A Survey of Unionid Mussels in the Upper Mississippi River (Pools 3-11)

Technical Bulletin No. 124
DEPARTMENT OF NATURAL RESOURCES
P.O. Box 7921, Madison, WI 53707
1981

ABSTRACT

Unionid mussels were collected during the summers of 1977-79 in the main channel and associated backwater areas of the Upper Mississippi River from Prescott, Wisconsin to Dubuque, Iowa, a total of 229 river miles. Living mussels were collected on 2,663 five-minute tows with a 10-ft dove-tail clam bar brail. SCUBA diving was also employed to collect living and dead mussels and to determine the efficiency of the brail. The average efficiency of brail runs was less than 1% when compared with SCUBA diving, which was considered 100% efficient.

Over 8,700 live mussels, representing 30 species, were taken on the brail. The shells of dead specimens collected by SCUBA diving added 7 more species. Of the two federally endangered mussels, Fat Pocketbook *(Proptera capax)* and Higgins' Eye *(Lampsilis higginsi)* historically found in this area, only the Higgins' Eye was collected in the study. The mean number of mussels collected per clam bar tow ranged from 0.3 in Pools 5 and 5A to 18.3 in Pool 10. Threeridge *(Amblema plicata)*, Pigtoe *(Fusconaia flava)*, and Pimpleback *(Quadrula pustulosa)* were the most abundant species. However, members of the *Truncilla* spp. may be more numerous than indicated due to brail selectivity against small species. Results of this study, when compared with earlier mussel surveys, showed a continuing trend of diminishing mussel species diversity.

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by
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Madison, Wisconsin
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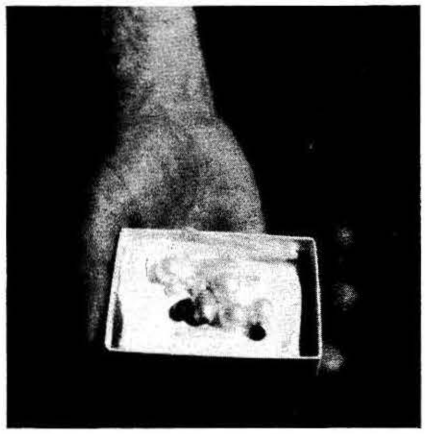
INTRODUCTION

The commercial harvest of freshwater mussels from the Mississippi River began in the last decade of the nineteenth century when J. F. Boepple, a horn button turner from Hamburg, Germany, pioneered the use of mussel shells for button production (Carlander 1954). Muscatine, Iowa, with its nearby mussel beds served as the birthplace for the pearl button industry. The mussel fishery and the button industry rapidly expanded along the Mississippi River as mussel beds near Muscatine were depleted (Coker 1921). By 1902, the fishery extended northward into Minnesota and Wisconsin. During that year, over 16 million pounds of mussel shells were harvested at a value of $66,110 (Carlander 1954). The mussel beds in the Mississippi River began to show signs of depletion by the 1930's. This, coupled with the advent of the plastic button, led to the decline of the mussel fishery.

Clamming in the Mississippi River drainage system was revived during the 1960's. Kokichi Mikimoto of Japan found that the freshwater mussel shell produced the best nucleus for high quality cultured pearls (Lopinot 1967). Since that time, Mississippi River shells have been sent to factories in Japan where they are processed to produce spheres which are implanted into oysters as nuclei for cultured pearls (Krumholz et al. 1970).



Freshwater pearls that have recently been collected from the Upper Mississippi River in the vicinity of Prairie du Chien, Wisconsin.

The rapid depletion of mussel beds during the heyday of the pearl button industry stimulated numerous studies of the Upper Mississippi River mussel resource (Coker 1914, Grier and Mueller 1922, Grier 1922, Ellis 1931). During the 1960's and 1970's, surveys were conducted to examine changes in mussel populations and to relate these changes to alterations in mussel habitat (Finke 1966, Coon et al. 1977, Fuller 1978 and 1980, Larsen and Holzer 1978). Due to concern expressed for the decline of several mussel species, two species historically found in Wisconsin, the Higgins' Eye *(Lampsilis higginsi)* and the Fat Pocketbook *(Proptera capax)** were placed on the Federal Endangered Species List during 1976. In May 1979 the Higgins' Eye, the only one of the two currently found in Wisconsin, was placed on the Wisconsin Endangered Species list.

The primary objectives of this survey were to determine distribution, relative abundance and species composition of the mussels in the Upper Mississippi River; monitor the commercial clam harvest; identify endangered or threatened species; and recommend appropriate management measures for the Wisconsin waters of the Mississippi River.

*The Fat Pocketbook is listed as *Potamilus capax* on the Federal Endangered Species list.

STUDY AREA

The study area included 229 miles of the Mississippi River extending from Lock and Dam No. 2 near Prescott, Wisconsin, where the Mississippi first enters Wisconsin, to Lock and Dam No. 11 at Dubuque, Iowa (Fig. 1). The Mississippi River is the border between Wisconsin and Minnesota and Iowa in this section. The Upper Mississippi River has a rich variety of aquatic habitat types which includes: the main channel, main channel borders, tail waters, side channels and river lakes, and sloughs (Rasmussen 1979). Sampling was done in all of these habitats with emphasis on the main channel border.

At the northern end of the study area in Pool 3 downstream from the mouth of the St. Croix River, the Mississippi develops extensive backwaters and rich wetland habitats until it reaches Lake Pepin just south of Red Wing, Minnesota. At this point the river becomes a river lake that is approximately 1 to 2.5 miles wide and nearly 22 miles long, extending to the delta of the Chippewa River. As it continues to flow downstream to the end of the study area at Dubuque, Iowa (Lower Pool 4 - Pool 11), the river returns to an intricate network of diverse aquatic habitats.

Throughout its course in the study area, the width of the river varies from 725 ft to 2,400 ft and occupies from 1/12 to 1/4 of the river bottomland. Steep bluffs 200 to 650 ft high border the bottomlands which are 1-6.5 miles wide. The grade of the river is less than 4 inches to the mile (Martin 1965). The areas drained by the Mississippi River are largely agricultural and forest lands.

The study area encompassed sections that were affected by the glaciers as well as part of the Driftless Area (not altered by the last glaciation). The floodplain material is clay, silt and loam, sometimes sandy and often dark with organic matter. It may be 10-30 inches thick and is underlain by several feet of sand which often grades into coarse gravel (Martin 1965).

In its original condition, the Upper Mississippi River consisted of a series of relatively deep pools separated by shoal bars and rapids. The channel was obstructed by rocks and snags, and during low water the flow through the shoals was divided into several chutes with narrow widths and depths as little as 30 inches (Carlander et al. 1966).

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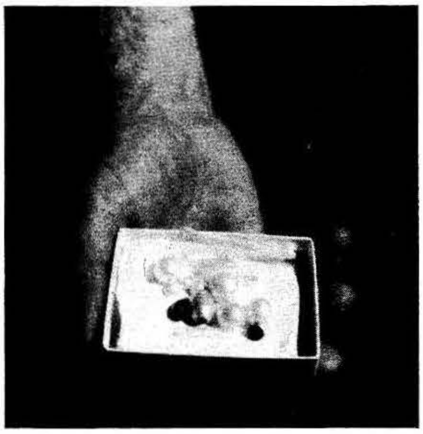

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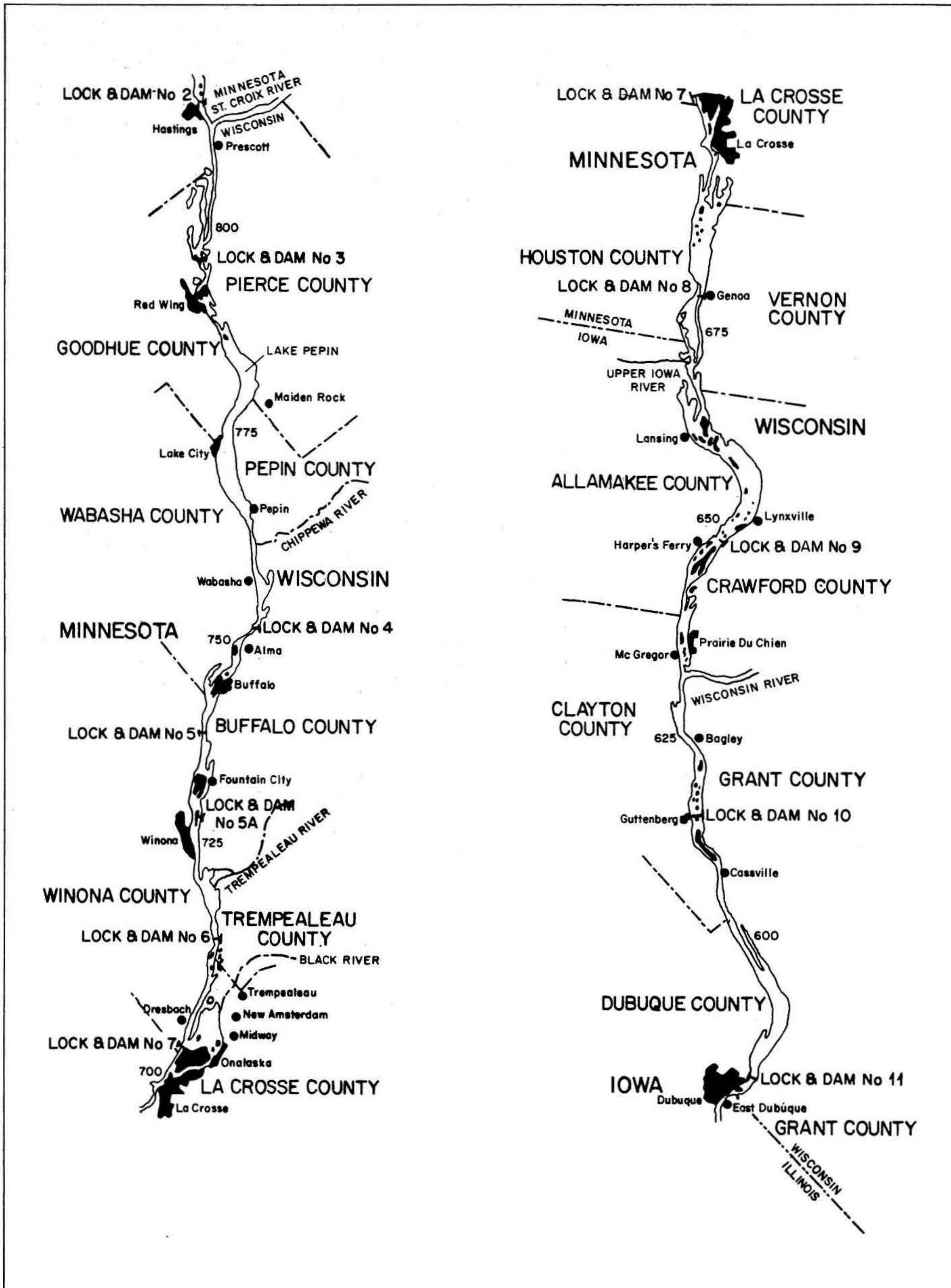

FIGURE 1. *Upper Mississippi River study area.*

Navigation on the Mississippi has been important from the time of first settlement to the present. Measures have been taken to develop the river into a more navigable corridor. As early as 1820 the U. S. Army Corps of Engineers was directed to remove snags and to maintain a boat channel. In 1878, Congress authorized a 4.5-ft channel between Minneapolis and the Missouri River. As commerce and technology grew, deeper channels were needed and a 6-ft channel was authorized in 1907. The existing 9-ft channel with its 28 locks and dams was authorized in 1930 (Rasmussen 1979).

The lock and dam system has had a major impact on the character and appearance of the Upper Mississippi River. Impoundment changed the Mississippi from a free-flowing river into a series of river lakes. The dams increased the permanent water area and stabilized the water level. However, installation of the dams marked the start of a man-induced aging process (Rasmussen 1979). Due to reduced currents, side channels, backwaters, gravel bars, and other areas are gradually being filled with sediment. Consequently, many ecologically rich areas are continously being lost as viable aquatic habitats.

METHODS

The period of the study extended from February 1977 to March 1980. Field sampling was conducted from May through October during 1977 and 1978 and from June through September in 1979. The first year's sampling included Pools 5A-8 and the Black River from the Onalaska Spillway downstream. The second phase of the study extended from Pools 3 to 5, and Pools 9-11 were surveyed in the third year.

The crowfoot bar or brail was first used as a capture device in 1897 (Carlander 1954) and is still a major commercial collecting apparatus. It is made from varying lengths of metal rod or wood and is fitted with 4-pronged hooks attached to the bar by short lines or chains. The brail is dragged along the bottom with the current. When the hooks come in contact with open shells, the mussels close their valves tightly on the prongs and then the brail can be raised to the surface. Some small mussels are not large enough to be captured by this means because they cannot clamp onto the hooks. However, small mussels are sometimes collected on the brail when the hooks become entangled in their byssus threads or in the vegetation they inhabit.

A brail was used during this study because it maximizes the amount of mussel data that can be obtained from one area in a given period of time (Fuller 1978). The brail used was a 10-ft wooden bar equipped with 200 dovetail hooks with beaded prongs. The hooks were made of several gauges of wire to help reduce size selectivity in mussel capture. This bar design has been accepted as the standard mussel gear by the Upper Mississippi River Conservation Committee. The clam bar was towed in a downstream direction for 5 min by a 16-ft motorized john boat.

In all areas except for Lake Pepin the runs were randomly selected from the navigation charts of the U. S. Army Corps of Engineers, but areas suspected of containing clams were also surveyed. At least six runs were made per river mile. In the Lake Pepin area, runs were made at 5-ft contours as well as on transects across the lake at predetermined locations selected from Minnesota Department of Natural Resources hydrographic maps. The locations of the runs were recorded on U.S. Army Corps of Engineers navigation charts.*

During 1977 and 1978 at the beginning and end of each run, water depths were recorded and bottom sediments were collected with a petite Ponar or Ekman dredge. The substrate was subjectively classified as gravel, sand, clay, or silt.

SCUBA diving was used at 61 locations in the various pools to augment the brail samples. During 1977 and 1978, SCUBA was also employed to determine the efficiency of the brail. The most productive areas in each pool during the initial brailing were revisited for SCUBA sampling. A 100-ft section of the initial run was marked, measured, and brailed. If the brailing yielded mussels, a 5-ft square metal frame was placed on the substrate in three locations within the marked 100-ft interval. All mussel specimens within the frame, both live and dead, were collected by the diver. The shells of dead specimens from the dives were retained. In 1979 only two 5-ft-square quadrants were sampled per site due to the greater densities of mussels in Pools 9-11.

