4.59	6.08	7.22	4.23	3.88	2.56	1.70	.88	.71	2.71
Thomp. Lake..	3.79	1.27	2.96	14.49	29.59	10.66	4.74	6.19	5.37	10.64	6.39	3.08	8.26
Ratio	1:18	1:5	1:11	1:3	1:5	1:1.5	1:1.1	1:1.6	1:2	1:6	1:7	1:4	1:3
Average height of river in ft..	7.77	7.89	12.34	10.02	9.18	6.19	4.36	2.26	3.78	3.44	4.26	4.97	

The average height of the river for the years represented in the several monthly grand averages is also given in the above table, and exhibits some relations to the relative plankton production in Thompson's Lake and the Illinois River, which, however, are so combined with other factors—such as seasonal temperature changes, the period of dominance of vegetation, and qualitative seasonal changes in the plankton itself—as not to be readily analyzed. We find in January–May a period of high levels and low temperatures, of flood invasion everywhere—but most potent in channel waters, a period in which production in the lake is from 3- to 18-fold that in the river and averages 8.4.

This is the time of greatest contrast, and also the time of highest levels (averaging 9.44 ft.) and therefore of continuous and largest run-off. It is also the season of largest plankton production, averaging 10.42 cm.^{3} per m.^{3},—8.4 times that in channel waters,—and is accordingly the period of greatest enrichment of the channel plankton by the run-off from the lake. The factors operative in producing this result are the high levels, with resulting increase in the impounded waters of the lake at a season of rising temperatures favorable to plankton production and to the enrichment of the waters by decay of the vegetation of the previous year's growth.

In June-September we have a period of falling levels, maximum temperatures, lowest water, and growth predominating over decay in the aquatic vegetation, which is relatively more abundant in the lake than in the river. It is therefore the season of greatest predominance of local environmental factors, and of run-off reduced to minimum volume and frequently interrupted. It is also the season of least plankton production, averaging 6.74 cm.^{3} per m.^{3}—only 1.54-fold that in channel waters. The midsummer season is therefore one of least enrichment of channel plankton, as a result of both the decreased and interrupted run-off and the decrease in the *relative* production in the lake. This latter feature results both from the decline in production in the lake and the low-water conditions in the river, where increased fertilization by sewage and slackened current tend to raise its level of production at this season. Other factors tending to bring about the conditions of production prevalent in this season are possibly the greater relative exhaustion of the fertility in lake waters during the midsummer and low water, as indicated in our chemical analyses by the generally lower level of the various forms of nitrogen in the lake than in the river. (Cf. on this point Plates XLV. and L.) This greater relative exhaustion may be attributed in part only to reduced interchange of river and lake waters at low levels and consequent reduction in influx of sewage from the channel, and to the utilization of some of the constituents which support the phytoplankton by the rapidly growing aquatic vegetation. These factors are not, however, potent enough to overcome the effect of impounding and consequent time for breeding which prevail in the lake more than in the river, and thus to lower the plankton production in the lake below that in the channel.

In October–December we find another season marked by rising water but not high levels, in fact, averaging only 4.22 ft.—a level insufficient to provide for any current through the lake or any considerable discharge in periods of decline. It is thus a season of slight and interrupted run-off. It is, however, a period of increased production, reaching 10.64 in October, declining to 3.08 in December, with an average of 6.70—a trifle below that of the midsummer period. Its relation to channel production changes decidedly, rising from a ratio of 1 to 1.54 in midsummer to 1 to 5. This five-fold greater plankton content in Thompson's Lake makes whatever run-off occurs of considerable enriching effect upon channel plankton, though prevailing low levels and large proportion of rising levels tend to reduce the actual volume contributed in this season. The factors operative in increasing the *relative* production in lake waters in this season are the influx of sewage-laden river water, and the decay of some of the succulent vegetation of the lake and its re-submerged margins at a season of plankton pulses of an amplitude increasing by virtue of other factors, internal or external. Rising levels also bring about an increase in current in the channel, while marked changes in the bacteriological and chemical condition of channel, waters attend this and the fall in temperature. The combined effect of these factors, as shown by a comparison of the records of 1897 (Pl. XI.)—when low levels continued and the autumnal decline in temperature was late—with those of other years, is to depress production in channel waters more than it falls in the lake. This fact, together with the increase in the impounding function of the latter as levels rise, suffices to bring about the increased *relative* production in lake waters in the closing months of the year.

Thompson's Lake and presumably other bottom-land waters of similar character, by virtue of their impounding function, are reservoirs in which flood waters are stored for a greater or less time, permitting the development in general at all seasons of the year of a plankton exceeding in volume from 1+-fold to 18- fold that coincidentally developed in channel waters of the adjacent river. The run-off from this and like areas elsewhere thus serves to enrich and maintain the river plankton proper. The slightly developed flood-plain of the Illinois and the consequent considerable area of such bottom-land waters—which equalize the floods, prolong the run-off, and favor the production of an abundant plankton in the impounded areas—become, accordingly, factors of great importance in causing the richness, abundance, variety, and long continuance of the unusual plankton production of the Illinois River.

The similarity in the course of plankton production in Thompson's Lake and elsewhere in our field of operations is shown in the following tabular summary, which gives the number of instances of agreement and disagreement in the direction of the changes in production in the four localities.

SIMILARITY IN DIRECTION OF CHANGE IN PRODUCTION IN THOMPSON'S LAKE AND AT OTHER STATIONS.

Year	Illinois River		Quiver Lake		Dogfish Lake		Flag Lake		Total	
	Agreement.	Disagreement.	Agreement.	Disagreement.	Agreement.	Disagreement.	Agreement.	Disagreement.	Agreement.	Disagreement.
1895...........	9	4	7	5	9	3	2	1	27	13
1896...........	18	8	12	13	18	8	16	9	64	38
1897...........	14	4	10	8	5	1	5	2	34	15
1898...........	21	4	22	3	......	......	......	......	43	7
1899...........	3	4	3	4	......	......	......	......	6	8
Total	65	24	54	33	32	12	23	12	174	81

This gives a grand total of 174 instances of similar direction of change in production out of a possible 255, or 68 per cent., for the 5 years included. It is noticeable that the years differ considerably in the degree of agreement detected, the latter years of fuller records exhibiting fullest agreement. They are also years of higher water, of greater uniformity of environment —because of greater extent of open water, of greater interchange of water in overflow stages, and therefore of greater agreement in the course of plankton production. The similarity in the course of plankton production in different bodies of water is in a large measure a function of the similarity of their environment and the resemblance of their planktons in the matter of constituent organisms.

STATION F, PHELPS LAKE.

(Table IX.; Pl. XXI., XL.,-XLII.)

ENVIRONMENTAL CONDITIONS.

This body of water lies on the western side of the river about a mile below the city of Havana, in the elevated bottom-lands below the mouth of Spoon River. It trends northeast and southwest for a distance of seven eighths of a mile, has a width of 400-600 feet, and a total area of 50-60 acres. Its bottom lies about 6.5 feet above low-water mark, and the greatest depth recorded in it at high water at the point of collection was only 10 ft. It is but slightly deeper toward the lower end. Its outlet is by a tortuous slough choked with driftwood, which runs for two fifths of a mile in a southerly direction to the river. The elevation of the bottom of this slough at its entrance to the river is 8-9 ft. above low-water mark, so that all run-off from the river drained by this slough ceases when it drains to this level, and it is not reinvaded by floods below this elevation. When the river falls below the level of the outlet and the lake drains as fully as the outlet permits, there still remain about 1.5 ft. of water from which no further run-off occurs. The volume is then slowly reduced by evaporation or increased by summer rains.

The lake is not fed by springs or tributaries of any sort beyond seepage from the level alluvial bottoms in which it lies, and which nowhere in the vicinity rise more than 10 feet above its bottom and generally very much less than this distance. At river stages of 11 ft. and above, backwater from Spoon River makes its way through a now abandoned channel to the lake and thence out to the river through the slough. Below this level, the current of the gentle run-off of the great tract of adjacent impounded backwaters with which this lake has then but a slight connection is the only movement in the area.

The surrounding bottoms are heavily wooded for a narrow margin along the lake, though the forest gives way to cultivated fields on both sides within a short distance. Its bottoms and shores are of a rich black alluvium, which in low-water seasons such as 1895 becomes the soil of a cultivated field.

The vegetation of this area is unique among our plankton stations in its character and relation to the plankton. In 1894 there was little vegetation present, and whatever aquatic growth had gained a foothold was eradicated by the dry autumn and by the cultivation of the soil in 1895. In 1896–1899 the occupation of the lake by water was more continuous, and *Potamogetons*, *Naias*, and even *Nelumbo*, gained a slight foothold along the margins. The principal vegetation was a dense mat of filamentous green algæ, such as *Spirogyra* and *Zygnema*, which covered the margins for a considerable distance into the lake. During the heated term of midsummer a dense felt of *Oscillaria* covered the bottom of the lake everywhere at times. These algæ were present during most of the summer, though most abundant in spring, and by their continuous and prompt decay they release into the lake waters a volume of nitrogenous and other substances which are utilized by the phytoplankton. The cumulative action of the longer-lived aquatic phanerogams in withdrawing from the lake large stores of food which are again released in the ensuing autumn or spring by the decay of the season's growth, is thus quite absent from this body of water. The rapidly growing and rapidly decaying algæ permit a repeated flux of nitrogenous and other substances utilized by the plankton as food in the course of a single season. This factor, combined with the complete impounding function of this lake below river levels of 8 to 9 feet and the absence of tributary and spring water, is, I believe, the secret of the unusual plankton production in this area.

The absence of coarse vegetation, the sheltered situation in a rift in a dense forest, and the shallowness of the whole lake during much of the summer, permit an unusual range of diurnal temperature-changes falling but a few degrees short of the diurnal range in the air. The records (Table IX.) frequently contain readings of 90° to 95° in the summer season. This lake swarmed with the fry of various native fishes and the introduced German carp, all of which make great inroads upon the vernal plankton. It was also the favorite haunt of many fish-loving water-fowl. This abundant animal life served in turn to enrich the lake waters with its nitrogenous wastes, at once available for utilization by the phytoplankton. There are thus many chains of food relations in this lake, in most of which, if not, indeed, in all, the plankton forms many links.

COLLECTIONS.

There is a total of 67 collections from this lake; 1 only in 1894, 29 in 1896, 9 in 1897, 22 in 1898, and 6 in 1899.

The single collection in 1894 was made by the oblique-haul method. The absence of collections in 1895 is accounted for by the fact that there was no water in the lake in that year. In 1896–1899 collections were made in various ways according to the conditions of access to the lake and the depth of the water. Owing to rafts of driftwood, access at any season through the slough is prevented. At high flood-levels, when ice did not prevent, it was possible to enter the lake by boat with our plankton pump and usual collecting apparatus. At all other seasons access by boat was impossible, and apparatus had to be carried across fields and through dense underbrush to the lake, and collections made by wading out into the lake or from a staging carried out from the shore for some distance over the water. There are accordingly but 9 pump collections. The remaining 57 were all made by dipping water from the surface and pouring it through the plankton net. Most of the collections represent, therefore, surface waters, but owing to the exceedingly shoal water they are, nevertheless, in the main representative of the plankton of the lake. Of the 67 collections, 32 were taken from water which in the deepest part of the neighborhood of collections was less than 14 inches. Owing to the roiling of the water caused by our movements, it was necessary to dip from considerable areas in order to secure the desired volume for straining.

Since a separate report on these collections is being prepared I shall only deal in this connection with those aspects of the data most intimately connected with the phenomena of the channel plankton.

PLANKTON PRODUCTION.

1894.

(Table IX.)

A single collection on June 8 yields a volume of 24.17 cm.^{3} per m.^{3}, an amount 7-fold that of the same season in 1896, almost equaled in 1897, and more than doubled in 1898.

1896.

(Table IX., Pl. XL.)

There are 29 collections in this year, extending from Jan. 8 to Nov. 17—when only a few scattered pools remained. This is the most fully represented year of our series in this lake. The yearly average is 13.17 cm.^{3} per m.^{3}, with a vernal maximum of 54.80 on Apr. 16, and an autumnal one of 51.60 on Oct. 15. This is the earliest vernal pulse recorded in our work, and should be correlated with the early rise in temperature in these shoal and protected waters. Thus, in Phelps Lake on Apr. 16 the surface temperature was 77° and the average for April 68.4° to 71° (Apr. 17) and 62.6° (average) in Quiver Lake, and to 66.3° (Apr. 17) and 63.2° in the Illinois River. This lake was thus apparently 5° to 6° warmer on the average than these other localities, and the vernal pulse is accordingly accelerated.

Owing to the elevations of the lake and its outlet, run-off from this area into channel waters practically ceases when river levels fall below 8 ft. In 1896 there were but 114 days of stages above 8 ft., 90 from Jan. 1 to Mar. 30, and 14 and 10 respectively in the floods of May-June, and August. Of the 114 days there were 28 of levels above 10 ft., when, owing to run-off from Spoon River, a current passes through the lake to the river regardless, as a rule, of rising or falling water. In addition there were 43 days of falling water when a run-off might be expected, making a total of only 71 days in this year in which there was any run-off to channel waters from this lake. The remaining 43 days of levels above 8 ft. were times of stationary (20) or rising (23) water, when discharge from Phelps Lake was diminished or cut off.

Of the 71 days of discharge, 61 fall in the winter, in January–March, and 5 each in June and August, at times of depression in production (Pl. XL.). Nevertheless, the plankton content in Phelps Lake at all of these times greatly exceeds that in channel waters. The ratio of Illinois River and Phelps Lake plankton in January is 1 to 189, in February, 1 to 607, in March, 1 to 274, in the June flood, 1 to 4, and in the August rise, 1 to 7. These latter ratios are somewhat exceeded by those of the average production for the year, 1.16 to 13.17 cm.^{3}, or 1 to 11. During the months of little or no discharge, April–December, production in the lake as shown in monthly averages is 4- to 1600-fold greater in Phelps than in the Illinois, the latter figure being reached in November and the other months averaging only 11-fold.

Thus, this lake contributed to the enrichment of channel plankton for a relatively brief part of the year, and at all times produced a plankton greatly in excess of that in channel waters. The sharp contrast between the poverty of channel waters and the wealth of this lake is due to the impounding function in the latter, and to the repeated flushings by storm waters of recent origin in the former. Full time for the normal utilization of the resources for growth of the plankton is permitted in the lake but not realized in the constantly replaced river water.

This is the only year in which collections were made in

Phelps Lake at weekly intervals for any length of time. Such intervals extend from the end of March to the last of August, and since similar series were made elsewhere we have an exceptional basis for comparison of the course of production in the several localities.

A comparison of the planktographs of the river and Phelps Lake (Pl. X. and XI.) reveals certain general similarities. These are expressed in the three major fluctuations of the year, the vernal, midsummer, and autumnal rises in production, which, in the main, have coincident limits, but very divergent amplitudes, in the two bodies of water. The absence of the sudden diluent action of flood waters is noticeable in Phelps Lake records, though declines in plankton content coincide with the flood invasions of both June and August. The absence of collections in September in Phelps Lake at the time of the decline in plankton content between the midsummer and autumnal rises is due to the very low stage of water in the lake, permitting no collection. Replenishment by autumn rains is followed by the large development in October (51.6 $\mathrm{cm.}^3$).

Not only is this general similarity between the movement in plankton production in Phelps Lake and the Illinois River traceable in 1896, but there is a more detailed agreement in the changes in the direction of movement in production in coincident or approximate collections. This is most clearly seen in the months of April to August, when collections are of sufficient frequency to trace with some certainty the course of production. During these five months there are 16 agreements in the direction of the change out of a possible 20—a total of 80 per cent.—between Phelps Lake and the Illinois River. In the year as a whole the agreements number 19, or 68 per cent., out of a possible 28. Two of the exceptions in April-May are due to the dislocation of the vernal pulses in consequence of the higher temperatures in the lake above noted. When we take into consideration the marked differences in the local environment of the plankton in these two localities and the considerable independence of this lake as contrasted with other reservoir lakes, such as Thompson's and Quiver, this marked degree of resemblance is the more striking.

A comparison of the course of production in Phelps Lake (Pl. XL.) and Thompson's Lake (Pl. XXXVII.) in 1896 reveals 14 agreements out of a possible 25, or 56 per cent. Of the 11 disagreements 3 fall in the period of few collections in the autumn months, when Phelps Lake was reduced to shallow pools, and 4 occur during the vernal pulse of April-May. A comparison of the planktographs and thermographs of the two lakes shows that in Phelps Lake the temperature is from 2° to 8° higher than in Thompson's Lake for a period of six weeks during the rise of the vernal pulse. Hence this culminates earlier by a fortnight in the former, and in consequence a dislocation of the course of production in the two lakes occurs in this period. The two planktographs are, however, strikingly alike in the fact that in the interval between March 31 and June 1 there are three pulses of regularly decreasing amplitude in both lakes. The similarity is thus greater than the percentage indicates.

A comparison of the course of production in Phelps and Quiver lakes (Pl. XL. and XXVII.) reveals 15 agreements out of a possible 28, or 54 per cent.—but little more than chance demands. In this case the environmental differences are greater, the effect of spring water, vegetation, and flood invasion interfering in Quiver Lake with the course of production.

A comparison with Dogfish Lake, where the disturbing factors of spring water and flood invasion are less immediate in their action, reveals a slightly greater degree of similarity—16 out of 28, or 57 per cent.

In the case of Flag Lake the agreement is still less, being only 11 out of 24, or 46 per cent. It is a noticeable fact that the disagreements are most numerous in Quiver, Dogfish, and Flag lakes, all of which are rich in vegetation, and these disagreements occur in greatest proportion during the months of May–August, when with changing river stages the proportional occupation of these lakes by vegetation fluctuates greatly—

a variable factor from which Phelps Lake is to a large extent exempt. The degree of agreements, as a whole, in production between Phelps Lake and other localities is seen in a total of 84 instances out of a possible 141, or 60 per cent.

1897.

(Table IX., Pl. XLI.)

There are only 9 collections in this year, at approximately monthly intervals with the exception of the last collections, when the interval was somewhat reduced. Collections cease in August, when the water entirely disappeared from the lake. The average plankton content for the year is 10 cm.^{3} per m.^{3}, the lowest annual average in which summer collections are included in this lake. The vernal pulse was not detected, if present, and the maximum record, 29.94 cm.^{3}, was on Aug. 26, the date of the last collection.

The hydrographic conditions were such (Pl. XLI.) that a current from the flooded bottom-lands about Spoon River passed through the lake uninterruptedly from Jan. 7 to May 13, and the run-off of impounded waters continued until the 25th, a total of 139 days. Throughout the period covered by our few collections they indicate that the plankton content of this area exceeded that in channel waters by from 1.6- to 11-fold with the single exception of Apr. 27, when the lake had 4.26 cm.^{3} to 5.11 in the channel. During the 139 days of run-off the production in the lake scarcely exceeds 5- fold that in the channel, but when discharge ceases the content rises to 10- to 11-fold that in the river—a phenomenon which illustrates the equalizing effect of general overflow on the one hand, and the effect of impounding in increasing production on the other.

The run-off from this lake in 1897 thus predominantly served to enrich channel plankton. The fact that production in Phelps Lake falls below that of the channel on Apr. 27, when a vernal pulse might be expected of an amplitude greater in backwaters than in channel,—as indeed it is in Thompson's (Pl. XXXVIII.), Quiver (Pl. XXVIII.), Dogfish (XXXII.), and

Flag (XXXIV.) lakes by 50 to 150 per cent.,—is to be attributed to the diluent effect of invading flood-waters from Spoon River, whose plankton content on Apr. 27 was only .05 cm.^{3} per m.^{3} The entrance of these flood waters, indicated by the check in the decline of the hydrograph (Pl. XLI.), was noticeable at the station on the day of collection, and is the cause of the increased turbidity in Phelps Lake on that day (Table IX.).

The similarity in the movement of production in Phelps Lake in 1897 to that in the other bodies of water examined by us, is very close. In the case of the Illinois River, 8 out 9 possible instances, or 89 per cent., are in agreement; in Thompson's Lake 7 out of 9, or 78 per cent.; in Flag Lake all instances are in agreement; in Quiver Lake 6 out of 9, or 67 per cent.; and in Dogfish Lake 4 out of 6, or 67 per cent. As a whole, 32 out of 40, or 80 per cent., of the changes in the direction of production in Phelps Lake accompany similar changes in direction in these other localities. All of the 8 exceptions to this agreement occur at levels below 8 ft., when local environments are more potent, and 5 of the 8 are found in Quiver and Dogfish lakes, where vegetation and access of tributary waters become proportionately more or less potent as levels fall or rise in May to August, when the 5 exceptions occur.

This unusual degree of agreement in 1897 must be attributed in large part to the hydrographic conditions in the period of comparison. For almost 5 months of the year levels were above 8 ft., when fluctuations have relatively but a slight effect on the various environments. Above this level the several localities are more or less submerged in the general overflow, and all share alike in the wide stretches of open water in which some current exists, and the commingling to an increasing extent, as levels rise, equalizes and obliterates local differences in production. The first 4 collections of this year were made under such conditions, and agree without exception in the course of production. The remaining 5 were taken at stages below 8 ft., in the very midst of the season of local diversification, and the proportion of agreements falls from 100 to 60 per cent., and is greatest in the most differentiated localities, Quiver and Dogfish lakes. It might also have been expected in Flag Lake (Pl. XXXIV.) if examination had continued there beyond the middle of July. It would seem, accordingly, that similarity in the course of plankton production in different localities is to a large extent a function of the community of environmental factors, and possibly also of the similarity of the constituent organisms.

1898.

(Table IX., Pl. XLII.)

There are 22 collections in this year, at fortnightly intervals, in March–December. The average production for the year is the unsurpassed amount of 44.08 cm.^{3} per m.^{3}, with a maximum, also unsurpassed in our records, of 224.48 on Aug. 23. An unusually high level of production is also maintained from Aug. 9 to Dec. 13, averaging 63.54 cm.^{3}, and falling below 30 in but two instances.

Water re-entered Phelps Lake with the flood of February, river stages passing 8 ft. on the 12th and 10 ft. on the 20th. From this latter date until June 28, with the exception of 4 days in May, levels continued above 10 ft., so that a continued current of overflow from the bottom-lands to the north passed through the lake to the river. Declining river stages continued from June 28, passing 8 ft. July 9, thus permitting a run-off for a total of 138 days from the lake to the river in the period of spring and summer floods. To this must be added 7 days of declining levels above 8 ft. in the November-December rise, making a total of 145 days of contributions to channel waters from this lake. This is the most extended period of contribution in the years of our operations, and is a result of the unusually high and prolonged floods which brought the average height of the river up to 8.02 ft., almost bank height, for the year.

The plankton content of Phelps Lake waters in the 10 collections made during the period of discharge above noted, is in excess of that in the channel in 7 instances by from 1.4- to 15- fold and averages 7.3. In three instances, March 3 and 1, (.01 and .02), March 29 (.20 and .43), and April 26 (10.72 and 15.81) the lake contains less than the river. All of these instances fall at times of high levels, exceeding 11 ft., when Spoon River floods invade this territory, and this deficiency in Phelps Lake is doubtless due to their diluent effect. Since our station for collections was located in the upper end of the lake (Pl. II.), the full effect of the flood would be detected at this point, but would be diminished by mingling with the lake waters and the adjacent impounded backwaters before it joined the channel. The first of these exceptions, on March 3, is not accompanied by increased turbidity (.45) in the lake (Table IX.), but the other two, March 29 and April 26, are attended by a marked rise in turbidity (.05 and .16). During this period of maximum spring flood in March and April, owing doubtless to this diluent action of Spoon River, the run-off from this area, as indicated by plankton content at the *upper* end of the lake, dilutes, or but slightly enriches, the channel plankton. This appears in the monthy averages (table following p. 342), which for March are .33 cm.^{3} for the river and but .25 for the lake. In April they are 4.4 and 5.6 respectively. In later months, during the declines of the spring flood, and owing to absence of the flushing action of Spoon River floods and to the rise in impounding function with decline in levels and delimitation of the lake, we find a rapid rise in the relative plankton content in lake waters. The production in coincident collections is greater in the lake than in the river by 3- to 15-fold, and the monthly averages for lake and river respectively rise to 40.44 cm.^{3} per m.^{3} and 11.30 in May; to 27.67 and 3.96 in June; and to 6.97 and .58 in July; that is, the production is from 3+- to 12- fold greater at this season in the lake than in the river. During the run-off in these months this lake and its contributing adjacent bottom-lands serve to increase, in some unknown ratio dependent on their relative volumes, the plankton content of the channel waters with which they mingle.

Although the frequency of the plankton collections is insufficient to trace with accuracy the course of production in Phelps Lake in this year, they yield many suggestions of recurrent pulses of production similar in duration, though of greater amplitude, to those more clearly defined in channel waters. A comparison of Plates XII. and XLII. will indicate the presence of pulses of production in *both* localities, culminating in the majority of instances at approximately monthly intervals. There are eight such culminations in Phelps Lake visible in the records of March–December, culminating in March, May, June, July, August, September, November, and December. In spite of the disparity in the records in this lake and the river, the similarity in the location of the pulses in the two localities is apparent in all of the above months but August and November—both of which are months of unusual hydrographic disturbances in channel waters.

A detailed comparison in the movement in production in this lake and the adjacent river shows agreement in the direction of movement in 14 out of 21 possible instances, or 67 per cent., 5 of the 7 exceptions falling in the hydrographic disturbances in August–September and November. In the case of Quiver and Thompson's lakes the problem of comparison is made difficult because the fortnightly collections in Phelps Lake and these localities are not upon coincident, but alternate, weeks, and makes the the similarity or difference probable rather than precise. A comparison shows 16 agreements out of a possible 20, or 80 per cent., in the case of Thompson's Lake, and 17 out of 20, or 85 per cent., in the case of Quiver Lake. Both of these lakes are affected by hydrographic changes at lower levels which do not disturb Phelps Lake, and we find that 6 of the 7 exceptions occur in the period of floods at low levels. As a whole the movements in production in the lake in 1898 agree with those elsewhere in 47 out of 61 possible instances, or in 77 per cent. In view of the fact that the records cover also the low-water period this is a notable degree of agreement, and is to be attributed to the unusually high average level for the year and to the equalizing effect of high water. This factor is not, however, in immediate operation during the last half of the year in so far as Phelps Lake is concerned, and other factors common to the whole environment or inherent in the common plankton must be responsible for the similarity in this period.

1899.

(Table IX., Pl. XLII.)

There are but 6 collections in this year,—in January–March, at fortnightly intervals. The hydrographic conditions are such that the lake is cut off from the river for 34 days during the 3 months, and of the remaining time there were only 32 days of stages above 10 ft. in which currents passed through the lake to the river, and 7 of falling stages at levels below 10 and above 8 ft., when the run-off continued, making a total of 39 days of contribution to channel waters. These times of contribution in January and March (Pl. XLII.) are also times of high plankton production for that season of the year. Thus the plankton content in Phelps Lake on Jan. 24 is 8.47 cm.^{3} per m.^{3} to .03 in channel waters. The run-off from the lake at that time is thus 286-fold richer in plankton than the water it joins. Again, in March, it is 3- to 9-fold greater. The monthly averages of production are (see table following p. 342) from 6- to 26-fold greater in the lake than in the river. This lake thus serves, even in winter conditions and under a thick and long-persisting coat of ice, as a rich breeding ground for plankton whose run-off enriches the channel plankton. This is due to its impounding function, which results in high production, as, for example, during the decline of the January flood (Pl. XLII.). Proof of this is seen in the sudden decline in production (from 9.3 cm.^{3} on Feb. 7 to .1 on the 21st) when flood waters from Spoon River were scouring out the lake beneath the ice.

The movement in production in these months in Phelps Lake bears little resemblance to that elsewhere, agreeing with changes in channel production (Pl. XIII.) in only 1 out of 6 possible instances, and in 3 and 2 respectively out of 6 in the case of Quiver and Thompson's lakes. This exceptional disagreement may perhaps be due to the changes elsewhere, incident to rising winter floods.

SUMMARY.

Phelps Lake is the richest in plankton of all the localities examined by us, averaging 19.65 cm.^{3} per m.^{3}, the mean of all collections, or 22.35 cm.^{3}, the mean of the monthly averages. This is 8- fold the production in the river and more than twice that in any other impounding area examined. We find, however, that the lake does not contribute to the river at levels below 8 ft., and is therefore cut off for a considerable part of the time. In the years 1894–1899 inclusive, the days of run-off were 14, 0, 71, 139, 145, and 86 days respectively, or an average of 76 days. As a rule the plankton content of the lake waters during periods of run-off exceeds that in the channel in varying degrees, and the lake by virtue of the impounding function serves to increase the plankton content of channel waters. The exceptions fall mainly at levels above 10 ft., when the diluent action of Spoon River floods affects the production in the lake. The high records of production which indicate the great relative and absolute fertility of this body of water are in the main found during summer and autumn months, when there is no discharge and the impounding function is at its maximum. This is confirmatory evidence of the effect of impounding when the disturbing factor of tributary water is absent and coarse vegetation is of little extent. Owing to its small area, its early separation from the channel, and its relation to Spoon River at high levels, the total contributions from this area are relatively small as compared with those from Thompson's and Flag lakes, and at times from Quiver Lake, and its relative fertility *during months of run-off*, as compared with these localities, is wont to rise above their level of production, especially at stages between 8 and 10 ft., when run-off is slight and impounding function dominant. Illustrations of this will be found in the monthly averages of 1897 and 1898 in April–June, the season of greatest run-off, when 4 of the 6 monthly averages are considerably larger in Phelps Lake than in the other localities.

The course of production in this lake, as has been shown, is predominantly like that in the other localities. It frequently has similarly located pulses, though their amplitude, especially in late summer and autumn, is often much greater than elsewhere. Moreover, in the majority of instances the direction of the changes in production in coincident or approximate collections is also similar to that elsewhere. In a total of 260 possible instances there is agreement in 169, or 65 per cent. This excess of agreement over the demands of chance, combined with its recurrence in successive years and its occurrence in the case of different localities, is confirmatory of the view that it is the result of the operation of common factors of the environment. The predominance of the disagreements at times of greatest local differentiation or disturbance, as in low water in summer or in rising floods, lends further support to the suggestion.

GENERAL COMPARISONS OF YEARS AND STATIONS.

It is my purpose to summarize in the following pages the results set forth in detail with respect to the individual localities in the several years, and to make the comparisons and draw the conclusions which follow from such a summary regarding the relative production in these different years and localities and the factors operative in modifying production.

The following table gives for the various localities the yearly averages of plankton, silt, and total catch, and the number of collections in each year.

Station	Year	No. of collections	Av. of monthly averages	Av. of all collections		
				Plankton	Silt	Total
Illinois River	1894	10	2.53	2.49	.28	2.77
	1895	50	5.91	3.22	.72	3.94
	1896	76	1.05	1.16	2.55	3.71
	1897	34	3.28	3.69	1.91	5.60
	1898	52	2.03	2.13	2.11	4.24
	1899	13	.42	.41	.94	1.35
	Grand av.		2.71*	2.19†	1.79	3.98
	Total	235				
Spoon River	1896	9	.007	.007	.349	.36
	1897	13	.983	1.257	1.173	2.43
	1898	11	.029	.029	.796	.83
	1899	3	.011	.011	2.2.6	2.23
	Grand av.		.256	.465	.939	1.41
	Total	36				
Quiver Lake	1894	14	.90	1.08	1.17	2.25
	1895	13	.65	.78	.70	1.48
	1896	31	2.19	2.59	.20	2.79
	1897	24	1.62	.88	.62	1.50
	1898	26	1.96	2.44	.40	2.85
	1899	7	.66	.67	.43	1.11
	Grand av.		1.75	1.70	.52	2.22
	Total	115				
Dogfish Lake	1895	12	3.30	3.25	2.15	5.40
	1896	30	3.99	5.01	.51	5.51
	1897	6	2.65	2.23	.22	2.45
	Grand av.		3.16	4.22	.88	5.10
	Total	48				
Flag Lake	1895	4	25.66	20.45	3.45	23.90
	1896	27	8.31	13.83	1.45	15.28
	1897	7	5.34	4.59	.69	5.28
	1898	6	5.31	2.83	4.30	7.13
	Grand av.		9.23	11.46	1.90	13.36
	Total	44				
Thompson's Lake	1894	5	8.89	8.89	2.23	11.12
	1895	14	13.31	9.67	1.44	11.11
	1896	27	6.67	9.00	.22	9.22
	1897	18	10.41	10.43	1.28	11.71
	1898	25	5.06	5.71	.79	6.50
	1899	7	1.15	1.21	.32	1.53
	Grand av.		8.26	7.94	.86	8.79
	Total	96				
Phelps Lake	1894	1	24.17	24.17	trace	24.17
	1896	29	14.74	13.17	.77	13.94
	1897	9	9.15	10.00	.54	10.53
	1898	22	37.34	36.31	7.76	44.08
	1899	6	3.74	3.74	.29	4.03
	Grand av.		22.35	19.65	2.95	22.60
	Total	67				

*Grand average of all monthly averages, not of annual averages.
†Grand average of all collections, not of annual averages.

1894.

(Pl. VIII., XXV., XXXV.)

Only three stations were established in this year: the Illinois River Station, with 10 collections; Quiver Lake, with 14; and Thompson's Lake, with 5. The appended table gives the production in monthly averages of plankton per m.^{3} for the seasons covered by the collections.

PLANKTON PRODUCTION IN 1894.*

Station	June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Mean of monthly averages	
Illinois River...	−	.74	+	5.12	+	9.67	−	1.36	−	.61	−	.10	−	.10	−	2.53
Quiver Lake...	−	.23	+	2.20	−	.74	+	2.12	+	.95	−	.02	−	.03	−	.90
Thomp. Lake..	+	24.92	+	10.74	−	1.08	+	6.40	..	.....	..	....	−	1.29	+	8.89

*The minus sign signifies below average and the plus sign above.

It is evident from comparisons with records in years of frequent collections, for example, in 1898, that the interval of collection is too great in 1894 to give a satisfactory basis for a discussion of production. As far as they go the data indicate a level of production below the average of our records. In the river and in Quiver and Thompson's lakes the monthly averages in 1894 are below the general averages for the respective months in 5 out of 7, 4 out of 7, and 2 out of 5 months respectively, a total of 11 out of 19. The mean of the monthly averages in 1894 for the river, 2.53 cm.^{3} per m.^{3}, is 7 per cent. below the mean of all monthly averages in 1894–1899, and that of Quiver Lake is 49 per cent. below its mean. Thompson's Lake, on the other hand, with 8.89 cm.^{3}, presents an excess of 8 per cent.

The low level of production in the river and Quiver Lake is attributable to the absence of overflow in June with its accompaniment of run-off of impounded and plankton-rich waters, to flushing action of the repeated rises in September, and to the relative dominance of coarse vegetation in the lake and, to some extent, in the river. The larger production in Thompson's Lake is attributable to freedom from the flushing action of floods in the prevalent low water and to the relatively stable hydrographic conditions. It is noticeable that production in the river is on the average 7-fold greater in July-August (Pl. VIII.), during stable low water, when current is slackened and impounding most prolonged, than in June and September, when high levels and flushing by floods occur.

The low level of production in the river in October–December is exceptional. Similar hydrographic conditions in 1897 Pl. XI.) yield a 5- to 10-fold greater production. It is not improbable that the monthly collections of 1894 may be intercalated in the depressions between plankton pulses of greater volume, and thus inadequately represent the real production. Production in Quiver Lake in the months represented in our records in 1894 exceeded that in channel waters only in September-October, when a slight run-off occurred, and that in Thompson's Lake in June, July, September, and December, but a run-off of any consequence occurred only in June and for a week each in July and September. Apparently the channel plankton in this year was largely independent and indigenous in origin, deriving but little enrichment from impounding backwaters, and not infrequently diluted by their contributions.

1895.

(Pl. IX., XXVI., XXX., XXXIII., XXXVI.)

To the river, represented by 50 collections, Quiver Lake, by 13, and Thompson's Lake, by 14, there are added this year, Dogfish Lake, represented by 12, and Flag Lake, by 4 collections in late autumn—a total of 93. The table on page 432 gives the monthly distribution of production in the several localities, and indicates their relation to the general averages.

This is a year of lowest levels, averaging only 3.61 ft. above low water, and also one of high plankton content. On the basis of means of monthly averages, the average content in the river, 5.91 cm.^{3} per m.^{3}, is the largest recorded, exceeding the average of all monthly averages, 2.71, by 118 per cent., and being second in the list if we base comparisons on the average of all collections. This high content in river waters must be attributed to stable hydrographic conditions, abrupt changes being limited to less than 8 weeks in the year (Pl. IX.), and to low water and consequent slackening in the channel with increase of time for the breeding of the plankton. The larger amounts of plankton were found only during stable conditions, and floods invariably depleted the volume of the plankton. These periods of stable conditions occur in summer and late autumn, and we find the plankton content at such times 3- to 30- fold that in contiguous flood conditions. In the river the monthly production exceeds the monthly average for our records in 5 out of the 9 months represented, the exceptions being February, when stagnation under the ice prevailed, April, a vernal period of low water without overflow, September, a month of repeated floods, and October, when an unusually early decline in temperature occurs.

PLANKTON PRODUCTION IN 1895.*

Station	Feb.		Apr.		May		June		July		Aug.	
Illinois River	−	0.01	−	3.18	..	.....	+	30.42	+	9.33	+	4.03
Quiver Lake	−	0.03	−	3.00	..	.....	..	.....	−	0.37	−	0.21
Dogfish Lake	..	.....		8.20	..	.....	−	0.12	+	2.99	−	1.11
Flag Lake	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....
Thompson's Lake	..	.....	+	28.20	+	61.44	−	9.42	+	4.83	−	3.09

Station	Sept.		Oct.		Nov.		Dec.		Mean of monthly Averages	
Illinois River	−	1.52	−	0.57	+	3.02	+	1.14	+	5.91
Quiver Lake	+	0.94	−	0.13	−	0.05	−	0.46	−	0.65
Dogfish Lake	+	3.15	−	0.52	+	5.01	+	5.32	+	3.30
Flag Lake	..	.....	+	57.76	+	14.40	+	4.82	+	25.66
Thompson's Lake	−	3.58	−	3.15	−	5.07	−	1.00	+	13.31

*The minus sign signifies below average and the plus sign above.

The stable conditions which attend low water thus favor the increase in the plankton content per m.^{3}, though by reason of the lower levels and slackened current the total volume produced in the stream as a whole must be greatly diminished by such hydrographic conditions.

The results of this low-water year upon production in Quiver Lake (Pl. XXX.) are as a whole diametrically opposite to those in the river. Here in the lake, production falls below the average, the mean of the monthly averages (.65 cm.^{3}) being 63 per cent. below that of all monthly averages of Quiver Lake, and but a ninth of the production in adjacent channel waters. The cause of this very marked contrast is to be found in the relative dominance of tributary waters of recent origin and of coarse aquatic vegetation in the lake,—a dominance increasing as levels fall,—and accordingly we find in this year of lowest levels the least annual production (see table on p. 429). Production is not only low on the average but also lower than the average in every month of record save September, when it rises 22 per cent. above the mean content for that month. This is a month of higher river levels, and a similar tendency to increased production is to be found in the August flood (Pl. XXVI.).

In Dogfish Lake, production in this year averages for the 8 months represented 3.3 cm.^{3} per m.^{3}—44 per cent. less than that in the adjacent channel waters and 408 per cent. more than that in Quiver Lake. This is 4 per cent. more than the average monthly content, and 18 per cent. less than production in the same months of the following year. The deficiency below channel production may be attributed to the effect of vegetation, and the excess over that in the contiguous waters of Quiver Lake to the absence of access of tributary waters of recent origin. Production is above the average for 4 of the 8 months, the exceptions being April, June, August, and October. The absence of overflow is apparently the cause of the suppression of the vernal pulses in April and June, and the dominance of vegetation may be responsible for the low production in August and October, both low-water months. The months of plankton content exceeding the monthly average are 4: July and September—months of flood, and consequently of impounding and greater extent of vegetation-free water—and November and December—times of lessened growth on the part of the aquatic vegetation, of rising levels, and of some decay of organic matters from the summer's growth.

Causes of like nature are the basis for the large production in Flag Lake in the late autumn months, when in October-No vember the production is 10- to 3- fold the average, and in December 9 per cent. above the mean for that month.

In Thompson's Lake the mean of the monthly averages, 13.31 cm.^{3} per m,^{3} is 61 per cent. in excess of the mean of all the months of our records, though but 3 of the 9 months represented in the records of 1895 are above the average. The first two of these, April and May, owe their predominance to a vernal pulse of unusual volume, and the small number of collections gives these months abnormally high averages, while the large production in July may be attributed to the enrichment of the lake in this year by an invasion of plankton-rich river water from the channel (Pl. XXXVI.). The deficiency shown in the records of the remaining 6 months, falling from 10 to 70 per cent. below the averages of our records for these months, finds its possible explanation in the relatively greater dominance of vegetation in the lake in this season, due to two successive years of low water and the prevailing low levels. Collections in this year were, moreover, taken near the margin of the vegetation belt of the lake.

Production in this, the second, year of low water, and the lowest in our term of operations in all the backwater plankton stations but Quiver Lake, is above the average in the year as a whole, though falling below it in 57 per cent. of the time represented,

The apparent suppression of the vernal pulse in the river and in Quiver and Dogfish lakes may be attributed to the absence of spring overflow and the consequent elimination of vast impounding and breeding areas normally present at this season, and also to the direct delivery of tributary water to the channel and increased relative diluent action of the slight April rise (Pl. IX.) in both the river and Quiver Lake. The low levels also serve to bring the vegetation of the two lakes named into early dominance, and the relative occupancy is also increased by the second year of low water and no removal of the accumulated growth by flood action. Thompson's Lake, on the other hand, owing to its great extent of open water, is less affected by the low levels, the cutting off of breeding backwaters, and the relative occupancy by vegetation, and consequently a vernal pulse of unusual dimensions reaches a culmination in its area.

The June-July pulse of the river, abnormal in its location and relative size and apparently without equivalent elsewhere, is due to the unusual development of a stagnation plankton in the sewage-laden river in a period when rising temperatures hasten the decay of its unusual load of organic matter.

The causes above enumerated render this the year of greatest fertility, in so far as our records reveal production, in the river and in Thompson's and Flag lakes, the next to the greatest in Dogfish Lake, and the least in Quiver Lake.

The low levels preclude any extensive impounding of flood waters and, moreover, the period of run-off is of slight extent. The rise in plankton content (Pl. IX.) in the river following the April, July, and September floods is suggestive of the effect of impounding, the plankton content (cf. Pl. XXVI., XXX., and XXXVI.) being generally greater in the discharging backwaters examined than in the recipient channel during these run-offs. At all other seasons in our records for this year there is scant opportunity for enrichment by tributary backwaters, and but little suggestion of it.

1896.

(Pl. X., XXII., XXVII., XXXI., XXXIII., XXXVII., XL.)

This is the most fully represented year in our series in the number of stations examined. There are 76 collections in the Illinois, 9 in Spoon River, and 31, 30, 27, 27, and 29 respectively in Quiver, Dogfish, Flag, Thompson's, and Phelps lakes—a total of 229. It was a year of higher levels, averaging 6.98 ft. above low water,—almost twice the record of the preceding year,—and witnessed a series of recurrent floods approaching or surpassing bank height of the stream.

The accompanying table gives a summary of the data of production.

PLANKTON PRODUCTION IN 1896.*

Station	Jan.		Feb.		March		Apr.		May		June		July	
Illinois River	–	.01	–	0.02	–	0.07	+	5.67	–	1.30	–	0.72	–	1.44
Spoon River	..	......	..	......	..	......	..	......	..	......	..	......	..	......
Quiver Lake	–	.03	+	1.75	+	1.85	+	12.12	–	2.99	+	1.26	–	0.30
Dogfish Lake	±	.53	+	2.04	+	3.43	–	15.11	+	9.63	+	2.64	–	0.91
Flag Lake	±	.29	+	3.06	+	1.02	+	17.72	+	51.93	–	2.13	–	3.33
Thompson's Lake	–	2.51	+	2.58	+	10.26	+	16.94	–	23.11	–	4.92	–	2.73
Phelps Lake	–	1.89	+	12.14	+	19.20	+	25.44	–	12.96	–	2.90	+	9.03

Station.	Aug.		Sept.		Oct.		Nov.		Dec.		Mean of monthly averages	
Illinois River	–	1.12	–	0.38	–	1.11	–	.02	+	0.76	–	1.05
Spoon River	–	0.018	–	0.005	+	.005	–	.005	–	.002	–	0.007
Quiver Lake	+	2.46	–	0.31	+	2.10	+	.24	+	0.92	+	2.19
Dogfish Lake	+	3.91	–	1.63	+	5.58	–	.26	–	2.20	+	3.99
Flag Lake	+	3.74	–	2.09	–	5.67	–	4.37	–	4.40	–	8.31
Thompson's Lake	–	4.74	–	4.20	–	2.81	–	2.66	–	2.56	–	6.67
Phelps Lake	–	8.80	..	......	–	23.04	–	32.00	..	......	–	14.74

*The minus sign signifies below average and the plus sign above.

While in 1895 production in the channel waters was both absolutely and relatively high, yielding the highest monthly mean (5.91 cm.^{3}) in our records, and exceeding production in the adjacent backwaters in 15 out of 27 monthly averages available for comparison (see table on p. 432), in 1896 we find the opposite extreme in production in these particulars.

In the first place, the mean production as seen in the mean of the monthly averages, 1.05 cm.^{3} per m.^{3}, or, in average of all collections, 1.16 cm.^{3} (see table on p. 429), is the least observed in our years of record. This is 61 or 47 per cent., according as we base computations upon means of monthly averages or of all collections, below the mean production in the Illinois. This ensues from the catastrophic effect of recurrent floods which periodically flushed the channel (Pl. X.), sweeping away the plankton-rich contents of the stream and replacing them with barren silt-laden flood waters of recent origin. There are 6 major and 5 minor flood culminations in this year, and most of them are marked by abruptness in rise, a factor which added to their destructive effects. The total movement in river levels in 1896 is only 45.7 ft. (see table p. 163), while that in 1895 is

51.9 ft. It is not so much the *extent* of movement in levels as it is *distribution* which produces this depression in production. Repetition of floods at relatively brief intervals is the cause of low production in *channel* waters in 1896.

Not only is the mean production in the river below normal, but all of the monthly averages are likewise from 97 to 35 per cent. below their averages except those of April and December, which are 23 and 7 per cent. above. Hydrographic conditions in these two months of higher production are such as to favor increase in plankton, since in both cases there is a period of 6–8 weeks of slowly declining levels with little or no interruption in which a more abundant plankton becomes established.

The relation of production in the channel and the backwaters in 1896 is also very different from that in 1895. While in 1895, owing to low levels in general and to the prolongation of rising levels, the backwaters were contributing but a slight and interrupted run-off to the channel, and production, as shown in monthly averages, was in the case of backwaters examined predominantly lower than in the channel, we find in 1896, owing to higher levels, that there is more impounding, and, owing to the slow declines, a larger continuance of it and more run-off to the channel. There are, for example, 157 days of falling levels above 6 ft. distributed through 10 months, while impounding and run-off continues for 90 days more at lower levels and in decreased volume. Not only are backwaters thus contributing to the channel for a much longer period in 1896, but their plankton content is predominantly higher than that in the channel. An examination of the relative production (see table on p. 436) reveals but 3 out of the 58 monthly averages of production in backwaters, excluding Spoon River, which are less than coincident production in the channel. These are for Dogfish and Quiver lakes in July, and for the latter in September—both months of lowest water, and consequent predominance of creek and spring water in Quiver and of vegetation in both lakes. This relatively greater production in the backwaters is not due to increased absolute production as compared with 1895 except in the case of Quiver and Dogfish lakes (2.59 and 5.01 cm.^{3}) when we find for these lakes the highest mean annual production in our years of records. In the case of Flag, Thompson's, and Phelps lakes the annual mean falls below the average on the basis of monthly averages, though the average of all collections in Flag and Thompson's lakes is above the general average in these lakes (see table on p. 429). The former basis of comparison is the better one, since it equalizes to some extent the inequality in the distribution of collections. The plankton content in backwaters in this year of recurrent floods is thus increased in some instances and but slightly reduced in others, with the net result of predominantly higher plankton content than in the current-swept channel, and a much greater total production.

The effect of the run-off of the impounded backwaters upon channel plankton may be seen in the river planktograph for 1896 (Pl. X.), where the March, June, August, October, and November floods in each case reduce the plankton as they rise, and are attended by a noticeable increase as levels fall again. That other factors are involved may be seen in the *rise* in plankton attending the *rising* flood of August, and in the declines following the increases in plankton content in the midst of rapid run-off in apparently favorable hydrographic conditions in nearly every instance above cited.

The effect of the midwinter flood following two years of low water, which permitted the accumulation in bottom-land forests, marshes, and backwaters of a great amount of vegetation, may be traced in the *large* production in winter and early spring. In the table on page 436 it will be noted that in the months of February–April production is above the average in every backwater in each month except in Dogfish Lake in April. Moreover, the largest records for this season of the year were obtained in this year in Dogfish, Flag, and Phelps lakes in all three months and in Quiver and Thompson's lakes in the first two, that is, in a total of 13 out of the 15 monthly averages. During the remainder of the year, from May to December, production in the backwaters generally falls below the average production for those months in the several localities. Out of the 51 monthly averages in this period (see table on p. 436) 37 are below the mean, and of the 14 above, 9 occur in Dogfish and Quiver lakes, where reduction in vegetation increases the production. The cause of this sharp contrast in the relative production in the two parts of the year, is to be found in the hydrographic conditions which affect the nutrition of the plankton. The rank vegetation which filled the forests, marshes, and margins of the lakes during the two years of low water was submerged by December flood, and by this early submergence and subsequent decay increased the production in winter months. This early consumption of the products of decay and the relatively early run-off of the spring flood combined to make vernal production relatively low in 1896. A comparison of the planktographs of the 6 localities (see plates named at the head of this section) will indicate the suppression of the April-May, or vernal, pulse in every locality but Phelps Lake. No plausible explanation for its occurrence here when it is not found elsewhere is apparent. Subsequent floods by their brief duration and frequent repetition tend to impoverish the backwaters by the removal of vegetation and organic debris, and by the run-off of nutrition in solution or suspension and of the developing plankton. In more stable conditions or floods of longer duration, when the backwaters are impounded for longer times, —largely by the restraining action of high water in the Mississippi,—decay is longer continued, and there is more opportunity for the utilization of its products by a plankton not removed quickly by the rapid run-off of the flood.

A comparison of the different regions even in this one year bears out this inference. Spoon River, scoured by repeated floods and swept by constant and relatively rapid current, contains only an insignificant amount (.007 $cm.^3$ per $m.^3$) of plankton. Quiver and Dogfish lakes, rid to some extent of the accumulated growing vegetation and enriched by dead vegetation in their submerged borders, yield in this year the largest annual mean of monthly averages (2.19 and 3.99) in our records.

In these lakes at levels prevalent in this year the impounding or reservoir function is at its height. The higher levels reduce the relative proportion of creek and spring water, and the absence of extreme high water cuts off to large extent the current of general overflow through the lakes. Accordingly, production here in the year as a whole exceeds the mean of all monthly averages by 25 (Quiver) and 26 (Dogfish) per cent., and exceeds the mean of the respective monthly averages in 8 and 7 of the 12 months. In the case of Thompson's Lake, on the other hand, the hydrographic conditions are such that its predominantly reservoir function is interfered with as each recurrent flood passes the level of 6 ft. and starts the current of channel water in at the northern, and out at the southern, end of the lake (Pl. II.). Accordingly production in this lake falls below the average of all monthly averages by 24 per cent., and the individual monthly means are likewise deficient in 9 of the 12 cases.

In Flag Lake the production (8.31 or 13.83 cm.^{3} per m.^{3}) is 10 per cent. below the mean of all monthly averages, or 21 per cent. above that of all collections, and exceeds the means of the monthly averages in 6 of the 12 months. The accumulated vegetation in and about this lake, and the moderate levels which develop the reservoir function of the area without permitting any current of overflow through it tend to keep up the level of production. It is in considerable excess of that in subsequent years, but falls below that of the exceptional conditions of the preceding autumn, discussed on page 385.

The moderate levels free Phelps Lake from currents of overflow and increase its impounding function, and we find here, accordingly, the largest production recorded in any of the backwaters in this year. The fact that the production (14.74 cm.^{3} per m.^{3}) falls 34 per cent. below the mean of all monthly averages for the lake and is deficient in 6 of the 12 months, may perhaps be due in part to the fact that in the previous year the lake had been a cultivated corn field and had not therefore been seeded by the spores and winter eggs of planktonts left on the drying up of the lake. In September the lake did temporarily dry up only to be re-entered by the October flood, in which an unusual plankton (51.6 cm.^{3}) at once developed.

1897.

(Pl. XI., XXIII., XXVIII., XXXII., XXXIV., XXXVIII., XLI.)

This year is represented by 34 collections in the Illinois. and 13 in Spoon River, and by 24, 6, 7, 18, and 9, in Quiver, Dogfish, Flag, Thompson's, and Phelps lakes. It was a year of protracted winter and spring flood, a late June rise, and prolonged low water in summer and autumn. The data of comparative production are given in the accompanying table.

PLANKTON PRODUCTION IN 1897.*

Station	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean of monthly averages
Illinois River........	− .04	+ .38	+ 5.11	− 5.62	− .27	+ 4.69	− 3.65	+ 8.83	+ 5.95	+ 1.00	− .56	+ 3.28
Spoon River........	+ .047	− .007	± .048	+ .440	+ .250	.. ..	+ .652	+ 5.13	.. ..	+ 1.671	+ .559	+ 1.225
Quiver Lake.........	− .19	− .34	+ 13.38	− 1.29	+ 1.26	+ .89	− .21	− .16	− .04	− .09	− .007	− 1.71
Dogfish Lake	− .15	− .48	− 8.18	− 1.94	− 2.48	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	− 2.65
Flag Lake	− .07	− .83	− 8.55	− 10.61	+ 4.87	+ 7.13	.. ..	.. ..	.. ..	.. ..	.. ..	− 5.34
Thompson's Lake ...	− .27	− .65	− 10.38	− 7.88	− 3.59	− 3.31	+ 19.40	+ 10.01	+ 35.35	+ 16.67	+ 6.98	+ 10.41
Phelps Lake	− .19	− 1.44	− 4.26	− 22.58	− .42	+ 9.49	− 25.70	.. ..	.. ..	.. ..	.. ..	− 9.15

*The minus sign signifies below average and the plus sign above.

The infrequency of collections in January–June and the suspension of work in Dogfish, Flag, and Phelps lakes before the year ended, render general comparisons with other years of less value because of insufficient data.

The annual channel production, 3.28 cm.^{3} per m.^{3},—the mean of monthly averages,—or 3.69, the average of all collections, is 21 or 68 per cent, respectively above the means, and 6 of the 11 months represented also exhibit a plankton content above the average. The causes of this large production are to be found mainly in the prolonged low water, slackened current, and sewage contamination of the last half of the year. No large vernal pulse appears in the records of the river or its backwaters. It was either intercalated between collections, and thus escaped detection, or the early winter flood, as in the previous year, by its washing away sources of nutrition prior to the season and temperature of greatest plankton development, tended to depress production below normal at this season. It was to be expected, however, that a large plankton development took place in the stable conditions attending the three months of declining levels which followed (Pl. XI.) the crest of the spring flood. If such a development took place it would tend to raise still higher the level of production established by our records for this year.

The relation which the backwaters bear to channel production in 1897 is correlated with the hydrographic conditions. In January–June, a period of continued high water, the plankton content in the backwaters exceeds that in the channel in 22 of the 30 monthly averages (see table on p. 441), or, omitting Spoon River, which does not properly belong in the category of backwaters, in 21 out of 25.

This was a period of extensive and long-continued impounding and of high levels, and, in the last three months (Pl. XI.), of rapid decline and therefore of speedy run-off and rapid current in channel waters, factors which favor the breeding of the plankton in the reservoir regions and cut down the time for its development in the channel, in which barren tributary waters of recent origin and plankton-rich backwaters impounded in the more or less current-free areas for a greater or less length of time, depending upon the direction and rate of change in river levels, are mingled in varying proportions.

In the low-water period, July–December, stability of hydrographic conditions continues throughout, while the extreme low levels maintained for so long a time make the channel waters very largely independent of backwaters and tributaries by reason of cutting off of communication in some cases and cessation of run-off in others. Along with this independence goes increased fertility by virtue of greater relative contamination by sewage and longer time for breeding by reason of the slackened current. As a result, production in channel waters reaches in July–November, 1897, a level unsurpassed in our records, rising above the monthly means of all years (see table following page 342) 11 per cent. in July, 245 per cent. in September, 250 per cent. in October, and 14 per cent. in November, but falling behind by 6 per cent. in August. As a result of this increased development of plankton in the channel the production in backwaters becomes *relatively* less with respect to the channel production than in times of high water. Thus in July–December, backwater plankton exceeds that in the channel in only 10 out of 19 monthly averages, or, omitting Spoon River, in 8 out of 15—a marked change from the excess in the preceding six months, 21 out of 25.

This is the only season in all our records in which the plankton content of Spoon River rises above the barren level of .1 $cm.^3$ per $m.^3$, or less. The production now rises to a level approximating, and in November–December exceeding, that in the channel as a result of the practical absence of current and consequent increase in the reservoir function of the stream.

The course of production this year in the various backwaters is in most instances strikingly similar to that in the channel in its major outlines. Thus in all of them (Pl. XXVIII., XXXII., XXXIV., XXXVIII., and XLI.) production rises gradually from the midwinter minimum to an unusually low vernal pulse in April-May and declines again in June-July. At this point collections were suspended in Dogfish and Flag lakes. Production in channel waters rises again in August and continues at high levels till November, and in like manner and with even greater amplitude in Thompson's Lake (Pl. XXXVIII.), while a similar movement is initiated in Phelps Lake (Pl. XLI.), only to be stopped by the drying up of the lake in

September. Quiver Lake, however (Pl. XXVIII.), pursues a different course, production there dropping to a level rarely exceeding .5 cm.^{3} for the remainder of the year. This results from the greater *relative* volume of spring and creek water in this lake. The discharge from Quiver Creek and the marginal springs continued with relatively much less diminution through the autumnal drouth than that from Spoon River, with the result of making this lake far less productive of plankton at this season than Spoon River (cf. Pl. XXIII. and XXVIII.).

1898.

(Pl. XII., XXIV., XXIX., XXXIV., XXXIX., XLII.)

This year is represented by 52 collections in the Illinois and 11 in Spoon River, and by 26, 6, 25, and 22 respectively in Quiver, Flag, Thompson's, and Phelps lakes. It was a year of normally located and fully developed spring floods, followed by low water in summer much disturbed by minor floods, with a subsequent autumnal rise of unusual proportions. This resulted in the highest average river levels in our years of operation, 8.02 ft.—a level almost equaling bank height.

The accompanying table gives the data of comparative production of the different localities in this year.

PLANKTON PRODUCTION IN 1898.*

Station	Jan.		Feb.		March		April		May		June		July	
Ill. River...	+	.45	+	.27	+	.33	—	4.40	+	11.30	—	3.96	—	.58
Spoon River	+	.017	—	.016	+	.124	..	.....	—	.023	—	.096	±	.036
QuiverLake	—	.02	—	.31	—	.74	—	.53	+	16.27	+	2.23	—	.16
Flag Lake..	..	.....	..	......	..	......	...	.....	..	......	..	......	—	.36
Thomp. L..	+	7.22	—	.64	—	.70	—	2.44	—	25.94	—	10.43	—	2.08
PhelpsLake	..	.....	..	......	—	.25	—	5.60	+	40.44	+	27.67	—	6.97

Station	Aug.		Sept.		Oct.		Nov.		Dec.		Mean of monthly averages	
Illinois River.......	—	.91	—	.69	—	.24	—	.25	+	.99	—	2.03
Spoon River........	—	.002	—	.002	—	.001	—	.001	—	.001	—	.02
Quiver Lake.......	—	.22	—	.33	—	.23	+	.73	+	1.74	+	1.969
Flag Lake.........	—	.03	+	15.54	..	......	—	......	..	......	—	5.31
Thompson's Lake..	—	2.63	—	2.66	—	1.25	—	1.17	+	3.58	—	5.06
Phelps Lake.......	+	139.85	±	47.25	+	32.31	+	51.14	±	21.96	+	37.34

*The minus sign signifies below average and the plus sign above.

The average production in the Illinois for the year is 2.03 cm.^{3} per m.^{3}, or 2.13 cm.^{3} if the average of all collections is taken instead of the mean of monthly averages. This is 25 per cent. below the mean of monthly averages, or 3 per cent. below that of all collections. This depression in production is due to the disturbed and irregular hydrographic conditions which throughout most of the year left insufficient time for the plankton to breed.

As shown by the + and — signs in the table, production in channel waters is below the average in 7 of the 12 months, and 4 of the 7 deficiencies fall continuously in the disturbed period of August–November. The decline below the average production in this disturbed period ranges from 72 to 86 per cent. The other 3 months of deficient production are April, June, and July—4, 45, and 86 per cent. below their averages. The April deficit is due to the delay in the vernal pulse, while those of June and July are due, possibly, to the after effects of the high vernal pulse of May. Production in excess of the average is found in January–March, during the unusually slow rise of the spring flood, in which the catastrophic effect alike of the sudden and higher floods and of stagnation under ice in low water is eliminated. Production is also high, by 86 per cent. in May, as a result of the delayed culmination of the vernal pulse —the largest one, moreover, found in our records in channel waters. It is also high by 40 per cent. in December, when declining levels (Pl. XII.) afford the stability necessary for the breeding of the plankton.

Production in Spoon River, as might be expected in a year of much flood water, falls to a barren level exceeding .1 cm.^{3} in but a single instance, in March (.124), when waters of general overflow mingle with those of the tributary to a considerable extent.

Production in the backwaters in 1898 again bears a striking resemblance, throughout, to the course it presents in the channel. The higher levels conduce to greater unity in the environment, and to greater interchange between many localities, and the plankton accordingly follows similar lines of development. This is noticeably prominent in the planktographs of the river and Quiver and Thompson's lakes, as will be seen by a comparison of Plates XII., XXIX., and XXXIX. The principal features of the common course of production are the coincidence of the May and June pulses, the subsequent low level of development throughout the summer and early autumn, and the December rise. These three bodies of water were submerged in the common flood of overflow in February–June, and the succeeding minor flushes of summer and autumn caused recurrent ingress and egress of water from and to the channel. The similarity in the course of production in these three localities and the lessened differences in the amplitude of production in this year are in no small measure the consequence of this equalizing action of this interchange due to floods.

Phelps Lake (Pl. XLII.) is the only one of our backwaters which diverges from this marked agreement, and its divergences are increased by its intimate connection with Spoon River during high levels and its isolation during the remainder of the year.

The vernal pulse of this year is noticeable for its amplitude, its meteroric appearance and disappearance, and its coincidence in different localities. It follows a prolonged period of extreme overflow, and a very gradual and somewhat tardy rise in vernal temperatures. It appears, moreover, at levels of 10–11 ft., just when great stretches of bottom-lands are contributing their last run-off to the channel. The submergence of the bottom-lands did not occur until late in February in this year, so that the period of vernal increase in the plankton was not preceded by a long interval of flood, as in 1896 and 1897, which might carry away in suspension or solution those organic substances in the vast amount of vegetable detritus which covered the bottom-land as a result of the low water of the preceding autumn, and which may have been utilized by the plankton in this extraordinary vernal development as a result of the juxtaposition of flood and vernal growing season.

The comparison of backwater and channel production in 1898 is in some contrast with that in 1897. In 1897, omitting Spoon River, production in backwaters exceeded that in the channel in 29 of 40 monthly averages, or in 73 per cent., while in 1898 the excess occurs only in 26 of 37, or in 67 per cent. The excess, moreover, is frequently of less amplitude in the latter year, as is seen in the relation of the means of the monthly averages of backwaters and channel in the two years. Thus in 1897 production in Thompson's Lake (10.41) was 217 per cent. in excess of that in the channel (3.28), while in 1898 (5.06 and 2.03) the excess was only 149 per cent. In Phelps Lake, on the other hand, production rose to the unparalleled height of 37.34, the mean of the monthly averages, 67 per cent. above the mean of all monthly averages, and fourfold that in the previous year, when the last 4 months were cut off by the drying up of the lake.

Production in Quiver Lake in this year is 1.96 cm.^{3}, mean of monthly averages, or 2.44, average of all collections—12 per cent. and 44 per cent. above the mean respectively of all years. This larger production is due to the excessive production in the vernal pulses in May and June and to the high levels of production in November and December, rising 138, 78, 217, and 176 per cent. above the average respectively for these months. The hydrographic conditions in these months in Quiver Lake are favorable to increased production. The May and June pulses are at levels (11 ft.) when impounded run-off from slightly submerged bottom-lands to the north was rapidly draining to the channel through the lake. In November and December there was at least double the usual volume of water in the lake, due to a 34 per cent. increase in river levels, with a considerable reduction in the *proportion* of tributary water and increase in the impounding function. In the remaining 8 months of the year, then, average production is 79 per cent. below the general average for those months in Quiver Lake. This very considerable depression in production falls in the main in the period of greatest hydrographic disturbance. This body of water, owing to its frequent invasion by channel waters and to its own influx of tributary water from Quiver Creek, is the most liable of all the backwaters examined by us to hydrographic disturbance. It is therefore not surprising that in this year of extreme disturbance we should find marked depression for a long period in this lake. The total movement in levels in 1898 is 67.2 ft. (see table p. 163), 44 per cent. above the average. Of this, 50.8 ft. fall in the 8 months of depressed production, that is, 76 per cent. of the movement occurs in 67 per cent. of the time. To this relative excess of fluctuation in levels, and probably to large access of local flood and spring water, we must attribute the low production in Quiver Lake in these months.

Thompson's Lake has an average production of 5.06 $cm.^3$, or, if all collections are averaged, 5.71 $cm.^3$, 39 and 28 per cent. below the respective averages for all years (see table, p. 429). Not only is the general average below normal, but all of the monthly averages, save only those of January (7.22) and December (3.58), are likewise deficient by from 2 to 88 per cent. The large January production is the largest plankton content in this month in any year or locality, and accompanies an invasion and impounding of sewage-laden river waters in the lake (cf. Pl. XLV. and L.).

The cause of the low production throughout the remainder of the year is again to be found in the hydrographic conditions. During 8 months of the year (at levels above 6 ft., see Pl. XXXIX.) the lake is swept by a gentle current entering at the northern end and discharging to the channel at the lower. There is, thus, in this year more than the usual run-off, not only of organic matters in solution and suspension, received with the waters of ingress, but also those developed in its impounded waters or about its shores. This tends to impoverish the waters, and interferes with the accumulation and flux of organic matter in the plankton which manifested itself in such amplitude in the low water of the preceding year (Pl. XXXVIII.). To a much less extent than in Quiver Lake is the depressing effect of flood waters seen in the broader expanse of this body of water. While in the former the production in months of flood disturbance falls 79 per cent. below the mean for that season, we find in the 10 months of depression in Thompson's Lake a falling off of only 46 per cent. The difference is due to the greater proportion of creek and spring water of recent origin in the former, and to the greater reservoir capacity and consequent longer impounding, as a rule, of the sewage-laden channel waters which predominate in the latter backwater.

Production in Phelps Lake is 37.34 cm.^{3} per m.^{3}, or, if all collections are averaged, 36.31—67 or 84 per cent. above the means for all years. In keeping with these facts we find that the monthly averages equal or exceed the means for their months in 7 of the 10 months of record, the greatest excess occurring during the period of complete isolation of the lake.

1899.

(Pl. XIII., XXIV., XXIX., XXXIX., XLII.)

This year is represented by 13 collections in the Illinois and 3 in Spoon River, and by 7 each in Quiver and Thompson's lakes and 6 in Phelps Lake, all in the first three months of the year. This was a period of a slow rise of the river in January to bank height, with an equally slow decline in the next month followed by an abrupt and well-sustained March flood. The data of comparative production are brought together in the following table.

PLANKTON PRODUCTION IN 1899.

Station	Jan.		Feb.		March		Mean of monthly averages	
Illinois River	—	.18	+	.81	+	.28	+	.42*
Spoon River	—	.005	—	.001	—	.026	—	.011
Quiver Lake	+	.77	+	1.05	—	.15	+	.66
Thompson's Lake	—	1.64	+	1.59	—	.21	—	1.15
Phelps Lake	+	4.69	—	4.70	—	1.82	—	3.74

*The + and — signs for this column refer to the relation of these averages to the mean of all January–March collections; otherwise they are used as heretofore.

The average production in these winter months in the river is .42 cm.^{3} per m.^{3}, or, if all collections are averaged, .41 cm.^{3}

This is the largest production for this period of the year in our records, exceeding the average, .24 cm.^{3}, by 75 per cent. and approximating or exceeding the monthly average in each instance. The cause is to be found in the relatively stable conditions at a level sufficient to prevent sewage stagnation beneath the ice-sheet which covered the stream prior to the March flood.

Spoon River continued to discharge barren waters (av. .011 cm.^{3}), while the backwaters, with the exception of Quiver and Thompson's lakes in March, produced a more abundant plankton than the channel. Quiver Lake produces .66 cm.^{3},—an excess of 20 per cent. above the usual production for this season,—and in the first two months has 2- to 3- fold the usual plankton content as a result of the moderate levels which make the lake a reservoir without greatly increasing its current. When, however, the general current of overflow passes through it with the March flood, production drops to one fifth of the mean for that month. In Thompson's Lake the mean production is 1.15 cm.^{3}, 56 per cent. below the mean production for these months. It also falls below in January and March, when hydrographic conditions are such (Pl. XXXIX.) that channel water is diverted through it, and rises above the mean by 25 per cent. in February, when the run-off is diminished by falling levels. In Phelps Lake the mean production, 3.74 cm.^{3}, is 23 per cent. below the mean for these months. This lowered production, which also falls below the mean in the last two months, is due, in part at least, to the invasion of Spoon River water with the higher levels.

The various years of our operations may be briefly characterized as follows.

1894. A year of low water and fairly stable hydrographic conditions, with nearly average production in channel and open backwaters and deficiency in the vegetation-rich Quiver Lake in the months of our records.

1895. A year of continued and but slightly interrupted low water, with stagnation destroying the winter plankton and tending to abnormal production in early summer in channel waters. Production is deficient in vegetation-rich backwaters (Quiver Lake) and in excess in open reservoir lakes (Thompson's Lake).

1896. A year of recurrent floods of moderate height and greatly diminished production in channel waters. The repeated summer invasions of the vegetation-rich backwaters by flood destroyed and removed much of the season's growth, and we find this the year of greatest plankton production in these areas (Quiver, Dogfish, and Flag lakes). The more open waters, poor in vegetation (Thompson's and Phelps lakes), have vernal pulses of considerable magnitude, but as summer and autumn production is not up to the average there is as a whole a deficiency in these areas.

1897. A year of prolonged winter-spring flood, followed by continued and abnormally low water in the last 5 months of the year. The early flood apparently reduces production everywhere, while the prolonged low levels lead to abnormally high production in the channel and in vegetation-poor backwaters (Phelps and Thompson's lakes). In Quiver Lake the relative dominance of vegetation and tributary waters of recent origin is so increased that production falls to a low level. Even tributary streams (Spoon River) so decline in run-off in the low-water period that an abundant plankton develops in their waters.

1898. A year of normally located spring floods, followed by repeated minor flushes in summer and autumn. There is a meteoric but normally located vernal pulse, with a low level of production throughout the remainder of the year in the channel and in backwaters intimately connected with it (Quiver and Thompson's lakes), and an abnormally high and well-sustained level of production in backwaters isolated from flood contact and free from vegetation (Phelps Lake).

The different localities may be briefly characterized as follows.

Illinois River. Channel waters contain a plankton which in constituent organisms, character of the course of production, and relation to environmental factors shows marked similarities to that found in the backwaters. The river is, however, more immediately and directly subject to ihe effect of floods, sewage, and stagnation, and exhibits less uniformity and regularity in its planktographs. High water and repeated floods are wont to depress its production, while stable conditions such as prevail more fully in falling levels and low waters often lead to increase in production. The run-off of impounded backwaters where plankton breeds, which attends falling levels, and the concentration of sewage in low water likewise conduce to increased production.

Spoon River. This is always plankton-poor save at lowest levels, when the slackened current renders the stream an impounding area. At high levels in spring impounded backwaters of the bottom-lands join it and tend slightly to increase its plankton content. It is immediately and predominantly a diluent of channel plankton.

Quiver Lake. This is an area subject to great vicissitudes of production by virtue of the variety of environmental factors operative and their changing efficiency with fluctuations in river levels. Influx of creek and spring water of recent origin and relative dominance of vegetation are increased at low levels, and production falls. Backwaters from the channel in floods below 6–8 ft. increase its impounding function, and decrease current, proportion of tributary water, and relative occupancy by vegetation, and production rises. In floods of higher levels the general current of overflow from submerged lands up-stream courses through the lake, and local factors are greatly reduced in their effect. As a whole it is the least productive of all the backwaters examined, but like the others has a rich plankton when it is filled with impounded backwaters, especially at the season of the vernal pulse.

Dogfish Lake. This resembles Quiver Lake in many features, but is freer from immediate access of tributary water and invasion of channel waters at lower levels. It has accordingly a higher and better sustained level of production.

Flag Lake. This, like Quiver Lake, is an area of great contrasts in production, resulting from its varying occupancy by vegetation as levels rise and fall and from the changes in nutrition available for the plankton attendant upon its growth and decay. In so far as the data go they indicate a production several fold greater than that attained in Quiver and Dogfish lakes.

Thompson's Lake. In this area, by virtue of its considerable size and freedom from immediate access of tributary water of much volume, the fluctuations of the hydrographic, and to some extent of the other, factors of the environment are in a measure equalized. Production is therefore less disturbed than in the backwaters previously named, pursuing what may be called a more normal course, and is accordingly greater than theirs,—excepting perhaps that of Flag Lake in seasons of high water,—being three-fold that in the channel, from which its main water supply is directly drawn. Owing to this intimate connection with the river and freedom from dominating local influences the planktograph of this lake is more like that of the river than are those of other localities. Comparative freedom from vegetation, highly developed impounding function, freedom from access of tributary water of recent origin, and close connection with channel waters rich in organic matter, all combine to cause the high production found in this area.

Phelps Lake. In this area production reaches the highest level found in any of our localities. It exceeds that in the channel eightfold, and that in the most productive backwaters elsewhere examined by us by two and one-half- fold to threefold. Ingress of flood water from Spoon River depresses production at high levels. At lower levels the freedom from vegetation of the coarser, more cumulative, and permanent sort, the abundance of algæ whose decay releases nutrition for the summer plankton, and the absence of tributary creek or spring waters, all favor the high production found in this area. Perhaps most potent of all factors is the isolation of the lake at high levels and consequent retention within its boundaries of the organic substances in solution and suspension in its waters, substances which in the other localities run off with the declining flood. During last stages of low water in Phelps Lake there is usually some dying off of the fish and other aquatic animals, possibly as a result of extreme temperatures, and the lake becomes a favorite resort for fish-feeding water-fowl. The organic substances thus released for immediate solution in the water and utilization by the phytoplankton may be of sufficient quantity to materially increase production at these low levels. It may be that the more complete access of light in these very shoal waters and the condensation caused by evaporation and seepage as the lake dries up are contributory to the increased plankton content, but none of these factors seems adequate to explain the excessively large production found in the summer and autumn in the shallow pools which form the remnant of the lake.

RELATION OF ENVIRONMENTAL FACTORS TO PLANKTON PRODUCTION.

The detailed discussion of the course of plankton production as defined by volumetric data found in the preceding section of this paper, has afforded many specific instances of the relationship existing between the movement in production and a number of factors in the environment. Prominent among these are hydrographic conditions, temperature, light, chemical conditions, vegetation, and the reproductive cycles of the constituent organisms of the plankton.

It is my purpose in the following pages to summarize, with a few references to specific illustrations, the conclusions as to general tendencies and the effect of these various factors upon the course of production in the river and its backwaters.

HYDROGRAPHIC CONDITIONS AND PLANKTON PRODUCTION.

This is a comprehensive designation for a great variety of major and minor influences which continually impinge upon the plankton as a result of its environment in water. In the case of the plankton of the Illinois River and its backwaters it is the unique factor which more than any other differentiates it from lake plankton. To a less degree it seems to differentiate this aquatic environment from other streams, as a result largely of the imperfectly developed flood-plain, and consequent unusual proportion of reservoir backwaters.

It is, moreover, an exceedingly variable factor, operating with almost constant change in each locality, and from season to season in the same locality. It is this element of fluctuation and the resulting chaos in the movements of production which particularly characterize the river as a unit of environment, and in a large measure differentiate it from the more stable lake. The changes depend primarily upon the unequal distribution of the rainfall and its run-off and the consequent fluctuations in levels with attendant changes in area, depth, conditions of ingress and egress of water in any given area, current, and age of the water.

The effect of the *area* of the body of water upon its plankton production in our situation is so masked by combination with other factors that the available data are inconclusive. Our largest vegetation-poor backwater, Thompson's Lake, produces less (8.26 cm.^{3}) than the smaller one, Phelps Lake (22.35 cm.^{3}). On the other hand, the largest vegetation-rich area, Flag Lake, produces 9.23 cm.^{3}—considerably more than the smaller Quiver and Dogfish lakes, 1.75 and 3.16 cm.^{3}—and these differences are, moreover, in all probability to be attributed to other factors than mere area.

The relative development of the shore-line is a corollary of the form of the body of the water, and is thus related to its area. In the case of the river, the development of the shoreline, as shown on page 284, is 78.3—a disproportionately large element in the environment of the plankton.

This factor of area has been introduced here in order to emphasize the fact that mere size in itself has apparently little to do with plankton production. Plankton is present in small as well as large bodies of water, with, of course, an increasing proportion of littoral influences as areas contract. Within our environment the submergence of all the localities, large and small alike, in the major floods, tends to obliterate areal differences, and to unify their plankton and to give them all much the same initial start in the season's course of production. This is noticeable in the marked similarity in the vernal planktographs of the several localities in years of high water. The areal differences in later months and lower river stages are, however, very considerable (cf. Pl. XX. and XXI.). Thus in Thompson's Lake there is a broad expanse of open water several square miles in extent, while in the last stages of Phelps Lake there are only a few pools, a few acres in extent (Pl. XXI.). Under similar climatic conditions production in both runs high, higher in fact than in other localities, and the same planktonts are dominant, though in varying proportions in the two. In general the plankton content per cubic meter runs very much higher in Phelps Lake, the smaller body of water. There is no evidence that the smaller size has anything at all to do with this larger production, but this instance suffices to show that a typical plankton with large production may be found in small areas. On the other hand, Quiver and Dogfish lakes, next in size to Phelps Lake, are the least productive of the backwaters. Thus, *area* in itself tends apparently neither to deter nor to promote production.

The effect of *depth*, in all of its relations, upon plankton production is manifestly not demonstrated in our data, since all of our collections have been made in shoal water of less than 10 meters in depth. Our deepest waters are Spoon and Illinois rivers, where spring and flood water of recent origin tend to depress production, and the shoaler waters are found in the backwater reservoirs where impounding favors larger plankton content. The significance attaching to the fact that our largest plankton production (224 cm.^{3} per m.^{3} on August 24, 1898) is found in Phelps Lake, the shoalest of all our localities, and in depths no greater than 20 centimeters, is a matter of conjecture, since many other factors are also involved. The highest production in this lake was, as a rule, found during the periods of shoaler waters, from 50 to 20 cm. Flag Lake also, in the shoal waters of the autumn of 1895, yielded a large production; and Thompson's Lake, in the low water of the autumn of 1897, gave the largest production on record for that season of the year in that body of water. The vernal pulses, noted for their large production, usually fall at the time of the run-off of large areas of *slightly* submerged bottom-lands. Shoalness, then, does not prevent large production. Indeed, there are some important reasons why shoal waters should, other things being equal, produce more plankton. Light pervades the water more completely, aeration by wind and waves preserves the gaseous equilibrium more perfectly than in deeper waters, and upon sedimentation the suspended organic matters in the water are not removed from the immediate proximinity of the growing phytoplankton. Their decay and solution renders them immediately available, while in deep waters only the slow process of diffusion, in the absence of vertical currents dependent upon temperature or hydrographic changes, brings them within the field of surface-dwelling plankton.

