

ILLINOIS
NATURAL HISTORY
SURVEY

1983 FINAL REPORT

EFFECTS OF THREE COMMERCIAL HARVESTING
METHODS ON MUSSEL BEDS



Aquatic Biology Section
Technical Report

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ILLINOIS NATURAL HISTORY SURVEY
RIVER RESEARCH LABORATORY
HAVANA, ILLINOIS 62644

JULY 1983



PROJECT NO. 3-327-R

AQUATIC BIOLOGY TECHNICAL SERIES 1983 (10)

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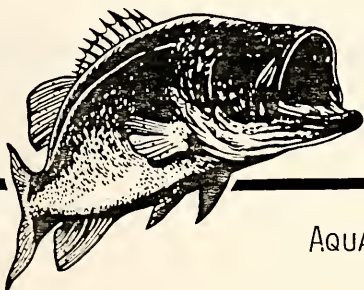
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July, 1983



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by

Richard E. Sparks and K. Douglas Blodgett

ILLINOIS NATURAL HISTORY SURVEY

RIVER RESEARCH LABORATORY

Havana, Illinois 62644

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The work on which this report is based was supported in part by funds provided by the United States Department of Commerce, NOAA, National Marine Fisheries Service, in conjunction with the Illinois Department of Conservation, under the Commercial Fisheries Research and Development Act, Public Law 88-309.

July, 1983

The Illinois Department of Conservation and National Marine Fisheries Service are not responsible for the form and content of data in this publication.

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ACKNOWLEDGEMENTS

We are grateful to: Worth H. Emanuel, a commercial clammer from Maiden Rock, Wisconsin, who located a mussel bed for our study and introduced us to several commercial clammers; Mr. Charles Gilpin, a commercial clammer from Dallas City, Illinois, who conducted the harvesting on our experimental plots; our SCUBA instructors, Mr. Jim Kerker and Jan Jannusche; Dr. Robert E. C. Sparks, Diving Officer, University of British Columbia, and President, Project DEEP, Inc. (Diving Extension Education Program), who arranged a short course in surface-supplied diving for us and flew out the instructors from the east coast in a borrowed plane; Larry DiGiacomo, Director, and Harold "Andy" Anderson, Training Supervisor, Commercial Diving Institute, Whitestone, New York; Mr. Mike Rhyner, who arranged a loan of a Motorola MiniRanger III Radar Ranging System from the Upper Mississippi River Basin Commission (now the Upper Mississippi River Basin Association); Mr. Mike Sweet, who was our first Federal Aid Program Manager at the Department of Conservation, before becoming an Endangered Species Specialist and Mr. Steve Harrison, our second program manager; Mr. John Cookson, Chief of the State-Federal Relations Branch, National Marine Fisheries Service; Dr. David Stansbery, Director of the Museum of Zoology, the Ohio State University, Columbus, Ohio, who offered valuable advice and encouraged us to use the mussel collection of the Museum; our summer divers, Mr. Don Craig and Mr. Bryan Hickman, who also assembled our surface-supply diving rig; Dr. Kenneth S. Lubinski and Miss Stephanie Swecker, who helped us when we needed extra

divers; the Illinois Department of Conservation for storing our diving boat over winter in the Fisheries Headquarters and especially Rudy Stinauer and Kenneth Hills; Mr. Bill Fritz, Manager, Commercial Fishing Program, Illinois Department of Conservation who arranged for us to talk to several commercial clammers including Mr. Charles Gilpin; Mr. Rob Roper, who wrote computer programs for analysis of the mussel data; Victoria Atchley, who entered data and with Katie Roat typed data sheets, this report, and manuscripts for publication; and to the following, who supplied us with equipment and parts and generally kept us running -- Mr. Bill McBride, President, Breathing Air Systems Division of Sub-Aquatics, Inc., Reynoldsburg, Ohio; Mr. Bill Miller and Sandy Bhene, Riverview Marina, Ft. Madison, Iowa; Mr. Jeff Brower, Jack Kugler, and Jeff Kugler, Great Lakes Boat Company, Hamilton, Illinois; Getz Fire Equipment Company, Peoria, Illinois; and Mr. William Schad, Fire Department, Havana, Illinois.

DISCLAIMER

The findings, conclusions, recommendations, and views expressed in this report are ours and should not be considered as the official position of any of the individuals, institutions, or agencies which sponsored the research or which are mentioned in this report. Mention of products or company names does not imply endorsement.

ABSTRACT

Freshwater mussels are harvested from the Upper Mississippi River and its major tributaries for use as nuclei in the Japanese cultured pearl industry. When this project began in 1979, regulations governing types of gear which could be used to harvest mussels had little scientific basis and varied between states.

Research divers using transect lines and 1-m² steel frames, surveyed a mussel bed in the Mississippi River at Ft. Madison, Iowa which had not been harvested previously and was not likely to be harvested during the study because the shells were known to be discolored and of no commercial value. We selected experimental 50 x 150-m plots within the bed which contained similar densities of mussels. A commercial clammer was contracted to use one method or type of gear on each experimental plot, and we recorded the numbers of mussels he kept and culled. Research divers sampled subplots within harvested areas and recorded the number of damaged, dislodged and undisturbed mussels.

Illinois regulations permit the taking of any mussels, other than rare or endangered species, not less than 6.35 cm (2 1/2 in) on the shortest line from the center of the hinge side at a right angle across the shell to the ventral edge. During the 1981 and 1982 field seasons of this study, however, buyers were only accepting washboards (Megaloniaias gigantea) greater than 9 cm (3 1/2 in) and three ridges (Amblema plicata), pigtoes (Fusconaia flava), and mapleleaves (Quadrula quadrula) greater than 7 cm

(2 3/4 in). The buyers' criteria effectively determine what the target mussels are for the commercial harvest.

For every target mussel taken in our study the crowfoot bar (also called mussel brail) dislodged 12.4 live mussels and damaged none, the basket dredge dislodged 35.3 and damaged 13.8, and the commercial diver dislodged 0.1 and damaged none. Although no damage attributable to the crowfoot bar was detected in this study, we have observed that the edge of the mantle and the shell can be nicked when mussels are forcibly removed from crowfoot hooks. Mussels probably recover readily from such minor damage. Damage from the basket dredge was probably lethal in most cases, because shells were crushed or pierced. Non-target thin-shelled species such as fragile papershells (Leptodea fragilis), pink papershells (Proptera laevissima), and pink heelsplitters (Proptera alata) were most susceptible to damage.

On 1 July 1982, Illinois regulations were amended to allow use of underwater air breathing devices. Crowfoot bars and hand picking remain legal and hand rakes, hand forks, and hand dredges (weighing less than 70 pounds) can be used in the Illinois and Mississippi rivers.

INTRODUCTION AND BACKGROUND

PEARL HUNTING

The accidental finding of a pearl in a freshwater mussel set off a "pearl rush" which usually lasted until the mussel beds in that particular stream were completely depleted or until so few pearls were found that people became discouraged. The first "pearl-rush" in this country probably occurred near Paterson, New Jersey in Notch Brook in 1857, when a shoemaker named Howell bit down on a 400 grain pearl in some mussels he had cooked for supper (O'Hara, 1980:4). Within two years not a single mussel was left in the stream, but an estimated \$115,000 worth of pearls had been extracted (O'Hara, 1980:4). The "pearl rush" in the Upper Mississippi River valley started in 1889, with the first pearl "strike" in Wisconsin in the Pecatonica River, a tributary of the Mississippi (O'Hara, 1980:6).

By 1890 people were hunting for pearls in Illinois waters and from 1889 to 1897 the pearl fisheries of the state produced at least \$250,000 (\$2,253,666 in 1980 dollars) worth of pearls (Kunz, 1897:395), although the Illinois River was not known as a prominent pearl-hunting river of the state (Danglade, 1914:8). While it is not known what percentage of the early market is attributable to pearl products alone (since shells were also being harvested for the button industry), Danglade had estimated that the average pearl slug yield for the river was one-half ounce per ton of shells, with the percentage of pearls per ton being much smaller (1914:36). Occasionally, pearls of great value were found in the lower Illinois River with one at Pearl (river mile 41.8) worth \$2,700 (\$19,731 in 1980 dollars)

and one found at Hardin (river mile 21.4) worth \$750 (\$5,481 in 1980 dollars) (Danglade, 1914:36). The washboard (M. gigantea) was the principal pearl bearing shell in the Illinois River and this mussel is still present in the lower Illinois River.