Efficiency of the brailing effort was calculated by comparing mussel densities from catches of brail and SCUBA diving efforts in the same vicinity. Mussel densities (number/square foot) calculated from brail runs covering 1000 ft^2 (100 ft run, 10 ft wide) were compared to mussel densities calculated from SCUBA effort covering 25 ft^2 to 75 ft^2. Brail efficiency was considered equal to the ratio between number brailed/ft^2 and number collected by SCUBA/ft^2 x 100%.

All mussel shells from both diving and brailing samples were identified and measured using the standard definition for length and height (Ortmann 1920, Ball 1922). Mussel identifications were confirmed by Samuel L. H. Fuller, Academy of Natural Sciences, Philadelphia, Pa. and Marian E. Havlik of Malacological Consultants of La Crosse, Wis. The vernacular and scientific names used in this report are the same as those found in Fuller (1978). Scientific names are included in the text only if they do not appear in Table 1. A maximum of two cleaned specimens of each species per run were catalogued for a reference collection.

After a suspected Higgins' Eye mussel was collected by brail or SCUBA diving, it was transported to the U. S. Fish and Wildlife Service National Fishery Research Laboratory in La Crosse, Wisconsin, and housed in an oxygenated aquarium. The specimen was then identified by a recognized authority and placed back into the river bed by a SCUBA diver. Every effort was made to keep the specimens alive and no mortalities occurred.

Historical changes in mussel populations were examined by comparing

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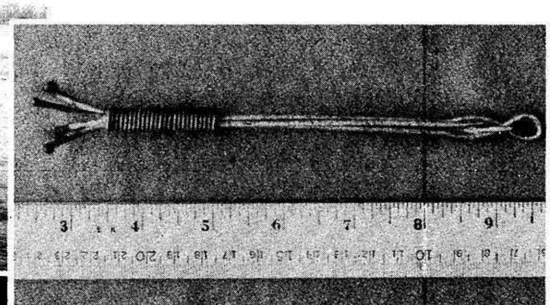
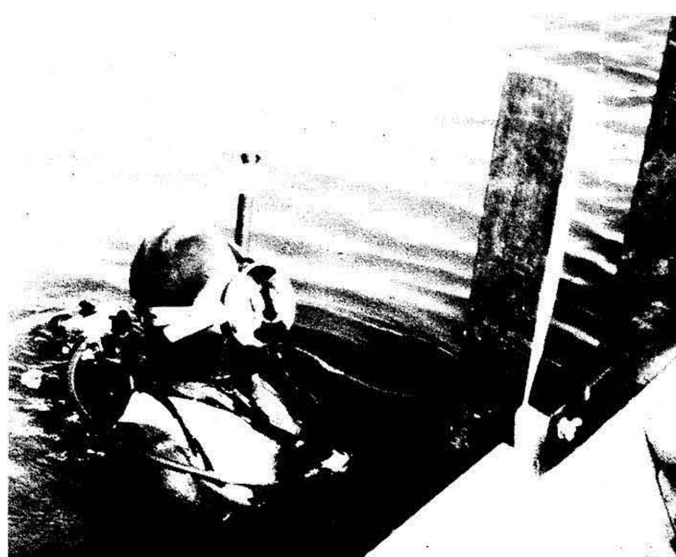
The 10 ft brail, equipped with 200 dovetail hooks, that was used during the study.



Close-up view of a dovetail hook with beaded prongs.

Live mussels attached to hooks of a brail.

The metal frame (5 ft²) that was placed on the substrate during SCUBA sampling.



A SCUBA diver preparing to board the boat after sampling the substrate.

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Diversity indexes were calculated as a measure of community health. This single calculated value incorporates two important components which contribute to species diversity: richness of species, and distribution of individuals among the species. The Shannon-Weaver diversity index (Hutcheson 1970) was used to compare mussel species diversity in different pools during 1977-79, and to compare diversity observed during this study with Finke's (1966) earlier study.

The relative abundance of Threeridge and Pigtoe was determined for all Pools, 3 through 11. In addition, the relative abundance of these two species was compared with results of equivalent efforts made in Lake Pepin, Pools 5, 6, 7, and 9 during 1965. When tests required, sampling results were randomly adjusted to assure equal weight for compared statistics.

During 1977 and 1978, the clamming industry was studied by identifying people involved, determining current markets, and monitoring the mussel harvest. The shell buyer in Prairie du Chien for the Tennessee Shell Company was the only outlet for mussels in Wisconsin during 1977 and 1978. He was provided with voluntary questionnaires that requested information on total tonnage, species harvested, location of clamming operations, quantity of equipment leased, price paid per ton, and principal markets. In addition, species composition and length-height measurements were taken periodically throughout the summer months from the commercial shell piles. The Borden Shell Company started buying shells in Prairie du Chien during the summer of 1979 after the commercial sampling was finished.

RESULTS AND DISCUSSION

BRAIL EFFICIENCY

Comparison of brail to SCUBA diving effort at 34 locations during 1977 and 1978 resulted in a calculated average brail catch efficiency of 0.7% of the available population, ranging from 0.1 to 2.5% (S.E. 0.2%). Repeated dives at the same location indicated that SCUBA effort was a complete collection technique that gave an adequate index of absolute mussel density. Therefore, SCUBA diving was assumed to be 100% efficient. Efficiency was calculated for sample efforts in Pools 3-8 and over a variety of substrates, but no relationships accounting for the variability were apparent. Krumholz et al. (1970) also reported that the brail was not as efficient in collecting mussels as SCUBA diving in the Wabash River. In comparing the two methods, he found that the brail was only 3.6% as effective as diving.

One reported disadvantage of the clam bar is its selectivity for larger mussels (Bridges 1958). The mean length and confidence intervals of Threeridge, Washboard, Pigtoe, and Pimpleback collected by diving and brailing were compared for Pools 9, 10, and 11. For 6 of 12 sets of comparable data, the mussels collected by diving were significantly smaller ($P < 0.10$): Threeridge in Pools 9-11, Washboard in Pool 11, and Pigtoe in Pools 10 and 11. There was no significant difference in the Pimpleback collected by diving and brailing.

Scruggs (1960) found that when Pigtoe less than 5.0 cm were present, the brail was more successful in catching Pigtoe larger than 5.0 cm. Likewise in the present study smaller specimens of Threeridge (< 3.5 cm) and Pigtoe (< 3.0 cm) collected on the crowfoot bar accounted for only 0.4% and 2.8% of the brail catch, respectively. Smaller specimens of Threeridge (6.5%) and Pigtoe (8.3%) were collected by SCUBA diving in greater numbers than with the brail.

Despite the inefficiency of the crowfoot bar, it is a useful collecting device for securing a synopsis of mussel community composition because larger areas can be sampled per unit time than with SCUBA diving. Furthermore, catch per unit effort (CPE) by brail varied in direct proportion to the size of the available population for a given area. Mussel densities calculated from brailing were highly correlated to densities calculated from SCUBA collections ($r = 0.89$).

MUSSEL DISTRIBUTION AND ABUNDANCE

Pools 3-11

Mussel collections by brail were made at 2,663 locations (Tables 1 and 2). On 34.3% of these runs mussels were found. The mussels were not randomly distributed but were usually clustered at specific areas. Brailing efforts produced 8,720 live individuals representing 30 species (Table 3). In addition, 1,705 juveniles were also collected on the brail. SCUBA diving provided no new live species but added the shells of 7 additional species not found among the live mussel specimens (Table 4). Species collected only as dead specimens were: Spectacle Case, Buckhorn, Ebony Shell, Bullhead, Elephant Ear, Fluted Shell, and Elktoe.

Threeridge was the most abundant

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RESULTS AND DISCUSSION

BRAIL EFFICIENCY

Comparison of brail to SCUBA diving effort at 34 locations during 1977 and 1978 resulted in a calculated average brail catch efficiency of 0.7% of the available population, ranging from 0.1 to 2.5% (S.E. 0.2%). Repeated dives at the same location indicated that SCUBA effort was a complete collection technique that gave an adequate index of absolute mussel density. Therefore, SCUBA diving was assumed to be 100% efficient. Efficiency was calculated for sample efforts in Pools 3-8 and over a variety of substrates, but no relationships accounting for the variability were apparent. Krumholz et al. (1970) also reported that the brail was not as efficient in collecting mussels as SCUBA diving in the Wabash River. In comparing the two methods, he found that the brail was only 3.6% as effective as diving.

One reported disadvantage of the clam bar is its selectivity for larger mussels (Bridges 1958). The mean length and confidence intervals of Threeridge, Washboard, Pigtoe, and Pimpleback collected by diving and brailing were compared for Pools 9, 10, and 11. For 6 of 12 sets of comparable data, the mussels collected by diving were significantly smaller ($P < 0.10$): Threeridge in Pools 9-11, Washboard in Pool 11, and Pigtoe in Pools 10 and 11. There was no significant difference in the Pimpleback collected by diving and brailing.

Scruggs (1960) found that when Pigtoe less than 5.0 cm were present, the brail was more successful in catching Pigtoe larger than 5.0 cm. Likewise in the present study smaller specimens of Threeridge (< 3.5 cm) and Pigtoe (< 3.0 cm) collected on the crowfoot bar accounted for only 0.4% and 2.8% of the brail catch, respectively. Smaller specimens of Threeridge (6.5%) and Pigtoe (8.3%) were collected by SCUBA diving in greater numbers than with the brail.

Despite the inefficiency of the crowfoot bar, it is a useful collecting device for securing a synopsis of mussel community composition because larger areas can be sampled per unit time than with SCUBA diving. Furthermore, catch per unit effort (CPE) by brail varied in direct proportion to the size of the available population for a given area. Mussel densities calculated from brailing were highly correlated to densities calculated from SCUBA collections ($r = 0.89$).

MUSSEL DISTRIBUTION AND ABUNDANCE

Pools 3-11

Mussel collections by brail were made at 2,663 locations (Tables 1 and 2). On 34.3% of these runs mussels were found. The mussels were not randomly distributed but were usually clustered at specific areas. Brailing efforts produced 8,720 live individuals representing 30 species (Table 3). In addition, 1,705 juveniles were also collected on the brail. SCUBA diving provided no new live species but added the shells of 7 additional species not found among the live mussel specimens (Table 4). Species collected only as dead specimens were: Spectacle Case, Buckhorn, Ebony Shell, Bullhead, Elephant Ear, Fluted Shell, and Elktoe.

Threeridge was the most abundant

TABLE 1. *Scientific and common names of mussels collected in Pools 3-11 of the Upper Mississippi River, 1977-79.*

Scientific Name	Common Name	Live/Dead*
Cumberlandia monodonta	Spectacle Case	D
Quadrula metanevra	Monkeyface	L
Q. quadrula	Mapleleaf	L
Q. nodulata	Wartyback	L
Q. pustulosa	Pimpleback	L
Tritogonia verrucosa	Buckhorn	D
Cyclonaias tuberculata	Purple Wartyback	L
Fusconaia flava	Pigtoe	L
F. ebena	Ebony Shell	D
Megalonaias gigantea	Washboard	L
Amblema plicata	Threeridge	L
Plethobasus cyphyus	Bullhead	D
Pleurobema cordatum	Ohio River Pigtoe	L
Elliptio crassidens	Elephant Ear	D
E. dilatata	Spike	L
Obliquaria reflexa	Threehorn	L
Proptera alata	Pink Heelsplitter	L
P. laevissima	Pink Papershell	L
Leptodea fragilis	Fragile Papershell	L
Ellipsaria lineolata	Butterfly	L
Truncilla truncata	Deertoe	L
T. donaciformis	Fawnfoot	L
Obovaria olivaria	Hickorynut	L
Actinonaias carinata	Mucket	L
Ligumia recta	Black Sandshell	L
Carunculina parva	Lilliput	L
Lampsilis teres	Yellow Sandshell	L
L. higginsi	Higgins' Eye	L
L. radiata siliquoidea	Fat Mucket	L
L. ovata ventricosa	Pocketbook	L
Arcidens confragosus	Rockshell	L
Lasmigona complanata	White Heelsplitter	L
L. costata	Fluted Shell	D
Alasmidonta marginata	Elktoe	D
Anodonta imbecillis	Paper Floater	L
A. grandis	Giant Floater	L
Strophitus undulatus	Strange Floater	L
Corbicula fluminea	Asiatic Clam	L

*L=collected live and dead; D=only collected dead.

mussel collected in the study area representing 59.2% of the brail catch (Table 3). Pigtoe and Pimpleback accounted for 8.7% and 7.8% of the brailed mussels, respectively. Threeridge was found on 21.5% of the runs, while Pigtoe had a 12.8% and Pimpleback an 11.9% frequency of occurrence (Table 2).

The Purple Wartyback and Yellow Sandshell were the only species represented by single live specimens. Specimens of Higgins' Eye were collected 5 times on the brail and 4 times by diving. No Fat Pocketbook, live or dead, were found during the study.

Pool 3

In Pool 3, 64 live mussels were collected on the brail representing 9 species (Table 3). Four additional species were found only as dead specimens. No juveniles were detected in this pool.

Pigtoe and Threeridge were the most abundant species, comprising 42.2% and 21.9% of the total brailed mussel catch, respectively. This is the only pool where Pigtoe was the dominant mussel species in the catch. Pigtoe was harvested on 9.5% of the runs. Pimpleback and Threehorn were as widely distributed as Threeridge, but were less abundant. Only 1 or 2 specimens were found of five additional species.

Of the 137 runs made in this pool, 16.1% were positive. The most productive site yielded 5 species and 14 mussels. Half of the runs were taken over a sand substrate.

Pool 4

Upper Pool 4

Pool 4 above Lake Pepin yielded 12 live species, 11 of which were taken on the brail. Dead specimens collected by diving included 6 additional species. A total of 135 adult mussels and 64 juveniles were collected in this area by brail.

Threeridge and Pigtoe were the most abundant species found in Upper Pool 4, making up 45.9% and 24.4% of the brailed mussels, respectively. Threehorn, Pimpleback, and Deertoe were next in abundance and frequency of occurrence. One or 2 specimens were found of 6 other species, plus 1 additional from SCUBA diving.

Of the 193 runs made in this area, 49 (25.4%) produced mussels. The largest number of mussels brailed at one site was 10, representing 6 species.

The substrates where the runs were made comprised three major bottom types: sand (27.5%), a combination of sand and silt (26.4%), and pure silt (21.2%).

Lake Pepin

Brail collections included 15 live species and diving added 3 more live species. A total of 383 adult mussels and 137 juveniles were collected in Lake Pepin by brailing. Dead specimens of 8 more species were discovered during SCUBA dives. The largest number of mussels brailed at one site was 16, comprising 4 species.