It is well established that the plankton is relatively more abundant in the surface than in the deeper waters of the ocean. The researches of Reighard ('94), Birge ('95), and Ward ('95) show conclusively that the surface waters of our larger lakes contain the greater part of the plankton. Thus, Reighard ('94) finds in Lake St. Clair from 1.2 to 37.2 times as much plankton in the surface stratum of 1.5 meters in depth as in the remaining bottom layer in depths of 2.2 to 8.4 meters. Birge ('95) finds 50 per cent., or more, of the *Crustacea* of the plankton in the upper 3 to 4 meters, and over 90 per cent. in the upper 9 meters in depths of 18 meters, and Ward ('95) reports 64 per cent. of the plankton in the upper 2 meters.

Of our total 640 collections, 389 were made in water over 2 meters in depth. In the Illinois there were 208 such out of 235; in Spoon River, 34 out of 35; in Quiver Lake, 60 out of 115; in Dogfish Lake, 27 out of 48; in Flag Lake, 8 out of 44; in Thompson's Lake, 48 out of 96; and in Phelps Lake, only 4 out of 67. Thus about 40 per cent. of our collections were made in water less than 2 meters in depth and at all river stages, and at all seasons of the year a considerable proportion of the Illinois and its backwaters has a depth not exceeding this limit. Moreover, less than 12 per cent. of our collections are in 5 or more meters of water, and these are confined almost entirely to the two streams. Our collections as a whole are therefore within the limit of depth of the surface stratum, which in deeper waters contains by far the greater proportion of the plankton. This feature of our environment has a tendency to increase the plankton content per cubic meter and to lower it when production is stated in volumes per square meter of surface. Thus, if we compare production in the Illinois River in August with that of Lake Michigan, as given by Ward ('95), we find that in quantity per m.^{3} of water the river (3.88) exceeds that of Lake Michigan. The average of Ward's August collections is 3.69 cm.^{3} per m.^{3} by the gravity method, or 1.23 cm.^{3} if we reduce it to centrifuge basis (see Ward '00). Production in our environment in this month (see table following p. 342) in all localities but Spoon River and Quiver Lake is from 1.5 to 47 times greater per cubic meter than in Lake Michigan; but if the average per sq. meter of surface be taken as a basis, Lake Michigan exceeds the most fertile of our localities at this season. The amount per sq. m. in Lake Michigan I find on computation to be 37.98 cm.^{3} estimated centrifuge measurement, while in the Illinois at average August river-levels (4 ft.) it is about 15 cm.^{3}, in Thompson's Lake only 9.29, and in Phelps Lake approximately 14 cm.^{3}

The *age of the water* is, other things being equal, one of the most vital of all the hydrographic factors environing the plankton. Rain and spring water of recent origin entering the river or its backwaters in tributary floods or by seepage from underground storage beds, is practically barren of plankton. This same water impounded in the reservoir backwaters, seeded by the spores and resting eggs of the planktonts deposited on the submerged territory on the recession of antecedent floods, and mingled more or less with the residual and plankton-rich waters of reservoir lakes and sloughs, soon develops an abundant plankton ; or, retained in the channel and mingled with plankton-bearing waters from a thousand sources, it develops a phyto- and then zoo-plankton as soon as the requisite *time for breeding* has elapsed. Illustrations which demonstrate the operation of this hydrographic factor permeate all of the data of the variable environment with which we are dealing. Attention has been called repeatedly in the detailed discussion of the movement in production to specific instances of the barrenness of flood waters of recent origin which invade plankton-rich areas. By dilution and replacement they lower plankton content in channel waters pre-eminently and to a less extent in backwaters, where their diluent action is less pervading and replacement less complete. The most perfect illustration of this will be found in the August flood of 1896 (Pl. X.).

Tributary streams such as Spoon River, whose waters are of recent origin, contain but little plankton. Quiver Lake falls in production as spring and creek waters preponderate in its area at low-water stages, while the phenomenally rich waters of Phelps Lake are poverty-stricken only so long as Spoon River floods maintain a current through the lake.

The time requisite for the development of the plankton in such waters of recent origin must necessarily vary with the attendant circumstances, such as climatic conditions, previous state of the plankton, and the proportions of the mingling waters. The *volumetric* pulses of plankton are frequently so located as to suggest the agency of floods in determining, to some extent at least, their location and amplitude. The apices of these pulses are found at varying intervals after the preceding depression occasioned by invasion of water of recent origin. Thus the August pulse in 1896 in channel waters makes full recovery in a week from the scouring effect of the flood (Pl. X.). In the backwaters this same flood (Pl. XXVII., XXXI., and XXXVII.) was attended by a rising pulse which culminated after an interval of 2 to 3 weeks. In a general way, 10–20 days suffice in most cases for production to recover from the disaster of, or respond to the stimulus of, the flood. It is evident, however, that this matter is greatly complicated with the rythmic, pulse-like character of the movement in plankton production.

In passing, attention should be called to the fact that recovery from the flood is not merely replacement by up-stream waters rich in plankton, as might be concluded regarding channel waters. It takes place also in the impounded backwaters under conditions of absolute independence of channel, as in Phelps, Dogfish, and Flag lakes. In these cases it is an indigenous development in impounded flood waters, and, by inference, there must be a process of like import in channel waters and areas more or less intimately connected therewith.

This necessity of some lapse of time before accessions of tributary flood and spring waters can produce a plankton of any considerable volume makes all important the impounding function of the backwaters of the Illinois River. They act not only as storage reservoirs whence the floods are drawn off in reduced and equalized volume, but they serve also as nurseries, where under favorable conditions the flood waters are seeded with planktonts whose progeny utilize the organic materials in suspension and solution in the invading flood or derived from the invaded territory. The plankton thus developed, or the product of its decay, is carried away by the run-off of the flood into channel waters unless utilized by the larger and more permanent residents of the backwaters as food, or sequestrated in some land-locked pool or lake as levels fall.

Intimately connected with the age of the water are the associated factors of *current and rate of renewal.* In and of itself alone, current has little demonstrable influence upon plankton production, but conjoined with other factors it becomes potent for ill. Thus, in narrow confines, as within the banks of a stream, by its mechanical action it fills the water with silt, which diminishes access of light and thus tends to decrease photosynthesis by the phytoplankton. The silt likewise, as has been pointed out on page 185, seems by adherence to impede the movements of the *Entomostraca*, and perhaps also of the *Rotifera*, and thus to exercise a deleterious effect upon them. The excess of moribund and dead individuals of these groups in flood waters is evidence of the destructive character of the silt-laden current.

When the existence of a current in a body of water involves the run-off of its contents and their replacement by water of more recent origin, the result tends to lower production, and the proportions of the depressing influence will rise with the rate of the current and the contraction of the volume, or with rapidity of replacement, in the main in proportion as they shorten the time for breeding of the plankton. Illustrations of this tendency appear in contrasting our various localities. In Spoon River, where current is rapid and renewal with recent water complete and frequent, production (.256) continues in minimum quantity and rises only when current slackens. In the Illinois River the current is perhaps as a rule less rapid than in Spoon River, replacement because of connecting backwaters less complete and frequent, and the replacing water has a greater proportion of older water by virtue of the longer water-course and the greater development of contributory impounding backwaters. Production is accordingly greater (2.71) in the larger stream. In Quiver Lake conditions in these particulars are extremely varied. As the lake emerges from the general overflow the extent and rate of the current declines, but the proportion of creek and spring water of recent origin is increased with resulting depression in production. When by reason of backwater from the channel at low levels the current is reversed, the run-off checked, and the flood and tributary waters are impounded,—as in the summer floods of 1896,—production rises. Current with attendant run-off and renewal of water in this lake constitutes one of the important factors in lowering its production (1.75) below that of the other backwaters.

In Dogfish Lake the factor of current and renewal by recent water is largely eliminated, and production (3.16) exceeds that in the contiguous waters of Quiver Lake.

In Flag Lake a current is only slightly present in high water and during the run-off of impounded floods. It is perhaps less noticeable here than at any other station examined, owing to the sheltered location and freedom from tributary relations. Renewal is therefore least rapid and production accordingly high (9.23).

In Thompson's Lake, owing to freedom from tributaries, to the large volume of the lake, and to the relatively small and frequently interrupted run-off, renewal is relatively infrequent and incomplete. Moreover, the water which replenishes the lake is drawn from the channel, and has a considerable proportion of old and plankton-rich contributions from impounding areas up-stream. Production is accordingly high in this area (8.26).

In Phelps Lake, current, other than that of run-off of contained waters, is absent at levels below 10 ft., above which Spoon River flood waters of recent origin find their way through the lake and depress production. At other seasons current is inconsiderable and soon ceases, and replacement no longer occurs. Impounding and production (22.35) are at their maximum here.

The net effect of the continued run-off and renewal of the water in a stream or lake upon the fertility of the locality will depend largely upon the inflow and discharge of nitrogenous and other food materials or living organisms developed at their expense. It is evident from the chemical data contained in this paper that a vast amount of organic matter is continually carried away from the drainage basin of the Illinois, and that the amount in the streams is usually greater than that in the backwaters. In general, production is less where this impoverishing process is facilitated by continuous and relatively rapid replacement (Spoon River, Quiver Lake, and the Illinois), is greater where the rate of renewal and total run-off is less (Dogfish, Flag, and Thompson's lakes), and is greatest when and where impounding is most complete (Phelps Lake at low water) and the organic matter in suspension and solution is retained within the lake and augmented by the synthetic activities of the phytoplankton and other vegetation.

The *fluctuations in hydrographic conditions* consequent upon changes to river levels constitute the one pre-eminent factor peculiar in the fluviatile environment in the extent to which it is developed and to which it influences and controls the course of plankton production. These fluctuations operate by bringing about changes in area, depth, and volume, in current, in age of the water, in rate of renewal and period of impounding, in relative proportions of tributary and impounded water, in chemical contents and sewage contamination, in relative dominance of vegetation, and in the interrelations of channel with backwaters and of the backwaters with each other. Illustrations of each and all of these results have been cited in the detailed discussion of the course of plankton production in the channel and the various backwaters. It will therefore suffice in the present connection to cite briefly certain prominent features, and to deal particularly only with some of the general phases of the problem not readily followed through the maze of details of the previous discussion.

The rise in levels results usually from access of tributary flood waters in local or up-stream territory, and rarely from backwater due to entrance of storm water in lower reaches of the river only. These flood rises occur in both high and low river stages, though they are more frequent and of shorter duration at lower levels, since in the much contracted volume of the stream at such stages slight increases in the run-off which would scarcely cause a ripple in the hydrograph in overflow stages, now cause considerable change.

The river channel itself is most immediately affected by this access of flood waters of recent origin, since tributaries, with few exceptions, discharge directly into the channel, and even when these courses across the bottom-lands are submerged in general overflow the tributary current is always maintained, in part at least, along its old path.

The result of this invasion is always a dilution of the plankton-rich channel water, or its partial replacement by the plankton-poor and silt-laden flood. Typical illustrations of its action appear in the planktograph of 1896.

The *rising* stages of the flood are the most disastrous. They carry the heaviest burden of silt, are formed of the most recent water, and usually, because of their sudden inroads, most completely replace the previous channel contents. The December flood of 1895 is a typical illustration. Rising suddenly from low levels (3 ft.) to overflow stage (12.6 ft.) in 12 days, it depletes the channel plankton from 2.6 cm^3 in the initial stages of the flood on the 20th (Pl. IX.) to .08 on the 25th, if not, indeed, earlier. Not only does it thus depress plankton content in channel waters but, with a less catastrophic completeness, that also in the backwaters. Thus in Thompson's Lake the plankton falls from 1.87 $cm.^3$ on the 19th to .13 on the 28th, in Quiver and Dogfish lakes, from .63 and 10.57 to .29 and .06, and in Flag Lake, from 6.38 to 3.26. The effectiveness of the depletion is greatest where overflow currents are best established, as in Thompson's and Dogfish lakes, and least where the currents are slight and impounding greatest, as in Flag Lake.

With the culmination of the flood the proportions of incoming storm water of recent origin decline rapidly, the effects of the run-off of impounded backwaters begin to appear, and recovery in production, other things being equal, marks this stage of the flood. Typical illustrations will be found in the June and August floods of 1896 (Pl. X.) and in the June flood of 1897 (Pl. XI.) and 1898 (Pl. XII.).

The results of flood in the backwaters are similar to those in the channel wherever currents of overflow are established and replacement of the plankton-rich contents of the lake by flood waters ensues, as has just been shown. Usually there are accessory bottom-lands, not swept by current, where a part of the original lake waters are retained, and where plankton breeds abundantly. As a result of this, the recovery from the depletion by flood—and this is usually not so complete as in the channel—is more prompt and attains a greater amplitude. A comparison of after effects of the June flood in 1896 in the river (Pl. X.) and in Quiver (Pl. XXVII.), Dogfish (Pl. XXXI.), Flag (Pl. XXXIII.), and Thompson's (Pl. XXXVII.) lakes will conclusively demonstrate these conditions. While the recovery from flood effects in the river is delayed till about June 10, in the various backwaters it occurs from a week to 10 days earlier.

It is evident from the pulse-like character of the movement in plankton production, to which attention has been called repeatedly in the detailed discussion, that the recovery from flood conditions is complicated with this phenomenon. Flood conditions in backwaters, by influx of waters laden with organic detritus, and by destruction, submergence, and decay of vegetation, tend to accelerate the appearance and, it may be, increase the amplitude, of the pulses. When, however, the invading waters have little plankton and largely replace the previous contents, they tend to delay and depress the pulses, and, as in the case of the May-June and August pulses, the flood may even obliterate the apex of a normally developing plankton pulse. Flood conditions thus affect these pulses profoundly, but they do not seem to be fundamentally their cause.

Periods of declining river stages stand in sharp contrast with rising levels. It is for the plankton a period in which reconstruction and growth are possible. The decreased proportion of recent water and the prolongation of impounding in backwaters, characterize this as a time of relatively stable conditions as contrasted with the chaos caused by the rising flood.

In a general way there is some correlation between the total annual movement in river levels and the average plankton content per cubic meter of water. In the table on page 466 the available data are tabulated for the channel plankton.

The arbitrary division by years results in one misleading presentation of the data. The December flood of 1895 (12.6 ft.) occurred in the last days of the year, while its effects continue beyond that limit. If we subtract the 9.8 ft. of this rise from the total movement (51.9) of 1895 and add it to that of 1896 (45.7), the resulting figures (42.1 and 55.5) will more nearly characterize the hydrographic conditions in which our plankton collections were made. After making allowances for the fact that our plankton averages imperfectly represent the actual production, it is still apparent that plankton production (per m.^{3}) is inversely proportional, in a varying ratio, to the extent of the total movement in river levels.

AVERAGE CHANNEL PLANKTON AND ACCOMPANYING MOVEMENT IN RIVER LEVELS.

Year	Total movement in river levels—in feet	Plankton per m.^{3} —in cm.^{3} *
1894	32.9	2.53
1895	51.9 (42.1)†	5.91
1896	45.7 (55.5)†	1.05
1897	44.8	3.28
1898	67.2	2.03

*Mean of monthly averages. †After transferring December rise to 1896.

In not a few of the years (Pl. VII.) the hydrograph falls into two periods dominated respectively by high- and by low-water conditions. This is seen typically in 1897, and with less contrast in 1894, 1895, and 1898, while in 1896 the recurrent floods obliterate almost all traces of such a division. In their totality these two hydrographic extremes present strong contrasts which must bear important relations to the plankton production. They are, moreover, so involved with other factors that no simple analysis of their results seems possible. For example, the high-water period is predominantly, as a rule, of low temperature, considerable ice, dilution of sewage, decreased light, increased access of recent water, increased current, decreased occupancy by, and lessened growth of, aquatic vegetation, and of greatly increased area and intimate and free connection with reservoir backwaters. The low-water period, on the other hand, is one of higher temperatures, no ice, concentration of sewage, increased light, reduced volume of tributary water,—which itself is of less recent origin than at high water,—slackened current, greater domination by, and growth of, aquatic vegetation, and of greatly contracted area and restricted connections with and contributions from the remaining backwaters. The complications arising from the combination of these various factors in varying degrees and the seasonal shifting of the two periods in the several years, render any sweeping generalizations impossible.

The following table gives in parallel columns the monthly means of plankton per m.^{3} and of river stages in feet above low-water mark.

PLANKTON PRODUCTION AND RIVER LEVELS.

Year	January		February		March		April		May		June	
	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton
1894	......	....	......	....	......	......	......	......	......	......	4.63	.74
1895	......	....	3.51	.01	......	......	5.41	3.18	......	......	1.88	30.42
1896	10.24	.01	8.83	.02	9.41	.07	7.28	5.67	6.58	1.30	7.38	.72
1897	......	....	11.13	.04	13.89	.38	13.40	5.11	9.41	5.62	5.54	.27
1898	5.08	.45	5.94	.27	12.99	.33	14.00	4.40	11.55	11.30	11.53	3.96
1899	7.99	.18	7.02	.81	13.05	.28	......	......	......	......	......	......
Mean	7.77	.21	7.29	.23	12.34	.27	10.02	4.59	9.18	6.08	6.19	7.22

Year	July		August		Sept.		Oct.		Nov.		Dec.		Ann'l Mean	
	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton	Stage	Plankton
1894	2.32	5.12	1.99	9.67	4.43	1.36	2.96	.61	2.97	.10	3.41	.10	4.63	2.53
1895	3.17	9.33	2.43	4.03	3.42	1.52	1.93	.57	2.20	3.02	6.16	1.14	3.61	5.91
1896	4.55	1.44	7.42	1.12	4.62	.38	6.04	1.11	5.89	.02	5.48	.76	6.98	1.05
1897	6.05	4.69	2.29	3.65	2.01	8.83	2.01	5.95	2.82	1.00	3.22	.56	6.90	3.51
1898	5.70	.58	3.66	.91	4.44	.69	4.86	.24	7.44	.25	6.59	.99	8.02	2.03
1899	....	......	.....	......	....	....	....	....	....	....	......	.....	......	.42
Mean	4.36	4.23	3.56	3.88	3.82	2.56	3.56	1.70	4.26	.88	4.97	.71	......	2.71

An inspection of the table shows at once the complexity of the problem, and yields the following generalizations.

In January-February, a period of sustained minimum temperatures, high levels are attended by a small, and low levels by a larger, plankton content, with the exception of stagnation conditions in February, 1895. This contrast results from the recent origin of the flood waters of these months, from the dilution of sewage and increased rapidity of run-off, and from the reduction in time of impounding under these hydrographic conditions.

March–May is a period of rising temperatures, maximum flood levels, and increasing plankton production. The data, in so far as they go, indicate that high levels tend to increase production and low levels to decrease it, in some instances at least. These months witness the maximum and the initial decline of the spring flood, as a rule, and the greatest volume and principal run-off of flood waters whose impounding has been more or less prolonged. The *proportion of impounded water* is greater in higher than in lower levels, and we find, accordingly, production increased in the former and decreased in the latter, as a general rule. It is noticeable that levels in May slightly exceeding bank height, as in 1897 and 1898, yield much greater production (5.62 and 11.30) than levels not attended by overflow, as in 1896, when production falls to 1.30 at a level of 6.58 ft.

The data of the June period are somewhat aberrant, in part as a result of insufficient data in some years, as 1895, and in part because of the relatively great irregularity of hydrographic conditions in this month in different years. The high production (30.42 $cm.^3$) in low levels (1.88 ft.) in 1895 attends sewage concentration. The data for the remaining years conform in the main to the conclusions concerning production in the three prior months, namely, that high levels favor and low levels depress production, and for the same reasons above cited. A comparison of production in 1896 and 1898 in June yields confirmatory evidence on this point.

With July begins the low-water period proper, which continues during the remainder of the year. Levels do not rise, in the means of the monthly averages, above 5 ft. in this period. The relation which existed between production and high water in March–June is reversed in the period of July–November. An inspection of the table shows that in 20 of the 25 months included in the table in this period this reversed relation obtains;

that is, levels *above* the average are accompanied by a *fall in production* to an amount below the average, and those *below*, by a *rise in production* above the average. Thus, in this period higher levels depress production and lower levels tend to increase it. Two of the 5 apparent exceptions are in October and November, 1894, when insufficient data are available, and one is in July 1897, when the customary vernal conditions (Pl. XI.) encroach upon the low-water period.

The cause of this changed relationship of levels and production in these months of predominantly low water is to be found in the relation which summer rises in levels bear to the impounding function of the backwaters. These summer rises are rarely above bank height. They flush the channel, are not extensively impounded in the backwaters, run off quickly, and accordingly depress production. The months of lower average levels are more stable, and, owing to slackened current, a more abundant plankton breeds, other things being equal, than in the more rapid current in the summer months of higher levels.

The relations in December between production and levels are again reversed. Indeed, suggestions of this reversal appear in November. In this month minimum temperatures are again reached and higher levels prevail, and production now is higher in the years of high levels and falls below the monthly mean in every year of low levels. The cause of this relation does not seem to lie in hydrographic conditions. It may possibly be involved in the changed sewage and bacterial content of the channel that accompany the increased current and the decline in temperatures. The submergence of the summer's growth of vegetation in the margin of the river and its connecting backwaters in years of higher levels may also be a contributory factor.

We thus find that in channel waters higher levels favor production only when they increase the impounding function and by long duration afford time for production and run-off of the plankton, and when they make available additional sources of nutrition. They depress production when they first appear, and when they are of short duration and merely flush the channel, as is predominantly the case during the low-water period. Lower levels depress production when they introduce stagnation conditions—as in the winter under the ice, and when they cut off contributory backwaters or otherwise reduce the run-off of impounded waters of long standing. They increase production when they lend stability to hydrographic conditions, increase the relative fertilization (sewage) of the stream, and by slackened current afford time for breeding.

In general terms, production in the backwaters exhibits relations to levels similar to those we have described for channel waters so long as the backwaters retain an intimate connection with the channel, that is, generally during high water, and for longest periods when, as in Thompson's Lake, the connection with the channel is most intimate. The diversification, as levels fall, of the several regions examined by us, renders generalizations impossible with respect to all of the backwaters, since one or another local factor sooner or later comes in to modify conditions. Moreover, some of the backwaters, as Phelps Lake, are cut off from the channel early and are not affected by changes in river levels, and, in general, the effect of the changes in channel levels, especially the minor ones, is reduced, equalized, or even obliterated, before it reaches the backwaters.

The *season* at which the initial stages of the major flood of the year occurs, affects the subsequent production. Thus in 1896 and 1897 floods begin early in the year. The result is the carrying away in the run-off of great quantities of organic matter in suspension (Table X.) before they have had time to decay and yield up in solution their nitrogenous and other constituents for the support of the plankton. Temperatures are low in these months, decay is not rapid, and the plankton is not produced in large quantities. The result is that the stream is locally impoverished by this early run-off of matters in suspension and to some extent in solution. In 1898, on the other hand, the flood does not reach overflow stages till late in February and is continued well into the early summer. Thus, while in 1896 and 1897 the vernal pulses of plankton production (9.39 and 5.62) are not large, in 1898 the production in this season rises to 35.68. Late high water, with decay and solution of organic substances increased by higher temperatures, occurs at the season of rapid plankton increase, and food matters which run off in the winter floods are here utilized and increase the amplitude of the plankton pulse. Winter floods thus tend to locally impoverish the plankton, and spring floods to increase it.

Enough has been said to indicate the supreme importance of hydrographic conditions in the fluviatile environment in determining the amplitude of plankton production and in differentiating local areas in our environment. It is the prime factor which distinguishes the fluviatile from the lacustrine environment, stamping the former with an instability as characteristic of the river as stability is of the lake.

TEMPERATURE AND PLANKTON PRODUCTION.

On pages 168–177 will be found a discussion of the temperature conditions at the various plankton stations and their general relations to the larger phases of plankton production. In the present connection the more detailed comparison will be made.

To facilitate this comparison of production and temperature conditions I have prepared the accompanying table (see p. 472), which gives the monthly means of production and of surface temperatures recorded at the times of collection in the river.

This table in conjunction with the one following page 342 suggests the coöperation of temperature in controlling in a large way the seasonal fluctuations in production. In general, in the colder months less plankton is produced than in warmer months. Thus in the river the mean production in the 5 months below 45° is but little more than 9 per cent. of that in the 7 months above this temperature, in Phelps Lake, only 40 per cent., and

Year	January		February		March		April		May		June	
	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton
1894	.....	.....	......	......	......	......	......	......	......	......	80.25	0.74
1895	.....	.....	32.	0.01	......	......	58.	3.18	......	......	80.	30.42
1896	32.75	0.01	33.7	0.02	39.52	0.07	64.54	5.67	72.7	1.30	74.7	0.72
1897	.....	.....	32.25	0.04	43.8	0.38	60.	5.11	66.3	5.62	75.	0.27
1898	32.7	0.45	32.12	0.27	43.3	0.33	53.32	4.40	65.8	11.30	78.8	3.96
1899	32.9	0.18	32.6	0.81	35.2	0.28	......	......	......	......	......	......

Year	July		August		September		October		November		December	
	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton	Temp.	Plankton
1894	82.25	5.12	83.5	9.67	77.5	1.36	58.	0.61	41.	0.10	39.	0.10
1895	79.	9.33	80.51	4.03	78.87	1.52	54.26	0.57	42.5	3.02	37.5	1.14
1896	80.7	1.44	82.	1.12	65.75	0.38	56.	1.11	44.	0.02	33.6	0.76
1897	81.02	4.69	80.9	3.65	77.07	8.83	65.1	5.95	45.7	1.00	33.02	0.56
1898	82.87	0.58	80.56	0.91	71.87	0.69	54.37	0.24	41.42	0.25	32.98	0.99
1899	.....	.....	......	......	......	......	......	......	......	......	......	......

in Thompson's Lake, 29 per cent. The difference would be increased if the aberrant data of the late autumn of 1897 were removed from the records. Low temperatures thus tend to depress production in both channel and backwaters, and high temperatures to increase it.

The minimum production of the year occurs in the river, and with few exceptions in the backwaters, in January-February, the two months of minimum temperature. With the period of rising temperatures in March-May there comes generally at all of the stations a rapid rise in plankton production, culminating in the vernal pulse in the last days of April or the first of May at about 60°-70°. The effect of this is seen in the generally high average production in April and May in both channel and backwaters. With the establishment of the summer period of maximum temperatures, which includes the months of June-September with the exception of a few days of rising and falling temperatures at the beginning and close of the season, there comes, as a rule, a decline in production from that of the vernal season. In channel waters this amounts to 16 per cent. of vernal production, or, omitting the single aberrant datum of June 1895, to 44 per cent. In the backwaters, owing to the combination with various local factors, such as tributary waters and vegetation, the change from vernal production in midsummer varies greatly in different localities. Thus, in Quiver Lake, where vegetation and the proportion of tributary waters is increased in summer, the decline in that season amounts to 87 per cent., while in Dogfish Lake, where vegetation alone is the main disturbing factor, the decline is 74 per cent. of the vernal production, as seen in the April-May averages. In Flag Lake, where also vegetation enters as a disturbing factor, the decline is 80 per cent. In Thompson's Lake, where disturbing local factors are less in evidence, it is but 69 per cent. In Phelps Lake, in contrast with all the other localities, production during the period of maximum heat exceeds that in the vernal season by 68 per cent. Thus the period of maximum heat in most localities attends a depression in production, but the exception in Phelps Lake is so striking as to preclude any conclusion that summer heat is necessarily inimical to large production, or that it is of necessity the most potent of the coöperating factors. The omission of the averages for August and September in 1898 from the Phelps Lake data would make the average production in the period of maximum heat 33 per cent. below that of the vernal months, and bring this locality into agreement with the other stations as to the depressing effect of summer heat in plankton production. It should be emphasized in this connection that these conclusions apply to catches of the silk net only, that the summer temperatures of our waters approximate 80° on the average and frequently rise above it, and that temperature is only one of the factors involved.

Following the period of maximum summer heat is that of decline in October-November—including also a part of September, or even December in some seasons—to the winter minimum. In general, this is a period of declining plankton in channel waters, where production in these two months falls 71 per cent. below that in the preceding four months of maximum heat, and in Quiver Lake, where it falls 48 per cent. below. On the other hand, in the rest of the backwaters there is a slight increase in these two months as compared with the production in the period of maximum heat. In Dogfish, Flag, Thompson's and Phelps lakes the October-November increase in percentages over the average summer production in each of these several localities is 33, 362, 26, and 11 per cent. respectively. In view of these divergent tendencies in production under similar temperature conditions it is evident that other factors are operative, or at least more potent, in controlling autumnal production. The October production is as a rule higher than that of November, and suggests a tendency towards an autumnal pulse comparable with the vernal pulse but of lesser amplitude. The vernal pulse occurs in rising temperatures of 60°–70°, and this autumnal one in falling temperatures of 60°–50°.

The month of December does not on the average quite attain the minimum winter temperature, though in some years, as in 1897 and 1898, it approached closely to it. Neither does the plankton production drop to so low a level on the average or in individual years in channel waters as during the two colder months which follow. In general the same relation exists in the backwaters, though exceptions occur—principally in Thompson's Lake.

Thus, in a large way, temperature plays an important part in controlling plankton production. Additional proof of its potency is to be found in the correlations between production and exceptional divergences from the normal course of temperature changes, such, for example, as early or late vernal rise or autumnal decline.

The accompanying table (p. 475), kindly furnished by Mr. W. G. Burns, Section Director for Illinois of the U. S. Weather Bureau, gives the vernal air temperatures for 1896–1898, and permits a comparison with the course of plankton production.

MONTHLY MEANS OF VERNAL TEMPERATURES FOR ILLINOIS AND OF PLANKTON PRODUCTION—CM.^{3} PER M^3.

		1896		1897		1898	
		Temperature (Fahr.)	Plankton	Temperature (Fahr.)	Plankton	Temperature (Fahr.)	Plankton
March .	North section...	31.9	.07	34.4	.38	39.0	.33
	Central section.	36.4		41.1		44.4	
	South'rn section	40.6		46.8		48.7	
	State, average..	35.6		39.5		43.4	
	Normal	37.6		37.6		37.6	
April ..	North section..	55.3	5.67	47.2	5.11	46.9	4.40
	Central section	59.9		51.3		50.5	
	South'rn section	63.6		55.0		53.0	
	State, average.	59.0		50.4		49.6	
	Normal........	51.8		51.8		51.8	
May ...	North section..	67.2	1.30	57.5	5.62	59.1	11.30
	Central section.	70.6		59.7		63.0	
	South'rn section	71.7		62.1		66.8	
	State, average..	69.5		59.3		62.2	
	Normal	61.8		61.8		61.8	

The most notable instances of correlation between deflections of temperature and plankton production are to be seen in the early spring of 1896 and the late autumn of 1897. These correlations have already been noted in connection with the discussion of production in the river and the several backwaters. The mean temperatures of the air here given corroborate our conclusions based on the relatively scanty data of water temperatures delineated in the thermographs of the plates accompanying this paper. Thus, the spring of 1896 was 2° below normal in the state as a whole in March, but was 7.2° above normal in April, and 9.4° above the mean for 1898. Mean plankton production is also higher in April in 1896 than in any other year. Indeed, in this month the descending scale of mean temperatures in 1896–1898 is accompanied by a similar scale of decreasing mean production of plankton, and, as has been noted in the discussions of the course of production in the river and backwaters, the vernal pulse of 1896 is from 10–14 days earlier than in 1898, when, as this table of mean temperatures shows, the April mean of air temperatures was 9°–10° below that of 1896.

So also in 1897, the means of our records of water temperatures for September, October, and November of that year are 2.9°, 7.6°, and 2.7° above the average of the monthly means for all years. This maintenance of high temperatures into the period of normal autumnal decline is apparently *one* of the factors tending to make production in these months of this year greatly exceed that of the same season in other years. In channel waters in these months of 1897 (see table following p. 342) production is from 13 to 250 per cent. above the mean of all years, and often 10- to 20-fold that in other years. In Thompson's Lake the excess in 1897 is even greater, ranging from 87 to 233 per cent. of the mean of all years, and from 1.6 to 28 times that in the same months in other years. The higher temperatures do not suffice, however, in the case of Quiver Lake, to overcome the other factors tending to depress production there in these months, and we must conclude that, although all-pervading and potent, temperature is nevertheless not always pre-eminent among the environing factors of the plankton.

We thus find that in a general way, in conjunction with other factors, rising temperatures tend to increase, and falling to decrease, plankton production, and that in the same locality the warmer months generally yield more plankton than the colder ones. On the other hand, minimum temperatures when once established are not of themselves inimical to a considerable plankton production. Evidence of this is to be found in the not infrequently increased production in December over that of several months preceding. This is perhaps most noticeable in the records of 1898. Thus in channel waters the amplitude of the December pulse (Pl. XII.) exceeds that of all other months since the last of June, and the December maximum in Phelps Lake (43.14) exceeds in amplitude *all other production in our records for 1898 in all other localities* save only the single apex of the vernal pulse (51.39) in Thompson's Lake. It is, however, only about one fifth of the August maximum (224.48, Pl. XLII.) in Phelps Lake itself, so that the depressing effect of lower temperatures is still apparent if we limit comparisons to a single locality.

The effect of the autumnal decline, and, in general, of lowered temperatures, in depressing production is apparent in not a few instances in our records. It can be seen in the October-November thermographs and curves of plankton production of channel waters in 1894–1898, and in those of Quiver Lake for the same years; is much less apparent in Thompson's Lake, especially in 1897, even when temperatures have fallen; and is often but feebly developed in Dogfish and Flag lakes in 1895–1897, while in Phelps Lake in 1896 and 1898 there are pulses of considerable magnitude (51.6, and 99.86) in this period of decline of temperature. The minima demarking these pulses are, however, of less than the usual amplitude. This depressing effect is thus traceable in all localities, but is better developed in stream than in lake waters, appearing most clearly in the channel and Quiver Lake, where, at this season of the year, tributary waters are present in considerable proportion.

Our water temperatures and the records of the United States Weather Bureau at Havana and elsewhere in our locality reveal many instances of heat pulses at various seasons of the year. There is little regularity in their duration or amplitude. When plotted from the means of the tri-daily readings of the air temperatures at Havana they do not exhibit delimitations as well defined as those, for example, of a fully observed plankton pulse. Their amplitude, except in winter months, rarely exceeds 20° between extremes, and their duration is usually less than a fortnight between minima. That these fluctuations affect the course of plankton production cannot be doubted. A detailed comparison of the course of production in 1896 and the thermograph of that year will show that, *predominantly*, rises of temperature attend or precede rising production, while declines in heat are often correlated with decreased production. This may be largely coincidence, or, in some cases, the common effect of cooler, barren flood-waters, especially in the case of the records of channel production. A close comparison, however, of the planktograph in Phelps

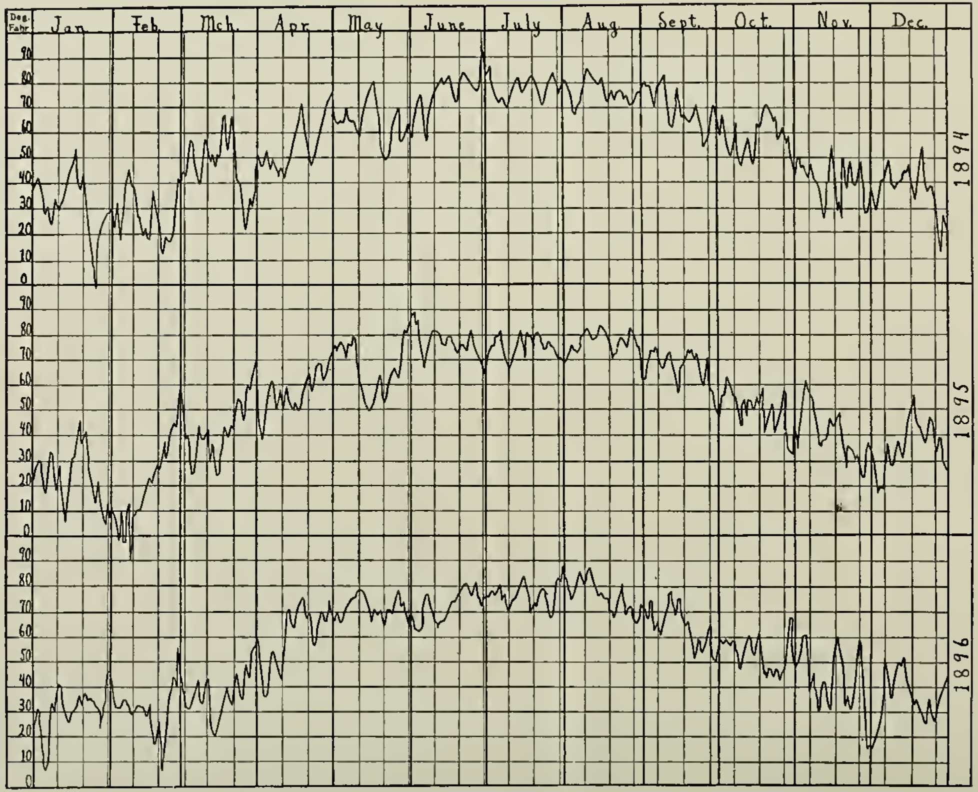

FIG. C.—Thermographs of tri-daily air temperatures at Havana.

Lake—where flood factors are largely excluded—and the thermograph (air) for 1896 will serve to suggest the possibility of a causal nexus between the two phenomena of fluctuations in heat and some of the movements in plankton production. The many exceptions to any close correlation emphasize, however, the fact that *heat* is only *one* of the many factors involved in the problem, and also indicate the necessity for much fuller plankton data, with closer interval and the proper quantitative representation of the minute forms now lost by leakage through the silk, for any adequate discussion of the problem. The present data serve only to suggest the problem for investigation.

The *effect of the ice-sheet* upon the course of plankton production is apparent in a number of instances in our records. The most noticeable case was the extermination of the plankton in the channel in February, 1895, by the ice-sheet of two months' duration; but this catastrophe was not repeated elsewhere in our records in this or other years. Indeed, owing to the fact that the period of the ice blockade is usually one of lower levels and more stable conditions, we find generally that production under the ice, even at minimum temperatures, rises above prior or subsequent levels. An inspection of the plates, especially those of 1898, will show repeated instances of this phenomenon in both channel and backwaters. One of the most striking phenomena in all our records is this winter production under the ice-sheet in 1898–1899, a production which in the river attained an amplitude in December (.99) not equaled since June, and in February (.81) one surpassed only by the August (.91) and December means. In Quiver Lake likewise, the December (1.74), January (.77), and February (1.05) means are all considerably in excess of the June–November production, the average of the winter months (1.19) being over threefold greater than that of the warmer months (.33) named. In Thompson's Lake also the midwinter production in this season was large, reaching an average of 1.94 for the winter months above named, and only 1.96 for the five preceding months, while the amplitude of the December and January pulses was surpassed but once from June to December. Conditions under the ice at minimum temperatures were thus in these years and localities quite as favorable to the quantitative development of the plankton as were the conditions prevalent in summer and autumn.

As a whole, then, temperature changes bear an important relation to the course of plankton production, but at times they are not more potent than other factors. An abundant plankton may develop at any temperature within the normal seasonal range provided other factors favor it, but generally the amplitude is less in lower or in falling temperatures, and greater in higher or in rising ones.

The relations here discussed between the *volume* of plankton and temperature depend primarily upon adaptations of particular species to temperature—a subject which will be discussed in another connection.

LIGHT AND PLANKTON PRODUCTION.

There are at hand no adequate data on this subject, and it is, moreover, complicated with the thermal and other forms of solar energy and with the problem of turbidity in the water itself. No detailed comparison is afforded by the data, especially since the more minute forms are not adequately represented by the catches of the silk net, and it is largely these synthetic organisms, chlorophyll-bearing algæ and flagellates, which are most dependent upon light for their growth and reproduction. Our data alike of light and plankton are thus deficient. Nevertheless, in the chain of relations, the catch of the silk net—largely of animal plankton—is, at most, but a few links removed from these synthetic organisms, and it must therefore in some measure reflect their quantitative fluctuations. Our data suggest a few inferences concerning the relation of light and plankton production.

The period of greatest illumination lies between March 20 and September 22, and owing to the proximity of these dates to the ends of the months it will be possible, for the purpose of utilizing our data in monthly totals and means, to divide the year into two periods, April–September and October–March, of greater and less illumination respectively. The contrast in illumination is further heightened by the fact—derived from the following table of cloudy days—that the number (at Havana, 159) of cloudy days between the vernal and autumnal equinoxes is only about one half that (311) between the autumnal and vernal. On the average, the season of greatest light is also the season of greatest production. Thus, in the channel waters average monthly production in April–September (4.76) is sevenfold that in October–March (.67), and in the backwaters, such as Quiver, Thompson's, and Phelps lakes, it is respectively 5-, 2.2-, and 1.6-fold greater. The records of individual years in all of the localities will be found to exhibit a similar relationship. We may infer, accordingly, that the increased light between the vernal and autumnal equinoxes tends to increase production, and that the decreased amount in the remainder of the year tends to lower it. It operates, of course, in conjunction with other factors, and our records contain not a few instances where production in the period of less illumination exceeds that in the period of greater light. For example, on December 20, 1898, in the *minimum* illumination of the year and under an ice-sheet 21 cm. thick, which still further reduced the light, the plankton production in Thompson's Lake reached an amplitude (2.58) exceeding that on June 21 (2.47) in the same lake in *maximum* illumination, an amplitude, moreover, surpassed but *once* from June to October. Other factors are thus, at times, at least, more potent than light in controlling production.

A phenomenon of like import exists in the conditions of illumination and production in Quiver and Thompson's lakes. Both lakes are of approximately the same depth, but the former, especially in low-water conditions, has remarkably clear water, the bottom being generally visible, while the latter is always more turbid, and light penetrates the water far less completely. Nevertheless, the lake, with most illumination, yields least plankton. The factors of vegetation of the coarser sort and of tributary waters serve here to modify and overbalance light as a controlling factor in production.

From the data of the U. S. Weather Bureau at Springfield, Mr. W. G. Burns, Section Director, has kindly furnished me the records of the number of cloudy days per month in 1894–1899 observed at Peoria, Havana, and Springfield. These are given in the accompanying table. The records for Havana have also been plotted on Plates VIII.–XIII. in the uppermost row of squares.

NUMBER OF CLOUDY DAYS.

	Year	January	February	March	April	May	June	July	August	September	October	November	December	Total	Rank
Springfield	1894	13	13	8	12	19	5	9	7	9	9	14	15	133	5
	1895	11	7	11	13	2	9	7	4	4	4	15	18	105	1
	1896	14	12	16	8	9	9	7	2	12	7	18	15	129	4
	1897	16	15	20	17	4	10	5	2	1	4	12	21	127	3
	1898	12	12	16	13	11	5	3	8	10	15	9	12	126	1
	1899	16	14	21	12	17	7	13	7	6	8	16	10	147	6
	Total	82	73	92	75	62	45	44	30	42	47	84	91	767	...
Havana	1894	7	8	7	6	4	0	0	3	3	6	10	7	61	1
	1895	6	3	10	9	3	4	4	3	4	2	13	13	74	3
	1896	7	6	4	3	5	6	4	2	11	3	10	9	70	2
	1897	10	10	17	13	6	6	0	4	2	4	12	15	99	6
	1898	11	10	11	6	8	4	3	8	2	16	5	7	91	5
	1899	7	6	16	4	5	3	5	3	3	6	10	7	75	4
	Total	48	43	65	41	31	23	16	23	25	37	60	58	470	...
Peoria.................	1894	11	9	6	8	9	0	3	5	8	6	12	11	88	1
	1895	10	8	10	8	4	5	6	5	4	2	18	19	99	2
	1896	17	10	8	3	6	8	6	2	10	10	16	14	110	4
	1897	13	14	18	16	5	6	1	4	3	3	15	19	117	5
	1898	15	14	14	10	13	6	2	8	4	16	11	13	126	6
	1899	12	12	16	10	8	2	5	5	6	6	13	11	106	3
	Total	78	6	72	55	45	27	23	29	35	43	85	78	646	...

The variations in the relative cloudiness in the three localities in many months and in the total number of cloudy days in the several years in the three localities render any correlation with production largely conjectural and close comparisons impossible. That the reduction in light due to clouds does in a measure affect production might be inferred from the August–October records in 1896 and 1898. In the two years named, cloudy days and production in August are 2 and 8, and 1.12 and .91 cm.^{3} per m.^{3} respectively; in September they are 11 and 2, and .38 and .69; and in October 3 and 16, and 1.11 and .24. Hydrographic conditions are not remarkably different in the two years, and while their differences in this respect are doubtless potent, causing differences in production, it still seems probable that the fluctuations in light are also operative. In any event in these three months the mean production runs higher in the year of fewer cloudy days and lower in the year of less sunshine. Similar relations will be found to exist generally in the production of the backwaters for these months (see table following p. 342). The statistical data of the synthetic organisms to be discussed in Part II. of this paper still further serve to demonstrate the correlation of light and plankton production. The necessity of light for the process of photosynthesis on the part of the phytoplankton places this factor at the very beginning of the chain of relations whose later links are the larger animals of the zoöplankton which constitute the greater proportion of the volume of the catch of the silk net—the basis of the present discussion.

VEGETATION AND PLANKTON PRODUCTION.

It is evident that our investigations afford a unique opportunity of determining the effect of vegetation (the word being here used to refer to the coarser aquatic growth as distinguished from the microscopic phytoplankton) upon the course of plankton production with reference to both its volume and constitution.

The conclusions to be drawn from our observations with reference to volumetric production, already suggested in the detailed discussion of production, will be summarized and discussed here, though some of the data upon which they rest lie outside the scope of the present paper.

1. Other things being equal, bodies of fresh water free from vegetation (submerged macro-flora) produce more plankton than those rich in such vegetation.* Thus, the amount of plankton produced (as indicated by the averages of all of our collections in the several localities examined) in our open waters is from two to eleven times as great as it is in our lakes closed by vegetation. As shown in the table on page 429, the average planktons in Thompson's and Phelps lakes are 7.94 and and 19.65 cm.^{3} per m.^{3} respectively, while in Quiver and Dogfish lakes the quantity is only 1.70 and 4.22. Flag Lake, with an average of 11.46 cm.^{3}, is an interesting exception to this contrast which will be discussed in another connection. The contrast is even more striking if the averages of the monthly averages for all the years are made the basis of comparison, as in the following table and diagram.

COMPARISON OF PLANKTON PRODUCTION IN VEGETATION-POOR AND VEGETATION-RICH WATERS.

Month	Vegetation-poor		Vegetation-rich		Ratio
	Quiver Lake	Dogfish Lake	Thompson's Lake	Phelps Lake	
January	.27	.53	3.79	3.29	1:9
February	.67	1.10	1.27	5.68	1:4
March	.77	1.96	2.96	5.68	1:3
April	7.26	10.50	14.49	11.77	1:1.5
May	6.85	5.79	29.59	25.33	1:4
June	1.25	1.75	10.66	11.40	1:7
July	.78	1.95	4.74	8.50	1:5
August	.77	2.51	6.19	58.12	1:20
September	.77	2.39	5.37	47.25	1:17
October	.69	3.05	10.64	27.68	1:10
November	.23	2.64	6.39	41.57	1:17
December	.63	3.76	3.08	21.96	1:6
Gr'd av. of monthly av.	1.75	3.16	8.26	22.35	1:6

On this basis, the waters full of aquatic vegetation produce throughout the whole year less plankton than waters free from such growths. Relatively few exceptions to this rela-

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* This relation of vegetation to the plankton may be formulated as follows: The amount of plankton produced by bodies of fresh water is, other things being equal, in some inverse ratio proportional to the amount of its gross aquatic vegetation of the submerged sort.

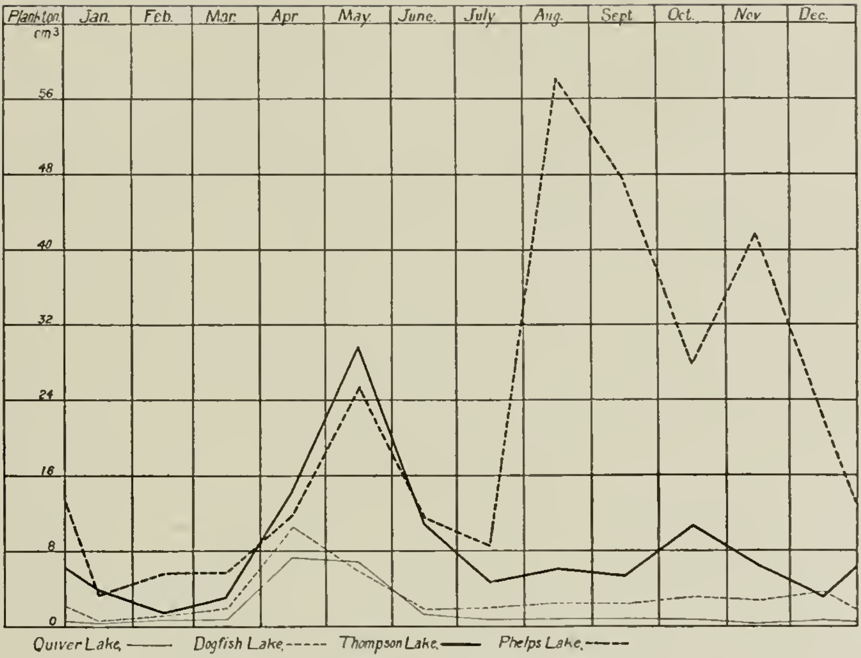

FIG. D.—Seasonal distribution of plankton production in vegetation-poor and vegetation-rich waters, based on the averages of the monthly averages for all years of collection.

tion will be found in the individual collections recorded in Tables V. and IX. and VI. and VII., or in the monthly averages of the table following page 342. This striking contrast is still more enhanced by the statement of the monthly ratios of productivity in waters rich and poor in vegetation. These range from 1 to 1.5 in April to 1 to 20 in August. The fluctuations in the ratio are of themselves very significant. During the period from February to July inclusive the ratio is at its lowest, ranging from 1 to 1.5 to 1 to 7. Excepting only the month of July, this is the period of high water, in which the vegetation, if present, occupies a much smaller proportion of the volume of the lake, and is therefore to a proportionate degree restricted in its effect upon the plankton. Under such flood conditions these several localities are more or less merged in the general overflowed district, and are to a varying degree traversed by waters from the bottom-lands above and adjacent to them, and the purely local factors of their environment, such as vegetation, thus become less potent. Again, it is not until the latter part of this period that the vegetation attains the development which continues throughout the remainder of the summer. The relative barrenness (in plankton) of the vegetation-rich waters is thus least striking when the vegetation is least in evidence.

During the period from August to November inclusive the ratios are very much higher, rising to 1 to 16 or 20. This is the low-water period, when the vegetation in the vegetation-rich lakes is at its maximum development both in quantity and in the relative volume of the lake occupied by it. It is also at such times that these several bodies of water are more distinct units of environment, with their local factors no longer merged by flood conditions. The relative barrenness of the vegetation-rich waters is thus greatest when the vegetation is at its maximum development and is most emphasized as a factor in the environment. The conclusion from this comparison of the mean production of plankton in vegetation-rich and in vegetation-poor waters in our locality is thus inevitable that vegetation (in the usual sense of the word) is inimical to the development of an abundant plankton. It may also be said that the contrast would be considerably heightened if it were possible to eliminate from all the collections on which this comparison is based the adventitious organisms—such as small insect larvæ, mollusks, oligochætes, *Hydra*, etc., which form a considerable volume of many of our catches in the vegetation-rich waters.

On the other hand, it must be maintained that the vegetation is only *one of the factors* concerned in the phenomenon presented by this contrast. It is quite probable that other factors, especially the current, tributary waters, and the chemical constituents of the water, affect the problem in hand. During high water both Thompson's Lake and the Dogfish-Quiver region are traversed by a considerable current from the bottom-lands above. The elevated deposits of Spoon River and the consequent crowding of the channel of the river to the east bluff at Havana force all of the water of overflow (at stages below about 16 feet) to seek the main channel. The configuration of the low-lying bottoms above is such (see Pl. II.) that the lakes in question form natural channels for the movement of a large body of impounded water. This movement is well marked at stages above eight feet. So far as I am able to judge from field observations, the current conditions in Thompson's Lake and the Dogfish-Quiver area are not greatly different. The current continues in both lakes as levels fall to six feet, at which level Thompson's Lake loses its connection with the river through the "cut road" (Pl. II.), and movements in it at lower levels are confined to those due to ingress and egress of water through the slough, and are consequently inconsiderable. On the other hand, Quiver Lake continues to be traversed by the discharge from Quiver Creek, and our collections were usually made in the channel in the vegetation. In Dogfish Lake at low stages there is no current traversing the lake. Phelps Lake lies at so high a level that only the floods exceeding eleven feet bring it into connection with the general current of overflow, which in this case generally comes from Spoon River. Below this level the only movement in its water is the gentle one due to the receding flood. So far, then, as the current is concerned, it is a common though not equally distributed factor at high-water stages in all areas compared, while at low water it is an important feature in the environment in Quiver Lake but is practically absent in the other three localities. This fact undoubtedly accounts *in part* for the barrenness of the waters of Quiver Lake (1.53 cm.^{3} per m.^{3}, or only .55 for the average of low-water periods—i. e. below 5 ft.) as compared with those of Dogfish (4.22), Thompson's (8.13) and Phelps (19.44) lakes. This current does not, however, traverse or appreciably affect the waters of Dogfish Lake, and their barrenness still remains for contrast with the productiveness of the vegetation-poor waters of Thompson's and Phelps lakes.

Data are not available for a full comparison of the chemical constituents of all the waters here under consideration. No data whatever are available for Dogfish and Phelps lakes, and only sanitary analyses for Quiver and Thompson's lakes. These shed no light on the relative amounts of phosphates and carbon dioxid in the water, both important elements in the growth of plants. On the other hand, data for a comparison of the ammonia and the nitrates are found in Tables XII. and XIII. and Plates XLVIII. and XLIX. The nitrates, in so far as they are concerned,—as shown in the accompanying table, which gives the averages for coincident periods of examination in 1897–1899,—offer no solution for the marked contrast in plankton production which the waters in question exhibit, for the amounts present differ but slightly in the two lakes. The plottings in Plates XLVIII. and XLIX. show that the nitrates run low during the period from June 1 to October 1, which is approximately that of the maximum development of vegetation. The averages for this period are .244 and .222 respectively for Thompson's and Quiver lakes in 1898. This is almost identical in the two lakes, and may represent an unutilized minimum of nitrates, the utilized portion supporting predominantly the phytoplankton in Thompson's Lake and the gross vegetation in Quiver Lake. During the remainder of the year the contrast between the two lakes in the matter of nitrates is more marked, the average being .923 and .684 respectively. So far as any contrast appears in the matter of nitrates the waters of Quiver Lake are, if anything, a trifle richer than those of Thompson's Lake.

CHEMICAL ANALYSES, SEPTEMBER, 1897, TO MARCH, 1899.
AVERAGES OF ALL ANALYSES—PARTS PER MILLION.

	Thompson's Lake	Quiver Lake
Free ammonia	.422	.199
Albuminoid ammonia	.546	.293
Nitrites	.048	.023
Nitrates	.640	.708

It is different, however, in the matter of nitrites, which are about twice as abundant in Thompson's Lake as in Quiver, and the same ratio also holds approximately for the free and albuminoid ammonia. These are all substances indicating organic matters in the process of decay, or available for decay and thus for plant nutrition. These data show clearly that in these particulars the waters of Thompson's Lake are much richer than those of Quiver, and this difference is undoubtedly one of the factors on which the contrast in plankton production depends. The more abundant plankton of the former lake may itself be one of the sources contributing to the organic decay here indicated.

This contrast in the chemical constituents in part at least follows from the sources from which the waters in the two lakes are derived. River water impounded from receding floods and more or less charged with sewage and industrial wastes constitutes the principal source of the water in Thompson's Lake. Spring and creek waters replace this very slowly, and every rise in the river introduces a new supply of richly fertilized water which at levels above six feet traverses the whole lake. Quiver Lake is subject to like invasions, but its more abundant supply of creek and spring water counteracts their influence to some extent and soon replaces their contributions.

A consideration of these other factors, current and chemical constituents, makes it probable that they also are efficient in causing the contrast in plankton productivity in the two lakes. How much of this contrast is due to vegetation and how much to their agency is a matter upon which conclusive evidence is needed. Experiment in the field may yield conclusions that will be final.

Some evidence corroborative of my contention that the vegetation of Quiver Lake is inimical to the development of its plankton is afforded from two sources; (1) the examination of Matanzas Lake, and (2) the comparison of the plankton production of Quiver Lake in years of abundant and scant vegetation.

Matanzas Lake (Pl. II.) more than any other body of water in our field of operations resembles Quiver Lake in the various factors of its environment, only upon a somewhat smaller scale. Like Quiver Lake it has free communication with the river at all levels, is subject to the same conditions of invasion and submergence, has an eastern sandy and springy shore with littoral vegetation, a western one of alluvium, and, between, a bottom changing from sand to mud. The depth and bottom configuration are very similar, and there is a supply of creek and spring water roughly proportionate to the size of the lake. The two lakes are thus strikingly alike save only in the matter of vegetation. The vegetation in Matanzas Lake is confined to a narrow belt of the littoral zone along the greater part of the eastern margin and to a little *Ceratophyllum* adjacent to it and fringing the western shore in places. Less than 5 per cent. of its area is thus occupied. Quiver Lake, on the other hand, has at all times a more abundant flora, which even in the years of its least development holds possession of not less than 30 per cent. of its area. Under these circumstances a comparison of the production of the two lakes should throw some light upon the effect of vegetation upon the development of the plankton.

No chronological series of collections has been made by us in Matanzas Lake. A few isolated collections have indicated that it is rich in plankton, and two thorough tests of the local distribution of the plankton, made in 1896, afford a basis for comparison with Quiver Lake at that time. Fifteen collections with the plankton pump were made in various parts of Matanzas Lake on July 9, and twenty-five, similarly distributed, on August 14. The averages of the plankton per m.^{3} of water in these collections and the amounts found in Dogfish and Quiver lakes on the days following (July 10 and August 15) are given in the accompanying table (p. 491). Averages for the months of July and August in the several years are also given for Quiver and Dogfish lakes.

The production of plankton in Matanzas Lake on the dates

PLANKTON PRODUCTION IN MATANZAS LAKE COMPARED WITH THAT IN QUIVER AND DOGFISH LAKES.

Date		Matanzas Lake	Quiver Lake	Dogfish Lake
1896,	July 9, 10	2.40	.30	1.18
	August 14, 15	6.20	3.42	2.90
1894,	July		2.20	
	August		0.74	
1895,	July		0.37	2.99
	August		0.21	1.11
1896,	July		0.30	0.91
	August		2.46	3.91
1897,	July		0.89	
	August		0.21	
1898,	July		0.16	
	August		0.22	
Averages,	July		0.78	1.95
	August		0.77	2.51

of collection above indicated is approximately twice that of Quiver and Dogfish lakes, where vegetation was at that time somewhat more abundant. In 1896 Quiver Lake was freer from vegetation than at any other time in the period of our operations, and the contrast between the production of the two lakes appears greater if we consider other years or the average for all collections in the months named. On the latter basis the ratio rises to 3 to 1 for July and 8 to 1 for August in the comparison of Matanzas and Quiver lakes. In the case of Dogfish Lake the contrast is less striking, but still evident. Matanzas Lake, similar in its environment to Quiver Lake save in the matter of vegetation, thus produces a more abundant plankton, and we may infer that the vegetation of the latter is inimical to the development of plankton in its waters.

A second line of evidence bearing upon the question under discussion is to be found in the production in Quiver Lake itself under different conditions of vegetation. In 1894, and still more in 1895, owing to low water in early summer, vegetation was very abundant in Quiver Lake. The growth of *Ceratophyllum* and *Elodea* choked its waters from shore to shore and from bottom to surface except in a narrow poorly defined channel found in the lower end of the lake. This part of the lake is shown in Plates XV. and XVI., which portray the conditions as they appeared in 1894 and 1896 respectively. The upper end of the lake and its western arm, Dogfish Lake, are shown in Plates XVII. and XVIII., the latter having been photographed in 1896, when the center of the lake was not so full of "moss" as during the preceding year. The repeated floods of 1896 swept the lake of much of its vegetation, and during the three following summers it never recovered the abundant flora which it presented in 1895. In 1897 and 1898 there was also much less vegetation than in 1895, though somewhat more than in 1896. The plankton production, as shown in Table V. and graphically presented in Plates XXV.–XXIX., does not uniformly rise and fall as the vegetation decreases or increases. The phenomenon of its fluctuations involves many other factors, among which the effect of vegetation may perhaps be detected. The average production for the years of vegetation, 1.08 and .78 cm.^{3} per m.^{3} of water, is surpassed in 1896 (2.59) and 1898 (2.44) but not in 1897 (.88). The marked increase in 1896 over the production of 1895 parallels the great change in vegetation, and is also accompanied by higher water, the average for the year being over three feet above that of 1895. This difference in levels also tended to decrease the relative extent of the vegetation in 1896. In Dogfish Lake also the contrast in vegetation in the two years, 1895 and 1896, is well marked, and the average plankton production rises from 3.25 to 5.01 cm.^{3} per m.^{3} The omission of winter collections in 1895 makes the contrast less striking. Allowing for this, it is probable that the plankton production is practically doubled in the year of decreased vegetation. This is approximately the ratio of increase in Quiver Lake in 1896 and 1898. Other causes, such as current and chemical conditions, doubtless share in producing this change in the plankton, but it seems highly probable that the reduction in vegetation caused a considerable part of this doubling in the plankton production. A comparison of the plankton production of the same body of water (Quiver and

Dogfish lakes) in different years thus shows that more plankton is produced in years of little, than in years of much, vegetation, and tends to confirm the view that abundant submerged vegetation is inimical to the production of plankton.

An inspection of the planktographs in Plates VIII.–XIII. and XXV.–XLII. shows the frequent occurrence of an autumn maximum, often well defined. In the planktographs of Quiver and Dogfish lakes, this autumn maximum is usually depressed or missing. The spring maximum occurs, as a rule, while the lake is full of water from the general overflow, and it is therefore not purely a local phenomenon. The midsummer and autumn plankton, on the other hand, is entirely a local product, and the depression of the autumn maximum must be due to local influences. In 1896, in both Quiver and Dogfish lakes the autumn maximum occurs in two or three sharply marked prominences, that of October 14 (3.52 and 6.60) being a *Melosira-Synchæta* assemblage, typical for the autumn season. This was a year in which there was little vegetation and high (for autumn) water, the vegetation being, consequently, at a minimum as a factor environing the plankton. In other years this autumn maximum (see Tables VI. and VII.) is less evident. In 1894 the apparent maximum on September 5–6 is almost wholly due to the development of *Oscillaria* at a time of local stagnation consequent upon backwater. In 1895 there was in Quiver Lake a maximum on September 6 (1.57), due in part to autumnal plankton and in part to adventitious organisms. Dogfish Lake exhibits a somewhat larger maximum (4.65) on September 17, which is mainly normal in its components. The November-December maximum of 1895 in this lake is wholly due to adventitious organisms, and may be disregarded in this connection. At their best, these maxima in vegetation-rich years are but one half to one third the magnitude of those of 1896, a vegetation-poor year. In Quiver Lake in 1897 and 1898 the autumn maximum is again depressed almost beyond discerning. Although vegetation was not abundant in the lake in these two years, the period of the autumn maximum was one of prolonged low water in both years, so that whatever vegetation was present occupied *relatively* a large proportion of the area and volume of the lake, especially as contrasted with the conditions in 1896. The available data thus indicate that vegetation is inimical to the production of plankton, as shown not only in the general averages but also in these maxima, which may be regarded as the expression *par excellence* of the productive capacity of the lake.

There still remains for consideration, with reference to the effect of vegetation upon plankton production, the result of our examination of Flag Lake. As before stated, this is a marsh choked with a rank semiaquatic growth whose extent, abundance, and relative occupation of the area of the lake equals or exceeds that in any other body of water examined by us. If our thesis that vegetation is inimical to the production of plankton be true, we might expect to find here, of all places, barren waters. This is not, however, the case; for, as shown in the table of comparison of plankton production on page 429, Flag Lake is very productive (11.46 cm.^{3} per m.^{3}), being exceeded only by Phelps Lake (19.65).

The only indication that vegetation is in the least inimical to the plankton in the lake is suggested in Plate XXXIII. The amount of plankton present from May 15 to October 1, the growing period of vegetation, is only 2.87 cm.^{3} per m.^{3}, while in spring and late autumn (April 1 to May 15 and October 1 to December 30) it is 32.89. In Phelps Lake, which, save for vegetation, is much like Flag Lake, the plankton during the period of dominance of vegetation in 1896 averages 7.64, and in 1898 52.43 cm.^{3}, 3 to 18 times as much as in the vegetation-rich waters of Flag Lake.

In the character of the vegetation in Flag Lake lies, I believe, the explanation of its fertility in plankton. Two kinds are predominant, neither of which is present in like abundance in Quiver Lake. These are (1) succulent vegetation, such as *Sagittaria, Pontederia, Nymphæa, and Nelumbo,* which die down and undergo considerable decay in the early fall, and (2) the emergent vegetation, principally *Scirpus*, which, on account of its growth and structure, does not reach an advanced stage of decay until ice and winter floods have broken it down. With rising spring temperature it yields to decay and releases a great store of nitrogen which the phytoplankton can utilize. Both of these types of vegetation are rooted in the humus and alluvial deposits of the lake, and both are to some degree emergent. They thus draw their supply of food (dissolved salts and gases) largely from soil waters and the air, and less from the supply in solution in the water of the lake. The submerged and nonrooting vegetation (*Ceratophyllum* and *Elodea*) is not abundant in Flag Lake, so that the food supply in the lake waters is not drawn upon to any great extent by the aquatic vegetation, and it thus becomes available for the phytoplankton, which, in turn, supports the zoöplankton. The products of decay of the succulent and emergent vegetation, on the other hand, are in large part released directly into the lake waters, and at times (fall and spring) when the plankton reaches its greatest development in this region. Owing to its character and to the protected situation of the lake the vegetation is never swept away by floods, nor is the lake traversed by any marked current as are both Thompson's and Quiver lakes. The fertilizing effect of the decaying vegetation is thus more localized in this region than in the other bodies of water examined by us.

The data from Flag Lake thus throw light upon the effect of emergent and rooted vegetation—which is typically of the littoral type—upon the plankton. They indicate that this kind of vegetation favors the development of the plankton by adding to the food materials in the water, while at the same time it does not to a large degree compete with the phytoplankton in the consumption of the food thus released by its decay.

In 1896 a series of examinations of the local distribution of the plankton in Quiver, Matanzas, and Thompson's lakes was made by the pumping method, and since the collections were made in the areas of vegetation as well as in the open water they might also be examined to determine, if possible, the effect of vegetation on the distribution of the plankton. Only the quantitative data are at present available, and the results are conflicting. In some cases the plankton is greater in the vegetation than in the adjacent open water; in others the reverse is true. These examinations were made at times of unstable river levels, and the movements of water consequent thereupon make any satisfactory analysis difficult. The general conclusion that lakes full of vegetation (Quiver) are everywhere poor in plankton, while those relatively free from it (Thompson's and Matanzas) support generally a more abundant plankton is in all cases upheld by these examinations.

This poverty of the plankton in vegetation-rich lakes was one of the surprises of our investigations, and, so far as I have been able to ascertain, it contradicts the general expectation among observers of aquatic life. It has its parallel in the paucity of life in tropical forests and among the pines and redwoods of the Sierras. It is fundamentally a problem of nutrition, and inheres in the utilization of the available food supply by a single type, or a few types, of plants which do not themselves in turn afford support for an abundant or varied animal life.

Wherever the depth of the water, the currents, the winds, or other factors, prevent the development of a submerged aquatic flora, the nutrient materials for plant growth—the oxygen, the carbon dioxid, the nitrates, phosphates, sulphates, and carbonates dissolved in the water—are utilized by the phytoplankton, which, in turn, supports the zoöplankton. The entire production of such a lake takes the form of plankton and, in turn, of those larger species, insect larvæ, mollusks, and fish, which are directly or indirectly supported by it. When, on the other hand, the conditions are such that a submerged nonrooted aquatic flora obtains possession of a lake,—as, for example, *Ceratophyllum* and *Elodea* in Quiver Lake,—these nutrient materials are appropriated by it to the great reduction, even practical exclusion, of the phytoplankton. In the struggle which must ensue between the phytoplankton and the submerged aquatic flora for the possession of a body of water capable of supporting either, the greater duration and permanence of the larger plants which constitute the submerged flora must in the long run inure to the advantage of the latter, hence they predominate over the phytoplankton wherever other conditions favor their appearance. This coarse submerged vegetation cannot in its living condition be utilized by the minute organisms of the zoöplankton, and only such as feed upon it in decay can find sustenance in the vegetation-rich lake. The absence of an abundant phytoplankton and of the greater part of the zoöplankton may thus be accounted for in waters rich in submerged and non-rooted vegetation. The total production of such a body of water consists mainly of a large amount of coarse aquatic vegetation, which but few animals can utilize in its living condition as food, and a much reduced plankton, largely of animal constituents, together with such larger and often attached species as find food in these elements.

Some light on the relation of vegetation and plankton to certain of the chemical constituents of the food of the aquatic flora can be gained from a comparison of Plates XLV., XLIX., and L., and Tables X., XII., and XIII., which show the results of analyses in 1898. The appended table also gives the average amounts of free ammonia and nitrates in Illinois River and in Quiver and Thompson's lakes in the period from June 1 to October 1 and in the remainder of the year—two periods which approximately represent the times of maximum and minimum of chlorophyll-bearing organisms.

AVERAGE OF ALL ANALYSES—PARTS PER MILLION.

Station	Free Ammonia		Nitrates	
	June 1 to October 1, 1898	Remainder of year	June 1 to October 1, 1898	Remainder of year
Thompson's Lake......	.154	.457	.244	.684
Quiver Lake......	.024	.199	.222	.923
Illinois River...........	.566	.786	.297	1.036

A comparison of these two lakes indicates more nitrates in Quiver than in Thompson's (.68 to .53 parts per million)—a phenomenon which may be explained by the proximity of the former to the river and the greater invasion by its richer (.81) waters. In the matter of free ammonia Thompson's Lake is much the richer (.352 to .138 parts per million), though it falls considerably below the river (.95) in this particular. The striking feature of the diagrams and tables is the marked reduction in nitrates and free ammonia during the period of growth, from June 1 to October 1, in both lakes as contrasted with that of quiescence, from October 1 to June 1. The former period is one of higher temperature and less flood water, thus favoring the process of decay and the concentration of its products. The marked decrease in both the free ammonia and nitrates during this period may be explained by the utilization of these products of decay by the chlorophyll-bearing organisms, which presumably are much in excess of those of the colder period. In Thompson's Lake the phytoplankton would be the principal consumer, while in Quiver Lake submerged vegetation assumes this role. The uniformity in the nitrates throughout this period, and the reduction to a similar amount (about .2 parts per million) in both lakes are significant of some sort of an equilibrium between the supply furnished by decay and its utilization in the growth of plants. This phenomenon of reduction of nitrates to a summer equilibrium is to some extent manifest in the analysis of soil waters (see Palmer, '97), and may in like manner be attributed to utilization of the nitrates by vegetation.

At first thought the volume of submerged vegetation seems large in comparison with that of the phytoplankton, which it replaces; but when the permanence and persistence of the constituent cells of *Ceratophyllum* are contrasted with the many generations of the algæ and diatoms of the plankton which arise during a season's growth, the difference is less evident. Furthermore, a much greater proportion of the cells of the phytoplankton contribute directly to the growth of the animal life of the lake.

The submerged vegetation—such as that found in Quiver Lake—affects the conditions of nutrition in other ways than those above indicated. The absence of roots and the slight hold which its lowermost stems can obtain upon the soft bottom facilitate its removal by floods and seines, and the nutriment stored in its tissues is thus taken from the lake, and its waters are impoverished to that extent. Again, both *Ceratophyllum* and *Elodea* are perennial, continuing beneath the ice from year to year and never wholly yielding to decay. The littoral vegetation of Flag Lake, with its large annual growth and well-marked periods of decay in autumn and spring, contributes more generously to the enrichment of the water. Thus, while robbing the water of its food material, the submerged vegetation often fails to make equivalent returns.

The submerged vegetation also interferes with the free operation of certain other factors which affect the plankton of open water. It shuts out the sunlight, and effectually modifies the temperature thereby. Thus, on a midsummer day the water in Thompson's Lake rarely shows a difference of more than three degrees (Fahr.) between surface and bottom in two meters of water. In the vegetation, on the other hand, the temperature contrast is much greater and within much narrower limits. On July 15, 1897, when surface waters were at 88.2°, the temperature was but 80° at 15 cm. below. The diurnal range of temperature is thus much less in vegetation than in open waters. The growing portion of the submerged vegetation is usually at or near the surface, while the deeper portions are older and often moribund. This vegetation thereby enjoys the full benefit of the sunlight, so essential to the growth of chlorophyll-bearing plants, while its occupation of the water—especially at the surface—shuts out the light to a considerable degree from the more open deeper waters, and in this way adds another effective barrier to the growth of the phytoplankton in surrounding water.

The dense growths of the *Ceratophyllum* also interfere with the movements of the water, and thus tend to establish and maintain local units of environment within a body of water. Lakes full of vegetation, like Quiver Lake, exhibit greater variations in the local distribution of the plankton than are found in open ones, such as Thompson's Lake. Greater differences in the component organisms also appear. The vegetation thus acts as a barrier, isolating differing assemblages of organisms. Thus, in Quiver Lake in one instance local aggregations or swarms of *Volvox*, of *Copepoda*, of *Oscillaria*, and of *Melosira* were detected in the examination of the local distribution of its plankton. To this isolation by the vegetation may also be attributed the considerable irregularity in the seasonal fluctuations of the amount of plankton, which is somewhat more evident in the planktographs of Flag Lake (Pl. XXXIII. and XXXIV.) and Dogfish Lake (Pl. XXX.-XXXII.) than in those of other stations. Such fluctuations, for example, as those in May, 1896, in Flag Lake, when the plankton fell from 203.52 cm.^{3} to 0.72 in 13 days, or the fluctuations in Dogfish Lake in 1895, which do not seem to be correlated with any fluctuating feature of the environment, may be referred in part to the isolation resulting from vegetation and the modifications of food supply and reproduction consequent upon it. The maximum-minimum contrast in Flag Lake was due to an excessive local development of *Bosmina* followed by its sudden disappearance. The cycle of changes in the succession of life are thus accentuated, and run a more rapid course in the midst of vegetation than they do in the larger unit of environment, the open water, where minor differences are quickly merged by the turmoil of current and waves.

The plankton catches made in vegetation-rich lakes usually contain a larger proportion of littoral and bottom-loving species than those from open water. There are the *Rhizopoda*—often those with the heavier shells—the attached diatoms, ciliates, and rotifers, together with many bdelloid and Ploiman rotifers not found in open water, the aquatic insects, both adult and larval, the oligochætes, the smaller mollusks, *Hyalella*, and *Hydra*. They materially increase the volume of the catches recorded in the tables, and show in the plates of the plankton of Quiver, Dogfish, and Flag lakes. The sessile organisms above named, with the *Bryozoa*, which often occur on *Ceratophyllum*, avail themselves of the plankton as food. *Hydra*, especially, increases when the plankton is more abundant. In Quiver Lake on May 8, 1896, *Hydra* was taken in plankton at the rate of over five thousand per m.^{3} of water. These organisms which find a substratum and shelter on the aquatic vegetation must have some important effect on the plankton, and their presence is doubtless one of the minor factors in the suppression of the plankton in lakes rich in submerged vegetation.

The economic aspects of the question of vegetation in bodies of water arise from the relation which it bears to the production of marketable fish. Quiver and Thompson's lakes are both seined by local fishermen, and their relative productivity as fishing grounds may be expressed in the market value of the leaseholds of the fishing privilege. Quiver Lake is so blocked with vegetation that clearing it for seining is at times an expensive operation, and this has a tendency to lower its market value. Thompson's Lake, on the other hand, is less accessible, and some clearing out of the littoral belt of vegetation is always necessary before seining, the operating expenses being thus somewhat increased. For years the leasehold of Quiver Lake has been purchased for a merely nominal sum, not exceeding $100, and it has often lacked a purchaser. Thompson's Lake, on the other hand, has been, in recent years at least, an object of increasing value, and brings over ten times this amount for a portion of the lake only. Thompson's Lake has an area of about 1,200 acres, while Quiver has only 230. Their market values are thus out of proportion to their respective areas. Capt. J. A. Schulte, of Havana, whose knowledge of the fishing industry in the Illinois River is extensive and accurate, estimates that in the same area Thompson's Lake will produce five times as much fish as Quiver, and production of fish thus stands in somewhat the same ratio as the average plankton production (1.75 and 8.26 cm.^{3} per m.^{3}). The productivity of the lake full of submerged vegetation, is, it seems, less than that of one free from it, whether measured in cubic centimeters of plankton or returns for marketable fish.

The data here presented concerning the inimical effect of submerged non-rooted vegetation upon the plankton suggest an interesting subject for field or laboratory experiment. Indeed, experimental proof is desirable for the generalization here advanced. How far it will find support in the examination of other localities remains to be seen, for no investigation bearing upon the question seems to have been made elsewhere. It should be noted that it is not maintained that all vegetation is inimical to the development of the plankton, but only such as successfully competes with the phytoplankton for the available plant food, and thus brings by its decay no additional sources for plant nutrition into the water. These conditions are approximately realized where the submerged non-rooted type of vegetation prevails. Where, however, by reason of the local conditions or the nature of the constituent plants, the aquatic vegetation adds by its decay to the fertility of the water owing to its utilization of sources of food in the soil and the air not available to the phytoplankton, we may expect to find the development of the plankton fostered by such vegetation. These conditions are realized wherever rooted, and especially emergent, vegetation prevails and contributes by its decay to the enrichment of the water. A belt of littoral vegetation of this sort may thus be of considerable effect in maintaining the plankton in a body of water.

INTERNAL FACTORS AND PLANKTON PRODUCTION.

Under this head attention will be called to certain phases of plankton production with which in the present state of our knowledge no environmental factors stand in apparent correlation. From this point of view, which lays emphasis upon the reacting organism rather than upon the stimulating environment, most of the relations and adaptations of the plankton to environmental factors might be treated under this head. But this has not been my method nor is it now my purpose to adopt it.

The phenomena of growth and reproduction of the constituent organisms of the plankton, on the other hand, owing to our ignorance of their controlling factors, can at present be treated only under this head. The volumetric data in themselves contain little evidence bearing directly upon the problem, but in the light of the statistical results the fluctuations in the plankton become dependent upon fluctuations in the rate of growth, and especially in that of the reproduction of its constituent organisms. These fluctuations are often concurrent, or, at most, shortly consequent, in many species at the same time and in several different localities, and give rise to the coincident volumetric pulses to which attention has so often been called in the preceding pages. Somewhat regular alternations of growth and rest, of fission and spore formation, or of parthenogenesis and sexual reproduction, are fundamentally the basis of the cyclic movement in production. The *amplitudes*, and to some extent the location and duration of the pulses, are plainly affected by the various factors of the environment discussed in preceding pages—by light, temperature, vegetation, tributary water, various hydrographic factors, and by food supply, and, possibly, also, by chemical conditions not directly concerned in nutrition, but the available data fail completely to afford any satisfactory environmental factor or group of factors which stands in correlation, even remotely obvious, with this cyclic movement in production. I therefore class this *periodic growth*, these *sexual cycles* which cause volumetric pulses, under the head of internal factors. The element of *periodicity* in itself does not seem to be consequent upon any known external factor.