Pearl hunting never assumed great financial importance on the Mississippi River (Nord, 1967:191) and little is on record concerning this aspect of the mussel industry. The value of the 1899 Illinois fishermen's catch from the Mississippi River of \$43,468 (\$401,858 in 1980 dollars) included \$1,425 (\$13,132 in 1980 dollars) worth of pearls (Townsend, 1902:683). In 1922 pearls and slugs accounted for \$1,370 (\$6,806 in 1980 dollars) of the \$11,436 (\$56,819 in 1980 dollars) value of the Illinois mussel catch from the Mississippi River (Sette, 1925:226).

Even today, commercial clammers carefully examine mussels with deformed shells, in the hopes of finding pearls or slugs in the mantle tissue at the site of the injury. Such finds are too rare to be a reliable source of income. For example, during the past seven years, Mr. Charles Gilpin, a commercial clammer from Dallas City, Illinois, has found between 20 and 30 pearls or slugs which he has felt worth keeping, and has sold one for \$800. One of his assistants found a pearl he sold for \$1500. Middlemen, who buy the fresh or "green" mussels from the commercial clammers and steam them out to remove the meats, regularly examine the bottom of the pots for pearls and slugs.

BUTTON INDUSTRY

In 1887, a button worker named John F. Boepple emigrated from Ottensen, Germany to the United States (O'Hara, 1980:4). He was searching for the source of some shells which had been shipped to his father twenty years earlier from a river reported to be full of mussels and located about 200 miles west of Chicago (O'Hara, 1980:4). He first found shells when he cut his foot on one while bathing in the Sangamon River at Petersburg, Illinois, but it wasn't until he came to the Mississippi River at Muscatine, Iowa, that he found the quality and abundance of mussels he needed to start manufacturing pearl buttons (O'Hara, 1980:4-5). By 1903, automatic facing and drilling machines were invented which greatly speeded up production, and the button industry began to boom (O'Hara, 1980:8).

Mississippi River

In 1899 there were 322 Illinois mussel fishermen working the Mississippi and the button-blank factories of Illinois employed 293 people (Townsend, 1902:678-679). Prices paid for shells in 1899 ranged from \$8-10 (\$74-92 in 1980 dollars) per ton. In 1922 there were 16 separate button plants in Illinois employing 455 people (Sette, 1925:193). The by-products from these plants, which included poultry grit and stucco, were valued at \$3,794 (\$18,850 in 1980 dollars) (Sette, 1925:193).

Surveys on the river after 1899 indicated that mussel beds were declining (Carlander, 1954:45). In response to the depleted condition of the resource, a biological station was established at Fairport, Iowa,

in 1930 by the U.S. Bureau of Fisheries. The Fairport Station conducted research on mussel propagation but mussel harvests continued to decline. The degradation of mussel beds was generally attributed to overharvesting and increasing pollution (Carlander, 1954:40,41,48).

As the beds around Muscatine were depleted, the mussel fishery spread into Wisconsin, Minnesota, and Missouri (Cohen, 1921:39). By 1922, there were only 387 people from Illinois employed in all types of fishing on the Mississippi River (Sette, 1925:193) compared to the 322 Illinois mussel fishermen on the Mississippi in 1899, and the mussel harvest was only 468,000 pounds (Table 1). In contrast, the harvest from the Illinois River the same year was 2,759,000 pounds (Table 1). Examination of catch weight and values for 1922 shows that prices paid for shells ranged from \$40-60 ton (\$198-298 in 1980 dollars), so the demand for shells had raised prices above the 1899 levels but the supply of suitable mussels had evidently fallen due to overharvest.

Mussel harvests on the Mississippi were greatly reduced after 1922. While the production of buttons from factories in Illinois, Iowa, and Missouri had remained stable from 1939 through 1948, most of the shells used in production during this time were imported from Tennessee and Arkansas (Carlander, 1954:51). By the mid-1960's the last pearl-button factory at Muscatine closed because the industry could no longer compete with the low cost of plastic buttons (Parmalee, 1967:4).

Table 1. Weight and Value of the Mussel Catch

Year	Illinois River		Illinois Catch from Mississippi River		State of Illinois ^a	
	Pounds	Value, \$	Pounds	Value, \$	Pounds	Value, \$
1894		1,063,500				1,313,628
1899		886,250				665
1908		340,337				43,468
1922	2,759,000	68,500	468,000	11,436	9,265,000	264,395
1931	1,034,400	8,341				
1955		1,230			18,000	254
1956	30,000	450			44,000	2,105
1957					9,000	1,000
1958	6,000	254			22,000	2,657
1959					100,000	2,000
1960					400,000	14,000
1961					100,000	3,000
1962					400,000	16,000
1963	900,000	22,500			1,812,000	41,843
1964	750,000	18,000			73,000	191,469
1965	2,318,000	75,335			1,358,000	59,000
1966	2,236,800	109,461	362,000	11,765	4,518,000	327,100
1967	776,960	38,848	2,489,200	130,806	7,115,300	604,308
1968	185,800	8,361	148,800	66,870	1,560,000	170,413
1969	663,300	43,117	545,500	30,003	328,000	23,000
1970	54,200	4,068			1,340,000	81,000
1971					125,000	11,000
1972					24,000	3,000
1973			350,000	51,886	412,600	61,000
1974	160,000	16,000				
1975	440,000	39,431				
1976	160,400	21,170				
1977	576,000	79,289				
1978	220,200	34,824				
1979	24,800	3,667				
1980	167,200	23,489				
1981	265,600	43,913				
	NO REPORTS OBTAINED					
1973		24,688				
1974		55,676				
1975		28,537				
1976		100,855				
1977		41,092				
1978		4,191				
1979		23,489				
1980		23,489				
1981		43,913				
1973						
1974						
1975						
1976						
1977						
1978						
1979						
1980						
1981						

^aFigures from 1971 to 1981 are for Wabash, Illinois and Mississippi only. Harvest from other rivers is probably minor. Figures probably underestimate actual harvest because not all mussel buyers may have been contacted in 1971-75, and of those contacted not all reported their catches (Fritz, 1982).

bValue of shells and pearls.

Sources:
 1894 -- Smith, 1898.
 1899 -- Townsend, 1902; Carlander, 1954.
 1908 -- Danglade, 1914.
 1913 -- Coker, 1921
 1922, 1931 -- U.S. Bureau of Fisheries. Report of the Commissioner of Fisheries, Administrative Report.
 1922 -- Sette, 1925.
 1955-1965 -- Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service.
 1965-1967 -- Lopinot, 1968.
 1968-1970 -- National Marine Fisheries Service, U.S. Department of Commerce.
 1971-1981 -- Fritz, 1982.

Illinois River

In 1907 a button or blank factory was established on the Illinois River at Beardstown and the next year another plant was located at Meredosia (Danglade, 1914:8). The average price of shells from the lower Illinois River was \$25 per ton (\$178 in 1980 dollars) in 1909. In 1912 there were 9 button factories on the lower river: 2 at Meredosia, 1 at Naples, 5 at Pearl, and 1 at Grafton (Danglade, 1914:8). In the same year the average price paid for shells had dropped to \$12-13 (\$89-95 in 1980 dollars) per ton with high-quality shells such as ebony shells (Fusconaia ebena) and sand-shells (Ligumia recta and Lampsilis anodontoides) commanding \$50-60 (\$365-439 in 1980 dollars) per ton (Danglade, 1914:12).

The earliest reliable commercial mussel harvest information for the Illinois River is contained in a statement made by Danglade:

The Illinois reached its maximum shell production during the season of 1909, when thousands of tons of good button shells were gathered and put in piles along the shore to await shipment. (1914:8)

Danglade also found that in 1912 the mussel fisherman in the river from Kampsville (river mile 32.0) to Grafton (river mile 1.0) averaged a daily yield of 500-700 pounds of shells per man (1914:23).

The "boom" in shell collection did not last and by 1911 overharvesting, siltation, land reclamation, and pollution were affecting mussel populations (Forbes and Richardson, 1913; Danglade, 1914:47,48). From 1909 to 1912 the number of boats engaged in mussel fishing on the entire river fell from

approximately 2,600 to 400 (Danglade, 1914: 8). In this same period, the number of commercial mussel fishermen working between Meredosia and Naples fell from 200 to 25-35 (Danglade, 1914:21). The total value of shells and pearls taken from the river dropped from \$139,000 (\$1,063,500 in 1980 dollars) in 1908 to \$128,692 (\$886,251 in 1980 dollars) in 1913 (Table 1).

Although the data are incomplete for the years following 1913, the values of the 1922 mussel catch and the 1931 catch were greatly reduced from previous years (Table 1). The mussel catch data for 1956 and 1958 follow the trend of previous years, showing greatly reduced harvests and values (Table 1).