In Lake Pepin, Threeridge and Pigtoe continued to be the most abundant species, accounting for 32.9% and 29.8% of the brail mussel catch, respectively. The mussels with the greatest frequency of occurrence on the crowfoot bar were Threeridge, Pigtoe, and Spike. The percent abundance of Spike, Deertoe and Paper Floater in Lake Pepin was the largest for any of the sample areas. Two species that are distinctive of Lake Pepin are the Spike and Fat Mucket. Another vernacular name for the Fat Mucket is Lake Pepin Mucket. A large percentage, 84.2%, of the Fat Mucket collected on the brail during the three years was found in Lake Pepin. A single Washboard, found otherwise only in the lower three pools, was taken by SCUBA diving. The only live specimen of Yellow Sandshell collected in the entire survey area was found in Lake Pepin. Pink Papershell and Mucket were also represented by single specimens on the brail.

Of the 527 runs made in Lake Pepin, 142 were positive and 385 negative. The substrate in the central portion of the lake was composed of fine silt and organic material and did not provide a suitable habitat for mussels. Transects, representing 140 runs, were taken across this area of the lake and accounted for a large percentage (36.4%) of the negative runs. These

TABLE 2. *The frequency of occurrence of mussels sampled by brailing in Pools 3 through 11 in the Upper Mississippi River, 1977-79.*

Species	Pool 3		Upper Pool 4		Lake Pepin		Lower Pool 4		Pool 5		Pool 5A		Pool 6		Pool 7		Pool 8		Black River		Pool 9		Pool 10		Pool 11		Total (1977-79)	
	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%	No. Runs	%
Total number of runs	137		193		527		130		194		128		194		179		276		29		222		246		208		2,663	
Threeridge	8	5.8	22	11.4	76	14.4	18	13.8	11	5.7	7	5.5	17	8.8	49	27.4	45	16.3	12	41.4	88	39.6	138	56.1	82	39.4	573	21.5
Pigtoe	13	9.5	22	11.4	65	12.3	11	8.5	12	6.2	3	2.3	8	4.1	19	10.6	14	5.1	2	6.9	44	19.8	81	32.9	48	23.1	342	12.8
Pimpleback	8	5.8	11	5.7	3	0.6	14	10.8	8	4.1	6	4.7	7	3.6	45	25.1	14	5.1	-	-	54	24.3	97	39.4	50	24.0	317	11.9
Mapleleaf	-	-	1	0.5	-	-	-	-	-	-	-	-	-	-	-	-	3	1.1	-	-	45	20.3	63	25.6	58	27.9	170	6.4
Threehorn	7	5.1	10	5.2	10	1.9	5	3.8	3	1.5	2	1.6	-	-	5	2.8	1	0.4	-	-	13	5.9	43	17.5	32	15.4	131	4.9
Fawnfoot	-	-	-	-	5	0.9	1	0.8	-	-	1	0.8	9	4.6	3	1.7	2	0.7	-	-	25	11.3	32	13.0	37	17.8	115	4.3
Hickorynut	-	-	1	0.5	-	-	1	0.8	1	0.5	2	1.6	10	5.2	12	6.7	16	5.8	-	-	11	5.0	34	13.8	17	8.2	105	3.9
Deertoe	-	-	6	3.1	14	2.7	-	-	-	-	-	-	1	0.5	7	3.9	4	1.4	-	-	17	7.7	30	12.2	25	12.0	104	3.9
Wartyback	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	8.6	47	19.1	38	18.3	104	3.9
Washboard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	13.5	41	16.7	15	7.2	86	3.2
Spike	1	0.7	1	0.5	30	5.7	3	2.3	-	-	-	-	2	1.0	1	0.6	-	-	-	-	19	8.6	16	6.5	2	1.0	75	2.8
Pocketbook	1	0.7	2	1.0	3	0.6	1	0.8	-	-	1	0.8	2	1.0	8	4.5	9	3.3	-	-	2	0.9	14	5.7	4	1.9	47	1.8
Giant Floater	-	-	1	0.5	-	-	1	0.8	-	-	1	0.8	3	1.5	2	1.1	5	1.8	-	-	13	5.9	10	4.1	10	4.8	46	1.7
Pink Heelsplitter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.6	1	0.4	-	-	8	3.6	16	6.5	5	2.4	31	1.2
Rockshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1.8	8	3.3	15	7.2	27	1.0
Black Sandshell	-	-	-	-	3	0.6	-	-	-	-	-	-	4	2.0	2	1.1	3	1.1	-	-	4	1.8	4	1.6	1	0.5	21	0.8
Fat Mucket	-	-	-	-	15	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.9	-	-	-	-	17	0.6
Strange Floater	-	-	-	-	-	-	-	-	-	-	1	0.8	-	-	-	-	-	-	-	-	3	1.4	8	3.3	4	1.9	16	0.6
Fragile Papershell	1	0.7	-	-	-	-	-	-	2	1.0	4	3.1	-	-	-	-	-	-	-	-	2	0.9	2	0.8	1	0.5	12	0.5
Monkeyface	-	-	-	-	-	-	1	0.8	-	-	-	-	2	1.0	-	-	-	-	-	-	-	-	7	2.8	1	0.5	11	0.4
Ohio River Pigtoe	-	-	-	-	-	-	3	2.3	1	0.5	-	-	-	-	-	-	-	-	-	-	5	2.3	-	-	-	-	9	0.3
Paper Floater	-	-	-	-	5	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.8	-	-	7	0.3
White Heelsplitter	1	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	0.8	3	1.4	6	0.2
Lilliput	-	-	1	0.5	3	0.6	1	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0.2
Pink Papershell	-	-	-	-	1	0.2	-	-	-	-	-	-	1	0.5	-	-	2	0.7	-	-	1	0.5	-	-	-	-	5	0.2
Butterfly	-	-	-	-	-	-	-	-	-	-	1	0.8	-	-	1	0.6	-	-	-	-	-	-	-	-	3	1.4	5	0.2
Mucket	2	1.5	-	-	1	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.4	-	-	4	0.2
Higgins' Eye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1.2	1	0.5	4	0.2
Yellow Sandshell	-	-	-	-	1	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	<0.1
Purple Wartyback	-	-	-	-	-	-	1	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	<0.1
Total number of spp.	9		11		15		13		7		11		12		13		13		2		21		23		22		30	

TABLE 3. *The number and percent abundance of mussels collected by brailing in Pools 3 through 11 in the Upper Mississippi River, 1977-79.*

	Pool 3		Upper Pool 4		Lake Pepin		Lower Pool 4		Pool 5		Pool 5A		Pool 6		Pool 7		Pool 8		Black River		Pool 9		Pool 10		Pool 11		Total (1977-79)	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Threeridge	14	21.9	62	45.9	126	32.9	60	52.2	27	48.2	12	33.3	25	27.5	287	63.8	138	57.7	64	92.8	529	42.4	3256	72.1	566	42.9	5166	59.2
Pigtoe	27	42.2	33	24.4	114	29.8	15	13.0	14	25.0	4	11.1	13	14.3	40	8.9	16	6.7	5	7.2	101	8.1	265	5.9	109	8.3	756	8.7
Pimpleback	8	12.5	13	9.6	3	0.8	15	13.0	8	14.3	7	19.4	8	8.8	68	15.1	18	7.5	-	-	117	9.4	301	6.7	118	8.9	684	7.8
Mapleleaf	-	-	1	0.7	-	-	-	-	-	-	-	-	-	-	-	-	3	1.3	-	-	86	6.9	138	3.1	194	14.7	422	4.8
Washboard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	132	10.6	127	2.8	32	2.4	291	3.3
Wartyback	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	3.5	104	2.3	65	4.9	213	2.4
Spike	1	1.6	1	0.7	71	18.5	6	5.2	-	-	-	-	2	2.2	2	0.4	-	-	-	-	77	6.2	34	0.8	3	0.2	197	2.3
Hickorynut	-	-	1	0.7	-	-	1	0.9	1	1.8	2	5.6	15	16.5	14	3.1	36	15.1	-	-	19	1.5	63	1.4	31	2.4	183	2.1
Fawnfoot	-	-	-	-	6	1.6	1	0.9	-	-	1	2.8	15	16.5	9	2.0	3	1.3	-	-	28	2.2	40	0.9	59	4.5	162	1.9
Threehorn	9	14.1	14	10.4	11	2.9	5	4.3	3	5.4	2	5.6	-	-	5	1.1	1	0.4	-	-	17	1.4	52	1.2	40	3.0	159	1.8
Deertoe	-	-	6	4.4	19	5.0	-	-	-	-	-	-	1	1.1	10	2.2	4	1.7	-	-	28	2.2	45	1.0	41	3.1	154	1.8
Giant Floater	-	-	1	0.7	-	-	1	0.9	-	-	1	2.8	3	3.3	3	0.7	5	2.1	-	-	29	2.3	12	0.3	15	1.1	70	0.8
Pocketbook	1	1.6	2	1.5	3	0.8	1	0.9	-	-	1	2.8	2	2.2	8	1.8	9	3.8	-	-	2	0.2	15	0.3	7	0.5	51	0.6
Pink Heelsplitter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0.2	1	0.4	-	-	14	1.1	19	0.4	6	0.5	41	0.5
Rockshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0.4	9	0.2	16	1.2	30	0.3
Black Sandshell	-	-	-	-	3	0.8	-	-	-	-	-	-	4	4.4	2	0.4	3	1.3	-	-	5	0.4	5	0.1	1	0.1	23	0.3
Strange Floater	-	-	-	-	-	-	-	-	-	-	1	2.8	-	-	-	-	-	-	-	-	3	0.2	12	0.3	5	0.4	21	0.2
Fat Mucket	-	-	-	-	16	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	0.2	-	-	-	-	19	0.2
Monkeyface	-	-	-	-	-	-	4	3.5	-	-	-	-	2	2.2	-	-	-	-	-	-	-	-	8	0.2	2	0.2	16	0.2
Fragile Papershell	1	1.6	-	-	-	-	-	-	2	3.6	4	11.1	-	-	-	-	-	-	-	-	2	0.2	2	<0.1	1	0.1	12	0.1
Ohio River Pigtoe	-	-	-	-	-	-	4	3.5	1	1.8	-	-	-	-	-	-	-	-	-	-	5	0.4	-	-	-	-	10	0.1
Paper Floater	-	-	-	-	5	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	<0.1	-	-	7	0.1
Butterfly	-	-	-	-	-	-	-	-	-	-	1	2.8	-	-	1	0.2	-	-	-	-	-	-	-	-	4	0.3	6	0.1
White Heelsplitter	1	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	<0.1	3	0.2	6	0.1
Lilliput	-	-	1	0.7	3	0.8	1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	0.1
Pink Papershell	-	-	-	-	1	0.3	-	-	-	-	-	-	1	1.1	-	-	2	0.8	-	-	1	0.1	-	-	-	-	5	0.1
Higgins' Eye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	0.1	1	0.1	5	0.1
Mucket	2	3.1	-	-	1	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	<0.1	-	-	4	<0.1
Purple Wartyback	-	-	-	-	-	-	1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	<0.1
Yellow Sandshell	-	-	-	-	1	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	<0.1
Total number	64		135		383		115		56		36		91		450		239		69		1247		4516		1319		8720	
Total number of spp.	9		11		15		13		7		11		12		13		13		2		21		23		22		30	

TABLE 4. *A species list of mussels collected in Pools 3-11 of the Upper Mississippi River, 1977-79, showing specimens taken live or dead by SCUBA diving and live by brailing.*

	Pool 3		Upper Pool 4		Lake Pepin		Lower Pool 4		Pool 5		Pool 5A		Pool 6		Pool 7		Pool 8		Black River		Pool 9		Pool 10		Pool 11	
Species	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Spectacle Case	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Monkeyface	-	-	-	-	-	0	*	0	-	-	-	0	*	0	-	0	-	0	-	-	-	0	*X	0	*X	0
Mapleleaf	-	-	*	-	-	0	-	0	-	-	-	-	-	-	X	-	*X	0	X	-	*X	0	*X	0	*X	0
Wartyback	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	*	0	*X	0	*X	0
Pimpleback	*X	-	*	0	*X	0	*X	0	*X	-	*X	0	*X	0	*X	0	*X	0	-	0	*X	0	*X	0	*X	0
Buckhorn	-	-	-	-	-	0	-	0	-	-	-	-	-	0	-	0	-	0	-	-	-	0	-	0	-	0
Purple Wartyback	-	-	-	0	-	-	*	0	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	-	-	-
Pigtoe	*X	0	*	-	*X	0	*X	0	*	0	*X	0	*	0	*X	0	*X	0	*	0	*X	0	*X	0	*X	0
Ebony Shell	-	0	-	0	-	0	-	0	-	-	-	0	-	-	-	-	-	0	-	-	-	0	-	0	-	0
Washboard	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	*X	0	*X	0	*X	0
Threeridge	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0	*X	0
Bullhead	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Ohio River Pigtoe	-	-	-	-	X	0	*X	0	*	-	-	0	-	0	-	0	-	0	-	-	*	0	-	0	-	0
Elephant Ear	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0
Spike	*	-	*	-	*X	0	*X	0	X	-	-	0	*	-	*	0	-	0	-	-	*X	0	*X	0	*X	0
Threehorn	*X	0	*X	0	*X	0	*	0	*X	0	*X	0	X	0	*X	0	*X	0	X	-	*X	0	*X	0	*X	0
Pink Heelsplitter	-	-	-	0	-	0	-	0	X	0	-	0	-	0	*X	0	*X	0	-	-	*X	0	*X	0	*X	0
Pink Papershell	-	-	-	-	*	0	-	0	-	-	-	-	*	-	-	-	*	-	-	-	*X	0	X	-	-	0
Fragile Papershell	*	0	X	0	-	0	-	0	*	0	*	-	-	0	X	0	X	0	-	-	*X	0	*X	0	*X	0
Butterfly	-	-	-	-	-	0	-	0	-	-	*	-	-	0	*	-	X	-	-	-	X	0	X	0	*X	0
Deertoe	-	0	*X	-	*X	-	-	0	-	0	-	-	*	-	*X	0	*X	0	-	-	*X	0	*X	0	*X	0
Fawnfoot	-	-	-	-	*	0	*X	-	-	0	*X	0	*	-	*X	0	*X	0	-	-	*X	0	*X	0	*X	0
Hickorynut	-	0	*	-	-	-	*	0	*	-	*	0	*	-	*	0	*X	0	-	-	*X	0	*X	0	*X	0
Mucket	*	0	-	0	*X	0	-	0	-	0	-	0	-	-	-	-	-	0	-	-	-	0	*	0	-	0
Black Sandshell	-	-	-	0	*	0	X	0	-	0	-	0	*	0	*	0	*	0	-	-	*X	0	*X	0	*X	0
Lilliput	-	-	*	-	*	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0	X	0	X	0
Yellow Sandshell	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	-	0
Higgins' Eye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	*X	0	*X	0
Fat Mucket	-	0	-	0	*	0	X	0	-	0	-	-	-	-	-	-	-	-	-	-	*X	0	X	0	-	0
Pocketbook	*	0	*X	0	*	0	*	0	X	0	*	0	*X	0	*X	0	*X	0	X	-	*X	0	*X	0	*X	0
Rockshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*X	0	*X	0	*X	0
White Heelsplitter	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0	*	0	*X	0
Fluted Shell	-	-	-	-	-	0	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	-	-
Elktoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Paper Floater	-	-	-	-	*	-	X	0	-	-	-	-	-	-	-	-	-	-	-	-	X	0	*X	0	X	0
Giant Floater	-	-	*	0	X	0	*X	0	X	-	*	-	*X	0	*X	0	*X	0	X	-	*X	0	*X	0	*X	0
Strange Floater	-	-	-	-	-	-	-	-	-	-	*	0	-	-	-	-	-	-	-	-	*X	0	*X	0	*X	0
Asiatic Clam	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	0	-	-	-	-
Number of dives	4		3		8		5		5		2		3		5		4		1		8		8		6	

X -- live specimen taken by SCUBA;
* -- live specimen taken by brail;
0 -- dead specimen taken by SCUBA

transect runs also accounted for 40.4% of all samples taken over a clay-silt substrate. Sand was found on 18.6% of the total runs.