NORMAL REGIMEN OF PLANKTON PRODUCTION.

The records of plankton production in the Illinois River, its tributaries, and backwaters, contained in this paper raise the question whether there is in this fluviatile environment a normal regimen of production. Is there in the course of production an orderly sequence, of any sort, of sufficient stability and of sufficient frequency in occurrence in successive years to justifiy its designation as a normal regimen?

A cursory inspection of the planktographs in the plates, of the data in the plankton tables, and of the table of monthly means following page 342 reveals at once an apparent state of chaos that accords well with the instability of most of the environmental factors of the plankton, notably the hydrographic. For example, the production in the same month in different years or in the different localities examined by us is exceedingly variable. Taking at random the month of August, we find that the *mean* production for this month in the years of examination ranges in the channel from .91 to 9.67; in Spoon River from .002 to .652; in Quiver Lake from .22 to 2.46; in Dogfish Lake from 1.11 to 3.91; in Flag Lake from .03 to 3.74; in Thompson's Lake from 1.08 to 19.40; and in Phelps Lake from 8.80 to 139.85 cm.^{3} per m.^{3}; and, furthermore, that the extreme range in these means—.002 to 139.85— is found coincidentally in the same year, 1898 (see table following p. 342). This does not afford a very satisfactory basis for predicting the probable August production in cubic centimeters of plankton in any of these localities. It is evident that there is little regularity in the *actual amplitude of production* in a given season and locality in successive years.

If the problem be approached from the standpoint of *relative* production in different localities at the same time, or in the same locality at different times, more semblance of order is traceable, though not equally so in all localities or in all months of the year. The relative rank of each locality in mean monthly production, as seen in the table following page 342, is tabulated below. For example, in the case of the Illinois River in the total of 51 monthly means there were 5, 6, 16, 12, 4, 10, and 1, instances when its production attained first to seventh rank respectively among the seven or less localities repre-

RANK IN PLANKTON PRODUCTION.

Rank	Illinois River	Spoon River	Quiver Lake	Dogfish Lake	Flag Lake	Thompson's Lake	Phelps Lake
1	5	0	4	2	4	13	28
2	6	1	2	2	11	27	4
3	16	1	14	10	1	8	1
4	12	1	14	8	5	3	1
5	4	12	15	2	2	0	1
6	10	5	4	0	0	0	1
7	1	8	0	0	0	0	0
Total	51	28	53	24	23	51	36
Average rank	3.9	5.6	.4	3.3	2.6	2.	1.5

sented in the months concerned. An examination of this table shows that in relative production (see table following p. 342) the localities tend to arrange themselves in a sequence which is represented by the average rank. As shown in the above table, this is as follows: Phelps Lake (1.5), Thompson's Lake (2.), Flag Lake (2.6), Dogfish Lake (3.3), Illinois River (3.9), Quiver Lake (4.), Spoon River (5.6). This is essentially the sequence in relative production represented by the averages of all collections and of the monthly means (see table following p. 342), except that Flag and Thompson's lakes are transposed. From the points of view either of average rank or of average production the *relations of production* in the 7 localities examined by us are, it appears, essentially similar. A considerable measure of stability in this respect may therefore be expected.

If we inquire if these relations in production expressed in terms of rank are equally constant for all localities and at all seasons, we find that there are departures from the average in all localities, and that different localities show different degrees of stability of relative production varying to some extent with the season. This appears in a comparison of the ranks of Phelps Lake and the Illinois River in the table above given. In the case of Phelps Lake (average rank, 1.5) 32 of the 36 months rank first or second, while in the Illinois (average rank, 3.9) but 28 of the 51 rank third and fourth. Obviously the divergences from the expected rank in production are greater in the river than in Phelps Lake. A further inspection of the table indicates that Phelps and Thompson's lakes and Spoon River exhibit the most stable relations in productive rank. It is in these bodies of water that we have found environmental conditions most uniform. In Flag, Quiver, and Dogfish lakes the divergences in rank are much greater, and it is in these localities that conditions of high and low water and of vegetation afford sharpest contrasts. In the Illinois River itself, where hydrographic fluctuations are most immediately effective, we find apparently the widest divergences in productive rank. Even in these instances of greatest divergence the tendency towards a certain rank in production in each locality is sufficiently evident to warrant the statement that in the main the relative rank in production in the several localities examined by us is well established and generally maintained.

Still more pertinent to the question of the existence of a normal regimen in production is the question of sequence in the course of production in successive years and in different localities in the same year. Do the planktographs form curves which may be superposed in successive years in the same locality or in different localities in the same year? A single glance at the plates which accompany this paper will suffice to reveal the chaotic complex of lines which such a superposition would produce. There is no such unity or similarity if we base the comparisons on the *actual volumetric production.* If, on the other hand, we disregard coincidence in amplitude of the curve and consider mainly the *direction of the changes,* similarity becomes increasingly apparent. It rarely approaches to the condition of complete parallelism, however, owing to the great variety in the amplitude of production in various years and localities.

If the data in the table following page 342 be analyzed with reference simply to the upward or downward movement in mean production from month to month and year to year in the various localities, we find certain tendencies appearing which may afford a basis for predicting the probable course of production to a slight degree in the localities examined and in the region as a whole. The following table exhibits the instances of upward and downward movement in the monthly means for each locality for each month of the year.

DIRECTION IN MOVEMENT OF MEAN MONTHLY PRODUCTION.

Station	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up
Illinois River	3	0	2	3	2	2	0	4	1	2	3	2	2	3	3	2	4	3	3	2	3	2	2	2
Spoon River	1	1	2	1	1	2	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1
Quiver Lake	2	1	0	4	1	3	0	4	2	1	0	3	4	1	3	2	2	3	4	1	3	2	1	4
Dogfish Lake	1	0	1	1	0	2	0	2	2	0	2	1	1	1	1	1	1	1	1	1	1	1	0	2
Flag Lake	1	0	1	1	0	2	0	2	0	2	2	0	0	2	1	1	1	1	0	1	2	0	1	1
Thompson's Lake	2	1	3	1	1	3	0	4	1	3	4	0	5	0	2	3	2	3	3	1	3	1	4	1
Phelps Lake	1	0	0	2	1	2	0	3	1	2	3	0	1	2	1	2	1	0	1	1	0	2	1	0
Total	11	3	9	13	6	16	1	19	8	11	15	7	14	9	12	12	12	12	13	7	13	8	10	11

This table, combined with the plottings of the averages of the monthly means at each station, shown in Fig. E (p. 508), indicates the following course in production which predominates in our records. Production falls in January, begins to rise in February, continues to increase in March, but only to a slight extent though more generally. In April the increase is practically universal and more extensive than in any other month of the year. In May the increase continues in the majority of instances (11 out of 19), and more frequently (63 per cent.) in the backwaters than in tributaries (50 per cent.). In either June or July there is a decline to a lower level of production in all localities. There is, however, considerable diversity in this matter in the several years and localities (partially as a result of imperfect records). This appears in the ratios of downward and upward movement in June (15 to 7) and in July (14 to 9). In the months of August and September there is a tendency towards a higher level of production in some of the backwaters, though on the whole the instances of rising and falling production are equal in number. In October and November produc-

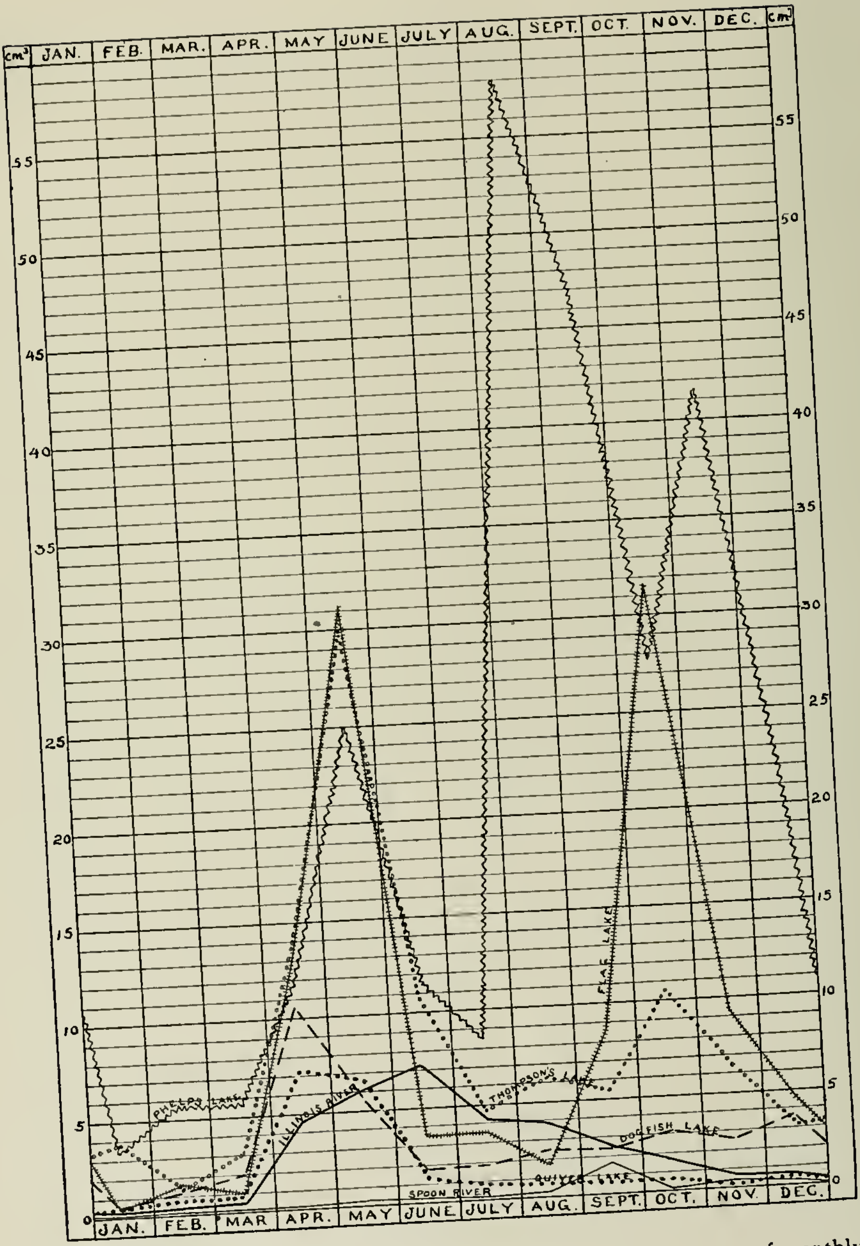

FIG. E.—Planktographs of all stations, plotted from averages of monthly means.

tion again drops to a low level, and this movement appears in 60–70 per cent. of the instances in each month. In December the decline in production is checked, and in a few cases the upward tendency reappears, only to give way again in most cases to the January minimum.

There is thus a general seasonal regimen apparent in the totals of all localities, and an approximately parallel seasonal routine for each of the localities, the degree of approximation varying with the locality and the season. But this regimen can be outlined only in the most general terms, and is everywhere subject to divergences that frequently reduce it well nigh to a semblance of chaos—a condition arising from the instability of this aquatic environment.

The course of production above outlined considers only the movement of the average monthly production, and consequently deals only with the larger and more general seasonal movements. It masks almost completely the minor fluctuations, and especially obliterates all consideration of the phenomenon of pulses discussed in the treatment of the course of production in the several localities.

It is in this matter of pulses, or, in other words, in the cyclic movement in plankton production, that the nearest approach to a normal regimen appears in our volumetric data. I have shown that wherever our collections were made at intervals of a week, or less, this movement is generally distinctly traceable. In the backwaters, where collections were usually less frequent, the cyclic character of planktographs is still apparent, even in fortnightly collections. This phenomenon is therefore, it seems, a constant feature of the movement in plankton production in our waters as it appears in the purely volumetric data. Suggestions of the occurrence of a similar movement in the plankton of other waters may be found occasionally in the data of other investigators, but nowhere, to my knowledge, is there at present a chronological series of collections of sufficient duration and brief enough interval of collection for comparison with the data presented in this paper. The main basis for the emphasis laid upon the subject in connection with my discussion of the volumetric data will be found in the statistical data of Part II. of this paper. In this connection it may be noted that the statistical data of other investigators lend some support to the probability that this cyclic movement in the plankton will be found to occur in other localities as well as in those examined by us. Instances suggesting this occurrence may be found in the statistical data of Amberg ('00), Steuer ('01), and the more recent work of Cohn ('03).

This cyclic movement consists in the repetition of rise and decline in production—a repetition broken in our records only by the imperfection of our data. Wherever collections are of sufficient frequency it is possible to trace it—sometimes, however, only with the aid of statistical data—continuously through all the vicissitudes of changing seasons, of summer heat and winter's ice, of the vernal rise and autumnal decline in temperature, and of high and low water. Moreover, it appears in all of our localities whenever collections have been made with a weekly, or even fortnightly, interval.

These pulses vary in duration from 2 to 7 weeks, though the majority occur in limits of 3 to 5. Their amplitudes vary greatly, and are plainly influenced by various environmental factors. Their limits are also frequently modified by these factors, though the evidence is not clear that any of the environmental factors we have discussed are correlated directly with the cyclic movement itself.

In the discussion of production in the backwaters the universal approximation in time of these pulses in the various localities, or even their precise coincidence in many instances, was recorded. The cause of this tendency toward uniformity in the direction of movement in production in these various localities at the same time is not apparent from the data at hand. Contributory to it are the facts of a plankton largely composed of the same species of planktonts, of a connection and commingling of waters in all of the localities in flood conditions, and of the operation of environmental factors common to all of the localities.

The normal regimen is accordingly not delineated by a planktograph of marked definiteness in its course, but is one formed by a sequence of recurring pulses of approximately a month's duration and varying amplitudes, low in winter floods, rising with the temperature to a vernal maximum of considerable magnitude, often, but not always, declining during the summer months, frequently rising again in late summer or autumn, and in some localities and years to an extent exceeding that of the vernal season, and falling with autumn temperatures but increasing in stable winter conditions after the minimum winter temperature is reached,—such is the general regimen of plankton production in the Illinois River and its backwaters.

If this cyclic movement in production be characteristic of the plankton generally, fresh water and even marine, it must follow that scattered and irregular collections, or those at intervals exceeding a week or at most a fortnight, may fail entirely to give an adequate representation of the course of production or relative fertility of a body of water. Chronological series throughout the whole seasonal range of climatic conditions and at close intervals—of one week or less—are necessary for any accurate delineation of production and fertility of water by the plankton method.

SOURCE AND MAINTENANCE OF THE POTAMOPLANKTON.

The existence of a very characteristic and abundant plankton in the Illinois River at once raised the question as to its source and maintenance. We find at Havana a stream which year in and year out carries by a burden of life, microscopic as to its individuals, to be sure, but in the aggregate a volume of surprising extent. This stream of life exhibits a routine of seasonal changes in constitution and quantity which neither flood, the ice of winter, nor the drouth of summer wholly interrupts. It recurs year after year with a regularity which stands in strong contrast with the fluctuations of the environment. Although the water in the stream is subject to continuous renewal,—the channel from Utica to the mouth discharging in from 5 to 25 days, according to the rate of the current,—the plankton is continuously maintained, and the seasonal routine is run in the face of this continuous renewal of the water. Furthermore, the plankton product of the stream is discharged at the mouth of the river practically in its entirety, for the organisms of the plankton cannot maintain their place in the stream against the current. The only organisms of the potamoplankton which remain, are those used as food by fishes and other animals which are not carried away by the current, and such as may be lodged—usually in encysted, and thus heavier, condition—along the bottom or banks of the stream. At times of flood the receding waters leave some of the plankton side-tracked in the reservoir backwaters—in the lakes, lagoons, bayous, and marshes of the bottom-lands. As river levels fall it may be slowly drawn off into the channel of the stream, or cut off from connection with the river. This continual discharge of the plankton, never to return, makes the problem of the maintenance of the potamoplankton, quantitatively at least, very different from that of the maintenance of the plankton in a lake.

Three suggestions arise in explanation of the perennial character of the plankton of the river: (1) The plankton enters with the tributary waters, in which case the problem is only removed a step; (2) it is autonomous, developing in the stream while the waters are in transit, in which case the solution lies in the river and its environment; or (3) the two elements, contribution and autonomy, are combined, in which case the share of each will appear on a comparison of the plankton of the river and of its tributary streams and backwaters.

The water in the channel of the river comes from three sources; from springs and seepage along the banks, from the impounded backwaters of the bottom-lands, and from tributary streams.

RELATION OF SEEPAGE WATERS.

The contribution from springs and from seepage are inconsiderable in comparison with that from the other sources. Wherever the river encroaches upon the bluffs, as, for instance, below Havana, seepage areas of some extent and springs of some size are to be found. Such banks, however, in immediate contact with the main stream itself, are of very limited extent. Furthermore, their contributions to the plankton are relatively still smaller. These springy banks abound in life—planarians, amphipods, isopods, oligochætes, and rhizopods, mainly limicolous species, which rarely leave their habitat to enter the river with the spring water. Such springy banks, exposed to midsummer's heat during low water, do at times teem with species common in the plankton. For example, a bank of this sort on the levee at Havana was covered with a brownish scum composed principally of *Synedra acus*, a diatom abundant in the plankton at cooler seasons of the year. The temperature of spring waters along the bluffs in midsummer is about 60°. Elsewhere in the warmer waters of this springy shore are to be found patches of green and red scum, where *Euglena viridis* and *E. sanguinea* were abundant, both species being common in the plankton at that time. Tiny rills of cool water traverse the oozy bank and carry stray individuals of these various species into the river, but their clear waters are poor in comparison with the brown water of the stream which they join, turbid with plankton. Their contributions are thus insignificant in amount and, while adding a trifle to its diversity, their main action is that of diluents of the potamoplankton.

RELATION OF TRIBUTARY STREAMS TO CHANNEL PLANKTON.

The relation of tributary streams to the potamoplankton in the channel of the Illinois is a much simpler problem than that presented by the backwaters. Their contributions enter the river in well-defined channels, and the areas of their respective basins are an index to the quantity of water they bring to the river. Their share in the formation of the potamoplankton can thus be more readily tested and estimated. Under conditions prior to the opening of the Chicago drainage canal the river received at Utica, the upper end of the basin under consideration in this paper, the drainage of 10,365 square miles of catchment-basin, over one third of the total basin of the stream, to which was added at La Salle, a few miles below, the water from the Illinois and Michigan Canal containing the sewage from the Chicago River. A large volume of water, richly fertilized, is thus provided for the reception of tributary streams, no one of which, with the exception of the Sangamon, has more than one ninth of the drainage basin above the point of its union with the river. The Sangamon has at its mouth a basin one fourth as large as that of the river above. This presence of a considerable initial volume and the distribution of tributary waters in relatively small streams at intervals along the course are conditions which favor the mingling of the constituent waters of the stream and tend to maintain the uniformity of the plankton in the main channel.

The tributary waters, with a few minor exceptions, such as Quiver Creek, enter the main channel directly. The elevated deposits built up across the bottoms by their agency confine their floods within their banks except during the maximum stages of overflow, when they contribute directly to the backwaters, but even under these conditions a strong current is still maintained along their customary channels directly to the main channel of the river. Their contributions are thus, as a rule, carried directly to the river and mingle with it without any period of impounding, and their effect upon the plankton is direct and immediate.

Two tributaries, Spoon River and Quiver Creek, were available for examination at Havana, in both of which collections were made by us which throw considerable light upon the character and quantity of their plankton contributions.

QUIVER CREEK.

In Quiver Creek we have a small tributary with a basin of only 220 square miles, largely of alluvial second bottom with more sand and less heavy loam and clay than the adjacent prairies. Its waters are discharged into the upper end of the eastern arm of Quiver Lake, and are impounded for a varying length of time before reaching the river. No channel defined by the configuration of the bottom traverses the lake, and since its area is relatively large in comparison with the discharge of Quiver Creek, the tributary waters are subject to considerable impounding when the lake is free from vegetation. When, however, vegetation is abundant, a fairly well-defined channel, through which the discharged waters make their way with perceptible movement, is kept open through the matted growths. The impounding period is thus reduced for the channel water under such conditions.

Collections were made in Quiver Creek, near Topeka, Ill., above McHarry's mill-pond, from September 1, 1896, to April 20, 1897, at intervals of ten days, by Mr. W. R. Deverman, who kindly volunteered this service for the Station. A tow-net of No. 20 silk was used, but no exact quantitative method was adopted, so that these collections are available only for qualitative comparisons.

The catch consisted largely of silt in the form of quartz grains and coarsely comminuted vegetable debris, with relatively few plankton organisms.

The several catches were uniformly diluted, and the plankton organisms counted in a uniform fraction of a cubic centimeter of the dilution from each catch. The various species detected and their monthly averages in numbers are given in the appended table. The figures have but slight quantitative value, though they will serve to illustrate in a general way the composition of the plankton and its seasonal changes, and will also afford a sufficient basis for a comparison of the constituent organisms of the plankton of Quiver Creek, Quiver Lake, and the river, though not for a comparison of their relative numbers per cubic meter in each of the three situations.

The plankton of Quiver Creek, as shown in the table, may be characterized as largely tycholimnetic, that is, composed of littoral species, shore-loving and bottom forms. This is seen

PLANKTON OF QUIVER CREEK, SEPTEMBER, 1896, TO APRIL, 1897.

Species.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
Algæ—totals	26	28	52	14	8	4	8	10	150
Closterium acerosum	2	4	12						18
lunula	10	16	6					2	34
gracile				2	2				4
Oscillatoria sp.	8	2	22	4	4	2	8	8	58
Unidentified	6	6	12	8	2	2			36
Diatoms—totals	651	194	684	676	730	90	222	2470	5717
Amphora	10			2					12
Cocconeis communis		4		8					12
Cyclotella	2								2
Cynatopleura solea	130	40	312	128	180	6	8	20	824
Diatoma vulgare	24	2	16	10	400*	4	10	52	518
Encyonema	2			2		2			6
Fragilaria virescens			6	8			2	4	20
Gomphonema constrictum			6					2	8
Melosira spinosa	2						2		4
varians	9		20	16					45
Meridion circulare								4	4
Navicula spp.	22	16	30	38	8	8	4	162	288
sp.	100*								100
Nitszchia sigmoides				2	2				4
Pleurosigma angulatum	4	2			4			4	14
Surirella ovata	4		2	2			6		14
splendida	342	118	218	176	38	32	18	14	956
Synedra acus		8	68	278	94	38	172	2202	2860
ulna		2		4	4			6	16
Unidentified		2	6	2					10
Rhizopoda—totals	86	10	46	41	34	30	22	14	283
Arcella angulosa						4			4
discoides			2				2		4
vulgaris	2		2						4
Centropyxis aculeata	2	2	4	2	2	4	4		20
ecornis	8		2	11	4	4	6		35
Cyphoderia ampulla				2					2
Difflugia acuminata	16			6	4	4		2	32
acuminata bifida								2	2
constricta							2		2
globulosa	54	8	32	14	18	10	6	10	152
sp.				2					2
Gromia sp.	2		2		2	2			8
Trinema enchelys	2		2	4	4	2	2		16
Mastigophora—totals	2	2	48					2	54
Eudorina elegans								2	2
Phacus longicauda		2							2
Synura uvella			46						46
Trachelomonas hispida	2								2
Unidentified			2						2
Rotifera—totals	17	2	22	2	6	2	4	2	57
Cathypna luna		2	6						8
Colurus obtusus	2								2
Conochilus sp.					2†				2
Distyla spp.	4		10						14
Mastigocerca sp.			2						2
Metopidia solidus	2			2					4
Notholca jugosa								2	2
Philodina megalotrocha			2						2
Rotifer actinurus					2				2
sp.	5								5
Unidentified	4		2		2	2			10
Rotifer eggs							4		4
Entomostraca—totals			8				2		10
Cyclops serrulatus			1						1
Nauplius			3				2		5
Ostracod			4						4
Miscellaneous—totals	12	2	15	18	3		3	9	62
Chironomus larva	4		1	6	1		1	7	20
Unidentified insect	2								2
Insect egg		2	14	2			2	2	22
Unidentified egg				8	2				10
Unidentified	6			2					8
Total number of species	32	18	33	29	22	16	19	19	63
Total number of individuals	794	238	875	751	781	126	261	2497	6323

*Estimated. †Eggs only.

in the predominance of the diatoms, the *Rhizopoda*, and *Chironomus* larvæ, and in the character of the few rotifers present. It is also evidenced by the erratic distribution and often small numbers of many of the species occurring in the creek waters.

There is little evidence in the data of marked seasonal changes. The diminished number, both of species and individuals, in the winter and spring months is due in part to the flood conditions prevailing at that time. The disappearance of the desmids in the colder months is apparent, as is also the decline in the diatoms, the effect of which is heightened by the greater proportion of dead and moribund individuals in the winter months. There is also some slight evidence in the table of a spring increase in March and April and of a late autumn maximum in November. From conditions observed in Spoon River and Quiver Lake during the summer months not included in the period of our Quiver Creek collections it seems probable that the plankton of this stream at that season of the year is more diversified by the addition of flagellates and rotifers. The flow of the stream is, however, much reduced at this season, and its contributions correspondingly small in quantity.

The inter-relations of this creek plankton are very patent. The diatoms are the predominant members, having one third of the species and nine tenths of the individuals. The rhizopods include one fifth of all the species and almost two thirds of the animal individuals. We have here a rich diatom flora supporting a rhizopod fauna. The remainder of the species, about one half, belongs to diverse groups and is numerically, at least, an insignificant element in the plankton assemblage, constituting but 4 per cent. of the total population.

A comparison of the plankton here delineated with that of the river at the same seasons of the year leads to the following conclusions:

1. The creek organisms all occur in the river plankton.
2. The facies of the river plankton is quite different from that of the creek in that it has a greater abundance and variety of organisms, a greater proportion of limnetic species, and a

much greater proportion of limnetic individuals, with a corresponding decrease in the relative numbers of the littoral individuals. This is very apparent throughout the whole season covered by the collections. Thus in autumn months, when *Melosira*, *Synura*, the ciliates, *Synchæta*, and various *Brachionidæ* characterize the potamoplankton, we find them but sparingly represented, or, as in the case of *Synchæta* and the ciliates, wholly absent from the creek plankton. So, also, in the winter months *Brachionus dorcas* and *Cyclops bicuspidatus*, so characteristic of the river plankton, form no part of the population of the creek. The perennial and abundant *Polyartha playtyptera* was at no time found in the creek. That limnetic species are not wholly absent from the creek is shown by the presence of *Melosira*, *Synura*, *Notholca jugosa*, *Eudorina*, and *Trachelomonas*, but their occurrences are isolated and their numbers few. The creek is thus not a center of distribution for such planktonts as these, their presence and numbers in the river being practically independent of their appearance in the tributary.

The abundance of diatoms in the creek waters suggests that these may find centers of distribution here. Most of the species, however, are quite as abundant in the river, with the exception of the *Surirellas*. These are present in small numbers in the potamoplankton, and are often moribund.

3. The creek waters act as diluents of the potamoplankton. The character of the Quiver Creek plankton and the quantitative studies on Quiver Lake support this view.

The contribution of Quiver Creek to the potamoplankton is thus largely of littoral species and of small quantity, and its effect is that of a diluent of the potamoplankton.

The following table, which gives the relative number of species in the plankton of Illinois and Spoon rivers and Quiver Creek, demonstrates the small number of species found in the creek, and the monotony of its composition as shown in the predominance of the *Rhizopoda* and the diatoms. The relative paucity of the *Mastigophora* in its fauna may be due in part to the

RELATIVE NUMBER OF SPECIES IN THE PLANKTON OF QUIVER CREEK AND SPOON AND ILLINOIS RIVERS.

Group	Quiver Creek	Spoon River	Illinois River
Algae—totals	25	34	74
Schizophyceæ	1	4	11
Chlorophyceæ	1	11	30
Bacillariaceæ	20	14	25
Conjugatæ	3	5	8
Protozoa—totals	18	63	154
Rhizopoda	13	17	30
Heliozoa	0	0	4
Mastigophora	5	28	62
Ciliata	0	16	55
Suctoria	0	2	5
Rotifera—totals	11	44	107
Rhizota	1	1	6
Bdelloida	3	4	6
Ploima	7	39	95
Crustacea—totals	2	13	49
Copepoda	1	5	17
Cladocera	0	7	26
Ostracoda	1	1	3
Other Crustacea	0	0	3
Miscellaneous—totals	4	16	45
Insect larvæ	1	5	6
Other forms	3	11	39
Total No. Species	60	170	429

method and season of collection. The meager representation of the *Ciliata* may be due to the absence of sewage contamination and hence of excessive bacterial development in the creek waters. The food supply of many species is thus lacking. The absence of a well-developed phytoplankton, aside from diatoms, and the fact that much of the vegetable debris of the silt is only in the early stages of decay may account for the small number of species of *Rotifera* and *Entomostraca*, groups which in part depend upon these sources of food either directly or indirectly. The recent origin of the creek water from rain, or springs and ground seepage, affords insufficient time for the breeding, not only of these organisms which form the more distant links in the chain of food relations, but also for many of the nearer ones, such as the algæ, which subsequently do appear in large numbers in the creek waters after they mingle with those of the impounding bottom-lands or the slowly moving current of the main stream.

No chemical analyses have been made of the water in Quiver Creek, but those made of samples taken at our plankton station in Quiver Lake are in a measure applicable to the creek itself, especially at low-water stages. In Table XIII. are data derived from weekly analyses from September 24 to December 3, 1895, and fortnightly analyses from October 19, 1897, to March 28, 1899, made by the Chemical Survey. A summary of the averages will be found in the table on page 521. These show a smaller amount of residue on evaporation in the lake (268.9) than in the Illinois River (367.5), which may be due in part to the deposition of suspended silt owing to the impounding action of the lake and to the sandy nature of the catchment-basin. The loss on ignition is somewhat less, and the oxygen consumed very much less (5.9 to 10.4), in the lake than in the river, indicating a smaller amount of organic matter in the former. The small amount of chlorine (4.8 to 21.6) exhibits the freedom of the lake from sewage contamination. The albuminoid ammonia, representing undecomposed organic matter, is also present in small quantity in the lake as compared with the river (.25 to .48), while the free ammonia, indicative of the first stages of decomposition, is still less (.165 to .860). The nitrates, the final products of decomposition, are not at all abundant in the lake (.66 to 1.58).

The lake waters, and by inference the tributary creek waters also, are thus deficient, as compared with the river, in organic matters and the products of their decay. These products are fundamental constituents in the nutrition of the phytoplankton, which in turn supports that part of the zoöplankton which does not depend upon the organic detritus in suspension for food. The chemical condition of the water of Quiver Creek is thus unfavorable to the development of a plankton quantitatively as great as that of the river. Furthermore, its waters, poorer in the plankton itself, not only dilute the plankton of the river, but even diminish the productivity of the river water by lowering the relative amount of its nutrient constituents.

SPOON RIVER.

In Spoon River we have a typical tributary of the larger type, from prairie country, with no unusual contamination by sewage or industrial wastes, draining 1,870 square miles, a little more than one tenth of the basin above its mouth, and dicharging directly into the main channel.

A detailed discussion of the environmental conditions in this stream and of its plankton production will be found on pages 340–350. It will suffice in this connection to recall the facts that the recent origin of the tributary waters, its greater turbidity, and burden of silt, all militate against plankton production in this tributary.

A consideration of the chemical conditions in Spoon River and in the Illinois throws much light on the nutrition available for the support of the plankton in tributary and channel waters, a very important factor in the matter of plankton production. In the following table the averages of all analyses in these two streams and in Quiver Lake are given.

CHEMICAL EXAMINATION OF WATER FROM THE ILLINOIS RIVER AT HAVANA, FROM SPOON RIVER NEAR ITS MOUTH, AND FROM QUIVER LAKE—PARTS PER MILLION.*

			Spoon River	Illinois River	Quiver Lake
Residue on evaporation		Total	522.3	367.5	268.9
		Dissolved	167.1	304.1	248.2
	Loss on ignition	Total	41.9	32.8	27.5
		Dissolved	24.4	25.1	25.6
Chlorine			3.8	21.6	4.8
Oxygen consumed			14.1	10.4	5.9
Nitrogen as		Free ammonia	.24	.86	.165
		Albuminoid ammonia	.60	.48	.25
		Total organic	1.29	1.03	.61
		Nitrites	.039	.147	.023
		Nitrates	1.01	1.58	.66

*Data from Tables X., XI., and XIII.

It is noticeable that Spoon River carries the largest amount of matter in suspension, both absolutely and relatively, as shown by the high total residue on evaporation (522.3 to 367.5 and 268.9) and by the smallest amount of the residue in solution (167.1 to 304.1 and 248.2). This is further shown by the fact that the solids removed by the army filter in Spoon River average 1,755 cubic centimeters per cubic meter to only 592 in the same year in the Illinois. The large amount of organic matter undecayed and undissolved, and therefore not available for the support of the plankton, is partially indicated by the high oxygen consumed (14.1 to 10.4 and 5.9), the high albuminoid ammonia (.60 to .48 and .25), and the high total organic nitrogen (1.29 to 1.03 and .61), when considered in conjunction with the small amount of residue in solution. On the other hand, the waters of Spoon River are quite deficient in forms of nitrogen more available for the phytoplankton, the free ammonia (.24), nitrites (.039), and nitrates (1.01) being in each case less than in the Illinois (.86, .147, and 1.58), while the chlorine (3.8), an index of sewage contamination, is less than a fifth of that in the channel (21.6).

Spoon River has therefore great resources, in so far as organic matters and the products of their decay are concerned, for the support of the plankton. Not all of the matter is in solution for immediate utilization, but there is still sufficient for a large plankton development, time for which has not been allowed in the tributary stream. The immediate effect of the access of the contributions of Spoon River to the channel is, in the average, a dilution of its inorganic nitrogen per m.^{3} of water, which is in some unknown measure made good by the contributions of silt, in part of organic origin. The net result is, of course, a large addition to the *total* resources of the channel waters available for the present and future development of the plankton.

The amount of nitrogen in its several forms which Spoon River carries is not small as rivers go, for this stream drains a plain unsurpassed in fertility by any other part of the catchment-basin of the Illinois. It also receives a moderate amount of sewage from the cities of Lewistown and Canton, and the drainage from a considerable number of towns. Its diluent effect upon the plankton of the Illinois is thus not due to the poverty of its own waters but rather to the excessive fertility of the main stream, a fertility resulting from the sewage and industrial wastes received by that stream from the cities of Chicago and Peoria.

The contrast in fertility as indicated by the analyses tabulated above is not as great as the differences in the plankton production of the two streams. The ratio of nitrates which perhaps most fully expresses their relative fertility is 1.01 to 1.58, while the ratio of the plankton production as expressed in the average of the monthly means of the catches by the silk-net method is 0.256 to 2.71. The failure of Spoon River to develop a more abundant plankton is thus apparently due to some other cause than the lack of nutritive elements in the water for the support of the plankton. The development of a considerable volume of plankton in it at times of low water and slack current makes patent the probability that the lack of time for breeding is at least one of the important factors in the relative paucity of the plankton of this tributary stream.

QUANTITATIVE COMPARISON.

A comparison of the quantities of plankton taken by means of the silk net in the two streams affords a fair contrast of their relative productivity. Certain sources of error are, however, present in the data of comparison, and as they are not equally distributed in the case of both streams they invalidate to some undetermined extent precise comparisons. These sources are the leakage of the plankton through the silk and the presence of silt. The plankton escaping through the silk is largely made up of the *Mastigophora* and small diatoms and algæ, and they are found alike in both streams. The presence of a more abundant plankton in the Illinois and the somewhat flocculent nature of much of its silt tend to induce more perfect filtration and to check slightly the leakage of small organisms through the silk. In Spoon River, on the other hand, the plankton is scant and the silt mainly of fine loam and clay in suspension, so that the silk net rarely clogs and the escape of small planktonts is but slightly impeded. This loss by leakage is far more significant in the case of Spoon River than it is in the Illinois, for the escaping plankton constitutes a relatively larger *proportion* of Spoon River's total product than an equally large or even greater loss would form of the total product of the Illinois. Again, the quantity of silt is both relatively and absolutely much greater in the waters of Spoon River than it is in the Illinois, and it is of a different nature. This greatly increases the difficulty of maintaining any uniformity of standard in the estimation of the silt content of the plankton catches in the two streams. These sources of error, although considerable, do not, however, invalidate the conclusions here drawn regarding the relative productivity of the two streams. They are still patent within any reasonable limit of error.

The plankton of Spoon River is very much less than that of the Illinois. The average amount present in a cubic meter of water in Spoon River, as shown by the average of the amounts in thirty-six collections made between August 18, 1896, and March 7, 1899, is .465 cubic centimeters. This average amount is reduced to 0.191 cubic centimeters if the two collections of September 11 and 30, 1897, are omitted. This average is still more reduced if we omit the collections from the last of August, 1897, to the close of the year—a period of exceptional and prolonged low water. The omission of these four months lowers the average to 0.044 $cm.^3$ per $m.^3$ of water, an amount which more truly represents the normal contributions of the tributary to the main stream in years of rainfall normal both in quantity and distribution.

The average plankton content of a cubic meter of Illinois River water, as shown by the average of 235 collections made between June 12, 1894, and March 28, 1899, is 2.19 cubic centi-

COMPARISON OF MONTHLY MEANS OF PLANKTON PRODUCTION IN ILLINOIS AND SPOON RIVERS, BASED ON ALL CATCHES.*

Year	January		February		March		April		May		June	
	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.
1894	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.74	.....
1895	.....	.....	0.01	.....	.....	.....	3.18	.....	.....	.....	30.42	.....
1896	0.01	.....	0.02	.....	0.07	.....	5.67	.....	1.30	.....	0.72	.....
1897	.....	.....	0.04	0.047	0.38	0.007	5.11	0.048	5.62	0.440	0.27	0.250
1898	0.45	0.017	0.27	0.016	0.33	0.124	4.40	.....	11.30	0.023	3.96	0.096
1899	0.18	0.005	0.81	0.001	0.28	0.026	.....	.....	.....	.....	.....	.....
Monthly av.	0.213	0.011	0.23	0.021	0.27	0.052	4.59	0.048	6.08	0.232	7.22	0.173

Year	July		August		September		October		November		December	
	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.
1894	5.12	.....	9.67	.....	1.36	.....	0.61	.....	0.10	.....	0.10	.....
1895	9.33	.....	4.03	.....	1.52	.....	0.57	.....	3.02	.....	1.14	.....
1896	1.44	.....	1.12	0.018	0.38	0.005	1.11	0.005	0.02	0.005	0.76	0.002
1897	4.69	.....	3.65	0.652	8.83	5.130	5.95	.....	1.00	1.671	0.56	0.599
1898	0.58	0.036	0.91	0.002	0.69	0.002	0.24	0.001	0.25	0.001	0.99	0.001
1899	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Monthly av.	4.23	0.036	3.88	0.221	2.56	1.712	1.70	0.003	0.88	0.559	0.71	0.201

*Amounts in this table are cubic centimeters of plankton per cubic meter of water after subtracting from the total catch the estimated amount of silt.

meters. This is 4.7 times as much as the average of all the Spoon River collections—11.5 times, if we omit the two exceptional collections of September 11 and 30, 1897, and 44 times, if we exclude the low-water period of the autumn of 1897 from both averages. This latter ratio, 1 to 44, represents the relative plankton content of the two streams except during periods of prolonged and extreme low water. Even in such low-water periods the waters of the tributary are less productive than those of the main stream. For example, the averages of the monthly averages of production for July–October, inclusive, in the two streams are respectively 2.89 and 5.78 cm.^{3}

of plankton per m.³ In November and December, however, the mean production in the tributary, for the only time in our records, exceeds by 67 and 7 per cent. the production in the channel. On the average, however, production in the tributary, even in most favorable conditions, is less than in the main stream, and the contributions of the tributary continue to be generally a diluent of the channel plankton.

If the means of the monthly averages are compared, the ratio, when all collections are included, between production in Spoon and Illinois rivers rises from 1 to 4.7 to 1 to 10.6. This ratio, which eliminates somewhat of the error resulting from differences in the number of collections in the two streams, probably represents more nearly the actual ratio of production in the two streams derivable from our data.

In the table which follows, the catches in the two streams upon coincident—approximately so in five instances—dates only are averaged. This reduces the number of catches in the Illinois River from 235 to 33, modifies some of the monthly averages, and changes the ratios of production in the Illinois and Spoon rivers, based on means of the monthly averages, from 1 to 10.6 to 1 to 9.9, but does not otherwise materially alter the relationship of production in tributary and channel waters as determined on the basis of all collections.

If the silt is not eliminated by estimation the average amount of the silk-net catch in the two streams is respectively 1.41 and 3.98 cubic centimeters per cubic meter. The change in the ratio is due to the greater proportion of silt carried by Spoon River.

In the table of plankton comparisons following page 342, the averages of the amount of plankton per cubic meter of water in the two streams is given by months for the years of our operations. Decimals to three places are not here indicative of great accuracy of measurement, They result from efforts to represent the small proportion which the plankton forms of the silt-laden catches from Spoon River. Considerable differences in these small quantities in this table and elsewhere in Spoon River tables have little significance save as they express relative quantities in catches of chronological sequence. Thus, in this table differences in successive months have more significance than those in the same month of different years.

COMPARISON OF MONTHLY MEANS OF PLANKTON PRODUCTION IN ILLINOIS AND SPOON RIVERS, BASED ON COINCIDENT CATCHES.*

Year	January		February		March		April		May		June	
	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.
1896	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	......
1897	.....	.....	0.040	0.047	0.380	0.007	5.110	0.048	5.620	0.440	0.270	0.250
1898	0.470	0.017	0.100	0.016	0.430	0.124	.....	.....	10.310	0.023	5.280	0.096
1899	0.220	0.005	0.110	0.001	0.540	0.026	.....	.....	......	.....	.....	......
Monthly av.	0.345	0.011	0.083	0.021	0.450	0.052	5.110	0.048	7.965	0.232	2.775	0.173

Year	July		August		September		October		November		December	
	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.	Ill. R.	Spoon R.
1896	.....	.....	0.68	0 004	0.380	0.005	1.105	0.005	0.020	0.005	0.765	0.002
1897	.....	.....	2.02	0.056	11.920	5.130	.....	.....	0.665	1.671	0.030	0.599
1898	0.140	0.036	1.620	0.002	0.610	0.002	0.170	0.001	0.140	0.001	1.260	0.001
1899	.....	.....	.....	.....	.....	.....	.....	.....	......	.....	.....	......
Monthly av.	0.140	0.036	1.440	0.021	4.303	1.712	0.638	0.003	0.275	0.559	0.685	0.201

*Amounts in this table are cubic centimeters of plankton per cubic meter of water after subtracting from the total catch the estimated amount of silt.

A detailed comparison of the production of the two streams by months has been made elsewhere (see pp. 340–350). For the purposes of the present discussion it will suffice to call attention to a few salient features found in the somewhat irregular data of the table.

In but few averages does the plankton in Spoon River equal in amount that of the Illinois. Not only is this true of the monthly averages with but three exceptions, but also of almost all of the single catches when comparison is made of those taken in the two streams on the same day, or on the nearest dates when they were not coincident. The exceptions are four, one in February, 1897, when flood conditions prevailed in both streams and the amount of plankton in each was small, and three in the autumn of the same year during the period of prolonged low water. During this period the discharge from Spoon River was very slight, the current scarcely perceptible, and the temperatures somewhat higher than usual at this season of the year, so that the tortuous channel of the stream through the bottom-lands became practically an impounding lagoon. A comparison of Tables III. and IV. and Plates XI. and XVII. shows a general correspondence during this period between the two streams in that the autumn maximum and winter decline are present in both, the maximum being somewhat greater in the Illinois and the decline somewhat less pronounced in Spoon River. It was during the period of this winter decline that Spoon River attained a somewhat greater productiveness than the main stream. The autumn rains of that year were long delayed and were largely absorbed by the parched earth, so that the run-off was but slight, and Spoon River was not subject to the repeated and often almost continuous flushing which characterizes many autumnal seasons. By reason of these unusual conditions Spoon River exhibited at this time more of the environmental features of an impounding backwater than those of a tributary stream, and in these conditions lies the occasion of the unusual plankton production manifested by the tributary at this season. As before stated, the *average* for this low-water period was greater in the main stream than in the tributary, though, as the data in the tables referred to show, there was a period of about two months in which the tributary directly increased the relative amount of plankton in the main stream.

In other years than 1897, and especially in other parts of the year, the contrast between the amounts of plankton in the two streams is much more marked. In general it is most pronounced during the spring and early summer at the time of the plankton maximum. Save in 1897 the contrast between the two streams is also well marked during the autumn maximum. The phenomenon of these maxima is thus a function of the main stream rather than of the tributary.

The great irregularities in the Spoon River plankton as contrasted with the main stream are due to the more profound effect of floods upon its life. In the main stream, floods less frequently and less thoroughly replace its waters owing to its greater volume and, especially, to its reserve of densely populated impounded backwaters. The small tributary, on the other hand, is scoured very completely by every considerable rain, and has no reserve waters to maintain its equilibrium. The oscillations in the quantity of life in its waters are thus more frequent and more extreme than in the main river.

The quantitative effect of the plankton of a tributary upon that of the main stream may be expressed in the following simple formula:

$$\frac{DP + dp}{D + d} = P'.$$

in which D and d represent the discharge from the catchment-basins of the main stream and tributary, P and p, the plankton per cubic meter of their respective waters, and P' that of the main stream below the junction with the tributary. In the case of Illinois and Spoon rivers the average discharge is approximately in the ratio of the areas of the catchment-basins. Both lie in the same storm belt, and the slightly increased rainfall in Spoon River basin, which is the more southerly, is more than counterbalanced by the accession of water from the Illinois and Michigan Canal due to the pumpage from Chicago River at Bridgeport. Accepting these areas as a basis for the ratio of discharge, we find that the average amount of plankton in the Illinois is reduced from 2.19 cubic centimeters per cubic meter to 2.00 if the low-water period of 1897 is retained—a decline of 9 per cent. If the low-water period is rejected from both averages the amount falls to 1.96 cubic centimeters—

a decline of 11 per cent. These figures are based on averages. Naturally in tributary floods the increased volume and lessened plankton will cause a much greater dilution, though of brief duration. In moderate and low-water stages the decline will be less than the above average and of longer duration. The relative discharge of the two streams also enters to further complicate the problem. But whatever form the ratio of production of the two streams may assume in a precise determination, it is safe to say that the general conclusion drawn from the present data will be confirmed.

QUALITATIVE COMPARISON OF PLANKTON OF SPOON AND ILLINOIS RIVERS.

The details of this subject, in so far as they pertain to the constituent species of the plankton of the two streams, will receive attention in the discussion of species in the second part of this paper. For the present only the general phases and most striking contrasts will be discussed.

With a view to presenting in concrete form the contrast in the relative population of the two streams I have prepared Table XIV., which gives statistical data compiled from the enumeration records. The table exhibits the number of individuals per cubic meter of water of the main groups of planktonts in the thirty-five collections in Spoon River, and in similar collections made on the same date in the Illinois River. In a few cases only, the Illinois River collections were made several days prior or subsequent to the Spoon River collection. The groups listed are the algæ, diatoms, *Rhizopoda*, *Mastigophora*, *Infusoria*, *Rotatoria*, *Entomostraca*, insect larvæ, and miscellaneous. The total numbers of individuals and of species are also given. These data are taken entirely from catches with the silk net, and are subject to the errors arising from leakage through the silk. The silt interferes in this case only in so far as it obscures the planktonts to a greater extent in Spoon River collections, and thus necessitates a greater dilution in counting and, in consequence, a greater factor in computation. The margin of error is accordingly somewhat greater in data from the silt-laden planktons of Spoon River. The leakage affects primarily the smaller flagellates, ciliates, and diatoms. For reasons previously given, the leakage introduces proportionately a greater source of error in the Spoon River data, and, in so far as it is operative, tends to increase the contrast between the two streams. From data now at hand it is not possible to estimate the extent of this error, but it should be borne in mind in considering the data in the table concerning these groups especially. In spite, however, of these sources of error, some points of contrast are so striking that certain conclusions seem justified.

There is a marked contrast in the total population. The ratio of the average number of planktonts in a cubic meter of Spoon River water to that in a like quantity from the main stream is 750,429 to 28,283,295, or 1 to 38—a ratio much greater than that found in the volumetric comparisons. It is due to the relative preponderance of small planktonts, especially the limnetic diatoms, in the collections from the main stream, as will be seen on comparison of the ratios of the other groups listed in the table. If the low-water period of 1897 be excluded from both averages the contrast between the two streams will be very much heightened. The data from these grand averages of all the coincident collections in the two streams are thus strongly confirmatory of the contrast in productiveness disclosed by the volumetric comparisons, and of the fact that the access of water from Spoon River causes a diminution in the number of organisms per cubic meter of water in the main stream.

The comparison of the representations of the various groups in the collections tabulated, throws some light on the qualitative differences in the plankton of the two streams.

The *algae*, other than diatoms, as in the case of all groups except the insect larvæ, are present in smaller numbers in Spoon River, the total ratio being 1 to 1.4—abnormally low because of a single unusual collection in the autumn of 1897. The ratio in 1898 and the latter part of 1896, 1 to 10, is probably a fairer statement. The number of species noted is 20 and 49 respectively. The main stream has a greater variety of the smaller *Chlorophyceæ* and of the blue-green algæ, while in both individuals and species the desmids are well represented in the tributary. Littoral species predominate in the latter, though limnetic forms also occur. It is significant that the algæ, primary links in the chain of food relations, have already attained a considerable development in the tributary waters.

The *diatoms* present the most striking contrast in the table, the ratio being 1 to 78. This great disproportion is caused by the larger numbers of certain limnetic diatoms, notably *Melosira*, *Asterionella*, *Fragilaria*, and *Synedra*, in the plankton of the main stream. These are present in the tributary, but only in smaller numbers, while species of littoral habitat present in both streams are relatively more abundant in Spoon River. The contrast between Quiver Creek and Spoon River in the proportions of their diatom flora is significant. In the creek the shores and bottom are more immediate and effective features of the environment than they are in the larger tributary, hence we find there that the diatoms are largely littoral forms, and they and the *Rhizopoda* which feed upon them constitute almost the total plankton. In Spoon River the same species occur, though data are lacking for quantitative comparisons with Quiver Creek. These littoral species are, however, overshadowed by the development of other and more typical plankton organisms, so that they constitute here a smaller relative proportion of the planktonts than they do in Quiver Creek. The littoral species find a place for development along the shores and bottom of the tributary streams, and by reason of the protection there afforded, or of their sessile habit, they have time for increase. The limnetic forms, on the other hand, are more at the mercy of the current, and though at low water they appear in numbers in Spoon River, they rarely find sufficient time at other seasons for their characteristic increase until they reach the main stream. The greater fertility of the water in the river is doubtless also a factor in causing the marked difference in the diatom flora of the two streams.

The *Rhizopoda* are twelve times as abundant in the Illinois as in Spoon River. During the winter and spring flood of 1897 the tributary waters contained more *Rhizopoda* than the main stream, but throughout the remaining period of our collections the tributary waters would serve, almost as a rule, as diluents of the rhizopodan fauna of the Illinois. This group of planktonts did not show an increase in the low-water period of 1897 similar to that of many other groups—a phenomenon to be explained by the fact that the diatoms, their main food supply, made no unusual growth during that period.

The species of *Rhizopoda* are about half as many in Spoon River as in the Illinois (17 to 30—see table on page 518), and all of the species from Spoon River are present in much the same relative proportions in the Illinois. There do not appear to be any which find their centers of distribution in the tributary. Its contributions of rhizopods thus neither diversify nor relatively increase the plankton in the main stream.

The data concerning *Mastigophora* are to a large extent vitiated by the error of leakage. The tabulations of the silk-net catches indicate their great predominance in the main stream, 1 to 24 as an average, though other seasons than the low water of 1897 exhibit a much greater contrast, that for the whole year 1898, for example, being 1 to 351. In the period of low water of 1897 the tributary stream showed a greater development of these organisms than the main stream, especially of the green forms.

The presence of these organisms in Spoon River in considerable numbers during the heated term of every year is indicated by the remarkable water-bloom which appears on clear still days about the middle of the afternoon. This is similar to that of the Illinois, but seems to be better developed, taking the form of a decided green scum on the surface. How far this indicates a *quantitative* predominance of the organisms of the water-bloom can only be determined when our filter catches shall have been examined. So far as the silk catches go they do not show the quantitative predominance of the water-bloom organisms in the tributary which the surface appearances would indicate. The greater turbidity, and the more sheltered situation and consequently quieter surface of Spoon River may tend to bring its quantitatively smaller water-bloom to the surface in a greater proportion than is possible in the more disturbed channel waters. These organisms form an early link in many chains of food relations in the plankton, and it is significant that they reach a considerable development in the plankton of tributary streams.

The species of *Mastigophora* are less than half as numerous in Spoon River as they are in the Illinois (28 to 62), and none was found peculiar to the tributary, or having there its center of distribution. Thus, excepting in periods of prolonged low water, the *Mastigophora* fauna of the plankton of the tributary neither increases nor diversifies that of the main stream.

The *Infusoria* in Spoon River are greatly exceeded by those of the main stream, the ratio being 1 to 20. The only marked exception to this relation occurs during the early part of the low-water period of 1897, when the ciliates, principally *Codonella*, attained a greater development in Spoon River. This excess was soon masked by the usual autumnal increase of *Carchesium* and *Epistylis*, and of the free ciliates preying upon these sessile forms, in the main stream. This autumnal increase is not shared to any great extent by the tributary, probably by reason of its lesser contamination by sewage. The infusorian fauna was by no means fully determined in the two streams, but so far as identifications were made, they indicate much less diversity in the infusorial fauna of Spoon River and no species peculiar to, or predominant in, the tributary. Thus, excepting the period of low water in early fall, the contributions of *Infusoria* from the tributary do not enrich the plankton of the main stream, and at no time do they tend to diversify it.

The *Rotatoria*, according to the grand average in Table XIV., are almost equally abundant in the two streams (1 to 1.9). This equality at once disappears if the low-water period of 1897 be excluded from the averages. The ratio in 1898 is 1 to 36, and as this is a year of normal hydrograph it may represent more nearly the true proportion in the production of rotifers in the two streams. The data in the remainder of 1897, in 1896, and in 1899, so far as they go, sustain this higher ratio. This ratio is somewhat greater than that of the algæ, rhizopods, and infusorians, which form earlier links in the chain of food relations. The rotifers, on the other hand, depend upon these groups for food, and become later links in the chain, and consequently do not, for lack of time, attain the development in tributary waters that they do in the main stream. The diatoms and *Mastigophora* also form considerable elements in the food of the rotifers, and since these groups are proportionally less frequent in Spoon River than in the main stream, the deficiency in this food element may be one cause of the lesser development of rotifers in the tributary. Most rotifers, however, do not exhibit such limitations in diet, and the effect of this deficiency in food must be largely quantitative.

The number of species of rotifers found in Spoon River is much less than that in the main stream (44 to 107—see p. 519), and none peculiar to the tributary was noted. The *Bdelloida*, which are principally shore-loving and bottom forms, constitute a relatively greater proportion of the species and individuals in the tributary, though their absolute numbers per cubic meter of water are rarely in excess.

In the low-water period of 1897 the limnetic species common in the main stream and in the residual backwaters reached an unusual development in Spoon River, even in excess of that in the main stream. The conditions then prevalent, the higher temperatures of a late autumn, stagnating water with little or no current, and the absence of the usual autumnal flushings, combined to favor the unusual phenomenon. During this season the contributions of Spoon River to the rotiferan fauna of the main stream would increase the amount of rotiferan plankton therein, though not diversifying it—as will be seen on comparison of the relative number of species in the two streams at that season.

Excepting, then, in seasons of prolonged low water in the autumn, the contributions of Spoon River to the rotiferan plankton of the main stream stream result in its dilution, and aside from a greater proportion of the littoral fauna they add little to its diversification.

The *Entomostraca* are numerically a very small factor in the life of Spoon River and form a very small volume of its plankton product, the ratio of the entomostracan population in the two streams being on an average 1 to 28. This ratio is well maintained if the years are considered individually, being 1 to 32 in that portion of 1896 represented in our collections, 1 to 35 in 1898, and 1 to 23 in 1897. The ratio in this latter year thus shows some effect of the prolonged low water, but not to the degree which is shown in the case of the rotifers. The *Entomostraca* illustrate most clearly the effect of the time element in the development of the plankton. Their growth is less rapid than that of any other type of planktonts, and in consequence they cannot attain in tributary waters the numbers that they do in the older waters of the main stream and its backwaters. The number of species is also much smaller in Spoon River than it is in the Illinois (13 to 49), and none peculiar to the tributary was noted. Most of the adult *Copepoda* belonged to a single species, *Cyclops serrulatus*, and it is probable that most of the immature stages should be referred to the same species. This seems to be a creek species, and to have its center of distribution here rather than in the main stream, where it never attains the numbers that most of the other *Copepoda* do.

The contributions of *Entomostraca* made by the tributary are thus very small at all times, and have only a diluent effect upon the entomostracan plankton of the main stream, adding some diversification in the case of a single species of *Cyclops*. Spoon River carries no marked contributions of *littoral Entomostraca* to the main river.

Of all the groups of planktonts the insect larvæ (principally *Chironomus*, with a few *Dixa* and *Tanypus* larvæ) alone are present in larger numbers per cubic meter in Spoon River than in the main stream. They are essentially littoral forms especially common about driftwood, which abounds in Spoon River—a fact which doubtless accounts for their frequent occurrence in the plankton of that stream.

The total number of species of planktonts noted in the collections from the two streams in my enumerations of the plankton, and listed in Table XIV., is not to be taken as representing the total number present. But a small part of each catch was examined, and rare species in both streams usually escaped detection. Their relation to each other, however, affords an index of the relative number of species present in different collections in the same or different streams provided the method of examination is similar. The silt makes uniformity of dilution impossible in many cases, and thus introduces some error into the data. The *average* number of species noted in a Spoon River collection was 24 to 69 in the Illinois, a difference less marked than that disclosed by the volumetric or the statistical comparison, but still significant of the relative paucity of the plankton of Spoon River and the more limited range of its constituent organisms.

The *total* number of species recorded from Spoon River is 170, while the Illinois yielded 429. The greater number of collections examined from the latter stream may explain a part of this difference. Without exception, all the identified species found in Spoon River have occurred also in the Illinois above the mouth of Spoon River. The only species in the tributary which seem to reach as great a development there as they do in the Illinois, or a still greater one, are the species of *Surirella*, especially *S. splendida*, several forms of *Closterium*, *Cyclops serrulatus*, and the dipterous larvæ above mentioned.

A comparison of the total population of the two streams throughout the thirty months covered by our collections, as shown in the final columns of Table XIV., throws some further light on the relations between the plankton of the two streams. Traces of the same seasonal routine appear in both; the spring maximum appears in both at about the same time, while the midsummer decline and the autumn maximum are evident, but not in all cases well defined. The environmental factors common to both, especially that of temperature, thus tend to produce similar effects. Throughout all these changes, save in the low-water period of 1897, the marked contrast in the total population continues unbroken, a constant witness to the effect of the great points of difference in the two habitats, namely, the age of their respective waters and their relative richness in the immediately available elements for the support of life. It is only when these points of contrast in the environment vanish, by reason of the slight current, as in the low water period of 1987, and by reason of the increase of the products of organic decay at such times in the water of Spoon River, that the plankton of the two streams approaches equality in production and exhibits a comparable assemblage of constitutent organisms.

The contrast between the autumn planktons of 1896 and 1898 and that of 1897 is not only due to the low water of this year, but also to frequent flushings which were caused by the many minor rises during the autumn of the two years first named. (See Plates X., XI.) These autumnal rises are due to general rains, which, as a rule, affect both Spoon River and the main stream at about the same time. The difference in their effect upon the plankton of the two streams is very evident in the data of Table XIV. The autumnal plankton of the Illinois shows a somewhat similar population in all three seasons. Spoon River, on the other hand, shows a great falling off in numbers—from several million to a few score thousand—in both autumns, in which these rises are frequent. The effect of these minor floods is thus deleterious to the plankton of the tributary in accordance with the general principle that they decrease the time for breeding the plankton in its waters. They also prevent the development of plankton maxima in the tributary by repeated removals of whatever accumulations are produced. Owing to the differences in their volumes and in the slope of their channels, these flushings are more complete and more rapid in the tributary than in the main stream, and their relative effect upon the plankton is greater in the former than in the latter.

How far the conclusions here drawn regarding the relations of tributary waters to the main stream will hold true for other localities can be determined only by examination. The local conditions in this instance are in some respects peculiar. The large amount of sewage in the main stream and the relatively small size of the tributary have here enhanced the contrast between their plankton content. The distinction between tributary and main stream in this instance is only an illustration of a wider generalization, broached in the discussion of the relation of the current to the plankton. In all types and conditions of the environment, *time for breeding* is a fundamental factor, and in the relation of tributary and main stream a contrast in the length of time afforded for this development is evident. Wherever this contrast occurs we may reasonably expect, other things being equal, that the *older* stream water will support the more abundant plankton, and that it will also exhibit the greater diversification in its constituent organisms.

The facts derived from the examination of the tributary waters of Quiver Creek and Spoon River indicate clearly that streams of this kind add but little to the total plankton of the main stream, and diversify it only by increasing the proportion of littoral species already present. Owing to the slight development of plankton in their waters, the immediate effect of their access is a dilution of the plankton per cubic meter of channel water. The initial steps in the sequence of plankton development in these tributary waters have been taken in the growth of the smaller algæ and diatoms, but the degree attained is still below that in the channel.

Channel plankton is therefore *not* in any considerable degree derived from or maintained by the contributions of plankton from tributary streams of the kind here examined, and these are typical of most of the tributaries of the Illinois not modified by industrial agencies. It is not merely the mingled plankton of confluent streams, for in quantity and components it is much greater and more diversified than that of the tributaries. The tributaries add to the *total* resources of the channel, and increase the *total* population slightly, while diluting some of the food elements and the plankton per m.^{3} These resources are utilized in the channel and backwaters, and the dilution of the plankton is thus made good. Tributary waters, then do not directly contribute to the channel plankton, and only, indirectly aid in its maintenance. They are in the main diluents of channel resources and of its plankton.

RELATION OF BACKWATERS TO CHANNEL PLANKTON.

The discussion of the relation of the backwaters to the potamoplankton is one fraught with difficulty both on account of the lack of full data and also because of the complexity of those at hand. The quantitative studies which have been made of Quiver, Dogfish, Thompson's, Flag, and Phelps lakes, each representing a particular type of the bottom-land waters, enable me to compare the *amount* of plankton present in these various regions with that of the main stream. So, also, the cursory examinations made on many of the collections afford a basis for some general statements as to the *nature* of the contributed plankton, though the data on which these statements rest cannot be given here, and their final verification will come, if at all, when the qualitative analyses of the plankton of these several regions shall have been completed. The absence of any accurate data as to the volume of water discharged into the river from the regions in question adds another element of uncertainty, while the problem is further complicated by the fact that many bottom-land waters receive tributary streams, of minor importance, as a rule, for the river as a whole, and yet of a size sufficient to affect profoundly the waters which they impound.

The slight development of the flood-plain, the low gradient, and the retardation of the run-off due to the floods of the Mississippi River, all combine to accentuate the importance of the impounding action of the backwaters of the Illinois River as compared with that of other streams. It thus seems probable that its plankton exhibits to an unusual degree the effect of such impounded backwaters upon the potamoplankton as a type.

The amount of water impounded, as compared with that in the channel, can be estimated roughly from data given by Cooley ('97). The area of the bottom-lands is 704.3 square miles, of which 76.6 are water and 60.6 marsh. The area of the river itself presumably included in the above area, from the mouth to Utica, is 32.4 square miles, having an average width of 755 feet and a length of 227 miles in the limits given. The average width of the bottom-lands is 3.1 miles exclusive of the river. At low-water stages the marshes have little water in them, and the average depths of the bayous and lakes are slight —probably less than one half that of the river, which at this stage has, according to the averages of Cooley's estimates, an average depth of 7.5 feet. From these data it follows that the total volume of impounded waters at low-water stages is somewhat less than that in the river channel itself, and much of this is cut off from the river at that stage. Rises in the level of the river up to ten feet above low water—which is about the average bank height—increase the impounded volume. In lower levels this increase is slight, but it becomes relatively greater as the level rises. When a height of ten feet is reached, connection has been established with the greater part of the permanent waters and marshes of the bottom-land, and the impounded volume must be at least double or triple that of the channel. At this level, overflow begins, though the higher bottoms are not covered until a depth of sixteen feet is reached. At a stage of overflow each additional foot of rise in the impounded area is equivalent approximately to the volume in the channel. Thus, at a maximum flood of eighteen feet there is about ten or eleven times as much water in the impounding area as is found in the channel. These estimates accord in a general way with the observed facts of current and run-off. A bank-full river has a current sufficient to discharge its content in five days, and, allowing for increase of current and discharge in these conditions, the maximum flood would require about fifty days for its run-off. Accessions of water during the run-off would naturally tend to prolong the process to some extent. An examination of the hydrograph (Pl. VII.) will show that the decline from the flood maximum to the ten-foot level (cessation of overflow) is accomplished in the neighborhood of fifty days in some cases, as, for example, in 1898.

A small part of the flood is thus impounded for the full period of the run-off, while in case of the greater part of the impounded volume sufficient time elapses before discharge into the channel for the breeding of an abundant plankton, so that the backwaters become very important factors in determining both the quantity and the nature of the plankton in the main channel. Contributions from tributary streams form the other large factor, but the ratio existing between the contributions from the two sources is not easily ascertained. The only data available are the areas of the catchment-basins of the tributaries, the statistics of rainfall, and the estimated volume of the impounded water. A rough comparison of these data would indicate that during the decline of the flood to the stage of initial overflow (bank height), the impounded waters contribute somewhat more than the tributary streams to the main channel. Their contributions decrease as the river falls, and the more rapidly below the level of bank height, while those from tributary streams come to form an increasing proportion, and at low-water stages almost the only natural source, of channel waters.

With a view to setting forth the contrast in the productivity of the plankton in all the areas concerned in this problem I have drawn up the table following page 342, which gives data compiled from Tables III. to IX. showing the average number of cubic centimeters of plankton per m.^{3} of water for each month in which collections were made, from June, 1894, through March, 1899. The silt has been eliminated *by estimation*, and all corrections, such as coefficient, have been made, so that the data are as comparable as the circumstances will permit. The data in the table are derived from 642 catches, and cover a sufficient range of seasons and years to yield averages significant of any larger relations existing between the several bodies of water examined, and also to illustrate the influence of certain common, as well as some contrasting, factors in this fluctuating environment.

The backwaters in the list of stations examined by us are typical of practically the whole range of the bottom-land waters of the Illinois, including, as they do, a reservoir and a spring-fed lake, both tributary at practically all seasons, a marsh, and a lake tributary for only a part of the season and free from vegetation. Results derived from an examination of these will therefore afford some conception of the relationship between the plankton of the backwaters of the stream as a whole and that of the channel.

In the discussion of production in these backwaters (pp. 350–454) I have noted the periods when hydrographic conditions permitted a run-off of the backwaters impounded in the several localities to the main channel, and instances in which their plankton contents served to increase or dilute that of the channel. It will suffice in the present connection to note that production is less in the backwaters than in the channel in only 48, or 26 per cent., of the 185 monthly averages—the total number of all of the monthly averages of all stations but the Illinois and Spoon rivers. In Quiver Lake we find 30 months out of 53, or 57 per cent., deficient in production as compared with the channel; in Dogfish Lake, 6 out of 25, or 24 per cent.; in Flag Lake, 2 out of 24, or 8 per cent.; in Thompson's Lake, 8 out of 52, or 15 per cent.; and in Phelps Lake, 2 out of 31, or 6 per cent.

Lakes most free from access of tributary water and from vegetation are most constant in their excess of production over channel waters. Thus we find that of these 48 instances of deficient production in the backwaters 30 occur in Quiver

Lake, where tributary creek and spring waters form a larger proportion of the content of the lake, and 19 of the 30 are in the low-water period, July–November, when the proportion of tributary waters is greatest and the impounding function at its lowest level, and vegetation at its height. Of the remaining 18 instances of deficiency, 6 are in Dogfish Lake, which is to some extent under the influence of the hydrographic conditions of Quiver Lake, and is likewise dominated by vegetation. Three of the 6 cases of deficiency appear in July-August, in the height of the dominance of vegetation and at times of slight run-off. Two instances at the same season and under similar conditions of vegetation and discharge appear in the monthly averages of Flag Lake. In the monthly averages of Thompson's Lake there are 8 instances of deficiency, but in half of these the deficiency is less than 30 per cent. There are but 2 cases of deficiency in Phelps Lake, both at times when Spoon River tributary water was passing through the lake. Furthermore, 33 of the total 48 instances of deficiency in production in backwaters, as compared with channel, occur in July–December, during the low-water period of least run-off of impounded backwaters, and of the remaining 15 instances during the January–June period some probably result from insufficient data, and others are found when the stagnation (*Moina*) pulse of June, 1895, occurred in the river.

We must, therefore, conclude that the greater part of the backwaters predominantly bring to the channel in their run-off a richer plankton than that with which their contributions are mingled. The extent of this predominance and its changes with the seasons and from year to year will be seen in the table of monthly means following page 342. It is summarized in the following table, which gives the mean plankton content in channel waters for each month and the average of the monthly means of the five backwaters, Quiver, Dogfish, Flag, Thompson's and Phelps lakes, together with the ratios between channel and backwater production in each month.

An inspection of this table shows that during the colder

	Jan.	Feb.	March	April	May	June	July
Channel plankton..	.21	.23	.27	4.59	6.08	7.22*	4.23
Backwater plankton	1.63	2.06	2.46	11.43	18.91	6.19	3.92†
Ratio.............	1 to 8	1 to 9	1 to 9	1 to 2.5	1 to 3	1 to .9‡	1 to .9‖

	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual
Channel plankton..	3.88	2.56	1.70	.88	.71	2.71
Backwater plankton	13.90	12.92	14.78	15.10	6.81	9.18
Ratio.............	1 to 3.6	1 to 5	1 to 8.7	1 to 17	1 to 9.6	1 to 3.4

*Omitting 1895, 1.42. †Omitting 1895, 2.96. ‡Omitting 1895, 1 to 4.4.

‖ Omitting 1895, 1 to 1.3.

months, from November to March, the backwaters have from 8 to 17 times the plankton content of the channel, and in the warmer season, from April to October, from 0.8 to 5 times as much. Omitting the aberrant record of June, 1895, from channel data, it becomes apparent that there is least difference between channel and backwaters in April-May and July, predominantly the months of greatest run-off of impounded backwaters.

Channel plankton of the Illinois River, therefore, has its source in a large degree in impounded backwaters, and is maintained to a considerable extent by their run-off.

INDIGENOUS PLANKTON OF THE CHANNEL.

It does not seem probable that the channel plankton is only the mingled plankton of the tributaries and backwaters. Growth and reproduction, modified, however, by the cyclic phenomenon, continue in the channel after plankton-laden backwaters unite with it. This increase is facilitated by the fact that channel waters are generally richer (see Tables X.–XIII.) in nitrogenous matters and the other products of decay than the backwaters. During high water, when the current is more rapid, the time for further breeding is considerably reduced, even to five days, from Utica to the mouth of the

Illinois. Under these circumstances the plankton indigenous to the channel itself is of small volume as compared with that contributed from backwaters. At low water, however, it may take 23 days, or more, for the water to traverse this distance. This frequently results in such a development of channel plankton that it not only rises above that in many of the backwaters, but also takes on a characteristic facies which at once stamps it as largely indigenous in the channel itself in its origin. Instances of this phenomenon appear with prolonged low water, as in June-July, 1895, when channel plankton exceeded that in all the backwaters and was characterized by the great abundance of *Moina*. In like manner in November-December of every low-water year there has been an unusual development of *Ciliata*, principally *Carchesium lachmanni* and predatory forms feeding upon it. This, at least as shown by the catches of the silk net, does not often exceed the plankton content elsewhere, but its dominant organisms form relatively a small proportion of the backwater plankton at such times. The channel plankton is, then, largely indigenous. The autumn of 1897 saw a similar indigenous devevelopment of *Chlamydomonas* in the river which was not equaled in the backwaters.

The plankton of the Illinois River is the result of the mingling of small contributions by tributary streams, largely of littoral organisms and the quickly growing algæ and flagellates, and of the rich and varied plankton of tributary backwaters, present to an unusual degree in the Illinois because of its slightly developed flood-plain, and from which it is never entirely cut off even at lowest water. Data are lacking as to the effect of the contributions of the Illinois and Michigan Canal upon the plankton of the river. To these elements is added such further development of the contributed or indigenous organisms as time permits or the special conditions of nutrition and sewage contamination facilitate. Though continually discharging, the stream maintains the continuous supply of plankton, largely by virtue of the reservoir backwaters—the great seed-beds from which the plankton-poor but well-fertilized contributions of tributary streams are continuously sown with organisms whose further development produces in the Illinois River a plankton as yet unsurpassed in abundance.

TOTAL ANNUAL PRODUCTION.

In the absence of any precise figures of the total annual discharge of the Illinois River at its mouth or at Havana, it is futile to attempt to compute with any considerable degree of accuracy the total plankton production of this stream or of any of its tributaries or backwaters examined by us. The estimates which follow, contain, therefore, a large element of conjecture.

On page 132, computations from available data indicate a run-off at Havana of approximately 0.688 second-foot per square mile of the drainage basin of 15,250 square miles. The mean of all the monthly averages (see table p. 429) of plankton production in channel waters is 2.71 cm.^{3} per m.^{3} of water. On this basis the total discharge in the average year becomes 25,408.3 cubic meters of plankton permanently removed each year by the discharge of the stream at Havana. From the stream as a whole, given the same *plankton content and run-off per square mile* as at Havana, the total production becomes 67,598.8 cubic meters of plankton. These figures represent in a measure the *unutilized* and permanently lost organic matter available for the support of the larger, more permanent animals resident in the river and its connecting waters. They are the *net* production over and above that plankton utilized by the organisms which retain their residence in the river or its backwaters above Havana or the mouth, and those whose death and decay have removed them from the plankton by sedimentation or solution. The total production is therefore greater in some unknown and apparently undeterminable ratio.

It is evident that production varies greatly from year to with the varying plankton content and discharge of the stream. In the accompanying table I have computed the total annual production of the Illinois River on the basis of a run-off of .688

cubic second-foot per square mile of the watershed of 27,914 square miles, and a plankton production equaling that of the average for the several years of the monthly means as determined by our collections at Havana.

TOTAL PLANKTON PRODUCTION.

Year	Mean river stage, in feet, above low water	Estimated run-off—in cubic meters	Mean plankton content per cubic meter	Total plankton discharged—in cubic meters
1894	4.63	18,085,780,000	2.53	45,757
1895	3.61	14,101,560,000	5.91	83,340
1896	6.98	27,265,620,000	1.05	28,629
1897	6.90	26,953,120,000	3.28	94,605
1898	8.02	31,328,120,000	2.03	63,596
Average..........	6.40*	25,000,000,000*	2.71	67,750*

*Approximate average, omitting 1894.

It should be borne in mind that the records for 1894 and 1895 are very incomplete, and do not as accurately represent the production as do those of later years. The change in discharge from year to year has also been computed as *directly* proportional to the average river stage. This is necessarily only a rough approximation, for discharge generally increases and decreases in greater ratios than river stages, so that the differences between the several years are probably greater than the figures indicate.

While the amounts given in the table are based on some conjectural factors, it may still be that more significance attaches to the *direction of the differences* in total production in the several years. The total production varies, it seems, considerably from year to year, the greatest departures from the mean being + 40 per cent. in 1897, a year of high production and river levels above the average, and — 58 per cent. in 1896, when recurrent floods checked production, at least at Havana, in the upper river, though it is not improbable that if the backwaters and the lower river were taken into account this seeming deficiency would be largely removed. These divergences from the mean total production are considerably less than those from the mean plankton content, 2.71 cm.^{3} per m.^{3}, which in 1895 and 1896 reach limits of + 118 per cent. and − 61 per cent. respectively. This greater uniformity in total production is brought about in part by the compensating effects of lessened plankton content in years of high water, and increased content in years of low water.

The mean total discharge is 67,750 cubic meters, or 149,050,000 pounds if we compute its weight as equal to that of the same volume of water. This represents the mean annual loss of *living* organic matter from the watershed of the Illinois. The total production, including the plankton impounded in the backwaters and that utilized there and in the channel as food by other organisms, as well as that perishing within the watershed and contributing by its wastes and decay to the growth of the coarser aquatic vegetation,—this total must indeed be much greater than the amount indicated by these imperfect computations. If we add to this the undetermined but probably not inconsiderable volume which leaks through the meshes of the silk net and is therefore not at all represented in our computations, we reach a total annual production of still greater magnitude.

TOTAL PRODUCTION AS AFFECTED BY LEAKAGE THROUGH THE SILK NET.

In an earlier paper ('97b) I have called attention to the extent of leakage through the silk as determined by the enumeration of catches made by silk, filter-paper, and the Berkefeld filter. An attempt was also made later, in connection with the enumeration of the organisms of the filter-paper catches, to determine the *volumetric* catch of plankton by this method. It was my endeavor to estimate the *proportions of silt and plankton* in these catches, as had previously been done in the case of those of the silk net. There is, however, in these filter-paper catches a silt of very different character. To that which we find in the catches of the silk net there is added a large amount of fine loam, clay, and sand which passes directly through the silk, and a very considerable quantity of minute flocculent particles, presumably bacterial zoöglea. This flocculent matter occupies a large part of the field as the catch is seen in the Rafter cell. It is a difficult matter to estimate with any certainty the proportion which such silt forms of the filter-paper catches. Nor is it possible to use the same standard of estimation upon the catches of both the silk and filter-paper, owing largely to the considerable volume of the flocculent debris in the distributed plankton and the uncertainty as to its compressibility in the centrifuge. My estimates of the silt, which will be found in the table beginning on page 552, in the light of the tabulated results of the enumeration seem to be too large, probably as the result of the influence of the standard used on the silk catches. It is, therefore, my opinion that the quantities of plankton given in this table are in the main below rather than above the actual amounts present. The facts upon which this opinion is based will appear in the discussion of the results of the enumeration. It should be said that the *relative* values of the estimated quantities of plankton in this table are probably above the actual ones. They are of more importance in indicating the *direction* of the seasonal movement in production than they are in expressing the exact amounts of plankton present.

Because of this great increase in the proportion and quantity of the silt found in these filter-paper catches, even in our clearest waters, the filter-paper method does not satisfactorily solve the *volumetric* problem. It is not a satisfactory method, and, indeed, it seems probable that the same difficulty will be met in all methods which remove all suspended solids in all but the clearest lake or ocean waters. This same difficulty has balked the efforts of Lohman ('03) to determine satisfactorily the *volumetric* loss by leakage through the silk in the application of the Hensen method to a marine plankton, which leaks through the silk. In passing, it may be noted that this planktologist of the Hensen school at Kiel, working with the subvention of the University of Kiel and the German Commission for the Investigation of the Sea, after testing upon the plankton of the Baltic and Mediterranean seas the correctness of my criticisms ('97b) upon the Hensen method, concludes that the loss is volumetrically of some importance, and numerically as large as that indicated by my determinations of the leakage in our field of operations, indeed, slightly larger in some instances.