CULTURED PEARL INDUSTRY

In the 1950's, Mikimoto of Japan perfected a method for growing pearls in oysters (Parmalee, 1967:4 and Peach, 1982:1). The procedure required spherical, nacreous beads, which must be nearly the size of the finished pearl. The Japanese produced the beads by slicing selected freshwater mussel shells from the Mississippi drainage, cubing the slices, then pressure grinding and polishing these cubes into beads. The beads were surgically implanted in the mantle of the pearl oysters, which were then carefully nurtured for several years in sea farms. The oysters coated the beads with layers of nacre usually less than 1 mm thick, to form the cultured pearl.

It is theoretically possible to use freshwater mussels to make cultured pearls, but the culturing techniques have yet to be worked out and will

require meticulous hand labor, which will be costly in this country. Pearls of America, Inc. of Fort Worth, Texas, and Tennessee Shell Company of Camden, Tennessee, reportedly have had some success in pilot pearl culturing programs (Peach, 1982:1). The American Shell Company of Knoxville, Tennessee, recently used shells of species whose nacre is naturally pink or purple to manufacture fine costume jewelry, but the required quantity of material is less than 25 tons per year (Peach, 1982:1), and so does not represent a large market for shells.

Mississippi River

The pearl-culture markets of the 1960's stimulated an increase in the number of licensed mussel fishermen and in the catch (Table 1 and Lopinot, 1968:6). From 1961 to 1966 the number of mussel-fishing licenses sold in Illinois rose from 69 to 1,279 (Lopinot, 1968:6). The pearl-culturists required thick-shelled mussels of the genera Amblema, Quadrula, Pleurobema, and Megalonaias (Cahn, 1949:49, in Starrett, 1971:267). The interest in these mussel species was fortunate as some of those valued as pearl-button stock, such as the ebony shell (Fusconaia ebena) and yellow sandshell (Lampsilis anodontoides) probably were not available in quantities to sustain the increased harvests brought by the pearl-culture industry. The Illinois catch from the Mississippi River during 1965-1967 consisted mostly of washboards (Megalonaias gigantea) (75-80%) and three ridges (Amblema plicata) (15-20%) (Lopinot, 1968:8).

The pearl-culture-related harvest did not last, peaking at over 2,000,000 pounds in 1966, then declining drastically in 1967 (Table 1)-- the result of Japanese requirements for larger shells and possible overharvesting in 1966 (Lopinot, 1968:19). During this period the market price paid for shells was \$40-60 per ton (\$99-149 in 1980 dollars) (Nord, 1967:187 and Lopinot, 1967:12).

Mussels are currently harvested from the five states adjoining the upper Mississippi River above St. Louis. Since 1975, the annual Illinois harvest of shells from the Mississippi River again has increased steadily to over 2 million pounds in 1981 (Table 1).

Illinois River

The harvests from the Illinois River topped 2 million pounds in 1965 and 1966, and were similar to earlier catches for the button industry (Table 1). From 1965 to 1967, the catch from the Illinois River was much greater than the catch by Illinois fishermen from the Mississippi River (Table 1). The catch from the Illinois declined abruptly in 1970 and has fluctuated greatly since 1974 at a much lower level than the Mississippi catch (Table 1).

Most of the shell beds fished commercially are located in the lower part of the Illinois River, where there were substantial standing crops of mussels in 1966-67 (Starrett, 1971:390). Since then, commercial clambers have also started harvesting beds along the middle reach of the Illinois River, at the lower end of Peoria Lake (Personal communication, June 1982, Mr. Charles Gilpin, commercial clammer, Dallas City, Illinois).

HARVESTING GEAR

There are local variations in the types of mussel harvesting gear and the names used to describe them, but the following list probably encompasses the major types:

- (1) Wading and hand-picking.
- (2) Diving with compressed air.
- (3) Hand dredges, forks, and rakes.
- (4) Basket dredge.
- (5) The crowfoot bar or brail.

Each of these will be described in more detail below.

Wading and Hand-Picking

In streams that are shallow enough for wading, mussels can be picked by hand from the bottom. Where the water is too turbid to see the mussels, they have to be located by the fingertips or feet. Mussels taken by wading and picking probably represent only a minor portion of the total mussel harvest. It is possible for the person doing the wading and picking to select mussels of commercial size, leaving undersize mussels undisturbed. Waders and pickers could remove all the commercial-sized mussels from shallow areas, but mussels in deep areas are not vulnerable to harvest by this method and even beds in shallows would receive a respite from harvest during periods of high water.

Diving With Compressed Air

Most commercial clammers who dive use a hookah rig, which consists of an air compressor in an anchored boat, with one or more hoses supplying compressed air to the face masks of the divers. Clammers generally do not use SCUBA because of the expense of buying and refilling the high-pressure air tanks. Divers can select commercial-size mussels by sight or feel, leaving undersize mussels undisturbed. In clear water, divers could remove all commercial-size mussels. In turbid waters, such as the Illinois and Mississippi rivers, the water is pitch black 18 inches or less beneath the surface and divers must feel for the mussels. In complete darkness and with a fairly uniform bottom, it is difficult for divers to maintain their orientation, and some divers and conservation officials feel it would be virtually impossible to systematically remove all commercial-size mussels from a bed in a turbid river.

It is possible for divers to lay out chains or ropes along the bottom in order to systematically cover an area, but commercial clammers do not use such methods at present. In the wintertime, the turbid Mississippi and Illinois rivers become clear enough to see the bottom in 10-15 feet of water, because there is little or no runoff carrying sediment into the rivers and ice cover prevents the wind from generating waves which roil the bottom. Some states, such as Illinois, prohibit commercial clamming during the winter, and commercial clammers may consider winter diving too risky and the expense of cold-water diving suits too costly. Also, mussels may burrow into the sediments for the winter.

Hand Rakes, Forks and Dredges

The basic design of the hand dredge or "digger" consists of a metal hoop, flattened on the side which rests on the bottom, with an attached net for holding dislodged mussels. Several metal teeth may be attached to the bottom side of the hoop, to assist in dislodging mussels and digging into the bottom. "Hand" dredges are attached by a rope and bridle to the bow of the boat, with a 16-20 ft handle to keep the hoop upright and to raise the dredge at the end of a drag along the bottom. The boat, powered by an outboard motor, is used to draw the dredge across the bottom.

Small rakes and forks are used in shallow water much the same way one would use a garden rake or pitchfork to remove pebbles or sticks from garden soil.

Basket Dredge

Basket dredges look like larger versions of the hand dredge, without the handle and with the net replaced by a basket made of heavy steel wire or flat steel. Spring-loaded teeth dig into the bottom and are designed to flip back if they meet a submerged log or other obstruction. The mesh size in the basket is selected so that undersize mussels fall through and are not brought to the surface. Basket dredges are attached to the boat by means of a bridle and are drawn across the bottom by the boat and raised with a power windlass. Interpretation of regulations governing the size and type of the dredge, and use of motorized equipment, was the subject of controversy when our research began. In Illinois in 1979 the

width of the dredge could not exceed 24 inches, and the power windlass could not be used to haul the dredge across the bottom, only to lift it from the bottom. Basket dredges reportedly can leave furrows in the bottom, and Mr. Worth Emanuel reported (Personal communication, 3 May 1979) that on occasion he has asked his divers to smooth the ridges left by dredges, following complaints by commercial fishermen that the ridges lift up the bottoms of seines, allowing fish to escape.

Crowfoot Bar or Brail

The crowfoot bar consists of gangs of multipronged hooks attached to a bar which varies in length. A bridle and rope are attached to the bar, which is dragged over the mussel bed. When a hook enters a live mussel whose shells happen to be open, the mussel will clamp on the hook and be dragged from the bottom. The crowfoot bar can be made selective for larger-sized mussels, by increasing the diameter of wire from which the hooks are made, or by adding a bead of material from a welding rod to the tip of the hooks. The gape of a mussel when it is actively siphoning is generally proportional to the size of the mussel; hence, the large-size hooks can only enter large-size mussels. Since not all living mussels may be actively siphoning and since many may not be oriented in just the right direction for a hook to enter the gape, the crowfoot bar is relatively inefficient. One of the purposes of our study was to measure the efficiencies of the various types of gear. Some commercial clambers use an outboard motor to draw the bar downstream across a bed, while others use an underwater sail or "mule" to catch the current and pull them along because they feel the noise of an outboard causes some of the mussels to close up. The mussels will also close if the bar strikes them before the hooks, so

commercial clambers put corks in the ends of bars made from pipes, to provide an air space and some buoyancy, or they may use a weighted wooden bar. Some commercial clambers put small wheels at the ends of the bars to keep the central portion of the bar slightly elevated above the bottom. One disadvantage that the crowfoot bar shares with the dredge is that thin-shelled mussels which cannot be sold commercially are brought to the surface.

