A Survey of the Commercially Valuable Mussels of the Wabash and White Rivers of Indiana[1]

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Abstract

The shells of several unionid mussels of the Wabash River system in Indiana are of considerable value in the manufacture of nuclei for cultured pearls in Japan. Because of increased exploitation of that fauna for commercial purposes, the Indiana Department of Natural Resources sponsored a survey to determine the status of the mussel populations over about 500 stream miles of the Wabash, White, and East Fork of the White rivers, and to gather data upon which to base recommendations for the preservation of that resource.

The survey, conducted by the University of Louisville, extended through 1966 and 1967 and included 99 collections made either with a crowfoot bar or by diving and hand-picking with or without auxiliary air supply. In those collections, 30 species of unionids were represented, but only 10 were considered important in the commercial market; representatives of those 10 species made up 77.1% of the total catch of the survey. The most abundant mussel in the commercial market as well as in the survey collections was the mapleleaf, *Quadrula quadrula* (Rafinesque). Data from the survey as well as from the commercial market indicated that the mussel stocks in the rivers were depleted seriously in 1966, mostly through the very efficient efforts of divers with auxiliary air supply. Those data led to the passage of Discretionary Order No. 136 by the Indiana Department of Natural Resources prohibiting the use of such gear in commercial musseling.

Mussels of commercial value grow very slowly; it requires from 4 to 5 years for a mapleleaf mussel to reach the legal size of 2.5 inches. The serious depletion of breeding stocks in 1966 probably will result in a very low yield of marketable shells at least until 1970 and perhaps later.

Introduction

Freshwater bivalve mussels of the family Unionidae have been in existence since early Mesozoic times in the lakes and rivers of the northern temperate and subtropical areas of the world (29). At present, there are between 500 and 600 living species of unionids within the continental United States (10), and of these, several are commercially valuable because of the quality of the material in their shells. Although the soft parts of these mussels are edible, no commercial market has ever been established for freshwater clams comparable to that for marine clams.

The shells of the freshwater mussels have become valuable at two different times in recent history of the United States, for two quite different reasons. During the last decade of the nineteenth century, the pearl button industry was established at Muscatine, Iowa, by J. P. Boepple, a German button cutter (8). That industry flourished for about

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50 years, but by the beginning of the twentieth century, the mussel beds in the Mississippi River began to show signs of depletion (28).

Even though the use of mussel shells in the manufacture of pearl buttons essentially disappeared in 1953, new demands were put upon the mussel populations by the cultured pearl industry.

Freshwater mussel shells from rivers in the United States are used in the manufacture of the spherical nucleus that is implanted in the oyster by the Japanese. Shells from the Wabash River and Tennessee River systems in the United States have an extraordinary translucence that makes them particularly valuable as nuclei. The diameter of the spherical nucleus prepared from mussel shells usually ranges from ⅛ to ¼ inch, but may be even larger on occasion. In preparing the nuclei, blemish-free mussel shells are cut into strips, then into squares, and then into cubes. The cubes are placed between rotating discs similar in shape to the stone of a grist mill, together with a slurry of abrasive material. The discs are rotated and the nuclei are worn down until they become spherical. At this point the spheres are selected on the basis of their perfection and are placed within the visceral mass of the living oyster. The yield of cultured pearls of superior quality using such nuclei is very high. The time required for a cultured pearl to be formed ranges from 1 to 5 years, depending on the desired thickness of the nacreous covering on the nucleus (27).

Persons associated with the mussel industry realized that the mussel supply is exhaustible and efforts were made to conserve this valuable natural resource. In April 1967, the Indiana Department of Natural Resources passed Discretionary Order No. 136 which restricted the methods for taking mussels for commercial purposes to handpicking, short forks, tongs, or brail (crowfoot) bar. The use of mechanical dredges and diving with auxiliary air supplies was prohibited.

Because of the very great demand for mussel shells of high quality in the cultured pearl industry, the beds of commercially valuable mussels in the Tennessee River have been virtually wiped out. Similarly, the mussel beds of the Wabash River system are in danger of serious depletion. In many instances, populations of desirable species of shells have been extirpated. However, it should be pointed out that the cultured pearl industry and their demands on mussel shells of the Wabash River is not the sole factor operating in the depletion of those shells. Pollution, whether it be industrial, domestic, or agricultural, has played a leading part in the decline of mussel populations in most Indiana streams. Also, the invasion of the Asiatic clam (*Corbicula fluminea* Muller) has become widespread in Indiana streams. Since the Asiatic clam does not form glochidia, and hence needs no fish host in its life history, it has a decided competitive advantage over other mussels. By late 1969, many sections of the Wabash and White rivers were heavily infested with Asiatic clams.