The table beginning on page 552 gives the volume of water filtered, the total catch, the computed catch per m.^{3}, the estimated per cent. of silt, and the computed volumes of silt and plankton (filter-paper catch) per m.^{3} The volumes of plankton per m.^{3} taken at the same time and place by the pump and silk net are also given, and the averages at the end of the collections for each year refer only to the coincident catches of this table. The omission of several silk-net catches in the data of 1896 and 1897 in this table makes its averages differ slightly from those of Table III.

The filter-paper catches, as in the case of the silk-net catches, represent the plankton from a *vertical* column of water from bottom to surface. Prior to the autumn of 1897 this water was collected by hose and pump, either in equal quantities at a series of levels from bottom to surface or during a continuous transit of the hose through this region, due precautions being taken to secure proportionate amounts from all levels. After this date a water-trap, consisting of a brass tube six feet in length and four inches in diameter, with a gate at the bottom, was used for securing the water for filtration. The water was taken to the laboratory, and after thorough agitation of the collection a sample of the required volume was withdrawn for filtration. The paper used was a hard-pressed filter-paper from Schleicher and Schüll, No. 575, and filtration was hastened by washing the filtering surface frequently by a spray from a rubber hand-bulb. The penetration of the small organisms among the fibers of the filter-paper, and perhaps even through it, causes some loss of material, so that the volume of the catch is somewhat reduced thereby. The estimates of silt in the table were not revised with reference to the silk-net records or after tabulation.

Recognizing the fact that these volumetric data are to an

FILTER-PAPER CATCHES, ILLINOIS RIVER.

All volumes in cubic centimeters.

Accessions number	Date	Water strained	Total catch	Total catch per m.^{3}	Estimated percentage of silt	Total silt per m.^{3}	Total plankton per m.^{3}	Catch of silk net
	1896							
22,366 e	3, VIII.	2500	.91	364	99.50	362.18	1.82	0.26
22,376 d	8, VIII.	1000	.08	80	99.00	79.20	.80	2.60
22,430 d	15, VIII.	1000	.16	160	99.00	158.40	1.60	1.16
22,436 d	21, VIII.	1000	.22	220	98.00	215.60	4.40	0.28
22,455 d	26, VIII.	1000	.13	130	99.00	128.70	1.30	0.43
22,464 d	29, VIII.	1000	.08	80	98.50	78.80	1.20	0.50
22,466 d	16, IX.	1000	.11	110	98.00	107.20	2.20	0.53
22,473 d	30, IX.	1000	.07	70	99.00	69.30	.70	0.23
22,481 d	14, X.	1000	.08	80	99.00	79.20	.80	0.18
22,497 d	17, XI.	1000	.04	40	96.00	38.40	1.60	0.02
22,509 d	3, XII.	1000	.03	30	90.00	27.00	3.00	0.58
22,512 d	29, XII.	1000	.05	50	75.00	37.50	12.50	0.94
		Average.................................					2.66	0.64
	1897							
22,518 d	3, II.	1000	.03	30	90.00	27.00	3.00	0.03
22,527 d	26, II.	1000	.04	40	90.00	36.00	4.00	0.05
22,533 d	22, III.	500	.03	60	90.00	54.00	6.00	0.38
22,539 d	27, IV.	1000	.07	70	80.00	56.00	14.00	5.11
22,552 d	25, V.	1000	.08	80	88.00	70.40	17.60	5.62
22,561 d	28, VI.	500	.11	220	99.00	217.80	2.20	0.27
22,564 d	14, VII.	1000	.08	80	75.00	60.00	20.00	8.16
22,564 e	16, VII.	1000	.13	130	80.00	104.00	26.00	6.40
22,572 d	21, VII.	1000	.13	130	96.00	124.80	5.20	0.92
22,580 d	30, VII.	1000	.06	60	96.00	57.60	2.40	1.05
22,588 d	10, VIII.	1000	.05	50	96.00	48.00	2.00	2.02
22,592 d	17, VIII.	1000	.04	40	96.00	38.40	1.60	1.98
22,595 d	24, VIII.	1000	.06	60	97.50	58.50	1.50	2.77
22,601 d	31, VIII.	1000	.20	200	75.00	150.00	50.00	9.45
22,603 d	7, IX.	1000	.34	340	65.00	221.00	119.00	8.47
22,608 d	14, IX.	1000	.05	50	82.00	41.00	9.00	19.80
22,610 d	21, IX.	1000	.19	190	90.00	171.00	19.00	3.00
22,612 d	29, IX.	1000	.14	140	80.00	112.00	28.00	4.04
22,618 d	5, X.	1000	.18	180	75.00	135.00	45.00	12.92
22,619 d	12, X.	1000	.05	50	95.00	47.50	2.50	5.17
22,622 d	19, X.	1000	.09	90	93.00	83.70	6.30	1.86
22,624 d	26, X.	1000	.04	40	99.00	39.60	.40	0.20
22,627 d	2 XI.	1000	.03	30	99.50	29.85	.15	0.06
22,631 d	9, XI.	1000	.04	40	99.50	39.80	.20	0.82
22,634 d	15, XI.	1000	.05	50	99.50	49.75	.25	1.86
22,635 d	23, XI.	1000	.03	30	99.20	29.76	.24	1.01
22,638 c	30, XI.	1000	.07	70	99.90	69.93	.07	1.27
22,643 c	7, XII.	1000	.02	20	99.90	19.98	.02	0.70
22,644 c	21, XII.	1000	.02	20	99.90	19.98	.02	0.30
22,647 d	28, XII.	1000	.06	60	99.90	59.94	.06	0.03
		Average.................................					12.86	3.52

FILTER-PAPER CATCHES, ILLINOIS RIVER—*Continued.*

Accessions number	Date	Water strained	Total catch	Total catch per m.^{3}	Estimated percentage of silt.	Total silt per m.^{3}	Total plankton per m.^{3}	Catch of silk net
	1898							
22,649 d	11, I.	1000	.05	50	99.70	49.85	.15	0.07
22,651 d	21, I.	1000	.06	60	99.90	59.94	.06	0.81
22,654 d	25, I.	1000	.16	160	99.50	159.20	.80	0.47
22,656 d	3, II.	1000	.03	30	98.00	29.40	.60	0.67
22,658 d	8, II.	1000	.08	80	99.00	79.20	.80	0.28
22,660 d	15, II.	1000	.12	120	99.50	119.40	.60	0.04
22,663 d	22, II.	1000	.41	410	99.99	409.96	.04	0.10
22,665 d	1, III.	1000	.04	40	99.90	39.96	.04	0.02
22,669 d	8, III.	1000	.04	40	99.90	39.96	.04	0.06
22,671 d	15, III.	1000	.05	50	99.50	49.75	.25	0.38
22,674 d	22, III.	1000	.05	50	99.20	49.50	.50	0.77
22,676 d	29, III.	1000	.04	40	99.80	39.92	.08	0.43
22,680 d	5, IV.	1000	.04	40	99.80	39.92	.08	0.53
22,682 d	12, IV.	1000	.03	30	99.20	29.76	.24	0.13
22,685 d	19, IV.	1000	.04	40	93.00	37.20	2.80	1.12
22,693 d	26, IV.	1000	.06	60	45.00	27.00	33.00	15.81
22,696 d	3, V.	1000	.07	70	35.00	24.50	45.50	35.68
22,697 d	10, V.	5000	.08	16	30.00	4.80	11.20	10.31
22,702 d	17, V.	1000	.08	80	60.00	48.00	32.00	5.22
22,705 d	24, V.	1000	.12	120	95.00	114.00	6.00	3.45
22,711 d	31, V.	1000	.08	80	92.00	73.60	6.40	1.84
22,715 d	7, VI.	1000	.04	40	90.00	36.00	4.00	5.28
22,716 d	14, VI.	1000	.03	30	94.00	28.20	1.80	6.99
22,721 d	21, VI.	1000	.07	70	85.00	59.50	10.50	2.88
22,723 d	28, VI.	1000	.08	80	85.00	68.00	12.00	0.69
22,725 d	5, VII.	1000	.07	70	96.00	67.20	2.80	0.14
22,730 d	12, VII.	1000	.05	50	96.00	48.00	2.00	0.64
22,733 d	19, VII.	1000	.05	50	92.00	46.00	4.00	0.88
22,737	26, VII.	1000	.06	60	30.00	18.00	42.00	0.67
22,749 d	2, VIII.	1000	.04	40	94.00	37.60	2.40	1.62
22,763 d	9, VIII.	1000	.08	80	80.00	64.00	16.00	0.97
22,765 d	16, VIII.	1000	.05	50	92.00	46.00	4.00	0.61
22,768 d	23, VIII.	1000	.06	60	94.00	56.40	3.60	0.51
22,770 d	30, VIII.	1000	.04	40	93.00	37.20	2.80	0.82
22,773 d	6, IX.	1000	.06	60	97.00	58.20	1.80	0.90
22,777 d	13, IX.	1000	.07	70	98.50	68.95	1.05	0.61
22,780 d	20, IX.	1000	.06	60	99.00	59.40	.60	0.95
22,782 d	27, IX.	1000	.06	60	92.00	55.20	4.80	0.31
22,785 d	4, X.	1000	.04	40	95.00	38.00	2.00	0.17
22,788 d	11, X.	1000	.07	70	99.50	69.65	.35	0.22
22,791 d	18, X.	1000	.03	30	99.00	29.70	.30	0.42
22,793 d	25, X.	1000	.08	80	99.70	79.76	.24	0.16
22,795 d	1, XI.	1000	.11	110	99.90	109.89	.11	0.14
22,799 e	8, XI.	1000	.08	80	99.80	79.84	.16	0.04
22,802 d	15, XI.	1000	.12	120	99.95	119.94	.06	0.10
22,804 d	22, XI.	1000	.20	200	99.99	199.98	.02	0.22
22,807 d	29, XI.	1000	.04	40	95.00	38.00	2.00	0.75
22,809 d	6, XII.	1000	.03	30	93.00	27.90	2.10	1.26
22,813 c	13, XII.	1000	.04	40	85.00	33.00	7.00	0.01
22,814 d	15, XII.	1000	.03	30	65.00	19.50	10.50	0.58
22,816 d	20, XII.	1000	.04	40	85.00	34.00	6.00	1.98
22,819 d	27, XII.	1000	.02	20	75.00	15.00	5.00	1.06
	Average................................						5.64	2.13

FILTER-PAPER CATCHES, ILLINOIS RIVER—*Continued.*

Accessions number	Date	Water strained	Total catch	Total catch per m.^{3}	Estimated percentage of silt	Total silt per m.^{3}	Total plankton per m.^{3}	Catch of silk net
	1899							
22,821 d	3, I.	1000	.04	40	82.00	32.80	7.20	0.22
22,826 d	10, I.	1000	.025	25	86.00	21.40	3.60	0.15
22,828 d	17, I.	1000	.05	50	95.50	47.75	2.25	0.50
22,831 d	24, I.	1000	.045	45	99.00	44.55	.45	0.03
22.833 d	31, I.	1000	.04	40	99.00	39.60	.40	0.01
22,838 d	7, II.	1000	.05	50	98.00	49.00	1.00	0.11
22,841 d	14, II.	1000	.05	50	90.00	45.00	5.00	1.15
22,845 d	21, II.	1000	.05	50	60.00	30.00	20.00	1.92
22,847 d	28, II.	500	.41	820	99.99	819.92	.08	0.07
22,850 d	7, III.	500	.20	400	99.90	399.60	.40	0.54
22,853 d	14, III.	1000	.16	160	99.90	159.84	.16	0.35
22,856 d	21, III.	1000	.23	230	99.80	229.58	.42	0.21
22,858 d	28, III.	1000	.04	40	99.80	39.92	.08	0.01
	Average....................................						3.16	0.41

undetermined extent invalidated by the errors above noted, I wish to call attention to the fact that they may still serve to indicate in some degree the extent of the leakage and its seasonal distribution—conclusions which are in some measure corroborated by the results of enumeration. The ratios of the volumetric determinations of the plankton by the silk and filter-paper methods in August–December, 1896, in 1897, in 1898, and in January–March, 1899, as shown by the averages, are respectively 1 to 4.1, 1 to 3.6, 1 to 2.6, and 1 to 7.7, or, averaging all collections, 1 to 3.3. If these figures approach the actual loss by leakage it becomes a matter of some volumetric importance.

An examination of the table reveals the fact that in a third of the cases the *estimated* plankton in the filter catch is exceeded by that of the silk net. It will be seen that most of these cases occur in instances of small plankton, where the tendency, above noted, to overestimate the silt is most effective in causing this apparent deficiency. In *all* cases the *total filter catch greatly exceeds* the total silk catch per m.^{3} (cf. Table III. and the one under discussion).

In general the preponderance of the filter catches is greatest in the warm season of May–September, the growing period of vegetation, in which green flagellates and small algæ and diatoms are most abundant numerically, and, therefore, quantitatively. Moreover, in 46 of the 105 instances the movement in production, as shown in the rise and fall of the plankton taken by the filter-paper and silk net, is in the *same direction*, though amplitudes reached are rarely proportionate. The coincidence is most marked when the catches of the silk net reveal changes in production of considerable magnitude, as, for example, during the rise and fall of the vernal pulse in 1897 and in 1898, and during the winter changes of 1898–99. There are suggestions in these records of vernal pulses of considerable magnitude, of a large midsummer production, and of a great development in the low water of 1897, when an enormous growth of *Chlamydomonas* turned the river to a livid green, and contributed to the maximum filter-paper record of 119 cm.^{3} per m.^{3}, 14-fold the coincident catch (8.47) of the silk net. There is also, even in these erratic data of the filter-paper catches, some evidence of the pulse-like character of the production of these minute organisms which form the greater part of the catch. This appears often to be coincident with the cyclic movement in the volumetric data of the silk net, and may best be seen in the records of the winter of 1898–99. The enumeration confirms beyond all question the existence of these recurrent pulses, dimly suggested in these volumetric records. The spring and summer plankton which leaks through the silk is largely made up of small algæ, flagellates, and diatoms, with some ciliates, principally *Codonella*, and rhizopods. The winter plankton thus lost is largely composed of broken colonies of *Synura*, together with many predatory and elusive *Infusoria*, largely representatives of the *Holotricha*, which multiply abundantly with the autumnal increase in bacteria.

It can be apparent to no one more than to the writer that such data as these are unsatisfactory in determining the precise *volumetric extent* of the leakage through the silk. That this leakage is, however, beyond all question considerable must become evident to any one who *actually works over collections* made by some finer filter than that of the silk net. The work in this line which I have done since the publication of my tests of the leakage through the silk net (Kofoid, '97b) has only confirmed my opinion as additional data, volumetric and enumerative, have accumulated. The corroboration of the correctness of my criticisms on this point by the recent work of Lohmann ('03) on marine plankton adds to the testimony against the Hensen plankton-method as a complete quantitative test of the productivity of water. The criticisms which Brandt ('99), Reighard ('98), and Ward ('99) have passed upon my conclusions in this respect have not stood the test of actual investigation, in so far as the work of Lohmann ('03) and Volk ('01 and '03) and my own investigations, as given in the preceding pages, are concerned. To my mind, owing to *silt contamination*, no purely volumetric test is sufficient to solve adequately the problem of productivity of water. It may be possible by pure cultures and measurements of many individuals to establish unit values for the various planktonts, so that volumetric determinations can be made from enumerative data, and to supplement these by chemical analyses, so that chemical values in proteids, silica, etc., can be in like manner approximated with sufficient accuracy for scientific purposes. This may seem chimerical at a distance, and it raises at once the question as to the utility of so great an undertaking. Something of the sort is, however, necessary if quantitative plankton investigations are to cease being merely desultory and disconnected and become joined in a substantial structure which comparative science alone can rear. The development of a scientific aquiculture demands some standard of this kind as a basis for its permanent success.

COMPARISON WITH OTHER BODIES OF WATER.

Comparisons of the quantitative production in the Illinois River with that in other localities are obviously of value only when based on similar or approximately similar data. As a result of our operations upon the Illinois and its backwaters we are able to compute the mean annual production on the basis of 235 observations extending over a period of five years. At present writing no series of observations of like, or even approximately like, extent has been published concerning any other body of water. Comparisons upon this basis are therefore not possible.

The scientific or economic value of comparisons upon other bases than the mean annual production or the full seasonal course of production cannot be great, unless it be for coincident seasons. Furthermore, data of production without comparable environmental data lose much of their significance.

The volumetric determination of the plankton of *streams* elsewhere has not been carried on to any considerable extent. Steuer ('01), in his paper upon the entomostracan fauna of the backwaters of the Danube at Vienna, gives a brief list of organisms observed in the plankton of the Danube itself, but no volumetric determinations. His conclusion regarding the potamoplankton—a term whose very validity he contests—is: "Das einzige wichtige Ergebniss der 'Potamoplanktonforschung' scheint mir bis jetzt die Feststellung der grossen Armuth unserer fliessenden Gewasser an Mikroörganismen zu sein." It is in a similar vein that Whipple ('99) notes the paucity of plankton organisms in rivers, resulting presumably from sanitary examinations of streams of New England. The results of our investigation upon the Illinois River place limitations on these conclusions. It is a question of time and nutrition and the absence of deleterious industrial wastes. Given ordinary stream water free from poisonous industrial wastes and sufficient time for breeding, a typical plankton may be expected, it seems, in every river, especially the larger ones, and in the lower reaches of those of the smaller type.

Steuer's volumetric work on the two backwaters of the Danube, covering, it seems, nineteen collections in a period of fifteen months, from June, 1898, to August, 1899, indicates a planktograph somewhat similar to our backwater planktographs in that he finds a vernal pulse in May and a midsummer rise in August. No trace, however, of the phenomenon of recurrent volumetric pulses–so prominent in our fuller records—appears in his infrequent data. His statement, "Den ganzen Winter hindurch ist hier *constant* das Planktonvolumen unmessbar gering" (italics are his) has no counterpart in winter production in our backwaters.

The plankton of the Elbe and its backwaters has been investigated by Schorler ('00), but no volumetric determinations were made of its channel plankton because of the difficulties occasioned by the current and by detritus in suspension. The quantity of plankton per m.^{3} in three of the backwaters was determined in twelve instances in April–October. There are in the data suggestions of a May-June maximum and of one in August, and the quantities are generally higher than the *averages* in our backwaters, though the greatest amount, 146 cm.^{3} per m.^{3}, falls below the highest of our records. The channel plankton of the Elbe was found generally to contain fewer species and individuals than its contiguous backwaters.

The plankton of the Oder has been examined by Zimmer and Schröder ('99), but no volumetric determinations were made. Regarding the quantitative conditions, Zimmer makes the general statement that these are influenced by temperature. The quantity in December–February is very small, rises in March, and again, to a greater degree, in May, but attains the maximum for the year in August, declining rapidly after the middle of September, and reaching the winter minimum in December.

A comparison of the seasonal course of production of plankton in the various lakes that have been explored in recent years, with those of our several stations, does not promise any profitable results, since most of the quantitative work is limited in seasons, or has been made at such long intervals as —in the light of our results—to raise some question as to the representative value of such collections for comparison. In addition to this, the very great divergence in the annual planktographs of such localities as have been examined, including our own, raises a doubt as to the value of any conclusions derivable from such data. Steuer ('01) has suggested that the geographical position of the bodies of water in a large measure determines the character of the planktograph. I should prefer rather to put the emphasis upon temperature, which is not everywhere merely a matter of latitude, and also to insist upon the dominance of *purely local conditions* over those more generally operative, such, for example, as temperature, in determining the amplitude of the movements of the planktograph and the general position of seasonal maxima. Illustrations in support of this view can be found in our own records—for example, in Phelps and Quiver lakes. These are bodies of water within three miles of each other, and with quite similar temperatures, yet their planktographs are in some years quite as different as any of those whose difference Steuer seeks to explain by latitudinal positions. Furthermore, the "Sommerschlaf" which he predicates as probable in tropical waters is least of all evident in Phelps Lake, the warmest of all our localities, where temperatures during midsummer approximate those of the tropics. More chronological series of collections at brief intervals, not exceeding a fortnight, from many localities are needed before general conclusions of permanent value concerning the seasonal course of plankton production will be possible.

The *maximum production* has been used by some writers as a basis of comparison of plankton production in different bodies of water. It doubtless has a slight value in suggesting the relative productivity of waters, though it would seem that an annual average of weekly or fortnightly collections would be very much more accurate. Difficulty attends these comparisons when deep and shallow waters are brought into contrast. If the volume of plankton under one square meter is made the basis the shallow waters are at a disadvantage, while if the amount per $m.^3$ is made the basis the more barren deeper strata reduce the average plankton content of deep waters to a relatively small figure. Since, however, all strata, at least of most bodies of fresh water, are productive of plankton, it seems best to express the production of a body of water in volume per cubic meter. I have therefore used this basis throughout my paper, and employ it in the following table of comparative production in some of the representative bodies of water thus far reported.

RELATIVE PLANKTON PRODUCTION BASED UPON MAXIMUM RECORD.

Locality	Investigator	Date	Depth —in meters	Plankton—in cm.³	
				Per sq. meter	Per cu. meter.
Illinois River	Kofoid	3, V, 1898	5.8	413.89	71.36
Spoon River	"	11, IX, 1897	4.12	60.11	14.59
Quiver Lake	"	3, V, 1898	4.2	353.98	84.28
Dogfish Lake	"	17, IV, 1895	2.51	102.16	40.70 †
Flag Lake	"	2, V, 1896	1.64	667.55	407.04
Thompson's Lake	"	1, V, 1895	1.5	184.32	122.88
Phelps Lake	"	23, VIII, 1898	.2	89.79	448.96
Turkey Lake	Juday, ('97)	12, VIII, 1896	1.5	1439.5*	684.*
		12, VIII, 1896	6.09	826.5*	135.5*
Lake St. Clair	Reighard, ('94)	17, IX, 1893	4.37	74.52	17.05
Lake Michigan	Ward, ('95)	11, VIII, 1894	107.8	176.29	1.64
Danube, backwaters	Steuer, ('01)	? V, 1898	3?	36	12.
Elbe, backwaters	Schorler, ('99)	20, V, 1898	3-4	438-584	146.
Garda See	Garbini, ('95)	——	50	62	1.24
Plöner See	Zacharias, ('96)	10, VIII, 1895	40	862	21.55
Plöner See	Apstein, ('96)	6, IX, 1892	17	1242	73.07
Dobersdorfer See	Apstein, ('96)	4, X, 1891	19.5	4242	218.05
Nävern See	Huitfeldt-Kaas, ('98)	?	7	520	74.29
Sognsvandet See	Huitfeldt-Kaas, ('98)	30(?), VI, ?	shallow	240	——
Waterneverstorfer See	Lemmermann, ('98)	1898	2	70	35.
Lac Leman	Jung, ('99)	18, VI, 1898	120	101.9	0.85
Vierwaldstätter See	Burckhardt, ('00b)	?	?	150.	——
Neuenburger See	Fuhrmann, ('00)	27, V, 1899	40	91.3	2.24
Katzen See	Amberg, ('00)	14, XI, 1898	5	6.2	1.24
Stühmer See	Seligo, ('00)	9, VIII, 1898	23	2340	101.79

*Reduced to settling method of measurement by multiplying by 5. See Juday ('97).

†All records for our stations reduced to settling method of measurement by multiplying by 2. See page 256.

A comparison of this maximum production in these various localities, upon the basis either of plankton per square or cubic meter, ranks our localities (barring Spoon River) among the more fertile regions. If the content per cubic meter be the basis. production in Phelps and Flag lakes exceeds that reported in any other body of water save only from the shoaler part of Turkey Lake (Juday, '97). This greater production in Turkey Lake disappears if *centrifuge* measurements are employed in both planktons, the ratios being 203.52 and 224.48 cm.^{3} for Flag and Phelps lakes to 136.8 and 27.1 cm.^{3} for Turkey Lake. The tendency on the part of this maximum production in all of the localities to fall in either the April-May period or in that of August-September is apparent, though in some cases, as, for example, those of Lakes Michigan and St.Clair, and Turkey Lake, the limitation of collections to a few weeks in midsummer precludes the possibility of a vernal pulse appearing in their records.

ECONOMIC CONSIDERATIONS.

The Illinois River and its backwaters, under present conditions, contribute annually to the wealth of the state over 10,000,000 pounds of marketable fish and 15,000 dozen turtles, with a wholesale market value of about $375,000. This amount will be very considerably increased if to this sum be added the increase due to retailers' profits, to the unmarketed catch of local fishermen and visiting sportsmen, and to the annual harvest of migrant water-fowl which are shot in great numbers for local use as well as for shipment to distant markets.

Fish from the Illinois River find their way into the local markets and are shipped by the car-load from the principal fishing centers, such as Peoria, Havana, and Beardstown, to Chicago, St. Louis, and New York City. The remarkable increase in the catch of the introduced German carp from practically nothing in 1894 to 5,890,200 pounds in 1901 is one of the factors which assures the economic value of the fishing industry in this stream. These fish find a ready sale among the foreign population of our great cities, and hold the market without fear of rivalry by any of our cheaper native food fishes.

In addition to these economic phases of the fishing industry of the Illinois River there are other considerations which arise from its value to the state at large as a field for sport and recreation. This cannot be estimated in dollars and cents. The backwaters and marshes teem with migrant water-fowl in autumn and spring, and the spring-fed lakes are the home of large-mouthed black bass (*Micropterus pallidus*), while the croppies, the striped bass, the white perch, and the various sunfish, to say nothing of the catfish and bullpouts, provide no mean sport for the less fastidious angler.

Are these present resources of the stream economically utilized under existing conditions? How may they be best conserved? What developments are possible which will tend to increase the production of this stream and multiply the numbers of those who resort to it for recreation and sport? Does the investigation reported in this paper have any bearing upon these problems? These are questions which continually occur to one familiar with this locality, observant of the operations of fishermen, and cognizant of some of the seasonal flux of life and matter in this water world of which fish are but a part.

The plankton is an integral part of the chain of food relations which extends from the water, with the gases, salts, and products of decay dissolved therein, on the one hand, to the fish and other vertebrates of commercial importance upon the other hand. The water, the carbon dioxid dissolved therein, the nitrogenous matters, and various salts in solution are utilized either by the grosser aquatic vegetation or by the microscopic phytoplankton. In the former case the growing plants are rarely utilized directly as food by any aquatic animals. A possible exception to this statement is found in the case of the turtles. Fishermen are accustomed to feed these animals, when penned up for the market, upon "moss" or *Ceratophyllum*, though it may be that the insect larvæ and mollusks found in the vegetation constitute the more important elements of the food. It is only when this growth of vegetation decays that it releases into the water the elements which conduce to its fertility.

The phytoplankton, on the other hand, multiplies very rapidly and is immediately available for the support of the microscopic animals of the zoöplankton, and this, and to some extent also the phytoplankton itself, is the immediate food of most young fish upon hatching and the customary food of some adult fishes,—such as *Polyodon* (Forbes, '88, and Kofoid, '99) and many minnows,—of the bivalve mollusks, and of many other organisms of sessile habit. The plankton is thus the prime source of food of fishes and of many other organisms utilized by fish as food. The chain of food relations, for example, between the food elements of the water and the black bass is in the main a short one, with the plankton as the principal link. Professor Forbes ('80) has shown that 86 per cent. of the food of the game fish consists of other fishes, principally *Dorosoma* with perch and minnows. In its youngest stages the black bass was found to be a plankton (*Entomostraca*) feeder, and later changing to a fish diet. It is interesting to note that its principal fish food, young *Dorosoma*, is itself in its younger stages a plankton feeder, secondarily adopting a limophagous habit. The bottom slime thus eaten by the growing and adult *Dorosoma* is a food largely because it contains so many organisms normal or adventitious to the plankton. Thus at all seasons the plankton forms an important link in the chain of food relations leading to the black bass.

The buffalo-fishes and the German carp are likewise to a large degree dependent for food upon the plankton in early stages of growth, and, like *Dorosoma*, subsequently adopt the limophagous feeding habit. The organisms of the plankton thus at all times enter largely into the sources of their food supply. The contents of the digestive tracts of these important food fishes examined by me at Meredosia during the spring months of 1899 were found uniformly to contain comminuted vegetable debris, which constitutes the greater part of the unstable ooze or slime which abounds in the backwaters of the river, and, associated with this, many *Entomostraca*, rotifers, rhizopods, and unicellular or colonial algæ, belonging to species common in the plankton at that season of the year. The moribund, the spore-forming, the egg-laden organisms of the plankton sink to the deeper strata, and together with the normal denizens of the bottom slime, which are everywhere adventitious in our plankton, form the food of these fishes of greatest commercial importance.

A very striking instance of the adaptation of the breeding seasons of fishes to food conditions is found in their nice adjustment, for the most part, to the seasonal course of plankton production in our waters. Most of our minnows, the dogfish and gar, the *Catostomidæ*, the carp, *Dorosoma*, and the *Etheostomidæ* spawn in central Illinois during April and the first of May, while the bass, the sunfishes, and many of the *Siluridæ* follow in May. This brings the maximum number of young fish, recently hatched and generally plankton feeders, just at the season of the vernal plankton pulse, which is often the maximum production of the year. It may well be that the abrupt diminution of plankton following the May and June pulses is accelerated to a large degree by the plankton-feeding habits of the fry of these fishes.

The plankton thus enters directly into the food of most young fishes and of some important adult fishes, and indirectly it is the primal source of food of most fishes. A knowledge of its local and seasonal distribution and of the environmental conditions which favor or impede its development is fundamental to any scientific utilization of the present resources of this stream or any future development of resources now unproductive.

The data at hand afford an opportunity of comparing the plankton production and the annual output of marketed fish. The reports of the Illinois River Fisherman's Association for 1894–1898 give the following statistics based upon estimates and partial records of leading men engaged in the fisheries. They are not exact records, but the error involved is no greater than that in the plankton data.

PLANKTON AND FISHERIES.

Year	Total number of pounds of fish marketed	Average plankton content in cm.^{3} per m.^{3}			Total plankton discharged—in cubic meters
		In channel	In backwaters	Total	
1894	8,276,227	2.53	4.40	6.93	45,757
1895	8,588,000	5.91	10.76	16.67	83,340
1896	7,252,811	1.05	7.18	8.23	28,629
1897	9,703,298	3.51	5.85	9.36	94,605
1898	10,647,466	2.03	12.42	14.45	63,596
Aver'ge	8,933,560	2.71	8.42	11.13	67,750

Hydrographic conditions control to some extent the relative possibilities and efficiency of fishing methods, and this adds to the difficulties of comparison.

While the relative and absolute amounts of plankton do not determine the number of marketable fish taken in any year, they do indicate in a measure the available primal food supply, and this is a factor in determining the growth, and therefore the weight, of the marketed catch. Some correspondence in plankton and the products of the fisheries might therefore be expected, though on account of the complexity of the problem and the limitations of our data it is difficult to demonstrate it in every case.

In 1894, when our data indicate a plankton production below the average in channel, in backwaters, in their sum, and in the estimated discharge, we find the total production of marketable fish also below the average (for 1894–1898). In 1895 our collections indicate an increase, approximating 50 per cent. in plankton production as exhibited by each of the methods tabulated, and there is also an increase in the product of the fisheries, though it amounts to only about 4 per cent. The *direction of the change in production* is the same in all cases. In 1896 plankton production falls in channel, in backwaters, in their sum, and in total discharge, the decline in all but the backwaters being greater than the increase from 1894 to 1895, and we find, accordingly, that the decline in the product of the fisheries is also greater than its antecedent rise to the level attained in 1895. In 1897 plankton production again rises in the channel, in the sum of channel and backwaters, and in total discharge, but not in the backwaters. This apparent decline in backwater production may be due to the elimination from our data, for a part of the year, of Phelps, Flag, and Dogfish lakes, thus giving undue weight to the depressing effect of the Quiver Lake data. The fact that in Thompson's Lake plankton production rises from 6.67 in 1896 to 10.41 in 1897 is an indication that plankton production in the open backwaters in 1897 rose above the level of that of 1896. In correspondence with the increased plankton production in channel, and total discharge, we find the product of the fisheries rising from 7,252,811 pounds in 1896 to 9,703,298 in 1897—a change not exceeded in any other year of the records. In 1898 the product of the fisheries continues to increase, reaching 10,647,466 pounds, but plankton production rises only in the backwaters and in the sum of channel and backwaters, falling in channel and total discharge.

There is thus, in general, a correspondence between plankton production and the product of the fisheries in that the *direction of movement* in both is usually the same. They rise or fall together. If we compare the changes of the product of the fisheries with those of the sum of plankton production in channel and backwaters, as given in the table on page 565, we see that the *direction of the change* is the same in both from year to year in every instance in 1894–1898. If similar comparisons are made of the product of the fisheries and plankton production in channel or backwaters alone, or in total discharge, we find that in three cases out of four the direction of the change is the same in both. It is also generally true that years in which plankton production is below the average are also ones in which the product of the fisheries falls below the mean.

Plankton production at Havana, provided a similar plankton content is maintained until the run-off reaches the mouth of the river, would result in an average discharge of 67,750 cubic meters of plankton, equivalent in weight to somewhat more than 149,050,000 pounds, or 15 times the annual production of fish. To this wastage of organic matter, which in great part is permanently lost to the drainage basin of the Illinois, should be added the unutilized nitrogen and other food elements in suspension and solution which escape with the run-off, especially of flood waters (see Table X.).

How shall this waste be prevented and the plankton be turned into marketable fish ? The problem is a complex one, but the results of this investigation should contribute towards its solution. The first step will be to impound the richly fertilized flood waters and thus to afford time for the utilization of their food elements by the developing plankton, which by various chains of food relations is joined to marketable fish. An illustration of the productive possibilities of impounded Spoon River floods is seen in Phelps Lake, our richest plankton station, and also the home of great numbers of young fish. Thompson's Lake, another impounding backwater, not only breeds an abundant plankton but contributes no insignificant portion of the 1,000,000 to 1,500,000 pounds of fish marketed annually at Havana.

The development in recent years of extensive systems of levees in the bottoms of the Illinois River for the purpose of protecting farm lands from untimely floods increases the importance of, and necessity for, the reservoir backwaters. In connection with these systems it might be feasible from an engineering point of view, and perhaps even profitable from the commercial standpoint, to convert some of the adjacent low-lying marshes, swamps, bayous, and lakes into reservoirs in which invading and richly fertilized storm waters might be impounded and retained as river levels fall. The increased volume of water thus provided should—in the light of our results—yield an abundant plankton, and support a large fish population. Under present conditions of abundance of most of our valuable food fishes in the Illinois, stocking such reservoirs is relatively a simple matter. If properly protected from escape at high water, such an area once stocked with the now rapidly disappearing *Polyodon*, whose roe is much sought for the manufacture of caviar, might become a very profitable investment.

As a basis for further development of the fishing industry it seems desirable that public and private waters should be more accurately defined, and that fishing privileges for market purposes in the former should be matters of license or franchise to responsible parties, so that legislation concerning methods and seasons of fishing could be more easily controlled. With the ever increasing industrial development in the drainage basin of the Illinois River, especially in Chicago and the minor cities along its banks, there is great danger that industrial wastes will so accumulate in the river waters that not only the plankton but also the fish and other animal inhabitants will be driven out or exterminated. Legal supervision over the discharge of such industrial wastes may soon become imperative for the Illinois River as it has for some European streams. With the legal status thus clearly defined, and with wise legislation which should efficiently prevent pollution of the stream by deleterious industrial wastes, protect the most desirable food and game fishes from depletion, and, at the same time, permit the full utilization of the annual crop of matured and marketable fish, there is no apparent reason why the Illinois River and its backwaters should not become an increasing source of wealth to the state, and the great waste which now occurs be utilized to a considerable extent in future development.

CONCLUSIONS.

The following are the more important conclusions arrived at from this examination of the plankton and its environment in the Illinois River and its backwaters, based upon the study of 645 collections made in 7 localities in 1894-1899.

1. There is little correlation between the seasonal flux in chemical conditions (as shown in data of sanitary analyses) and the seasonal course of plankton production (as shown in the catches of the silk net). The nitrogenous matters are influenced by the plankton pulses, especially when diatoms are multiplying rapidly, but the changes are not uniform or proportional.

2. The plankton in the Illinois River is distributed with a uniformity approximately equal to that found in German lakes and in Lake St. Clair. The average departure from the mean in short distances (3 miles) probably falls within ± 10 per cent. Chronological catches in periods of 2 to 15 days in 14 series yield an average departure of ± 14.1 per cent. In the river, in 205 miles of the course the average departure in flood conditions was ± 51 per cent., or ± 43 per cent. if the river is divided into four sections, or ± 29.7 per cent. if computations are based on total catch of the net.

3. The average departure from the mean plankton content in two tests in a cross-section of the river is ± 27.2 or ± 23.2, or, omitting marginal collections, ± 21.9 or ± 12.1 per cent.

4. The plankton method can be applied to a stream as legitimately as to a lake.

5. The mean of the monthly averages of 235 collections in the Illinois River is 2.71 cm.^{3} of plankton per m.^{3} of water.

6. The plankton of the river channel is subject to great seasonal and annual variations. The monthly averages of all collections indicate a period of minimum production of plankton in January-February, of rising production in March, of maximum production for the year in April–June, usually culminating in a vernal maximum about the end of April and often declining rapidly to a low level in June. The *average* monthly production declines gradually during the remainder of the year to the winter minimum in December.

7. Individual years vary greatly from these averages as a result of hydrographic, climatic, and other environing conditions in varying combinations.

8. The waters of Spoon River contain but a very small amount of plankton (.465) except at very lowest stages, when the flow is at a minimum. Its production at other times (.044) is less than one fiftieth of that in channel waters which it joins. Chemical conditions in this tributary are apparently such as to support a large plankton. The recent origin of the water is the cause of the low production. Its diluent effect on the plankton content of the channel is about 10 per cent.

9. Quiver Lake produces less (1.75) than channel waters. At high stages its production is relatively larger, and most resembles that in channel waters, while at low levels, when submerged vegetation is dominant and access of tributary waters of recent origin relatively great, its production is both relatively and actually low. It is predominantly a diluent of channel plankton.

10. Dogfish Lake produces (3.16) more than channel waters, freedom from access of tributary waters permitting a higher production than in the contiguous waters of Quiver Lake.

11. Flag Lake also produces more (9.23) than channel waters, the freedom from access of tributary waters, the impounding function, and decaying vegetation favoring high pro-

duction. The planktographs of this lake are marked by extreme changes in brief time, and by depression in production with the emergence of vegetation.

12. Thompson's Lake also produces more (8.26) than channel waters, and maintains its higher level of production more generally. Its impounding function and the freedom from access of tributary waters contribute to this result.

13. Phelps Lake produces the most abundant plankton (22.55) of all our localities, freedom from vegetation and from access of tributary waters, and the highly developed impounding function contributing to this result. The maximum production in our records, 224.5 cm.^{3} per m.^{3}, was found in this lake on Aug. 23, 1898. This lake is marked by relatively and absolutely high production in summer and autumn.

14. The course of plankton production in channel and backwaters throughout the year exhibits a series of recurrent pulses, culminating in maxima and separated by minima, which give the planktograph the appearance of a series of "frequency of error" curves of varying amplitudes. These pulses generally have a duration of 3 to 5 weeks, and tend to coincide in their location in all localities coincidently examined by us. This similarity in the direction of movement in production amounts quantitatively to 65 per cent. of the possible comparisons in our records. This cyclic movement in production is plainly influenced, accelerated or retarded, or its amplitude extended or depressed, by environmental factors, but is not itself traceable to any one or any combination of them. A brief interval of examination—not more than one week—is essential to a demonstration of the existence of these pulses.

15. Area and depth, within limits of our environment, show little relation to plankton production.

16. Age of the water is an important factor in determining production in streams. Young waters from springs and creeks have but little plankton, and even such tributaries as Spoon River (drainage basin 1,870 square miles) contain but little plankton, principally of more rapidly developing organisms.

This barren water, impounded for 10–30 days in backwater reservoirs such as Phelps Lake, develops an abundant plankton. The rate of run-off and replacement of impounded waters determines to some extent the amplitude of production. This is greatest where run-off is least and rate of renewal slowest.

17. Fluctuations in hydrographic conditions constitute the most immediately effective factor in the environment of the potamoplankton. Rising levels usually witness a sharp decline in plankton content (per m.³) as barren storm waters mingle with or replace plankton-rich waters of channel and reservoir backwaters. Falling levels are periods of recovery and increase in plankton. Stability in hydrographic conditions conduces to rise in production at all seasons of the year, and instability is always destructive. Winter floods tend to lower plankton production; spring floods increase it.

18. Temperature affects production profoundly. Below 45° the plankton content in the river is only about 9 per cent. of that present above this temperature, and in backwaters but 29 to 40 per cent. Minimum production is at times of minimum temperature. The vernal pulse in production attends the vernal rise in temperature and culminates at about 60°–70°. With the establishment of the midsummer temperatures (about 80°) production falls from 44 to 87 per cent. in channel and backwaters. It *rises*, however, 68 per cent. in Phelps Lake, so that other causes than temperature may be operative in producing the midsummer decline. The autumnal decline in temperatures is accompanied by decline in production in the channel and in Quiver Lake, but by an increase in other backwaters, which exhibit a tendency toward an autumnal pulse. The decline to winter minimum occurs in December.

An early spring accelerates, and a late spring retards, the vernal pulse, and a late autumn prolongs the autumnal production. Summer heat pulses often attend plankton increases. Minimum temperatures are not prohibitive of large plankton production. The December production in Phelps Lake in 1898 (43.14 cm.³) exceeds the *vernal* maximum elsewhere in all localities but one, but falls much below the summer production in Phelps Lake. The ice-sheet is not inimical to a considerable plankton production unless stagnation conditions occur.

19. Light affects plankton production. The half year with more illumination and fewer cloudy days produces from 1.6 to 7 times as much plankton as that with less illumination and more cloudy days. Seasons of unusual cloudiness are accompanied by depression in production.

20. Lakes rich in submerged vegetation produce less plankton than those relatively free from it, in an annual ratio of 1 to 6 and a monthly ratio varying from 1.5 to 20 to that of 1 to 20. The higher ratios generally prevail in periods of dominance of vegetation. Quiver Lake produces more plankton when free from vegetation than when it abounds in it. The emergent and rooted vegetation of Flag Lake conduces by its autumnal and vernal decay to large plankton production, but tends to depress production in summer.

21. The normal regimen of the course of plankton production in the Illinois River and its backwaters does not form a definite seasonal planktograph, but consists rather of a series of recurrent plankton pulses, whose varying amplitudes are largely determined by the fluctuating environmental factors of the unstable fluviatile environment. Hence planktographs of the same locality in different years and of the different stations in the same year show resemblances only in such fundamental features as the winter minimum and the vernal pulse. The relative productive rank of the several localities is generally maintained, and more completely in the more stable environments.

22. The plankton of the Illinois River is largely autonomous. Seepage and creek waters are diluents of its plankton and add little to its diversity. Even Spoon River is generally a diluent, reducing the plankton content 10 per cent. and adding but few diversifying species to its population. The reservoir backwaters, on the other hand, generally contain a more abundant plankton than the channel, the amount, on the bases

of monthly averages, being from 1.3 to 17 times as great. At all levels, waters from impounding areas in the bottom-lands are drawn into the channel, mingled with the plankton-poor contributions of tributaries, and further enriched by the growth of indigenous channel plankton. The reservoir backwaters are thus of great importance both as a source of the channel plankton of the Illinois River and in its maintenance.

24. The total annual production of plankton in the Illinois River, on the basis of normal discharge and a plankton content at the mouth of the river equal to that of our average record at Havana, is 67,750 cubic meters.

25. Filter-paper catches indicate the presence, on an average, of a plankton 3.3 times the volume of that taken by the silk net. Leakage through the silk is therefore a matter of some volumetric importance.

26. The annual production of plankton and of the fisheries of the Illinois River show some correlation in their changes from year to year.

University of California,
August 23, 1903.

TABLE I.

Highest and Lowest Water, Range, and Total Movement by Months, of River Levels, from Gage-readings below Copperas Creek Dam. 1879 1899.

BASIS OF REFERENCE, LOW WATER OF 1873 AND 1879.

YEAR	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1879	3.88	2.65	1.23	1.33	6.93	4.10	2.83	4.35	10.80	4.63	6.17	7.13	11.60	9.75	1.85	3.43	9.55	2.95	6.60	7.25	13.60	2.05	1.55	2.14
1880	11.23	5.93	5.30	5.81	11.05	9.18	1.87	3.23	10.55	8.10	2.45	4.00	11.67	8.98	2.69	5.84	13.53	11.37	2.16	4.88	11.35	9.28	2.07	2.85
1881	1.70	1.40	0.30	0.45	11.52	1.65	9.87	10.08	16.37	11.72	4.65	6.17	15.88	13.50	2.38	5.06	14.50	8.05	6.45	6.70	10.83	5.97	4.86	8.31
1882	15.75	10.23	5.52	5.72	11.70	8.80	2.90	4.33	14.30	12.00	2.30	4.07	13.62	11.60	2.02	2.56	13.85	12.20	1.65	4.95	15.68	13.45	2.23	4.95
1883	8.55	4.18	4.37	4.64	19.25	3.80	15.45	16.65	18.32	11.80	6.52	6.93	13.45	11.22	2.23	4.31	12.58	11.02	1.56	3.98	12.00	11.15	0.85	2.11
1884	7.63	5.23	2.40	2.86	15.45	6.72	8.73	9.40	16.48	12.00	4.48	7.36	16.50	11.25	5.25	5.27	11.28	8.88	2.40	3.09	8.65	6.85	1.80	2.77
1885	14.85	10.12	4.73	8.48	11.83	8.68	3.15	3.30	14.40	8.52	5.88	7.22	14.63	12.98	1.65	3.00	13.97	8.22	5.75	5.98	8.18	5.93	2.25	2.63
1886	13.12	10.98	2.14	4.18	15.15	10.33	4.82	6.39	14.63	12.12	2.51	5.30	13.85	12.00	1.85	3.19	13.72	11.40	2.32	4.24	12.30	5.70	6.60	6.78
1887	9.20	2.55	6.65	6.65	16.25	9.20	7.05	8.33	14.55	10.58	3.97	4.39	10.42	5.60	4.82	5.08	5.50	2.28	3.22	3.44	2.80	1.93	0.87	1.75
1888	7.80	3.75	4.05	5.85	11.50	5.50	6.00	6.75	13.70	11.90	1.80	4.43	13.82	9.00	4.82	4.91	10.63	6.80	3.83	6.77	12.03	7.20	4.83	6.13
1889	6.10	3.20	2.90	4.25	4.97	3.00	1.97	3.35	8.20	4.50	3.70	6.10	7.15	5.60	1.55	2.97	6.17	3.20	2.97	4.99	11.20	4.17	7.03	5.60
1890	11.70	6.27	5.43	6.98	10.70	8.50	2.20	2.40	10.05	7.70	2.35	3.75	12.10	10.22	1.88	3.13	10.70	9.52	1.18	2.84	11.90	9.50	2.40	3.85
1891	4.20	3.00	1.20	1.70	7.63	3.00	4.63	5.23	9.28	7.40	1.88	3.01	13.60	9.53	4.07	5.14	12.58	5.47	7.11	7.31	8.33	5.10	3.23	5.57
1892	4.70	4.50	0.20	0.66	6.00	4.70	1.30	2.90	7.87	6.10	1.77	2.67	13.00	7.93	5.07	6.61	18.80	11.50	7.30	10.13	16.25	12.93	3.32	6.58
1893	4.00	3.80	0.20	0.30	12.56	3.80	8.76	8.86	17.60	12.80	4.80	8.80	14.80	11.20	3.60	6.05	15.07	12.00	3.07	3.34	11.93	8.50	3.43	3.40
1894	4.40	3.50	0.90	2.00	4.80	3.80	1.00	1.50	10.40	4.50	5.90	7.20	9.00	6.90	2.10	2.40	7.93	6.43	1.50	2.73	6.28	3.80	2.48	3.41
1895	3.80	2.83	0.97	1.04	7.45	2.90	4.55	4.55	7.60	5.03	2.57	2.86	6.20	4.60	1.60	3.13	4.40	2.70	1.70	2.10	2.73	0.93	1.80	2.69
1896	13.10	8.40	4.70	5.84	10.20	8.53	1.67	2.50	10.67	8.33	2.34	2.81	8.30	7.00	1.30	3.18	8.90	4.97	3.93	6.59	9.10	5.47	3.63	3.97
1897	13.10	4.43	8.67	10.37	12.37	10.30	2.07	3.20	16.33	12.00	4.33	4.90	16.18	11.40	4.78	4.57	11.30	7.07	4.23	4.33	7.83	3.87	3.96	7.16
1898	7.97	3.20	4.77	5.51	11.60	7.30	4.30	5.23	18.05	11.10	6.95	7.45	18.55	11.37	7.18	7.68	13.90	9.66	4.24	6.09	13.70	9.67	4.03	4.13
1899	9.00	7.10	1.90	3.06	10.63	5.70	4.93	8.10	13.80	11.23	1.57	5.11	12.80	9.37	3.43	3.43	9.17	6.93	2.24	4.34	9.10	4.00	5.10	5.70
Av.	8.37	5.12	3.26	4.18	10.93	6.16	4.76	5.75	13.05	9.24	3.76	5.33	12.72	9.57	3.15	4.13	11.33	7.74	3.59	5.05	9.79	6.55	3.25	4.41

TABLE I.—*Concluded.*

HIGHEST AND LOWEST WATER, RANGE, AND TOTAL MOVEMENT BY MONTHS, OF RIVER LEVELS, FROM GAGE-READINGS BELOW COPPERAS CREEK DAM. 1879–1899.

BASIS OF REFERENCE, LOW WATER OF 1873 AND 1879.

YEAR	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER				EXTREMES		TOTAL	
	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1879	6.77	2.00	4.77	8.30	3.60	0.75	2.85	3.63	0.95	-0.02	0.97	3.45	1.55	0.48	1.07	2.74	3.40	1.47	1.93	2.63	6.50	3.38	3.12	3.98	11.60	-0.02	11.62	50.72
1880	9.33	4.35	4.98	5.23	4.85	1.50	3.35	5.43	3.57	2.40	1.17	2.88	3.05	1.68	1.37	3.14	1.92	1.50	0.42	1.34	1.70	1.40	0.30	0.91	13.53	1.40	12.13	45.51
1881	8.95	2.55	6.40	8.59	2.65	1.18	1.47	1.65	1.40	0.90	0.50	2.60	7.55	1.52	6.03	6.75	13.80	7.58	6.22	7.46	16.15	12.40	3.75	4.88	16.37	0.90	15.47	68.70
1882	15.15	8.28	6.87	7.19	8.22	4.25	3.97	4.56	5.50	2.47	3.03	4.10	3.80	2.42	1.38	2.05	4.90	3.40	1.50	2.17	8.28	3.60	4.68	5.61	15.75	2.42	13.33	52.34
1883	11.35	8.13	3.22	4.55	9.33	2.53	6.80	6.90	2.52	1.55	0.97	2.78	4.35	1.90	2.45	3.78	10.97	4.63	6.34	6.82	11.08	7.73	3.35	3.86	19.25	1.55	17.70	67.31
1884	7.50	5.33	2.17	6.94	5.22	1.73	3.49	5.38	4.85	1.70	3.15	5.09	9.75	4.85	4.90	7.72	6.95	5.20	1.75	3.32	9.40	5.30	4.10	7.04	16.50	1.70	14.80	66.44
1885	6.27	3.82	2.45	7.32	6.17	3.53	2.64	6.29	6.87	5.10	1.77	4.19	8.67	5.82	2.85	4.12	11.23	8.80	2.43	4.38	10.60	8.40	2.20	4.07	14.85	3.53	11.32	60.98
1886	5.55	1.70	3.85	4.00	2.40	1.30	1.10	2.71	3.32	1.72	1.60	2.09	3.63	2.62	1.01	2.67	3.23	2.47	0.76	1.97	2.93	2.50	0.43	1.23	15.15	1.30	13.85	44.75
1887	2.10	1.00	1.10	1.43	1.73	1.00	0.73	1.02	2.30	1.65	0.65	0.95	2.60	2.00	0.60	1.39	2.40	1.90	0.50	0.75	3.90	2.15	1.75	2.05	16.25	1.00	15.25	37.23
1888	9.50	6.90	2.60	5.16	6.60	2.65	3.95	4.75	2.43	1.40	1.03	2.19	2.45	1.47	0.98	2.25	3.60	2.03	1.57	2.55	3.22	2.30	0.92	1.64	13.82	1.40	12.42	53.40
1889	10.75	7.40	3.35	4.87	7.10	2.40	4.70	5.00	4.20	2.40	1.80	3.14	2.78	2.20	0.58	1.95	4.40	3.05	1.35	2.52	7.37	3.72	3.65	4.37	11.20	2.20	9.00	49.19
1890	11.52	4.95	6.57	6.80	4.92	2.55	2.37	2.63	2.90	2.40	0.50	0.96	3.50	2.65	0.85	1.05	3.80	3.00	0.80	1.20	3.88	3.30	0.58	1.00	12.10	2.40	9.70	36.58
1891	7.53	2.50	5.03	5.28	4.50	2.50	2.00	4.12	2.78	2.13	0.65	0.73	2.08	1.77	0.31	0.54	3.63	1.95	1.68	1.78	4.60	3.65	0.95	1.01	13.60	1.77	11.83	41.48
1892	15.95	10.55	5.40	5.42	10.30	3.42	6.88	7.13	3.80	3.00	0.80	1.92	3.00	2.70	0.30	0.46	3.10	2.70	0.40	0.48	4.30	3.10	1.20	1.50	18.80	2.70	16.10	42.46
1893	8.37	2.40	5.97	6.10	2.35	1.30	1.05	1.15	2.00	1.35	0.65	1.40	2.50	2.05	0.45	0.85	2.60	2.50	0.10	0.10	4.00	2.60	1.40	1.40	17.60	1.30	16.30	41.53
1894	3.83	1.90	1.93	2.10	2.90	1.50	1.40	2.58	5.80	3.00	2.80	4.70	4.67	2.70	1.97	3.10	3.00	2.80	0.20	0.40	3.80	3.00	0.80	0.80	10.40	1.50	8.90	32.92
1895	5.40	1.50	3.90	7.30	4.27	1.77	2.50	3.52	5.80	2.20	3.60	8.75	2.60	1.20	1.40	2.73	2.60	1.90	0.70	1.64	13.14	2.53	10.61	11.48	13.14	0.93	12.21	51.89
1896	7.63	2.23	5.40	8.90	8.80	5.93	2.87	4.60	5.73	4.00	1.73	4.05	7.57	4.63	2.94	5.60	7.00	5.03	1.97	3.02	6.50	4.40	2.10	2.10	13.10	2.23	10.87	53.16
1897	7.97	4.10	3.87	4.55	3.97	1.70	2.27	2.46	1.90	1.70	0.20	0.70	1.90	1.70	0.20	0.40	3.20	1.80	1.40	1.83	3.23	2.70	0.53	2.39	16.33	1.70	14.63	46.86
1898	9.47	2.00	7.47	8.29	5.40	2.33	3.07	5.32	5.00	3.00	2.00	5.57	6.70	3.70	3.00	3.86	9.07	6.80	2.27	3.55	8.33	5.90	2.43	4.16	18.55	2.00	16.55	66.84
1899	5.20	3.50	1.70	3.80	3.70	1.70	2.00	4.06	3.17	1.70	1.47	2.80	3.10	2.20	0.90	1.20	4.30	3.10	1.20	2.10	5.83	3.60	2.23	2.66	13.80	1.70	12.10	46.36
Av.	8.39	4.15	4.23	5.82	5.19	2.26	2.93	4.14	3.66	2.18	1.48	3.10	4.18	2.49	1.69	2.78	5.19	3.55	1.69	2.40	6.61	4.18	2.43	3.24	14.84	1.70	13.14	50.31

TABLE II.

Highest and Lowest Water, Range, and Total Movement by Months, of River Levels, from Gage-readings below LaGrange Dam, 1883-1899.

BASIS OF REFERENCE, LOW WATER OF 1879.

YEAR	JANUARY				FEBRUARY				MARCH				APRIL				MAY				JUNE			
	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1883	9.08	4.78	4.30	5.21	21.82	4.48	17.34	18.82	20.90	12.80	8.10	8.10	13.60	11.63	1.97	3.43	13.35	11.35	2.00	3.30	14.70	11.90	2.80	5.00
1884	7.10	4.35	2.75	5.50	16.60	8.50	8.10	10.05	16.70	12.65	4.05	7.95	17.35	12.10	5.25	5.90	12.00	9.20	2.80	4.10	9.05	8.05	1.00	3.60
1885	16.30	9.00	7.30	9.50	14.20	9.40	4.80	5.00	15.50	9.45	6.05	7.45	16.10	13.40	12.70	3.65	16.00	8.70	7.30	7.40	8.75	7.10	1.65	5.75
1886	14.25	9.75	4.50	6.30	16.75	11.40	5.35	7.20	16.35	13.00	3.35	5.00	14.60	13.05	1.55	2.35	13.95	11.95	2.00	3.65	13.40	5.70	7.70	7.90
1887	8.10	2.15	5.95	6.20	17.15	8.25	8.90	9.62	16.65	10.50	6.15	6.28	10.25	5.25	5.00	5.45	5.35	2.07	3.28	3.38	2.20	1.00	1.20	2.07
1888	7.50	2.80	4.70	8.04	9.60	6.28	3.32	6.13	13.48	9.70	3.78	5.55	13.85	8.98	4.87	5.34	11.30	7.88	3.42	5.26	12.45	8.22	4.23	5.56
1889	5.75	3.00	2.75	3.92	4.85	2.92	1.93	3.49	8.44	5.30	3.14	6.80	8.24	4.80	3.44	7.78	6.95	2.64	4.31	10.57	11.81	5.25	6.56	9.17
1890	13.18	6.20	6.98	8.71	11.45	8.38	3.07	3.58	10.05	7.92	2.13	4.31	11.32	9.60	1.72	2.37	10.87	8.70	2.17	2.99	9.95	8.03	1.92	4.14
1891	2.90	1.55	1.35	2.95	5.33	1.63	3.70	4.36	7.25	5.30	1.95	2.64	12.80	7.27	5.53	5.80	12.50	4.87	7.63	9.50	6.15	4.27	1.88	3.83
1892	3.90	2.67	1.23	3.01	6.00	2.67	3.33	4.94	7.10	6.15	0.95	2.23	14.65	7.25	7.40	9.30	19.25	12.93	6.32	7.45	18.13	14.40	3.73	4.92
1893	2.80	2.25	0.55	0.82	14.33	2.50	11.83	11.92	16.67	14.30	2.37	4.40	16.80	12.50	4.30	4.65	17.60	13.87	3.73	6.10	15.13	8.03	7.10	7.73
1894	3.27	2.50	0.77	1.80	5.35	2.55	2.80	4.85	8.68	4.55	4.13	4.99	7.75	5.67	2.08	2.60	6.75	5.35	1.40	3.96	5.15	2.30	2.85	3.87
1895	2.40	1.62	0.78	2.58	5.72	2.05	3.67	6.37	6.20	3.80	2.40	2.88	4.65	3.57	1.08	2.19	3.35	1.40	1.95	2.77	1.50	0.10	1.60	3.29
1896	12.30	7.90	4.40	5.03	9.38	7.92	1.46	4.15	9.60	7.48	2.12	2.42	7.35	6.00	1.35	2.35	8.05	4.07	3.98	6.08	8.50	4.80	3.70	5.17
1897	13.25	3.90	12.35	11.51	11.75	10.13	1.62	3.05	17.10	11.87	5.23	5.35	17.93	12.88	5.05	5.88	12.80	7.05	5.75	6.03	6.85	3.28	3.57	6.64
1898	7.13	1.95	5.18	7.94	11.43	6.60	4.83	8.61	18.90	11.07	7.83	8.53	19.82	12.62	7.20	8.12	15.40	10.62	4.78	6.85	15.28	10.08	5.20	5.27
1899	9.53	6.13	3.40	9.11	10.97	6.00	4.97	9.22	14.40	11.48	2.92	4.38	13.55	9.35	4.20	4.50	12.25	6.92	5.33	10.81	12.08	4.32	7.76	7.86
Av	8.16	4.26	4.07	5.78	11.34	5.98	5.36	7.14	13.18	9.25	3.92	5.25	12.95	9.17	3.80	4.80	5.04	7.62	4.00	5.89	10.07	6.27	3.79	5.39

TABLE II.—*Concluded.*

Highest and Lowest Water, Range, and Total Movement by Months, of River Levels, from Gage-readings below LaGrange Dam. 1883-1899.

BASIS OF REFERENCE, LOW WATER OF 1879.

YEAR	JULY				AUGUST				SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER				EXTREMES		TOTAL	
	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement	Highest	Lowest	Range	Movement
1883	13.80	8.30	5.50	6.42	8.30	2.50	5.80	5.80	2.40	1.30	1.10	1.70	3.30	1.40	1.90	2.80	9.20	3.40	5.80	5.90	10.40	7.00	3.40	4.90	21.82	1.30	20.52	71.38
1884	8.15	5.30	2.85	4.40	5.70	1.80	3.90	5.30	5.40	1.40	4.00	7.60	8.80	5.40	3.40	5.00	7.10	5.10	2.00	4.20	8.90	5.10	3.80	6.40	17.35	1.40	15.95	69.80
1885	7.50	4.15	3.35	4.40	5.35	3.70	1.65	5.70	6.05	4.50	1.55	3.40	7.60	5.00	2.66	3.05	10.25	7.80	2.45	5.30	9.20	6.80	2.40	5.10	16.30	3.70	12.60	65.70
1886	5.40	1.40	4.00	4.30	3.10	1.10	2.00	4.10	3.10	1.15	1.95	2.60	3.00	2.10	0.90	2.40	2.65	1.90	0.75	0.95	2.65	2.00	0.65	1.45	16.75	1.10	15.65	48.20
1887	1.10	0.25	0.85	1.65	0.47	-0.08	0.55	1.68	0.72	0.15	0.57	0.96	0.90	0.58	0.32	0.66	1.05	0.50	0.55	1.40	2.80	0.95	1.85	1.00	17.15	0.08	17.23	40.41
1888	9.48	7.25	2.23	6.37	7.48	2.12	5.36	6.23	1.95	0.72	1.23	2.36	1.50	0.58	0.92	1.64	3.32	1.18	2.14	3.66	2.95	1.75	1.20	2.11	13.85	0.58	13.27	58.25
1889	12.03	6.92	5.11	5.86	6.75	1.78	4.97	5.14	3.58	1.54	2.04	3.90	1.86	1.10	2.96	7.22	4.45	2.10	2.35	4.10	6.88	3.39	3.49	4.20	12.03	1.10	13.13	72.15
1890	9.40	2.38	7.02	8.00	2.40	0.95	1.45	2.87	1.35	0.85	0.50	1.66	2.97	1.00	1.97	4.35	2.45	1.38	1.07	1.72	2.93	1.35	1.58	3.64	13.18	0.85	12.33	48.34
1891	5.90	1.65	4.25	5.29	4.45	1.13	3.32	9.13	1.50	0.47	1.03	1.69	0.55	0.12	0.43	1.77	2.70	0.20	2.50	3.65	3.28	1.82	1.46	2.09	12.80	0.12	12.68	52.68
1892	16.07	10.85	5.22	5.96	10.45	2.57	7.88	8.28	2.48	1.53	0.95	2.12	1.55	1.10	0.45	0.59	2.20	1.23	0.97	1.24	3.70	2.20	1.50	2.33	19.25	1.10	18.15	57.37
1893	7.80	1.40	6.40	8.77	1.35	0.05	1.30	1.45	0.72	0.10	0.62	1.21	1.40	0.70	0.70	1.10	1.20	1.0	0.20	0.64	3.10	0.95	2.15	3.14	17.60	0.05	17.55	51.93
1894	2.27	0.70	1.57	1.85	0.90	-0.07	0.97	2.25	5.35	0.90	4.45	8.78	2.87	0.75	2.12	4.30	1.95	1.42	0.53	1.59	2.60	1.75	0.85	1.67	8.68	-0.07	8.75	42.60
1895	4.88	0.10	4.78	6.61	3.78	0.45	3.33	6.58	4.97	1.07	3.90	9.52	1.88	0.48	1.40	2.83	1.47	0.60	0.87	1.35	11.90	1.60	10.30	11.47	11.90	-0.10	12.00	58.44
1896	8.30	1.97	6.33	12.98	9.95	5.45	4.50	7.23	5.52	3.45	2.07	6.09	6.20	3.82	2.38	4.28	5.70	4.50	1.20	2.60	5.40	3.8	1.58	1.77	12.30	1.97	10.33	60.15
1897	7.28	3.68	3.60	9.05	3.45	1.00	2.45	3.00	1.20	0.85	0.35	0.85	0.95	0.73	0.22	0.45	2.07	0.92	1.15	2.01	2.22	1.65	0.57	1.71	17.93	0.73	17.20	55.53
1898	9.80	1.68	8.12	8.57	5.60	1.75	3.85	7.44	5.43	2.23	3.20	10.53	5.25	2.95	2.30	3.77	8.05	5.37	2.68	3.56	7.80	5.40	2.40	6.17	19.82	1.68	18.14	85.36
1899	5.22	3.07	2.15	6.87	4.87	0.50	4.37	8.02	2.55	0.45	2.10	3.54	1.90	0.65	1.25	2.69	3.58	1.88	1.70	2.89	4.15	2.32	1.83	2.30	14.40	0.45	13.95	72.19
Av.	7.95	3.59	4.30	6.31	4.96	1.57	3.39	5.31	3.13	1.34	1.87	4.03	3.09	1.54	1.54	2.88	4.08	2.38	1.70	2.75	4.76	2.69	2.41	3.61	15.48	0.80	14.68	59.15

TABLE III.

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1894																	
11378	12 VI	88	77.5	77	Smooth		4.10	4.73	0.23	O. H.*100 ft.	2.00	236	0.13	33	0.74	0.36	1.10	*O. H.= Oblique haul of plankton net.
11389	29 VI	82.5	83	83	"			4.00	+0.10	" " " "	2.25	"	0.08	5	0.73	0.03	0.76	
11397	13 VII	81	82.5	82.5	"		3.75	2.09	0.09	" " " "	2.30	"	0.25	2	2.39	0.05	2.44	
11410	30 VII		82	81	"			2.00	0.00	" " " "	3.00	"	0.63	2	7.85	0.16	8.01	
11428	15 VIII	.	83.5	82	Rippled	Waterclearing	.	1.70	0.00	" " " "	3.00	"	0.80	5	9.67	0.51	10.18	
11444	4 IX	. . .	77.5	77.5	"		.	3.00	0.00	" " " "	2.75	"	0.21	3	2.38	0.07	2.15	
11449	17 IX	. . .			"	Rather turbid		5.80	0.00	" " " "	2.50	"	0.13	75	0.34	1.03	1.37	
11460	17 X		58		"		. . .	2.70	0.10	" " " "	2.25	"	0.08	20	0.61	0.15	0.76	
11463	11 XI	..	41	41	Waves			3.00	0.00	" " " "	2.00	"	0.03	60	0.10	0.15	0.25	
11468	15 XII	44	39	39	"		. . .	3.20	0.60	" " " "	2.00	"	0.04	70	0.10	0.24	0.34	
													Yrly Av.		2.49	0.28	2.77	
	1895																	
11474	23 II		32		Ice 37 cm.		5.90	3.37	+0.21	O. H. 97 ft.	2.50	229	0.08	99.9	0.01	0.86	0.87	
11485	9 IV		52		Rippled			4.97	+0.07	" " 100 "	2.50	236	0.49	90	0.52	4.67	5.19	
11495	29 IV		64		Smooth			4.65	0.05	" " " "	2.75	"	0.51	2	5.83	0.12	5.95	
22000	19 VI	..	80		Rippled		.	1.80	0.00	" " " "	3.50	"	2.05	0	30.42	0.00	30.42	
22010	6 VII	75	80.5	79.5	"	Clear, br'wnish	.	2.15	0.07	" " " "	3.50	"	2.00	0	29.68	0.00	29.68	Much floating vegetation.
22017	18 VII	82.2	80	79	Waves	Turbid		3.90	+1.40	" " " "	3.00	"	0.53	2	6.61	0.13	6.74	
22022	23 VII	74	80	79.5	Rippled	Very turbid		5.20	0.08	" " " "	2.50	"	0.08	20	0.68	0.17	0.85	Much drift and vegetation floating.
22028	29 VII	73.5	75.5	75.5	Smooth	" "	3.97	5.38	+0.10	" " " "	2.25	"	0.05	30	0.33	0.14	0.47	
22027	1 VIII	92	78.5	77.8	"	Slightly "	3.65	4.20	-0.60	" " " "	2.50	"	0.07	30	0.52	0.22	0.74	
22031	5 VIII	73.3	79	79	Waves	" "	3.65	3.13	0.53	" " " "	2.50	"	0.09	5	0.91	0.04	0.95	
22035	8 VIII	83.5	79	78	"	" "		2.63	0.15	" " " "	2.25	"	0.10	5	0.91	0.04	0.95	
22038	12 VIII	76	84.8	82.5	Rippled	Turbid	2.15	2.40	+0.10	" " " "	3.50	"	0.40	2	5.82	0.12	5.94	
22042	15 VIII	84	85.3	83.2	"	Clear, greenish		2.35	0.03	" " " "	3.50	"	0.41	2	5.96	0.12	6.08	Greenish water-bloom.
22045	21 VIII	75	81.5	88.5	"		3.35	2.08	0.03	" " " "	3.50	"	0.40	2	5.82	0.12	5.94	
22049	24 VIII	80	80	78.5	"	Slightly turbid	2.87	2.35	+0.25	" " " "	3.50	"	0.53	3	7.63	0.24	7.87	
22050	26 VIII	80	79.5	79	"	Dark, clear	3.50	2.78	+0.03	" " " "	3.00	"	0.34	2	4.24	0.08	4.32	
22054	29 VIII	71	80	80	Waves	Slightly turbid	1.50	2.58	0.10	" " " "	2.50	"	0.37	7	3.65	0.27	3.92	Some vegetation floating.
22057	31 VIII	69	77.5	77.5	"	" "	3.50	2.65	0.00	" " " "	2.50	"	0.48	5	4.83	0.25	5.08	
22059	2 IX	82	77	75.5	"	" brownish	3.50	2.45	0.10	" " " "	2.50	"	0.28	2	2.91	0.06	2.97	
22060	4 IX	72	74.5	74	"	" "	3.50	3.00	+0.65	" " " "	2.50	"	0.21	7	2.07	0.16	2.23	
22061	5 IX	78	74	72.5	Rippled	Very turbid	4.25	5.70	+2.70	" " " "	2.50	"	0.14	15	1.26	0.22	1.18	Much drift and fine debris.
22063	6 IX	84	73	72	"	" "	3.60	6.85	+0.15	" " " "	2.50	"	0.11	15	0.99	0.17	1.16	
22065	7 IX	68	72	72	Waves	Turbid	4.58	5.88	0.00	" " " "	2.25	"	0.09	20	0.69	0.17	0.86	
22066	9 IX	90.2	74.5	72.5	Rippled	"	4.42	5.38	-0.15	" " " "	2.50	"	0.14	30	1.04	0.44	1.48	Some *Lemna* floating.
22069	11 IX	92.5	81	77	Waves	"	3.96	4.25	-0.58	" " " "	2.50	"	0.10	25	0.80	0.26	1.06	Some vegetation floating.
22070	12 IX	85.4	79	78	Rippled	"	3.50	3.90	-0.35	" " " "	2.75	"	0.25	15	2.48	0.44	2.92	
22073	14 IX	67	75.5	75.5	"	Slightly turbid	3.66	3.38	-0.28	" " " "	2.75	"	0.30	7	3.25	0.24	3.49	

TABLE III.—*Continued.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1895-Cont																	
22074	16 IX	73	74.5	74.5	Rippled	Slightly turbid	3.58	3.20	+0.75	O. 11. 100 ft.	2.50	236	0.18	20	1.53	0.38	1.91	Some *Lemna* & *Wolffia* floating.
22076	18 IX	81.5	76	75.5	Waves	Yellowish. "	3.81	3.58	−0.10	" " " "	2.00	"	0.14	25	0.89	0.30	1.19	Very little *Lemna* floating.
22079	20 IX	81.5	79	78	"	" "	4.66	3.20	−0.23	" " " "	2.75	"	0.17	15	1.69	0.29	1.98	
22080	23 IX	61	76.5	76.5	Rippled	Slightly "	3.50	2.75	−0.13	" " " "	2.30	"	0.14	10	1.23	0.14	1.37	
22086	25 IX	60.5	73.5	72.5	Waves	Yellowish. "	3.35	2.63	−0.08	" " " "	2.25	"	0.12	10	1.03	0.11	1.14	
22085	27 IX	71.5	73	72	Smooth	" clear	3.70	3.23	+0.60	" " " "	2.25	"	0.11	10	0.95	0.10	1.05	Backwater due to rise in Spoon R.
22087	2 X	68.5	63.5	61	Rippled	Turbid	3.20	2.55	−0.20	" " " "	2.50	"	0.05	30	0.37	0.16	0.53	
22093	11 X	50	56.5	56.5	Smooth	Dark, clear	3.10	2.20	0.00	" " " "	2.50	"	0.08	10	0.76	0.08	0.84	
22100	15 X	55	55.8	56.7	"	" "	3.10	2.20	0.00	" " " "	2.50	"	0.08	10	0.76	0.08	0.84	
22106	23 X	40	50.5	50.5	Rippled	Clear	3.20	2.35	0.00	" " " "	2.40	"	0.06	10	0.55	0.06	0.61	
22107	30 X	30.2	45	45	"	Slightly turbid	3.20	2.25	−0.05	" " " "	2.50	"	0.05	20	0.42	0.11	0.53	
22108	5 XI	64	49.8	48.5	Waves	Clear	3.30	2.30	+0.08	" " " "	2.50	"	0.08	30	0.59	0.25	0.84	
22114	14 XI	48	44.4	44	"	Slightly turbid	3.30	2.70	0.00	" " " "	3.25	"	0.33	10	4.09	0.45	4.54	Some *Corixa* removed.
22117	20 XI	29.2	42.8	43.2	"	" "	3.50	2.78	+0.03	" " " "	3.00	"	0.25	5	3.02	0.16	3.18	
22118	27 XI	30.8	33	33	"	" "	3.35	2.87	−0.05	" " " "	3.50	"	0.31	5	4.37	0.23	4.60	
22119	4 XII	20.5	32.2	32.3	"	" "	3.60	3.20	0.00	" " " "	3.25	"	0.15	2	2.05	0.02	2.07	Ice forming and floating.
22120	11 XII	44.2	32.3	32.3	Ice 2.5 cm.	" "	3.53	3.05	−0.20	" " " "	4.00	"	0.23	35	2.54	1.36	3.90	
22121	18 XII	48	39.3	39.2	Smooth	" "	3.50	2.85	+0.15	" " " "	3.50	"	0.18	35	1.74	0.93	2.67	
22126	20 XII	41	41.2	41.2	"	Muddy	4.27	7.60	+2.40	" " " "	3.00	"	0.24	15	2.60	0.45	3.05	Some debris floating.
22130	25 XII	35.1	40.8	41	Rippled	Turbid	5.18	10.30	+0.75	" " " "	2.75	"	0.68	99	0.08	7.85	7.93	" " "
22131	27 XII	47.5	39	39	Waves	"	5.08	11.50	+0.50	6 V. H. 5.08 m.*	1.75	240	0.94	99	0.07	6.79	6.86	*V. H.=Vertical haul. Much debris.
22136	28 XII	38	38.6	38.6	Very rough	Very turbid	6.00	11.93	+0.43	5 V. H. 6 m.	1.50	236	0.64	99.9	0.01	4.06	4.07	Much debris.
22142	30 XII	28.5	36.5	37.5	Waves	Turbid	6.10	12.50	+0.25	" "	1.50	"	0.28	99.9	0.01	1.77	1.78	
													Yrly	Av.	3.22	0.72	3.94	
	1896																	
22143	1 I	29.2	33.3	33.3	Waves	Turbid	6.10	12.60	0.00	5 V. H. 6 m.	1.50	236	0.25	99.9	0.01	1.58	1.59	Some floating ice.
22144	6 I	42	32.2	32.2	Rippled	"	5.80	12.20	--0.10	6 " 5 "	1.50	"	0.08	95	0.03	0.48	0.51	Ice 2.5 cm. to 7.5 cm. in places.
22146	8 I	31	32.1	32.1	"	Slightly turbid	5.80	11.90	−0.10	" " " "	1.50	"	0.19	99.9	0.01	1.20	1.21	River partly frozen over.
22147	10 I	43.7	32.4	32.3	Smooth	Turbid	5.50	11.40	+0.25	" " " "	1.50	"	0.16	99.9	0.01	1.01	1.02	Ice breaking up.
22148	13 I	32.8	32.3	32.4	Rippled	"	5.34	10.80	−0.20	" " " "	1.50	"	0.13	99.5	0.01	0.82	0.83	Little ice left.
22149	15 I	31.2	32.2	32.1	"	"	5.30	10.40	−0.20	" " " "	1.50	"	0.29	99.9	0.01	1.83	1.84	River free from ice.
22150	20 I	41.2	32.8	32.6	"	Very turbid	4.90	9.50	−0.30	7 " 4.5 "	1.50	248	0.30	99.9	0.01	1.80	1.81	Much fine debris.
22156	25 I	28	33	33	"	Turbid	4.88	8.60	−0.20	" " " "	1.50	"	0.39	99.9	0.01	2.35	2.36	" " "
22159	30 I	45	34.5	34.3	Smooth	Slightly turbid	4.65	8.10	0.00	" " " "	1.59	"	0.34	99.5	0.01	2.17	2.18	Some debris, water clearing.
22161	4 II	39	34.2	34.1	Rippled	Very "	4.90	8.50	0.00	" " " "	2.00	"	0.88	99.9	0.01	7.08	7.09	Much debris.
22162	10 II	36.5	34	34	Waves	" muddy	5.00	8.90	+0.10	" " " "	1.50	"	0.64	99.9	0.01	3.86	3.87	" "
22168	20 II	13	32.2	32.2	Ice 5 cm.	Clear	5.00	8.50	0.00	" " " "	1.50	"	0.40	99.5	0.01	2.41	2.42	Few holes in the ice.
22169	25 II	52	34.5	34	Very rough	"	5.00	8.90	+0.50	" " " "	1.50	"	0.45	99	0.03	2.69	2.72	Very little ice.
22188	3 III	33	35	35	Waves	"	5.40	10.10	+0.10	6 " 5 "	2.00	236	1.75	99.5	0.07	14.77	14.84	Much fine drift.