REGULATIONS

The midwestern states have different regulations governing the types of gear and methods used in harvesting mussels. For example, at the time this project was initiated in 1979, the states of Wisconsin, Missouri, and Iowa allowed taking of mussels from the Mississippi River by diving with compressed air, while Illinois did not (Table 2). In parts of the Upper

Table 2. Legal mussel collection methods (L) of five Upper Mississippi River states in 1979.

State	Collecting Methods						
	Brail	Hand Picking	Diving with Compressed Air	Rake	Fork	Hand Dredge	Basket Dredge
Iowa	L	L	L				
Illinois	L	L		L	L	L	
Minnesota	L				L	L	
Missouri	L	L	L	L	L		
Wisconsin	L	L	L		L		

Sources: Waters, 1980:198 and Illinois Department of Conservation, Conservation Laws.

Mississippi River, the state boundaries fall across mussel beds, so that one type of gear might be legal on part of the bed and illegal on another part.

NEED FOR THIS RESEARCH

Although there is a need to determine whether harvesting for the cultured pearl industry is depleting mussel beds to the point where the populations will not be sustained, our research was not designed to answer this question. The purpose of our research was to quantify the effects of three harvesting methods on a mussel bed, in order to answer the following questions: (1) How many target (commercial) and nontarget mussels are disturbed or damaged by the gear on the bottom and not brought to the surface? (2) Of those brought to the surface, how many are kept (target mussels) and how many culled? (3) Of the culled mussels, how many are damaged, and how many are able to burrow back into the bottom?

The three harvest methods we investigated were diving with compressed air, the basket dredge, and the mussel brail. When our research began in 1979, many biologists and conservation agents felt that Illinois regulations should be amended to allow diving and that differences between hand dredges, which were legal, and basket dredges, which were not, needed to be clarified. This would make Illinois regulations more consistent with Missouri and Iowa, which control the side of the Upper Mississippi River opposite Illinois. The rationale for the proposed change was that the basket dredge was a nonselective, destructive harvesting technique, while commercial divers were highly selective and did not harm nontarget mussels,

but there were no data to support this rationale. The mussel brail is probably the most commonly used harvesting gear and is also a favorite sampling technique for biologists. Hence, we were interested in determining the efficiency of the mussel brail, both as a sampling technique and as a harvesting method. The brail is often used to locate beds, because a wide area can be searched fairly quickly with minimal expense, especially if an underwater sail is used to pull the boat and its attached brail rather than a gasoline-powered engine. By comparison, diving is more costly, slow, and best suited to beds with dense populations of target mussels. The brail does have some undesirable characteristics as a harvesting method: nontarget mussels are caught and brought to the surface and there is potential for injury when mussels are removed from the crowfoot hooks.

A literature search conducted in preparation for this study revealed no other study in which the effects of commercial harvesting methods were compared side by side under controlled conditions in large, turbid rivers, such as the Mississippi and Illinois. In the late 1960's, the state of Ohio contacted all the states in the Midwest for the purpose of establishing a management policy for freshwater mussels. The consensus was that little was known regarding the management of mussels (Clark, 1971:26-33), despite previous experience with depletion of mussel beds by harvesting for the pearl button industry and despite research and management efforts to propagate and restore beds at that time (Carlander, 1954:40-51).

METHODS

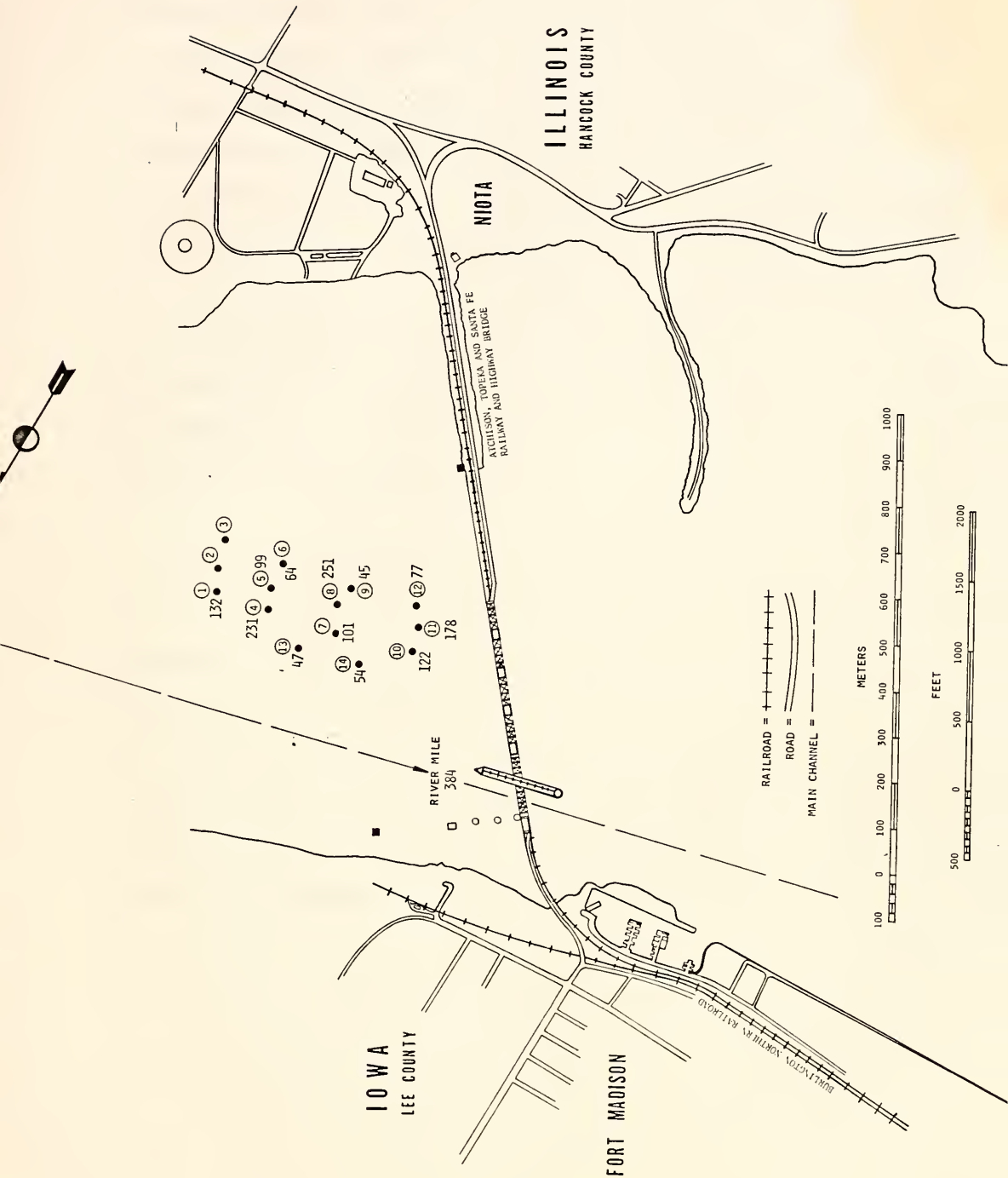
STUDY SITE

Mr. Worth H. Emanuel used to operate shell camps along most of the Upper Mississippi River, and remembered that an unharvested bed existed in the east side of the Mississippi River just upstream from Niota, Illinois and Ft. Madison, Iowa (Figure 1). We sampled the bed 23 May 1979 with a crowfoot bar, and found that the species composition and densities were comparable to published descriptions of other beds in the Upper Mississippi River. The bed was unharvested because a high proportion of the shells contained a tolberg layer, which made them unsuitable for use in the cultured pearl industry. The tolberg layer appeared as a brown or yellow stain in the nacre. It contained an organic wax to which the nacre from the pearl oyster would not adhere (Latendresse, 1980:174). By using a bed of no commercial value, we avoided the problem of having to police the bed to eliminate uncontrolled harvesting between sampling periods.