Lower Pool 4

The clam bar yielded 115 adult mussels and 10 juveniles, representing 13 species in Pool 4 below Lake Pepin. In addition, SCUBA diving added 3 live species and the shells of 11 dead species. This is the largest number of species represented only by dead specimens in any particular segment of the entire study area.

Threeridge accounted for more than half (52.2%) of the mussels collected on the brail in this section. Pimpleback and Pigtoe each contributed 13.0% of the brailed mussel catch. Monkeyface, a species rarely taken above Pool 10, was recorded on one run (4 individuals). The most unique specimen collected during the survey and found only in this section was a Purple Wartyback, which is and always has been a rare species in the Upper Mississippi River (Fuller 1978). Another collection of Purple Wartyback has been made by commercial clammers in Andalusia Slough, Pool 16 (Fuller 1980). Until recently, there apparently have been no living records of this species in Pools 3-11 since the Ellis survey of 1930-31 (van der Schalie and van der Schalie 1950). Five other species were represented by single specimens on the brail.

Of the 130 runs, 36 (27.7%) yielded mussels. Eighteen mussels representing 3 species were collected with the brail at the most productive site in this area. Another run produced more species, 6, but fewer mussels, 11. More than half (52.3%) of the bottom types sampled in this area were sand.

Pool 5

In Pool 5, 56 adult mussels and 52 juveniles of 7 species were collected on the brail. SCUBA diving added 4 more live (all of which had been previously recorded in northern pools on the brail except the Pink Heelsplitter) and 5 dead species. Threeridge made up 48.2% of the brail catch and Pigtoe represented 25.0% of the total, but were taken on only 5.7% and 6.2% of the runs, respectively. Pimpleback was next in abundance, with only 1-3 brailed specimens taken of the remaining 4 species.

Of the 194 runs made in this pool, only 25 produced mussels. This is the lowest percentage, 12.9%, of positive runs in the entire study area. The largest number of mussels collected at one site on the brail was 9, representing 3 species. The largest number of species found at one location was 4 and accounted for 8 mussels. The major bottom types in the area of the runs were sand, a combination of sand and silt, and silt, comprising 41.2%, 21.6% and 21.1% of the substrates, respectively.

Pool 5A

The brail collected 36 adult mussels and 172 juveniles, representing 11 species. Dead specimens of 9 more species were added by SCUBA diving. Threeridge was the dominant species followed by Pimpleback, Pigtoe, and Fragile Papershell, accounting for 33.3%, 19.4%, 11.1%, and 11.1% of the brail mussel catch, respectively. As in Pool 5, these were taken on a relatively small proportion of runs. Only 1 or 2 specimens were recorded of the 7 other species.

In this pool, 128 runs were made and 24 were positive. The largest number of mussels collected by the brail at one site was 5 and they represented 4 species. Over three-fourths (76.5%) of all runs were taken over a sand bottom.

Pool 6

Pool 6 yielded 13 live species, 12 of which were taken on the brail. Dead specimens collected by diving added 5 more species. A total of 91 adults and 432 juveniles were harvested. Threeridge was the most abundant species collected in this pool, comprising 27.5% of the brail catch, and was found on the most runs (8.8%). Both Hickorynut and Fawnfoot each accounted for 16.5% of the brailed mussels. Threehorn was collected on the brail in all pools except for Pool 6 where it was only taken by SCUBA diving. Deertoe and Pink Papershell were the only species collected as single specimens.

Mussels were harvested on 38 of the 194 runs. The majority (72.7%) of runs were taken over a sand or silt and clay substrate. The most productive run in this pool yielded 12 mussels and 6 species.

Pool 7

In Pool 7, 563 juveniles and 450 adult mussels representing 18 species were collected on the brail. Approximately one-third of all the juveniles captured in the entire study area were from Pool 7. SCUBA diving added 2 more live species and dead specimens of 4 species.

Threeridge was by far the most dominant species (63.8% of the total brail catch) and continued to dominate the catch downriver. Pimpleback and Pigtoe were the next most abundant species, accounting for 15.1% and 8.9% of the catch, respectively. Pimpleback, though fewer in numbers, was as widely distributed as Threeridge (25.1% of the runs compared to 27.4%). The five species with the lowest percent abundance were represented only by 1-3 individuals.

Of the 179 runs made in this pool, 46.9% produced mussels. The largest number of mussels collected on one run was 42, representing 8 species. The majority (66%) of the samples were located over a sand substrate.

Pool 8

Pool 8 yielded 15 live species, 13 of which were taken on the brail. Dead specimens collected by diving added 8 more species. A total of 239 adult mussels and 84 juveniles were collected by the brail. Threeridge was the most abundant species (57.7% of the catch and present on 16.3% of the runs). Hickorynut, Pimpleback and Pigtoe were the next most abundant species, all taken on approximately 5% of the runs. The percent abundance for Pocketbook and Pink Papershell was greater in this pool than in any other part of the study area.

Of the 276 runs made in this pool, 74 (26.8%) produced mussels. Twenty-five specimens representing 4 species were collected at the most productive site in this pool. Another run produced more species, 5, but not as many mussels, 15. More than half of the runs (54.7%) were made over a sand substrate.

Black River

The Black River is a major tributary of the Mississippi River which drains into Pool 8. Only 2 live species were collected on the clam bar but SCUBA diving added 4 more live species (all of which had previously been recorded upstream in the Mississippi River) and the shells from 2 additional dead species. No juveniles and 69 adults were brailed in the Black River.

Threeridge accounted for 92.8% of the brail catch (found on 41.4% of the runs) and Pigtoe made up the remaining 7.2% (6.9% of the runs). Sand was the bottom type on 48.3% of the runs. Of the 29 runs made in this area, 12 (41.4%) produced mussels. The most productive run in this area yielded 2 species and 20 specimens.

Pool 9

In the lower three pools the number of mussels and their frequency of occurrence increased markedly. A total of 26 live species were collected in Pool 9, 21 on the brail and 5 additional species by SCUBA diving. Dead specimens collected by diving added 9 more species. The brail yielded 1,247 adult mussels and 18 juveniles.

Threeridge was the most abundant species in this pool, accounting for 42.4% of the brail catch. Washboard (taken for the first time on the brail), Pimpleback, and Pigtoe were next in abundance, making up 10.6%, 9.4% and 8.1% of the brailed mussels, respectively. Threeridge, followed by Pimpleback, Mapleleaf, and Pigtoe, was the most frequently brailed mussel. Wartyback and Rockshell were taken live for the first time (3.5% and 0.4% of the brailed catch, respectively). Pink Papershell was the only species represented by a single specimen on the brail. Dead specimens of Higgins' Eye were collected in this pool, but no living specimens were found.

Approximately half of the 222 runs (53.2%) were positive. The most productive run yielded 56 specimens, representing 8 species. Four other runs had 9 species but not as many mussels.

Pool 10

More live species were collected in this pool than in any other section of the study. The clam bar collected 23 species and SCUBA diving added 4. Dead specimens of 6 additional species were collected by diving. A total of 4,516 adult mussels and 89 juveniles were collected on the brail. This is more than three times the number of adult mussels collected in any other pool, and a higher yield of adult mussels than the rest of the pools combined.

Threeridge dominated the brailed mussel catch (72.1%). Next in abundance were Pimpleback, Pigtoe, Mapleleaf, and Washboard. Threeridge was found on 56.1%, Pimpleback on 39.4%, and Pigtoe on 32.9% of the runs. This is the highest frequency of occurrence for these species in all of the pools. Mapleleaf was collected on 25.6% of the runs, but the Washboard, fifth in abundance, was taken on only 16.7% of the runs. Mucket was the only species represented by a single specimen in this pool.

More dead and live specimens of Higgins' Eye were collected in Pool 10 than in any other area. Shells representing 13 dead and 6 live Higgins' Eye were found by brailing and diving in this section of the river. Two live specimens, one on the brail and one from diving, were collected on the Iowa side of the main channel north of Prairie du Chien; 2 in the East Channel on a single brail run; 1 on the brail near the Glen Haven landing; and 1 by SCUBA diving at a site near the Guttenberg Airport.

The highest percentage of positive runs in the entire study area, 70.7%, was recorded from this pool. Of the 246 runs made, 174 produced mussels. One of the Pool 10 runs produced 164 mussels and 9 species which is the greatest number of specimens collected at a single site. Another run produced more species, 12, but only 48 mussels.

Pool 11

Pool 11 yielded 24 live species, 22 of which were taken on the brail. Dead specimens collected by SCUBA diving added 9 more species. A total of 1,319 adult mussels and 83 juveniles were collected in this area by brail.

Threeridge and Mapleleaf were the most abundant and frequently occurring species found in Pool 11, followed by Pimpleback and Pigtoe. Fawnfoot increased in number and frequency of occurrence throughout these last three pools and reached its maximum in Pool 11. Black Sandshell and Fragile Papershell were the least abundant species and were represented on the brail by single specimens.

Three Higgins' Eye were collected in Pool 11: 1 by brailing off Hurricane Island and 2 by diving near the confluence of the Turkey River.

Of the 208 runs made in this pool, 115 (55.3%) produced mussels. The largest number of mussels collected at one site was 78, representing 9 species. Ten species were found at another site but accounted for only 49 specimens.

Pool Comparisons

The average total number of mussels caught per run or the catch per unit effort (CPE) varied considerably among pools during this study, ranging from 18.3 in Pool 10 to 0.3 in Pools 5 and 5A (Fig. 2). Pools 9, 10, and 11 are the areas in the study with the most abundant mussel fauna. Of these areas, Pool 10 had more species, 23, and the highest CPE. The pools north of Pool 9 did not have as many species or specimens.

Species diversity also varied widely among pools (Fig. 3). Pools 9, 6, 11, and 5A had the highest Shannon-Weaver diversity index values and were essentially the same. Black River collections exhibited the lowest diversity, while Pool 7 collections had the lowest diversity for the Mississippi River.

In general, community diversity improves as the number of different species in a sample increases, but the Shannon-Weaver function of community diversity is also influenced by how evenly or equitably the individuals are distributed among the species (Lloyd and Ghelardi 1964). Pool 10 had the most abundant fauna and the largest number of species found in any area but had a relatively low diversity index, due in part to the large proportion (72.1%) of Threeridge. On the other hand, Pools 5A and 6 had some of the highest species diversity values but had CPE values of less than 1.0.

Threeridge was the most abundant species in all of the pools except Pool 3, and reached its greatest abundance in Pool 10. It was also the most widely distributed, occurring in the highest percentage of runs in all pools except 3 and 5. Pigtoe and Pimpleback were generally the next most abundant and frequently occurring mussels.

While some of the mussels were found fairly consistently up and down the river (e.g., Threeridge, Pigtoe, Pimpleback, Threehorn, Pocketbook) or sporadically throughout its length (e.g., Ohio River Pigtoe, Fragile Papershell, Monkeyface), certain species exhibited a definite northern or southern range within the study area. The Fat Mucket is a northern species, found only at three locations below its major concentrations in Lake Pepin. Apparently restricted to the more southerly pools (9-11) were the Wartyback, Rockshell, Higgins' Eye, and Washboard (although 1 specimen of Washboard was taken in Lake Pepin by diving). The Hickorynut increased considerably in abundance and frequency of occurrence from north to south.