TABLE III.—*Continued.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method.	Coefficient	Vol. water strained—in liters	Vol. of catch in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1896-Cont.																	
22189	9 III	50	38	37.1	Rippled	Clear	5.70	10.20	0.00	6 V.II. 5 M.	1.50	236	0.78	98.5	0.07	4.89	4.96	One haul with tow-net. No drift.
22191	17 III	42	35.8	35.8	Waves	Turbid	5.33	9.70	−0.10	" " " "	1.50	"	0.80	99	0.05	5.03	5.08	
22193	24 III	46.6	40.7	40.5	Very rough	"	5.03	8.80	−0.20	7 " 4.5 "	1.50	248	0.96	99.5	0.03	5.77	5.80	Fine floating debris.
22198	30 III	58	48.1	48	Waves	"	5.03	8.10	0.10	" " " "	1.50	"	1.11	98	0.13	6.58	6.71	" " "
22205	10 IV	69.5	46.4	46.2	"	"	4.72	7.40	+0.10	8 " 4 "	1.50	252	1.13	75	1.68	5.05	6.73	
22209	17 IV	73	66.3	66	"	Slightly turbid	4.88	7.30	−0.10	7 " 4.5 "	1.60	248	1.15	40	4.45	2.97	7.42	
22215	24 IV	78	72	71.8	Rippled	Turbid	4.60	6.90	0.00	8 " 4 "	2.00	252	2.15	45	9.39	7.68	17.07	
22218	25 IV	72	68	67.5	Waves	Slightly turbid	4.50	6.90	0.00	" " " "	2.00	"	2.13	45	9.30	7.61	16.91	
22219	29 IV	72.5	70	70	"	0.40[*]	4.57	7.10	+0.10	" " " "	1.75	"	1.30	60	3.61	5.42	9.03	[*] Disc used; depth visible in m.
22222	1 V	79	68.8	68.8	Very rough	0.30	4.65	7.10	0.00	" " " "	1.50	"	0.85	65	1.77	3.29	5.06	
22230	8 V	78.5	76	76	Waves	0.42	4.27	6.50	−0.20	9 " 3½ "	1.50	236	0.88	50	2.80	2.80	5.60	
22234	13 V	85	82.3	82.3	"	0.60	4.35	5.50	−0.20	" " " "	1.50	"	0.70	20	3.56	0.89	4.45	
22238	18 V	64.9	71.2	71.2	Rippled	0.33	3.96	4.90	0.00	" " " "	1.50	"	0.54	75	0.86	2.57	3.43	
22239	19 V	61	69.3	69.4	"	0.36	4.20	5.40	+0.50	8 " 3¾ "	1.50	"	0.30	80	0.38	1.53	1.91	
22242	20 V	71.3	68.5	68	"	0.12	4.65	6.20	+0.80	8 " 4 "	1.50	252	0.38	90	0.23	2.03	2.26	
22252	22 V	66	70	70	"	0.10	5.10	6.90	+0.40	Pump	...	125	0.38	80	0.61	2.43	3.04	Pump first used.
22267	25 V	77	75.3	75.2	Waves	0.18	5.30	7.40	+0.10	"	...	"	0.51	65	1.43	2.65	4.08	
22273	29 V	74	73	73	Rippled	0.22	5.33	7.90	+0.20	"	...	"	1.02	99	0.08	8.08	8.16	Much fine veget'le debris
22274	1 VI	67	69	69.2	"	0.20	5.38	8.30	+0.10	"	...	"	0.74	99	0.06	5.86	5.92	" " " "
22276	3 VI	68	68.1	67	"	0.24	5.49	8.50	+0.10	"		"	0.83	98	0.13	6.51	6.64	" " " "
22286	6 VI	93.5	79	78.5	Waves	0.40	5.80	8.40	0.10	"		"	0.54	95	0.22	4.10	4.32	
22288	11 VI	68.5	73	72.3	Smooth	0.16	5.34	8.10	−0.10	"		"	0.70	70	1.68	3.92	5.60	
22294	13 VI	75	73	72.8	Rippled	0.33	5.49	7.90	−0.10	"		"	0.42	65	1.18	2.18	3.36	
22296	17 VI	75	75.8	75.8	Waves	0.40	4.57	7.55	−0.05	"		"	0.39	75	0.78	2.34	3.12	
22302	20 VI	85	79.8	79.5	"	0.66	4.57	7.35	−0.10	"		"	0.26	65	0.73	1.35	2.08	
22304	27 VI	75.8	80	80	"	0.85	4.73	6.00	−0.20	"		"	0.18	35	0.94	0.50	1.44	*Lemnaceæ* floating.
22309	2 VII	86	80.8	80.5	"	1.15	4.27	5.15	−0.15	"	...	250	0.22	35	0.57	0.31	0.88	
22313	6 VII	75.5	80.5	80.5	Rippled	0.40	4.12	4.70	−0.10	"	...	"	0.13	50	0.26	0.26	0.52	
22332	10 VII	86	79.5	78.5	Waves	0.33	3.70	4.00	−0.10	"	...	"	0.30	20	0.96	0.24	1.20	
22338	14 VII	82	82.4	82.2	"	0.43	3.65	3.30	0.20	"		750	0.39	15	0.44	0.08	0.52	
22342	18 VII	71.8	79	79	Rippled	0.24	3.25	2.50	0.20	"	...	250	0.25	5	0.95	0.05	1.00	
22343	20 VII	78	77	76.5	Smooth	0.27	3.81	4.10	+0.90	"	...	"	0.51	2	2.00	0.04	2.04	*Lemnaceæ* floating. Back water
22345	20 VII	81	83.2	78.5	"	0.28	3.91	4.10	+0.94	"	...	"	0.56	trace	2.24	trace	2.24	from rise in Spoon River.
22348	21 VII	85	83.5	83.5	Waves	0.30	3.91	4.30	+0.20	"	...	"	0.41	3	1.59	0.05	1.64	
22350	23 VII	71	80	74.5	Rippled	0.27	3.76	4.20	0.00	"	...	"	0.26	2	1.02	0.02	1.04	
22351	24 VII	70.5	78	78	Smooth	0.29	3.88	4.80	+0.60	"	...	"	0.20	2	0.78	0.02	0.80	
22354	25 VII	78	78	77.8	Rippled	0.39	4.12	5.30	+0.50	"		"	0.12	5	0.46	0.02	0.48	
22355	27 VII	85.5	80	79.2	"	0.40	4.27	6.10	+0.40	"		"	0.24	3	0.93	0.03	0.96	*Lemnaceæ* floating.
22356	28 VII	82	82	80	Waves	0.40	4.56	6.40	+0.30	"		"	0.56	8	2.06	0.18	2.24	Few " floating.

TABLE III.—*Continued.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1896-Cont																
22358	29 VII	94	82.8	82	Waves	0.34	4.56	6.80	+0.40	Pump	250	0.88	2	3.45	0.07	3.52	
22361	30 VII	96	84	83.5	Rippled	0.22	4.73	7.00	+0.20	"	"	1.30	25	3.90	1.30	5.20	
22364	1 VIII	80.5	81	80	"	0.20	4.95	7.90	+0.60	"	"	1.00	90	0.40	3.60	4.00	Much drift.
22366	3 VIII	79	80.3	80.3	Waves	0.11	5.27	8.50	+0.20	"	"	1.30	95	0.26	4.94	5.20	Cattle-yard refuse floating.
22367	4 VIII	80.3	81.5	81.4	Rippled	0.27	5.27	8.60	+0.10	"	"	0.80	85	0.48	2.72	3.20	*Ceratophyllum* "
22370	5 VIII	92	84	83.2	Waves	0.40	5.25	8.60	0.00	"	"	0.53	85	0.32	1.80	2.12	*Lemnaceæ* "
22372	6 VIII	87	84.1	84	Smooth	0.45	5.25	8.60	0.00	"	"	0.90	70	1.08	2.52	3.60	Few *Lemnaceæ*. Cattle-yd. refuse.
22375	7 VIII	86	85	84.5	Rippled	0.42	5.28	8.50	−0.10	"	"	1.09	45	2.40	1.96	4.36	*Lemnaceæ* floating.
22376	8 VIII	94.5	86	85.5	Waves	0.42	5.20	8.40	−0.10	"	"	1.30	50	2.60	2.60	5.20	" few.
22379	10 VIII	91.2	86.5	86.2	"	0.26	4.98	8.20	−0.10	"	"	1.00	40	2.40	1.60	4.00	" floating.
22399	12 VIII	75.5	85.1	85.1	Rippled	0.31	4.95	7.90	−0.20	"	"	1.13	40	2.71	1.81	4.52	" "
22430	15 VIII	84	82	78	"	0.36	5.18	7.40	−0.20	"	"	0.58	50	1.16	1.16	2.32	
22431	18 VIII	68.8	77.3	78	"	0.17	4.88	7.50	0.00	"	"	0.68	75	0.68	2.04	2.72	*Lemnaceæ* floating.
22436	21 VIII	85	79	78	"	0.30	4.50	7.10	−0.10	"	"	0.46	85	0.28	1.56	1.84	" " Average of 10 catches =0.48.
22455	26 VIII	75	77.5	77	Waves	0.45	4.88	6.50	−0.10	"	"	0.36	70	0.43	1.01	1.44	
22464	29 VIII	73	74.3	74	Waves	0.42	4.60	6.00	−0.20	"	"	0.42	70	0.50	1.18	1.68	
22466	16 IX	65	73.5	73.5	Rippled	0.24	3.81	4.10	−0.05	"	"	0.38	65	0.53	0.99	1.52	
22473	30 IX	52	58	58	"	0.34	3.81	4.30	0.00	"	"	0.23	75	0.23	0.69	0.92	
22481	14 X	57	57	57	"	0.40	4.75	6.90	0.00	"	"	1.52	97	0.18	5.90	6.08	*Lemnaceæ* floating.
22489	29 X	71	55	55	Waves	0.66	4.27	5.10	−0.10	"	"	0.78	35	2.03	1.09	3.12	Few " Av. 10 catches= 0.783.
22497	17 XI	58	44	43.8	Rippled	0.42	4.27	6.25	+0.15	"	"	0.58	99	0.02	2.30	2.32	
22509	3 XII	34.5	32.2	33.3	Waves	0.66	4.42	6.00	−0.10	"	"	0.58	75	0.58	1.74	2.32	Floating ice. Much *Crenothrix*.
22512	29 XII	39	35	35	Rippled	1.10	3.90	4.50	0.00	"	"	0.26	10	0.94	0.10	1.04	*Crenothrix* floating.
												Yrly	Av.	1.16	2.55	3.71	
	1897																
22518	3 II	34.5	32	32	Ice 25.4 cm.	0.40	7.30	11.60	−0.10	Pump	250	0.14	95	0.03	0.53	0.56	
22527	26 II	17	32.5	32.5	Waves	0.15	6.40	11.70	+0.10	"	"	1.26	99	0.05	4.99	5.04	Ice forming.
22533	22 III	46	43.8	43	Rippled	0.20	7.00	15.20	+0.70	"	"	0.12	20	0.38	0.10	0.48	
22539	27 IV	56	60	60	Waves	0.35	7.50	11.60	−0.10	"	"	1.42	10	5.11	0.57	5.68	
22552	25 V	66.5	66.3	65.8	Rippled	0.60	5.00	8.00	-0.20	"	"	1.56	10	5.62	0.62	6.24	
22561	28 VI	83	75	75	Waves	0.02	4.80	6.90	+0.20	"	"	6.65	99	0.27	26.33	26.60	Much fine debris.
22564	14 VII	71.5	79	78.8	Rippled	0.42	2.60	6.30	−0.30	"	"	2.72	25	8.16	2.72	10.88	Some *Potamogeton* float'g.
22569	16 VII	75	78	......	"	0.30	2.70	5.90	−0.10	"	"	4.00	60	6.40	9.60	16.00	Taken 1 ft. below surface.
22572	21 VII	84	81.1	81.1	Waves	0.20	2.75	5.20	−0.10	"	125	0.46	75	0.92	2.76	3.68	
22574	23 VII	90	83	......	Smooth	0.30	.....	5.00	−0.10	"	"	1.08	20	6.91	1.73	8.64	Taken 1 ft. below surface. Green water-bloom.
22580	30 VII	87	84	82.8	Waves	0.25	3.25	4.60	+0.10	"	250	0.31	15	1.05	0.19	1.24	
22583	3 VIII	96	89	86.5	Smooth	0.30	3.35	3.60	−0.20	"	"	0.56	10	2.02	0.22	2.24	Heavy green water-bloom.
22588	10 VIII	78	81	80.8	Rippled	0.25	2.75	2.30	0.00	"	"	0.56	10	2.02	0.22	2.24	
22592	17 VIII	70	79	76	"	0.30	2.44	1.90	0.00	"	"	0.55	10	1.98	0.22	2.20	

TABLE III. *Continued.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894–1899.

Accessions Number	Date	TEMPERATURE, F. Air	Surface	Bottom	Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. water strained in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
	1897-Cont.																
22595	24 VIII	72.5	77.5	76	Rippled	0.37	2.55	1.80	0.00	Pump	250	0.73	5	2.77	0.15	2.92	
22601	31 VIII	78	80	80	"	0.33	2.44	1.80	0.00	"	"	2.41	2	9.45	0.19	9.64	
22603	7 IX	84	80	80	"	0.15	2.44	1.80	0.00	"	"	3.23	5	8.47	0.45	8.92	
22608	14 IX	95	83	82	Waves	0.33	2.44	2.00	0.00	"	"	5.21	5	19.80	1.04	20.84	
22610	21 IX	75	71	70.5	Rippled	0.35	2.44	2.00	0.00	"	"	0.75	trace	3.00	trace	3.00	
22612	29 IX	84	74.3	69	Smooth	0.20	2.38	2.00	0.00	"	125	0.51	1	4.04	0.04	4.08	Heavy green water-bloom.
22616	1 X				"			1.90	0.10	"	250	2.42	1	9.58	0.10	9.68	One foot below surface.
22618	5 X	80	71	70	Waves	0.22	2.40	1.90	0.00	"	"	3.23	trace	12.92	trace	12.92	
22619	12 X	67	65	64	"	0.30	2.46	1.90	0.00	"	"	1.36	5	5.17	0.27	5.44	
22622	19 X	73	65	63	Rippled	0.30	2.44	2.00	0.00	"	"	0.58	20	1.86	0.46	2.32	
22624	26 X	77	59.5	59	Waves	0.35	2.50	2.10	0.00	"	"	0.34	85	0.20	1.16	1.36	
22627	2 XI	53	54	54	Rippled	0.66	2.60	2.50	0.00	"	"	0.16	90	0.06	0.58	0.64	
22631	9 XI	53	50	49.5	"	0.45	2.70	2.60	0.00	"	"	0.82	75	0.82	2.46	3.28	
22634	15 XI	38.5	47	47	Waves	0.75	2.75	2.80	0.00	"	"	0.58	20	1.86	0.46	2.32	
22635	23 XI	36	43	43	Rippled	0.89	2.60	2.80	0.00	"	"	0.63	60	1.01	1.51	2.52	
22638	30 XI	29	34.5	35.5	Waves	0.65	3.05	3.20	+0.20	"	"	0.53	40	1.27	0.85	2.12	Little ice along margins.
22643	7 XII	30	32	32.5	Rippled	0.71	2.28	3.00	0.00	"	"	0.25	30	0.70	0.30	1.00	Some floating ice.
22641	14 XII	35	35.9	36	"	0.50	2.80	3.40	+0.10	"	"	0.34	10	1.22	0.14	1.36	
22644	21 XII	25	32	32.5	Ice 7.5 cm.	0.61	1.83	3.20	−0.10	"	"	0.37	80	0.30	1.18	1.48	
22647	28 XII	31	32.2	32.3	" 6-10 "	0.54	3.50	3.20	0.00	"	"	0.70	99	0.03	2.77	2.80	
												Yrly	Av.	3.69	1.91	5.60	
	1898																
22649	11 I	46.5	32	32.5	Ice 6 cm.	0.75	3.01	3.70	+0.10	Pump	250	0.18	90	0.07	0.65	0.72	Ice on river since Dec. 17. Air-holes increasing.
22651	21 I	41	34	34.5	Rippled	0.12	3.80	5.80	+0.40	"	"	0.27	25	0.81	0.27	1.08	Ice went out Jan. 11 and 12.
22654	25 I	33	32.1	32.1	Waves	0.12	3.05	6.80	+0.60	"	258⅓	1.22	90	0.47	4.25	4.72	River full of floating ice and slush, 2-5 cm.
22656	3 II	30	32	32.5	Ice 16 cm.	0.25	3.75	7.40	+0.10	"	250	0.24	30	0.67	0.29	0.96	River closed Jan. 27.
22658	8 II	43	32	32.2	" " "	0.35	3.90	7.10	0.20	"	"	0.71	90	0.28	2.56	2.84	Ice rotten, full of rifts and air-holes.
22660	15 II	32	32.5	33	Waves	0.10	4.00	9.00	+0.40	"	"	1.11	99	0.04	4.40	4.44	Ice went out Feb. 9-10.
22663	22 II	31.5	32	32.1	Rippled	0.15	4.50	10.70	+0.40	"	126⅔	2.60	99.5	0.10	20.41	20.51	Ice formed Feb. 21, now floating, 2-5 cm.
22665	1 III	32.5	33	34	Waves	0.20	4.50	11.40	0.00	"	250	1.12	99.5	0.02	4.46	4.48	
22669	8 III	55	37	37	"	0.30	5.50	11.00	0.10	"	"	0.51	97	0.06	1.98	2.04	
22671	15 III	58	46	46	"	0.30	5.70	12.10	+0.20	"	"	0.38	75	0.38	1.14	1.52	
22674	22 III	60	51	50.5	"	0.25	6.60	14.10	+0.40	"	"	0.21	20	0.77	0.19	0.96	
22676	29 III	45	49.5	49	Rippled	0.20	7.00	16.50	+0.70	"	"	0.12	10	0.43	0.05	0.48	
22680	5 IV	32	48.3	48.3	Waves	0.20	7.20	17.30	0.30	"	"	0.22	40	0.53	0.35	0.88	
22682	12 IV	58	52	51.5	"	0.23	6.10	14.80	0.30	"	"	0.08	60	0.13	0.19	0.32	
22685	19 IV	46	56	56	"	0.42	6.40	13.10	0.30	"	"	0.56	50	1.12	1.12	2.24	
22693	26 IV	64	57	56	Rippled	0.50	5.40	12.00	0.20	"	"	4.16	5	15.81	0.83	16.64	
22696	3 V	57.5	60	60	"	0.60	5.80	11.10	−0.10	"	"	8.92	trace	35.68	trace	35.68	

TABLE III.—*Continued.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1897-Cont.																
22697	10 V	70	62	61	Waves	0.60	5.80	10.30	—0.10	Pump	250	2.63	2	10.31	0.21	10.52	
22702	17 V	68	64	63	"	0.20	6.00	10.10	+0.20	"	"	1.74	25	5.22	1.74	6.96	
22705	24 V	89.2	73	71.5	Smooth	0.55	6.40	13.60	+0.30	"	"	0.88	2	3.45	0.07	3.52	Invasion of cold flood waters.
22711	31 V	77	70	68	Waves	0.33	7.30	13.60	—0.20	"	"	0.54	15	1.84	0.32	2.16	
22715	7 VI	82	78	77	Rippled	0.50	6.70	12.50	—0.20	"	"	2.20	40	5.28	3.52	8.80	
22716	14 VI	85	82.3	78	"	0.30	6.00	11.90	0.00	"	"	1.84	5	6.99	0.37	7.36	Streaky with flood waters. *Lemnaceæ* floating.
22721	21 VI	80	77	76.6	"	0.40	5.64	10.80	—0.10	"	"	0.90	20	2.88	0.72	3.60	
22723	28 VI	90.5	78	77	Waves	0.30	5.34	10.00	—0.20	"	"	0.43	60	0.69	1.03	1.72	
22725	5 VII	83	80.5	80	"	0.22	5.20	8.70	-0.20	"	"	0.44	92	0.14	1.62	1.76	*Lemnaceæ* floating.
22730	12 VII	80	78	77	Rippled	0.35	4.30	7.00	—0.20	"	"	0.32	95	0.64	1.22	1.86	" "
22733	19 VII	91	84	81.5	Waves	0.30	2.90	4.70	—0.30	"	"	0.44	50	0.88	0.88	1.76	
22737	26 VII	96	89	84	Rippled	0.30	2.85	2.90	—0.20	"	"	0.24	30	0.67	0.29	0.96	
22749	2 VIII	71.5	78.3	78	"	0.45	2.60	2.70	+0.10	"	"	0.45	10	1.62	0.18	1.80	
25763	9 VIII	80	83	79	Smooth	0.38	2.95	3.20	+0.20	"	"	0.27	10	0.97	0.11	1.08	Masses of *algæ* rising above shore.
22765	16 VIII	90	77	76	Waves	0.35	3.00	3.70	+0.40	"	"	0.51	70	0.61	1.43	2.04	
22768	23 VIII	88	82	81	Very rough	0.45	2.70	4.20	—0.30	"	"	0.64	80	0.51	2.05	2.56	
22770	30 VIII	92.5	82.5	80	" "	0.40	3.07	3.90	—0.20	"	"	0.41	50	0.82	0.82	1.64	
22773	6 IX	66	79	79.5	Rippled	0.30	3.30	4.70	+0.70	"	"	0.45	50	0.90	0.90	1.80	
22777	13 IX	74	62.5	61	Very rough	0.37	3.30	4.20	—0.20	"	"	0.38	60	0.61	0.91	1.52	
22780	20 IX	82	73	72.5	Rippled	0.37	3.15	4.20	—0.20	"	"	0.34	30	0.95	0.41	1.36	
22782	27 IX	72	73	73	"	0.52	3.30	4.90	0.00	"	500	0.77	80	0.31	1.23	1.54	
22785	4 X	72	71.5	71.5	"	0.50	3.30	4.00	—0.10	"	250	0.28	85	0.17	0.95	1.12	
22788	11 X	62.5	65	65	Waves	0.40	3.00	3.90	+0.10	"	"	0.22	75	0.22	0.66	0.88	
22791	18 X	38.5	52.5	52	Very rough	0.68	3.00	3.80	+0.10	"	"	0.42	75	0.42	1.26	1.68	
22793	25 X	43.5	48.5	48	Rippled	0.45	3.60	4.30	+0.10	"	"	0.41	90	0.16	1.48	1.64	
22795	1 XI	60.5	44.8	44.8	Very rough	0.28	3.60	6.30	+0.10	"	"	0.72	95	0.14	2.74	2.88	
22799	8 XI	40.7	46.5	46.5	Rippled	0.30	4.20	6.70	0.00	"	"	1.02	99	0.04	4.04	4.08	
22802	15 XI	45	40.8	40.7	Waves	0.28	4.40	7.10	+0.20	"	"	1.21	98	0.10	4.74	4.84	
22804	22 XI	21.3	40	40	Very rough	0.20	4.50	8.50	+0.20	"	"	5.60	99	0.22	22.18	22.40	
22807	29 XI	44	35	35	Waves	0.50	4.80	8.30	0.00	"	"	0.75	75	0.75	2.25	3.00	
22809	6 XII	30	34.2	34.2	Rippled	0.70	3.90	7.20	—0.30	"	"	0.35	10	1.26	0.14	1.40	Ice forming. River frozen across in places.
22813	13 XII	18	32.5	33	"	0.90	4.50	6.70	—0.10	"	"	1.50	99.9	0.01	5.99	6.00	River closed by ice except in few places.
22814	15 XII	38	32.7	32.8	Waves	0.72	4.20	6.60	—0.10	"	"	0.18	20	0.58	0.14	0.72	" " " " "
22816	20 XII	36.3	33	33	Rippled	0.93	4.13	5.90	—0.10	"	"	0.52	5	1.98	0.10	2.08	" " in places. Ice melting.
22819	27 XII	33	32.5	33.5	"	0.75	3.75	6.10	0.00	"	"	0.27	2	1.06	0.02	1.08	Ice along margins only.
												Yrly	Av.	2.13	2.11	4.24	
	1899																
22821	3 I	42.3	32.7	32.7	Waves	0.45	4.35	6.50	+0.10	Pump	250	0.16	65	0.22	0.42	0.64	River closed by ice Dec. 31. Few air-holes left.
22826	10 I	33	32.5	32.8	Rippled	0.35	4.75	7.90	+0.10	"	"	0.15	75	0.15	0.45	0.60	" " Collection in air-holes.

TABLE III.—*Concluded.*

PLANKTON DATA, ILLINOIS RIVER, STATION E. 1894 1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. of water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1899-Cont.																
22828	17 I	29.5	33	33	Ice 5 cm.	0.20	4.80	8.20	+0.10	Pump	250	0.62	80	0.50	1.98	2.48	River closed by ice. Air-holes increasing.
22831	24 I	41	34	34	Rippled	0.23	4.90	8.90	0.00	"	"	0.74	99	0.03	2.93	2.96	Ice gone from river except at margins.
22833	31 I	12	32.3	32.4	Ice 16 cm.	0.28	4.80	8.00	0.00	"	"	0.53	99.5	0.01	2.11	2.12	River closed by ice Jan. 27. Very few air-holes.
22838	7 II	15	32.5	32.5	Ice 25 cm.	0.65	4.58	7.30	0.10	"	266.7	0.33	90	0.11	1.12	1.23	" " Air-holes closing up.
22841	14 II	26.5	32.5	32.5	Ice 31 cm.	0.68	4.20	6.60	0.10	"	250	0.36	20	1.15	0.29	1.44	" " " "
22845	21 II	43.5	33	33	Ice 13 cm.	0.85	4.00	5.50	0.20	"	"	0.60	20	1.92	0.48	2.40	" " " increasing.
22847	28 II	34	32.5	32.5	Ice 4.4 cm.	0.04	5.40	10.20	+0.90	"	"	0.37	95	0.07	1.41	1.48	Ice rotten, full of holes.
22850	7 III	30	32.8	32.8	Rippled	0.05	6.30	12.90	0.00	"	"	0.18	25	0.54	0.18	0.72	River closed above by ice of Mar. 6.
22853	14 III	34	34	34	Waves	0.06	5.85	13.10	0.20	"	"	0.22	60	0.35	0.53	0.88	Ice went out Mar. 8 9.
22856	21 III	51	36.5	36.8	"	0.06	6.90	13.70	+0.30	"	"	0.08	35	0.21	0.11	0.32	
22858	28 III	31	37.5	37.5	"	0.10	6.60	13.50	+0.40	"	"	0.07	98	0.01	0.27	0.28	
												Yrly	Av.	0.41	0.94	1.35	
												Grnd	Av.	2.19	1.79	3.98	

TABLE IV.

PLANKTON DATA, SPOON RIVER, STATION M. 1896 1899.

Accessions Number	Date	TEMPERATURE, F			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1896																
22433	18 VIII	70	73.5	73	Rippled	0.03	1.27	7.50	0.00	Pump	250	0.10	99+	0.004	0.396	0.40	Current 0.32 miles per hour.
22453	25 VIII	78.5	79.5	77	"	0.30	4.57	6.60	0.10	"	"	0.04	80	0.032	0.128	0.16	
22471	16 IX	74	70.3	70.3	Smooth	0.07	3.26	4.20	+0.10	"	"	0.17	99+	0.007	0.673	0.68	Water very muddy.
22478	30 IX	61	58	58	"	0.21	3.66	4.30	0.00	"	"	0.04	99	0.002	0.158	0.16	
22485	14 X	65	57.1	57.1	"	0.35	3.86	6.90	0.00	"	500	0.09	99	0.002	0.178	0.18	Current scarcely perceptible.
22495	29 X	68	60	58	Rippled	0.20	3.66	5.10	0.10	"	250	0.20	99	0.008	0.792	0.80	

TABLE IV.—*Concluded.*

PLANKTON DATA, SPOON RIVER, STATION M. 1896–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river above low water	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch in cm.^{3}	Percentage of silt	Vol. plankton per m.^{3} water—in cm.^{3}	Vol silt per m.^{3} water—in cm.^{3}	Total catch per m.^{3} water—in cm.^{3}	Remarks
		Air	Surface	Bottom													
	1896-Cont.																
22502	17 XI	65.5	48.5	48	Smooth	0.38	3.81	6.30	+0.10	Pump	250	0.13	99+	0.005	0.515	0.52	
22510	3 XII	32	33.5	34	Ice 6 cm.	0.50	4.27	6.00	−0.10	"	250	0.05	99+	0.002	0.198	0.20	River closed above by ice.
22514	28 XII	39	32.8	33	Floating ice	0.90	3.85	4.50	−0.10	"	500	0.05	99+	0.001	0.099	0.10	Ice running out.
												Yrly	Av.	0.007	0.349	0.36	
	1897																
22515	3 II	31	32	32.3	Ice 18 cm.	1.65	3.80	11.60	−0.10	Pump	250	0.06	99	0.002	0.238	0.24	Closed above by ice.
22522	26 II	14	32.5	32.5	Rippled	0.05	7.80	11.70	+0.10	"	250	0.23	90	0.092	0.828	0.92	Slush ice floating. Very muddy.
22534	22 III	46	47	47	"	0.02	8.00	15.20	+0.30	"	125	0.82	99.9	0.007	6.553	6.56	Much drift. River out of its banks.
22536	27 IV	53	61.5	61.3	"	0.05	6.75	11.60	−0.10	"	125	0.60	99	0.048	4.752	4.80	Very muddy.
22549	25 V	57.5	67	66.5	Smooth	0.25	6.15	8.00	−0.20	"	250	0.22	50	0.440	0.440	0.88	Brownish water-bloom.
22556	28 VI	76	76	75.5	"	0.04	5.60	6.90	+0.20	"	250	0.25	75	0.250	0.750	1.00	
22585	10 VIII	78.2	80.8	78.8	"	0.06	3.96	2.30	0.00	"	250	0.07	80	0.056	0.224	0.28	
22599	26 VIII	88.5	78	72	Rippled	0.25	3.05	1.80	0.00	"	250	0.52	40	1.248	0.832	2.08	
22606	11 IX	94	86	76	Smooth	0.13	4.12	2.00	0.00	"	250	1.92	5	7.296	0.384	7.68	
22613	30 IX	85	73	67.5	"	0.20	1.68	2.00	0.00	"	250	0.78	5	2.964	0.156	3.12	
22628	2 XI	49.8	51.5	50.5	"	0.20	1.94	2.50	0.00	"	250	0.35	3.5	1.351	0.049	1.40	
22639	30 XI	31.5	37	38	Ice 2.5 cm.	0.45	4.58	3.20	−0.20	"	250	0.50	0.5	1.990	0.010	2.00	No current.
22648	28 XII	31	33	34	Ice 20 cm.	0.50	3.35	3.20	0.00	"	255	0.16	5	0.599	0.031	0.63	River closed Dec. 17.
												Yrly	Av.	1.257	1.173	2.43	
	1898																
22655	25 I	32.5	32	32.1	Slush ice 2-5 cm.	0.05	5.78	6.80	+0.60	Pump	125	0.21	99	0.017	1.663	1.68	River still closed. Ice rotten.
22664	22 II	32	32.4	32.2	Ice along shore	0.15	5.20	10.70	+0.40	"	125	0.13	98.5	0.016	1.024	1.04	Ice along shores. River closed Feb. 8-12.
22677	29 III	45	49.5	49	Rippled	0.04	9.10	16.50	+0.70	"	250	0.31	90	0.124	1.116	1.24	
22698	10 V	70	63.5	63	"	0.20	6.30	10.30	−0.10	"	250	0.19	97	0.023	0.737	0.76	
22712	7 VI	79	78.5	78	Smooth	0.21	7.90	12.50	−0.20	"	250	0.24	90	0.096	0.864	0.96	
22727	5 VII	82	80	79.5	Rippled	0.30	6.30	8.70	−0.20	"	250	0.18	95	0.036	0.684	0.72	
22761	5 VIII	83	77	75	"	0.20	3.90	2.80	0.00	"	250	0.10	99.5	0.002	0.398	0.40	Green water-bloom.
22775	12 IX	72.8	69	65	"	0.15	3.90	4.40	−0.10	"	250	0.38	99.9	0.002	1.518	1.52	
22786	4 X	73.5	71.5	71.5	"	0.35	2.70	4.00	−0.10	"	250	0.06	99.8	0.001	0.239	0.24	Green water-bloom.
22797	2 XI	53.7	45.1	44.8	Smooth	0.31	4.65	6.50	+0.20	"	250	0.09	99.9	0.001	0.359	0.36	
22811	6 XII	30	33	33.2	Ice above	1.50	5.40	7.20	−0.30	"	250	0.04	99.5	0.001	0.159	0.16	Closed above by ice.
												Yrly	Av.	0.029	0.796	0.83	
	1899																
22823	3 I	45.3	32.8	33	Ice 19 cm.	0.41	2.85	6.80	+0.10	Pump	250	0.13	99	0.005	0.515	0.52	Closed above by ice.
22839	7 II	13	32.5	32.5	Ice 25 cm.	1.05	2.85	7.30	−0.10	"	250	0.26	99.9	0.001	1.039	1.04	Closed above by ice.
22851	7 III	29	32.3	32.5	Rippled	0.013	5.40	12.90	0.00	"	250	1.28	99.5	0.026	5.094	5.12	
												Yrly	Av.	0.011	2.216	2.23	
												Grnd	Av.	0.465	0.939	1.41	

TABLE V.

Plankton Data, Quiver Lake, Station C. 1894 1899.

Accessions Number	Date	Temperature, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1894																	
11368	6 VI		67.8					*5.63	−0.15	O. H. 100 ft.	2.00	236	0.04	5	0.32	0.02	0.34	
11386	26 VI				Smooth		1.80	*4.00	0.00	" " " "	2.00	"	0.03	45	0.14	0.11	0.25	
11398	13 VII		80					*2.09	−0.09	" " 125 "	2.35	295	0.36	20	2.29	0.57	2.86	Catch 2 ft. below surface. Current ⅓ mile per hour.
11401	19 VII		80		Smooth			*1.95	0.00	" " " "	2.35	"	0.31	15	2.10	0.37	2.47	From channel cleared in vegetation.
11416	2 VIII		81					*2.17	+0.10	" " 100 "	2.30	236	0.19	15	1.58	0.27	1.85	Down main channel.
11417	2 VIII		80.5					*2.17	+0.10	" " " "	2.30	"	0.21	75	0.51	1.54	2.05	Across main channel.
11430a	20 VIII	81	77.5	75.5	Smooth			*1.90	0.10	" " 122.5 "	2.00	289	0.10	50	0.35	0.34	0.69	Down main channel.
11430b	20 VIII				"			*1.90	0.10	" " 100 "	2.20	236	0.18	70	0.50	1.18	1.68	Across main channel.
11445	5 IX			73				*3.20	0.10	" " 117.3 "	2.40	277	0.25	5	2.06	0.11	2.17	
11446	6 IX							*3.20	0.00	" " 100 "	2.75	236	0.75	60	3.50	5.25	8.75	
11450	17 IX							*5.80	0.00	" " " "	2.10	"	0.15	40	0.80	0.53	1.33	Current scarcely perceptible.
11461	17 X							*2.70	−0.11	" " " "	2.50	"	0.60	85	0.95	5.41	6.36	
11462	11 XI			35				*3.00	0.00	" " " "	2.00	"	0.05	95	0.02	0.40	0.42	Ice at margins of lake.
11469	16 XII	39.5	43.3					*3.20	0.00	" " " "	2.00	"	0.03	90	0.03	0.22	0.25	
													Yrly	Av.	1.08	1.17	2.25	
	1895																	
11473	23 II	32			Ice 35 cm.		1.50	*3.37	+0.21	O. H. 100 ft.	2.00	236	0.06	95	0.03	0.48	0.51	
11486	9 IV	54						4.85	0.00	" " " "	2.10	"	0.32	50	1.42	1.43	2.85	
11494	29 IV	64						*4.65	−0.05	" " " "	2.50	"	0.41	2	4.57	0.09	4.66	
22012	8 VII	80.3	78	77.3	Rippled	Clear		2.28	+0.20	" " " "	2.10	"	0.11	98	0.02	0.96	0.98	Channel cleared in vegetation for haul.
22024	26 VII	77.5	79	77	"	Dark	1.95	4.20	0.40	" " " "	2.10	"	0.16	50	0.71	0.71	1.42	In channel in vegetation.
22036	9 VIII	80.5	76	75		Clear	1.35	2.40	0.17	" " " "	2.00	"	0.07	45	0.33	0.26	0.59	In channel in vegetation.
22048	24 VIII	76	73.5	73	Rippled	Dark	1.60	2.35	+0.20	" " " "	2.00	"	0.04	75	0.08	0.25	0.33	Vegetat'n decaying, water foul; strong odor of H_2S.
22062	6 IX							5.85	+0.15	" " " "	2.10	"	0.32	45	1.57	1.28	2.85	
22077	19 IX	83.5	78.5	78	Waves	Turbid	1.60	3.43	0.15	" " " "	2.00	"	0.12	70	0.31	0.71	1.02	Much floating vegetation.
22102	16 X	54	54	54.5	"	Dark	1.40	2.20	0.00	" " " "	2.00	"	0.06	75	0.13	0.38	0.51	Collection at surface above veg., very rough water.
22110	12 XI	46.5	41.5	43	Rippled	Clear	1.70	2.70	0.03	" " " "	2.00	"	0.06	90	0.05	0.46	0.51	Much scattered veg.
22125	19 XII	39.8	40.8	41	Waves	Dark	2.60	5.20	−2.35	" " " "	2.20	"	0.27	75	0.63	1.89	2.52	Much floating vegetation.
22135	28 XII	41.4	37.8	37.9	"	Turbid	4.00	11.43	+0.43	S V. H. 4 m.	1.50	252	0.08	40	0.29	0.19	0.48	Some drift.
													Yrly	Av.	0.78	0.70	1.48	
	1896																	
22151	20 I	41.5	33.6	33.5	Rippled	Turbid	3.66	9.50	0.30	O. H. 100 ft.	2.00	236	0.04	90	0.03	0.31	0.34	
22175	27 II	60.5	42	41.8	Smooth	"	3.66	9.60	+0.30	S V. H. 3 m.	1.50	"	0.29	5	1.75	0.09	1.84	
22197	30 III	62.2	57	50	Rippled	Slightly turbid	3.20	8.10	0.10	O. H. 100 ft.	2.25	"	0.20	3	1.85	0.06	1.91	
22204	10 IV	68.2	46.7	46.6	Rough	Turbid	2.82	7.40	+0.10	" " " "	2.50	"	0.31	trace	3.29	trace	3.29	River water driven into lake by wind.
22210	17 IV	74	71	65.5	"	Slightly turbid	2.82	7.30	0.10	" " " "	3.50	"	1.10	"	16.32	"	16.32	
22213	24 IV	73	68	64.2	Rippled	Clearing	2.55	6.09	0.00	" " " "	3.50	"	1.13	"	16.76	"	16.76	Little *Ceratophyllum* present.
22224	2 V	60	68	68	"	0.70	2.74	7.10	0.06	" " " "	2.50	"	0.40	"	4.24	"	4.24	Bottom covered with *Ceratophyl'm*
22228	8 V	83	79	70	"	1.00	2.74	6.50	0.20	" " " "	3.00	"	0.80	20	8.14	2.04	10.18	" " " "

*At Copperas Creek.

TABLE V.—*Continued.*

PLANKTON DATA, QUIVER LAKE, STATION C. 1894–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1896-Cont.																	
22237	16 V	67.8	68.5	68.5	Rough	0.34	2.28	4.90	—0.20	O.H. 100 ft.	2.00	236	0.10	40	0.51	0.34	0.85	Haul 1 ft. below surface because
22251	22 V	66	69	66.3	Rippled	0.16	3.00	6.90	+0.40	Pump	......	125	0.19	35	0.99	0.53	1.52	Vegetat'n abundant. [of vegeta'n.
22272	29 V	72.5	77.8	70	"	0.25	3.05	7.90	+0.20	"	......	"	0.18	25	1.08	0.36	1.44	Vegetation abundant.
22278	5 VI	80	73	68	"	2.60	3.35	8.50	0.00	"	......	"	0.35	7	2.60	0.20	2.80	Much floating vegetation.
22293	13 VI	......	74.1	72.8	"	1.25	3.13	7.90	—0.10	"	......	"	0.21	40	1.01	0.67	1.68	Much floating *Ceratophyllum* and
22300	18 VI	82	81.5	73	"	1.75	3.05	7.50	—0.05	"	......	250	0.20	5	0.76	0.04	0.80	*Ceratophyl'm* on bottom. [*Lemnaceæ*.
22305	27 VI	75	79.7	77.8	"	0.40	2.44	6.00	—0.20	"	......	"	0.20	15	0.68	0.12	0.80	Vegetation largely removed by
22311	3 VII	76.5	78.3	77.5	Smooth	0.85	2.13	4.95	—0.20	"	......	"	0.13	5	0.49	0.03	0.52	[seines and wind.
22334	10 VII	83.5	84	75	Rippled	1.00	1.88	4.00	—0.10	"	......	"	0.10	25	0.30	0.10	0.40	Floating *Lemnaceæ*.
22341	17 VII	89	77	74.5	"	0.60	1.47	2.70	—0.20	"	......	500	0.13	15	0.22	0.04	0.26	Floating *Lemn.* [Fl'ting *Lemn.*
22353	25 VII	75	77	72.8	Smooth	0.50	2.29	5.30	+0.50	"	......	250	0.07	40	0.17	0.11	0.28	Current into lake from river.
22363	1 VIII	75	80.5	80.5	Rippled	0.28	3.05	7.90	+0.60	"	......	"	0.55	trace	2.20	trace	2.20	Current into lake from river.
22374	7 VIII	......	......	......	"	0.40	2.97	8.50	—0.10	"	......	"	1.10	1	4.36	0.04	4.40	Floating *Lemn.* [Fl'ting *Lemn.*
22429	15 VIII	84	82	78	"	0.30	3.05	7.40	—0.20	"	......	"	0.93	8	3.42	0.30	3.72	Fl'ting *Cerat.* and *Lemn.* River
22439	22 VIII	83	80	74	"	0.35	2.87	6.09	—0.20	"	......	"	0.40	trace	1.60	trace	1.60	*Lemn.* fl'ting. [invading lake.
22463	29 VIII	72	72	71	"	0.50	2.57	6.00	—0.20	"	......	"	0.18	"	0.72	"	0.72	*Lemnaceæ* floating.
22469	16 IX	76	71.5	71.5	Waves	0.35	1.97	4.20	+0.10	"	......	"	0.15	8	0.55	0.05	0.60	" "
22475	30 IX	78	57.3	56	Rippled	1.30	3.03	4.30	0.00	"	......	"	0.07	75	0.07	0.21	0.28	
22483	14 X	......	......	......	"	1.00	2.75	6.09	0.00	"	......	"	0.88	trace	3.52	trace	3.52	Few *Lemnaceæ* floating.
22492	29 X	70.3	60.5	59.3	Waves	1.60	2.14	5.10	—0.10	"	......	"	0.19	10	0.68	0.08	0.76	
22500	17 XI	64	49.5	48	Smooth	1.15	2.59	6.30	+0.10	"	......	"	0.10	40	0.24	0.16	0.40	Few *Lemn.* floating. [spr'gy shore.
22508	3 XII	38	35.5	39	Ice 8 cm.	Bottom visible	2.60	6.00	—0.10	"	......	"	0.24	20	0.77	0.19	0.96	Covered with ice except along
22513	29 XII	39	36.5	38	Ice 5 cm.	"	1.96	4.50	0.00	"	......	"	0.28	5	1.06	0.06	1.12	Covered with rotten ice.
													Yrly	Av.	2.59	0.20	2.79	
	1897																	[springy shore.
22520	3 II	35	32	32.5	Ice 14 cm.	0.80	4.27	11.60	—0.10	Pump	......	250	0.07	80	0.06	0.22	0.28	Closed by ice except along
22526	26 II	17	32	32.3	Rippled	0.30	4.27	11.70	+0.10	"	......	"	0.14	45	0.31	0.25	0.56	Lake open in lower half.
22532	22 III	46	45.5	45	"	0.45	5.19	15.20	+0.30	"	......	"	0.13	35	0.34	0.18	0.52	
22541	27 IV	59	61	60	Waves	0.70	4.20	11.60	—0.10	"	......	"	3.52	5	13.38	0.70	14.08	
22554	25 V	65	69.5	65.8	Rippled	0.80	3.10	8.00	—0.20	"	......	"	0.34	5	1.29	0.07	1.36	Some *Lemnaceæ* floating.
22560	28 VI	......	77.1	78	Waves	0.35	2.70	6.90	+0.20	"	......	"	0.37	15	1.26	0.22	1.48	R. water invading lake. [scattered clumps.
22571	21 VII	80.5	79	78	"	0.45	2.10	5.20	—0.10	"	......	"	0.37	5	1.41	0.07	1.48	Vegetation reduced to fringe along shores and
22573	23 VII	94	85.5	......	Smooth	0.70	......	5.00	—0.10	"	......	125	0.14	20	0.90	0.22	1.12	Taken 1 ft. below surface.
22581	30 VII	87	82	......	Waves	0.50	......	4.60	+0.10	"	......	250	0.13	33	0.35	0.17	0.52	Taken 1 ft. below surface.
22584	3 VIII	97	92.5	84.8	Smooth	0.80	1.55	3.60	—0.20	"	......	"	0.12	18	0.39	0.09	0.48	Vegtation along shores.
22587	10 VIII	78	81	80.8	Rippled	0.50	1.32	2.30	0.00	"	......	"	0.16	25	0.48	0.16	0.64	
22593	17 VIII	70	73	69.5	"	0.55	1.17	1.90	0.00	"	......	"	0.08	70	0.10	0.22	0.32	
22596	24 VIII	73	78	77	"	0.58	1.22	1.80	0.00	"	......	"	0.05	85	0.03	0.17	0.20	
22602	31 VIII	79	77	75	"	0.45	1.12	1.80	0.00	"	......	"	0.15	95	0.03	0.57	0.60	

TABLE V.—*Continued.*

Plankton Data, Quiver Lake, Station C. 1894–1899.

Accessions Number	Date		TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. of silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
			Air	Surface	Bottom													
	1897-Cont.																	
22604	7	IX	81	77	77	Rippled	0.36	1.37	1.80	0.00	Pump	250	0.23	83	0.16	0.76	0.92	Some floating vegetation.
22607	14	IX	97	82.5	81	Waves	0.50	1.17	2.00	0.00	"	"	0.10	30	0.28	0.12	0.40	Some floating vegetation.
22609	21	IX	77	65.5	64.3	Rippled	1.00	1.15	2.00	-0.10	"	"	0.10	90	0.04	0.36	0.40	Some floating algæ.
22615	1	X	73	71	69	Smooth	0.75	1.02	1.90	—0.10	"	"	0.14	88	0.07	0.49	0.56	Lake still quite free from vegetat'n.
22621	19	X	73	62	60	Rippled	0.75	1.10	2.00	0.00	"	"	0.08	97	0.01	0.31	0.32	
22625	2	XI	44.1	47.5	47.5	"	0.42	1.12	2.50	0.00	"	"	0.28	90	0.11	1.01	1.12	
22633	15	XI	36.3	46	46.3	"	1.00	1.30	2.80	0.00	"	"	0.43	95	0.09	1.63	1.72	River water invading lake.
22637	30	XI	29	34.5	37	Ice 2.5 cm.	Bottom visible	1.07	3.20	0.20	"	"	1.60	99	0.06	6.34	6.40	Lake closed by ice.
22642	14	XII	34.2	36.3	36.5	Rippled	0.40	1.50	3.40	−0.10	"	500	0.18	96	0.01	0.35	0.36	Water roiled by seining.
22646	28	XII	32	32.8	34	Ice 22 cm.	Bottom visible	1.42	3.20	0.00	"	250	0.04	98	0.003	0.157	0.16	Lake closed by ice except along east [shore since Dec. 17.
													Yrly	Av.	0.88	0.62	1.50	
	1898																	
22650	11	I	46	36.5	38	Ice 5 cm.	0.38	1.65	3.20	0.00	Pump	250	0.07	99	0.003	0.277	0.28	Lake closed by rotten ice.
22652	25	I	34	33	33.5	Ice 5 cm.	0.20	2.15	6.80	+0.40	"	"	0.11	92	0.04	0.40	0.44	Lower end of lake open; river invad- [ing.
22659	8	II	43	32	32.5	Ice 4-6 cm.	0.40	1.50	7.10	-0.20	"	"	0.06	88	0.03	0.21	0.24	Lake covered by ice. Water over adjacent bottoms.
22662	22	II	31.5	32.1	32.2	Rippled	0.40	3.15	10.07	+0.40	"	"	0.17	15	0.58	0.10	0.68	Old ice out Feb. 14; new ice forming; [river wat. in w. ½.
22668	8	III	52	40	40	Waves	0.50	4.05	11.00	0.10	"	"	0.27	25	0.81	0.27	1.08	Lake free of ice.
22673	22	III	60	52.5	51.3	Rippled	0.60	5.40	14.10	+0.40	"	"	0.24	30	0.67	0.29	0.96	
22679	5	IV	32	47.5	47.5	Waves	0.12	4.90	17.30	−0.30	"	"	0.40	98	0.03	1.57	1.60	
22684	19	IV	46	56	56	"	0.45	4.90	13.10	−0.30	"	500	0.77	33	1.03	0.51	1.54	
22695	3	V	59.5	62	61.5	Rippled	1.00	4.20	11.10	0.10	"	250	10.75	2	42.14	0.86	43.00	
22700	11	V	73	66.3	62	"	1.00	3.45	10.10	−0.20	"	"	1.21	3	4.70	0.14	4.84	
22704	24	V	88	82	72	"	0.22	4.70	13.60	+0.30	"	"	0.58	15	1.97	0.35	2.32	Muddy river water in lower levels.
22714	7	VI	83	80	78	"	1.50	4.50	12.50	0.20	"	"	1.54	50	3.08	3.08	6.16	[Some floating *Ceratophyllum*.
22720	21	VI	80.2	77.6	77	"	1.15	3.81	10.80	−0.10	"	"	0.38	10	1.37	0.15	1.52	
22726	5	VII	84	81.5	78.5	"	0.75	3.05	8.70	−0.20	"	"	0.11	80	0.09	0.35	0.44	Some floating *Lemna*.
22734	19	VII	91	84	81.3	Waves	0.60	1.80	4.07	−0.30	"	"	0.08	33	0.22	0.10	0.32	
22748	2	VIII	70.5	73	71.5	Smooth	Bottom visible	1.20	2.70	+0.10	"	"	0.06	70	0.07	0.17	0.24	
22766	16	VIII	88	77	76	Rippled	0.60	2.00	3.70	+0.40	"	"	0.12	60	0.19	0.29	0.48	
22771	30	VIII	92.5	82.5	81	Waves	0.60	1.65	3.90	0.20	"	"	0.17	40	0.41	0.27	0.68	
22778	13	IX	74	65.5	60	"	1.12	1.80	4.20	0.20	"	"	0.07	35	0.18	0.10	0.28	
22783	27	IX	72	73.3	73	Rippled	0.75	2.20	4.90	0.00	"	500	0.34	30	0.48	0.20	0.68	
22789	11	X	62.5	64	64	"	0.75	1.25	3.90	+0.10	"	250	0.07	25	0.21	0.07	0.28	
22794	22	X	40	51	51	Waves	1.07	1.75	4.10	+0.10	"	"	0.10	40	0.24	0.16	0.40	
22800	8	XI	40	46.3	46.3	"	0.75	2.55	6.70	0.00	"	"	0.27	31	0.75	0.33	1.08	
22805	22	XI	23.5	41	41	"	0.88	3.00	8.50	+0.20	"	"	0.21	15	0.71	0.13	0.84	
22810	6	XII	30	..	35	"	0.75	2.78	7.20	0.30	"	"	0.52	3	2.02	0.06	2.08	Lake closed by ice except channel [in middle
22817	20	XII	36.3	35	38	Ice 9 cm.	1.65	1.90	5.90	−0.10	"	"	0.38	4	1.46	0.06	1.52	Lake closed by ice since Dec. 13.
													Yrly	Av.	2.44	0.40	2.85	

TABLE V.—*Concluded.*

PLANKTON DATA, QUIVER LAKE, STATION C. 1894–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1899																
22822	3 I	42.3	36	39	Ice 24 cm.	1.20	2.40	6.80	+0.10	Pump	250	0.20	8	0.74	0.06	0.80	Lake closed by ice since Dec. 13.
22829	17 I	29.5	33	34	Ice 20 cm.	0.18	2.93	8.20	+0.10	"	"	0.25	3	0.97	0.03	1.00	Open strip along east side. Ice elsewhere.
22834	31 I	12	32.5	33	Ice 16 cm.	0.28	2.85	8.00	0.00	"	"	0.76	80	0.61	2.43	3.04	Lake open Jan. 24. Closed since 27th.
22842	14 II	31	32.5	34.5	Ice 35 cm.	1.65	2.38	6.60	−0.10	"	"	0.47	2	1.84	0.04	1.88	Lake covered with ice since Jan. 27.
22848	28 II	32.5	32.5	32.5	Ice 28 cm.	0.04	3.25	10.02	+1.10	"	"	0.13	50	0.26	0.26	0.52	Lake covered with ice since Jan. 27.
22854	14 III	34	34.5	34.5	Waves	0.06	4.58	13.10	−0.20	"	"	0.08	55	0.14	0.18	0.32	Lake opened March 10.
22859	28 III	31	38.5	38.8	Waves	0.12	4.50	13.50	+0.40	"	"	0.05	18	0.16	0.04	0.20	
												Yrly	Av.	0.67	0.43	1.11	
												G'nd	Av.	1.70	0.52	2.22	

TABLE VI.

PLANKTON DATA, DOGFISH LAKE, STATION L. 1895–1897.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1895																	
11493	29 IV	......	66	......	Smooth	......	......	......	......	O. H. 100 ft.	3.50	236	0.85	35	8.20	4.41	12.61	
22002	19 VI	......	81	......	Rippled	......	......	......	......	" " " "	2.00	"	0.14	90	0.12	1.07	1.19	
22009	5 VII	......	85	80	"	Roiled from veget'n	......	2.10	......	" " " "	3.00	"	0.38	5	4.59	0.24	4.83	Channel cut through vegt.
22021	22 VII	82	82.5	80	Waves	Dark, green	......	5.23	......	" " " "	2.50	"	0.20	35	1.38	0.74	2.12	Much vegt. floating in chan.
22034	7 VIII	80.5	79.5	76	Smooth	Slightly turbid	1.22	2.78	......	" " " "	2.00	"	0.14	50	0.60	0.59	1.19	Chan. reopened thro' vegt.
22046	23 VIII	84.3	76	76	Waves	Dark, clear	0.92	2.15	......	" " " "	2.25	"	0.20	15	1.62	0.29	1.91	Strong stench decay'g vegt.
22058	2 IX	79.5	72	72	Rippled	Slightly turbid	1.00	2.45	−0.10	" " " "	3.25	"	0.48	75	1.65	4.96	6.61	No odor.
22075	17 IX	78	75.5	73.5	"	Clear	1.35	3.68	+0.48	" " " "	3.25	"	0.45	25	4.65	1.55	6.20	Much floating vegetation.
22101	16 X	51	54.4	54	"	"	1.00	2.20	0.00	" " " "	2.25	"	0.18	70	0.52	1.20	1.72	" clogged by "
22109	12 XI	38	42.5	40.5	"	"	1.00	2.70	+0.03	" " " "	2.50	"	0.63	25	5.01	1.67	6.68	Some vegetation in way.
22124	19 XII	40	42.5	42.8	Waves	Roiled	1.80	5.20	+2.35	" " " "	2.50	"	1.33	25	10.57	3.52	14.09	Wind and water shifting vegt.
22134	28 XII	42.5	38.4	38.4	" rough	Turbid	4.35	11.93	+0.43	" " " "	2.50	"	0.53	99	0.06	5.56	5.62	Drift on surf., vegt. on bot.
													Yrly	Av.	3.25	2.15	5.40	

TABLE VI.—*Concluded.*

PLANKTON DATA, DOGFISH LAKE, STATION L. 1895–1897.

Accessions Number	Date		Temperature, F. Air	Surface	Bottom	Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
	1896																		
22157	25	I	27.5	33	33.2	Rippled	Slightly turbid	2.59	8.60	−0.20	O. H. 100 ft.	2.50	236	0.50	90	0.53	4.77	5.30	Lake partly cov'rd by ice.
22173	27	II	56	32.2	34	Ice 3.8 cm.	" "	3.10	9.60	+0.30	12 V. H. 2.5 m.	1.50	"	0.32	trace	2.04	trace	2.04	12 vertical hauls, each 2.5 m.
22196	30	III	63.2	57.3	49	Rippled	Clear	2.74	8.10	−0.10	O. H. 100 ft.	2.75	"	0.30	2	3.43	0.07	3.50	
22203	10	IV	59.5	45.1	45	Waves	Slightly turbid	2.44	7.40	+0.10	" " " "	3.00	"	0.43	trace	5.47	trace	5.47	Some *Ceratophyllum* floating.
22211	17	IV	81.5	74	67.2	"	Clear	2.51	7.30	−0.10	" " " "	4.00	"	1.20	"	20.35	"	20.35	Debris and vegt. floating.
22214	24	IV	73.3	68.8	63.9	Rippled	"	2.25	6.90	0.00	" " " "	4.00	"	1.15	"	19.50	"	19.50	No vegetation at surface.
22223	2	V	63.9	68	68	"	0.70	2.36	7.10	0.00	" " " "	3.90	"	0.88	8	13.39	1.16	14.55	*Ceratophyllum* on bottom.
22229	8	V	78.6	82	68	"	0.66	2.10	6.50	−0.20	" " " "	3.85	"	0.8	trace	13.06	trace	13.06	Lake filling with vegt.
22240	19	V	64.5	68	67.5	"	1.27	1.93	5.40	+0.50	Dipped		125	2.30	"	18.40	"	18.40	Dipped from surf. waters.
22244	21	V	75	71.3	68	"	2.00	2.30	6.50	+0.30	Pump		250	0.45	80	0.36	1.44	1.80	Taken in midst of vegt.
22271	29	V	74.4	79	67.5	Smooth	2.20	2.66	7.90	+0.20	"		"	0.75	2	2.94	0.06	3.00	" " " "
22277	5	VI	80.3	74	65	Rippled	2.00	2.75	8.50	0.00	"		125	0.80	4	6.14	0.26	6.40	Much *Cerat.* at surface.
22292	13	VI	85.5	76	69.8	"	Bottom visible	2.59	7.90	−0.10	"		"	0.21	3	1.63	0.05	1.68	Much drifting *Cerat.*
22301	20	VI	84.5	84	74	"	" "	2.44	7.35	−0.10	"		250	0.43	5	1.63	0.09	1.72	*Wolffia* and *Cerat.* abund.
22303	27	VI	75.8	79.8	75	Smooth	" "	1.98	6.00	0.20	"		"	0.30	5	1.14	0.06	1.20	*Lemnaceæ* and *Cerat.* "
22310	3	VII	76.5	78	74.5	"	" "	1.68	4.95	0.20	"		"	0.44	10	1.58	0.18	1.76	Water greenish, vegt. "
22333	10	VII	83.5	81.8	75	Rippled	1.02	1.45	4.00	0.10	"		"	0.31	5	1.18	0.06	1.24	Vegt. abundant, H_2S odor.
22340	17	VII	89	77.8	74.8	"	0.56	0.91	2.70	0.20	"		"	0.16	45	0.35	0.26	0.61	" "
22352	5	VII	74	73	73	Smooth	0.52	1.73	5.30	+0.50	"		"	0.20	35	0.52	0.28	0.80	" "
22362	1	VIII	77.3	80.8	80	Rippled	0.52	2.44	7.90	+0.60	"		"	0.64	2	2.51	0.05	2.56	Much *Lemnaceæ* floating.
22373	7	VIII	88	85.6	75.3	"	1.43	2.77	8.50	0.10	"		"	1.00	3	3.88	0.12	4.00	Vegetation floating out.
22418	15	VIII	84	78.5	78.5	"	1.11	2.44	7.40	0.20	"		"	2.90	3	11.25	0.35	11.6	Much *Wolffia.*
22458	22	VIII	82.5	79	73	"	1.00	2.33	6.90	0.20	"		"	0.34	45	0.75	0.61	1.36	Much *Lemnaceæ.*
22462	29	VIII	70.3	72.8	71	"	0.66	2.05	6.00	−0.20	"		"	0.30	2	1.18	0.02	1.20	Vegt. in lake somewhat reduced.
22468	16	IX	73.5	72.3	72	Waves	0.30	1.52	4.20	+0.10	"		"	0.83	8	3.06	0.26	3.32	
22476	30	IX	63.5	57	56	Rippled	0.70	1.52	4.30	0.00	"		500	0.27	65	0.19	0.35	0.54	
22482	14	X	78	60	58	"	1.05	2.39	6.90	0.00	"		250	1.65	trace	6.60	trace	6.60	*Lemnaceæ* floating.
22493	29	X	70.5	60.5	50.3	Whitecaps	1.50	1.98	5.10	0.10	"		"	2.28	50	4.56	4.56	9.12	Vegt. not visible. Much debris.
22499	17	XI	67.2	52	49.3	Rippled	2.00	2.08	6.30	+0.10	"		"	0.11	40	0.26	0.18	0.44	
22507	3	XII	38.5	37	39	Ice 9 cm.	Bottom visible	1.98	6.00	0.10	"		"	0.55	trace	2.20	trace	2.20	
														Yrly	Av.	5.01	0.51	5.51	
	1897																		
22519	3	II	35	32	32.8	Ice 14–20 cm	0.45	3.72	11.60	0.10	Pump		250	0.07	70	0.08	0.20	0.28	Lake closed by ice Jan. 6.
22525	26	II	15	32	32.5	Rippled	0.20	3.66	11.70	+0.10	"		"	0.28	80	0.22	0.90	1.12	Lake open in middle.
22531	22	III	44	43.5	43	"	0.23	4.27	15.20	+0.30	"		"	0.14	15	0.48	0.08	0.56	
22540	27	IV	59	61	60	Waves	0.80	3.60	11.60	0.10	"		"	2.05	0.3	8.18	0.02	8.20	
22553	25	V	65.5	68	66	Rippled	0.65	2.60	8.00	−0.20	"		"	0.50	3	1.94	0.06	2.00	*Lemn.* on surf., *Cerat.* on bot.
22559	28	VI	86	76.2	74.5	Waves	0.23	2.10	6.90	+0.20	"		"	0.63	1.5	2.48	0.04	2.52	Little vegt. appearing.
														Yrly	Av.	2.23	0.22	2.45	
														Grnd	Av.	4.22	0.88	5.10	

TABLE VII.

Plankton Data, Flag Lake. Station K. 1895–1898.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom														
	1895																	
22104	17 X	54	58	55	Smooth	Dark, br'wnish	0.25	2.38	+0.15	Dipped	......	125	7.60	5	57.76	3.04	60.80	Much decaying veget'n.
22113	13 XI	39.3	41	41.5	“	“ yellowish	0.20	2.70	0.00	“	......	125	2.00	10	14.40	1.60	16.00	“ “ “
22123	19 XII	39.8	42.5	42.8	Waves	“ brownish	0.45	5.20	+2.35	“	......	125	1.33	40	6.38	4.26	10.64	“ “ “
22133	28 XII	38	38.2	38.2	Whitecaps	Turbid	2.40	11.93	+0.42	O. H. 100 ft.	2.75	236	0.70	60	3.26	4.90	8.16	
													Yrly	Av.	20.45	3.45	23.90	
	1896																	[with ice.
22158	25 I	29	34.8	35.2	Waves	Sligbtly turbid	2.13	8.60	—0.20	O. H. 100 ft.	2.00	236	0.04	15	0.29	0.05	0.34	Upper end lake covered
22182	28 II	47	38.7	38.2	“	Clear	2.40	9.80	+0.20	Pump	......	125	0.45	15	3.06	0.54	3.60	Ice just gone.
22195	30 III	57	53	47.8	Rippled	Turbid	1.67	8.10	—0.10	O. H. 100 ft.	2.50	236	0.64	85	1.02	5.76	6.78	
22202	10 IV	53.5	45.8	45.8	Waves	“	1.60	7.40	+0.10	“ “ “ “	2.75	236	0.65	7	7.05	0.53	7.58	
22208	17 IV	71.4	63.7	63.6	“	Slightly turbid	1.60	7.30	—0.10	“ “ “ “	3.10	236	1.65	trace	21.69	trace	21.69	*Ceratophyllum* on bottom.
22217	25 IV	68.8	69	65.4	Rippled	Clear	1.50	6.90	0.00	“ “ “ “	3.20	236	1.80	“	24.42	“	24.42	Pl. from upper 5m. acc't *Cerat.*
22225	2 V	65	68	67	“	1.10	1.64	7.10	0.00	“ “ “ “	5.00	236	9.60	“	203.52	“	203.52	Some veget'n floating.
22232	9 V	85.3	78	74	“	Bottom visible	1.45	6.30	—0.20	“ “ “ “	3.75	236	3.00	“	47.70	“	47.70	Plankton as in 22225.
22236	15 V	79	70	68	“	“ “	1.20	5.10	—0.20	“ “ “ “	2.25	236	0.15	50	0.72	0.71	1.43	Plankton taken near surface.
22254	23 V	72	74	67.2	“	0.85	1.67	7.10	+0.20	Pump	......	125	0.15	90	0.12	1.08	1.20	*Cerat.* and *Lemn.* abundant.
22269	29 V	72	70	68	“	1.65	1.80	7.90	+0.20	“	......	125	1.00	5	7.60	0.40	8.00	“ “ “ “
22279	5 VI	91	78	67	“	Bottom visible	2.15	8.50	0.00	“	......	125	0.45	40	2.16	1.44	3.60	Veg. emerging ex. few small areas.
22291	13 VI	76.3	70.3	68.8	“	“ “	1.83	7.90	—0.10	“	......	125	0.24	trace	1.92	trace	1.92	*Scirpus* 60 cm. above surface.
22299	18 VI	84	82.5	75	Smooth	“ “	1.80	7.50	—0.05	“	......	125	0.34	15	2.31	0.41	2.72	“ 1 m. “ “
22331	10 VII	84	72	71.8	“	“ “	0.37	4.00	—0.10	“	......	125	0.56	25	3.36	1.12	4.48	Coll. at outlet. *Algæ* common.
22344	20 VII	91	83	81.8	“	“ “	0.49	4.10	+0.90	“	......	125	1.25	50	5.00	5.00	10.00	“ “ “ “
22360	30 VII	96	85	80	“	“ “	1.46	7.00	+0.20	“	......	250	0.58	30	1.62	0.70	2.32	“ midlake. *Oscillaria* rising.
22378	10 VIII	95	81.5	80.2	“	1.19	1.98	8.20	—0.10	“	......	250	1.23	trace	4.92	trace	4.92	Vegt. shift'g. “ abundant.
22435	21 VIII	87	78.3	73	“	Bottom visible	1.68	7.10	—0.10	“	......	250	0.60	12	2.11	0.29	2.40	*Lemn.* floating. *Cerat.* “
22459	28 VIII	83	71	70	“	“ “	1.35	6.20	—0.10	“	......	250	1.05	trace	4.20	trace	4.20	
22470	16 IX	72	71	71	“	“ “	0.78	4.10	—0.05	“	......	250	1.13	45	2.49	2.03	4.52	
22477	30 IX	66	59.5	57	“	“ “	0.92	4.30	0.00	“	......	250	0.60	30	1.68	0.72	2.40	Vegetation dying.
22484	14 X	65	58	57.5	Rippled	0.60	1.53	6.90	0.00	“	......	250	0.94	3	3.65	0.11	3.76	*Lemn.* fl't'g. Water-fowl abund.
22494	29 X	68	61.5	61	Waves	0.60	1.00	5.10	—0.10	“	......	62.5	1.60	70	7.68	17.92	25.60	Water full of debris of vegetation.
22501	17 XI	63	56.5	54.2	Smooth	1.00	1.28	6.25	+0.15	“	......	250	1.15	5	4.37	0.23	4.60	
22505	3 XII	31.8	37	39	Ice 14 cm.	1.00	1.14	6.00	—0.10	“	......	250	1.13	1	4.48	0.04	4.52	Small area not frozen over.
22511	29 XII	44.2	37	37	Smooth	Bottom visible	0.65	4.50	0.00	“	......	250	1.08	trace	4.32	trace	4.32	Collection at outlet. Lake par-
													Yrly	Av.	13.83	1.45	15.28	[tially covered by rotten ice.
	1897																	
22517	3 II	32	32.3	33	Ice 20 cm.	0.45	2.95	11.60	—0.10	Pump	......	250	0.10	90	0.04	0.36	0.40	Lake closed since Jan. 6.
22523	26 II	13	32	32.3	“ “ “	0.20	2.30	11.70	+0.10	“	......	250	0.22	90	0.09	0.79	0.88	“ “ “ “ “
22530	22 III	46	42.2	42.1	Waves	0.18	4.27	15.20	+0.30	“	......	250	0.23	10	0.83	0.09	0.92	
22538	27 IV	55	60	60	“	0.40	2.85	11.60	—0.10	“	......	250	2.25	5	8.55	0.45	9.00	

TABLE VII.—*Concluded.*

Plankton Data, Flag Lake, Station K. 1895-1898.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm 3	Percentage of silt	Vol. plankton per m3. water—in cm.3	Vol. silt per m.3 water—in cm.3	Total catch per m.3 water—in cm.3	Remarks
		Air	Surface	Bottom													
	1897-Cont.																
22551	25 V	60	64	63	Smooth	0.95	1.95	8.00	−0.20	Pump	250	2.72	2.5	10.61	0.27	10.88	Vegt. begin'g to emerge.
22558	28 VI	79.5	75	72	Rippled	Bottom visible	1.50	6.90	+0.20	"	"	1.74	30	4.87	2.09	6.96	Few small open places in vegetation.
22568	16 VII	80	80	77	Smooth	0.40	0.75	5.90	−0.10	"	83.3	0.66	10	7.13	0.79	7.92	In vegetation. Lake full of veget'n.
												Yrly	Av.	4.59	0.69	5.28	
	1898																
22728	5 VII				Rippled			8.70	−0.20	Pump	253.4	0.67	90	0.26	2.38	2.64	At outlet. Lake full of vegetat'n.
22731	12 VII							7.00	−0.20	"	250	0.56	88	0.27	1.97	2.24	" "
22735	19 VII							4.70	−0.30	"	"	1.37	95	0.27	5.21	5.48	" "
22738	27 VII							2.70	−0.20	"	"	2.22	93	0.62	8.26	8.88	" "
22760	5 VIII					Bottom visible	0.30	2.80	0.00	"	"	0.33	98	0.03	1.29	1.32	" "
22774	6 IX	66	77.5		Rippled	0.23	0.45	4.70	+0.70	"	"	5.55	30	15.54	6.66	22.20	" "
												Yrly	Av.	2.83	4.30	7.13	
												Grnd	Av.	11.46	1.90	13.36	

TABLE VIII.

Plankton Data, Thompson's Lake, Station G. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.3	Percentage of silt	Vol. plankton per m.3 water—in cm.3	Vol. silt per m.3 water—in cm.3	Total catch per m.3 water—in cm.3	Location	Remarks
		Air	Surface	Bottom															
	1894																		
11371	7 VI		71	69.5			2.13	5.40	−0.10	O. H. 100 ft.	3.00	236	2.02	3	24.92	0.77	25.69	Off G Pt.	
11395	10 VII		86	80			1.37	2.40	−0.05	" "	2.75	"	0.94	2	10.74	0.22	10.96	" " "	
11875	14 VIII	79	76	74				1.75	+0.05	" "	2.75	"	0.93	90	1.08	9.76	10.84	" " "	Water rolled by strong wind.
11431	21 IX							4.90	0.00	" "	3.00	"	0.53	5	6.40	0.34	6.74	" " "	
11467	14 XII	41	39	39				3.20	0.00	" "	2.00	"	0.16	5	1.29	0.07	1.36	" " "	
													Yrly	Av.	8.89	2.23	11.12		
	1895																		
11489	10 IV		55					4.95	−0.10	O. H. 100 ft.	3.50	236	1.90	trace	28.20	trace	28.20	Off G Pt.	
11496	1 V		66.5			Very clear		4.30	−0.20	" "	4.50	"	3.22	"	61.44	"	61.44	" " "	

TABLE VIII.—*Continued.*

PLANKTON DATA, THOMPSON'S LAKE, STATION G. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Coefficient	Vol. water strained—in liters	Vol. of catch—in cm.3	Percentage of silt	Vol. plankton per m.3 water—in cm 3	Vol. silt per m.3 water—in cm 3	Total catch per m.3 water—in cm.3	Location	Remarks
		Air	Surface	Bottom															
	1895-Cont.																		
22003	20 VI	.... ..	75	......	....	Clear	....	2.00	+0.10	0. H. 100 ft.	2.75	236	0.85	5	9.42	0.49	9.91	Off G Pt.	
22007	3 VII	.... ..	....	....	....	....	....	2.10	0.00	" "	2.60	"	0.56	2	6.05	0.12	6.17	" " "	
22019	19 VII	89.5	80	78.5	Rippled	Turbid	1.22	4.10	+0.20	" "	2.50	"	0.40	15	3.60	0.64	4.24	" " "	Turbid from high wind.
22029	3 VIII	86	79	77.5	....	Clear	1.93	3.63	−0.38	" "	2.80	"	0.70	60	3.32	4.99	8.31	" " "	Much floating Ceratophyllum.
22043	16 VIII	85	81.5	81	Rippled	"	1.37	2.28	−0.08	" "	2.50	"	0.30	20	2.54	0.64	3.18	" " "	Catch from upper levels
22055	30 VIII	71	75	74	"	Slightly turb.	1.37	2.65	+0.10	" "	2.75	"	0.73	60	3.40	5.11	8.51	" " "	[over vegetation.
22071	13 IX	73	76	73.5	Waves	" "	1.83	3.65	−0.25	" "	2.75	"	0.59	25	5.16	1.72	6.88	" " "	Much floating vegetation.
22083	27 IX	56.3	67	67	Rippled	Dark, clear	1.50	3.23	+0.60	" "	2.25	"	0.35	40	2.00	1.34	3.34	" " "	Catch from upper levels.
22103	17 X	51.3	52.8	54.2	Smooth	Turbid	1.40	2.38	+0.15	" "	2.50	"	0.33	10	3.15	0.35	3.50	" " "	Water-fowl abundant.
22112	13 XI	40	41.8	42	Waves	"	1.30	2.70	0.00	" "	2.40	"	0.83	40	5.07	3.38	8.45	" " "	Bottom still covered with vegetation.
22122	19 XII	40	39.8	39.8	"	Slightly turb.	1.60	5.20	+2.35	" "	2.00	"	0.26	15	1.87	0.33	2.20	" " "	Ice melted by rain of previous day.
22132	28 XII	38	37.6	38	"	Turbid	3.30	11.93	+0.43	" "	2.00	"	0.15	90	0.13	1.14	1.27	Off K Pt.	Vegetation on bottom.
													Yrly	Av.	9.67	1.44	11.11		
	1896																		
22152	21 I	35	34	34.6	Rippled	Turbid	1.83	9.30	−0.20	0. H. 100 ft.	2.40	236	0.38	35	2.51	1.35	3.86	South end	2-14 cm. ice; open water at S. end.
22180	28 II	41	38.2	38.2	Waves	Clear	3.50	9.80	+0.20	Pump	......	125	0.38	15	2.58	0.46	3.04	Off G Pt.	No ice on lake.
22194	30 III	63	51	47	Rippled	Turbid	2.59	8.10	−0.10	0. H. 100 ft.	2.75	236	0.88	trace	10.26	trace	10.26	" " "	Fine debris on surface.
22201	10 IV	49	45	45	Waves	"	2.59	7.40	−0.10	" "	2.60	"	0.58	"	6.39	"	6.39	" " "	
22207	17 IV	73	68	67	"	Slightly turb.	2.59	7.30	−0.10	" "	3.50	"	1.06	2	15.42	0.31	15.73	" " "	Fine debris on surface.
22216	25 IV	66	67.8	66.5	Rippled	Clear	2.25	6.90	0.60	" "	3.80	"	1.80	trace	29.00	trace	29.00	" " "	*Ceratophyllum* on bottom.
22226	2 V	67	68	67	Waves	0.45	2.51	7.10	0.00	" "	4.20	"	2.66	5	43.99	2.31	46.30	" " "	" "
22231	9 V	73.5	78	71	"	1.00	2.40	6.30	−0.20	" "	3.50	"	0.88	trace	13.06	trace	13.06	" " "	" "
22235	15 V	71.5	70.8	70	"	0.32	1.90	5.10	−0.20	" "	3.80	"	1.88	0	30.29	0.00	30.29	" " "	Catch 1 ft. below surface because of veg.
22255	23 V	73	74.8	68	Rippled	1.15	2.44	7.10	+0.20	Pump	......	125	1.65	2	12.94	0.26	13.20	" " "	*Ceratophyllum* abundant.
22270	29 V	65.8	71.8	70.5	Waves	1.00	2.68	7.90	+0.20	"	......	"	1.91	trace	15.28	trace	15.28	" " "	" and Lemnaceæ common.
22280	5 VI	80	77	66	Rippled	1.10	2.75	8.50	0.00	"	......	"	0.26	5	1.98	0.10	2.08	" " "	South end of lake full of vegetation.
22290	13 VI	71.8	71.4	70.8	Waves	1.00	2.59	7.90	−0.10	"	......	"	0.23	3	1.79	0.05	1.84	" " "	Some vegetation near.
22298	18 VI	84	81.5	75	Rippled	1.00	2.50	7.50	−0.05	"	......	"	0.64	trace	5.12	trace	5.12	" K "	Ceratophyllum and lotus at surface.
22308	30 VI	86.5	82	78.5	"	0.52	1.98	5.45	−0.15	"	......	"	1.35	"	10.80	"	10.80	North end	North end of lake full of vegetation.
22336	11 VII	88	82	78	Waves	0.35	1.53	3.90	−0.10	"	......	"	0.27	2	2.12	0.04	2.16	Off Sand Pt.	Potamogeton and Ceratophyllum near.
22346	21 VII	83	81.2	76.5	"	0.50	1.30	4.30	+0.20	"	......	"	0.21	5	1.60	0.08	1.68	North end	" " " "
22359	30 VII	94	85	82.4	Rippled	0.60	2.29	7.00	+0.20	"	......	250	1.13	1	4.48	0.04	4.52	Off G Pt.	Clumps of Ceratophyllum and Potam.
22377	10 VIII	84	84	83	"	0.55	2.77	8.20	−0.10	"	......	"	2.25	trace	9.00	trace	9.00	" " "	Wolffia floating. Ceratophyllum near.
22434	21 VIII	87	79	75	Smooth	0.61	2.39	7.10	−0.10	"	......	"	0.63	"	2.52	"	2.52	" " "	*Ceratophyllum* near.
22458	27 VIII	80.3	77	74.5	Waves	0.50	2.24	6.30	−0.20	"	......	"	0.70	4	2.69	0.11	2.80	North end	
22467	16 IX	68	72.5	72.5	Smooth	0.30	1.52	4.10	−0.05	"	......	257	0.91	trace	3.54	trace	3.54	Off Sand Pt.	
22474	30 IX	60	55.5	55	Waves	0.16	1.53	4.30	0.00	"	......	250	1.25	3	4.85	0.15	5.00	" " "	

TABLE VIII.—*Continued.*

PLANKTON DATA, THOMPSON'S LAKE, STATION G. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Location	Remarks
		Air	Surface	Bottom														
	1896-Cont.																	
22480	14 X	62	57.3	56	Rippled	0.70	2.44	6.90	0.00	Pump	250	0.13	10	0.47	0.05	0.52	Off Sand Pt.	
22491	31 X	68.3	57.3	56	Waves	0.60	2.14	5.10	+0.10	"	"	1.40	8	5.15	0.45	5.60	" " "	
22498	17 XI	62	48	46	"	0.42	2.14	6.25	+0.15	"	"	0.70	5	2.66	0.14	2.80	" " "	
22506	3 XII	35	36.8	39	Ice 11 cm.	0.50	2.14			"	"	0.64	trace	2.56	trace	2.56	" G "	Lake covered with ice.
												Yrly	Av.	9.00	0.22	9.22		
	1897																	
22516	3 II	31.1	32	32.8	Ice 20 cm.	0.45	4.00	11.60	0.10	Pump	250	0.11	65	0.15	0.29	0.44	Off K Pt.	Lake covered with ice.
22524	26 II	10	32	36	Ice 10 cm.	0.40	3.66	11.70	+0.10	"	"	0.11	30	0.39	0.17	0.56	" " "	" " " "
22529	22 III	46	43	42.3	Waves	0.18	4.57	15.20	+0.30	"	"	0.22	26	0.65	0.23	0.88	" G "	No ice.
22537	27 IV	60	60	59.5	Whitecaps	0.50	3.75	11.60	−0.10	"	"	2.62	1	10.38	0.10	10.48	" " "	
22550	25 V	60	66	65	Rippled	0.45	2.90	8.00	−0.20	"	"	2.14	8	7.88	0.68	8.56	" " "	
22557	28 VI	76.5	78.9	75	"	0.068	2.10	6.90	+0.20	"	"	1.02	12	3.59	0.49	4.08	" " "	
22566	15 VII	81	76.4	75.6	"	0.30	1.80	6.00	−0.30	"	127	0.48	18	3.10	0.68	3.78	Below K "	*Potamogeton* a few rods away.
22577	27 VII	79	81	80.2	Waves	0.25	1.65	5.00	−0.10	"	250	1.10	20	3.52	0.88	4.40	Off Sand "	Little vegetation in north end.
22580	16 VIII	69	71	71	"	0.20	1.07	1.90	0.00	"	"	4.48	6	16.85	1.07	17.92	" " "	Outlet drying up.
22597	23 VIII	72.5	77.5	76	Rippled	0.15	1.07	1.80	0.10	"	125	2.80	2	21.95	0.45	22.40	" " "	
22605	11 IX	95	85	81	Smooth	0.13	0.92	2.00	0.00	"	250	2.72	8	10.01	0.87	10.88	" " "	
22611	28 IX	84	71	68	"	0.15	0.92	2.00	0.00	"	125	1.42	12	10.00	1.36	11.36	" " "	No discharge through slough.
22620	19 X	65	59	59	Rippled	0.15	0.75	2.00	0.00	"	"	4.91	10	35.35	3.93	39.28	" " "	
22626	2 XI	48	48.3	48.3	Waves	0.06	0.70	2.50	0.00	"	250	5.78	11	20.58	2.54	23.12	" " "	
22632	15 XI	34	40	42	"	0.10	0.79	2.80	0.00	"	"	6.04	5	22.95	1.21	24.16	" " "	Connection with river re-established.
22636	30 XI	26	33	36.5	Ice 5-7.5 cm.	0.15	0.61	3.20	−0.20	"	"	2.94	45	6.47	5.29	11.76	" K "	Lake covered with ice since 29th.
22640	14 XII	36.5	34.5	35	Waves	0.08	1.20	3.40	−0.10	"	500	4.72	15	8.02	1.42	9.44	" Sand "	Ice out Dec. 12.
22645	28 XII	27	34	37.4	Ice 22.8 cm.	0.52	1.07	3.20	0.00	"	250	1.81	18	5.94	1.30	7.24	" K "	Lake covered with ice since Dec. 17.
												Yrly	Av.	10.43	1.28	11.71		
	1898																	
22653	25 I	33	35	41.2	Rippled	0.40	1.25	6.40	+0.10	Pump	250	1.92	6	7.22	0.46	7.68	Off K Pt.	
22657	8 II	40.5	35	37	Ice 10 cm.	0.40	1.55	7.10	+0.20	"	"	0.20	20	0.64	0.16	0.80	" " "	
22661	22 II	28	32	32.1	Ice 4-6 cm.	0.30	1.80	10.50	+0.20	"	"	0.24	33	0.64	0.32	0.96	Margin bel'w K Pt	
22667	8 III	46	39	38	Rippled	0.38	3.45	11.00	−0.10	"	"	0.17	12	0.60	0.08	0.68	Off G Pt.	
22672	22 III	66	50.5	49.8	Waves	0.20	4.20	13.90	+0.30	"	"	0.22	10	0.79	0.09	0.88	" K "	
22678	5 IV	32	47	47	"	0.20	3.65	17.40	0.30	"	"	0.16	30	0.45	0.19	0.64	Margin bel'w K Pt	Strong wind made collection in open lake impossible.