ESTABLISHMENT OF PERMANENT PLOTS

Establishment of permanent plots in the bed of the Mississippi River presented special problems. Recreational boaters or river ice invariably removed surface markers. Subsurface markers had to be designed to avoid hazard to boaters, and had to be strong enough to resist being pulled loose if they were snagged by fishermen's hooks. We developed the

Figure 1. Map of study area (right). Two black squares show position of transponders used for distance determinations. Black circles show location of ground anchors in the bottom of the river, which mark upstream left corners of 50-m wide by 150-m long plots. Anchors and plots are numbered from 1 to 14 (in open circles). Other numbers refer to the total number of live mussels taken in four 1-m² samples prior to harvest. For example, a total of 132 live mussels were taken at anchor number 1. Sampling was never completed at anchors 2 and 3 because of submerged brush and trees.



following methods to overcome these problems, and successfully established twelve permanent plots which were used in the summers of 1981 and 1982.

Temporary marker buoys, consisting of plastic jugs attached to cement blocks, were laid out in a grid pattern over the mussel bed. The marker buoys were placed so that they represented the upstream left corner of plots which measured approximately 50 m wide (across the river) and 150 m long (from upstream to downstream, see Figure 1).

Divers then screwed steel ground anchors into the bottom at the locations marked by the cement blocks. The divers tied one-centimeter nylon ropes and marker buoys to the ground anchors, then the temporary buoys were removed. The ground anchors were 1.2 meters tall, and were normally used to anchor house trailers against high winds.

The position of the ground anchors was accurately determined using a Motorola MiniRanger III. Two radar transponders were placed on shore, one on the Atchison, Topeka, and Santa Fe railway bridge abutment and another on a guide cell upstream from the swing span on the bridge (Figure 1). The transceiver and console were placed in the boat and the position of the boat determined by triangulation from the shore stations. The position of the ground anchors was determined by picking up the marker buoy and slack rope and positioning the boat until the line was taut and straight up and down in the water.

Marker buoys were left in place only when we were working on the bed. On weekends and over winter the marker buoys were unclipped from the line and another length of line with a cement block attached was clipped on and stretched downstream from the ground anchor. The anchors were relocated using the MiniRanger and a grappling hook (Figure 2). Temporary marker buoys were thrown out at locations determined by the MiniRanger readings. A grappling hook was then dragged across the bottom downstream from the marker buoy until the bottom line from the anchor was snagged and brought to the surface. The extra line and cement block were then unclipped and a buoy attached. Once the permanent anchor was located, the rest of the plot could be laid out from that point.

QUANTITATIVE SAMPLING USING SURFACE-SUPPLY DIVING

We equipped a 24-foot pontoon boat with an air compressor, primary and secondary storage banks, and a control console for two-way voice communication with a diver using a Kirby-Morgan Band Mask or Superlite 17 helmet (Figure 3).

The boat was anchored just upstream from the marker buoy attached to the ground anchor. The diver descended and stretched a bottom line downstream from the ground anchor to establish the left boundary of the plot. He then placed four 1-m² steel frames against the line, arranged from upstream to downstream (Figure 3). The guide line and voice commands from the console tender were necessary because the visibility was zero, and the diver had to do everything by touch. The console tender knew the approximate location of the diver in relation to the marker buoy by

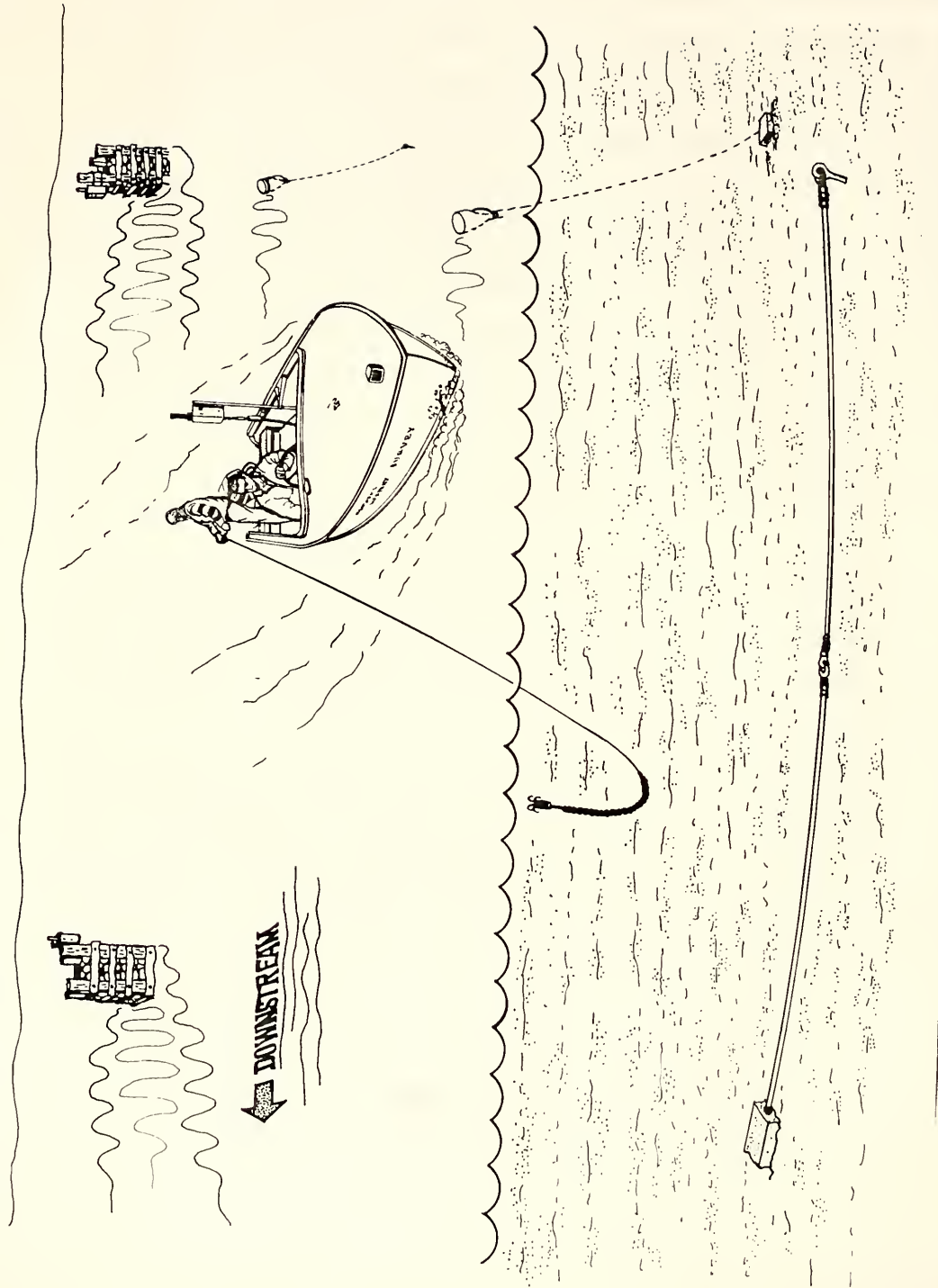


Figure 2. Method for relocating permanent plot markers on the river bottom.

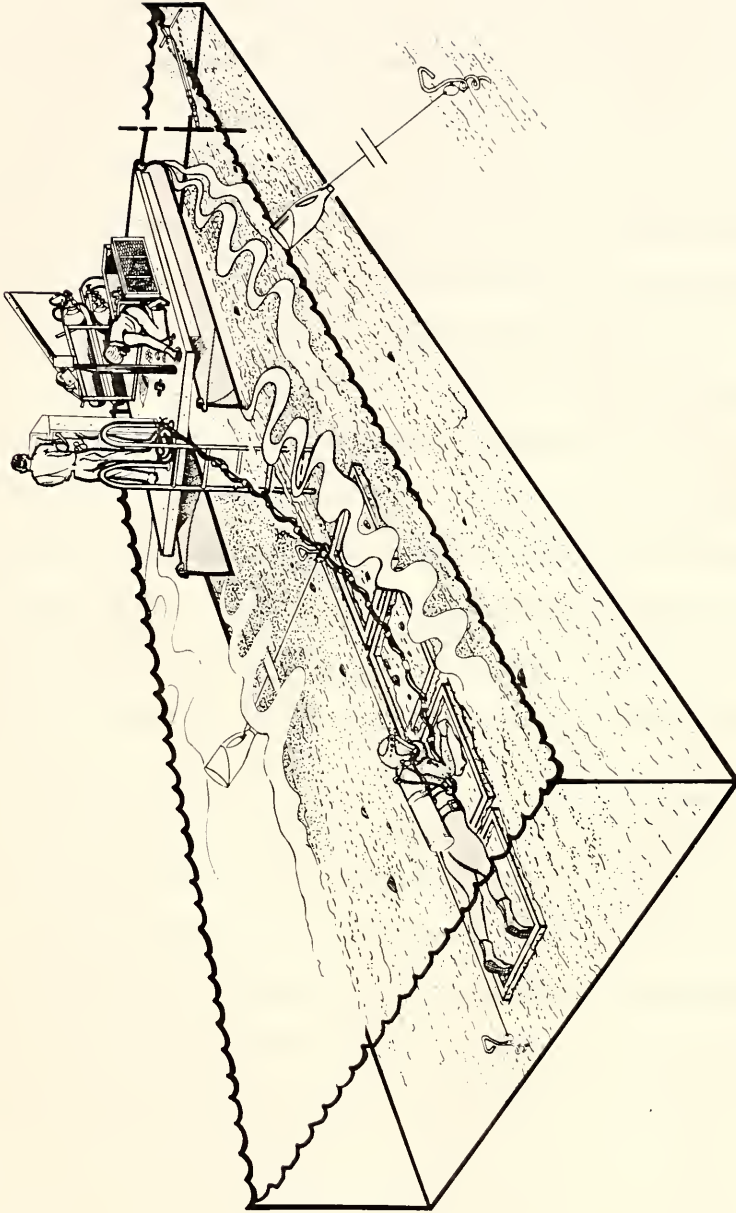


Figure 3. Use of surface-supply diving and 1m² steel frames for quantitative sampling of mussels.