The mean lengths (cm) for the 3 predominant mussel species, Threeridge, Pigtoe, and Pimpleback, are depicted in Figure 4. Trends for average size of each species demonstrated a similar pattern of decrease in size downstream to a small size in Lake Pepin, then increased to maximal mean length in Pool 6, and generally decreased in mean length thereafter downstream. Lake Pepin and Pools 9, 10 and 11 Threeridge populations were smaller than those in other areas. The smaller mean size of mussels suggests that the recruitment in those 4 pools may be better than in other areas despite the small number of juveniles found in these areas. Juveniles are found in higher numbers in other pools but a higher percentage of them may not be surviving. This relationship was

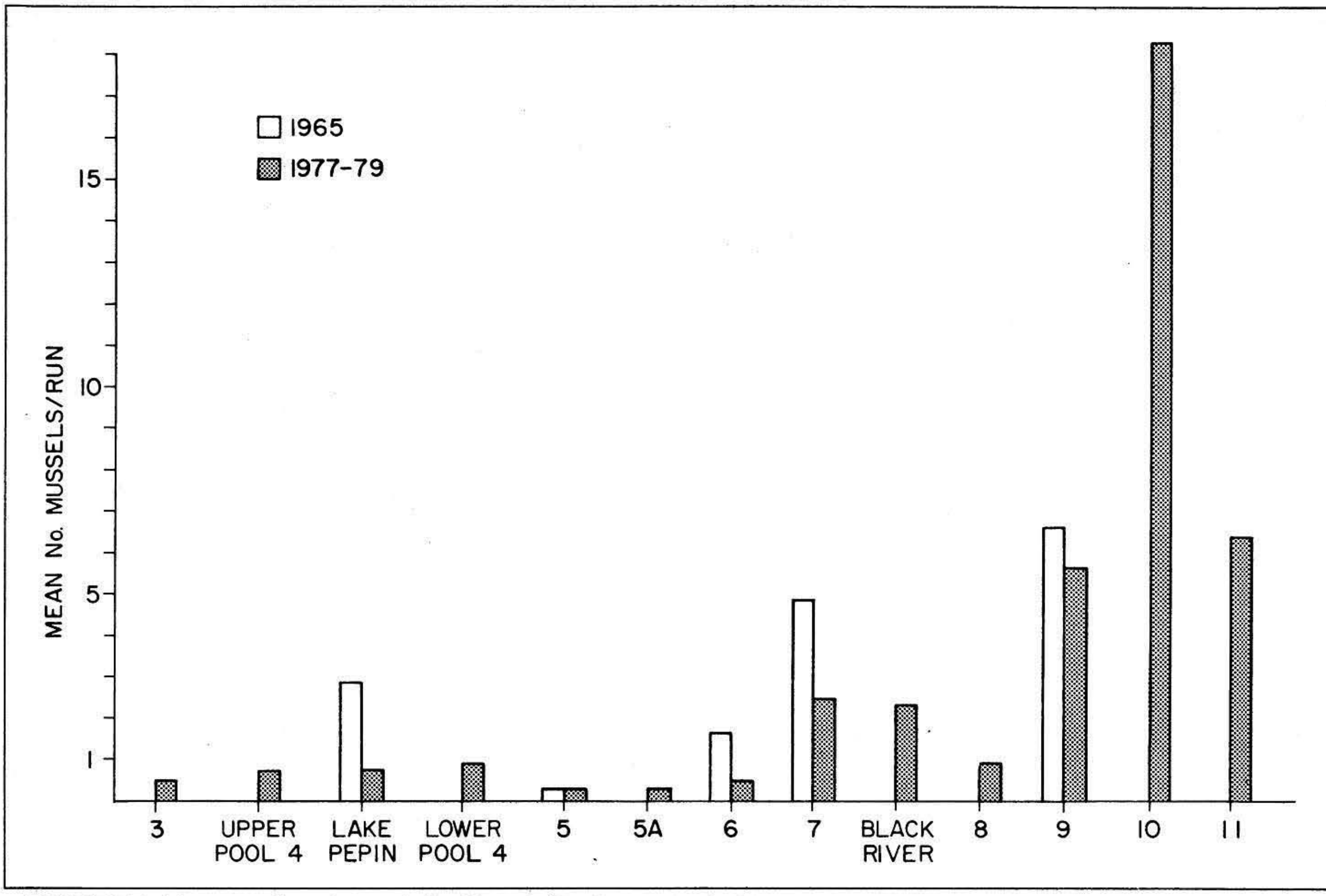


FIGURE 2. *Mean number of mussels/brail run in Pools 3-11 in the Upper Mississippi River.*

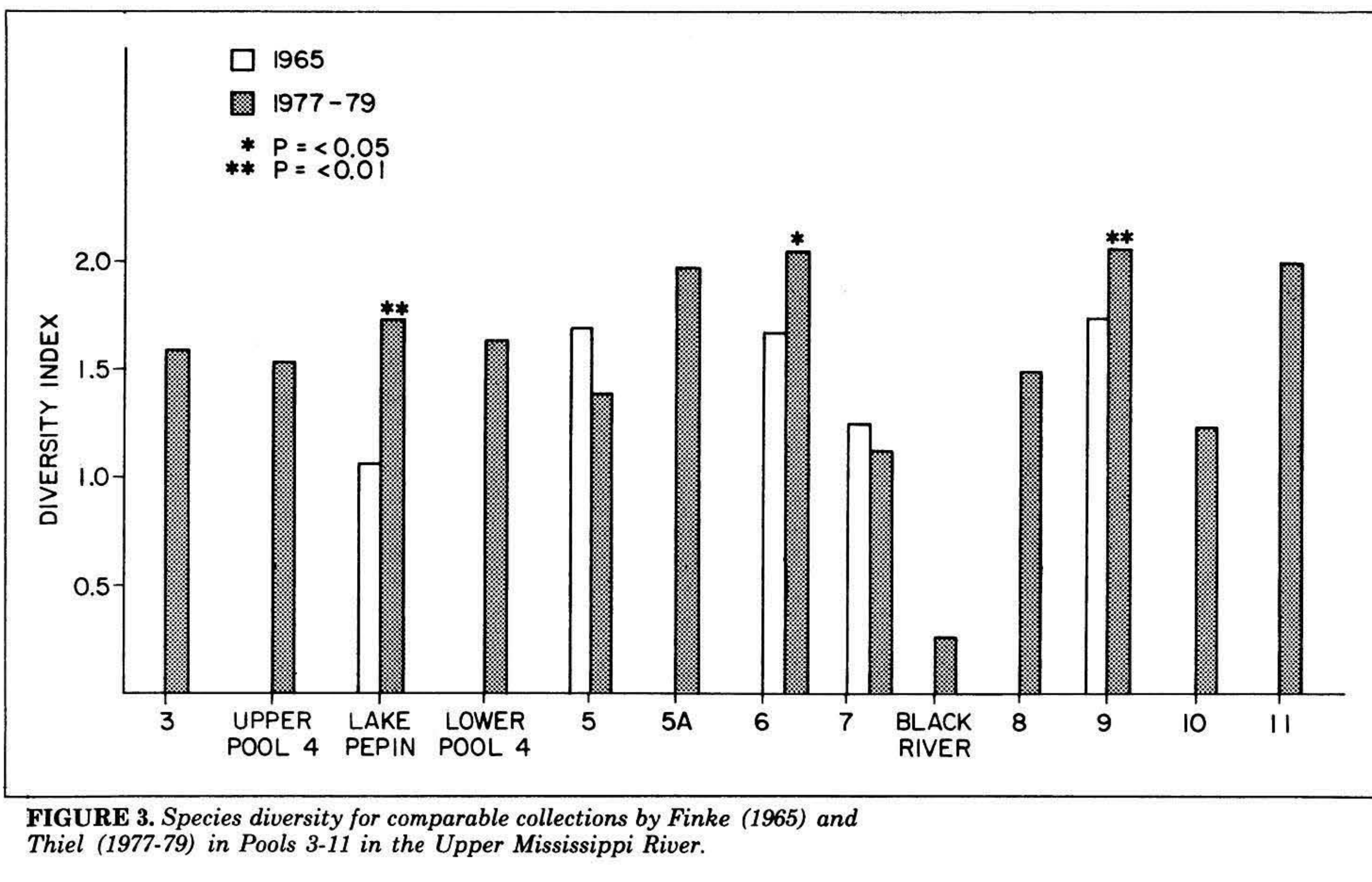


FIGURE 3. *Species diversity for comparable collections by Finke (1965) and Thiel (1977-79) in Pools 3-11 in the Upper Mississippi River.*

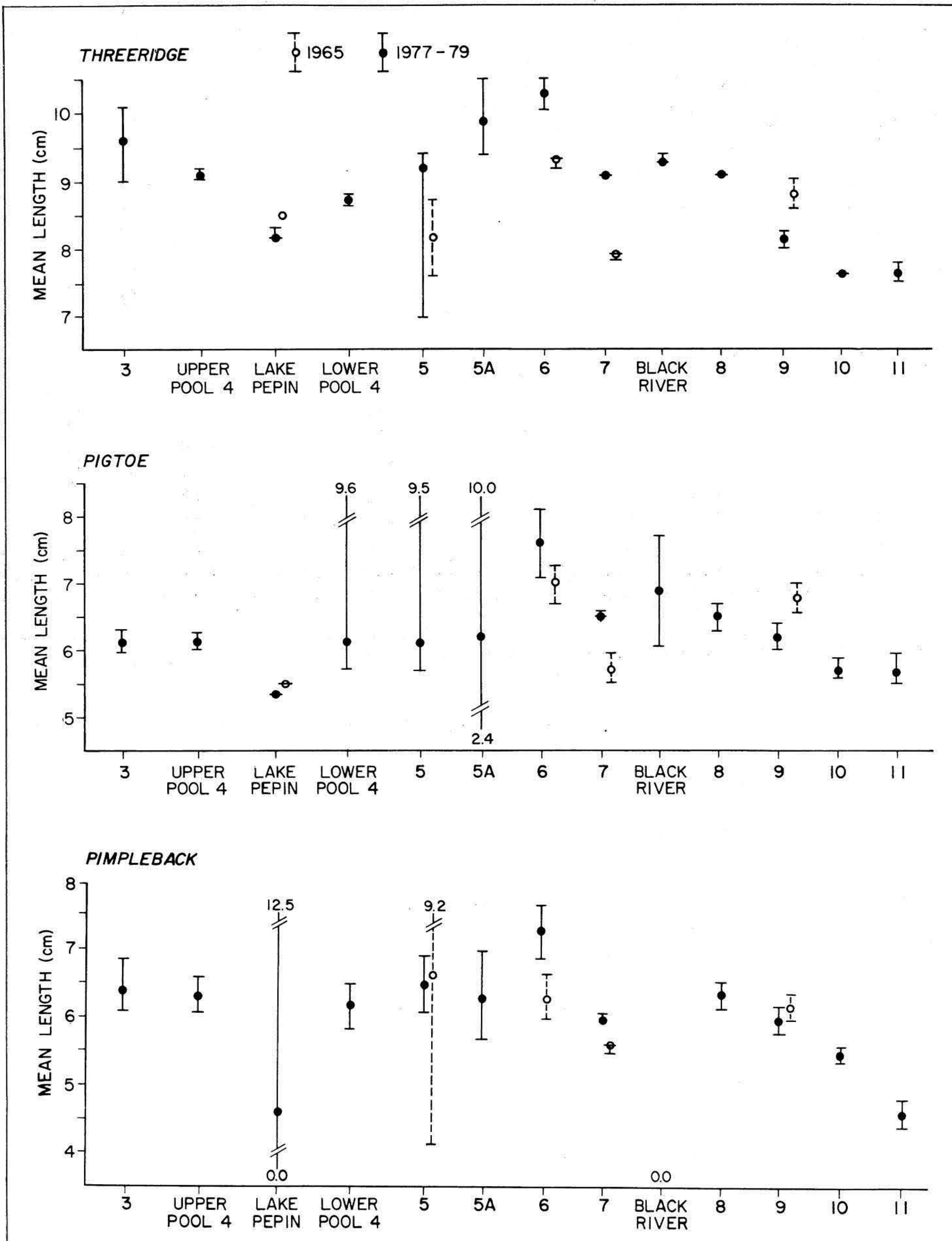


FIGURE 4. *Mean length and 99% confidence intervals for the three predominant mussel species in Pools 3-11, Upper Mississippi river, in 1977-79 (Thiel) compared to 1965 (Finke).*

less clear for the other two species.

In Pools 3-8, only 16 Threeridge less than 3.5 cm were collected by diving and brailing. Ten times the number of small Threeridge, 160, were found by diving and brailing in Pools 9-11. Of all the Pigtoe collected in Pools 3-8, only 6 were less than 3.0 cm. Small Pigtoe harvested in Pools 9-11 numbered 30. There were 4 Pimpleback less than 3.0 cm found in Pools 3-8 and 21 harvested in Pools 9-11. This appears to indicate that recruitment is better in Pools 9-11 than the upper pools.

Historical Comparisons

The number of mussel species present in the Upper Mississippi River has declined since earlier surveys. Baker (1905) noted 32 species and Shimek (1921) collected 39 species of mussels from the McGregor, Iowa region in Pool 10. Their sampling locations are not precisely known so comparisons with the present study are not possible. However, only 27 species were found from all of Pool 10 in this study.

Grier (1922) reported 37 mussel species from his entire study area, which included segments in what are now Pools 4-6 (Table 5). Sampling during the present study in Grier's area produced 26 species. This represents a 30% loss of mussel species. Grier divided his study area into 10 sections. When these areas are looked at individually, the greatest species decrease was at the northernmost part of his study in Upper Pool 4 where the drop in species was 70%; the lowest species reduction, 40%, was in the area of what is now Lower Pool 4 and Pool 5.

In 1930-31 Ellis collected 38 species from areas in Pools 4, 7, 8, 9, and 10 (van der Schalie and van der Schalie 1950). Four of Ellis' 14 study zones were within the present study area, and corresponding runs taken in this survey yielded 30 species. This represents a 21% species loss. The zone with the greatest species reduction, 47%, was in a section of Lower Pool 4 and the area with the least reduction, 4%, was located in parts of what are now Pools 7, 8, and 9.

In comparing the Grier and Ellis surveys with the present one, the number of species collected varied greatly between areas and time periods sampled. In all cases, however, both of the earlier collections contained more species per equivalent sample area than were found during this study. These two early surveys found the Butterfly throughout the entire study area but it is now found in modest populations mainly in the lower pools. The Pink Heelsplitter, White Heelsplitter and Strange Floater were once located more universally throughout the study area but they are now abundant mainly in the southern pools.

Dead specimens collected in this study verified the past existence of many of the species reported by Grier and Ellis. In Grier's area only dead specimens represented the following species in 1978: Buckhorn, Bullhead, Ebony Shell, Elephant Ear, and Fluted Shell. No living or dead specimens of Higgins' Eye, Rockshell, White Heelsplitter, Elktoe, Snuffbox *(Dysnomia triquetra)*, or Western Pondmussel *(Ligumia subrostrata)* were collected where Grier previously had reported their presence.

Species listed by Ellis that were only found as dead specimens in comparable areas during 1977-79 were Buckhorn, Ebony Shell, Elephant Ear, Bullhead, and Elktoe. Species collected by him that were not found in the present study as live or dead specimens were the Fat Pocketbook, Salamander Mussel *(Simpsoniconcha ambigua)*, and Ellipse *(Actinonaics ellipsiformis)*. Grier also did not find an Ellipse. The Fluted Shell was the only species not noted by Ellis, but found as dead specimens in his area during this study.