TABLE VIII.—*Concluded.*

PLANKTON DATA, THOMPSON'S LAKE, STATION G. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.^{3}	Percentage of silt	Vol. plankton per m.^{3} water—in cm.^{3}	Vol. silt per m.^{3} water—in cm.^{3}	Total catch per m.^{3} water—in cm.^{3}	Location	Remarks
		Air	Surface	Bottom														
	1898-Cont.																	
22683	19 IV	49	59.8	59.8	Whitecaps	0.40	3.60	13.30	−0.20	Pump	250	1.30	15	4.42	0.78	5.20	Lee of W. shore.	Some vegetation on bottom.
22694	3 V	54	61.5	61	Waves	0.85	3.30	11.20	0.00	"	"	13.11	2	51.39	1.05	52.44	Off G Pt.	
22699	11 V	71	64	58	Rippled	0.60	3.35	10.20	+0.10	"	"	3.90	4	14.98	0.62	15.60	" " "	
22703	24 V	77	76	68	Smooth	0.45	4.00	13.50	+0.40	"	275	3.24	3	11.44	0.35	11.79	" " "	Spoon River flood backing into lake.
22713	7 VI	81	80	76	Waves	1.30	3.95	12.60	−0 20	"	250	4.79	4	18.39	0.77	19.16	" " "	
22719	21 VI	77	77	75	Whitecaps	0.75	3.20	10.85	−0.15	"	267	0.68	3	2.47	0.08	2.55	" " "	Some *Lemnaceæ* floating.
22724	5 VII	83	81.5	79.5	Waves	0.45	2.80	8.80	−0.20	"	250	0.58	65	0.81	1.51	2.32	" " "	
22732	19 VII	86	83	81.5	Whitecaps	0.30	2.90	4.90	−0.30	"	"	1.02	18	3.35	0.73	4.08	Off Sand Pt.	
22750	2 VIII	70.5	75	75	Rippled	0.22	0.90	2.60	0.00	"	"	1.14	50	2.28	2.28	4.56	" " "	
22764	16 VIII	85	75.5	75	Whitecaps	0.25	1.05	3.45	+0.35	"	"	1.12	90	0.45	4.03	4.48	" " "	
22769	30 VIII	89	81	80.3	"	0.30	1.45	4.00	−0.20	"	"	1.33	3	5.16	0.16	5.32	" " "	
22776	13 IX	69.5	65	65	"	0.30	1.05	4.35	−0.15	"	"	0.83	20	2.66	0.66	3.32	North end	
22781	27 IX	73	72.3	72	"	0.33	1.45	4.90	+0.10	"	500	1.72	23	2.65	0.79	3.44	Off Sand Pt.	
22787	11 X	60.8	64	64	"	0.10	1.20	3.90	+0.20	"	250	0.93	75	0.93	2.79	3.72	" " "	
22792	25 X	50.3	50.5	50	"	0.27	1.43	4.30	+0.10	"	"	0.58	33	1.56	0.76	2.32	" " "	
22798	8 XI	40	46	46	Waves	0.38	2.18	6.70	0.00	"	"	0.46	16	1.55	0.29	1.84	Off G Pt.	
22803	22 XI	18	39	39	Whitecaps	0.50	2.03	8.40	+0.20	"	"	0.33	40	0.79	0.53	1.32	Lee of W. shore.	
22808	6 XII	27.5	34	36.3	Ice 13.2 cm.	0.83	2.25	7.30	−0.30	"	"	1.18	3	4.58	0.14	4.72	Off G Pt.	Lake partly covered with ice.
22815	20 XII	37.7	33	39.6	Ice 21 cm.	0.93	1.90	6.00	−0.10	"	"	0.68	5	2.58	0.14	2.72	" " "	" " " " "
												Yearly	Av.	5.71	0.79	6.50		
	1899																	
22820	3 I	38.5	39.5	39.5	Rippled	0.92	2.10	6.80	+0.20	Pump	250	0.96	6	3.61	0.23	3.84	Off G Pt.	Lake partly covered with ice.
22827	17 I	29.5	35	37	Waves	0.43	2.55	8.15	+0.05	"	"	0.26	10	0.94	0.10	1.04	" " "	" " " " "
22832	31 I	0	34	36.5	Ice 16 cm.	0.20	2.45	8.00	−0.10	"	"	0.23	60	0.37	0.55	0.92	" " "	" covered with ice since Jan. 26.
22840	14 II	20.5	33.3	37	Ice 36 cm.	0.63	1.80	6.70	−0.10	"	"	0.48	20	1.54	0.38	1.92	" " "	" " " "
22846	28 II	40.5	33.3	37.5	Ice 23 cm.	0.10	3.00	9.80	+0.90	"	"	0.48	15	1.63	0.29	1.92	" " "	" partly covered with ice.
22852	14 III	36.5	34	34	Whitecaps	0.06	4.20	13.20	−0.05	"	"	0.15	40	0.36	0.24	0.60	" " "	" " " " "
22857	28 III	29	37.5	37.5	"	0.08	4.20	13.50	+0.40	"	"	0.12	90	0.05	0.43	0.48	" " "	No ice.
												Yearly	Av.	1.21	0.32	1.53		
												Grand	Av.	7.94	0.86	8.79		

TABLE IX.

PLANKTON DATA, PHELPS LAKE, STATION F. 1894-1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 24 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.^{3}	Percentage of silt	Vol. plankton per m.^{3} water—in cm.^{3}	Vol. silt per m.^{3} water—in cm.^{3}	Total catch per m.^{3} water—in cm.^{3}	Remarks
		Air	Surface	Bottom													
11373	1894 8 VI	......	......	......	......	......	......	......	......	O. H. 100 ft.	236	5.70	trace	24.17	trace	24.17	Coefficient=4.
	1895																No water in lake this year.
22145	1896 8 I	30	32.1	32.2	Ice	Turbid	1.37	11.95	......	Pump	125	0.16	70	0.38	0.90	1.28	From level 2 feet below surface.
22155	24 I	29.6	32.8	33.4	Ice 13 cm.	"	0.76	8.80	−0.10	"	"	0.50	15	3.40	0.60	4.00	" " 1 foot " "
22184	28 II	41	47.8	48	Smooth	Clear	1.00	9.80	+0.20	"	"	1.58	4	12.14	0.50	12.64	Level not recorded.
22199	31 III	70	58.2	57.6	Rippled	"	0.61	8.00	−0.10	Dipped	"	2.40	trace	19.20	trace	19.20	
22200	9 IV	48	47.2	47.2	"	"	0.53	7.30	0.00	"	"	0.80	2	6.27	0.13	6.40	Algæ abundant.
22206	16 IV	89	77	76.5	"	"	0.49	7.40	−0.10	"	"	6.85	trace	54.80	trace	54.80	" "
22212	23 IV	83	73	72.5	"	"	0.53	6.90	−0.10	"	"	3.20	2	25.09	0.51	25.60	" and young fish abundant.
22220	30 IV	72.2	76	74.9	"	*0.38	0.38	7.10	0.00	"	"	1.95	trace	15.60	trace	15.60	" " " "
22227	8 V	86	78	78	Smooth	0.30	0.42	6.50	−0.20	"	"	2.80	"	22.40	"	22.40	" " " "
22233	13 V	78	76.5	76	"	0.45	0.38	5.50	−0.20	"	"	0.85	"	6.80	"	6.80	" present.
22241	20 V	64	66.5	67	"	0.25	0.45	6.20	+0.80	"	"	1.00	20	6.40	1.60	8.00	" "
22208	27 V	73	77	76.3	"	0.31	0.45	7.60	+0.10	"	"	2.05	1	16.24	0.16	16.40	" "
22275	3 VI	61.3	63	63	"	0.48	0.48	8.50	+0.10	"	"	0.18	2	1.41	0.03	1.44	" disappearing.
22287	9 VI	67.8	74.5	74.5	Rippled	0.49	0.54	8.25	−0.05	"	"	0.44	5	3.31	0.18	3.52	" few.
22297	17 VI	83.3	89.5	86	Smooth	0.46	0.46	7.55	−0.05	"	"	0.41	15	2.79	0.49	3.28	" and *Potamogetons* present.
22306	27 VI	78	85	84	"	0.33	0.33	6.00	−0.20	"	"	0.55	8	4.05	0.35	4.40	Margin of lake contracting. *Oscillaria* scum.
22312	3 VII	86	85.3	84	"	*0.31	0.31	4.95	−0.20	"	"	0.81	2	6.35	0.13	6.48	" " " Algæ covering most of surf.
22335	10 VII	85.5	92	90	"	0.25	0.25	4.00	−0.10	"	"	1.20	trace	9.60	trace	9.60	" " centr. 10 m. since last visit. Less algæ.
22339	15 VII	81.8	81	81.5	"	0.25	0.30	3.10	−0.20	"	"	1.38	1	10.93	0.11	11.04	Some algæ on bottom.
22349	22 VII	79	83.3	82.3	"	0.20	0.33	4.20	0.10	"	"	0.93	2	7.29	0.15	7.44	Lake margins expanded to 2 m. of original line.
22357	29 VII	85.8	86.2	85.5	"	0.23	0.33	6.80	+0.40	"	"	1.40	2	10.98	0.22	11.20	Very little vegetation visible.
22369	5 VIII	87	87.4	87	"	0.30	0.30	8.60	0.00	"	"	1.05	3	8.15	0.25	8.40	Margins contracted 18 m. Little vegetation.
22398	12 VIII	81.3	82.1	82.1	"	*0.25	0.25	7.90	−0.20	"	"	1.40	5	10.64	0.56	11.20	" " 22 m. Reddish scum.
22432	19 VIII	69.5	72.3	72	"	*0.23	0.23	7.30	−0.20	"	"	0.83	8	6.11	0.53	6.64	" " 24 m. *Elodea*, Naias, and algæ.
22452	25 VIII	85.2	86.3	86.3	Rippled	*0.23	0.23	6.60	−0.10	"	"	1.43	10	10.30	1.14	11.44	" " 27 m. More algæ.
22479	1 X	50	50.5	50.5	Smooth	*0.08	0.08	4.40	+0.10	"	50	0.81	15	14.28	2.52	16.80	" at 24 m. Water birds feed'g. Vegt. increas'g.
22486	15 X	44	45	45	"	*0.08	0.08	6.90	0.00	"	25	1.34	3	51.60	1.60	53.20	Only few shallow pools left. Much algæ.
22496	30 X	42	45	......	Rippled	0.05	0.08	5.00	−0.10	"	10	0.13	75	3.25	9.75	13.00	Pools still more reduced.
22503	17 XI	63.5	66	......	Smooth	*0.08	0.08	6.25	+0.15	"	25	0.80	trace	32.00	trace	32.00	Water in pools. Little algæ.
												Yearly	Av.	13.17	0.77	13.94	
22521	1897 3 II	32.3	32.3	33	Ice 23 cm.	0.56	1.60	11.60	−0.10	Pump	250	0.06	33	0.16	0.08	0.24	Water entered lake Jan. 6. Current in from Spoon R.
22528	26 II	14	32.5	32.5	Ice 20 cm.	0.20	1.52	11.70	+0.10	"	"	0.14	60	0.22	0.34	0.56	
22535	22 III	46	47.6	47.3	Rippled	...	2.50	15.20	+0.30	"	125	0.30	40	1.44	0.96	2.40	Bottoms between river and lake under water.
22542	27 IV	75	60.2	60	"	0.12	1.50	11.60	−0.10	"	250	1.12	5	4.26	0.22	4.48	Current in from Spoon River.
22555	25 V	63	77	69.8	"	0.35	0.51	8.00	−0.20	Dipped	"	5.82	3	22.58	0.70	23.28	Normal margin. Some vegt. Mud deposit, 6-8 cm.

TABLE IX.—*Concluded.*

PLANKTON DATA, PHELPS LAKE, STATION F. 1894–1899.

Accessions Number	Date	TEMPERATURE, F.			Surface	Turbidity	Depth—in meters	Stage of river—in feet	Change in 25 hours—in feet	Method	Vol. water strained—in liters	Vol. of catch—in cm.³	Percentage of silt	Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³	Total catch per m.³ water—in cm.³	Remarks
		Air	Surface	Bottom													
	1897-Cont.																
22562	29 VI	89	91	89	Rippled	0.02	0.50	7.10	+0.20	Dipped	125	0.21	75	0.42	1.26	1.68	Considerable *Potamogeton.*
22570	19 VII	82	80	80	Smooth	*0.30	0.30	5.40	−0.10	''	''	1.21	2	9.49	0.19	9.68	Margin contracted 5 m.
22586	10 VIII	75	78	78	''	*0.20	0.20	2.30	0.00	''	''	2.78	3.5	21.46	0.78	22.24	Water only 10 m. in width. Blue-green scum.
22600	26 VIII	91	91	90.5	Rippled	*0.20	0.20	1.80	0.00	''	''	3.78	1	29.94	0.30	30.24	No vegetation. Lake drying up.
												Yearly	Av.	10.00	0.54	10.53	
	1898																
22666	3 III	35	35	35.5	Rippled	0.45	1.35	11.30	−0.10	Dipped	125	0.07	98	0.01	0.55	0.56	Water entering from river.
22670	15 III	52	45.5	45	Smooth	0.10	1.45	12.10	+0.20	''	''	0.22	70	0.53	1.23	1.76	'' '' '' Spoon River.
22675	29 III	59	48.5	48	Rippled	0.05	3.00	16.50	+0.70	Pump	250	0.50	90	0.20	1.80	2.00	
22681	12 IV	66	52	51	''	0.20	2.50	14.80	−0.30	''	''	0.13	7	0.48	0.04	0.52	
22692	26 IV	51	54	53	''	0.16	1.50	12.00	−0.20	Dipped	125	1.41	5	10.72	0.56	11.28	Connection with river at upper end broken.
22701	17 V	57	61	69.5	''	0.45	0.60	10.10	+0.20	''	''	9.54	0.2	76.17	0.15	76.32	
22710	31 V	67	70	68	''	0.13	2.00	13.60	−0.20	''	''	0.64	8	4.71	0.41	5.12	
22717	14 VI	83.5	80	76	''	0.12	1.30	11.90	0.00	''	''	6.55	0.1	52.35	0.05	52.40	
22722	28 VI	82.5	85	84	Smooth	0.30	0.60	10.00	−0.20	''	''	1.86	80	2.98	11.90	14.88	Some vegetation at margin.
22729	12 VII	84	80	75	''	0.15	0.45	7.00	−0.20	''	''	1.29	1	10.22	0.10	10.32	Little *Potamogeton.* Water roiled by fish.
22736	26 VII	90	92	91	''	0.13	0.40	2.90	−0.20	''	''	0.58	20	3.71	0.93	4.64	'' '' [River 5 feet below lake level
22762	9 VIII	86	90.5	89	''	0.07	0.20	3.20	+0.20	''	''	7.67	10	55.22	6.14	61.36	Many young catfish. No connection with river.
22767	23 VIII	94	95	....	Waves	0.07	0.20	4.20	−0.30	''	''	28.78	2.5	224.48	5.76	230.24	Some lotus appearing.
22772	6 IX	63	75	....	Rippled	0.03	0.15	4.70	+0.70	''	''	5.37	3	41.67	1.29	42.96	
22779	20 IX	88	86	....	''	0.07	0.15	4.20	−0.20	''	''	6.95	5	52.82	2.78	55.60	
22784	4 X	73	75	....	''	0.08	0.15	4.00	−0.10	''	''	3.60	4	27.65	1.15	28.80	
22790	18 X	42	45	....	''	0.08	0.10	3.80	+0.10	''	''	6.60	30	36.96	15.84	52.80	
22796	2 XI	44	44.7	....	Smooth	*0.08	0.08	6.50	+0.20	''	''	19.06	70	45.74	106.74	152.48	Lake much contracted.
22801	15 XI	47	46.7	....	Rippled	*0.13	0.13	7.00	+0.10	''	''	13.87	10	99.86	11.10	110.96	
22806	29 XI	44	36	....	Ice forming	*0.18	0.18	8.30	0.00	''	''	0.98	0.2	7.83	0.01	7.84	
22812	13 XII	21	32	....	Ice 14 cm.	*0.06	0.06	6.70	−0.10	''	''	5.42	0.5	43.14	0.22	43.36	
22818	27 XII	36.5	....	35	Ice 11 cm.	0.28	0.16	6.10	0.00	''	''	0.12	20	0.77	0.19	0.96	
												Yearly	Av.	36.31	7.76	44.08	
	1899																
22825	10 I	28.5	....	34.8	Ice 14 cm.	*0.30	0.30	7.90	+0.10	Dipped	125	0.16	30	0.90	0.38	1.28	
22830	24 I	28	38	....	Ice 6 cm.	*0.35	0.35	8.90	0.00	''	''	1.08	2	8.47	0.17	8.64	
22837	7 II	5	32.5	....	Ice 25 cm.	0.15	0.33	7.30	−0.10	''	''	1.18	1.5	9.30	0.14	9.44	No open places in ice.
22844	21 II	39	32.7	....	Ice 26 cm.	*0.35	0.35	5.50	−0.20	''	''	0.08	85	0.10	0.54	0.64	'' '' '' '' ''
22849	7 III	13.5	32.7	32.7	Ice 16 cm.	0.15	1.50	12.90	0.00	''	''	0.26	15	1.77	0.31	2.08	Flood water entering. No open places in ice in lake
22855	21 III	42.5	37	36.5	Rippled	0.05	1.60	13.70	+0.30	''	''	0.26	10	1.87	0.21	2.08	No ice on lake. [proper.
												Yearly	Av.	3.74	0.29	4.03	
												Grand	Av.	19.65	2.95	22.60	

TABLE X. Part 1.

Chemical Data and Plankton, Illinois River, May, 1894, to December, 1896.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION						Chlorine	Oxygen consumed	NITROGEN AS					Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition					Free ammonia	Albuminoid ammonia	Total organic	Nitrites	Nitrates		
								Total	Dissolved	Suspended									
1894																			
22 V	7.20—	...	...		285.4	...	...	89.95	...	...	9.5	6.7	.315	.42	...	None	2.2	.74*	.36*
11 VII	2.20—	...	...	...	307.9	...	...	107.9	...	...	25.7	11.2	.395	.46		Much	.6	2.39*	.05*
17 VIII	1.90+	...	...	...	318.8	...	...	80.17	...	...	39	6.8	1.945	.63	...		.06	9.67*	.51*
29 IX	4.20+	...	...	...	273.6	...	...	41.46	...	...	23	6.7	.45	.33		None	2.55	.34*	1.03*
12 XI	3.00	...	...	...	316.2	...	...	73.5	...	...	37.75	6.2	.6	.195			2.6	.1 *	.15*
Average, May 22 Nov. 12					300.4	...	...	78.6	...	...	26.99	7.52	.741	.407	...	...	1.6	2.65	.42
1895																			
24 IX	3.57	s.	c.	.1	295.2	...	...	22		...	32.5	5.3	.67	.282	...	.15	.4	1.23*	.14*
1 X	2.75—	d.	"	.1	350.6	...	...	47.4			11	8.1	.6	.416	...	.05	.3	.37*	.16*
8 X	2.20	s.	"	.1	351.6			15.4			48	5.9	.6	.268	...	.45	1.35	.76*	.08*
15 X	2.25+	"	"	.1	424.8		...	11.6			62	5.3	.09	.508	...	.5	.9	.76	.08
23 X	2.35	d.	l.	.1	433		...	10.2			64	5.7	.64	.364	...	.35	.45	.55	.06
29 X	2.25—	"	"	.1	389.2		...	23.2			56	5.8	.6	.318	...	.175	.9	.42*	.11*
5 XI	2.37+	"	c.	.1	398	...		23.4			60	6	.7	.502	...	.25	1.5	.59	.25
11 XI	2.67+	s.	"	.1	378.4	...	...	19.6		...	56	5.2	1.5	.47	...	.25	1.8	4.09*	.45*
19 XI	2.75+	"	"	.03	370.4	...	...	19.6	...		52	5.3	1.1	.476		.16	2.4	3.02*	.16*
26 XI	2.90+	v. d.	"	.2	384	...	...	24	...	...	55	7.4	.4	.714		.13	2.6	4.37*	.23*
3 XII	3.20+	"	m.	.04	400.2	...	...	11.8	...		51	8	1	1.1	...	.15	3.2	2.05*	.02*
10 XII	3.25—	d.	"	.03	388.2	...	...	10.8	...		47	11.1	2	.686	...	.05	3.95	2.54*	1.36*
17 XII	2.80	"	c.	.03	432.8		...	25.6			52	8.05	2.87	1.01		.017	3	1.74*	.93*
24 XII	10.00+	v. d.	m.	muddy	658.8		...	26.8		...	27	14.9	2.25	1.28	...	.06	2.12	0.08*	7.85*
31 XII	12.60+	"	c.	"	536			28			9.5	9.3	.8	.746		.05	3.4	0.01*	1.77*
Average, Sept. 24 Dec. 31					411.4		...	21.3	...	...	45.5	7.4	1.05	.609		.189	1.88	1.51	.91
1896																			
1 I	12.60	v. d.	c.	muddy	288.4	257.2	31.2	20	19.6	.4	10	7.8	.8	.426	1.1	.07	3.75	.01	1.58
8 I	11.90	"	m.	"	384.8	273.6	111.2	20	20	0.0	8	8	.55	.368	.8	.07	5.93	.01	1.2
14 I	10.60	s.	l.	.6	313.2	308	5.2	15.2	16	0.0	9	8.55	.7	.394		.08	6.25	.01*	1.82*
21 I	9.30	d.	"	.15	300.4	298	2.4	14.4	12.8	1.6	10	8	.8	.394	1.3	.1	5.5	.01*	1.8 *
28 I	8.10	v. d.	c.	.4	353.6	340.8	12.8	28.4	22.4	6	12	11	1.2	.452	1.2	.111	5	.01*	2.17*
4 II	8.50	d.	"	muddy	338	302	36	22.8	15.2	7.6	12	10.9	1.2	.532	1	.055	3.4	.01	7.08
10 II	8.90	"	"	"	324.8	298	26.8	28	26	2	10	6.5	.9	.352	1	.05	4.25	.01	3.86
18 II	8.70	"	"	"	310	291.2	8.8	19.2	17.2	2	9	7.2	.65	.488	.82	.04	4.25	.01*	2.41*
25 II	8.90	v. d.	m.	"	2896	394	2502	56	16	40	1.8	45	.5	2.25	4.75	.12	2	.03	2.69
3 III	10.20	d.	c.	"	323.6	262	60.8	14.6	14.6	0.0	9	8.5	.9	.601	.95	.04	4	.07	14.77
10 III	10.00	"	"	.5	269.6	260	9.6	16.4	16.4	0.0	8.5	6.4	.7	.484	.7	.045	3.5	.07*	4.89*
17 III	9.70	"	"	.1	304.8	282	22.8	14.8	12	2.8	11	7.1	.5	.4	.7	.023	3.5	.05	5.03

TABLE X. PART 1—*Continued.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, MAY, 1894, TO DECEMBER, 1896.
(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION						Chlorine	Oxygen consumed	NITROGEN AS					Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition					Free ammonia	Albuminoid ammonia	Total organic	Nitrites	Nitrates		
								Total	Dissolved	Suspended									
1896-Cont.																			
24 III	8.80	d.	c.	.2	317.2	281.2	36	18.4	15.6	2.8	10	6.4	.68	.4	.95	.035	3.5	.03	5.77
31 III	8.00	"	"	.3	326.8	293.6	33.2	14.8	14	.8	10	7.65	.95	.44	1.1	.45	2.75	.13*	6.58*
7 IV	7.40	"	"	.2	325.2	303.6	21.6	15.6	11.6	4	13	7.3	.75	.46	.6	.075	2.25	1.68*	5.05*
14 IV	7.50	"	"	.5	358	298.4	59.6	21.6	14	7.6	12	7.6	.7	.44	1.2	.11	2.25	4.45*	2.97*
21 IV	7.00	"	"	.3	358	308.8	49.2	20	14.4	5.6	13	10.3	.5	.56	1.35	.11	1.87	9.39*	7.68*
28 IV	7.00	v. d.	m.	muddy	504.4	315.2	189.2	24.4	22	2.4	3.2	13.3	.04	.46	1.3	.12	1.25	3.61*	5.42*
5 V	6.90	d.	c.	.3	364.4	333.2	31.2	18	18	0.0	13.5	8.9	.45	.44	1	.275	1.67	2.8 *	2.8 *
11 V	5.90	"	"	.2	360.8	329.2	31.6	20	12	8	14	9.7	.62	.56	1.1	.35	1.75	3.56*	.89*
19 V	6.20	"	"	.3	374.8	332	42.8	18	18	0.0	15	9	1	.4	1.2	.225	1.5	.38	1.53
26 V	7.50	v. d.	m.	muddy	443.6	299.2	144.4	16.8	11.2	5.6	15	12.5	.45	.56	....	.375	2.4	1.43*	2.65*
2 VI	8.40	d.	c.	.7	351.2	271.2	80	20.4	20	.4	11	12.1	.4	.44	1.1	.3	2.5	.06*	5.86*
9 VI	8.25	"	"	.2	338.8	282.8	56	20	20	0.0	12.5	10.5	.4	.44	1	.25	3.25	1.68*	3.92*
16 VI	7.60	"	"	.2	362	318	44	16	14	2	38	12	.5	.56	1.3	.2	2.2	.78*	2.34*
23 VI	6.80	....	....	....	356	302	54	36	22	14	18	12.7	.5	.4	1.1	.2	2.	.73*	1.35*
30 VI	5.30	....	....	....	328	308	20	30.4	20	10.4	17	10.2	.52	.4	1.08	.25	2.8	.94*	.5 *
7 VII	4.60	....	....	....	360	318	42	24	16.8	7.2	20	13.3	.56	.4	1.36	.3	1.3	.26*	.26*
14 VII	3.40	....	....	....	372	324	48	22	18	4	23	13.1	.32	.32	1.6	.5	1.1	.44	.08
21 VII	4.20	....	m.	....	320	292.4	27.6	14	14	0.0	20	10.2	.76	.4	2.8	.35	.4	1.59	.05
28 VII	6.30	....	"	....	515.2	277.6	237.6	25.2	20	5.2	11	15.2	.01	.62	1.44	.09	1	1.06	.18
4 VIII	8.55	d.	"	muddy	333.6	249.6	84	36	26	10	13	10.4	.22	.4	.88	.175	1.2	.48	2.72
11 VIII	8.20	"	"	.15	342.4	308.8	33.6	28.4	8	20.4	16	10.1	.28	.44	.8	.35	1.4	2.4 *	1.6 *
26 VIII	6.55	"	"	.4	344.8	323.6	21.2	9.2	9.2	0.0	18	13.4	.24	.44	1.2	.15	1.7	.43	1.01
1 IX	5.70	"	"	.5	364.8	286.8	78	20	14	6	18	14.2	.36	.88	1.12	.11	1.3	.5 *	1.18*
9 IX	4.40	"	"	muddy	378.8	302.4	76.4	22	21.6	.4	20	15.3	.44	.5	1.36	.08	.95	....	....
15 IX	4.20	"	"	.3	379.6	319.6	60	13.2	13.2	0.0	23	13.6	.4	.56	.96	.14	1.7	.53*	.99*
22 IX	4.80	"	"	.4	381.6	294.8	86.8	15.2	14	1.2	26	14.6	.6	.56	1.20	.14	1.6	....	....
29 IX	4.30	"	"	.3	348.8	272	76.8	16.4	6.4	10	24	11.1	.8	.64	.96	.125	1.5	.23*	.69*
6 X	6.35	"	"	muddy	400	350.4	49.6	22.8	9.6	13.2	28	12.8	.72	.32	.96	.175	1.5	....	....
12 X	6.95	"	"	"	369.6	316	53.6	29.6	23.2	6.4	16	10.6	.28	.36	1.04	.125	1.6	.18*	5.0 *
21 X	6.30	"	"	"	336	318	18	18	18	0.0	14	8	.32	.44	1.12	.055	1.8	....	....
27 X	5.40	"	"	"	366	324	42	44	24	20	16	9.8	.28	.58	.96	.04	1.2	2.03*	1.09*
4 XI	5.20	"	"	"	340	310.8	29.2	17.2	17.2	0.0	18	11	.56	.32	.88	.04	1.3	....	....
10 XI	5.40	"	"	"	342	322.4	19.6	28	21.6	6.4	20	10.5	.76	.52	.96	.03	1.5	....	....
18 XI	6.25	"	"	"	364.8	335.6	29.2	22.8	22	.8	20	9.3	1.48	.44	1.2	.035	1.2	.02*	2.3 *
25 XI	6.50	"	"	"	373.6	348	25.6	26	18	8	16	9.4	.68	.36	1.28	.05	2	....	....
2 XII	6.20	"	"	"	362.8	354.4	8.4	12	9.6	2.4	16	8.3	.64	.36	1.2	.055	2.8	.58*	1.74*
9 XII	5.90	"	l.	"	349.6	348	1.6	24.4	24	.4	18	10.1	.92	.36	.88	.055	1.9	....	....
16 XII	5.70	"	"	"	376	368.4	7.6	20.8	18.8	2	16	10	.92	.4	.96	.025	1.7	....	....

TABLE X. PART 1—*Concluded.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, MAY, 1894, TO DECEMBER, 1896.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION						Chlorine	Oxygen consumed	NITROGEN AS					Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition					Free ammonia	Albuminoid ammonia	Total organic	Nitrites	Nitrates		
								Total	Dissolved	Suspended									
1896-Cont.																			
23 XII	5.25	d.	l.	muddy	355.6	348	7.6	12	12	0.0	16	11	1.06	.4	.96	.055	1.4	.....	.....
30 XII	4.40	"	"	.3	364.8	359.2	5.6	16.4	16	.4	18	10	1.32	.36	.96	.035	1.5	.94*	1.1 *
Average, Jan. 1—June 30					439.9	301.6	137.9	21.5	16.9	4.7	12.1	10.6	.66	.52	1.19	.138	3.08	1.18	3.87
" July 7—Dec. 30					365.7	318.9	47.2	29.5	16.5	4.9	18.4	11.3	.6	.46	1.15	.13	1.54	.84	1.39
" Jan. 1 Dec. 30					404.2	309.9	94.3	21.5	16.7	4.8	15.1	10.9	.63	.49	1.17	.134	2.34	.106	2.99

TABLE X. PART 2.

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, 1897.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1897																								
6 I	9.5+	v. d.	m.	.....	504.4	259.6	244.8	25.2	20	10	15.7	8.5	7.2	.6	.56	.36	.2	1.4	.88	.52	.04	2		
13 I	12.4+	d.	c.		329.6	259.6	70	25.2	10	10	13.7		.....	.44	.44	.....	.....	.96	.....	.....	.035	2.8		
20 I	12.9+	"	"		294.4	270.8	23.6	18	16.8	8	8.2		.....	.32	.36	.....	.....	.8	.....	.....	.035	3.5		
26 I	12.6+	slight	little	.3	294	293.2	.8	21.2	14.8	4.3	6.5	.....	.....	.08	.2	.....	.....	.64	.....	.....	.025	3.6	.03*	.53*
2 II	11.7—	d.	l.		308.8	307.6	.2	9.2	9.2	8	9.7	.....	.....	.352	.32	.....	.....	.8	.....	.....	.022	3.5	.....	.....
9 II	11.1—	"	"	.2	333.2	321.6	11.6	12	11.2	10.8	10.1			.68	.4			.8	.....	.....	.035	3		
16 II	10.4+	"	c.		338	318.8	19.2	18	13.2	12	10.4		.....	.88	.36	.....	.....	.8	.....	.....	.05	2.4		
23 II	11.3+	"	"	.....	322	298.8	23.2	47.2	34	11	9.5	.....	.....	.8	.48	.....	.....	.8	.....	.....	.055	2	.05*	4.99*
2 III	11.9+	"	l.	.....	289.6	256.4	33.2	44	31.2	8	8.2	.....	.....	.48	.28	.....	.....	.63	.....	.....	.07	2.9	.....	.....
9 III	12.4+	"	c.	.....	283.2	258.8	24.4	48.8	35.6	7	8	.....	.....	.48	.36	.....	.....	.6	.....	.....	.03	2.4	.....	.....
16 III	13.8+	"	l.	.....	261.2	246.8	14.4	49.6	43.2	7	9.5	.....	.....	.32	.32	.....	.....	.67	.....	.....	.05	2.8	.....	.....
24 III	15.8+	"	c.		274.8	257.2	17.6	42.8	34.8	6	7.8	.....	.....	.112	.2	.....	.....	.51	.....	.....	.07	3.5	.38*	.1 *

TABLE X. PART 2—*Continued.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, 1897.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1897–Cont.																								
30 III	15.8—	d.	c.	......	277.6	256	21.6	45.6	37.2	4	6.4	......	......	.048	.2	......	......	.51	......	......	.04	3.5	......	
6 IV	15.4—	"	"	......	261.6	231.2	30.4	37.6	26.4	4	10.4	......	......	.168	.32	......	......	.67	......	......	.07	2.8	......	......
13 IV	13.7—	"	l.	......	259.6	242.4	17.2	37.6	32	4.4	8.8	......	......	.136	.32	......	......	.67	......	......	.06	2.4	......	......
20 IV	12.3—	"	"	.2	292	270.8	21.2	50	41.6	7	8.9	......	......	.064	.36	......	......	.83	......	......	.055	2.2	......	......
28 IV	11.5—	"	c.	......	315.2	273.6	41.6	39.2	33.6	9	10.3	......	......	.096	.44	......	......	.95	......	......	.065	2	5.11*	.57*
4 V	11.0±	"	"	......	316	296	20	41.2	39.2	10	12	......	......	.072	.52	......	......	.95	......	......	.095	1.5	......	......
11 V	10.3—	"	l.	.15	304.8	283.2	21.6	25.2	22	10	10.7	......	......	.07	.44	......	......	.71	......	......	.08	1.8	......	......
18 V	9.3—	"	"	.1	296.8	293.6	3.2	32	22.8	10	9.2	......	......	.072	.36	......	......	.83	......	......	.075	1.4	......	......
25 V	8.0—	"	"	......	334.8	320	14.8	34	28	12	11	......	......	.28	.44	......	......	1.07	......	......	.1	1.1	5.62	.62
1 VI	6.8—	"	c.	......	347.6	314.8	32.8	49.2	22.8	13	9	......	......	.52	.52	......	......	1	......	......	.25	.9	......	......
8 VI	5.6—	"	l.	......	340.4	326.8	13.6	23.2	19.6	15	11.9	......	......	.56	.36	......	......	1.01	......	......	.35	1.2	......	......
15 VI	4.4 -	"	c.	......	347.2	328	19.2	36	32	17	12.5	......	......	1	.56	......	......	1.05	......	......	.37	.8	......	......
22 VI	5.1+	"	"	......	384	335.6	48.4	30	28.8	22	11.9	......	......	.88	.8	......	......	1.17	......	......	.3	1.4	......	......
29 VI	7.1+	"	"	......	348	247.6	100.4	54	35.2	9	11.3	......	......	.28	.44	......	......	.93	......	......	.27	1.5	.27*	26.33*
6 VII	7.4—	"	"	......	391.6	292	99.6	73.2	35.6	11	11.2	8.8	2.4	.88	.44	.32	.12	.92	.48	.44	.4	1.6	......	......
13 VII	6.6—	"	l.	.3	318	286	32	28	24	15	12.7	8.7	4	.36	.44	.352	.088	.96	.92	.04	.3	1.1	8.16*	2.72*
21 VII	5.2—	"	"	.2	306	290.4	15.6	32	29.2	15	10.8	8.9	1.9	.8	.72	.384	.336	1.8	.68	1.12	.23	.8	.92	2.76
28 VII	4.8—	"	c.	......	369.2	328	41.2	20.4	18.4	23	14	12.7	1.3	.498	.526	.496	.03	1.04	.68	.36	.38	1.1	1.05*	.19*
4 VIII	3.5—	"	"	.07	340	268	72	24	14	22	12.8	9.5	3.3	.4	.4	.352	.028	1.4	1.08	.32	.27	1	2.02*	.22*
11 VIII	2.3±	"	"	.15	428	296.8	131.2	20	17.6	21	15.8	11.5	4.3	.72	.64	.512	.128	1.4	1	.4	.24	1	2.02*	.22*
18 VIII	1.9±	"	"	.15	317.6	277.2	40.4	17.6	10	22	12.5	11	1.5	.72	.56	.32	.24	1.16	.92	.24	.26	.5	1.98*	.22*
25 VIII	1.8±	"	"	.04	416.4	312.4	104	16.8	14.4	29	12.8	11.5	1.3	.48	......	.416	......	1.3	.82	.48	.4	.9	2.77*	.15*
1 IX	1.7—	"	"	.15	442.4	322	120.4	26	24	33	13.2	9.5	3.7	.48	.52	.32	.2	1.14	.74	.4	.16	.3	9.45*	.19*
8 IX	1.9+	"	"	.1	393.2	302.4	90.8	23.2	18.4	35	12	10.5	1.5	.48	.52	.36	.16	1.06	.78	.28	.11	.35	8.47*	.45*
15 IX	2.0±	"	"	.2	365.6	347.2	18.4	23.6	20	48	12.7	11.7	1	.8	.56	.44	.12	.98	.9	.08	.07	.6	19.8 *	1.04
22 IX	2.0±	"	"	.1	384.8	337.2	47.6	14	13.2	47	13	11.4	1.6	.8	.64	.44	.2	1.3	.86	.44	.07	.7	3 *	trace *
29 IX	2.0±	"	"	.1	388.4	342.8	45.6	25.2	8	50	12.5	10.5	2	.56	.64	.48	.16	1.26	.94	.32	.37	1	4.04	.04
6 X	1.9±	"	"	.15	344.8	313.2	31.6	26	22	42	11.3	9.5	1.8	.56	.6	.4	.2	1.18	1.02	.16	.15	.4	12.92*	trace *
13 X	1.9±	"	"	......	414.8	352	62.8	24	22	54	12.6	12.5	.1	1	.56	.48	.08	1.1	.94	.16	.15	.2	5.17*	.27*
20 X	2.0±	"	l.	.05	403.2	360.4	42.8	28.4	26.4	55	12	8.8	3.2	.96	.6	.4	.2	1.02	.78	.24	.55	.7	1.86*	.46*
27 X	2.2+	"	"	.2 n. f. .3	408.8	377.2	31.6	22.4	20.8	60	10.6	9.4	1.2	1.08	.52	.4	.12	1.02	.9	.12	1	1.7	.2 *	1.16*
3 XI	2.5±	"	"	.1	390	363.2	26.8	32.8	32	58	11.8	10.5	1.3	1.16	.44	.32	.12	.94	.7	.24	1	.8	.06*	.58*
10 XI	2.8+	"	"	.07	400.4	374.8	25.6	30.8	26.8	58	11.4	10.5	.9	1.28	.48	.4	.08	1.1	.94	.16	.9	1.7	.82*	2.46*
17 XI	2.8±	"	"	.07 n. f. .10	392	363.2	28.8	40	28	58	9	8	1	1.52	.52	.44	.08	.94	.78	.16	.26	2.3	1.86*	.46*
24 XI	2.8±	"	"	.10 n. f. .13	398	384.8	13.2	43.6	40	56	8.7	8	.7	2.4	.44	.4	.04	1.06	.86	.2	.2	1.8	1.01*	1.51*

TABLE X. PART 2—*Concluded.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, 1897.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
								Loss on Ignition							Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1897 Cont.																								
30 XI	3.2	d.	l.	.10	360.8	359.2	1.6	32.8	24.4	47	7.7	6.2	1.5	2.8	.48	.36	.12	.85	.77	.08	.09	2.1	1.57	.85
7 XII	3.0	"	"	.08 n.f. .15	386.8	368.8	18	42	36.8	47	8	7.5	.5	3.58	.6	.52	.08	1.09	.85	.24	.1	.4	.7	.3
14 XII	3.4	"	"	.06	368.8	365.6	3.2	32	22.8	49	8.2	7.7	.5	3.58	.68	.48	.2	1.17	.93	.24	.13	2	1.22	.14
21 XII	3.2	"	"	.10 n.f. .15	382	373.2	8.8	28	26	46	9.5	9	.5	3.52	.64	.52	.12	1.25	.97	.28	.03	1.2	.3	1.18
28 XII	3.2	"		f. .10 n.f. .20	405.6	398.8	6.8	20.8	20	46	14	9	5	5.6	.8	.56	.24	1.25	.85	.4	.1	1.25	.03	2.77
Average, Jan. 6–June 29					317.6	283.4	34.2	34.1	26.7	9.5	7.6	8.5	7.2	.376	.398	.36	.2	.836	.88	.52	.103	2.265	1.91	5.52
" July 6–Dec. 28					381.4	340.6	40.7	28.7	23.1	40.2	11.5	9.7	1.8	1.376	.541	.41	.13	1.14	.76	.378	.308	1.053	3.64	.81
" Jan. 6–Dec. 28					351.4	312	39.3	31.6	24.9	24.8	9.6	9.6	2	.893	.46	.416	.118	.988	.717	.421	.203	1.659	3.31	1.73

TABLE X. PART 3.

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, JANUARY, 1898, TO APRIL, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
								Loss on Ignition							Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1898																								
4 I	3.2	d.	l.	.1 n.f. .2	391.2	383.6	7.6	26.4	25.2	42	8.7	8	.7	4	.64	.48	.16	1.41	1.25	.16	.165	1		
11 I	3.7	"	c.	.15	400.8	395.6	5.2	18	17.2	44	9.1	8.4	.7	4.4	.64	.44	.2	1.64	.96	.68	.21	1	.07	.65
18 I	5.2	"	"	.15	407.2	376	31.2	20	20	38	11.8	7.8	4	4.6	.6	.52	.08	1.24	.84	.4	.13	.8	.81*	.27*
25 I	6.8	"	m.	.15	424.4	292.4	132	39.2	23.2	24	15	8.8	6.2	2.72	.64	.36	.28	1.32	.84	.48	.175	1.4	.17	4.25
1 II	7.3	"	c.	.3	303.6	280.8	22.8	29.6	29.2	16	9.5	8.1	1.4	1.08	.48	.4	.08	.92	.64	.28	.11	2.4	.07*	.20*
8 II	7.1	"	l.	.3	334	306.4	27.6	56	37.2	15	10.5	8.5	2	1.44	.55	.32	.23	.92	.68	.24	.125	1.77	.28	2.56
15 II	9	"	c.	.3	454.4	298.4	156	36.8	26.4	15	15.1	7.7	7.4	1.6	.6	.32	.28	1.24	.6	.64	.06	1.2	.04	4.4
22 II	10.7	"	"	.4	394.4	233.6	160.8	33.2	30.4	9	15	7.4	7.6	.73	.68	.28	.4	1.32	.64	.68	.03	3.2	.1	20.41
1 III	11.4	"	l.	.5	258	248	10	35.2	28.8	10	10.5	8	2.5	.68	.44	.36	.08	.84	.68	.16	.045	2.5	.02	4.46

TABLE X. PART 3—*Continued.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, JANUARY, 1898, TO APRIL, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.^{3} water—in cm.^{3}	Vol. silt per m.^{3} water—in cm.^{3}
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1898-Cont.																								
8 III	11 —	d.	l.	.4	281.2	278	3.2	28	20	7	10.7	8.8	1.9	.6	.44	.36	.08	.92	.76	.16	.02	1.6	.06	1.98
15 III	12.1+	"	c.	......	299.2	256.8	42.4	34	21.6	8	10.5	7.5	3	.72	.44	.32	.12	1	.64	.36	.055	1.25	.38	1.14
22 III	14.1+	"	l.	.3	260	238.4	21.6	34	30	7	7.9	7.5	.4	.36	.4	.36	.04	.92	.68	.24	.055	1.25	.77	.19
29 III	16.5+	"	c.	.7	236	226.4	9.6	27.6	24	4	9.5	8.2	1.3	.152	.4	.32	.08	.93	.61	.32	.08	1.2	.43	.05
5 IV	17.3—	"	l.	.5	238.8	212.8	26	33.2	24.8	6	9.5	8.6	.9	.088	.4	.36	.04	.85	.73	.12	.055	1	.53	.35
12 IV	14.8—	"	c.	......	237.6	194.4	43.2	27.6	23	4.2	12.3	9.2	3.1	.088	.44	.4	.04	1.09	.93	.16	.035	.85	.13	.19
19 IV	13.1—	"	l	.25	250.8	244.8	6	44	40.8	6	11.8	9.2	2.6	.16	.44	.36	.08	.85	.73	.12	.05	.75	1.12	1.12
26 IV	12 —	"	"	.15	335.2	256.8	78.4	27.6	24.8	9	12	9.1	2.9	.088	.52	.32	.2	1.01	.77	.24	.035	1.1	15.81	.83
3 V	11.1—	"	"	.1 n.f. .25	316	287.2	28.8	50.8	40.8	11	9.1	7.3	1.8	.34	.48	.4	.08	.98	.74	.24	.065	.85	35.68	trace
10 V	10.3—	"	"	.05	319.2	299.6	19.6	49.2	37.2	11	11.3	8.1	3.2	.08	.6	.44	.16	1.38	.74	.64	.07	1	10.31	.21
17 V	10.1+	"	c.	.05	338.8	316.4	22.4	64	62.5	12	9.3	8	1.3	.36	.36	.28	.08	.9	.78	.12	.06	.75	5.22	1.74
24 V	13.6+	"	l.	.05 n.f. .25	261.2	256.8	4.4	30.8	26.8	10	9	7.5	1.5	.128	.4	.32	.08	.74	.58	.16	.075	.8	3.45	.07
31 V	13.6+	"	c.	.1 n.f. .4	261.2	255.2	6	31.6	26.8	7	8.5	8	.5	.184	.32	.28	.04	.74	.62	.12	.2	.85	1.84	.32
7 VI	12.5—	"	l.	.1 n.f. .2	296	285.6	10.4	39.6	36.8	7	8.5	7.5	1	.24	.28	.2	.08	.64	.52	.12	.22	.55	5.28	3.52
14 VI	11.9±	s.	"	.05 n.f. .2	318.8	279.6	39.2	30.2	25.6	9	7.7	7.5	.2	.16	.28	.24	.04	.68	.64	.04	.14	.45	6.99	.37
21 VI	10.8—	"	"	.1	329.6	318.4	11.2	46.8	18	14	8.6	7.7	.9	.32	.36	.32	.04	.84	.72	.12	.2	.45	2.88	.72
28 VI	10 —	"	"	.03	308.8	......	......	18	......	11	7.9	7	.9	.094	.24	.2	.04	.72	.64	.08	.22	.5	.69	1.03
5 VII	8.7—	d.	c.	.06	342.5	326.4	16.1	28	24	16	8.5	6.8	1.7	.48	.36	.24	.12	.92	.48	.44	.22	.35	.14	1.62
12 VII	7 —	"	l.	.04 n.f. .12	304.4	294	10.4	16.8	14	17	8.5	8	.5	.28	.44	.36	.08	.88	.76	.12	.13	.4	.64	1.22
19 VII	4.7—	"	"	.03 n.f. .04	319.6	297.6	22	18	16	15	8.4	8	.4	.32	.4	.32	.08	.8	.68	.12	.13	.3	.88	.88
26 VII	2.9—	"	"	.03 n.f. .05	310.8	309.2	1.6	22	21.2	16	9	8.5	.5	.6	.44	.36	.08	1.04	.8	.24	.04	.2	.67	.29
2 VIII	2.7+	"	c.	.03	330.8	308.8	22	16	15.2	22	8.9	7.8	1.1	1	.48	.366	.114	.88	.68	.2	.04	.3	1.62	.18
9 VIII	3.2+	"	l.	.15 n.f. .2	370.8	354.8	16	44	33.6	29	9.3	8.4	.9	.52	.6	.44	.16	1.28	.92	.36	.2	.15	.97	.11
16 VIII	3.7+	"	c.	.04	374.8	354.8	20	29.2	26.8	37	8.5	8	.5	.36	.4	.36	.04	.96	.8	.16	.17	.15	.61	1.43
23 VIII	4.2—	"	l.	.04 n.f. .1	360.8	343.2	17.6	22	20	46	8.1	6.1	2	.608	.416	.352	.064	.88	.72	.16	.42	.15	.51	2.05
30 VIII	3.9—	"	"	.04	337.2	316.4	20.8	24.8	20	40	8.5	7.5	1	.76	.52	.36	.16	1.04	.72	.32	.22	.05	.82	.82
6 IX	4.7+	"	"	.06	333.2	299.6	33.6	28	24.8	32	9.5	6.5	3	1	.48	.32	.16	1	.68	.32	.05	.05	.90	.90
13 IX	4.2—	"	c.	.03	356	331.6	24.4	36	34	38	7.5	7	.5	.84	.32	.28	.04	.88	.68	.2	.25	.25	.61	.91
20 IX	4.2—	"	"	.04	372	328	44	48	28	36	7.1	6.6	.5	.88	.36	.24	.12	.76	.6	.16	.28	.3	.95	.41
27 IX	4.9±	"	l.	.05	304.8	280.8	24	39.2	26.8	35	6.8	5.8	1	1.16	.32	.28	.04	.68	.52	.16	.29	.45	.31	1.23

TABLE X. PART 3—*Concluded.*

CHEMICAL DATA AND PLANKTON, ILLINOIS RIVER, JANUARY, 1898, TO APRIL, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION						Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
								Loss on Ignition								Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved	Suspended		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1898 Cont.																									
4 X	4 —	d.	c.	.04	322	304	18	30.8	21	....	25	6.7	5.8	.9	.8	.32	.24	.08	.72	.52	.2	.14	.5	.17	.95
11 X	3.9+	"	l.	.05 n.f. .15	336.4	318.8	17.6	35.2	34	....	25	6.2	5.5	.7	.8	.36	.28	.08	.53	.45	.08	.24	.4	.22	.66
18 X	3.8+	"	"	.04 n.f. .05	344	332.8	11.2	32	28	..	29	7	5.8	1.2	.76	.288	.24	.048	.73	.57	.16	.32	.65	.42	1.26
25 X	4.3+	"	"	.06 n.f. .1	390.4	360.8	29.6	43.6	36		38	8	6.6	1.4	1.84	.408	.288	.12	.85	.65	.2	.105	.8	.16	1.48
1 XI	6.3+	"	c.	.04	360	339.2	20.8	30	31.2	....	28	7	5.5	1.5	1.76	.36	.28	.08	.69	.45	.24	.04	.45	.14	2.74
8 XI	6.7+	"	"	.07	370.8	336.8	34	32	30	....	19	7.4	5.4	2	.96	.32	.236	.084	.67	.51	.16	.04	.75	.04	4.04
22 XI	8.5+	"	"	.04	400.8	310	90.8	46	36	...	13	9	7	2	.6	.4	.208	.192	.79	.47	.32	.035	.9	.22	22.18
29 XI	8.3+	"	"	.05	360	342	18	37.2	36		12	8	6.2	1.8	.48	.304	.224	.08	.63	.51	.12	.035	1.25	.75	2.25
6 XII	7.2—	"	"	.07	379.2	370	9.2	47.2	40	.....	16	7.8	6.8	1	.92	.336	.224	.112	.69	.57	.12	.04	.35	1.26	.14
13 XII	6.7—	....	"		392.8	391.2	1.6	66	59	...	17	8.3	8	.3	1.08	.384	.272	.112	.81	.674	.136	.02	.1	.01	5.99
20 XII	5.9—	d.	"	.04 n.f. .08	385.6	384	1.6	56.5	56	...	20	9.1	8.4	.7	1.24	.464	.272	.192	.89	.69	.2	.02	.35	1.98	.1
27 XII	6.1+	"	l.	.07 n.f. .4	394	390	4	51.2	50	...	27	12.5	9.5	3	2.4	.48	.4	.08	.89	.77	.12	.016	.2	1.06	.02
Average, Jan. 4–June 28				..	317.5	270.7	474	35	27.7	....	13.6	10.3	8	2.3	1	.464	.346	.128	1.001	.729	.272	.103	1.171	3.76	2.04
" July 5–Dec. 27				.	362.1	332.9	29.1	35.1	30.5	..	25.9	8.2	7	1.2	.897	.398	.309	.088	.833	.634	.198	.139	.39	.64	2.15
" Jan. 4–Dec. 27					339.4	300.9	38.4	35.1	29.1	..	19.6	9.3	7.5	1.7	.95	.431	.327	.103	.92	.683	.237	.121	.809	2.20	2.10
1899																									
3 I	6.5+	d.	c.	.4	334.8	316.8	18	54	42	..	19	11.2	12.2	2	1.72	.52	.384	.136	1.17	.85	.32	.025	.1	.22	.42
10 I	7.9+	"	"	.3	328.8	314.8	14	32.8	30		16	12	8.8	3.2	1.4	.44	.36	.08	.93	.69	.24	.02	.3	.15	.45
17 I	8.2+	"	"	.2	317.2	254.8	62.4	50	48	...	11	14	8.7	5.3	.72	.52	.304	.216	.97	.61	.36	.035	.85	.5	1.98
24 I	8.9+	"	"	.25	296	262.8	33.2	52	48	......	11	12	8.1	3.9	1.04	.48	.288	.192	.85	.57	.28	.035	.65	.03	2.93
31 I	8 +	"	"	.15	287.2	270.8	16.4	48	46	.....	12	9.4	8	1.4	.96	.44	.24	.2	.85	.61	.24	.021	.9	.01	2.11
7 II	7.3—	"	l.	.1 n. .45	326	318.8	7.2	48	42		15	9	8	1	1.12	.4	.288	.112	.86	.58	.28	.024	1.5	.11	1.12
14 II	6.6—	"	"	.1 n.f. .25	372	364	8	58	56	.	20	12.2	9	3.2	1.48	.528	.368	.16	1.02	.74	.28	.03	1.76	1.15	.29
21 II	5.5—	"	"	.15 n.f. .3	360	354	6	56	51.2	..	20	9.8	9.1	.7	1.76	.512	.416	.096	1.22	.86	.36	.075	1.15	.07	1.41
28 II	10.2+	v. d.	v. m.	.6	750	178	572	82	40		10	37	9.9	27.1	1.12	1.36	.4	.96	2.34	.58	1.76	.042	.75	1.42	.48
7 III	12.9+	"	"	.7	442	194	248	66	40		10	27.3	15	12.3	.76	.84	.384	.456	1.94	.74	1.2	.04	.95	.54	.18
14 III	13.1—	d.	m.	.5	370	152.4	217.6	58	33.2	..	5.8	23.8	13.5	10.3	.6	.72	.32	.4	1.78	.66	1.12	.023	.8	.35	.53
21 III	13.7+	"	"	.7	364	178.8	185.2	52	42	...	5.2	19.8	12.8	7	.56	.56	.304	.256	1.35	.6	.75	.035	1.25	.21	.11
28 III	13.5+	"	"	.5	268.8	242	26.8	50	46		5.8	15.8	11.6	4.2	.56	.48	.32	.16	1.07	.63	.44	.04	1.35	.01	.27
Average, Jan. 3–March 28					370.5	261.7	108.8	54.4	43.4	..	12.4	16.6	10.4	6.3	1.06	.6	.337	.263	1.26	.67	.59	.034	.95	.41	.94
Average, May 22, '94–Mar. 28, '99					367.5	304.1	61.4	32.8	25.1	4.8	21.6	10.4	8.5	2.4	.86	.48	.355	.131	1.03	.69	.34	.147	1.58	1.91	2.00

TABLE XI. Part 1.

Chemical Data and Plankton, Spoon River, August, 1896, to December, 1897.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
								Loss on Ignition							Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1896																								
11 VIII	8.1—	d.	l.	.3	286	267.2	18.8	22	12.4	5.8	8.6	......	......	.022	.4	......	......	.88	......	......	.1	1	......	......
26 VIII	6.5—	''	''	.1	310	300.4	9.6	8	4	3.5	5.8	......	......	.064	.48	......	......	.88	......	......	.035	1	.032*	.128*
2 IX	5.5—	''	c.	.2	262.8	234.8	28	20	10	3.4	7.7	......	......	.034	.48	......	......	.88	......	......	.000	.1	......	......
9 IX	4.3—	''	''	muddy	300	265.6	34.4	10	10	3.9	7.1	......	......	.074	.4	......	......	.72	......	......	.000	.1	......	......
15 IX	4.1—	v.d.	m.	''	473.6	184.4	289.2	18	12	2.3	14.2	......	......	.072	.56	......	......	1.28	......	......	.075	.8	.007*	.673*
22 IX	4.9±	d.	c.	.4	381	294.8	86.8	15.2	14	2.6	14.6	......	......	.6	.56	......	......	1.2	......	......	.14	1.6	......	......
29 IX	4.3—	''	''	muddy	365.6	273.6	92	12	12	3.5	6.1	......	......	.058	.24	......	......	.56	......	......	.035	1.2	.002*	.158*
6 X	6.2+	''	''	''	366.4	282	84.4	16	16	4.8	6.6	......	......	.014	.32	......	......	.48	......	......	.007	1.2	......	......
12 X	6.9±	''	l.	.15	362.4	328	34.4	25.2	24	4	4.3	......	......	.02	.16	......	......	.72	......	......	.013	1.5	.002*	.178*
21 X	6.2—	''	c.	muddy	348.8	317.6	31.2	14	14	4	4.7	......	......	.008	.32	......	......	.64	......	......	.005	.9	......	......
27 X	5.3—	''	''	.3	370	316	54	42	28.8	4	5.5	......	......	.048	.28	......	......	.56	......	......	.000	.5	.008*	.792*
4 XI	5.1+	v.d.	m.	muddy	468	226	242	28	22	4.6	18	......	......	.114	.64	......	......	1.36	......	......	.013	.9	......	......
10 XI	5.4+	d.	c.	''	366	296	70	22	20	4.1	6.9	......	......	.09	.36	......	......	.64	......	......	.01	1.6	......	......
18 XI	6.4+	''	''	''	360	330.8	29.2	21.2	16	3.7	4.4	......	......	.04	.16	......	......	.64	......	......	.022	1.8	.005*	.515*
25 XI	6.4—	''	''	''	340	316.8	23.2	50	9.2	3.6	3.4	......	......	.016	.16	......	......	.72	......	......	.006	2.2	......	......
2 XII	6.1—	''	l.	.3	338	324.8	13.2	34	34	3.8	4.1	......	......	.008	.16	......	......	.68	......	......	.006	2	.002*	.198*
9 XII	5.9±	''	''	.3	342.8	338.4	4.4	26.8	26.8	4.4	4.3	......	......	.016	.18	......	......	.56	......	......	.006	1.8	......	......
16 XII	5.7±	''	c.	muddy	297.2	292.4	4.8	28	28	3.3	2.7	......	......	.004	.24	......	......	.48	......	......	.003	1	......	......
23 XII	5.2—	''	l.	''	308	306.4	1.6	32.8	18	3.6	4	......	......	.006	.16	......	......	.4	......	......	.022	.7	......	......
30 XII	4.5+	''	''	.2	317.6	314.4	3.2	24	15.6	4	4	......	......	.016	.14	......	......	.48	......	......	.005	1.1	.001*	.099*
Average, Aug. 11—Dec. 30 ...					348.2	290.5	57.7	23.5	17.3	3.8	6.9	......	......	.066	.32	......	......	.74	......	......	.025	1.2	.008	.343
1897																								
5 I	8.6+	v.d.	m.	.8	1462	160.4	1301.6	22	10	2	37.5	8.9	28.6	.292	1.28	.32	.96	6.4	.88	5.52	.027	1	......	......
13 I	12.4+	d.	c.	......	428	302	126	26	8	2.6	8.6	......	......	.104	.28	......	......	.56	......	......	.025	3.7	......	......
20 I	12.9+	v.d.	m.	......	632.8	202.4	430.4	19.6	16	2.4	16.8	......	......	.236	.6	......	......	1.28	......	......	.085	2.7	......	......
26 I	12.6±	s.	l.	.15	315.2	307.2	.8	17.6	11.6	4.2	4	......	......	.152	.16	......	......	.48	......	......	.018	3.6	......	......
1 II	11.8—	''	''	.03	353.2	351.2	2	28.8	24	3.4	2.3	......	......	.126	.08	......	......	.32	......	......	.004	3.6	.002*	.238*
9 II	11.1—	d.	c.	......	319.2	203.2	116	16.4	12.8	2.8	16.3	......	......	.412	.52	......	......	1.28	......	......	.038	1.8	.092*	.828*
16 II	10.4±	''	''	......	367.2	360.4	6.8	16.8	16	3.5	7.9	......	......	.244	.32	......	......	.72	......	......	.06	2.5	......	......
23 II	11.3+	v.d.	m.	.5	2285.2	197.6	2087.6	221.2	32	1.4	82.8	11.1	71.7	.176	3.52	.48	3.04	7.2	1.2	6	.045	2.3	......	......
2 III	11.9±	d.	l.	......	359.6	308	51.6	36.4	29.2	3.1	5.1	......	......	.162	.2	......	......	.47	...	...	.06	3	......	......
9 III	12.4+	v.d.	v.m.	.5	1000.8	168	832.8	75.6	38	1.2	36	9.5	26.5	.328	1.36	.304	1.056	2.51	.83	1.68	.055	1.3	......	......
16 III	13.8±	d.	m.	.3	699.2	238.4	460.8	80.8	40.8	2.8	27.8	7.3	20.5	.192	1.08	.224	.856	1.95	.51	1.44	.04	2.5	......	......
24 III	15.8+	''	''	.4	950.8	214.8	736	111.2	29.2	1.2	46.8	11	35.8	.152	1.6	.272	1.328	2.83	.83	2	.06	2.4	.007*	6.553*
30 III	15.8—	''	c.	......	258	229.2	28.8	36.8	29.6	4.3	9.8	......	......	.26	.36	......	......	.67	......	......	.062	2.4	......	......
6 IV	15.4—	v.d.	m.	......	374	215.2	158.8	39.2	22	2.8	14.6	......	......	.094	.44	......	......	.91	......	......	.046	2.2	......	......
13 IV	13.7—	d.	c.	......	408.4	288.4	120	39.6	32.2	3	7.3	......	......	.044	.28	......	......	.51	......	......	.04	3.2	......	......
20 IV	12.3—	''	l.	......	353.2	311.2	42	55.2	54	3	5.3	......	......	.024	.24	......	......	.43	......	......	.03	3.5	......	......

TABLE XI. PART 1—*Concluded.*

CHEMICAL DATA AND PLANKTON, SPOON RIVER, AUGUST, 1896, TO DECEMBER, 1897.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1897-Cont.																								
28 IV	11.5−	d.	c.		465.2	261.2	204	40.8	34	3.1	15.8			.014	.52			.95			.08	.9	.048*	4.752*
4 V	11 +	"	"		321.2	292	29.2	37.2	34	3.2	5.4			.028	.2			.39			.034	2.8		
11 V	10.3−	"	l.	.1	319.2	284.8	34.4	25.6	24	3.3	5.6			.064	.36			.71			.028	2.2		
18 V	9.3−	"	"	.15	288	262	26	36.4	29.2	3.7	6.1			.028	.36			.67			.025	1.6		
25 V	8 −	"	c.		311.2	278.8	32.4	36	34	3.4	6.3			.072	.4			.83			.035	.8	.44	.44
1 VI	6.8−	"	"		317.2	263.6	43.6	29.6	26.4	3.2	7.5			.078	.52			1			.035	1.3		
8 VI	5.6−	"	"		327.2	283.6	43.6	31.2	30	3.5	7			.08	.44			.97			.06	.6		
15 VI	4.4−	"	"		351.2	296	55.2	30	20	3	7.7			.102	.4			.97			.05	.2		
22 VI	5.1+	"	"		353.2	296	57.2	26	18	3.6	7.5			.034	.48			.93			.04	.7		
29 VI	7.1+	"	"		338	306	32	27.2	26	3.4	5.3			.04	.24			.65			.045	.45	.25 *	.75 *
6 VII	7.4−	v.d.	v.m.		2930	187.6	2742.4	106	20.4	.6	35.8	8	27.8	.068	2.4	.4	2	4.76	.84	3.92	.12	.24		
13 VII	6.6	d.	c.	.7	361.6	308.4	53.2	22.8	16.4	2.6	11.2	7.4	3.8	.07	.44	.32	.12	.92	.84	.08	.09	1.5		
21 VII	5.2	"	l.	.05	298	276	22	18	16	3.5	6.7	5.8	.9	.1	.72	.32	.4	1	.52	.48	.045	.7		
28 VII	4.8	v.d.	m.	.7	368	220	148	20	10	2.2	13	7.5	5.5	.036	.48	.384	.096	.84	.68	.16	.19	.9		
4 VIII	3.5−	d.	c.		298.8	236	62.8	14	14	2.2	18.4			.126	.24			.8			.065	.65		
11 VIII	2.3+	"	"		314	223.2	90.8	21.2	16	2.1	12.6			.186	.8			1.24			.25	.8	.056*	.224*
18 VIII	1.9+	"	"		281.2	220	61.2	13.2	12	2.5	10			.18	.4			.92			.095	.65		
25 VIII	1.8+	"	"		312	311.2	.8	15.2	9.2	2.5	8			.226	.36			.58			.015	.3	1.248*	.832*
1 IX	1.7−	"	"		322.4	282	40.4	20.4	18	2.7	9.8			.214	.36			.82			.025	.15		
8 IX	1.9+	"	"		342	276.8	65.2	16	12.8	2.8	11			.226	.48			.74			.04	.2	7.296*	.384*
15 IX	2 +	"	"		380	291.2	88.8	20	18	3.4	12.8			.408	.6			.98			.013	.5		
22 IX	2 +	"	"		353.2			13.2		4.8	12.2			.152	.64			1.14			.022	.15		
29 IX	2 +	"	"		356.8	280.4	76.4	20	6.4	2.9	11			.208	.52			1.18			.017	.1		
6 X	1.9+	"	"		340.4	286	54.4	19.6	16	2.6	12.3			.202	.48			1.02			.017	.1		
13 X	1.9+	"	"		362.8	300.4	62.4	27.2	11.6	5.1	8.75			.38	.4			.94			.014	.05		
20 X	2 +	"	"		373.6	306	67.6	20.4	19.6	16	11			.56	.52			.78			.02	.1		
27 X	2.2+	"	"		341.8	320	24.8	22	21.2	19	8.5			.336	.52			1.1			.2	.5		
3 XI	2.5+	"	l.		325.6	290.8	34.8	24.8	24	3	7.9			.138	.4			.54			.015	.7	1.351*	.049*
17 XI	2.8+	"	c.		303.6	268	35.6	28.8	16.8	7.3	8.7			.056	.44			.94			.016	.75		
24 XI	2.8+	"	"	.1	300	274.8	25.2	23.2	20	3	8.3			.012	.36			.94			None	.2		
30 XI	3.2−	"	"		275.2	264.8	10.4	26.8	20	3.5	5.9			.03	.4			.61			.002	.6	1.99	.01
7 XII	3 +	"	l.	.1	326	324.8	1.2	28		6.2	7.5			.002	.52			.77			.002	1		
14 XII	3.4−	"	c.	.2	327.6	299.6	28	30.8	27.2	4.8	7.5			.008	.32			.69			.015	.6		
21 XII	3.2−	"	l.	.3	347.6	233.2	14.4	22.8	20	6	7.2			.012	.4			.65			None	.35		
28 XII	3.2±	"	"	.15	348	339.2	8.8	20.4	18.8	4.8	7.4			.066	.32			.61			.003	.55	.599	.031
Average, Jan. 5—June 29					383	187.8	195.2	37	26.1	2.9	15.5	9.5	3.6	.072	.33	.32	1.448	1.06	.85	3.32	.043	2.04	.14	2.26
" July 6—Dec. 28					435.7	264.8	170.9	20.5	15	4.6	10.5	7.1	9.4	.16	.54	.356	.204	1.02	.72	1.18	.051	.49	2.09	2.55
" Jan. 5—Dec. 29					408.8	225.5	183.2	28.9	20.7	3.7	13.1	8.5	2.4	.148	.58	.336	1.19	1.04	.79	2.36	.047	1.28	1.115	1.258

TABLE XI. Part 2.

Chemical Data and Plankton, Spoon River, January, 1898, to May, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1898																								
4 I	3.2±	d.	c.	.3	312.4	301.2	11.2	32	14.4	4.2	7.4			.226	.32			.61			.014	.8		
11 I	3.7+	v. d.	v. m.	.5	659.2	273.6	385.6	30.8	18.8	4	25.3	8.9	16.4	.28	1.12	.44	.68	2.16	.76	1.4	.2	1.03		
18 I	5.2−	d.	m.		957.2	190.8	766.4	58	28	10.5	54.8	13	41.8	1.272	1.92	.32	1.6	4.76	.68	4.08	.125	.95		
25 I	6.8+	"	"	.8	389.6	208	181.6	34.8	22.8	3	23.4	15	8.4	.396	.8	.56	.24	1.84	.84	1	.18	1.1	.017	1.663
1 II	7.3+	"	c.	.8	282.8	224.8	58	24.8	17.2	3.8	14	12.1	1.9	.352	.48	.36	.12	1	.8	.2	.08	1.6		
8 II	7.1−	"	"		277.2	246.8	30.4	29.2	25.6	3.5	10.6			.4	.4			.84	.8	.04	.03	1.25		
15 II	9 +	v. d.	"	.1	906.8	145.6	761.2	44.8	24.4	.8	28.2	8.8	19.4	.36	.1	.44	.56	2.76	.58	2.2	.05	.85		
22 II	10.7+	d.	"		358.8	254.8	104	21.2	14.8	3.3	9.7			.27	.36			.84			.02	.9	.016	1.024
1 III	11.4±	"	l.	.15	305.2	286.4	18.8	24	22.4	3.7	5.1			.148	.22			.36			.017	2.1		
8 III	11 −	"	"	.15	311.6	272.8	38.8	26.8	21.6	4	5.1			.2	.16			.28			.016	1		
15 III	12.1+	"	m.	.4	689.2	228.8	460.4	66	36.8	2.8	23.9	6.2	17.7	.2	.84	.28	.56	1.72	.52	1.2	.04	1.5		
22 III	14.1+	v. d.	v. m.	.5	2106	178.4	1927.6	164	22.8	1	72.1	.8	64.6	.136	3.36	.36	3	7.16	.68	6.48	.04	1.4		
29 III	16.5+	"	"	.8	1111.2	194.8	916.4	87.2	24	1.2	34.7	8.3	26.4	.12	1.76	.32	1.44	3.81	.61	3.2	.035	1.05	.124	1.116
5 IV	17.3−	d.	l.		254.4	220	34.4	30	25.6	4.1	9.5			.16	.44			.85			.05	1		
13 IV	14.5−	"	c.	.6	241.6	218.8	22.8	25.6	21.2	4	8.8			.06	.4			.85			.04	1		
19 IV	13.1−	"	l.		318	265.6	52.4	32	29.2	3.5	7.9			.044	.36			.77			.03	.55		
26 IV	12 −	"	c.		356.8	255.6	101.2	34.8	26.4	3.3	9.4			.022	.36			.85			.04	1.1		
3 V	11.1−	"	m.		433.2	238.4	194.8	44.8	19.4	3.2	11.2			.046	.44			.9			.035	.85		
10 V	10.3−	"	c.		344	237.2	106.8	37.2	27.6	3.8	7			.034	.28			.58			.035	1.2	.023	.737
17 V	10.1+	v. d.	v. m.		2662	178.4	2483.6	150	34	1.2	39	8.6	30.4	.12	1.44	.44	1	5.94	.86	5.08	.07	1.1		
24 V	13.6+	"	m.		734.4	184.8	549.6	64	31.2	2	25.9			.046	.96			1.86			.05	.9		
31 V	13.6−	"	v. m.	.5	1553.2	190.8	1362.8	74.4	19.2	1.7	48	6.5	41.5	.014	2.32	.32	2	5.14	.5	4.64	.07	1		
7 VI	12.5−	d.	c.	.05	378	320.8	57.2	50.8	42	3.1	6.5			.014	.22			.6			.065	.4	.096	.864
14 VI	11.9±	"	m.		929.6	222.8	706.8	57.6	29.2	2.4	9.3			.017	1.08			4.44			.06	.6		
21 VI	10.8−	"	c.	.03	778.4	317.2	461.2	454.8	32.8	3.3	5.3			.015	.24			.32			.03	1.3		
28 VI	10 −	v. d.	m.		676.8			30.8		2.6	18.5			.006	.64			1.4			.04	.75		
5 VII	8.7−	d.	l.	.05	342.4	302.8	39.6	20.8	20	3.2	4.5			.017	.24			1.16			.015	.5	.036	.684
12 VII	7 −	"	"	.08	298	244.8	53.2	15.2	12.8	3.2	6.6			.052	.6			1.08			.036	.25		
19 VII	4.7−	"	c.	.15	357.2	314.8	42.4	16.8	13.2	5.1	6.5			.062	.32			.8			.017	.2		
26 VII	2.9−	"	"		294.4	276.8	17.6	28	25.2	3.3	5.3			.082	.36			.6			.001	.1		
2 VIII	2.7+	"	"		326	280.8	45.2	14	12.8	3.5	5.8			.074	.32			.8			.02	.1	.002*	.398*
9 VIII	3.2+	"	m.		663.6	174	489.6	34	19.2	2.8	15			.082	.6			1.44			.135	.25		
16 VIII	3.7+	"	c.		263.2	212.8	50.4	24	22	3	7.3			.17	.28			.64			.1	.2		
23 VIII	4.2−	"	"	.1	320.4	227.6	92.8	25.2	22.8	2.7	7.6			.016	.28			.56			.003	.15		
30 VIII	3.9−	"	"		338	242	96	25.6	24	2.9	7.2			.014	.32			.6			.05	.15		
6 IX	4.7+	v. d.	v. m.		5846	168.9	5677.9	158	20.8	3.2	79			.096	3.6			8.32			.034	.4		
13 IX	4.2−	d.	c.		307	253.2	53.8	25.2	22	2.9	6.6			.026	.2			.48			.014	.2	.002*	1.518*
20 IX	4.2−	"	"	.03	329	236.8	92.2	22	22	3.1	6.6			.014	.24			.48			.028	.25		

TABLE XI. PART 2—*Continued.*

CHEMICAL DATA AND PLANKTON, SPOON RIVER, JANUARY, 1898, TO MAY, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.3 water—in cm.3	Vol silt per m.3 water—in cm.3
								Loss on Ignition						Free ammonia	Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter		Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1898-Cont.																								
27 IX	4.9+	d.	c.	.03	356.4	286.8	69.6	35.2	27.2	3.5	6	...	...	.016	.2		...	.56	...	...	.02	.6		
4 X	4 —	"	"	.05	345.2	318	27.2	29.2	26	3.5	4.3			.016	.16	...	...	.36	...	...	.005	.35	.001	.239
11 X	3.9+	"	l.	.1	327.6	298.4	29.2	32	27.2	3.2	4.6	...	...	.008	.2	...	...	.33	...	...	.008	.45	...	
18 X	3.8+	"	"	.05	326	312	14	32	31.2	3.5	4	...	...	.01	.144		...	.29	...	...	.004	.25		
25 X	4.3+	"	"	.1	318	304.8	13.2	28	24	4	3.8	...	...	.016	.144		...	.33	...	...	.005	.45		
1 XI	6.3+	"	c.	...	320.8	300	20.8	32.8	30	4.7	6.3	...	...	.042	.24		...	.49	...	...	.017	.3	.001*	.359*
8 XI	6.7±	"	l.	...	336.8	316	20.8	30	28	3.8	5.2	...	...	.036	.24		...	.35	...	...	.006	.6	...	
15 XI	7 +	"	"		328	309.2	18.8	30	27.2	4.2	5.5	...	...	.02	.208		...	.43	...	...	.014	.55	...	
22 XI	8.5+	"	"	.1	332	324	8	32	30	4.5	3.3	...	...	.012	.096			.33	...	...	.004	.65		
29 XI	8.3+	"	"	.03	335.2	332	3.2	46.4	42	3.5	2.8	...	...	.022	.128			.27	...	...	.007	.8		
6 XII	7.2	s.	"	.02	326.8	326	.8	40	36	3.9	2.2	...	...	.03	.09	...		.21	...		.007	.3	.001	.159
13 XII	6.7—	"	c.	.02	367.6	366.8	6.8	50.8	48.8	4.4	3	2.7	.3	.02	.078	.074	.004	.29	.21	.08	.004	.25	...	...
20 XII	5.9—	d.	"	.08	486.8	338.8	148	66	60	5.2	15.2	...	...	.008	.56			1.25	...	...	.03	.5		
27 XII	6.1+	"	"	...	330.8	240.8	90	48	40	5.8	27.1	...		.28	.88			1.81	...	...	.02	.25		...
Average, Jan. 4–June 28					704.9	224.8	480	67.7	24.2	3.2	20	9.5	26.8	.19	.794	.384	1.12	2.02	.69	2.68	.056	1.01	.055	1.081
" July 5–Dec. 27				...	558.5	281.1	277.4	32.3	27.4	3.7	9.6	2.7	.3	.047	.413	.074	.004	.93	.21	.08	.023	.34	.007	.526
" Jan. 4–Dec. 27				...	631.7	253	378.7	51.9	25.8	3.4	14.8	8.9	24.4	.119	.603	.355	1.018	1.47	.65	2.46	.039	.67	.029	.796
1899																								
3 I	6.8+	d.	l.	muddy	334.8	316.8	18	34	31.6	4.6	6.8	...	...	.14	.24	...		.49		...	.004	.55	.005	.515
10 I	7.9+	v. d.	v.m	f. .6 muddy	458.8	220.8	238	34	32	4	35.8	17	18.8	.56	1.12	.52	.6	2.29	1.09	1.2	.06	.35		
17	8.2+	d.	c.	f. .2 muddy	317.2	254.8	62.4	50	48	11	14	87	5.3	.72	.52	.304	.216	.97	.61	.36	.035	.85		
24 I	8.9+	"	"	f. .25 muddy	278.8	258.8	20	42	40	4.2	11.6			.492	.48			.77	...	...	.022	.45		
31 I	8 ±	"	l.	.25	326	316.8	9.2	54	44	14	9.6	...	...	.948	.44	...	...	.81	...	...	.026	.6		
7 II	7.3—	"	"	.15	363.2	360.8	2.4	58	54	4.1	3.3	...	...	.222	.112	...	...	.3	...	...	.009	1.5	.001	1.039
14 II	6.6—	"	"	.2	368	364.8	3.2	66	62	11.5	7.5	...	...	.692	.272	...	...	.66	...	...	.015	1.55	...	
21 II	5.5	"	"	.03	376.8	369.2	7.6	46	43.2	4.6	3	...	...	.13	.096	...	...	.276	...	...	.013	1		...
28 II	10.2+	v. d.	v.m. "	f. .1 muddy	763.2	112	651.2	74	36	1	29.8	16.3	13.5	.44	1.28	.52	.76	2.5	.86	1.64	.035	.6		
7 III	12.9±	"	"	f. .1 v. mud.	1080.8	150	930.8	132	44	1.6	46	18.7	27.3	.592	2.4	.56	1.84	5.54	1.34	4.2	.045	1	.026	5.094
14 III	13.1—	"	"	f. .4 v. mud.	1492	150	1342	128	41.6	6	38	15.8	22.4	.64	1.76	.384	1.376	3.38	.86	2.52	.05	1.1		
21 III	13.7+	"	"	f. .7 v. mud.	2922	108.2	2818.8	242	32	1	105.5	13	92.5	.56	4	.368	3.632	11.87	.55	11.32	.04	1.5		

TABLE XI. PART 2—*Concluded.*

CHEMICAL DATA AND PLANKTON, SPOON RIVER, JANUARY, 1898, TO MAY, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.3 water—in cm.3	Vol. silt per m.3 water—in cm.3
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1899-Cont. 28 III	13.5+	d.	m.	f. .03 muddy	328	254	74	34	30	3.8	9.8	......	......	.45	.4	......	......	.6	......	......	.022	1	......	......
9 V	7.9—	"	"	f. .1 muddy	442.8	244.8	198	39.6	27.2	3.4	17.5	8	3.5	.118	.44	.256	.184	1.05	.73	.32	.065	1.56	......	......
30 V	14 —	"	v.m	f. .06 muddy	1566.8	264	1302.8	103.6	47.6	2.1	35.5	7	28.5	.144	1.44	.224	1.216	3.45	.81	2.64	.046	1.64	......	......
Average, Jan. 3—May 30					761.3	249.4	511.9	75.8	40.9	5.1	24.9	22.9	26.5	.457	1	.392	1.228	2.337	.86	3.03	.032	1.02	.011	2.216
" Aug. 11, '96—May 30, '99					522.3	167.1	274.3	41.9	24.4	3.8	14.1	12.7	17.9	.245	.604	.359	1.133	1.292	.75	2.58	.039	1.01	.384	.969

TABLE XII.