Materials and Methods

All together, 99 collections were made either by crowfoot bar or by diving and handpicking at 63 sites in the Wabash River, the White River, and the East Fork of the White River.

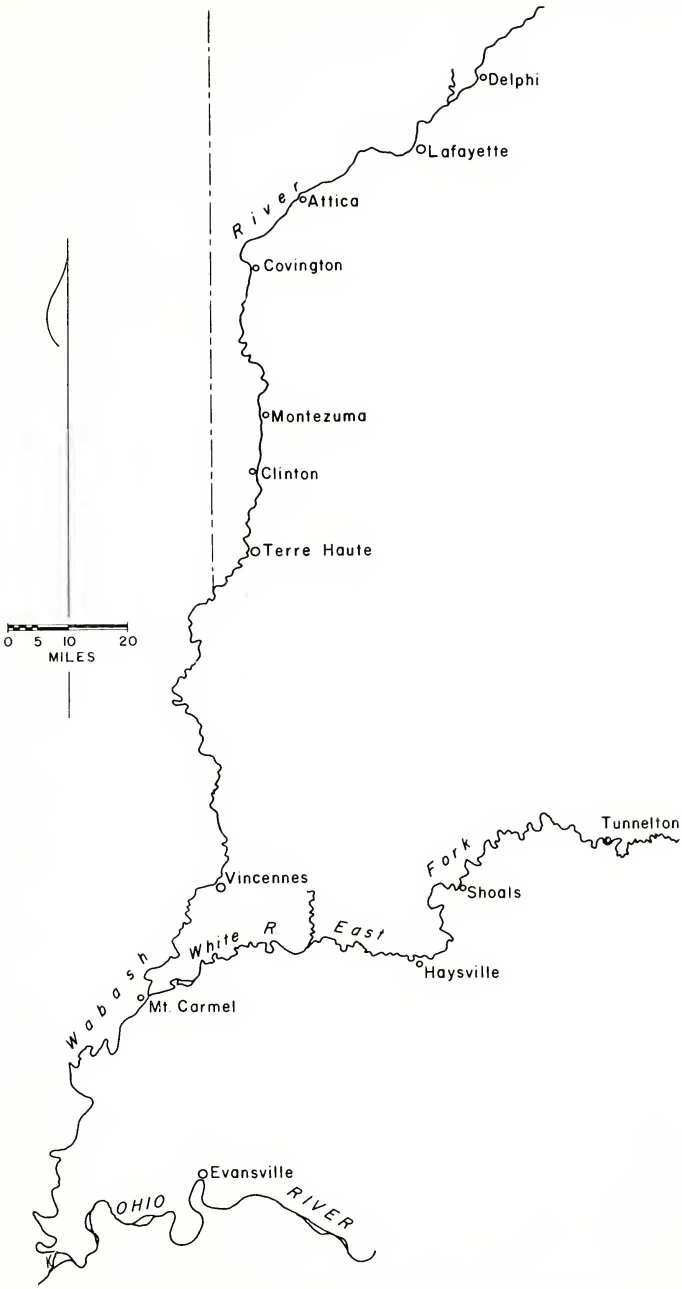

FIGURE 1. *Sections of the Wabash and White rivers included in the study area. Collections were made at approximate 10-mile intervals from Delphi, Indiana, to the mouth of the Wabash River and from Tunnelton, Indiana, on the East Fork of the White River to the mouth of the White River.*

Sampling Stations

The area under investigation extended from Delphi, at Wabash River Mile 331, to the Ohio River, and in the East Fork of the White River from Tunnelton, at White River Mile 158, to its mouth at Mt. Carmel, Illinois, a total of about 500 miles of stream (Fig. 1). In sampling the study area for distribution and relative abundance of commercially important mussels, the river was divided into 10-mile stretches, and 1 mile of each stretch was marked off and sampled intensively using crowfoot bars either alone or in conjunction with diving and handpicking. The location of each sampling station by river mile was obtained from flood-plain charts published by the U. S. Army Corps of Engineers. Rather than sampling every tenth mile, a 1-mile section out of each 10 miles, suitable for operation of the crowfoot bar, was selected. If no such section was available in any 10-mile stretch, a 1-mile section either immediately above or below that stretch was sampled. All together, 63 such sampling sites were selected and the crowfoot bar operated over those 63 miles of stream.

Many of the sites were visited more than once to determine whether the population had changed either because of changes brought about by the activities of the mussel fishermen, or by some other change such as increased pollution.