There has been a shift in species dominance since the impoundments of the Mississippi River. Threeridge is presently the dominant species, but it was not the most abundant species collected in pre-impoundment studies done by Grier during 1920. The relative abundance of Pigtoe, Pimpleback, Mapleleaf and Washboard was also greater during the present study than in the Grier survey. Many species

TABLE 5. *Comparisons between the abundance of mussels found in the Upper Mississippi River in surveys by Grier (1920), Ellis (1930-31) and DNR (1977-79) (percent of total catch).*

Species	Grier (1920) (Pools 4-6)	Ellis (1930-31) (Pools 4,7-10)	DNR (1977-79) (Pools 3-11)
Ebony Shell	3.0	0.3	-
Ohio River Pigtoe	1.5	0.3	0.1
Hickorynut	7.0	1.6	2.1
Pimpleback	3.0	3.3	7.8
Mapleleaf	<1.0	<0.1	4.8
Monkeyface	4.7	0.9	0.2
Purple Wartyback	<1.0	<0.1	<0.1
Threehorn	1.7	2.4	1.8
Pigtoe	7.2	4.5	8.7
Threeridge	9.7	8.5	59.2
Washboard	<1.0	0.9	3.3
Buckhorn	<1.0	7.5	-
Mucket	2.4	1.2	<0.1
Higgins' Eye	<1.0	0.1	0.1
Fat Mucket	14.4	10.1	0.2
Butterfly	<1.0	0.6	0.1
Deertoe	1.1	1.7	1.8
Pocketbook	12.2	7.8	0.6
Yellow Sandshell	1.5	17.4	<0.1
Black Sandshell	3.1	1.1	0.3
Western Pondmussel	<1.0	-	-
Bullhead	<1.0	<0.1	-
White Heelsplitter	1.4	1.2	0.1
Fluted Shell	<1.0	-	-
Pink Heelsplitter	3.9	6.6	0.5
Rockshell	<1.0	0.2	0.3
Elephant Ear	<1.0	<0.1	-
Spike	3.8	4.2	2.3
Elktoe	<1.0	0.1	-
Fawnfoot	<1.0	0.2	1.9
Giant Floater	5.9	5.3	0.8
Paper Floater	1.3	0.6	0.1
Strange Floater	1.5	1.4	0.2
Fragile Papershell	4.1	8.8	0.1
Pink Papershell	<1.0	0.3	0.1
Lilliput	<1.0	0.2	0.1
Snuffbox	<1.0	-	-
Wartyback	-	0.3	2.4
Salamander Mussel	-	<0.1	-
Ellipse	-	0.2	-
Fat Pocketbook	-	0.2	-

markedly decreased overall from 1920 to 1977-79, including Hickorynut, Monkeyface, Mucket, Fat Mucket, Pocketbook, Pink Heelsplitter, Giant Floater, and Fragile Papershell.

The relative abundance of mussels has also changed considerably since the 1930-31 Ellis survey. Threeridge has increased the most, from 8.5% of the total catch in 1930-31 to 59.2% in 1977-79. Mapleleaf, Pimpleback, and Pigtoe accounted for 4.8%, 7.8%, and 8.7% of the brail catch in 1977-79 but only < 0.1%, 3.3%, and 4.5% of the 1930-31 catch, respectively. Washboard, Wartyback, and Fawnfoot were also substantially more numerous in the present survey than in the Ellis study. The Yellow Sandshell showed the greatest decrease in relative abundance between the two surveys; it went from 17.4% in the Ellis survey to less than 0.1% in the 1977-79 study. Fragile Papershell, Fat Mucket, and Pocketbook also dropped in abundance from 8.8%, 10.1% and 7.8% of the catch, respectively, in the earlier study to less than 1.0% of the catch in the 1977-79 survey. Other mussels showing declines included Fat Mucket, Pocketbook, Yellow Sandshell, Pink Heelsplitter, Giant Floater, and Fragile Papershell.

The Lilliput is more widespread today than previously reported by Grier (1922). Fuller (1980) also found this to be the case. It was not even considered a regular part of the fauna by the van der Schalies (1950). Because of its small size, it is probably much more common currently than collection records indicate (Mathiak 1979).

The Finke survey (1966) of Lake Pepin, Pools 5, 6, 7, and 9 yielded 23 species (Table 6). In comparable areas with equivalent effort, the present study noted 27 species. In Pool 9, more species (21) were noted in the present study than were accounted for by Finke, who found 18 species. In his other areas of study, Lake Pepin, Pools 5, 6, and 7, Finke reported 21 species while 22 living species were found in comparable areas by the current study. Two species, the Higgins' Eye and Ebony Shell, collected live by Finke, were only found as dead specimens in his study area in 1977-79. Finke did not find the following species live that were collected in comparable areas with equivalent effort in this survey: Wartyback, Paper Floater, Mucket, Lilliput, Rockshell, Fawnfoot and Ohio River Pigtoe.

Mussel species diversity in collections made by Finke (1966) also varied between the pools (Fig. 3). The greatest species diversity in both the Finke and present study was in Pool 9. The lowest species diversity found in the Finke survey was in Lake Pepin. The species diversity was greater in Pools 5 and 7 in the 1965 survey than in the 1977-79 study. However, 1977-79 mussel collections in Lake Pepin, Pool 6, and Pool 9 were significantly more diverse than similar collections made in 1965. This increase in diversity since 1965, however, was probably more apparent than real. The smaller number of runs made by Finke in 1965 may have resulted in a sampling error showing less species diversity. Further loss of marginal mussel populations (i.e., 6 species represented by 5 or fewer specimens) may produce a shift to net loss in mussel species diversity if trends continue.

Mussel densities (CPE) were always greater in 1965 than in 1977-79, with the exception of Pool 5 where they were the same (Fig. 2). The CPE was 4 times greater in Lake Pepin during 1965 than in 1977-79, 3 times larger in Pool 6, 2 times greater in Pool 7, and slightly larger in Pool 9. The sparse

TABLE 6. *Comparisons of the relative abundance (%) of mussels collected by brailing in Pools 5, 6, 7, 9, and Lake Pepin by the Wisconsin Department of Natural Resources surveys of Finke (1965) and Thiel (1977-79).*

	Lake Pepin		Pool 5		Pool 6		Pool 7		Pool 9	
Species	1965	1977-79	1965	1977-79	1965	1977-79	1965	1977-79	1965	1977-79
Threeridge	71.5	32.9	42.1	48.2	52.3	27.5	60.6	63.8	29.7	42.4
Pigtoe	11.2	29.8	-	25.0	7.5	14.3	8.7	8.9	14.8	8.1
Pimpleback	0.3	0.8	21.1	14.3	13.1	8.8	20.0	15.1	24.9	9.4
Mapleleaf	-	-	-	-	-	-	0.2	-	3.6	6.9
Threehorn	-	2.9	-	5.4	3.7	-	1.5	1.1	1.2	1.4
Fawnfoot	-	1.6	-	-	-	16.5	-	2.0	-	2.2
Hickorynut	-	-	-	1.8	1.9	16.5	5.2	3.1	4.1	1.5
Deertoe	-	5.0	-	-	-	1.1	0.2	2.2	0.1	2.2
Wartyback	-	-	-	-	-	-	-	-	-	3.5
Washboard	-	-	-	-	-	-	-	-	5.8	10.6
Spike	0.8	18.5	-	-	4.7	2.2	-	0.4	3.0	6.2
Pocketbook	1.0	0.8	-	-	3.7	2.2	0.2	1.8	0.5	0.2
Giant Floater	1.3	-	5.3	-	2.8	3.3	0.7	0.7	5.0	2.3
Pink Heelsplitter	0.8	-	-	-	-	-	0.2	0.2	2.9	1.1
Rockshell	-	-	-	-	-	-	-	-	-	0.4
Black Sandshell	3.4	0.8	10.5	-	7.5	4.4	0.5	0.4	1.6	0.4
Fat Mucket	8.4	4.2	5.3	-	-	-	-	-	0.1	0.2
Strange Floater	-	-	5.3	-	-	-	-	-	-	0.2
Fragile Papershell	0.3	-	-	3.6	-	-	-	-	-	0.2
Monkeyface	-	-	-	-	-	2.2	0.7	-	-	-
Ohio River Pigtoe	-	-	-	1.8	-	-	-	-	-	0.4
Paper Floater	-	1.3	-	-	-	-	-	-	-	-
White Heelsplitter	-	-	-	-	-	-	-	-	-	-
Lilliput	-	0.8	-	-	-	-	-	-	-	-
Pink Papershell	-	0.3	5.3	-	-	1.1	-	-	-	0.1
Butterfly	0.3	-	5.3	-	-	-	0.5	0.2	1.9	-
Mucket	-	0.3	-	-	-	-	-	-	-	-
Higgins' Eye	-	-	-	-	-	-	0.5	-	-	-
Yellow Sandshell	0.8	0.3	-	-	1.9	-	-	-	0.6	-
Purple Wartyback	-	-	-	-	-	-	-	-	-	-
Ebony	-	-	-	-	0.9	-	-	-	0.1	-
Buckhorn	-	-	-	-	-	-	-	-	0.1	-

TABLE 7. *Average length and height of mussels subsampled from commercial clamming operations in 1977 and 1978.*

				Length (cm)		Height (cm)	
Year	Species	No.	Percent	Avg.	Range	Avg.	Range
1977	Washboard	749	51.4	15.5	12.1-19.0	10.8	7.2-16.6
	Threeridge	697	47.9	9.6	7.6-12.5	7.3	6.3- 9.2
	Mapleleaf	8	0.5	8.5	7.9- 9.0	7.1	6.5- 7.7
	Pimpleback	2	0.1	7.7	7.3- 8.0	7.3	7.0- 7.6
1978	Washboard	621	48.2	15.2	11.4-19.0	10.6	8.5-13.0
	Threeridge	640	49.7	9.5	7.4-12.0	7.2	5.8- 8.5
	Mapleleaf	24	1.9	8.2	5.8- 9.6	7.2	6.1- 8.5
	Pigtoe	1	0.1	6.8	-	7.0	-
	Pimpleback	3	0.2	8.4	-	7.4	7.0- 7.7
Total 1977-78	Washboard	1,370	49.9	15.4	11.4-19.0	10.7	7.2-16.6
	Threeridge	1,337	48.7	9.6	7.4-12.5	7.3	5.8- 9.2
	Mapleleaf	32	1.2	8.3	5.8- 9.6	7.2	6.1- 8.5
	Pigtoe	1	<0.1	6.8	-	7.0	-
	Pimpleback	5	0.2	8.1	7.3- 8.4	7.4	7.0- 7.7

mussel populations in Pool 5 in both 1965 and 1977-79 were probably caused by the negative impact of the Chippewa River's bedload. Threeridge, Pigtoe and Pimpleback dominated the catches during both studies, but since the CPE was larger in 1965 than in 1977-79, the density of these species has apparently also declined.

A significant difference in mussel length is implied when confidence intervals of compared groups do not overlap (Fig. 4). Mussels collected in 1977-79 were significantly longer than in 1965 for 5 of 13 cases of comparable data. During 1977-79 Threeridge collected in Pools 6 and 7, Pigtoe in Pool 7, and Pimpleback in Pools 6 and 7 were larger than those species collected in 1965. In only two cases did specimens collected in 1965 have a greater mean length than those collected in 1977-79: Threeridge and Pigtoe from Lake Pepin and Pool 9. This may indicate better recruitment in these areas today.

GRAVIDITY

Marsupia are the areas of the female gills where eggs and glochidia, larval mussels, are found during the reproductive season. Usually, the glochidia are released into the water and attach to a species-specific host fish (Bridges 1958). During the first year of study, some of the mussels were examined in the field. If examination of the marsupia revealed the presence of eggs or glochidia, the mussels were recorded as gravid females.

Gravidity data were collected for 13 species, but the majority of the examined mussels were Threeridge and Pimpleback. Since no Washboard specimens were collected during 1977, there were no gravidity data for this species. The first gravid mussels noted at the start of the survey in May were Threeridge and Pimpleback. Of the 54 Threeridge dissected, the minimum length of a gravid female was 5.3 cm and the maximum was 11.5 cm. The size range of the 23 gravid Pimplebacks that were examined was 4.2 to 8.6 cm.

When the minimum lengths of gravid females are applied to the length frequency data from brailing and diving, the majority of Threeridge and Pimpleback mussels taken during the study were mature specimens. The percent of the sampled Threeridge and Pimpleback large enough to be sexually mature were 91.4% and 86.4%, respectively.

COMMERCIAL HARVEST

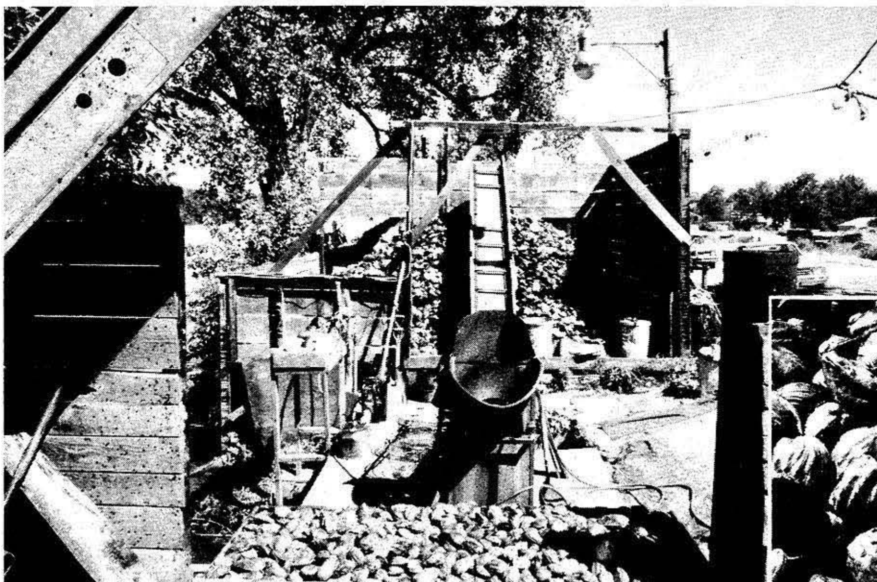
Washboard and Threeridge are the two most commercially important species of mussels in the Upper Mississippi River. According to subsamples taken from commercial mussel piles during 1977 and 1978, Washboard represented 49.9% and Threeridge accounted for 48.7% of the catch (Table 7). Mapleleaf, Pimpleback and Pigtoe comprised less than 2% of the commercial catch. Even though Washboard and Threeridge were taken in about equal numbers, the Washboard is more massive and accounted for a larger proportion of the tonnage.

Pools 9 and 10 are the only areas where both Threeridge and Washboard are abundant enough to make commercial harvest profitable. Although Threeridge is the most abundant species in the study area, the catch rate appears too low in Pools 3-8 to make harvest economical. However, Threeridge is numerous in Pools 9 and 10, making up 65.7% of this study's catch in these areas. In Pools 3-8, only a single live specimen of a Washboard was collected by this survey, but Washboard made up 4.5% of the catch in Pools 9 and 10.