CHEMICAL DATA AND PLANKTON, THOMPSON'S LAKE, SEPTEMBER, 1897, TO MARCH, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.3 water—in cm.3	Vol. silt per m.3 water—in cm.3
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1897 28 IX	2.00±	d.	c.	......	310.8	269.2	41.6	26.8	14.4	16	17	......	......	.01	1.08	......	......	1.9	......	......	.01	.07	10.00	1.36
19 X	2.00±	"	"	......	358.4	299.2	59.2	28.8	19.6	16	17.1	......	......	.29	.92	......	......	......	......	......	.06	.35	35.35	3.93
2 XI	2.50±	v. d.	m.	......	510	336.4	173.6	38.4	24.8	17	26	......	......	.04	1.32	......	......	1.9	......	......	.035	.9	20.58	2.54
16 XI	2.80±	d.	c.	......	406.8	285.2	121.6	34	20	17	17.9	......	......	.09	.92	......	......	1.82	......	......	.024	.8	22.95*	1.21*
30 XI	3.20—	"	"	......	350.8	318.8	32	40	18	20	13.3	......	......	.28	.64	......	......	1.25	......	......	.013	1.3	6.47	5.29
14 XII	3.40—	v. d.	m.	......	436	302.8	133.2	39.2	30.8	29	17.3	......	......	.32	.4	......	......	1.73	......	......	.13	1	8.02	1.42
28 XII	3.20±	d.	l.	.2	374	367.6	6.4	23.2	22.4	36	9.8	......	......	.72	.6	......	......	1.09	......	......	.04	1.1	5.94	1.30
Average, Sept. 28—Dec. 28					392.5	311.3	81	32.9	21.4	21	16.9	......	......	.25	.84	......	......	1.38	......	......	.044	.78	15.62	2.44
1898 11 I	3.70+	d.	c.	.2	270.8	256	14.8	23.6	14.8	26	8.7	......	......	.088	.6	......	......	1.16	......	......	.06	.5	......	......
25 I	6.40+	"	"	.2	311.2	301.2	10	21.2	18	28	8.7	......	......	.998	.64	......	......	1	......	......	.035	1.2	7.22	.46
8 II	7.10+	"	l.	.6	306.4	......	......	40	......	18	11.6	......	......	2.2	.44	......	......	.92	......	......	.15	1.3	.64	.16
22 II	10.50+	"	"	.6	286	272.4	13.6	32.8	29.2	15	11.2	......	......	1.16	.52	......	......	1	......	......	.04	.8	.64	.32
8 III	11.00—	"	"	.6	266.8	263.2	3.6	33.6	30	8	8.7	......	......	.56	.36	......	......	.84	......	......	.03	1.5	.60	.08
22 III	13.90+	"	"	......	279.2	230.8	48.4	32	24.8	7	10.6	......	......	.4	.4	......	......	.8	......	......	.045	1.2	.79	.09
25 IV	17.40—	"	c.	......	262.8	223.6	39.2	29.6	26	6	13.2	......	......	.168	.4	......	......	.85	......	......	.05	1	.45	.19

TABLE XII.—*Concluded.*

CHEMICAL DATA AND PLANKTON, THOMPSON'S LAKE, SEPTEMBER, 1897, TO MARCH, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.3 water—in cm.3	Vol. silt per m.3 water—in cm.3
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Loss on Ignition			Total	By dissolved	By suspended matter	Free ammonia	Albuminoid Ammonia			Total	Dissolved	Suspend'd	Nitrites	Nitrates		
								Total	Dissolved						Total	Dissolved	Suspended							
1898-Cont.																								
19 IV	13.30−	d.	l.	.9	240	223.2	16.8	34	32.8	5	11	......	......	.16	.44	......	......	.93	......	......	.04	.5	4.42	.78
3 V	11.20±	"	"	.3	273.2	267.2	6	37.2	36.4	9	9.4	......	......	.112	.52	......	......	1.06	......	......	.045	.4	51.39	1.05
11 V	10.20+	s.	"	.1	304	282.4	21.6	54	53.2	10	12.5	......	......	.088	.64	......	......	1.46	......	......	.045	.5	14.98	.62
24 V	13.50+	d.	"	.4	268	256.1	11.9	36	34	10	10.8	......	......	.16	.48	......	......	1.06	......	......	.055	.5	11.44	.35
7 VI	12.60−	"	"	.04	279.6	256.4	23.2	39.6	20	6	8	......	......	.24	.32	......	......	.64	......	......	.22	.25	18.39	.77
21 VI	10.85	s.	"	.02	251.2	......		24	......	10	8.6	......	......	.12	.4	......	......	.96	......	......	.09	.65	2.47	.08
5 VII	8.80−	d.	"	.3	288	240.4	47.6	22	18.4	13	8.1	......	......	.16	.44	......	......	1	......	......	.06	.25	.81	1.51
19 VII	4.90−	"	c.	.2	312.8	274.8	38	16.8	14.8	15	9	......	......	.12	.44	......	......	.88	......	......	.003	.15	3.35	.73
2 VIII	2.60±	"	"	......	324.4	280.4	44	16	15.2	16	13.3	......	......	.002	.64	......	......	1.2	......	......	None	.3	2.28	2.28
16 VIII	3.45+	"	"	......	355.6	298.4	57.2	40	29.2	20	12.5	......	......	.24	.64	......	......	1.12	......	......	.01	.25	.45	4.03
30 VIII	4.00−	"	"	......	333.2	307.2	26	22.4	22	25	9.2	......	......	.146	.52	......	......	.88	......	......	.001	.05	5.16	.16
13 IX	4.35−	"	"	......	314	280	34	32	23.6	24	9.2	......	......	.2	.44	......	......	.88	......	......	.015	.1	2.66	.66
27 IX	4.90+	"	"	......	285.2	265.2	20	34.8	32	23	8.5	......	......	.16	.52	......	......	.96	......	......	.002	.2	2.65	.79
11 X	3.90+	"	"	......	366.8	262.8	104	34	20.8	20	11.7	......	......	.072	.52	......	......	.97	......	......	.005	.25	.93	2.79
25 X	4.30+	"	"	.1	312	270.8	41.2	28	16.8	22	8.5	......	......	.122	.4	......	......	.77	......	......	.23	.25	1.56	.76
8 XI	6.70±	"	"	......	344	320	24	34	32	28	7	......	......	.64	.4	......	......	.71	......	......	.045	.7	1.55	.29
22 XI	8.40+	"	"	......	357.6	332	25.6	40.8	36	24	7.2	......	......	.24	.36	......	......	.67	......	......	.02	.5	.79	.53
6 XII	7.30−	"	l.	.1	372	366	6	44.8	34	16	8	......	......	.44	.35	......	......	.81	......	......	.04	.15	4.58	.14
20 XII	6.00−	"	c.	.15	350.8	350	.8	50	48	17	9	......	......	.16	.56	......	......	.97	......	......	.02	.35	2.58	.14
Average, Jan. 11—June 21					276.8	257.5	19.3	33.6	29	12	10	......	......	.496	.47	......	......	.97	......	......	.069	.79	9.45	.41
" July 5—Dec. 20					332	296.8	35.2	31.9	26.3	20	9.3	......	......	.207	.47	......	......	.91	......	......	.037	.26	2.26	1.14
" Jan. 11—Dec. 20					304.4	278.7	25.7	32.8	27.5	16	9.7	......	......	.352	.47	......	......	.94	......	......	.054	.53	5.71	.79
1899																								
3 I	6.8 +	d.	l.	.07	394.8	382.2	12.6	56	42	20	9.4	......	......	.16	.52	......	......	1.05	......	......	.018	.3	3.61	.23
17 I	8.2 +	"	c.	f. .15 muddy	327.2	312.8	14.4	52	50	17	11	......	......	1.32	.4	......	......	.97	......	......	.033	.8	.94	.10
31 I	8 ±	"	"	f. .2 muddy	302.8	274.8	28	54	42	12	12	......	......	.922	.44	......	......	.89	......	......	.03	.8	.37	.55
14 II	6.6 −	"	l.	.3	348	339.6	8.4	54	53.6	15	11.5	......	......	1.08	.432	......	......	1.02	......	......	.03	1.7	1.54	.38
28 II	10.2 +	v. d.	v.m.	f. .5 muddy	348.8	202	146.8	58	40	13	19.5	9.7	9.8	1.28	.64	.32	.32	1.54	.54	1	.04	.5	1.63	.29
14 III	13.1 −	d.	m.	f. .5 muddy	366	156	210	50	38	6.8	23.2	11.3	11.9	.68	.8	.352	.448	1.7	.58	1.12	.025	.9	.36	.24
28 III	13.5 +	"	"	f. .4 muddy	305	214.8	90.2	52	42	5.5	17	......	......	.52	.52	......	......	1.23	......	......	.035	1.4	.05	.43
Average, Jan. 3—Mar. 28					341.8	268.9	72.9	53.7	43.9	12.8	14.8	10.5	10.9	.852	.536	.336	.384	1.2	.56	1.06	.03	.9	1.21	.32
" Sept. 28, '97—Mar. 28, '99					326.4	282.9	44.6	36.5	28.3	16.3	11.9	10.5	10.9	.422	.546	.336	.384	1.05	.56	1.06	.048	.64	6.68	1

TABLE XIII.

Chemical Data and Plankton, Quiver Lake, September to December, 1895; October, 1897, to March 28, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.^{3} water—in cm.^{3}	Vol. silt per m.^{3} water—in cm.^{3}
								Loss on Ignition							Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1895																								
24 IX	2.67—	d.	c.		284.2			21.6		2.1	2.45			.122	.118						.02	.399	.31 *	.71 *
1 X	2.75—	s.			254.6			29.2		2.45	2.15			.08	.132						.001	.28		
8 X	2.20±		l.		249.6			20		1.8	1.6			.03	.056							.12		
15 X	2.20+		"		256.6			14.8		2.2	1.4			.024	.088							.22	.13 *	.38 *
23 X	2.35±				244.2			15.4		2	1.5			.016	.06							.84		
29 X	2.30—		l.		250			5.2		1.75	1.25			.02	.082							.2		
5 XI	2.30+	s.	"		234			25.2		2.3	1.6			.03	.144							.14		
11 XI	2.67+				242.2			22.2		2.3	1.25			.014	.064						.001	.42	.05 *	.46 *
19 XI	2.75+		l.		236			22		1.9	1.35			.036	.096						.004	.28		
27 XI	2.85—	s.	"		226.4			6.4		1.8	1.1			.008	.062						.002	.3		
3 XII	3.20+	"	"		306.6			7.2		2.5	1.6			.008	.072						.02	2.8	.63 *	1.89 *
Average, Sept. 24—Dec. 3					253.1			17.2		2.1	1.57			.035	.089						.008	.477	.28	.86
1897																								
19 X	2 ±	d.	l.	.08	238.8	233.2	5.6	17.2	16	1.9	4.9			.056	.56						.01	.4	.01	.31
2 XI	2.50±	"	"	.13	250.8	238.8	12	24	24	2	4.6			.012	.16			.48			.006	.7	.11	1.01
16 XI	2.80±	"	"	.04	245.2	241.2	4	17.2	16.4	1.8	2.6			.032	.208			.26			.015	.55	.09*	1.63 *
30 XI	3.20—	s.	"	.04	250	250		21.6	12	1.8	2.5			.02	.056			.21			.004	.9	.06	6.34
14 XII	3.40—	d.	"	.06	254.8	226.8	28	19.2	17.6	2	3.3			.028	.09			.33			.03	.8	.01	.35
28 XII	3.20±	s.	v. l.	.03	245.2	241.2	4	23.2	20.8	2.7	2.3			.032	.046			.25			.01	.85	.003	.157
Average, Oct. 19—Dec. 28					247.4	238.5	8.9	20.4	17.8	2	3.3			.03	.186			.31			.012	.7	.047	1.633
1898																								
11 I	3.20±	d.	c.	.2	229.2	214	15.2	22.4	20	1.8	2.7			.04	.2			.24			.018	1.1	.003	.277
25 I	6.80+	"	"	.4	273.2	264	9.2	32.8	32	7	5.8			.536	.24			.68			.105	2.75	.04	.4
8 II	7.10—	"	l.	.5	314	291.2	22.8	36	29.2	12	8.3			1.2	.4			.64			.11	2.5	.03	.21
22 II	10.07+	"	"	.6	262.8	254.8	8	24	22	9.1	9			.504	.44			1.08			.03	1	.58	.1
8 III	11.06—	"	"	.4	258	256.4	1.6	30	28	7	7.9			.36	.36			.64			.04	1	.81	.27
22 III	14.10+	"	"	.5	246	241.2	4.8	26	24.8	4.3	7.6			.112	.28			.6			.075	1.45	.67	.29
5 IV	17.30—	"	c.		310.4	206	104.4	30	22	1.8	14.1			.024	.6			1.09			.044	1.75	.03	1.57
19 IV	13.10—	"	l.	.7	240.4	239.6	.8	26	25.6	4.3	8.8			.046	.44			1.61			.033	.65	1.03	.51
3 V	11.10—	"	"	.2	244.4	240.4	4	38.4	32.8	6	8.1			.092	.32			.82			.022	.35	42.14	.86
11 V	10.10—	s.	"	.06	277.6	274.4	3.2	42.4	36	6.8	8.8			.05	.48			.98			.015	.4	4.70	.14
24 V	13.60+	d.	c.		264	237.6	26.4	20	17.6	4.4	11			.106	.5			.9			.05	.8	1.97	.35
7 VI	12.50—	"	l.	.03	286.4	258	28.4	59.2	34.8	5.5	7.6			.036	.24			.52			.12	.4	3.08	3.08
21 VI	10.80—	s.	"	.05	276	268.4	7.6	28	16	6.6	7.2			.015	.24			.6			.02	.35	1.37	.15

TABLE XIII.—*Concluded.*

CHEMICAL DATA AND PLANKTON, QUIVER LAKE, SEPTEMBER TO DECEMBER, 1895: OCTOBER, 1897, TO MARCH 28, 1899.

(Parts per million.)

Date	Stage of river	APPEARANCE			RESIDUE ON EVAPORATION					Chlorine	OXYGEN CONSUMED			NITROGEN AS AMMONIA				ORGANIC NITROGEN			NITROGEN AS		Vol. plankton per m.³ water—in cm.³	Vol. silt per m.³ water—in cm.³
								Loss on Ignition							Albuminoid Ammonia									
		Turbidity	Sediment	Color	Total	Dissolved	Suspend'd	Total	Dissolved		Total	By dissolved	By suspended matter	Free ammonia	Total	Dissolved	Suspended	Total	Dissolved	Suspend'd	Nitrites	Nitrates		
1898-Cont.																								
5 VII	8.70—	d.	l.	.04	284.8	258.8	26	22.4	12	9.6	8.1			.05	.4			.72			.01	.15	.09	.35
19 VII	4.07—	"	"	.04	250.8	244	6.8	16	14	4.9	7			.01	.32			.48			.008	.2	.22	.1
2 VIII	2.70+	s.	"	.03	240.8	240	.8	12	11.6	2.3	3.3			.018	.1			.2			.004	.25	.07	.17
16 VIII	3.70+	d.	"	.04	241.2	226	15.2	18	18	2	3			.016	.134			.28			.007	.15	.19	.29
30 VIII	3.90—	s.	"	.03	237.2	231.6	5.6	17.2	16	2.3	3.3			.01	.144			.36			.002	.1	.41	.27
13 IX	4.20—	d.	"	.03	248.8	246.8	2	24	23.2	2.1	3.4			.02	.09			.272			.003	.15	.18	.1
27 IX	4.90+	"	"	.04	260	256.8	3.2	26	25.2	2.1	3.5			.04	.222			.4			.008	.25	.48	.2
11 X	3.90+	s.	"	.04	264	252.8	11.2	26.4	24	1.8	3			.032	.112			.21			.005	.2	.21	.07
25 X	4.30+	"	"	.05	268.8	260	8.8	24	22	2.8	2.8			.018	.068			.25			.009	.3	.24*	.16*
8 XI	6.70+	d.	"	.06	279.2	274	5.2	31.2	26	4.5	4.2			.03	.196			.39			.004	.5	.75	.33
22 XI	8.50+	"	"	.1	295.6	294	1.6	33.6	32	8.5	6.6			.146	.36			.63			.016	.6	.71	.13
6 XII	7.20—	s.	"	.05	332	326.8	5.2	40	34	13	7			.062	.304			.69			.009	.2	2.02	.06
20 XII	5.90—	"	"	.03	242	238	4	28	27.2	3	2.2			.02	.062			.114			.002	.15	1.46	.06
Average, Jan. 11—June 21					267.8	249.6	18.2	39.6	26.2	5.8	8.2			.24	.364			.753			.052	1.115	4.19	.63
" July 5—Dec. 20					265	257.6	7.4	24.5	21.9	4.5	4.4			.036	.193			.384			.006	.246	.54	.18
" Jan. 11—Dec. 20					266.4	253.6	12.8	28.2	24.1	5.2	6.3			.138	.275			.569			.029	.68	2.44	.40
1899																								
3 I	6.8 +	s.	l.	.05	254.8	254	.8	34	30.4	6.5	5.3			.36	.216			.45			.011	.05	.74	.06
17 I	8.2 +	d.	c.	f. .25 muddy	316.8	263.2	53.6	46	41.2	8.8	12.8			.774	.52			1.01			.03	.8	.97	.03
31 I	8 ±	"	"	"	290	266.8	23.2	44	40	11	9.8			.85	.44			.81			.02	.85	.61	2.43
14 II	6.6 —	s.	l.	.04	308.8	304	4.8	40	36	5.6	13.5			.022	.12			.26			.003	.8	1.84	.04
28 II	10.2 +	v. d.	v.m.	f. .4 muddy	492.8	192	300.8	74	44	10	23			1	.96	.44	.52	2.1	.7	1.4	.035	.6	.26	.26
14 III	13.1 —	d.	m.	f. .6 muddy	312	159.6	152.4	50	40.8	5.6	18	12.5	5.5	.6	.64	.288	.352	1.46	.74	.72	.035	.95	.14	.18
28 III	13.5 +	"	"	"	274	217.2	56.8	40	32	4.6	13.3			.476	.4			.92			.017	2	.16	.04
Average, Jan. 3—March 28					321.3	236.7	84.6	46.9	37.8	7.4	13.7	12.5	5.5	.583	.471	.364	.436	1	.72	1.06	.022	.86	.67	.43
					268.9	248.2	25.1	27.5	25.6	4.8	5.9	12.5	5.5	.165	.251	.364	.436	.61	.72	1.06	.023	.66	1.62	.62

TABLE XIV.

RELATIVE NUMBER OF PLANKTONTS IN ILLINOIS RIVER AND SPOON RIVER.

Date	ALGÆ		DIATOMS		RHIZOPODA		MASTIGOPHORA		INFUSORIA	
	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon
1896										
18 VIII	83, 200	6, 080	8, 896, 000	11, 280	28, 800	5, 960	1, 508, 000	3, 360	23, 800	3, 540
25 VIII	4, 840	576	1, 025, 200	29, 376	18, 080	768	110, 000	960	11, 200	192
16 IX	5, 446	1, 200	350, 489	3, 360	16, 850	2, 880	75, 845	....	40, 106	240
30 IX	10, 840	....	682, 200	6, 240	14, 280	8, 160	175, 000	....	27, 672	2, 400
14 X	4, 560	2, 160	816, 400	10, 080	30, 400	2. 640	1, 111, 200	480	65, 200	1, 200
29 X	....	480	....	19, 200	....	5, 280	....	480	....	1, 920
17 XI	2, 800	480	1, 064, 500	480	25, 200	3, 360	88, 800	480	44, 000	7, 200
3 XII	396	480	963, 916	7, 200	873	500	179, 606	240	10, 083	480
28 XII	3, 280	....	165, 960	....	120	480	64, 880	120	1, 440	240
Average	14, 420	1, 495	1, 745, 583	9, 688	16. 825	3, 336	414, 166	680	27, 938	1, 935
1897										
3 II	40	....	231, 900	240	300	720	42, 420	160	3, 400	....
26 II	....	....	339, 480	....	10, 700	37, 440	46, 600	3, 840	18, 800	2, 880
22 III	2, 700	....	1, 231, 900	240, 000	2, 240	105, 600	172, 100	9, 600	18, 240	19, 200
27 IV	1, 600	....	328, 414, 320	102, 000	11, 520	379, 200	27, 987, 400	....	515, 920	42, 000
25 V	68, 400	7, 500	79, 827, 200	3, 048, 000	25, 760	40, 900	9, 029, 360	43, 200	29, 600	98, 400
28 VI	49, 000	2, 500	1, 937, 600	85, 200	232, 600	13, 200	148, 006	3, 700	12, 186, 000	1, 300
10 VIII	74, 680	3, 800	2, 318, 160	54, 000	8, 400	1, 200	439, 600	18, 000	27, 600	....
26 VIII	166, 760	24, 000	847, 320	4, 800	19, 200	....	408, 160	53, 000	180, 000	5, 000
11 IX	406, 400	816, 000	282, 440	662, 400	118, 000	28, 800	1, 624, 800	5, 030, 400	12, 000	249, 600
2 XI	28. 980	145, 000	148, 880	744, 000	3, 900	2, 400	1, 100	33, 600	26, 500	55, 200
30 XI	940	....	90, 725	24, 000	800	....	11, 100	116, 400	244, 420	4, 900
28 XII	1, 200	3, 600	65, 400	36, 000	16, 640	....	15, 400	54, 000	45, 600	19, 200
Average	66, 725	85, 534	34, 644, 610	416, 920	37, 505	50, 788	3, 577, 171	447, 158	1, 109, 007	41, 473
1898										
25 I	387	....	174, 901	16, 800	66. 338	19, 200	22, 059	2, 400	190, 017	39, 000
22 II	3, 159	....	211, 653	4, 800	141, 524	21, 600	227, 448	....	69, 498	14, 400
29 III	5, 400	....	132, 140	27, 320	1, 400	1, 760	324, 800	640	42, 020	18, 880
10 V	68, 800	6, 240	314, 224, 400	1, 778, 400	49, 800	14, 880	84, 967, 600	55, 680	129, 600	11, 520
7 VI	17, 200	2, 400	30, 803, 600	31, 200	23, 600	21, 600	597, 000	7, 400	1, 516, 000	63, 600
5 VII	50, 040	18, 000	3, 772, 000	7, 200	19, 360	10, 800	536, 800	51, 600	20, 440	108, 000
5 VIII	308, 040	16, 800	360, 240	50, 400	16, 800	14, 400	252, 400	112, 800	129, 600	3, 600
12 IX	57, 060	3, 700	1, 217, 000	8, 400	28, 000	22. 800	19, 500	2, 400	56, 640	6, 000
4 X	25, 000	1, 440	837, 200	37, 440	12, 580	4, 840	265, 600	16, 800	35, 900	1, 440
2 XI	18. 500	5. 500	981, 000	15, 000	32, 060	2, 500	5, 500	3. 600	69, 060	16, 800
6 XII	520	....	251, 250	9, 120	1, 000	480	1, 708, 000	4, 320	7, 620	3. 480
Average	50, 373	4, 916	32, 087, 762	180, 553	35, 678	12, 260	8. 084, 246	23, 422	206, 036	26, 065
1899										
3 I	20	....	10, 300	3, 840	220	960	143, 020	3, 360	108, 940	1, 920
7 II	....	....	66, 750	....	1, 125	1. 200	117, 000	7, 200	6, 000	1, 200
7 III	140	....	59, 120	800	3, 200	38, 400	899, 200	....	30, 820	....
Average	53	....	45, 390	1, 547	1, 515	13. 520	386, 407	3, 520	48, 586	1, 040
Grand Av....	43, 539	30, 513	23, 031, 820	293, 788	289, 637	23. 281	3, 921, 328	161, 149	468, 051	22, 999
Ratio	1.4	1	78	1	12	1	24	1	20	1

TABLE XIV.—*Concluded.*

RELATIVE NUMBER OF PLANKTONTS IN ILLINOIS RIVER AND SPOON RIVER.

Date	ROTATORIA		ENTOMOSTRACA		INSECT LARVÆ		MISCELLANEOUS		TOTAL SPECIES		TOTAL PLANKTONTS	
	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon	Illinois	Spoon
1896												
18 VIII	361,680	2,720	68,160	600	160	240	4,120	680	114	71	10,973,920	34,460
25 VIII	185,720	768	31,480	360	80	1,488	1,520	216	100	22	1,388,120	34,704
16 IX	45,592	3,600	63,070	3,360	.....	240	2,607	240	85	19	600,005	14,520
30 IX	48,642	960	16,400	560	...	280	2,400	1,480	85	20	977,434	20,080
14 X	131,600	3,560	9,120	480	320	80	4,640	240	68	22	2,173,440	20,920
29 X	....	480	....	2,560	.. ..	240	....	40	....	23	....	30,680
17 XI	172,800	2,880	4,920	40	80	80	5,360	2,880	63	20	5,408,460	17,880
3 XII	86,700	840	9,340	..	....	80	1,665	....	56	12	1,252,579	9,820
28 XII	100,340	240	26,140	130	40	30	520	120	42	9	362,720	1,360
Average	141,634	1,561	28,539	899	85	309	2,854	655	77	24	2,892,085	20,492
1897												
3 II	10,460	500	3,520	60	...	40	1,040	....	44	10	293,080	1,720
26 II	26,200	2,880	2,100	480	..	..	6,400	5,280	45	16	450,280	52,800
22 III	47,180	20,000	21,320	9,600	440	. .	2,080	19,200	81	11	1,498,200	423,200
27 IV	1,276,000	34,800	67,000	4,200	320	600	4,000	28,800	67	20	358,278,080	591,600
25 V	2,287,160	217,400	84,720	600	..	2,100	10,240	2,500	90	36	91,362,440	3,460,600
28 VI	351,900	27,900	22,700	1,900	100	800	40,900	200	71	33	14,968,406	136,700
10 VIII	658,120	15,300	116,100	700	160	400	24,400	...	102	33	3,667,220	93,400
26 VIII	2,059,360	1,330,200	86,240	600	..	400	15,760	...	80	32	3,782,800	1,418,000
11 IX	1,744,250	2,362,400	618,750	10,000	..	4,000	26,000	......	62	49	4,832,640	11,467,600
2 XI	8,900	1,072,800	19,500	7,900		100	1,900	.	65	29	239,660	2,061,000
30 XI	109,840	1,965,600	55,340	600	.....	....	7,000	2,400	46	19	520,165	2,113,900
28 XII	9,040	1,135,200	5,720	10,800	.	. .	1,760	....	48	13	160,760	1,258,800
Average	715,701	682,082	91,918	3,987	85	703	11,757	4,898	67	25	40,004,478	1,923,277
1898												
25 I	126,603	2,600	4,788	600	77	....	7,661	5,000	74	18	592,831	85,600
22 II	48,649	800	3,285	.....	....	....	3,285	200	35	9	708,501	41,800
29 III	115,880	17,920	22,180	3,160	80	.	1,940	720	100	31	645,840	70,400
10 V	2,663,400	24,480	235,400	2,800	400	400	13,200	960	78	40	402,352,600	1,895,360
7 VI	903,000	22,900	438,800	14,700	400	2,100	23,600	. .	67	31	34,323,200	165,900
5 VII	153,000	8,400	4,920	1,200	760	3,700	5,040	200	96	23	4,562,360	209,100
5 VIII	1,294,240	61,200	22,160	. ..	80	2,000	3,360	....	81	41	2,386,920	261,200
12 IX	197,960	2,400	24,720	100	.....	1,400	2,420	1,500	89	20	1,603,300	48,700
4 X	105,020	2,880	33,880	....	40	160	2,700	.....	79	24	1,287,720	65,000
2 XI	156,300	9,600	8,600	100	....	....	4,360	200	75	24	1,275,380	53,300
6 XII	64,280	7,280	9,740	120	....	....	680	...	40	17	2,043,090	24,800
Average	529,848	14,587	73,498	2,089	167	887	6,204	798	74	25	41,071,067	265,560
1899												
3 I	41,300	6,720	2,840	40	....	....	2,640	......	47	18	309,280	16,840
7 II	112,310	....	13,976	600	....	600	861		29	6	318,022	10,800
7 III	108,860	800	18,500	. .	....	.....	2,140	12,000	47	6	1,121,980	52,000
Average	87,490	2,507	11,772	213	...	200	....	.....	41	10	583,094	26,547
Grand Av...	465,067	238,828	63,983	2,255	104	616	6,805	2,430	69	24	28,283,295	750,429
Ratio....	1.9	1	28	1	.17	1	2.8	1	2.9	1	38	1

TABLE XV.

Solids in Suspension at Station E, Berkefeld Filter.

Accession number	Date	Cu. cm. strained	Cu. cm. silt	Silt per cu. m.	River gage
22631	9, XI, 1897	5,000	1.40	280	2.6
22634	15, XI, 1897	10,000	1.53	153	2.8
22635	23, XI, 1897	5,000	1.50	300	2.8
22638	30, XI, 1897	5,000	2.75	550	3.2
22643	7, XII, 1897	5,000	6.56	1,312	3
22641	14, XII, 1897	5,000	1.28	256	3.4
22644	21, XII, 1897	5,000	5.26	1,052	3.2
22647	28, XII, 1897	5,000	.93	186	3.2
22649	11, I, 1898	5,000	4.25	850	3.7
22651	21, I, 1898	5,000	7.60	1,520	5.8
22654	25, I, 1898	5,000	5.01	1,002	6.8
22656	3, II, 1898	5,000	4.00	800	7.4
22658	8, II, 1898	5,000	2.71	542	7.1
22660	15, II, 1898	5,000	7.86	1,572	9
22663	22, II, 1898	5,000	8.01	1,602	10.7
22665	1, III, 1898	5,000	3.60	720	11.4
22669	8, III, 1898	5,000	2.51	502	11
22671	15, III, 1898	5,000	3.71	742	12.1
22674	22, III, 1898	5,000	2.34	468	14.1
22676	29, III, 1898	5,100	4.90	961	16.5
22680	4, IV, 1898	5,000	3.91	782	17.6
22682	12, IV, 1898	5,000	4.40	880	14.8
22685	19, IV, 1898	5,000	1.81	362	13.1
22693	26, IV, 1898	5,000	2.04	408	12
22696	3, V, 1898	5,000	2.07	414	11.1
22697	10, V, 1898	5,000	2.29	458	10.3
22702	17, V, 1898	5,000	3.97	794	10.1
22705	24, V, 1898	5,000	3.01	602	13.6
22711	31, V, 1898	5,000	2.11	422	13.6
22715	7, VI, 1898	5,000	1.98	396	12.5
22716	14, VI, 1898	5,000	1.43	286	11.9
22721	21, VI, 1898	5,000	1.27	254	10.8
22723	28, VI, 1898	5,000	2.80	560	10
22725	5, VII, 1898	5,000	1.90	380	8.7
22730	12, VII, 1898	5,000	1.94	388	7
22733	19, VII, 1898	5,000	2.04	408	4.7
22737	26, VII, 1898	5,000	1.56	312	2.9
22749	2, VIII, 1898	5,000	1.58	316	2.7
22763	9, VIII, 1898	5,000	2.58	516	3.2
22765	16, VIII, 1898	5,000	1.69	338	3.7
22768	23, VIII, 1898	5,000	3.08	616	4.2
22770	30, VIII, 1898	5,000	2.42	484	3.9
22773	6, IX, 1898	5,000	2.90	580	4.7
22777	13, IX, 1898	5,000	2.54	508	4.2
22780	20, IX, 1898	5,000	2.40	480	4.2
22782	27, IX, 1898	5,000	....	....	4.9
22785	4, X, 1898	5,000	2.30	460	4
22788	11, X, 1898	5,000	1.70	340	3.9
22791	18, X, 1898	5,000	1.26	252	3.8
22793	25, X, 1898	5,000	4.00	800	4.3
22795	1, XI, 1898	5,000	3.20	640	6.3
22799	8, XI, 1898	5,000	2.77	554	6.7
22802	15, XI, 1898	5,000	4.41	882	7.1
22804	22, XI, 1898	5,000	5.82	1,164	8.5
22807	29, XI, 1898	5,000	1.48	296	8.3
22809	6, XII, 1898	5,000	.74	148	7.2
22813	13, XII, 1898	5,000	3.74	748	6.7
22814	15, XII, 1898	5,000	1.17	234	6.6
22816	20, XII, 1898	5,000	1.04	208	5.9
22819	27, XII, 1898	5,000	1.26	252	6.1
22821	3, I, 1899	5,000	4.20	840	6.8
22826	10, I, 1899	5,000	3.75	750	7.9
22828	17, I, 1899	5,000	6.30	1,260	8.2
22831	24, I, 1899	5,000	4.06	812	8.9
22833	31, I, 1899	5,000	3.06	612	8
22835	1, II, 1899	5,000	3.42	684	8
22838	7, II, 1899	5,000	1.15	230	7.3
22841	14, II, 1899	5,000	1.42	284	6.6
22845	21, II, 1899	5,000	1.80	360	5.5
22847	28, II, 1899	5,000	27.08	5,416	10.2
22850	7, III, 1899	5,000	20.30	4,060	12.9
22853	14, III, 1899	5,000	17.40	3,480	13.1
22856	21, III, 1899	5,000	16.82	3,364	13.7
22858	28, III, 1899	5,000	9.35	1,870	13.5
Average for 1898				592.22	

TABLE XV.—*Continued.*

SOLIDS IN SUSPENSION AT STATION M, BERKEFELD FILTER.

Accession number	Date	Cu. cm. strained	Cu. cm. silt	Silt per cu. m.	River gage
22639	30, XI, 1897	5,000	1.57	314	3.2
22648	28, XII, 1897	5,000	1.20	240	3.2
22655	25, I, 1898	5,000	13.11	2,622	6.8
22664	22, II, 1898	5,000	5.64	1,128	10.7
22677	29, III, 1898	2,500	25.11	10,044	16.5
22698	10, V, 1898	5,000	5.10	1,020	10.3
22712	7, VI, 1898	5,000	3.38	676	12.5
22727	5, VII, 1898	5,000	1.63	326	8.7
22761	5, VIII, 1898	5,000	3.58	716	2.8
22775	12, IX, 1898	5,000	6.62	1,324	4.4
22786	4, X, 1898	5,000	2.20	440	4
22797	2, XI, 1898	5,000	2.92	584	6.5
22811	6, XII, 1898	1,900	.61	321	7.2
22823	3, I, 1899	5,000	2.56	512	6.8
22839	7, II, 1899	5,000	.94	188	7.3
22851	7, III, 1899	5,000	40.35	8,070	12.9
Average for 1898				1,745.55	

TABLE XV.—*Continued.*

SOLIDS IN SUSPENSION AT STATION C, BERKEFELD FILTER.

Accession number	Date	Cu. cm. strained	Cu. cm. silt	Silt per cu. m.	River gage
22633	15, XI, 1897	10,000	.98	98	2.8
22637	30, XI, 1897	5,000	1.47	294	3.2
22642	14, XII, 1897	5,000	1.50	300	3.4
22646	28, XII, 1897	5,006	.58	116	3.2
22650	11, I, 1898	5,000	3.31	662	3.7
22652	25, I, 1898	5,000	2.71	542	6.8
22659	8, II, 1898	5,000	2.24	448	7.1
22662	22, II, 1898	5,000	2.80	560	10.7
22668	8, III, 1898	5,000	2.04	408	11
22673	22, III, 1898	5,000	1.66	332	14.1
22679	4, IV, 1898	5,000	9.38	1,876	17.6
22684	19, IV, 1898	5,000	2.68	536	13.1
22695	3, V, 1898	5,000	1.63	326	11.1
22700	11, V, 1898	5,000	1.10	220	10.1
22704	24, V, 1898	5,000	1.58	316	13.6
22714	7, VI, 1898	5,000	1.02	204	12.5
22720	21, VI, 1898	5,000	.84	168	10.8
22726	5, VII, 1898	5,000	.40	80	8.7
22734	19, VII, 1898	5,000	1.10	220	4.7
22748	2, VIII, 1898	5,000	1.03	206	2.7
22766	16, VIII, 1898	5,000	1.65	330	3.7
22771	30, VIII, 1898	5,000	2.01	402	3.9
22778	13, IX, 1898	5,000	1.85	370	4.2
22783	27, IX, 1898	5,000	1.62	324	4.9
22789	11, X, 1898	5,000	1.06	212	3.9
22794	25, X, 1898	5,000	.89	178	4.3
22800	8, XI, 1898	5,000	1.14	228	6.7
22805	22, XI, 1898	5,000	1.75	350	8.5
22810	6, XII, 1898	5,000	.93	186	7.2
22817	20, XII, 1898	5,000	.78	156	5.9
22822	3, I, 1899	5,000	1.66	332	6.8
22829	17, I, 1899	5,000	5.48	1,096	8.2
22834	31, I, 1899	5,000	3.06	612	8
22836	1, II, 1899	5,000	2.15	430	8
22842	14, II, 1899	5,000	1.12	224	6.6
22848	28, II, 1899	5,000	19.78	3,956	10.2
22854	14, III, 1899	5,000	12.99	2,598	13.1
22859	28, III, 1899	5,000	8.82	1,764	13.5
Average for 1898				378.46	

TABLE XV.—*Continued.*

SOLIDS IN SUSPENSION AT STATION G, BERKEFELD FILTER.

Accession number	Date	Cu. cm. strained	Cu. cm. silt	Silt per cu. m.	River gage
22632	15, XI, 1897	5,000	7.85	1,570	2.8
22636	30, XI, 1897	5,000	5.36	1,072	3.2
22640	14, XII, 1897	5,000	7.50	1,500	3.4
22645	28, XII, 1897	5,000	1.41	282	3.2
22653	25, I, 1898	5,000	2.10	420	6.8
22657	8, II, 1898	5,000	2.26	452	7.1
22661	22, II, 1898	5,000	1.92	384	10.7
22667	8, III, 1898	5,000	3.23	646	11
22672	22, III, 1898	5,000	4.01	802	14.1
22678	4, IV, 1898	5,000	4.68	936	17.6
22683	19, IV, 1898	5,000	3.18	636	13.1
22694	3, V, 1898	5,000	1.66	332	11.1
22699	11, V, 1898	5,000	1.37	274	10.1
22703	24, V, 1898	5,000	3.10	620	13.6
22713	7, VI, 1898	5,000	.96	192	12.5
22719	21, VI, 1898	5,000	1.25	250	10.8
22724	5, VII, 1898	5,000	1.48	296	8.7
22732	19, VII, 1898	5,000	2.42	484	4.7
22750	1, VIII, 1898	5,000	3.80	760	2.6
22764	16, VIII, 1898	5,000	4.14	828	3.7
22769	30, VIII, 1898	5,000	3.80	760	3.9
22776	13, IX, 1898	5,000	4.23	846	4.2
22781	27, IX, 1898	5,000	2.06	412	4.9
22787	11, X, 1898	5,000	6.86	1,372	3.9
22792	25, X, 1898	5,000	4.12	824	4.3
22798	8, XI, 1898	5,000	2.85	570	6.7
22803	22, XI, 1898	5,000	1.45	290	8.5
22808	6, XII, 1898	5,000	1.08	216	7.2
22815	20, XII, 1898	5,000	1.55	310	5.9
22820	3, I, 1899	5,000	2.66	532	6.8
22827	17, I, 1899	5,000	3.88	776	8.2
22832	31, I, 1899	5,000	3.52	704	8
22840	14, II, 1899	5,000	3.18	636	6.6
22846	28, II, 1899	5,000	8.91	1,782	10.2
22852	14, III, 1899	5,000	13.86	2,772	13.1
22857	28, III, 1899	5,000	11.65	2,330	13.5
Average for 1898				556.48	

TABLE XV.—*Concluded.*

SOLIDS IN SUSPENSION AT STATION F, BERKEFELD FILTER.

Accession number	Date	Cu. cm. strained	Cu. cm. silt	Silt per cu. m.	River gage
22666	3, III, 1898	5,000	4.20	840	11.3
22670	15, III, 1898	5,000	9.08	1,816	12.1
22675	29, III, 1898	5,000	15.25	3,050	16.5
22681	12, IV, 1898	5,000	4.76	952	14.8
22692	26, IV, 1898	5,000	4.95	990	12
22701	17, V, 1898	5,000	2.26	452	10.1
22710	31, V, 1898	5,000	6.12	1,224	13.6
22717	14, VI, 1898	5,000	5.63	1,126	11.9
22722	28, VI, 1898	5,000	2.09	418	10
22729	12, VII, 1898	5,000	3.84	768	7
22736	26, VII, 1898	5,000	7.16	1,432	2.9
22762	9, VIII, 1898	5,000	10.00	2,000	3.2
22767	23, VIII, 1898	5,000	12.47	2,494	4.2
22772	6, IX, 1898	5,000	24.12	4,824	4.7
22779	20, IX, 1898	4,500	16.01	3,558	4.2
22784	4, X, 1898	5,000	12.43	2,486	4
22790	18, X, 1898	5,000	11.18	2,236	3.8
22796	2, XI, 1898	5,000	7.24	1,448	6.5
22801	15, XI, 1898	5,000	6.51	1,302	7.1
22806	29, XI, 1898	5,000	2.91	582	8.3
22812	13, XII, 1898	5,000	.70	140	6.7
22818	27, XII, 1898	5,000	2.23	446	6.1
22825	10, I, 1899	5,000	3.90	780	7.9
22830	24, I, 1899	5,000	2.34	468	8.9
22837	7, II, 1899	5,000	4.44	888	7.3
22844	21, II, 1899	5,000	1.64	328	5.5
22849	7, III, 1899	5,000	9.48	1,896	12.9
22855	21, III, 1899	5,000	18.57	3,714	13.7
Average for 1898				1,572	

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EXPLANATION OF PLATES.*

PLATE I.

Map of the Illinois River Basin, modified from a map in Cooley's "Lakes and Gulf Waterway," facing p. 58. Boundary of catchment-basin of whole system shaded, those of individual tributaries marked by dotted lines.

PLATE II.

Map of field of operations of the Illinois Biological Station at Havana, Ill., 1894–1899. Locations of plankton stations in Illinois River (E), Spoon River (M), Quiver Lake (C), Dogfish Lake (L), Flag Lake (K), Thompson's Lake (G), and Phelps Lake (F).

PLATE III.

Illinois River bottoms at high water in spring flood in March, 1898, looking westward. River gage about fifteen feet above low-water mark. Taken from base of the eastern bluff, just below field headquarters (see Plate II.) on Quiver Chute. Entire bottoms submerged, Quiver Chute and Illinois River united, Seeb's Lake showing dimly through the forest on west side, beyond this the broad expanse of Flag Lake, with low forest intervening between it and Thompson's Lake. Western bluff visible.

PLATE IV.

Illinois River at low water during summer of 1894. Taken from same point as Plate III. River gage about 2 ft. above low water, showing minimum levels since erection of dam at LaGrange. Mud spit between Quiver Chute and Illinois River exposed. Summer foliage and atmospheric conditions obscuring bottom-land waters to westward.

PLATE V.

West bank of Illinois River a short distance below plankton station, looking northeastward. Taken during low water in midsummer of 1894. Sloping shore of black alluvium covered by low vegetation. Narrow marginal belt of vegetation visible. River about 400 feet in width.

PLATE VI.

Sun-spots, rainfall, and river levels. Upper section of figure taken from Lockyer ('01). Middle section gives fluctuations in average rainfall in Illinois above and below the mean, as given in records of U. S. Weather Bureau. Lower section gives fluctuations in mean annual river levels, compiled from records at Copperas Creek dam, 1878–1899. Average of all annual means shown at the left.

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* Plates IV., XV., XVII., and XXI. are from the Biennial Report of the Director of this Laboratory for 1893 and 1894; plates II., V., VIII., XVIII., XIX., and XX., from that for 1895 and 1896; and plates III. and XVI., from that for 1897 and 1898.

PLATE VII.

Hydrographs of Illinois River, 1879–1899, from records of State Canal Commissioners published in reports U. S. Army Engineers, taken at lower gage on Copperas Creek dam, and from records of U. S. Army Engineers, taken at lower gage on LaGrange dam, 1883–1899. Mean hydrograph at the right based on means of monthly averages.

PLATE VIII.

Seasonal distribution of plankton in Illinois River, Station E, in 1894. Volume of plankton in cm.^{3} per m.^{3} of water shown by heavy black ordinants, the diagonal-lined apices of which indicate the estimated proportion which silt forms of the total catch. Thermograph in dotted lines, from records of surface temperatures made at the times of plankton collection. Hydrograph in continuous line, plotted from records at Copperas Creek. Heavy black areas at top of plate indicate the relative number of cloudy days per month at Havana, the vertical space equaling seven days.

PLATE IX.

The same for 1895. Hydrograph from Jan. 1 to Aug. 8 is that at Copperas Creek, and thereafter in the main from Havana records. Relative thickness of ice-sheet indicated by black area at bottom of plate, 1 mm. equaling 6 cm. of ice.

PLATE X.

The same for 1896. Hydrograph entirely from Havana records.

PLATE XI.

The same for 1897.

PLATE XII.

The same for 1898.

PLATE XIII.

The same for 1899.

PLATE XIV.

Spoon River near its mouth, looking toward southwest from first bend in the stream. Plankton station (M) located near trestle. Taken at moderately low water.

PLATE XV.

Quiver Lake in midsummer, 1894, at low-water levels, looking northward from Station C (see Pl. II.) toward the mouth of Dogfish Lake. Littoral vegetation in foreground. Driftwood indicating high-water margin. Lake rich in vegetation. Plankton station located in narrow strip of open water in middle of lake.

PLATE XVI.

Quiver Lake, from same location, in low water of 1897. Only a small amount of marginal vegetation visible. Dogfish Lake also largely free from vegetation.

PLATE XVII.

Western shore of upper end of Quiver Lake, looking northward, showing richness of vegetation. Emergent *Nelumbo lutea* Pers., with leaves, flowers, and seed pods. Submerged *Ceratophyllum demersum* L. Taken in low water of summer of 1894.

PLATE XVIII.

Dogfish Lake, looking northeastward, in low-water summer conditions. Lake full of *Ceratophyllum*, *Elodea*, and *Potamogeton*. Plankton station (L) near center of lake.

PLATE XIX.

Flag Lake in autumn of 1895 at plankton station (K), looking north-northeastward. Scattered dwarfed clumps of *Scirpus* and an abundance of *Nymphæa* constitute the principal vegetation in this open area.

PLATE XX.

Thompson's Lake from shore station (G), looking southwestward, in low-water conditions of midsummer. Lotus bed in distance, and broad belt of submerged vegetation, principally *Ceratophyllum*, along shore. Plankton station (G) in open water to the right (northward).

PLATE XXI.

Phelps Lake, looking southwestward from plankton station (F), in midsummer in 1894, just as the lake was drying up.

PLATE XXII.

Seasonal distribution of plankton in Spoon River (Station M) in 1896. Scale of plottings of plankton 0.1 cm.^{3} per vertical unit, instead of 1 cm.^{3}, as in case of all other stations. Dotted portion of ordinant indicates estimated proportion of silt in total catch. Thermograph plotted from surface temperatures of water at times of collection of plankton, and hydrograph from gage-readings in the adjacent Illinois River at Havana. Ice indicated by black areas below diagram, 1 mm. equaling 6 cm. of ice.

PLATE XXIII.

The same for 1897. The excess of plotted plankton-silt ordinants over limits of diagram is indicated by figures at top.

PLATE XXIV.

The same for 1898–1899.

PLATE XXV.

Seasonal distribution of plankton in Quiver Lake (Station C) in 1894. Scale of plotting of plankton-silt is 0.4 cm.^{3} per vertical unit. Hydrograph is that of the Illinois River at Copperas Creek. Thermograph is that of surface temperatures at times of plankton collections.

PLATE XXVI.

The same for 1895. Hydrograph from Jan. 1 to Aug. 8 is that of the Illinois River at Copperas Creek, and thereafter, from river gage-readings at Havana.

PLATE XXVII.

The same for 1896. Hydrograph from gage-readings in the Illinois River at Havana.

PLATE XXVIII.

The same for 1897.

PLATE XXIX.

The same for 1898–1899.

PLATE XXX

Seasonal distribution of plankton in Dogfish Lake in 1895. Hydrograph from Jan. 1 to Aug. 8 is that of the Illinois River at Copperas Creek, and thereafter, at Havana.

PLATE XXXI.

The same for 1896. Hydrograph is that of the Illinois River at Havana.

PLATE XXXII.

The same for 1897.

PLATE XXXIII.

The same for Flag Lake (Station K) for 1895–1896.

PLATE XXXIV.

The same for 1897–1898.

PLATE XXXV.

Seasonal distribution of plankton in Thompson's Lake (Station G) in 1894. Hydrograph is that of the Illinois River at Copperas Creek.

PLATE XXXVI.

The same for 1895. Hydrograph from Jan. 1 to Aug. 8 is that of the Illinois River at Copperas Creek, and thereafter, at Havana.

PLATE XXXVII.

The same for 1896. Hydrograph is that of the Illinois River at Havana.

PLATE XXXVIII.

The same for 1897.

PLATE XXXIX.

The same for 1898–1899.

PLATE XL.

The same for Phelps Lake in 1896.

PLATE XLI.

The same for 1897.

PLATE XLII.

The same for 1898–1899.

PLATE XLIII.

Seasonal distribution of chemical data and plankton in Illinois River in 1895–1896. Chlorine, oxygen consumed, free ammonia, albuminoid ammonia, total organic nitrogen, nitrites, and nitrates, in parts per million, plotted according to scales specified at the left, and plankton in cm.^{3} per m.^{3}, according to scale at the left, in the form of a continuous planktograph. The hydrograph, with scale at the right, is plotted in the usual form as a continuous curve. The planktograph, and the chlorine and nitrite plots are also in continuous line s, but, owing to distribution of data are more angular. Nitrite scale should read 0.1 to 0.3.

PLATE XLIV.

The same for 1897.

PLATE XLV.

The same for 1898–1899.

PLATE XLVI.

The same for Spoon River (Station M), for 1896–1897. Nitrite scale should read 0.1 instead of 10.

PLATE XLVII.

The same for 1898–1899. Plankton scale at the left should read 0.1 to 0.4 instead of 1 to 4.

PLATE XLVIII.

The same for Quiver Lake (Station C) for 1895 and 1897.

PLATE XLIX.

The same for 1898–1899.

PLATE L.

The same for Thompson's Lake for 1897, 1898, and 1899. Nitrite scale should read 0.1 instead of 1.

ERRATA AND ADDENDA

Page 99, line 6 from bottom, for (*'87*) read (*'85*); line 5 from bottom, after *Rolfe*, read, (*'94*).

Page 100, line 3, page 132, line 10, page 264, line 11 from bottom, page 457, lines 7 and 15 from bottom, page 458, line 14, and page 541, line 8, for *Ward* (*'95*) read *Ward* (*'96*).

Page 159, Feb. 18, for *6.8* read *8.8*; June 30, for *3.5* read *5.5*.

Page 160, Oct. 9, for *1.19* read *1.9*.

Page 161, Nov. 24, for *6.6* read *8.6*.

Page 169, line 14, for *Table I.* read *Tables III.–IX*.

Page 170, line 15 from bottom, for *VIII*, read *VII*.

Page 202, line 9, for (*'96*) read (*'97*).

Page 253, line 15 from bottom, for (*'97*) read (*'97a*).

Page 263, line 12, for *1899* read *1896*.

Page 282, line 11 from the bottom, for —43 per cent. read ± 43 per cent.

Page 288, line 2 from bottom, transpose *31.8* and *28.8*.

Page 290, line 2, for *2 to 5* read *1 to 15*.

Page 295, line 18, omit the first eight words; line 20, for *2.12*, *1.08*, and *4.01*, read respectively, *3*, *22*, *0.72*, and *3.94*.

Page 311, line 14, and last line page 313, for *node* read *mode*.

Page 319, line 14 from bottom, for *LII.* read *XLIV.*; line 4 from bottom, for *the* read *an*.

Page 323, line 9 from bottom, read *in 1897* after *catches*.

Page 332, lines 16 and 17, for *exceeded* read *preceded*.

Page 343, line 14, for *cm.* read *cm.*^{3}.

Page 350, line 17, for *qualitatively* read *quantitatively*.

Page 357, line 6 from bottom, after *16.76* read *on the 24th*.

Page 358, line 18, after *and* read *decreases the*.

Page 367, after heading *Dogfish Lake* read *Station L*.

Page 371, line 4, before *decaying* read *to*.

Page 372, line 16, after *maximum* read *in Quiver Lake*.

Page 381, after heading *Flag Lake* read *Station K*.

Page 385, line 14, for *ubella* read *uvella*.

Page 403, line 17, for *flood* read *floods*; line 18, before *July* read *of*.

Page 405, line 1, after *relative* read *annual*; line 8, for *1897* read *1896*.

Page 414, line 12 from bottom, for *river* read *area*, and for *drains to* read *reaches*.

Page 416, line 12 from bottom, for *is* read *was*.

Page 422, line *3* from bottom, for *5* read *3–5*.

Page 424, line 12, for (*.45*) read (*45 cm.*); line 13, for (*.05*) read (*5 cm.*); line 16 from bottom, for *flood* read *floods*.

Page 429, line 4 from bottom, for *22.35* read *22.55*.

Page 439, line 2 from bottom, for *the* read *their*.

Page 440, line 8, for *mean* read *means* and for *the* read *their*.

Page 463, line 4, for *to* read *in*; line 5, for peculiar *in* read peculiar *to*.

Page 484, in table, transpose *Vegetation-poor* and *Vegetation-rich*.

Page 501, line 1, for *show* read *shown*.

Page 505, last line of table, column 4, for *.4* read *4*.

Page 510, line 9, add, *and Volk* ('*03*).

Page 546, line 15 from bottom, after *is* read *in the main*.

Page 549, line 1 below heading, page 551, line 1, and page 556, line 3, for ('*97b* read ('*97a*).

Page 556, line 7, before '*03* read '*01 and*.

Page 560, table, second column, line 4 from bottom, for ('*00b*) read ('*00*),; line 6 from bottom, for *Jung* read *Yung*; line 16 from bottom, for ('*95*) read ('*93*); line 17 from bottom, for ('*99*) read ('*00*); line 19 from bottom, for ('*95*) read ('*96*).

Page 584, at head of second column, for *1897* read *1898*; under remarks, line 4, for *above* read *along*.

Pages 597 and 598, below table, read *Bottom visible.

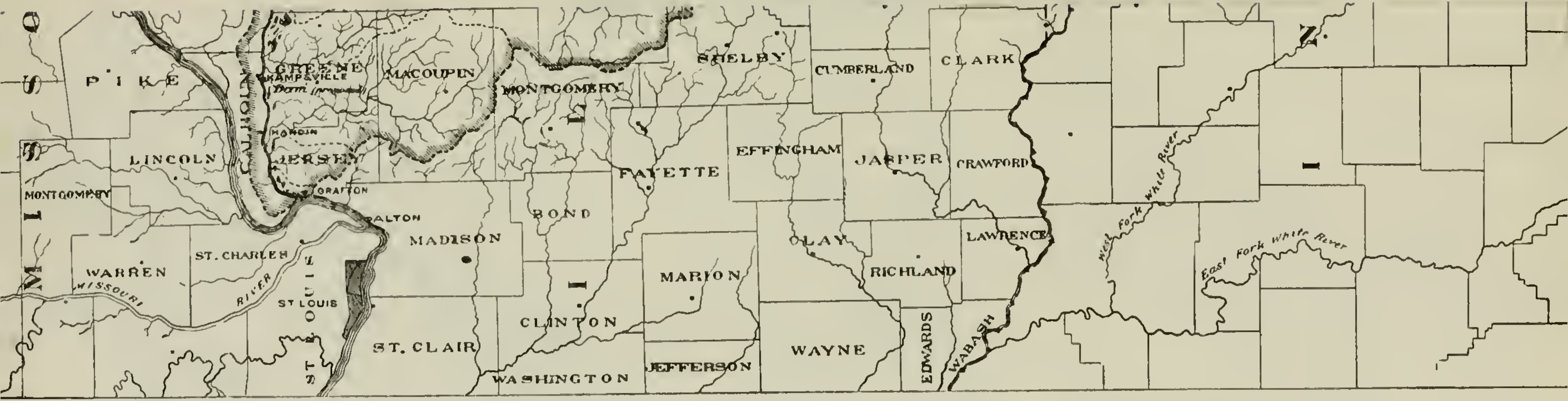
Page 598, eighth column, line 7 from bottom, for *0.16* read *0.28*.

Pages 599–603, 606–610, 612, and 613, below table, read *Plankton not collected on same date as sample for water analysis.

Pages 599–613, columns 2–4, meaning of symbols, abbreviations, etc., as follows:

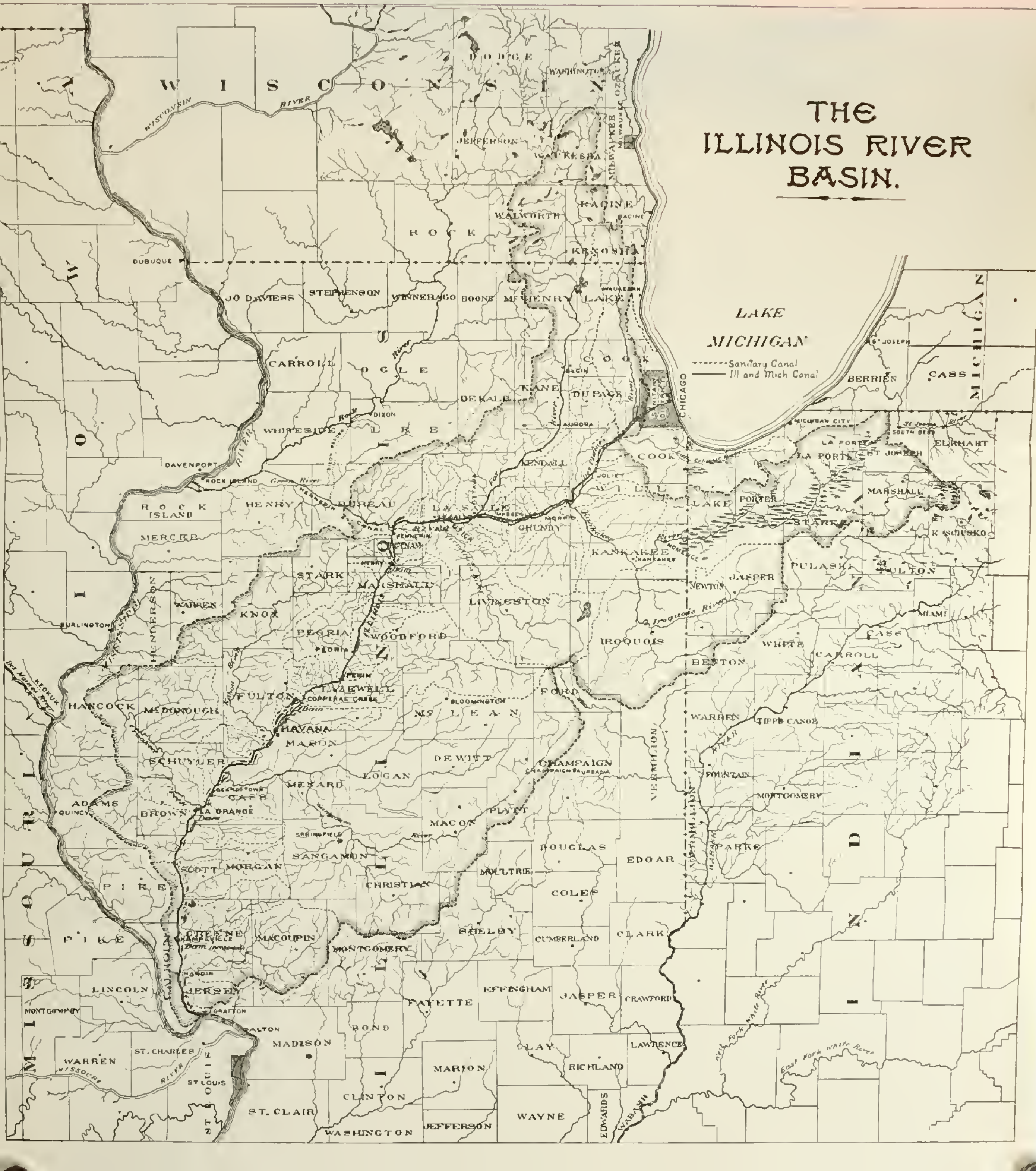
+ = rising river level.
− = falling river level.
± = stationary river level.
c. = considerable.
d. = distinct; decided.
f. = filtered.
l. = little.
m. = much.
n. f. = not filtered.
s. = slight.

v. d. = very decided.
v. m. = very much.
Decimal in color column = volume of standard ammonium chloride solution required to develop the same tint when diluted to fifty cubic centimeters with ammonia-free water and treated with the usual amount of nessler reagent



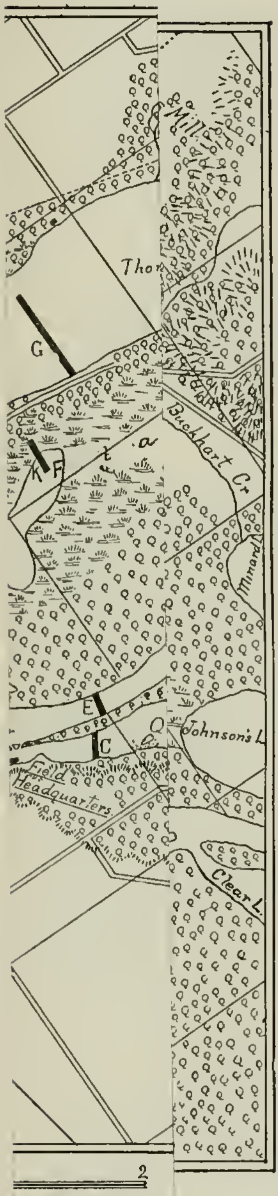
ILLINOIS RIVER AT HIGH WATER. NEAR FOOT OF QUIVER LAKE

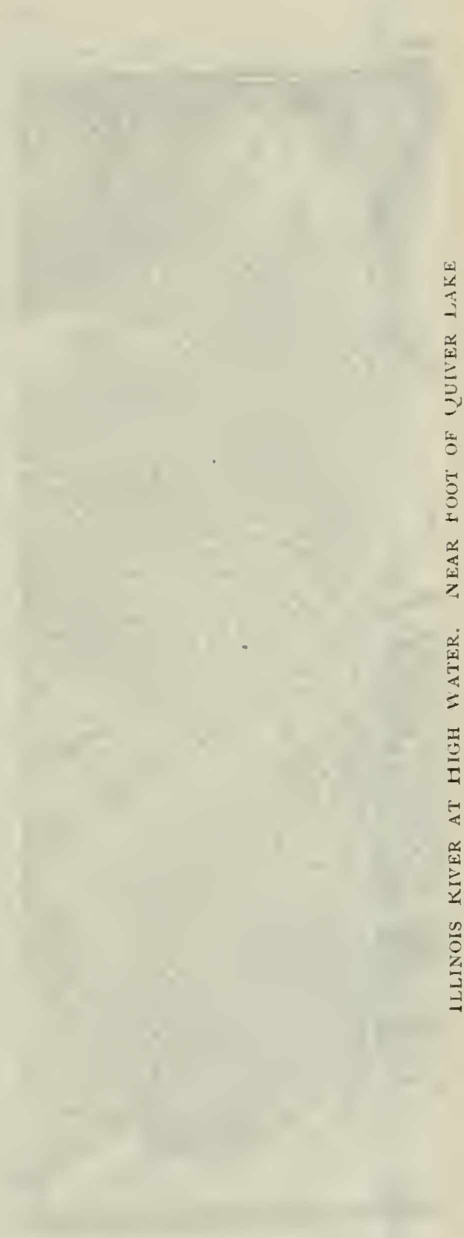
THE ILLINOIS RIVER BASIN.



OPERAT

Plate II.





ILLINOIS RIVER AT HIGH WATER. NEAR FOOT OF QUIVER LAKE

Plate II.

FIELD OF BIOLOGICAL STATION OPERATIONS. LOW WATER.

AFTER U. S. GOVERNMENT SURVEYS, REVISED BY MEMBERS OF THE STATION STAFF

DRAWN BY LYDIA M. HART

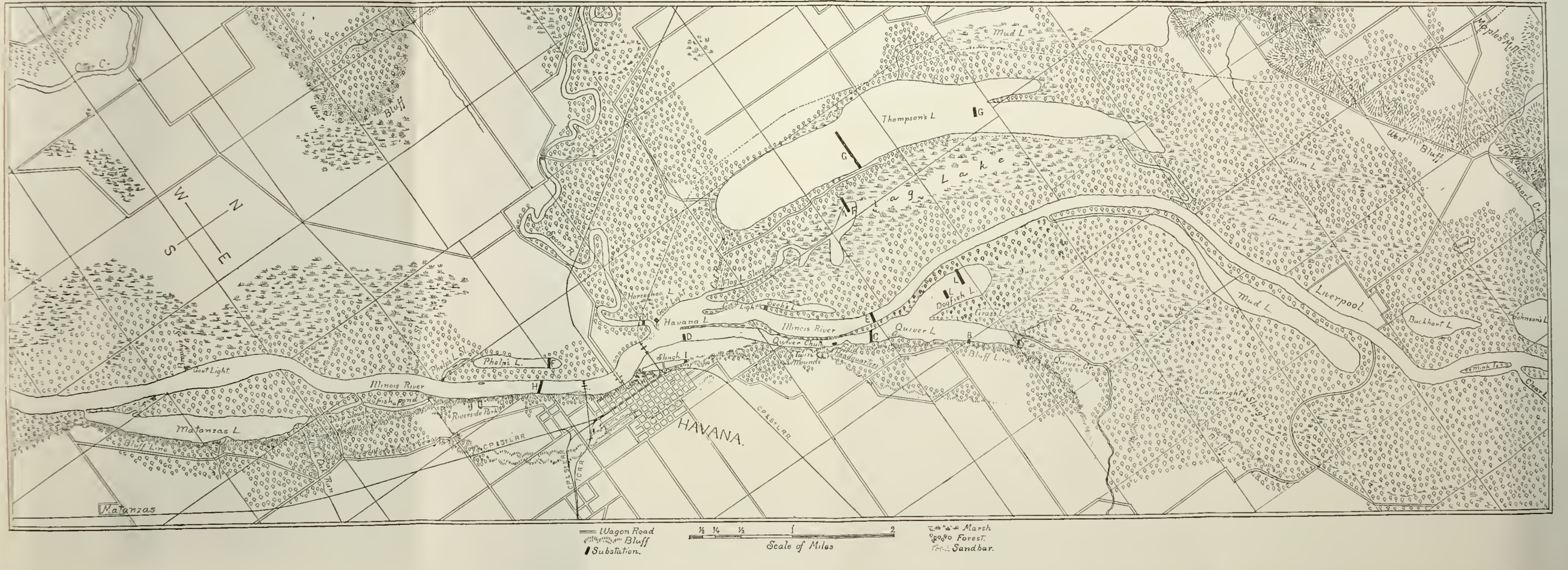


Plate III.

Illinois River at High Water. Near Foot of Quiver Lake

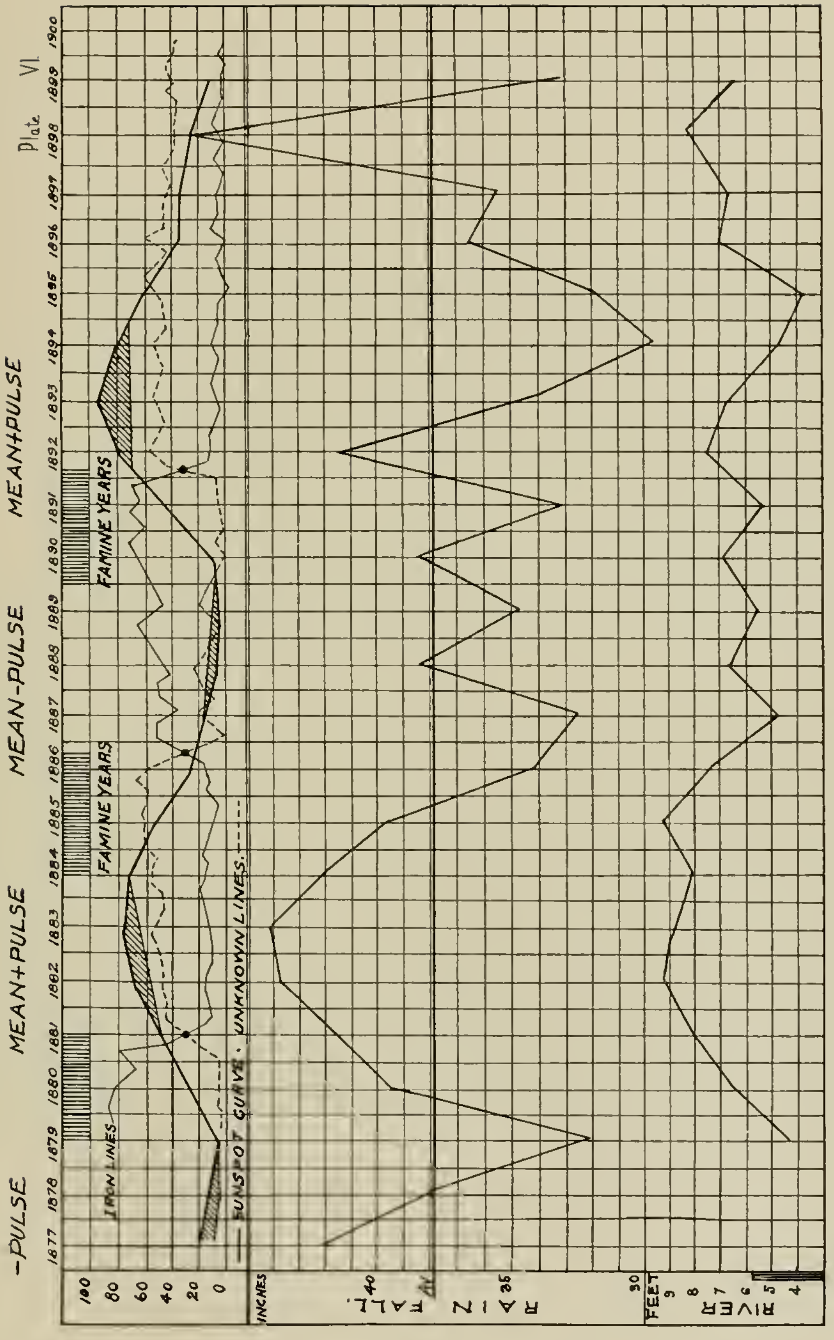
Plate IV

Illinois River at Low Water. Near Foot of Quiver Lake

Plate V.

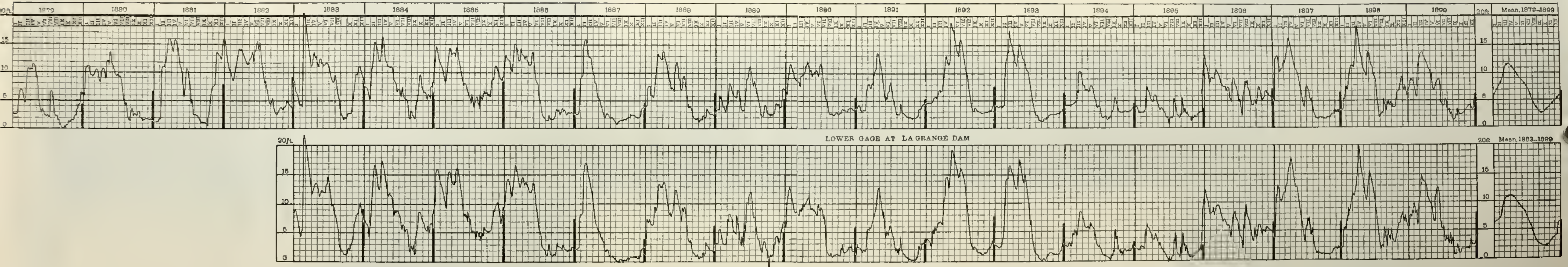
Illinois River at Low Water, from West Bank. Station E

Plate VI



Curves of River Level, Rainfall, and Sunspots

Plate VII


LOWER GAGE AT COPPERAS CREEK DAM.

LOWER GAGE AT LA GRANGE DAM

General Hydrograph of Illinois River, 1879 to 1899

Seasonal Distribution of *Plankton*, at Station E. 1894. Plate VIII

Seasonal Distribution of *Plankton*, at Station E. 1895. Plate IX.