The Crowfoot Bar

The crowfoot bar or brail bar (Fig. 2) has been used for collecting mussels since 1897 in the upper Mississippi River and its tributaries (8, 10). Crowfoot bars are fabricated from sections of iron pipe 0.75 to 1.0 inch in diameter and 10-20 feet in length. At intervals of 1 to 3 inches over the length of the bar, 3-foot lengths of seine cord or trot line are attached by loose half hitches. Three crowfoot hooks are attached at equal intervals to each strand of cord, and one end of a loose wire or rope bridle is attached to each end of the bar. When in use, the bar is towed downstream by a length of rope attached by a snap hook to an iron ring mounted in the center of the bridle. Crowfoot hooks are constructed from two 10- or 12-inch lengths of No. 9 or No. 11 steel wire bent into loops, then twisted together in such a manner that the ends of the loops may be bent at equal intervals into 4 adjacent curved hooks (Fig. 2). The crowfoot bar in use today is constructed essentially as it was 70 years ago.

Crowfoot bars are carried in pairs in johnboats, each bar carried on two iron stanchions, mounted one on either end of each side of the boat. When in use, a 0.5-1.0 inch manila rope is affixed to the bridle ring and the whole bar comes to lie on the river bottom, perpendicular to the shoreline with the strands of hooks spread out behind the bar on the bottom. The connecting line is allowed to assume an angle of approximately 45° to the plane of the river bottom. Then it is attached to a cleat mounted on the bow of the boat.

The boat usually is carried downstream by the current with the aid of a sea anchor, commonly referred to as a mule, attached by cords to the

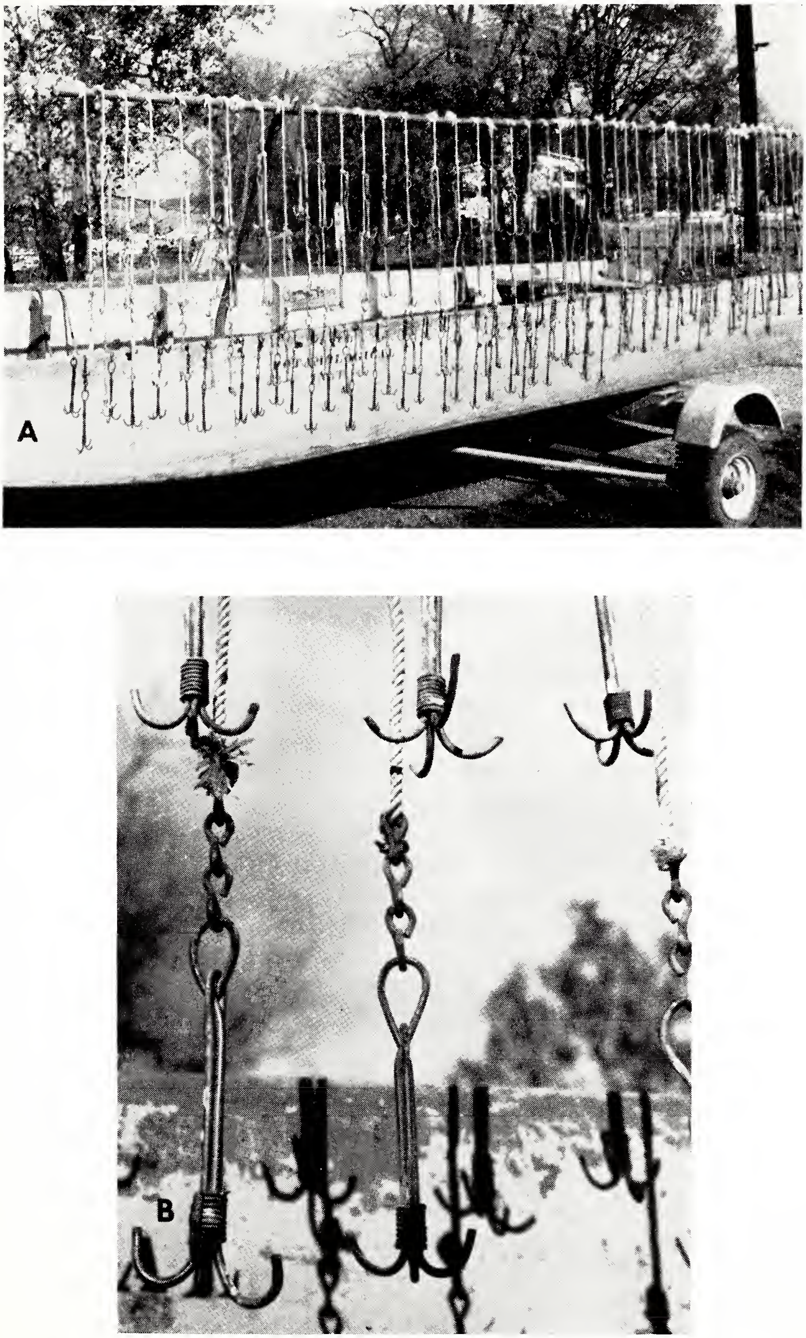

FIGURE 2. A. *Johnboat with crowfoot bar on stanchions.* B. *Detailed view of crowfoot hooks.*

stern of the boat. Sea anchors are made of canvas, wood, or metal about 3 feet deep and 5 feet long. The boat may be steered by adjusting the cords that attach the mule to the boat. Whenever there is insufficient current for the mule to propel the boat, an outboard motor is used.