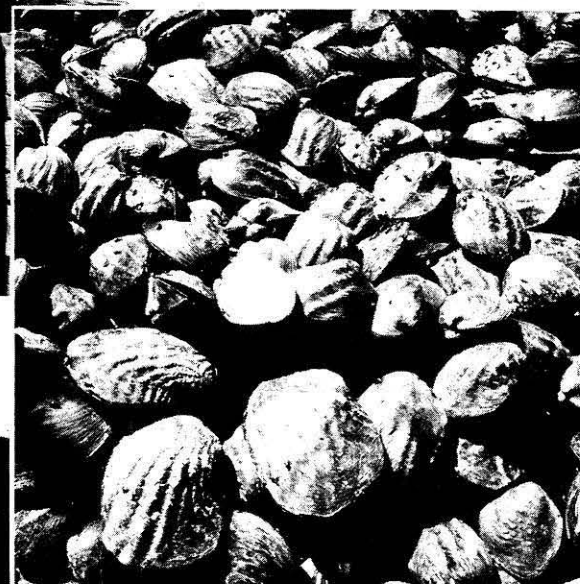
The location of recent historical beds in Lake Pepin and Upper Pool 4 were mapped by a commercial clammer, Worth Emanuel. Only 13 of the 527 runs made on Lake Pepin and 8 of the 193 runs from Upper Pool 4 in 1978 yielded more than 5 mussels. Of the more productive runs made on Lake Pepin and Upper Pool 4, 10 corresponded to commercial beds. This suggests that historical beds in these areas are no longer productive enough to support commercial clammers. No mussels are currently being harvested commercially in this area.

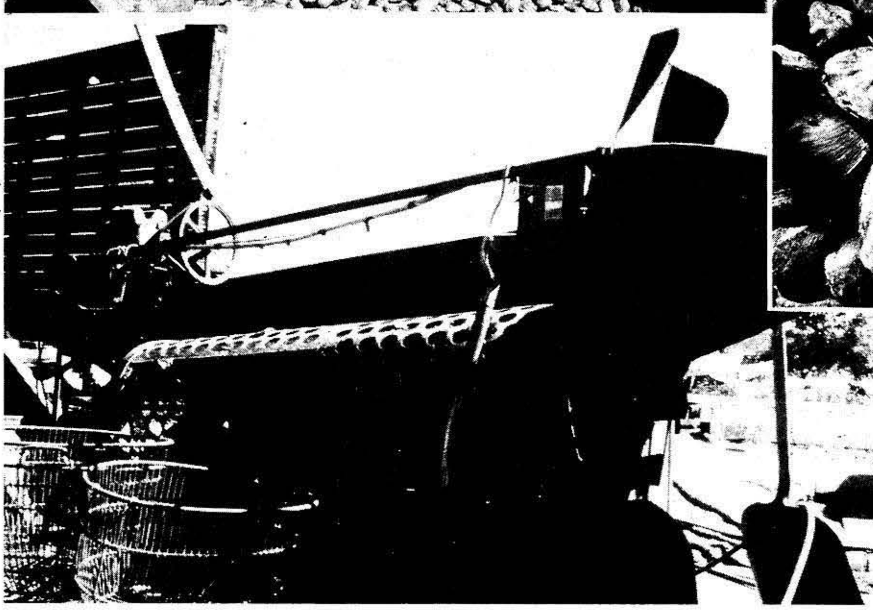
In 1977, 98% of the mussels were taken from Iowa backwaters in Pool 10 and the remaining 2% came from pollywoggers working in the shallows near Prairie du Chien. Due to low water conditions during 1977, clam bars were not used because the river current was too slow to propel the mule-driven boats. (A mule is an underwater canvas sail used to direct the boat downstream.) Diving rigs were the only gear utilized in 1977. A maximum of 12 diving rigs were in operation at one time.

In 1978, mussels were collected in Pools 9 and 10 from both Wisconsin and Iowa waters, with 69% taken from Iowa and the remaining 31% from Wisconsin. A total of 9 brailing boats were leased by commercial clammers



A commercial clamming operation at Prairie du Chien. Mussels are steamed in a cooker (foreground) and shoveled into a separator (center). The shells fall through the openings of the separator onto a conveyor belt and are deposited on the clam pile (background). (Top left)





The separator sorts the shells from the "meat". Steamed mussels are placed in a rotating drum; the shells fall through the openings onto a conveyor belt and the "meat" remains in the drum. (Bottom left)

A commercial shell pile composed mainly of Threeridge. (Above)

from the buyer during the summer of 1978. Two diving rigs were used during August and September to harvest mussels.

The local buyer for the Tennessee Shell Company in Prairie du Chien purchased 150 tons of green or uncooked mussels during 1977 and 124 tons in 1978. He, in turn, sold cooked shells to the Tennessee Shell Company of Camden, Tennessee. The price of a ton of green mussels in 1977 was $100 and $140 in 1978. In order to be acceptable to the commercial clam buyer during this period, Washboard had to be 4 inches (10.2 cm) and Threeridge 2.75 inches (7.0 cm) in the smallest dimension.

The minimum legal size limit for mussels taken from both Wisconsin and Minnesota waters is 1.75 inches (4.5 cm). Iowa has no size limit regulations. Washboards subsampled from the commercial clammers' piles averaged 6.1 inches (15.4 cm) in their greatest dimension or length (Table 7). Washboards harvested by brailing and diving in this study numbered 507. Only 11.2% of the sampled Washboards were as large as or larger than the subsampled commercial average of 6.1 inches. Threeridge from the commercial shell pile had an average length of 3.8 inches (9.6 cm). Of the 5,166 Threeridge captured by brailing during the present study, only 11.4% were as large as or larger than the subsampled commercial average.

Diving is a much more effective method of collecting mussels compared to brailing, which removes only about 1% of the mussel population. During 1977, divers accounted for 98% of the commercial harvest. An experienced diver can determine the commercial species and size of the mussels by touch alone. This prevents undersized mussels and noncommercial mussel species from being accidentally brought to the surface. In areas with known populations of endangered mussels diving would cause less disturbance to the endangered species than brailing because the mussels could immediately be put back in the substrate.

More field data need to be compiled on the effect the brail has on mussels. Some authors (Miller 1972, Imlay 1972a) believe that the brail can cause injury or death to undersized and noncommercial mussels and the mussels returned to the water are not able to re-orient themselves in the substrate. Fuller (1974) noted that gravid females may abort eggs when disturbed.

Some species of mussels are still suffering from overharvesting during the button era. The reduction of breeding stock was too great and reproduction did not offset mortality. Decreased abundance of Butterfly, Mucket and Yellow Sandshell today is due at least in part to excessive commercial harvest in the early 1900's (Fuller 1978).

BOTTOM TYPES AND WATER DEPTHS

Larsen and Holzer (1978) concluded that hard substrate and stabilized sand in Pools 5A-8 provided prime mussel habitat. However, after SCUBA surveys in 1978, it became apparent that the bottom sediment data from this study were not adequate to define limiting factors controlling quality of mussel habitat. Sediment types varied considerably within a single brail run and mussel densities on similar substrates varied greatly between locations. Other studies (Fuller 1978, Coon et al. 1977) had similar difficulties in demonstrating a relationship between substrate and mussel densities.

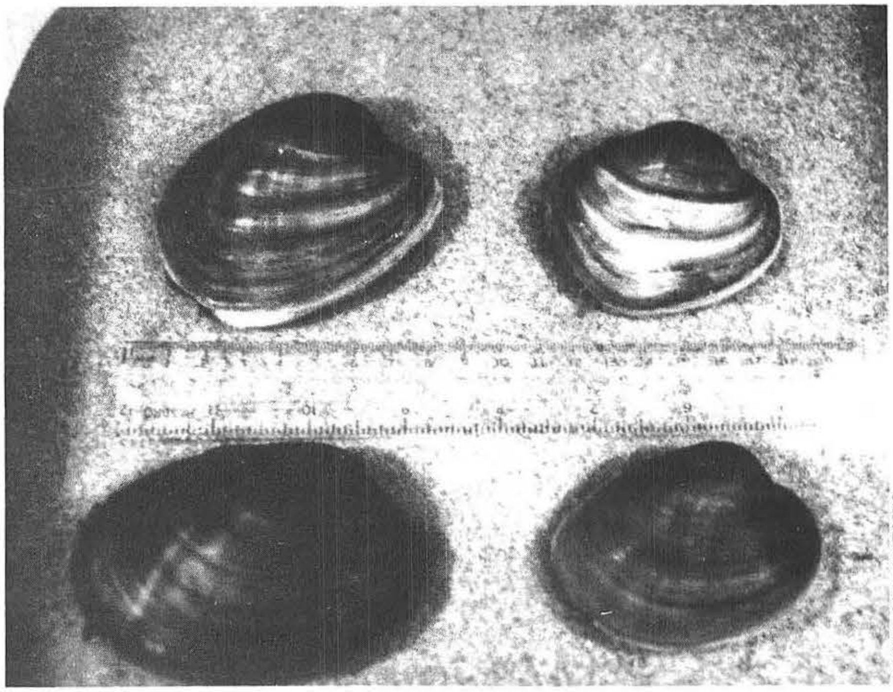
The water levels during the summer of 1977 and the summer of 1978 varied as much as 6.1 ft. The difference in water stages within the same summer varied considerably also. This made it impossible to validly compare water depths with sites and species. Fuller (1978) abandoned attempts to record water depths after it became evident that changing river stages invalidated comparisons between and among sites and taxa.

ENDANGERED SPECIES

The Fat Pocketbook, a federal endangered species, has historically been collected in the Upper Mississippi River (Shimek 1921, van der Schalie and van der Schalie 1950). However, no living or dead evidence of this species has been recorded from Pools 3-11 since the earlier surveys. The Fat Pocketbook presently is extremely rare or extirpated in the Upper Mississippi River.

The Higgins' Eye mussel is a state and federal endangered species. It is basically a big river species found in the Mississippi River drainage above the confluence of the Missouri River. Historically it was never abundant (Shimek 1921, Baker 1928, van der Schalie and van der Schalie 1950), and its range and numbers in the main stem of the Mississippi River have become greatly diminished. Specimens of Higgins' Eye have been taken at single sites from both the St. Croix and Wisconsin Rivers (Fuller 1978, Mathiak 1979). However, all other recent records of this species are from the main stem of the Mississippi River; current records in the main stem range from Brownsville, Minnesota to Oquaqua, Illinois (Imlay 1971, Larsen and Holzer 1978).

During the present study, no Higgins' Eye were collected in Pools 3-8.



Leif Marking, USF&WS

Female (upper two) and male (lower two) Higgins' Eye mussels.

The shells of 11 dead Higgins' Eye were found in Pool 9, but no live specimens were collected. Pool 11 yielded 3 live and 1 dead Higgins' Eye.

In this study as well as in other recent investigations, more Higgins' Eye have been taken from Pool 10 of the Upper Mississippi River than in any other pool (Fuller 1978, Mathiak 1979, Havlik and Stansbery 1978). The Pool 10 collection from 1979 had 6 live and 13 dead specimens. More specifically, the East Channel at Prairie du Chien has yielded more Higgins' Eye than any other area. Of the 5 live Higgins' Eye taken on the brail in 1979, 2 were collected from one site in the East Channel. A dead specimen was also collected in the East Channel by SCUBA.

AN EXOTIC SPECIES

The Asiatic Clam was found live during brailing and diving operations only in Pool 9. However, dead specimens were found along the shore in Pools 10 and 11, suggesting their presence in these pools also.

This exotic species was not thought to inhabit the Upper Mississippi River north of Cairo, Illinois until Eckblad (1975) reported finding it near Lansing, Iowa (Pool 9) in an effluent channel of a power-generating plant and elsewhere. It has apparently spread even farther north because Fuller (1978) found specimens in the St. Croix River near Hudson, Wisconsin.

The Asiatic Clam poses a potential threat to the native unionid mussels in the Upper Mississippi River drainage. Since the Asiatic Clam does not form glochidia, it needs no fish host in its life history. This gives it a decided competitive advantage over other mussels (Krumholz et al. 1970). Fortunately, the habitat preferences of the Asiatic Clam and most unionid mussels in the Upper Mississippi River probably are dissimilar (Fuller 1980). The Asiatic clam prefers a sand substrate which is not the desired bottom for most Mississippi River unionids.

COMPARISONS WITH STATEWIDE POPULATIONS

With the appearance of Mathiak's (1979) recent work on the current distribution of mussels throughout Wisconsin, some interesting comparisons can be made. The 3 most abundant species in the Upper Mississippi River (Threeridge, Pigtoe and Pimpleback) are also widespread in the state. On the other hand, the species of greatest abundance and occurrence throughout the state, the Fat Mucket, was found on the River in only 2 pools. Of 11 species found in low density (each comprising 0.1% or less of the brailed catch), 5 were also rare in the interior of the state: Yellow Sandshell, Purple Wartyback, Higgins' Eye, Pink Papershell, and Butterfly. The remaining 6 were found regionally or statewide. Fluted Shell, Elktoe, Ellipse, Bullhead, and Salamander Mussel are species once collected in the Upper Mississippi River but are now found live only in other waters of the state. The Wisconsin range of 4 species is confined to the Mississippi River: Butterfly, Wartyback, Washboard, and Ebony Shell.

FACTORS AFFECTING MUSSEL DISTRIBUTION AND ABUNDANCE

Impoundment, Dredging and Navigation

The impoundment of the Mississippi River to allow for navigation, dredging to maintain the channel, and the direct effect of barge traffic have all had an impact on the mussel fauna. The lock and dam system on the Upper Mississippi River was installed in the 1930's (U.S. Army Corps of Engineers 1974). Impoundment reduces the current and provides habitats that are less suitable for some river-dwelling mussels (Isom 1969). The reduction of current also causes a more rapid deposition of silt, which is the most detrimental of the adverse effects associated with damming (Fuller 1974).

Pre-impoundment studies done by Ellis in 1930-31 (van der Schalie and van der Schalie 1950) and Grier (1922) reported more species than were found in the same areas by Finke (1966) and the present study. Impoundment is probably one of the several reasons for the faunal decline.

Impoundment has been detrimental to some mussel species and beneficial to others. This is due in part to the fact that certain mussels prefer a specific bottom type and others are found on a variety of sediments. Less adaptable species tend to be sporadic or restricted and widely adaptable species tend to be cosmopolitan (Cvancara 1975).

Fuller (1978) concluded that channel maintenance dredging and associated activities have only a minor impact on fresh-water mussels. In a study designed to determine emergence capability from dredge spoil material, Marking and Bills (1977) found that over 50% of the Fat Mucket and Pocketbook had the ability to emerge from about 7 inches of sand or silt overlays.