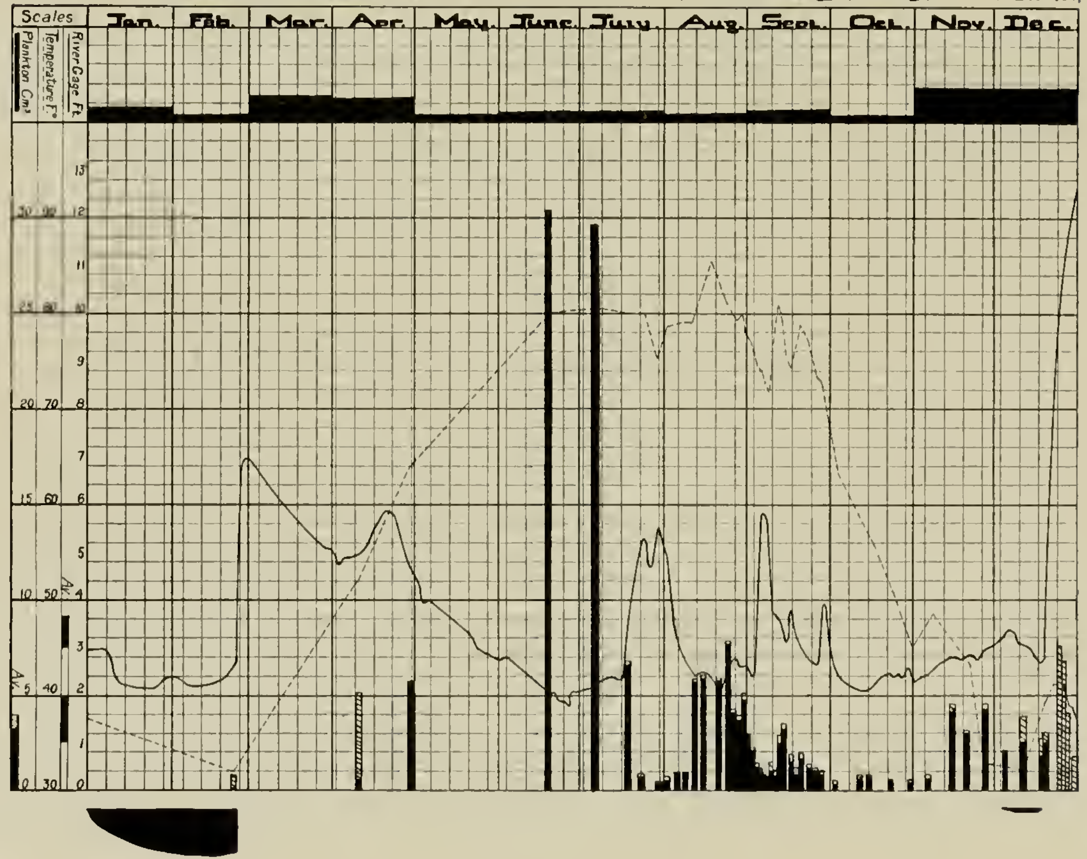
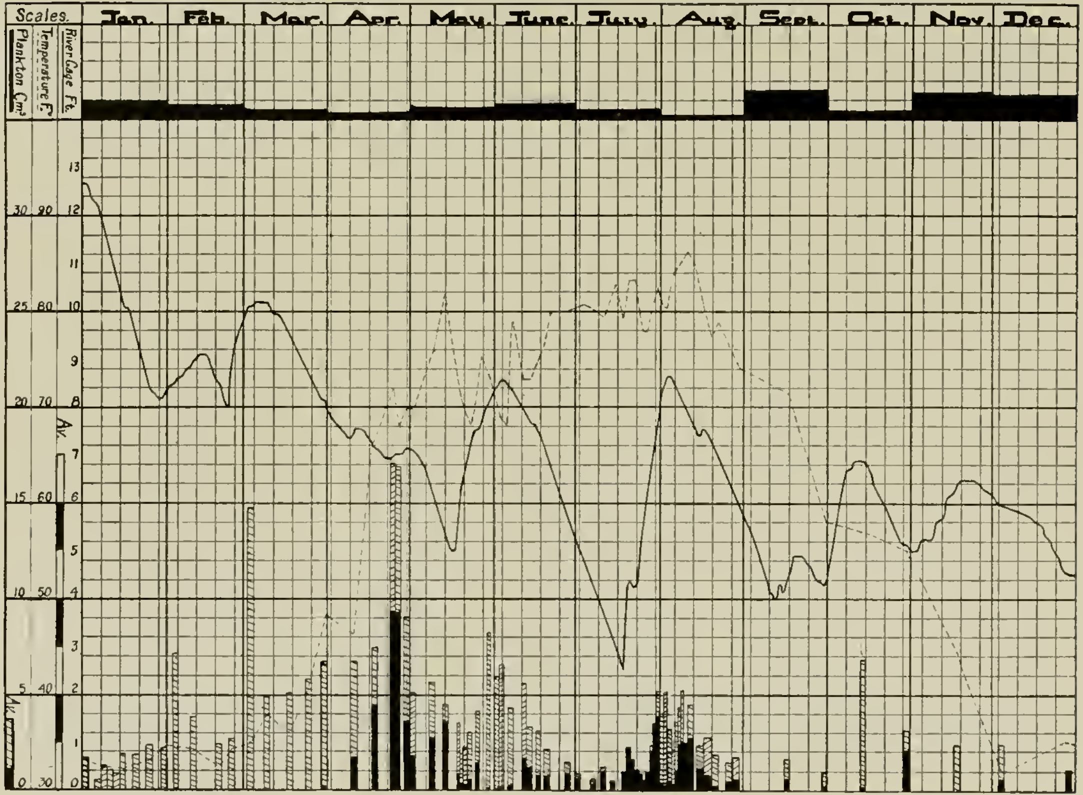
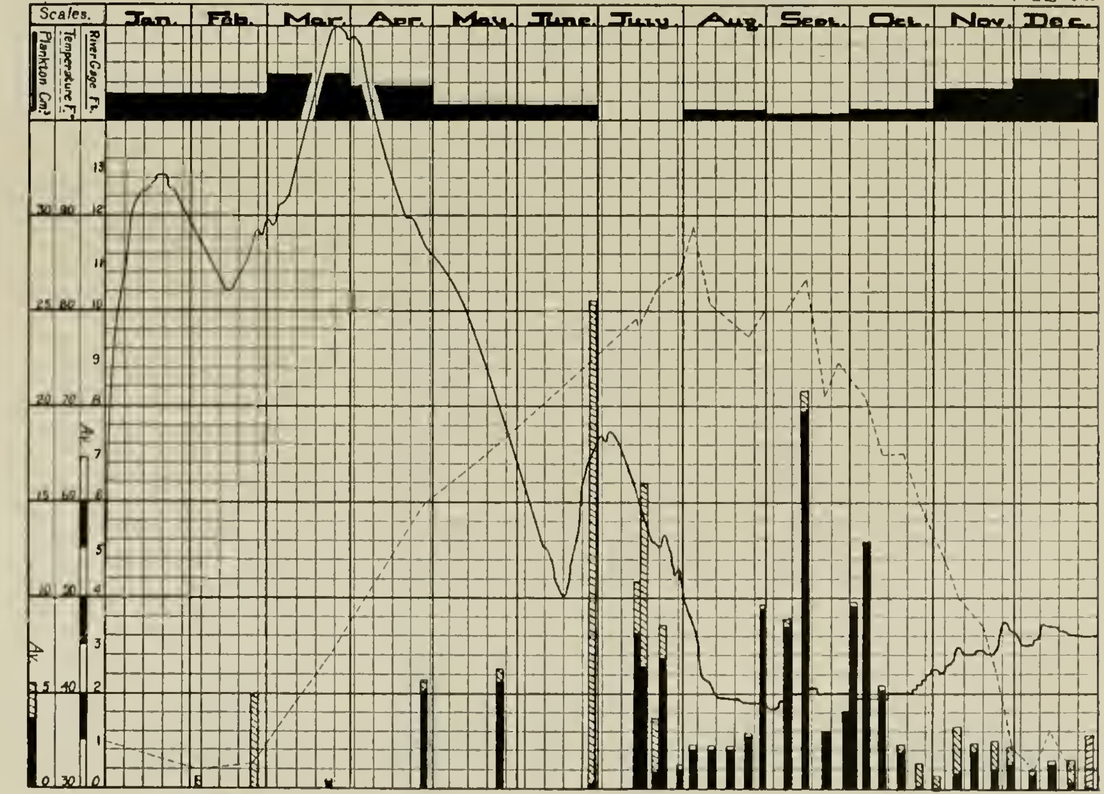


Plate X.

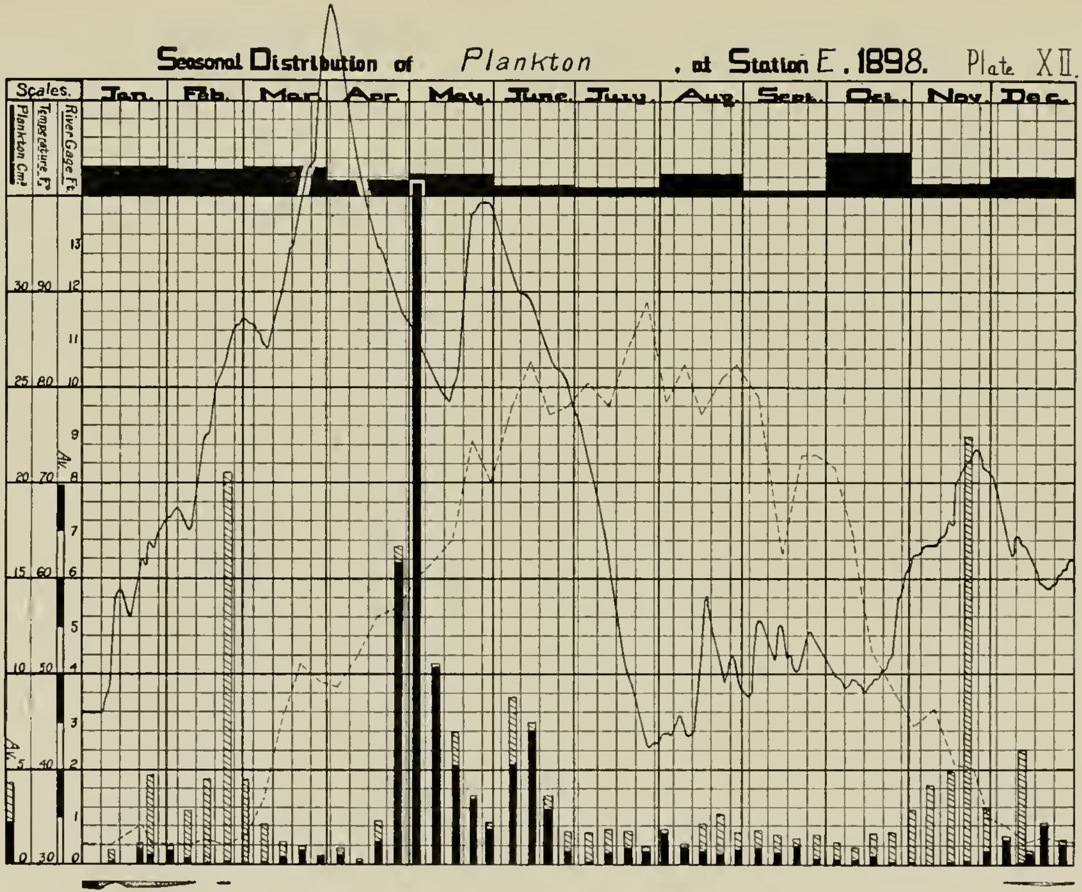
Seasonal Distribution of *Plankton*, at Station E, 1896.



Seasonal Distribution of *Plankton*, at Station E. 1897. Plate XI



Seasonal Distribution of *Plankton* , at Station E. 1898. Plate XII.



Seasonal Distribution of Plankton, at Station E. 1899. Plate XIII.

Plate XIV

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Quiver Lake. Full of Vegetation

Plate XVI.

QUIVER LAKE. FREE OF VEGETATION

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Quiver Lake at Head. Lotus Bed

Plate XVIII.

Dogfish Lake

Plate XIX.

Flag Lake

Plate XX

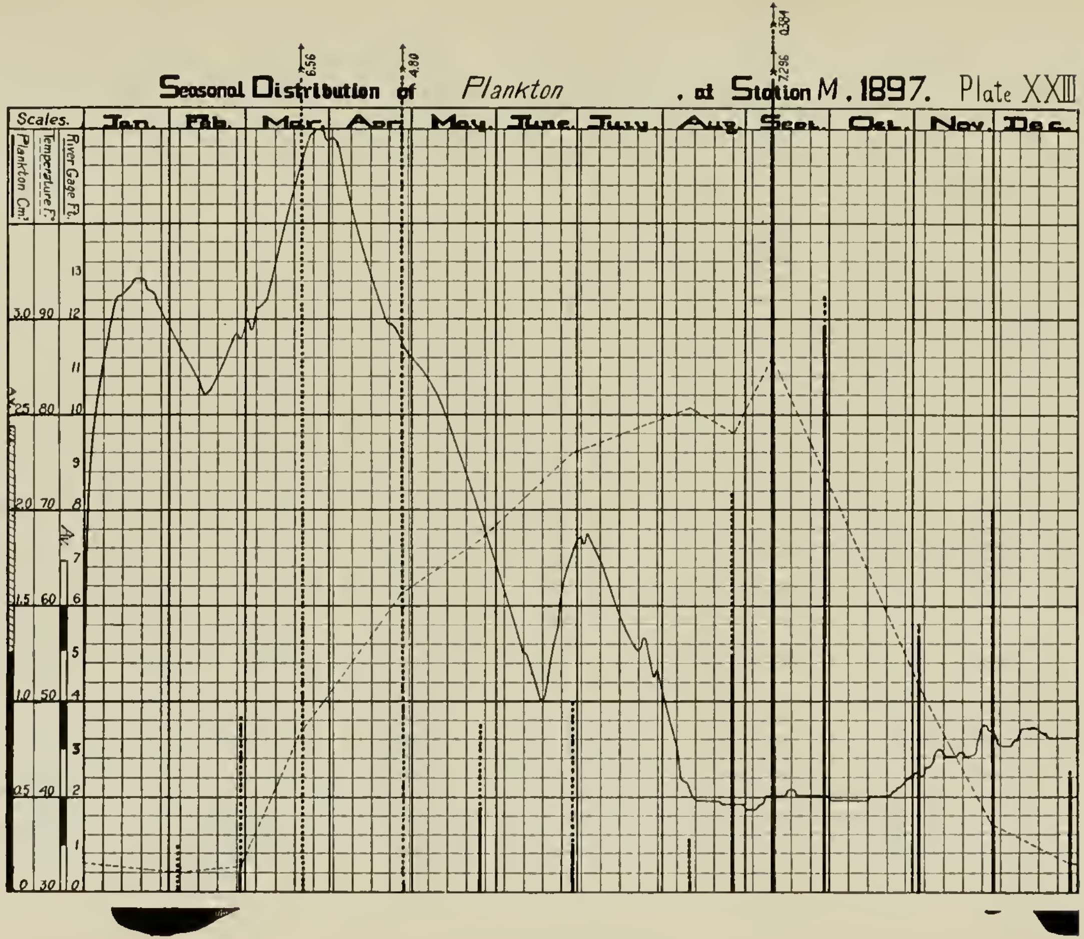
Thompson's Lake

Plate XXI

Phelps Lake, nearly Dry. Dead Fish and Mussels

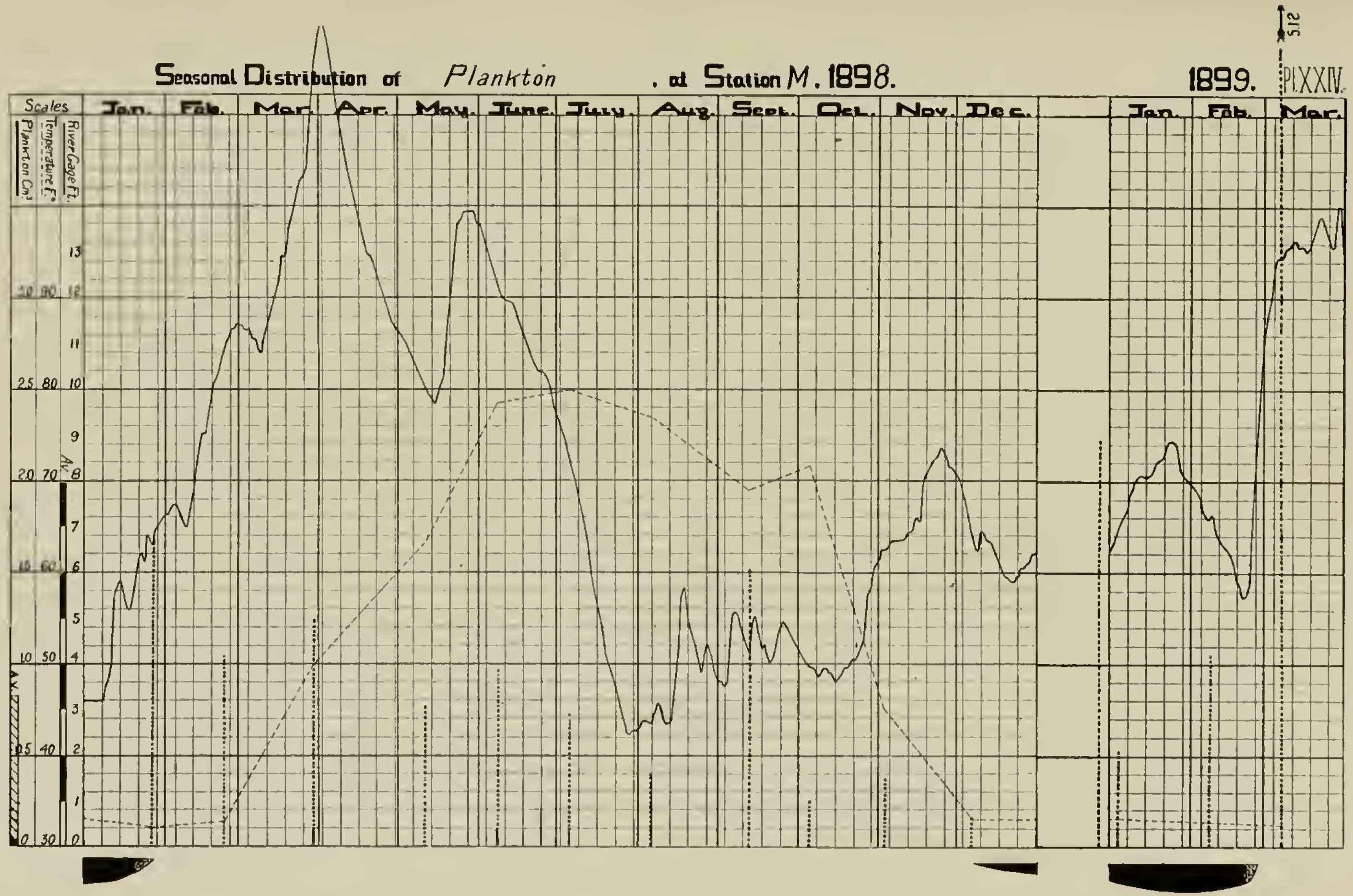
Seasonal Distribution of *Plankton* . at Station M, 1896. Plate XXII.

Seasonal Distribution of *Plankton* at Station M, 1897. Plate XXIII



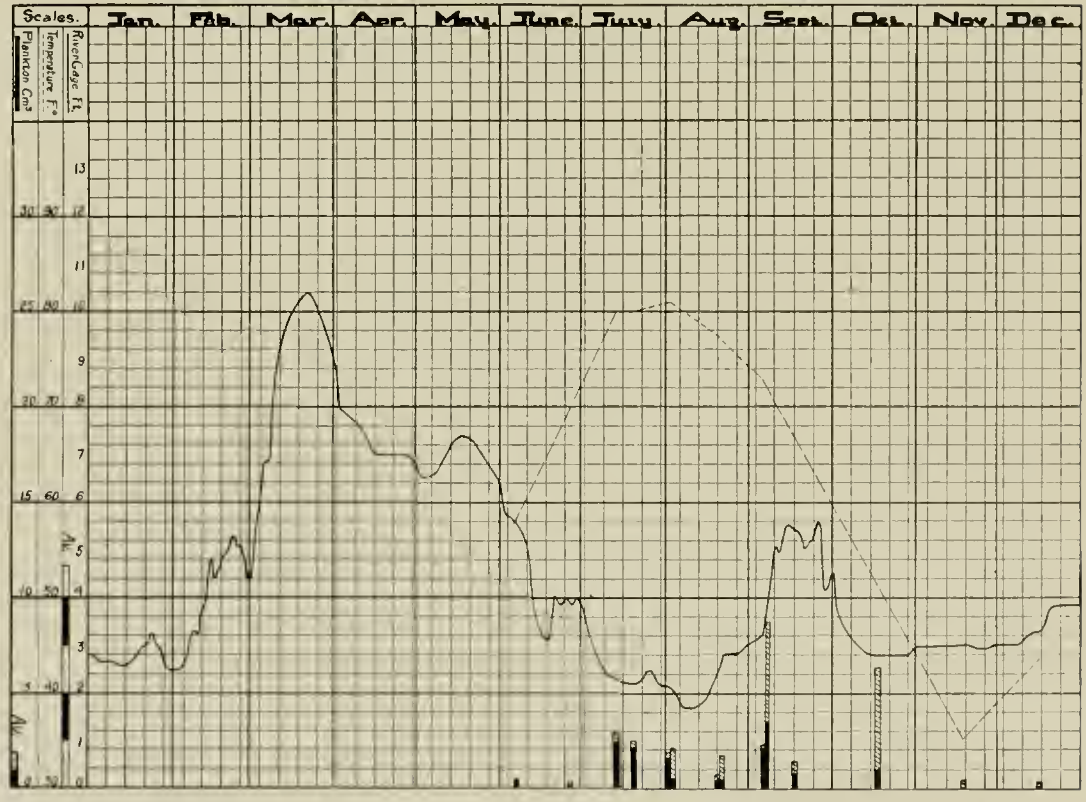
Pl. XXIV.

Seasonal Distribution of *Plankton* . at Station M. 1898. 1899.



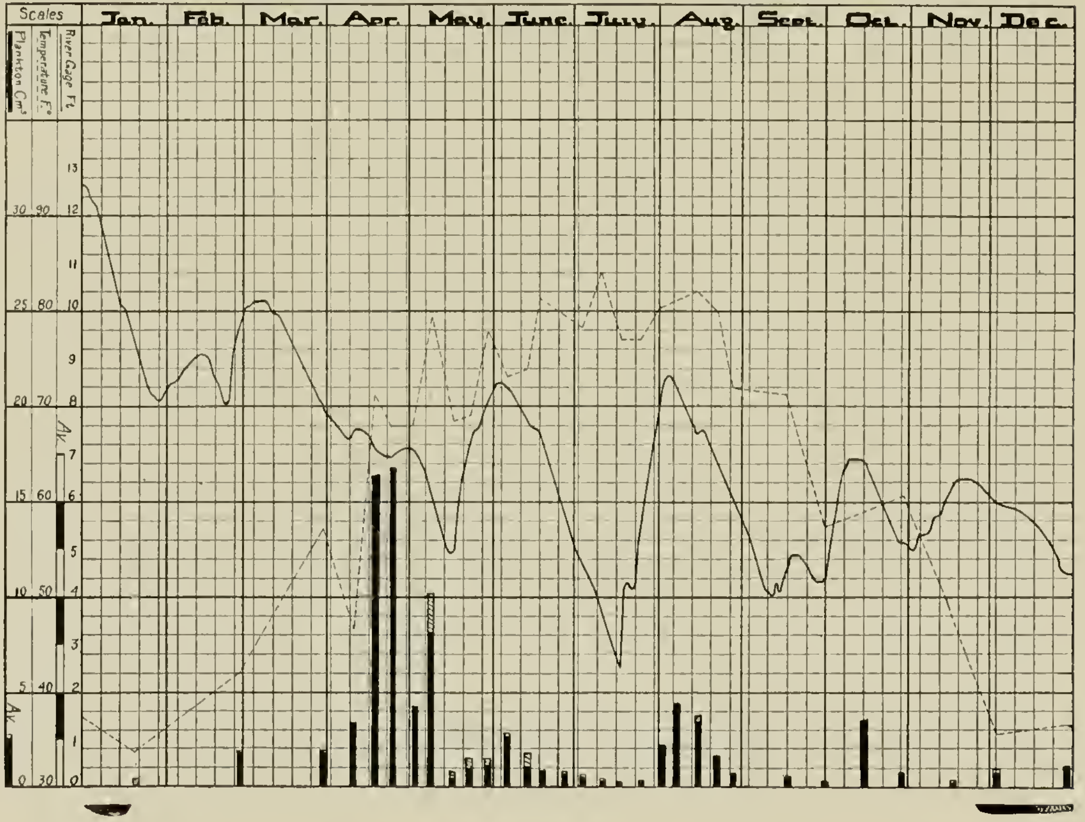
Seasonal Distribution of *Plankton*, at Station C. 1894.

Plate XXV.



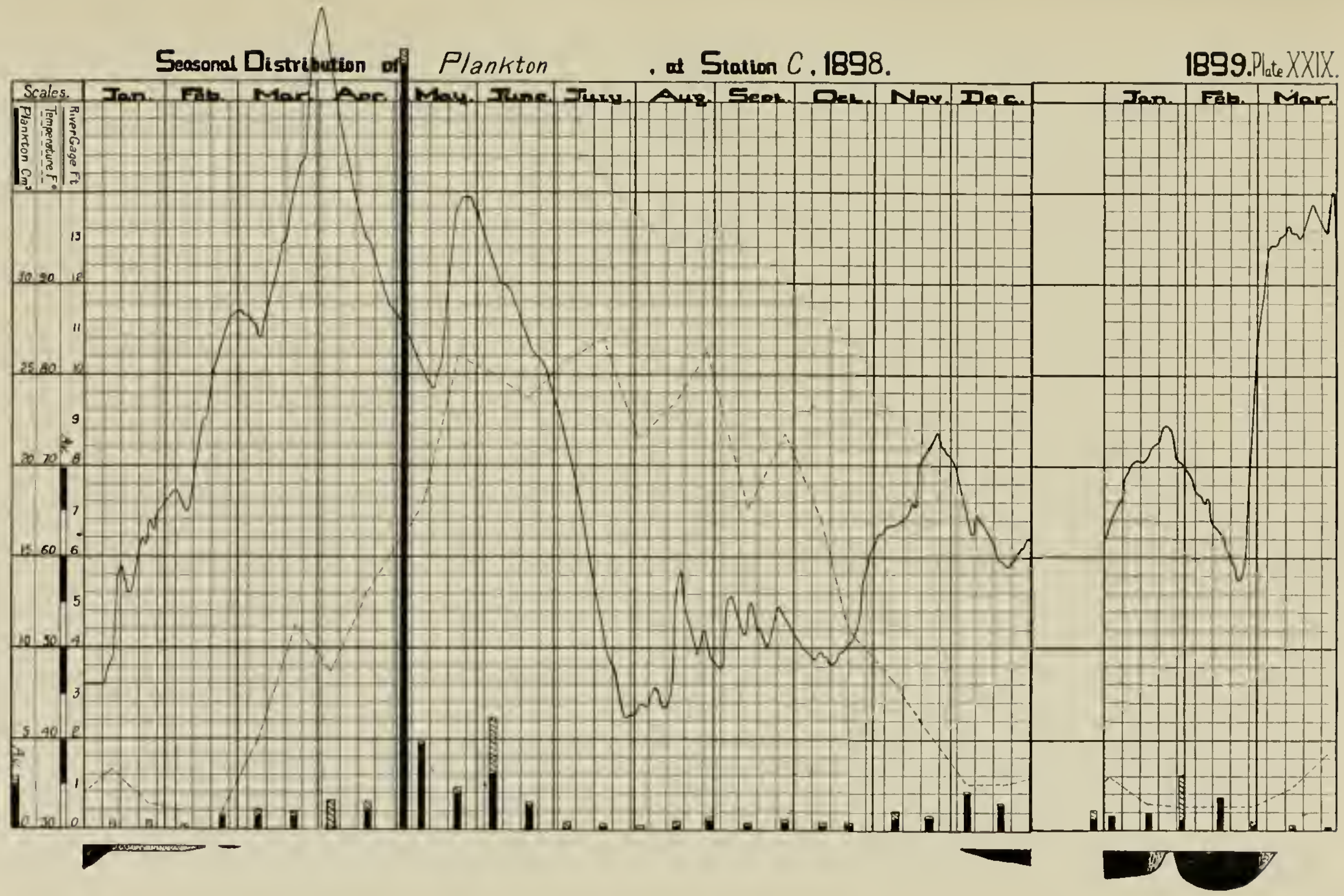
Seasonal Distribution of *Plankton* . at Station C. 1895. Plate XXVI.

Seasonal Distribution of *Plankton* . at Station C. 1896. Plate XXVII.



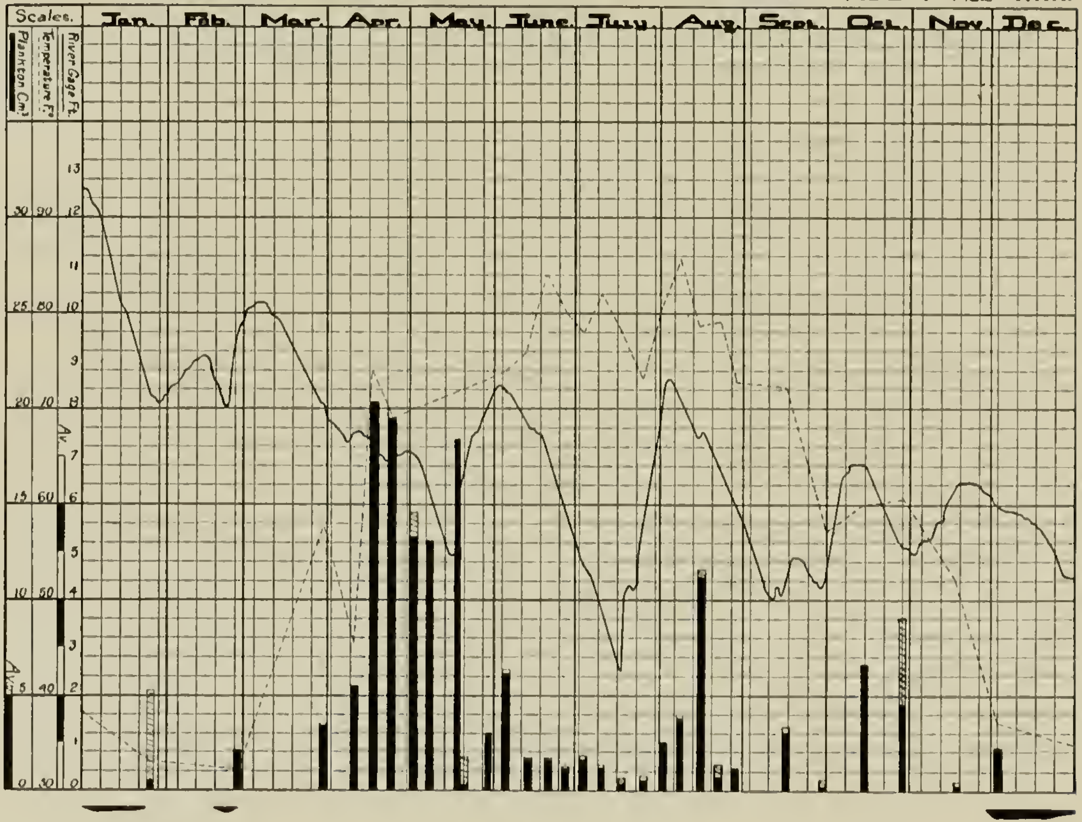
Seasonal Distribution of *Plankton* , at Station C. 1897. Plate XXVIII

Seasonal Distribution of *Plankton* , at Station C. 1898. 1899. Plate XXIX.



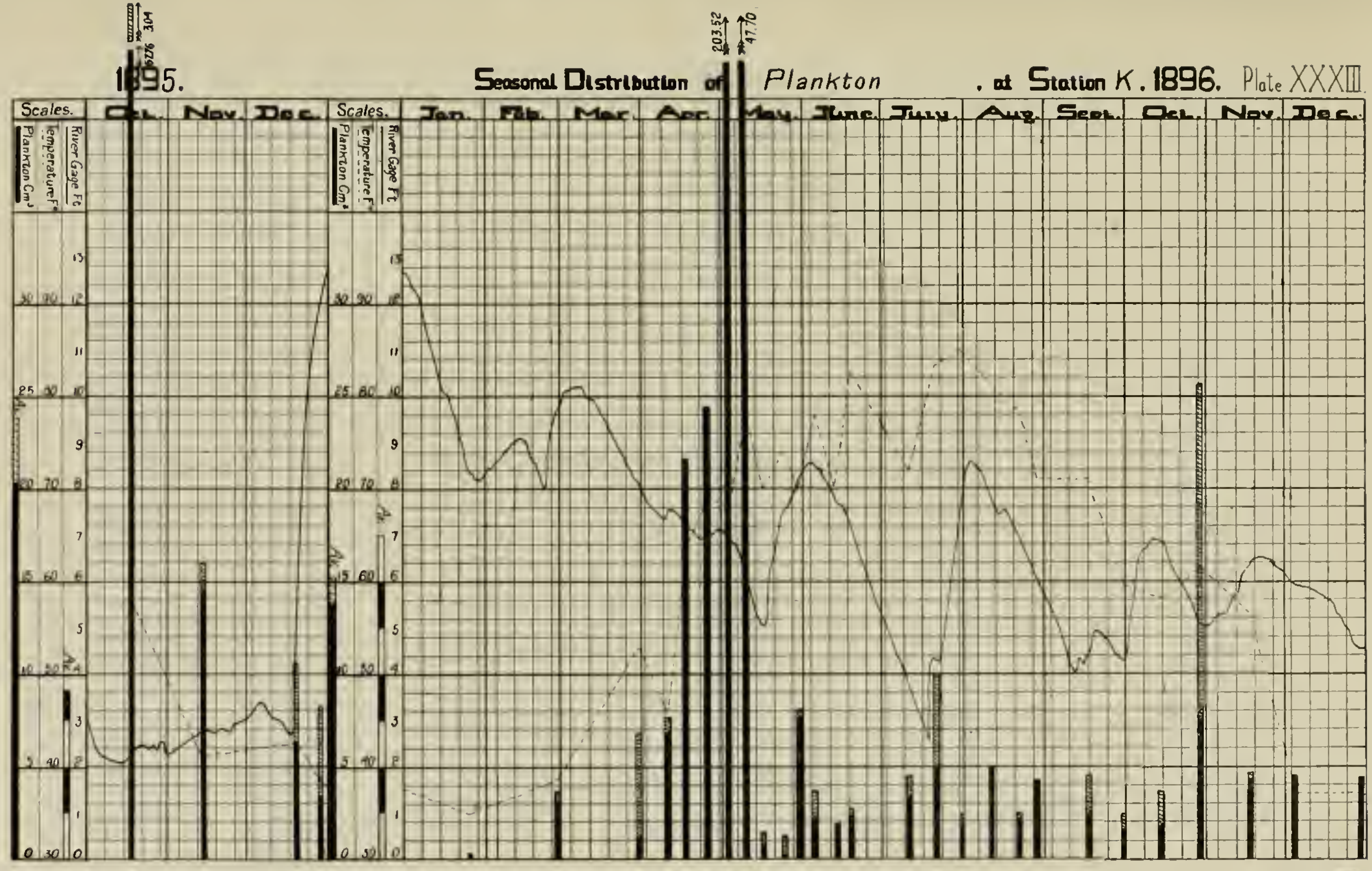
Seasonal Distribution of *Plankton* at Station L. 1895. Plate XXX.

Seasonal Distribution of *Plankton*, at Station L. 1896. Plate XXXI.

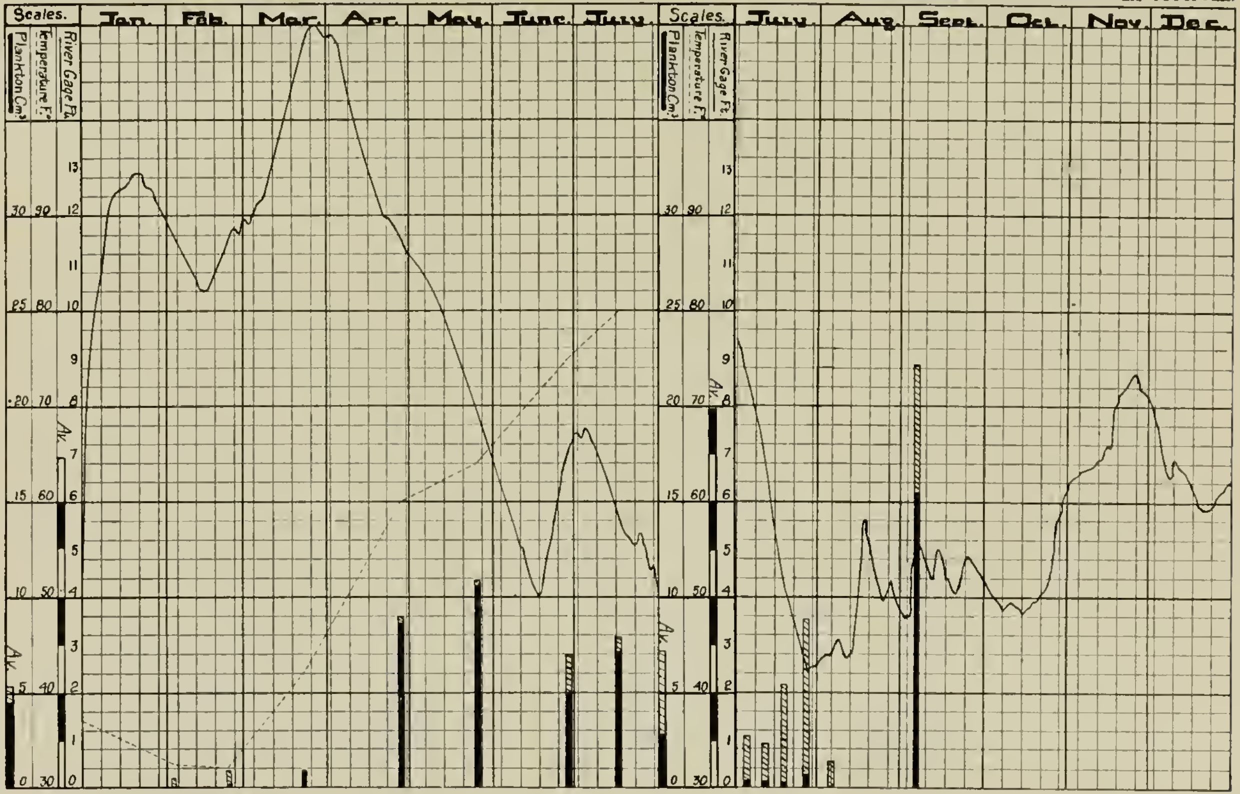


Seasonal Distribution of *Plankton* . at Station L . 1897. Plate XXXII.

Seasonal Distribution of *Plankton* . at Station K. 1896.

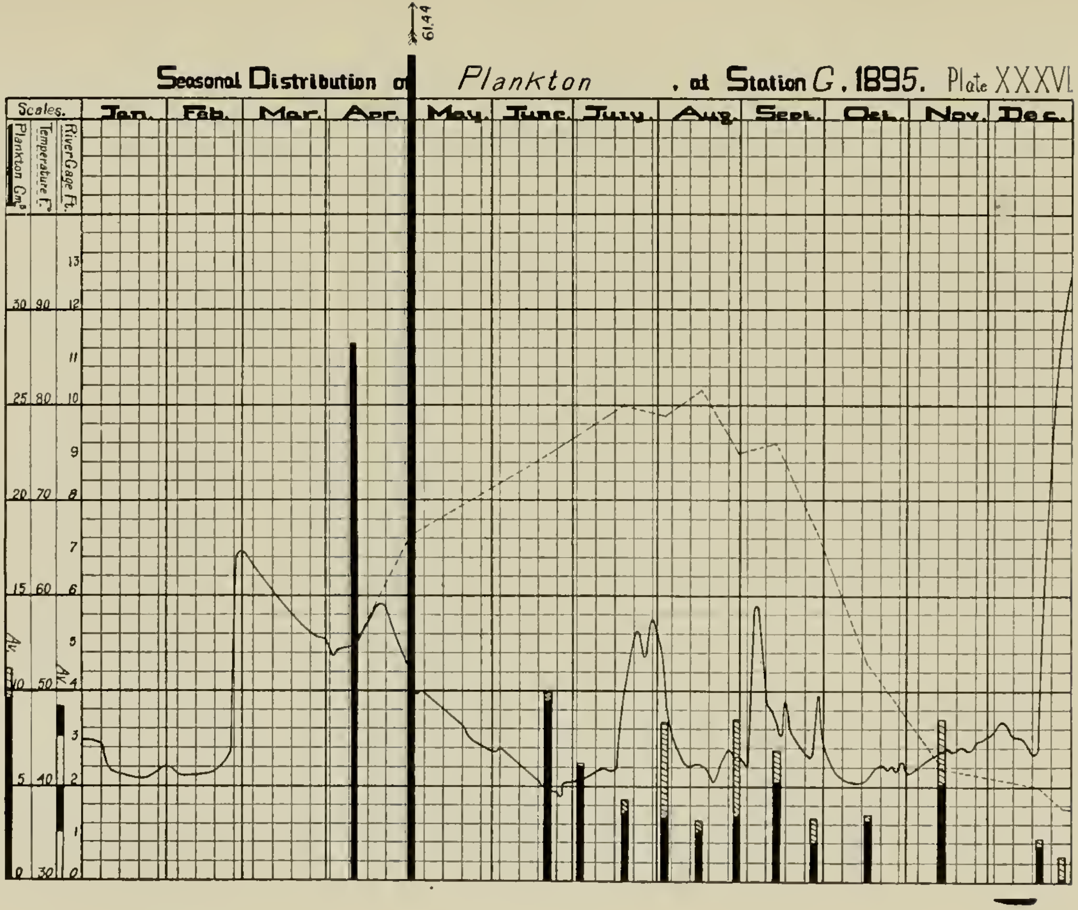


1897. Seasonal Distribution of *Plankton*, at Station K, 1898. Plate XXXIV.

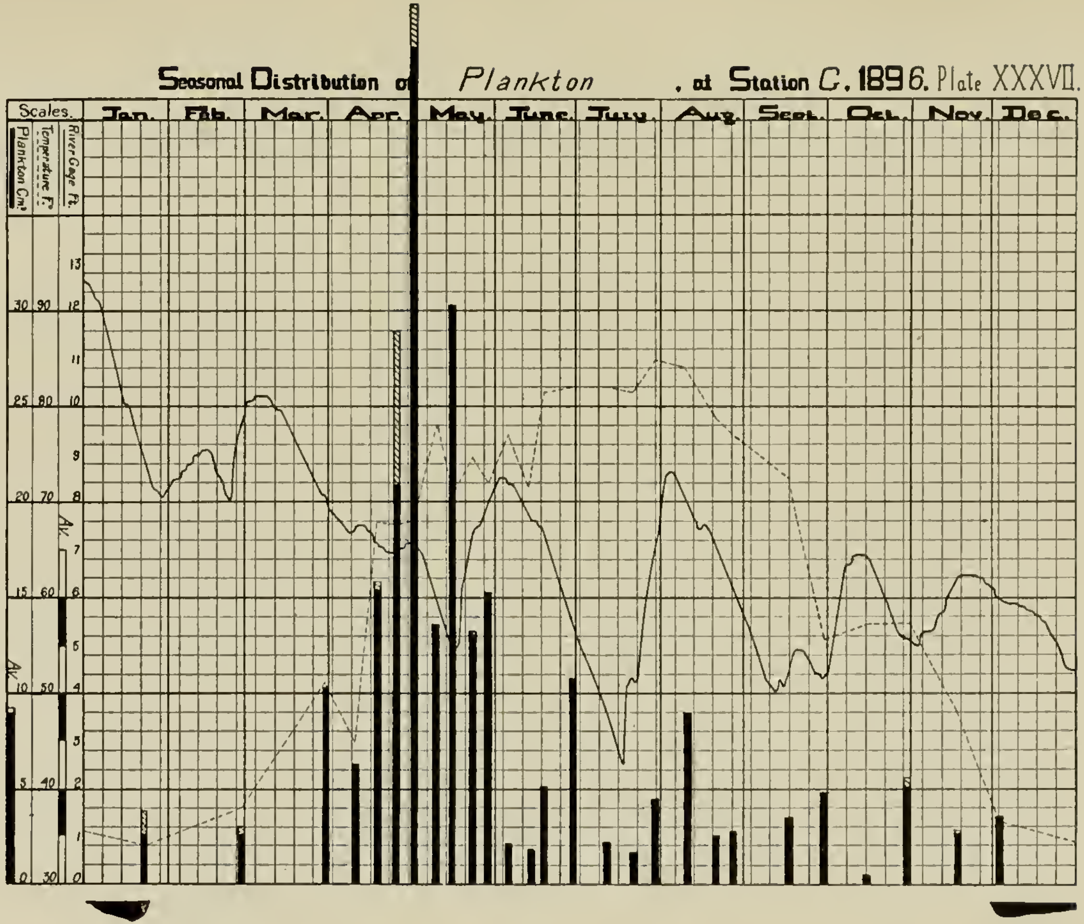


Seasonal Distribution of *Plankton* . at Station G . 1894. Plate XXXV

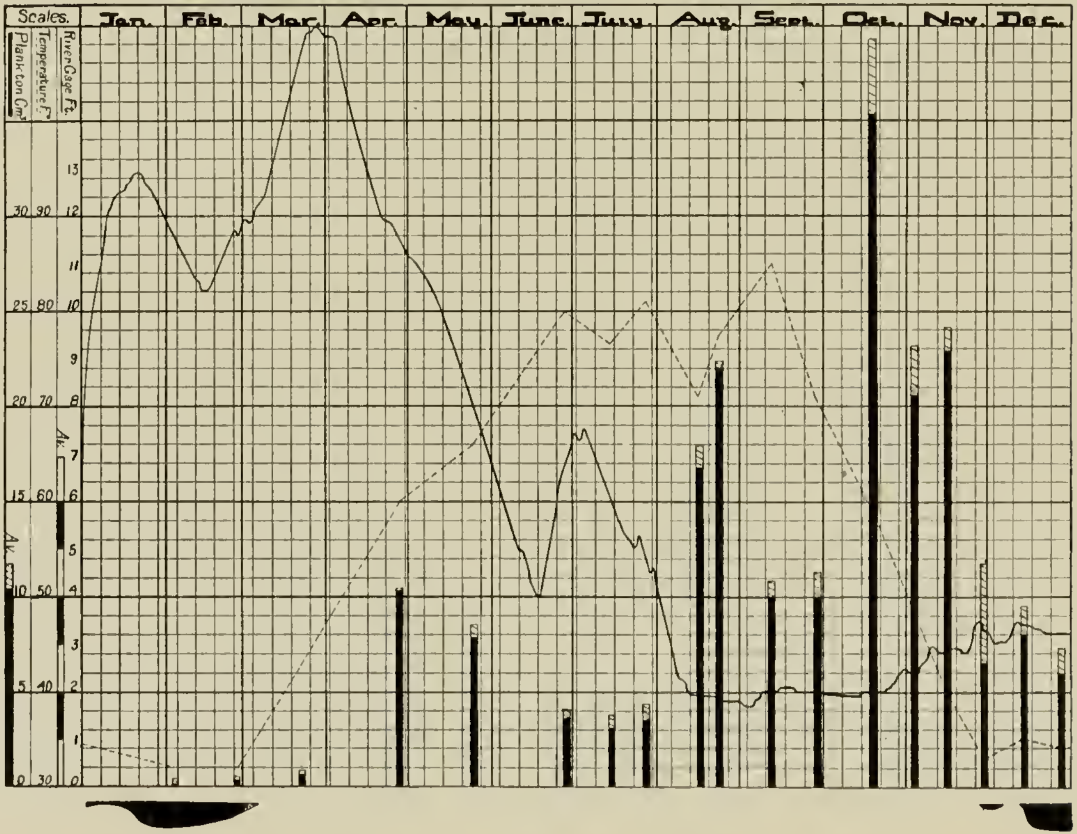
Seasonal Distribution of *Plankton* at Station G. 1895. Plate XXXVI.



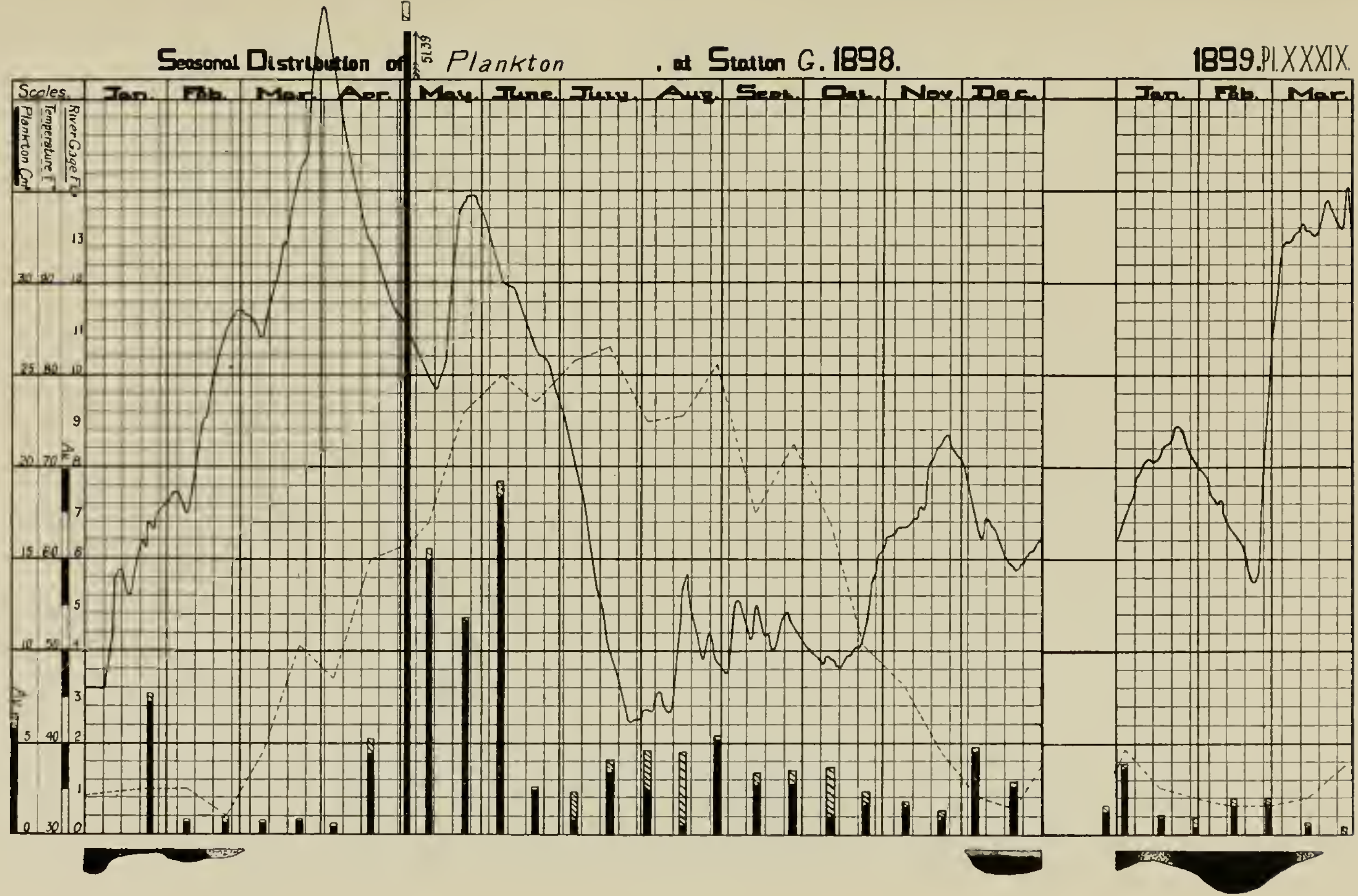
Seasonal Distribution of *Plankton* , at Station C, 1896. Plate XXXVII.



Seasonal Distribution of *Plankton* at Station C. 1897. Plate XXXVIII.

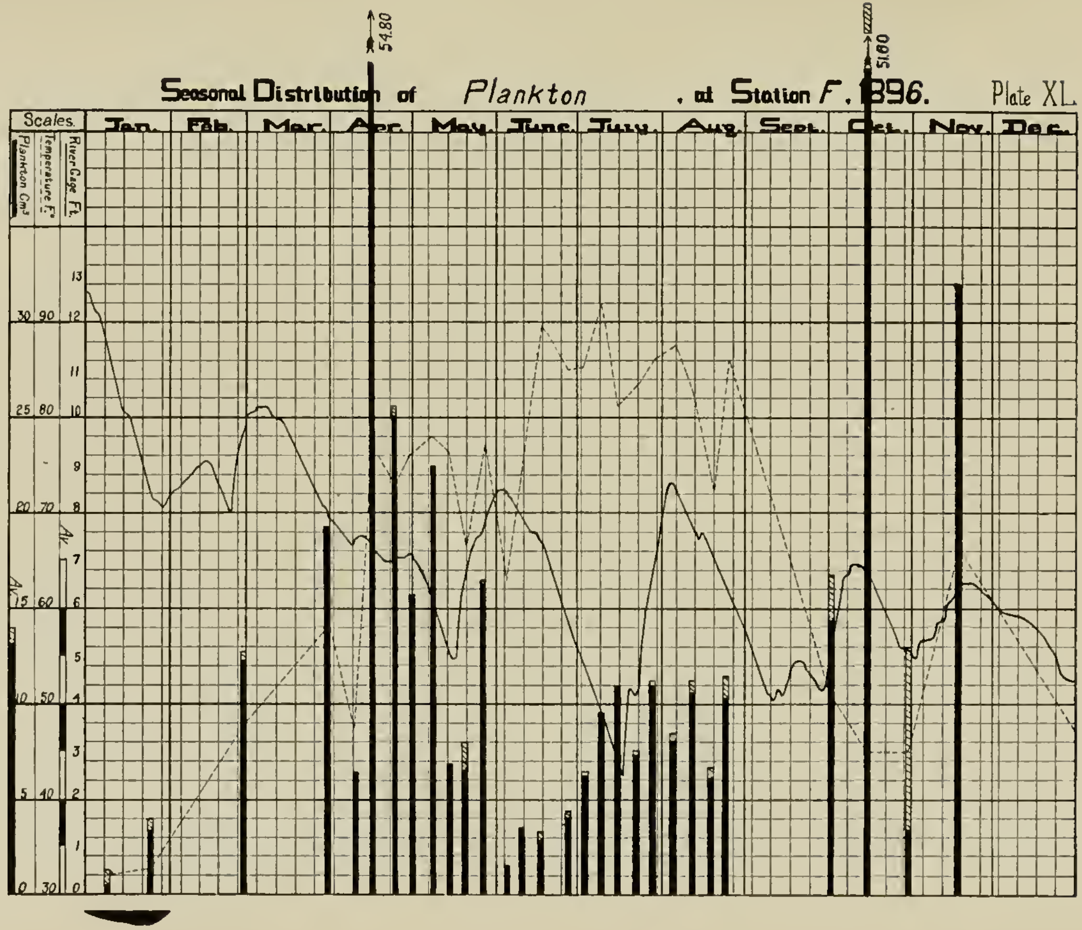


Seasonal Distribution of Plankton, at Station G. 1898.



Seasonal Distribution of *Plankton* at Station F. 1896.

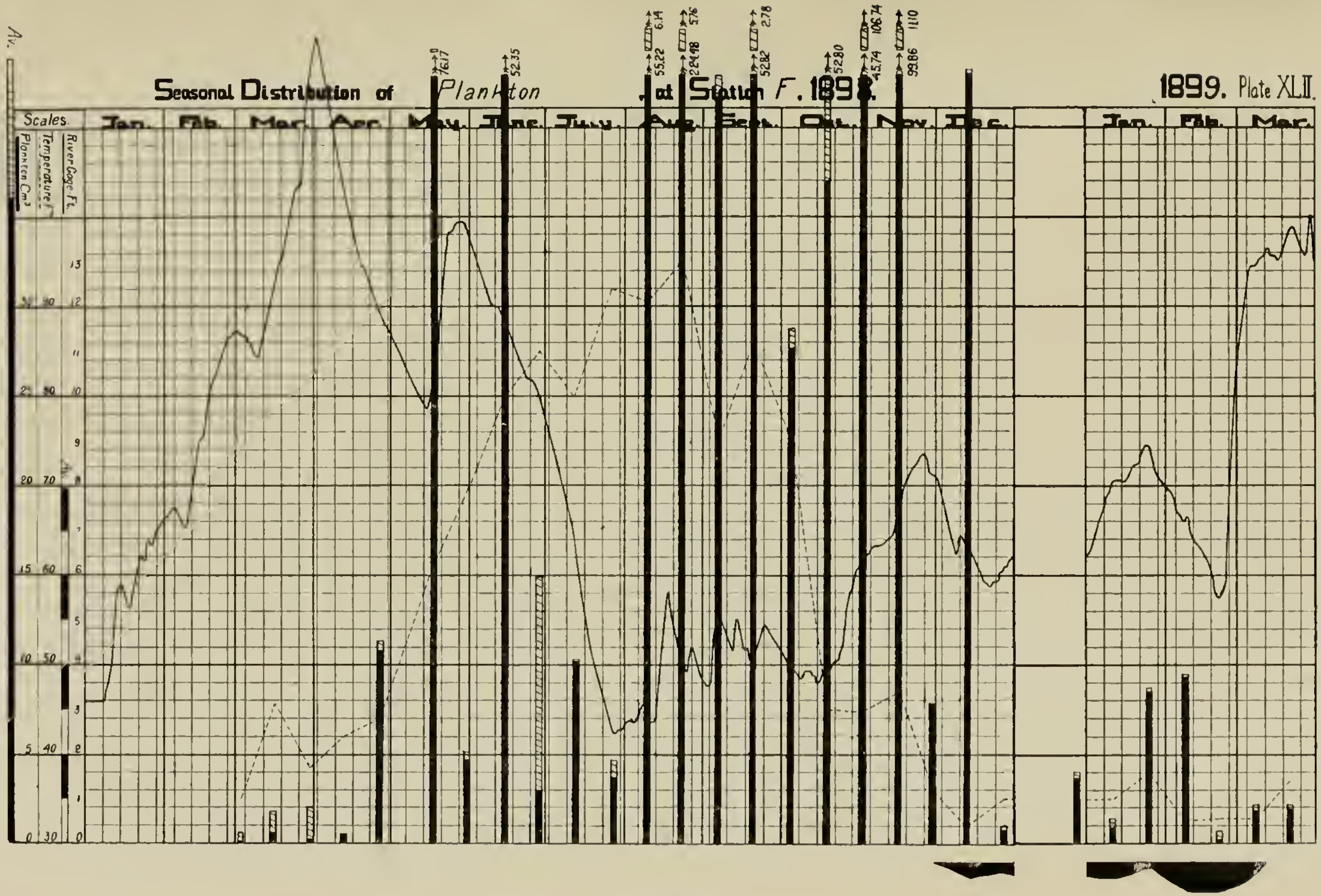
Plate XL.



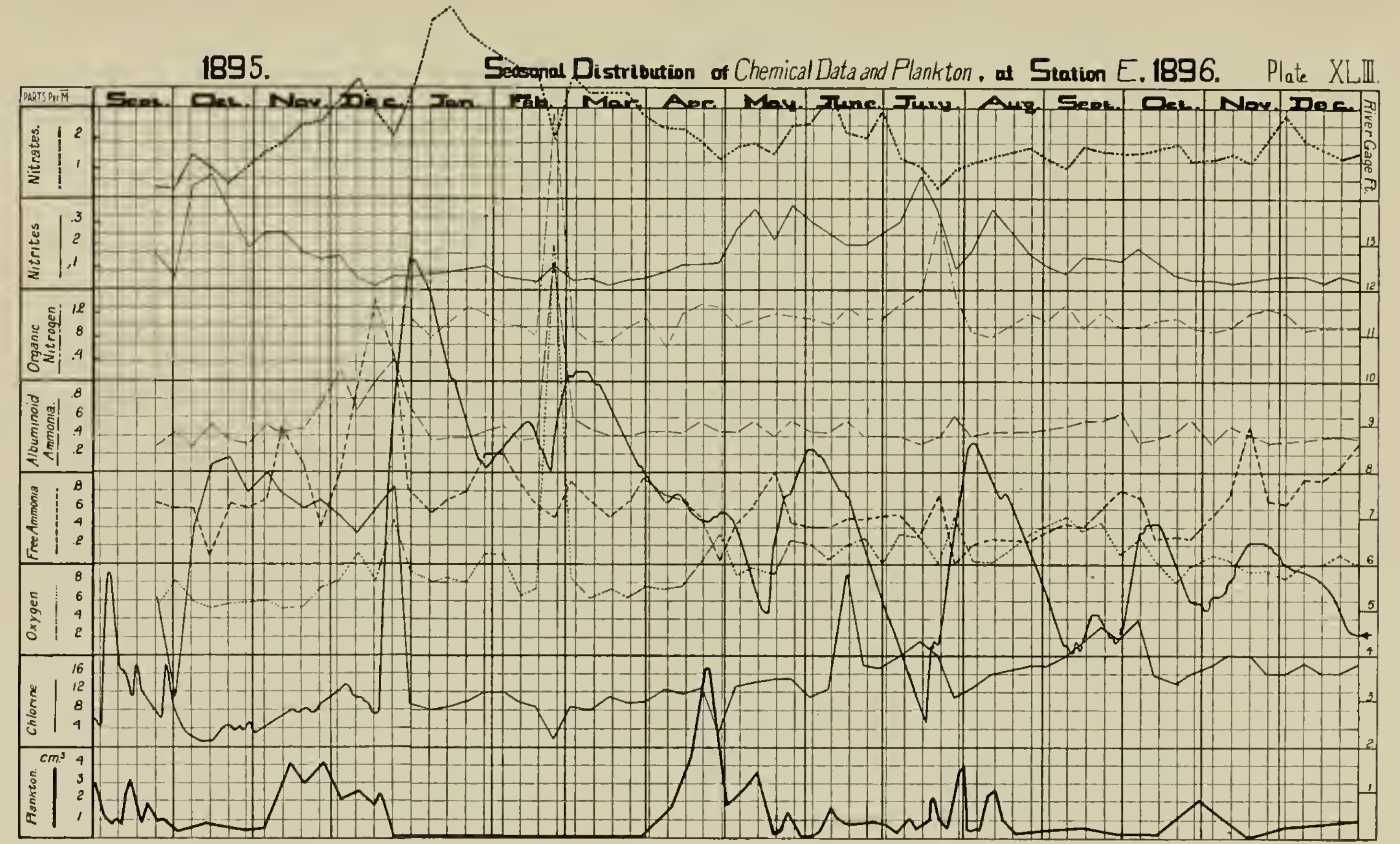
Seasonal Distribution of *Plankton* . at Station *F*. 1897. Plate XLI.

Seasonal Distribution of *Plankton* at Station F. 1898. 1899.

Plate XLII.



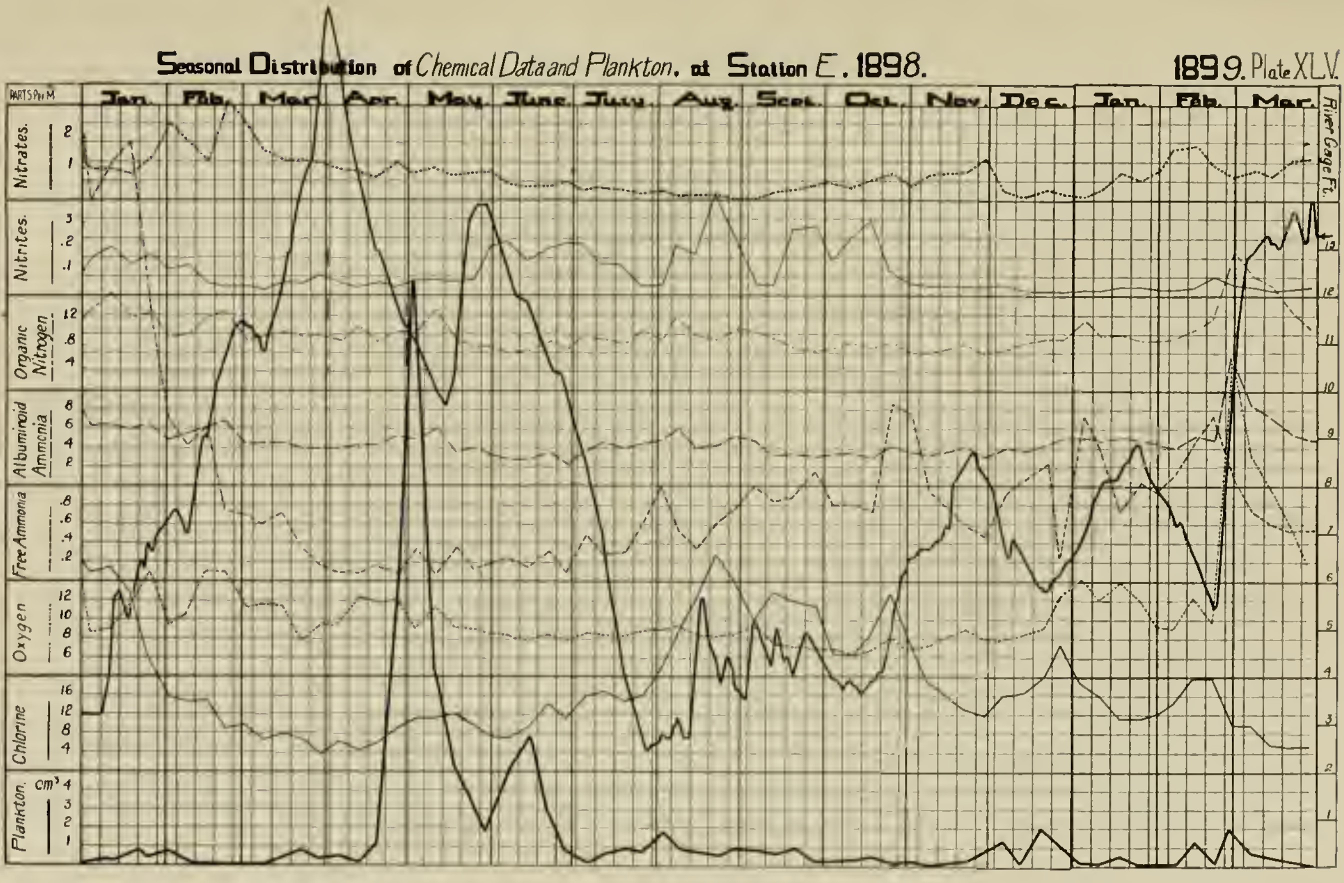
1895. **Seasonal Distribution** of *Chemical Data and Plankton*, at **Station** E, 1896. Plate XLIII.



Seasonal Distribution of Chemical Data and Plankton, at Station E. 1897. Plate XLIV.

Seasonal Distribution of *Chemical Data and Plankton*, at Station *E*. 1898.

1899. Plate XLV.



1896. Seasonal Distribution of *Chemical Data and Plankton.* at Station M. 1897. Plate XLVI.

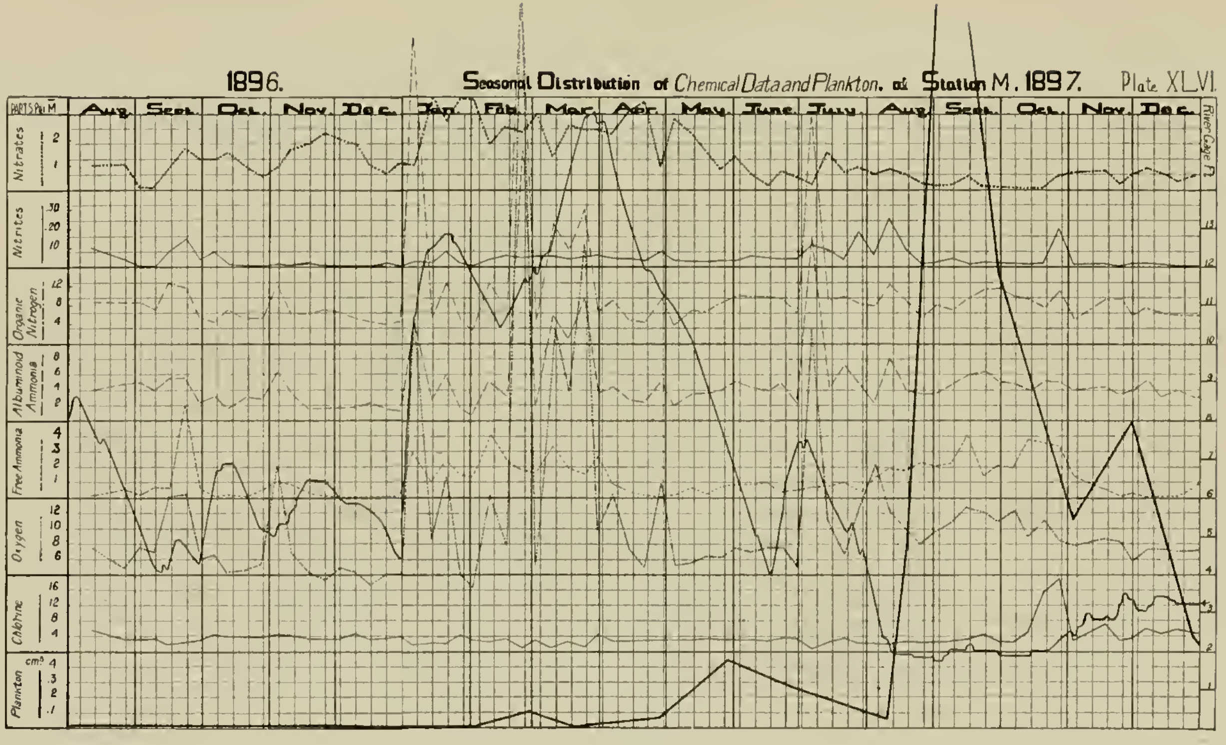
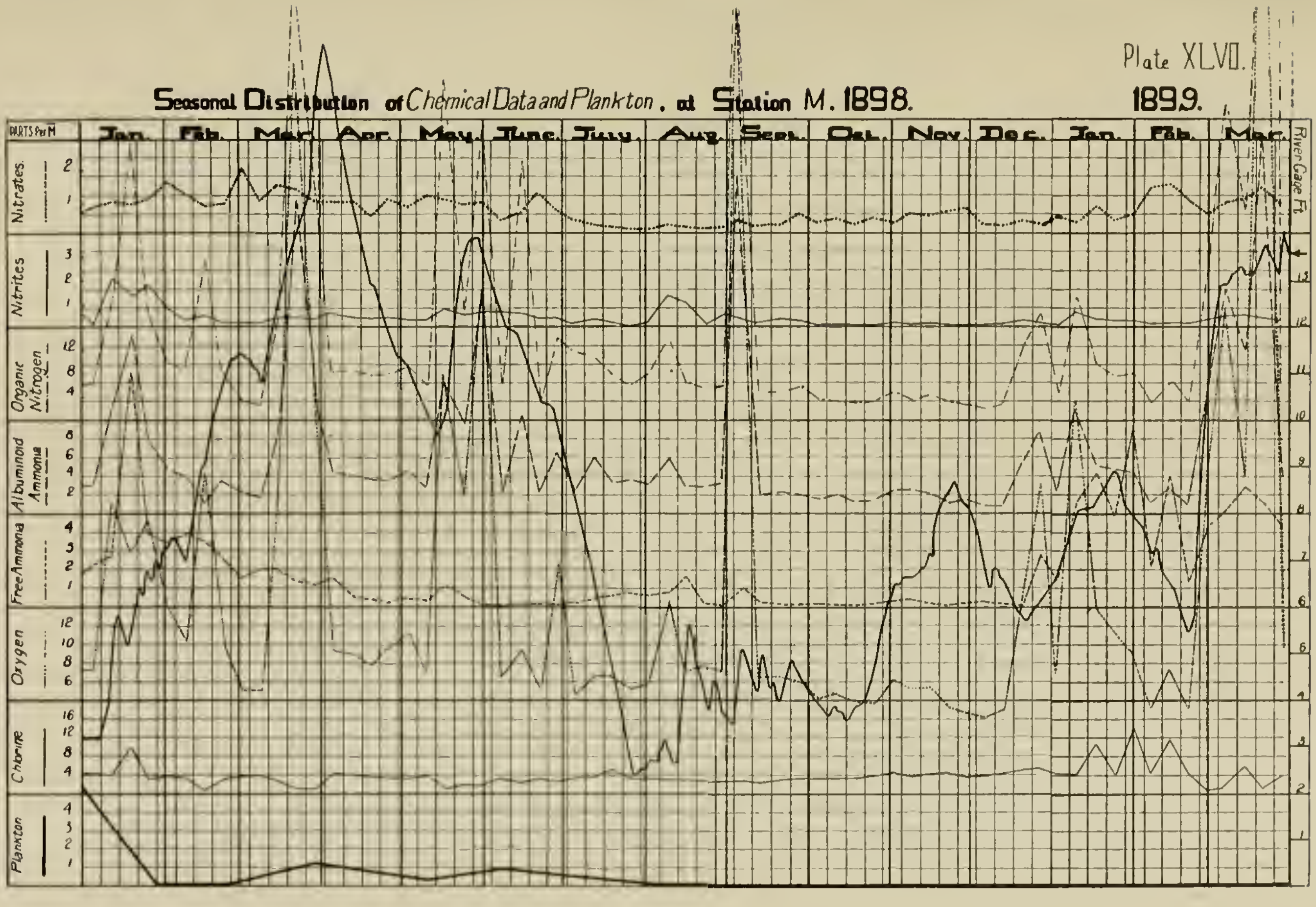
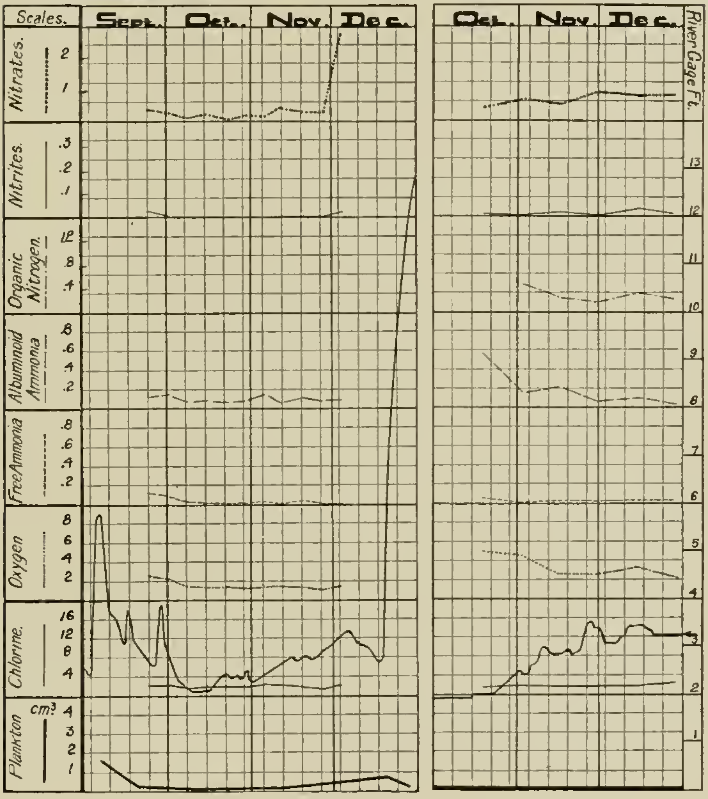


Plate XLVII.

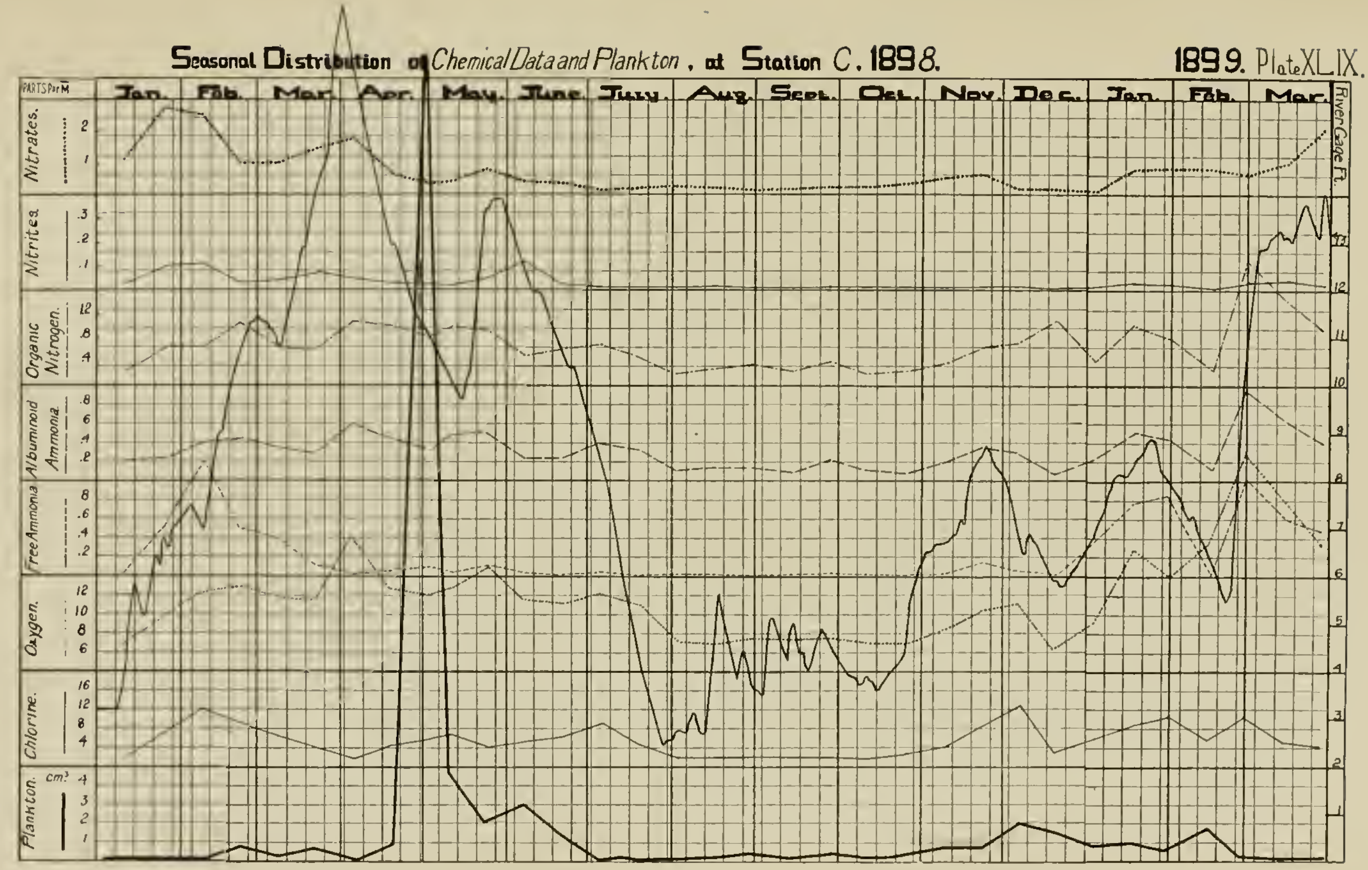
Seasonal Distribution of Chemical Data and Plankton, at Station M. 1898. 1899.

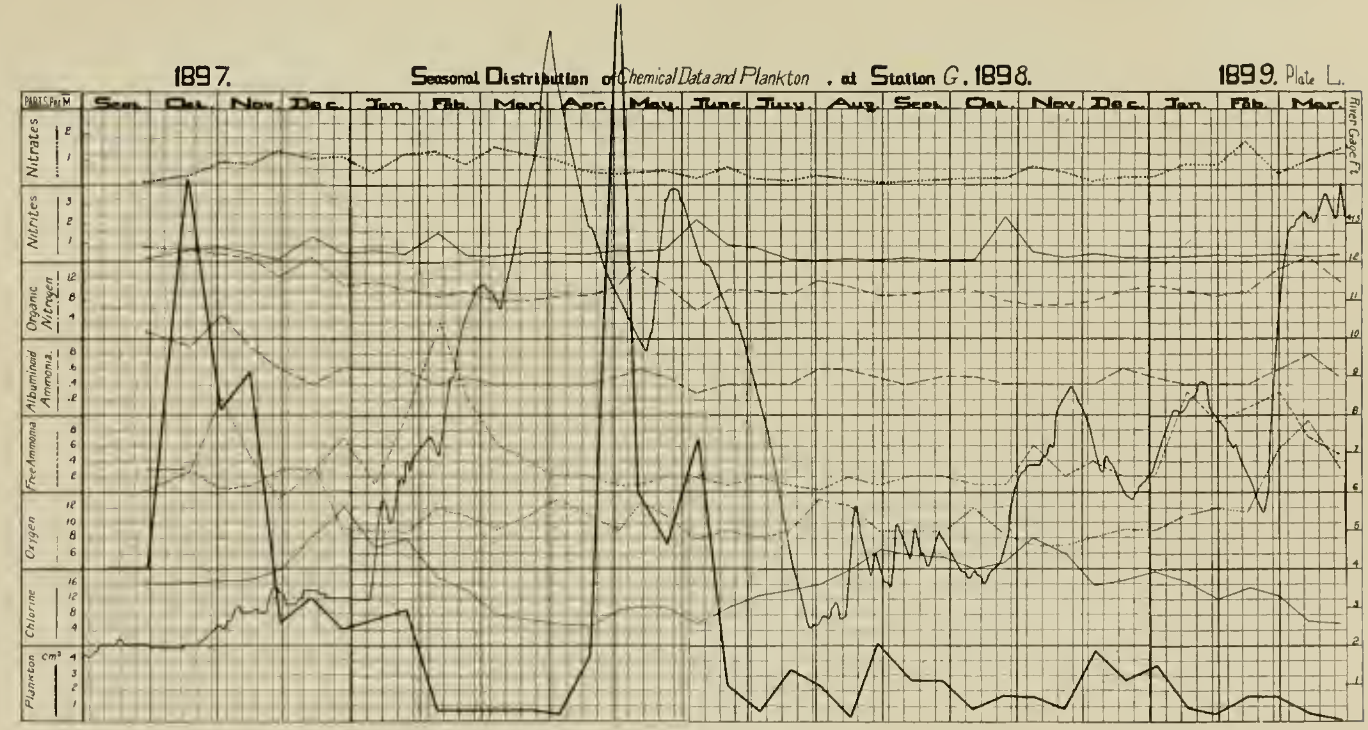


Seasonal Distribution of Chemical Data and Plankton.
at Station C 1895. 1897. Plate XLVIII.



Seasonal Distribution of Chemical Data and Plankton, at Station C. 1898. 1899. Plate XLIX.





Seasonal Distribution of Chemical Data and Plankton, at Station G. 1898.

Plate L.

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