observing the angle of the umbilical hose and the position of the diver's bubbles. The 1-m² frames were difficult to handle in the current, so the frames were raised and lowered using a winch mounted on the boat. The diver held onto the downstream edge of the frame, much like a water skier holding onto a rope, and called for more or less slack on the winch line, as needed.

Divers worked from the side in placing the frames on the bottom, and sampled the frames starting with the one farthest downstream and working upstream, after we found that the diver's activities dislodged some mussels, causing them to tumble downstream into the next frame.

Divers lay on the bottom and reached upstream to sample within the frame. The substrate in this area ranged from sand to fine mud, so the divers were instructed to collect every solid object resembling a shell, down to a size of a few millimeters. Divers routinely retrieved large numbers of fingernail clams, so they probably picked up any juvenile mussels that were present. The divers first collected all mussels that lay on the surface and were easily picked up without pulling or digging. These were considered mussels which had been disturbed or dislodged and were placed in a separate collection bag. The collection bags were heavy canvas with nylon mesh bottoms and stainless steel closures at the top. The diver then removed all remaining undisturbed mussels, digging down within the frame until he could not find any more live mussels. Sticks and substrate were scooped out by hand, and all other material was placed in collection bags.

Mussels were identified, counted, and measured from hinge line at right angles across the shell to the ventral side (the dimension which determined the legal size). If dead shells were not too badly eroded, they also were identified. Any damage to live mussels was described, i.e. whether the shell was crushed or punctured.

Mussels were not returned to the plots, but were taken downstream of the bed and released. Care was taken to avoid resampling areas which had already been sampled. A given plot was resampled by setting the guide line several meters to the right of the original guide line.

In the summer of 1981, divers sampled four 1-m² frames within each of the 12 plots, and we recorded the total number of live mussels taken (Figure 1). The population density of mussels varied dramatically over distances as short as 50 m (Figure 1). There appeared to be a very narrow band, containing a high density of mussels, extending irregularly from upstream to downstream (Figure 1). Mr. Worth H. Emanuel remembered the high density portion of the bed extending much further to the Illinois shore, but a bed of submergent and emergent aquatic plants now occupies a portion of this area and rapid sedimentation evidently has covered the eastern portion of the bed, or has created conditions unsuitable for mussels.

Because densities approaching those found in commercially-harvested beds occurred in very small portions of our study area, it was apparent that we would have to do the commercial harvesting at precisely-determined locations in areas of greatest mussel density.

CONTROLLED HARVEST

Diving

Mr. Charles Gilpin harvested an area of approximately 530 m² using his own equipment and techniques he would normally employ. We told him to stop when he had reduced the harvestable population to the point where he would normally move on to another area.

When Mr. Gilpin finished, we moved our own boat into the same area and sent research divers down to sample.

Basket Dredge

Mr. Charles Gilpin used a steel basket dredge which he pulled across the bottom using a 20-ft mussel boat and a 200 hp outboard engine. The mouth of the dredge was 58 cm (22 3/4 in) wide and 30.5 cm (12 in) tall. It had a toothed, spring-loaded lip. The 11 teeth were 4.4 cm (1 3/4 in) long and spaced 5 cm (2 in) apart. On 19 August 1981 he made a single dredge haul from near ground anchor 8 toward ground anchor 3 (Figure 1). The dredge haul was made late in the afternoon, after the other two harvesting methods had been completed, and the research divers did not return to sample the dredge track until the following day. Instead of 1-m² frames, the diver used smaller, rectangular frames whose width was equal to that of the dredge track and whose enclosed area equalled 1/2 m². The diver laid 4 of these in the dredge track for sampling, then moved them directly upstream and sampled again so that he sampled a total of $8 \times 0.5 \text{ m} = 4 \text{ m}^2$.

Much to our surprise, the dredge did not make an obvious trench in the bottom, and although our divers found some crushed shells and some low ridges (1 to 2 cm) which might have been made by the dredge, the divers had little confidence that they were placing the steel frames exactly within the dredge track. The dredge also scraped away a surficial layer of fine mud leaving sandy mud, but this trail also was intermittent and unreliable.

Hence, the results of dredging in 1981 are not included in this report, but were used to modify the procedure as follows: On 3 September 1982, the dredge boat and research divers' boat were anchored side by side on the test plot. We attached a buoy to the dredge which was then lowered to the bottom. A research diver located the dredge and screwed in a ground anchor with an attached buoy. Mr. Gilpin then made a dredge haul from anchor 8 toward anchor 4, using the anchor 4 buoy as a target. By watching the buoy attached to the dredge, we observed that the dredge was pulled in a slight arc, because of a cross current. Mr. Gilpin tied off his boat to the upstream buoy, then we anchored next to him and again marked the position of the dredge with a ground anchor and buoy. The procedure was repeated on a second track, from anchor 8 toward anchor 6. Guidelines were then stretched from the anchors marking the beginnings of the dredge tracks to the anchors marking the ends of the dredge tracks. The special $1/2 \text{ m}^2$ steel frames were then used to sample a total of 4 m^2 at the beginning and end of each dredge track. We did not attempt to sample at the midpoint of the dredge track, because we knew the guideline at that point was at its maximum distance from the actual arc described by the dredge.

Crowfoot Bar

On 3 September 1981, Mr. Gilpin made repeated hauls with an 8-ft crowfoot bar from downstream of anchor 8 towards anchor 11, using a 20-ft mussel boat. After each haul, he tied off to a buoy, and separated his catch into "keepers" and "culls". We then identified, measured, and counted the mussels in each category.

SURVIVAL AND MOVEMENT OF DISPLACED MUSSELS

In order to determine whether culled mussels will reburrow in the bottom and survive, we filed a single vertical line into the shells of 26 pink heelsplitters (Proptera alata) and 10 mapleleaves (Quadrula quadrula) and released them at ground anchor 8. The mussels were undamaged specimens culled from the crowfoot catch by Mr. Gilpin. A diver carried the mussels to the ground anchor in a collection bag. He knelt on the bottom with the ground anchor centered between his legs and dumped the mussels from the bag at approximately chest level so they fell on the bottom in a random position, just as they would if thrown from a boat.

A diver later attempted to relocate the marked mussels by kneeling at the anchor and searching the bottom with his fingers in the immediate vicinity. The diver then searched a wider circle by touching the anchor with one hand and extending as far as possible with the other hand, a radius of approximately 1.7 m. Mussels were sorted according to whether they were within the initial search area or the larger area, and according to whether they were laying on the surface or embedded in the normal position.

RESULTS AND DISCUSSION

EFFICIENCY AND SELECTIVITY OF GEAR

From the point of view of a research biologist, ideal sampling gear would be 100% efficient for target organisms. In our case, the ideal gear would collect all live mussels within the sample area. We believe our research divers actually were 100% efficient in sampling within the steel frames in our study area, where even small mussels could be easily distinguished from the sand and mud substrate. In contrast, the crowfoot bar collected only 0.6% and the basket dredge only 0.3% of the total live mussels available in their path (Figure 4). The crowfoot bar and basket dredge were equally efficient (2.5%) in harvesting mussels with shell heights greater than 6 cm (legal criterion). However, it is the shell buyers' criteria which effectively determine what the target mussels are. Using buyers' criteria, the commercial diver took 61.2% of the target mussels available on the bottom, the dredge harvested 4.6%, and the crowfoot bar only 1.7% (Figure 4, bottom).