Other investigators have found the effects of dredging to be harmful in varying degrees. Studies done by Imlay (1972a) demonstrated that mussels generally fail to climb out of smothering conditions. Ellis (1936) reported that lethal limits of silt coverage on experimental mussel beds varied from 0.25 inch for the least resistant species to 1.0 inch for some of the most resistant species. Yokley (1976) found that mussels collected downstream from a dredging site had slower growth rates than mussels sampled upstream from the site. According to a study done on Pools 8, 9, and 10 of the Mississippi River (Coon et al. 1977), areas of recent dredging produced few, if any, live mussels, even though the dredge spoils of these areas contained many shells.

Another result of the impoundment of the Mississippi River has been the heavy barge traffic powered by towboats, which seriously disrupts the substrate with undertow and increases the turbidity (Coon et al. 1977, Starrett 1971). The first barge through Lake Pepin in the spring caused a tenfold increase in suspended solids immediately after passage (Great I 1978). A field study on the Mississippi River near the mouth of the Minnesota River revealed that turbidity returned to ambient levels within 30 minutes after barge tow passage at the surface, and after a somewhat longer period at the bottom (Colingsworth et al. 1973). The effect of navigation on mussel communities has yet to be fully documented.

Siltation and Sedimentation

Siltation is a continuing cause for the decrease in mussel species in the Upper Mississippi River. The deposition of sediment in the Mississippi River and its backwater has continued, especially since its impoundment in the 1930's. Recent studies in Pools 7, 8, and 9 have indicated that sediments are accumulating at a rate of 0.7 to 2.9 cm per year (Great I 1980).

Silt has a smothering effect on some species by clogging the gills with sediment or stimulating excess mucus secretion (Stansbery 1970). Ellis (1931) noted that siltation causes many species to be eliminated or greatly reduced in numbers. He reported that silt resulting from erosion was especially deleterious to young mussels.

The bottom of Lake Pepin in 1912 consisted of fairly coarse gravel mixed with mud (Wilson and Danglade 1914). As early as 1930, Ellis (1931) noted that siltation drastically reduced mussel populations in Lake Pepin. Finke (1966) and the present study found a great abundance of silt in Lake Pepin. No adult unionid mussels and limited numbers of juveniles were found in the silt-laden central portion of the lake. Scruggs (1960), Bates (1962) and Isom (1969) documented that extensive silt deposits, accumulated since the Tennessee River was impounded, created an unfavorable habitat for the survival of young mussels and decreased the species diversity. The small number of juveniles found in this study could also be the result of siltation.

The most highly restrictive ecological factor for unionid mussels is a shifting sand bottom (Murray and Leonard 1962). Clark (1976) noted that stream bottoms of silt and sand are usually unstable. Such constantly shifting bottom limits or prevents the establishment of mussel beds. Stern (1978) found that mussels were least abundant or absent entirely from shifting sand bottoms in the Wisconsin River.

The Chippewa River bedload historically formed a natural dam at the foot of Lake Pepin. Large amounts of sand from the Chippewa River continue to contribute great quantities of bedload to the Mississippi River and are responsible for about 20% of all maintenance dredging along the Mississippi River within the St. Paul U.S. Army Corps of Engineers District, Pools 1-10 (Great I 1980). The area downstream from the Chippewa's entry into the Mississippi River has to be frequently dredged to allow navigation. The largest number of species represented only by dead specimens was found in Lower Pool 4, just downstream from the Chippewa River, indicating that historic beds were in this area but are no longer present.

It has been verified that sediment from the Chippewa River affects the Mississippi River as far downstream as Pool 5A (Great I 1980). The sparse mussel fauna found in Pools 5 and 5A is probably the result of an unstable sand substrate caused by the discharge from the Chippewa River.

Species Adaptability

Threeridge was the most abundant mussel in the study area. The dominance of Threeridge has been documented in other recent investigations of the Upper Mississippi River (Finke 1966, Fuller 1978, Coon et al. 1977, Havlik and Stansbery 1978). The Threeridge was able to adapt to the changing river substrates since impoundment. Imlay (1972b) noted that the Threeridge is a very tolerant species that can survive on mud, sand or gravel.

The Fawnfoot is another silt-tolerant species capable of surviving on substrates that most other species cannot tolerate (Ellis 1931, Scruggs 1960). Due to their small size, they are not adequately sampled on the clam bar (Fuller 1978). In 1977-79, 339 Fawnfoot were collected by SCUBA diving while only 162 were sampled on the brail. Consequently, the Fawnfoot population in the Upper Mississippi River may be significantly greater than indicated by recent mussel surveys. Many of the juveniles sampled during the survey were *Truncilla* spp.

Other species have exploited the impounded conditions of the Mississippi River. The Mapleleaf was identified by Ortmann (1925) as a mud-loving species. This species was 48 times more numerous in the present study than in the Ellis' pre-impoundment study of 1930-31. Fuller (1978) noted that this species can tolerate impoundment. Pigtoe, Pimpleback and Wartyback were also more abundant during the present study than before impoundment (van der Schalie and van der Schalie 1950). Fuller (1978) also reported that these species do not have narrow habitat requirements and can survive on a variety of substrates.

Some species have not fared as well in the impounded river. According to Fuller (1978), the following species prefer gravel or rocky areas: Spectacle Case, Buckhorn, Fluted Shell, Elktoe, and Purple Wartyback. Rocky habitats never have been commonplace in the Upper Mississippi River, but they are now extremely rare. The area occupied by natural rocky areas and man-made wing dams has decreased due in part to elevated sedimentation rates and dredge disposal activities. Collectively, these species were never historically abundant, but with the exception of one live Purple Wartyback, only dead shells of these species were collected during 1977-79. These species are on the verge of extinction in the Upper Mississippi River because of their stringent habitat requirements.

SUMMARY AND CONCLUSIONS

The Mississippi River has undergone a succession of changes in the last century. Heavy exploitation of mussels during the heyday of the pearl button industry, the development of the lock and dam system, habitat destruction, dredging, pollution, and siltation have dramatically affected mussel habitat and population status. Comparison of the present data with earlier studies and the collection of 7 species only as dead specimens indicate a definite trend toward reduction in species numbers, diversity and absolute abundance. Mussel populations in the Upper Mississippi River are facing an uncertain future.

A total of 30 live species was collected during the survey. Threeridge followed by Pigtoe and Pimpleback were the most abundant species collected in the study area. Although mussel populations in Pools 3-11 are dominated by these three species, their numbers appear to be declining. The catch per unit effort, which is related to density, has declined in Pools 6, 7, and 9 and Lake Pepin since 1965. The Higgins' Eye, a state and federal endangered species, was found only in Pools 9, 10, and 11. Pool 10 supports more species and the most abundant mussel population in the entire study area.

During the present study, commercial clamming was nonexistent in Pools 3-8. The absence of commercial clamming in this area is due to the low abundance of commercial mussel species. Mussels are currently being commercially harvested only in Pools 9 and 10. These are the only areas where the 2 most important commercial species, Threeridge and Washboard, are abundant enough to make fishing efforts economically feasible. To insure that mussel beds are not overharvested in the future, the commercial catch should be monitored and regulated.

The various phases of dredging have a potential detrimental effect on the mussels. The dredge sites and disposal areas should continue to be monitored for mussels. More study is needed to determine what effects navigation, with the resulting substrate disruption, has on the mussel fauna.

Endangered as well as more common mollusks cannot continue to exist unless their environment meets at least the minimal requirements for survival. Restraints on collecting and possession are of no value if the habitat is destroyed (Taft and Stansbery 1976). All existing mussel beds and prime mussel habitat should be protected and managed. Wing dams and rock rubble substrates are of special concern. These areas are preferred and are excellent habitats for various species of mussels. All alterations such as Army Corps of Engineers dredging or harbor construction should be evaluated for potential impact on mussel populations. Measures to reduce erosion and bedload in the Mississippi and Chippewa Rivers, such as land use management and riprap, should be encouraged.

population in the Upper Mississippi River may be significantly greater than indicated by recent mussel surveys. Many of the juveniles sampled during the survey were *Truncilla* spp.

Other species have exploited the impounded conditions of the Mississippi River. The Mapleleaf was identified by Ortmann (1925) as a mud-loving species. This species was 48 times more numerous in the present study than in the Ellis' pre-impoundment study of 1930-31. Fuller (1978) noted that this species can tolerate impoundment. Pigtoe, Pimpleback and Wartyback were also more abundant during the present study than before impoundment (van der Schalie and van der Schalie 1950). Fuller (1978) also reported that these species do not have narrow habitat requirements and can survive on a variety of substrates.

Some species have not fared as well in the impounded river. According to Fuller (1978), the following species prefer gravel or rocky areas: Spectacle Case, Buckhorn, Fluted Shell, Elktoe, and Purple Wartyback. Rocky habitats never have been commonplace in the Upper Mississippi River, but they are now extremely rare. The area occupied by natural rocky areas and man-made wing dams has decreased due in part to elevated sedimentation rates and dredge disposal activities. Collectively, these species were never historically abundant, but with the exception of one live Purple Wartyback, only dead shells of these species were collected during 1977-79. These species are on the verge of extinction in the Upper Mississippi River because of their stringent habitat requirements.

SUMMARY AND CONCLUSIONS

The Mississippi River has undergone a succession of changes in the last century. Heavy exploitation of mussels during the heyday of the pearl button industry, the development of the lock and dam system, habitat destruction, dredging, pollution, and siltation have dramatically affected mussel habitat and population status. Comparison of the present data with earlier studies and the collection of 7 species only as dead specimens indicate a definite trend toward reduction in species numbers, diversity and absolute abundance. Mussel populations in the Upper Mississippi River are facing an uncertain future.

A total of 30 live species was collected during the survey. Threeridge followed by Pigtoe and Pimpleback were the most abundant species collected in the study area. Although mussel populations in Pools 3-11 are dominated by these three species, their numbers appear to be declining. The catch per unit effort, which is related to density, has declined in Pools 6, 7, and 9 and Lake Pepin since 1965. The Higgins' Eye, a state and federal endangered species, was found only in Pools 9, 10, and 11. Pool 10 supports more species and the most abundant mussel population in the entire study area.

During the present study, commercial clamming was nonexistent in Pools 3-8. The absence of commercial clamming in this area is due to the low abundance of commercial mussel species. Mussels are currently being commercially harvested only in Pools 9 and 10. These are the only areas where the 2 most important commercial species, Threeridge and Washboard, are abundant enough to make fishing efforts economically feasible. To insure that mussel beds are not overharvested in the future, the commercial catch should be monitored and regulated.

The various phases of dredging have a potential detrimental effect on the mussels. The dredge sites and disposal areas should continue to be monitored for mussels. More study is needed to determine what effects navigation, with the resulting substrate disruption, has on the mussel fauna.

Endangered as well as more common mollusks cannot continue to exist unless their environment meets at least the minimal requirements for survival. Restraints on collecting and possession are of no value if the habitat is destroyed (Taft and Stansbery 1976). All existing mussel beds and prime mussel habitat should be protected and managed. Wing dams and rock rubble substrates are of special concern. These areas are preferred and are excellent habitats for various species of mussels. All alterations such as Army Corps of Engineers dredging or harbor construction should be evaluated for potential impact on mussel populations. Measures to reduce erosion and bedload in the Mississippi and Chippewa Rivers, such as land use management and riprap, should be encouraged.

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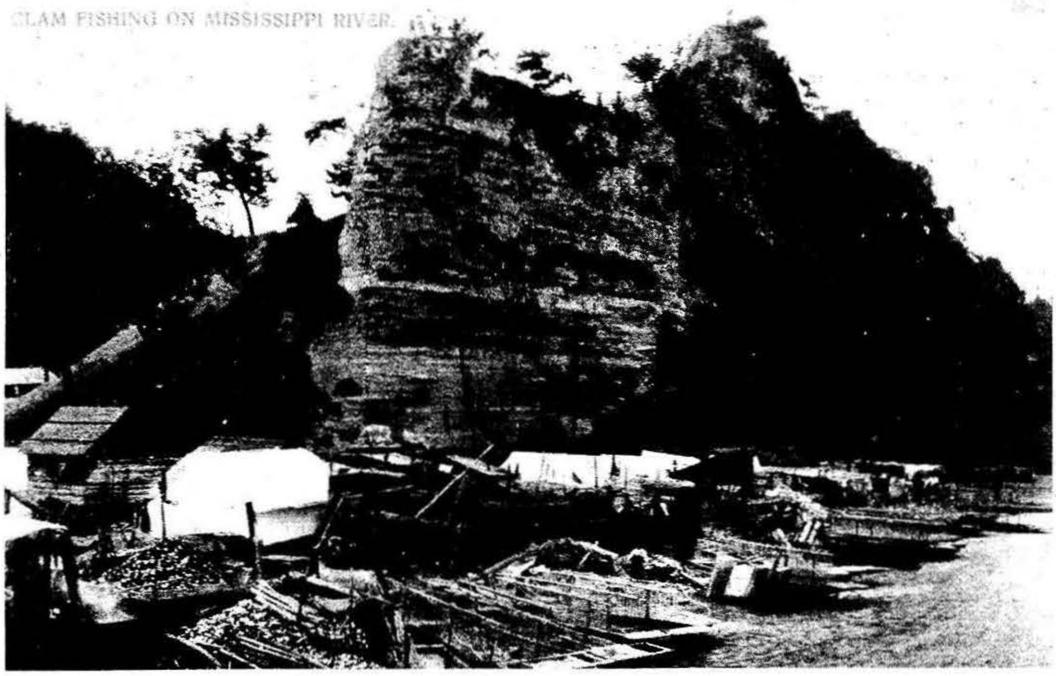

Postcard mailed from Garnavillo, Iowa on February 8, 1908, depicting clam fishing on the Mississippi River.

ACKNOWLEDGMENTS

I wish to express my gratitude to Helen E. Kitchel, Michael T.Talbot, Kenneth L. Von Ruden and other DNR field staff for their assistance in sample collections and data tabulation. Samuel L. H. Fuller, of the Academy of Natural Sciences of Philadelphia, and Marian E. Havlik, of Malacological Consultants of La Crosse, Wisconsin, deserve a special thanks for their consultations and mussel identifications. I also gratefully acknowledge Donald R. Thompson and Eugene L. Lange for their statistical advice; the personnel at the U. S. Fish and Wildlife Service, National Fishery Research Laboratory in La Crosse for allowing us to house endangered species at their facility; and Donald Lessard and Worth Emanuel for their assistance with the commercial aspects. The manuscript was critically reviewed by James A. Holzer, Randall E. Duncan, and Randle L. Jurewicz.

This study was supported in part by funds supplied by the federal Commercial Fishing Act and the federal Endangered Species Act of 1973, Project E-1.

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