If the legal criterion for a target mussel is used, almost all of the mussels (94.4%) harvested by the basket dredge were target mussels (Figure 5, top), while only half (52.2%) of the mussels taken by the crowfoot bar

$$\text{SAMPLING OR HARVEST EFFICIENCY} = \frac{\text{TARGET MUSSELS TAKEN} \times 100\%}{\text{TARGET MUSSELS AVAILABLE}}$$

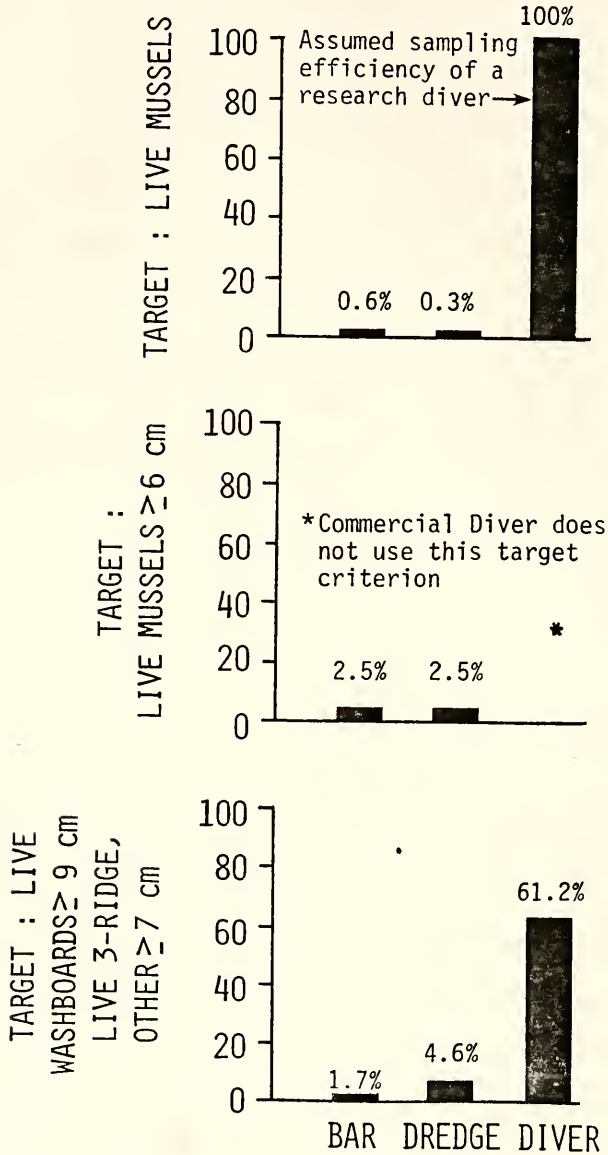


Figure 4. Sampling or harvest efficiency of gear. In the top graph, the target is all live mussels. In the middle graph, the target is all mussels >6 cm in height (legal criterion), and the target in the bottom graph is washboards >9 cm and three ridge and a few other species >7 cm (shell buyers' criteria).

SELECTIVITY

$$\text{SELECTIVITY} = \frac{\text{TARGET MUSSELS TAKEN}}{\text{TOTAL MUSSELS TAKEN}} \times 100\%$$

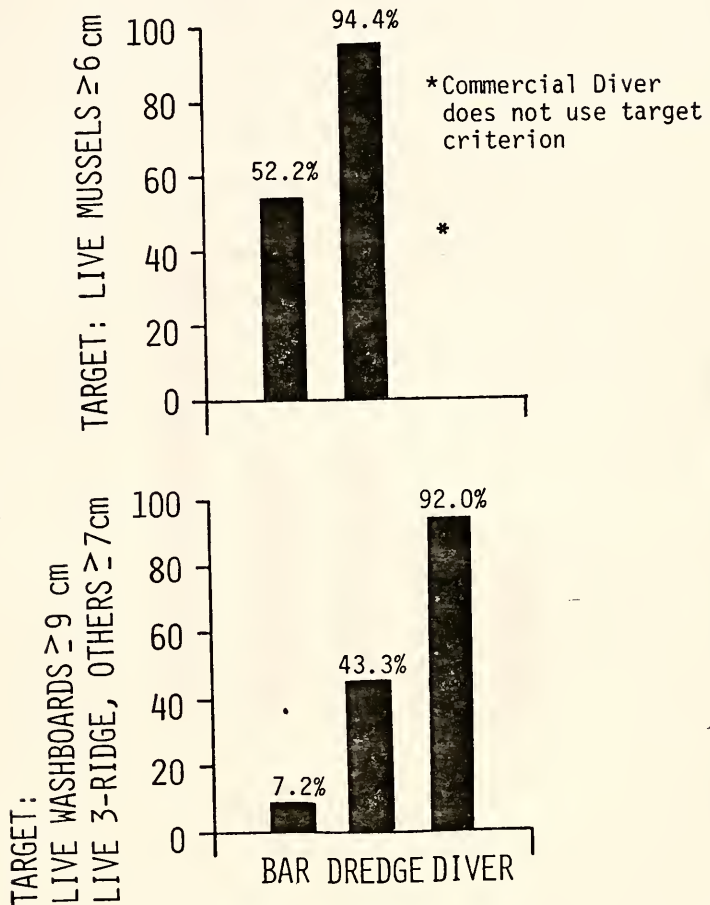


Figure 5. Selectivity of gear. Top graph: selectivity based on legal criterion for target mussels. Bottom graph: selectivity based on buyers' criteria for target mussels.

were target mussels (Figure 5, top). Using buyers' criteria, the diver was much more selective (92.0%) than either the dredge (43.3%) or the crowfoot bar (7.2%, see Figure 5, bottom). The mesh size of the basket in the dredge retains only larger mussels, while the crowfoot bar evidently collects a fairly wide range of sizes (Figure 5).

Although the mussel bar was inefficient, in terms of sampling live mussels or harvesting commercial mussels, it evidently removed a substantial portion of the mussels which were vulnerable to the crowfoot hooks on the very first haul across the bottom (Figure 6). On the first haul, 69 live mussels were taken, and on the second only 37, with the catch rate usually declining slightly thereafter with each successive pass (Figure 6). The study bed was probably ideally suited to use of the mussel bar because there were very few sticks or leaves to foul the hooks and no rocks or large obstructions to snag the hooks. Thus, the efficiencies we report for the mussel bar are probably maximal.

DAMAGE AND DISLODGE MENT OF MUSSELS

We defined dislodged mussels as the sum of the mussels which the research diver found displaced on the bottom following harvest plus mussels brought to the surface and culled. The damaged category likewise include those found with broken shells on the bottom plus those in the harvest.

No damage attributable to the crowfoot bar or to the diver was detected in this study, but we have observed that the edge of the mantle and the shell can be nicked when mussels are forcibly removed from crowfoot hooks.

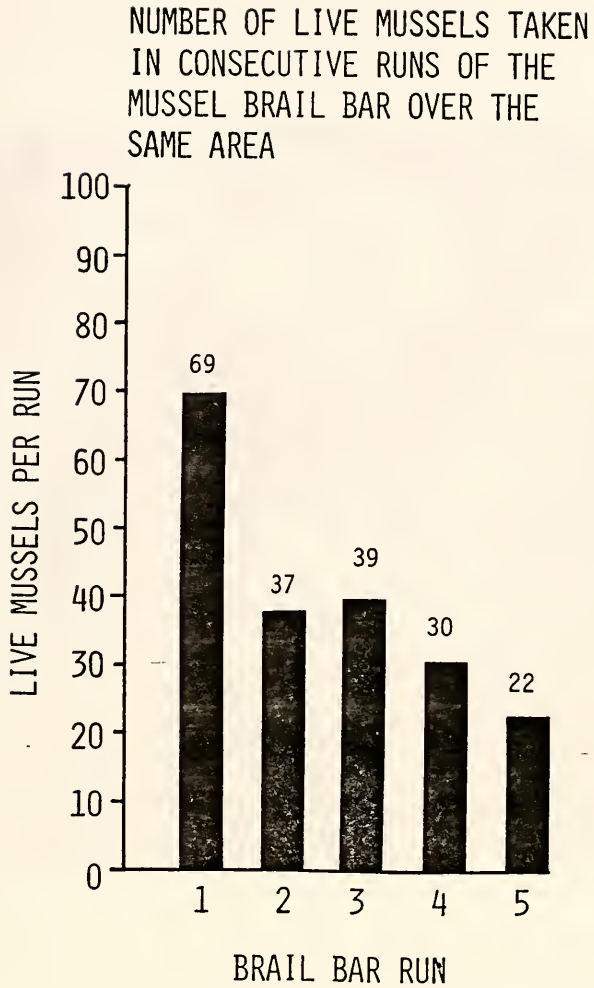


Figure 6. Live mussels taken in consecutive runs of the mussel bar over the same area.

Mussels probably recover from such minor damage. Damage from the basket dredge was probably lethal in most cases, because shells were crushed or pierced (Figure 7). Non-target, thin-shelled species such as papershells (Leptodea fragilis), pink papershells (Proptera laevis), and pink heelsplitters (Proptera alata) were most susceptible to damage.

For every mussel of legal size taken, the dredge and the bar dislodged and damaged the following numbers of mussels:

	<u>Dredge</u>	<u>Bar</u>
Damaged	7.9	0.0
Dislodged	15.1	0.8

Using the buyers' criteria for target mussels, the three harvesting methods dislodged and damaged the numbers of mussels given below, for every target mussel taken:

	<u>Diver</u>	<u>Dredge</u>	<u>Bar</u>
Damaged	0.0	13.8	0.0
Dislodged	0.1	35.3	12.4

Diving caused the least disturbance and damage to the mussels and was the most selective technique, while the dredge was the most destructive. The proportion of damage would be less if the dredge were used on a bed with higher ratio of target to fragile-shelled species. The bar dislodged some mussels, but damaged few or none.

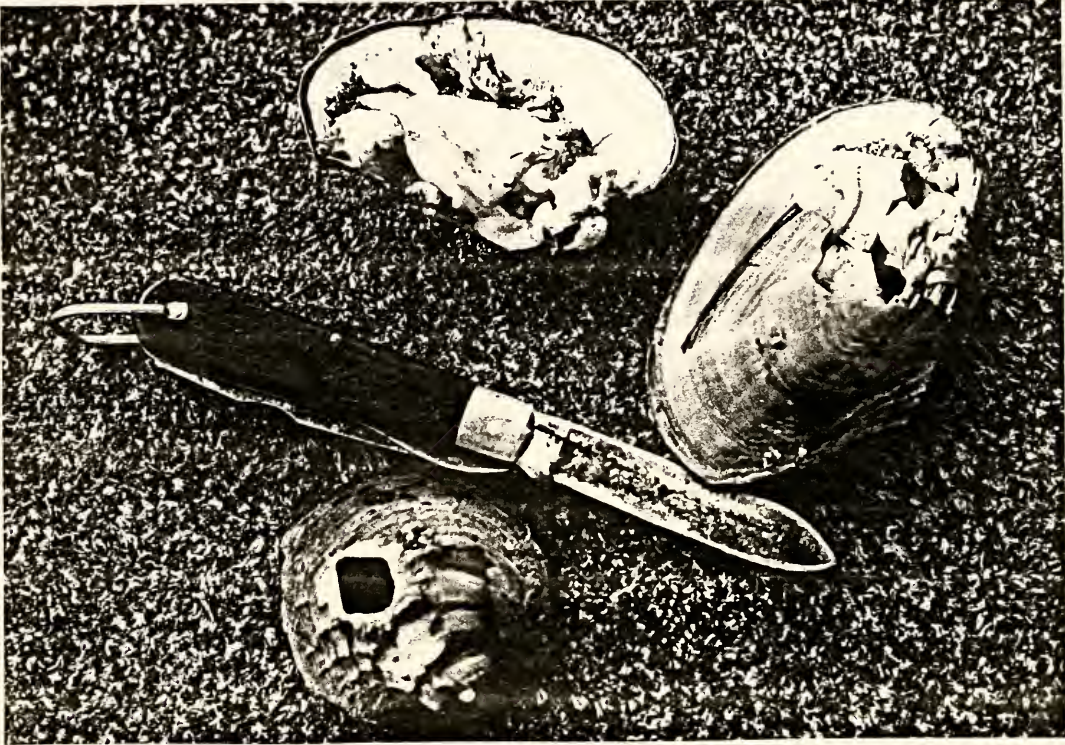


Figure 7. Mussels damaged by basket dredges. Two mussels are crushed, one punctured by a tooth from the dredge. The pocketknife is shown for scale.

SURVIVAL AND MOVEMENT OF DISLODGED MUSSELS

The numbers of marked pink heelsplitters and mapleleaves recovered one week and one year after release on 18 August 1981 are noted below:

	18 Aug 81	25 Aug 81	27 Aug 82
Pink Heelsplitters	26	22	1
Mapleleaves	10	8	3

On 4 September 1982 one additional marked pink heelsplitter was recovered during post-harvest sampling in a dredge track. The diver found this mussel alive, in the normal position within the sediment, but both valves had been crushed by the dredge. This individual had travelled across the current a distance of approximately 3 1/2 m in one year. The other mussels we failed to recover simply may have moved outside of the area we had searched. All recovered mussels were alive, so we have no evidence of delayed mortality attributable to capture by the crowfoot bar and subsequent culling. However, there are several reasons why one should not conclude that there are no delayed effects. First, our sample size was very small. Second, we do not know the fate of mussels we failed to recapture. Third, we did not determine the fate of mussels which were culled following harvest with the dredge. An additional study would have to be performed to measure the longterm effects of disturbance, capture and culling on both undersize commercial species and nontarget species. We recommend two approaches: (1) Comparison of size and age structure, growth rates, percentage of gravid females, and recruitment in harvested and unharvested beds. (2) An

experimental approach, similar to the one used in this study, but with half the marked mussels carefully embedded in the substrate in their natural position by the diver and the other half scattered into an enclosure. With this design, longterm effects attributable to failure of the mussels to embed themselves could be separated from direct effects of capture, such as injury from the gear, exposure to the air, etc.

SUMMARY AND RECOMMENDATIONS

- (1) The dredge was the most destructive of the three harvesting methods used in this study, damaging 13.8 mussels and dislodging 35.3 for every target mussel harvested (using the buyers' criteria for target mussels). Our findings support the prohibition against basket dredges in the Illinois conservation laws. We also feel that a ban on hand dredges should be considered. Although we did not determine the effects of hand dredges, they are essentially smaller versions of the basket dredge.
- (2) The crowfoot bar caused no damage to mussels in our study, but we have observed commercial operations in which the edge of the mantle and shell were nicked when mussels were forcibly removed from the crowfoot hooks. Mussels can probably recover quickly if such damage is minor. The bar disturbs 12.4 mussels for every target mussel (buyers' criteria)-harvested. This includes mussels disturbed on the bottom and those brought to the surface and culled.

Of 36 culled mussels we marked and dropped on the bottom, 30 were recaptured in one week and released again. Five marked mussels were recaptured after one year. All recaptured mussels were alive, but we do not know the fate of mussels we failed to recapture. Mussels which were not recaptured had probably moved themselves or been displaced by the water current beyond the search area, as evidenced by the fact that one was fortuitously recaptured by a diver sampling another area. One week after release, 75% of the recaptured mapleleaves and 55% of the

recaptured pink heelsplitters had burrowed into the bottom in their normal position. The substrate in our study area varied from sand to mud. Mussels in reaches with rock or rubble bottoms might have more difficulty re-establishing their normal position in the substrate.

Because the bar appears to be non-destructive, and offers some advantages over diving to commercial clammers, we feel it should be retained as a legal device. A bar is cheaper than diving equipment, and is safer to use. A bar can be used to harvest an extensive area and to locate new beds, whereas diving is best suited to harvesting dense populations in restricted areas. The bar could be made more selective for the target mussels, by increasing the diameter of the wire or the metal beads on the crowfoot hooks.

- (3) Diving appears to be the least harmful and most selective method for harvesting mussels. It is unlikely that divers can remove all legal size mussels in deep rivers such as the Illinois and Mississippi where the visibility is zero. Some restrictions might be considered in the shallower Wabash, which occasionally becomes clear enough in some areas to see the bottom. These are the only 3 rivers in Illinois where mussel fishing is allowed without specific authorization from the Department of Conservation. In addition to protection of the mussel resource, some attention should be given to protection of the commercial divers. We observed several instances in which equipment or procedures presented either an immediate hazard to the diver or risk of chronic disease, such as lipoid pneumonia.

- (4) Comparisons should be made of size distributions and recruitment in mussel beds which are harvested and unharvested to determine whether size restrictions should be changed. An unharvested bed was used in this study and such beds are presumably available elsewhere, where a high percentage of the shells have a tolberg layer and are therefore of no commercial value. Shell buyers currently demand larger shells than required by Illinois law, so the legal size could be raised without causing any economic hardship.

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