In the stream bottom, mussels orient themselves with the open posterior portion of the valves facing upstream. As the crowfoot bar hooks trail down the river bottom, they may become lodged between the open valves of the mussel. The presence of a hook between its valves irritates the mussel and it immediately closes its shell, thereby effectively attaching itself to the hook.

Mussel fishermen using crowfoot bars choose an area of clean river bottom known to support large populations of mussels. A bar is lowered, pulled along for an appropriate time, and then returned to the boat. As it is returned to the boat, its counterpart is lowered to the river bottom so that fishing is continuous. The speed of such dragging is slow, usually not more than 0.5 mph. While one bar is fishing, the other bar is cleaned of its clams and any debris and made ready for fishing again. As fishing proceeds, the two bars continue to be alternated over the entire stretch of stream.

In the present study, we used a 14-foot johnboat carrying 2 crowfoot bars, each 10 feet long, and each fitted with 150 crowfoot hooks, affixed in groups of 3 to each of 50 three-foot lengths of seine cord (Fig. 2). To move about at will, the boat was powered with an 18-horsepower outboard motor.

Crowfoot bars are most effective in water more than 6 feet deep and on bottoms of clay or sand with little large gravel. Crowfoot bars were of little use in water less than 3 feet deep or in areas having bottoms covered with dead twigs, mats of dead leaves, or other such debris. In such situations, the hooks became entangled shortly after they touched the river bottom.

Each collection made during this study routinely used a pair of crowfoot bars, and on some occasions auxiliary samples were taken with SCUBA (self-contained underwater breathing apparatus) gear. At each station, one crowfoot bar was dragged downstream for about 20 min and then replaced by the second bar and the process repeated over the 1-mile section.

Diving and Handpicking

Diving was performed with SCUBA gear similar to that used by sportsmen and by commercial mussel fishermen. A tank of compressed air carried on the back enables the diver to stay under water for 30-45 min. In some instances, a portable compressor is fixed to a small raft, and two or more divers are supplied with air continuously.

Mussels are placed in a bucket and taken to the surface for unloading. SCUBA gear is a very effective technique for sampling mussel populations since it can be used any time except during flood conditions, and hence virtually no area of the Wabash or White river systems of Indiana is impregnable to such diving methods. On several occasions, SCUBA gear was used to collect in an area that had been collected previously with a crowfoot bar to determine the relative efficiencies of the two methods.

In addition to diving, many samples were collected by handpicking mussels in shallow water. In some areas, this was the most productive method of collecting.

Reproduction

The cultured pearl industry of today is just as dependent upon the continuous production of freshwater mussels as the pearl button industry was a half century ago. Effective practices for the conservation of any resource necessitates a knowledge of the complete biology of the organism concerned.

For this part of the study, the gonads of 369 individual mussels, representing 15 species, were examined (Table 1). The reproductive processes of *Quadrula quadrula* (Rafinesque) were studied intensively, and the extents of the breeding seasons were determined tentatively for that species and for *Quadrula metanevra* (Rafinesque), *Quadrula pustulosa* (Lea), *Obovaria olivaria* (Rafinesque), *Tritogonia verrucosa* (Barnes), *Megalonaias gigantea* (Barnes), *Amblema costata* Rafinesque, and *Actinonaias carinata* (Barnes). Principal emphasis was placed on those 8 commercially valuable species, and limited data were available on 6 others as follows: *Lampsilis anodontoides* (Lea), 2 males, 2 females; *Lampsilis ovata ventricosa* (Barnes), 2 males, 1 female; *Obliquaria reflexa* Rafinesque, 1 male, 2 females; *Elliptio crassidens* (Lamarck), 2

TABLE 1. *Numbers, kinds, and sexes of freshwater mussels from the Wabash and White rivers, Indiana, used in studies of reproduction. Only those species for which at least 15 specimens were available for study are listed. Data for the other species are given in the text.*

Species	Number of Specimens		
	Male	Female	Total
Actinonaias carinata	9	14	23
Amblema costata	11	9	20
Megalonaias gigantea	11	6	17
Obovaria olivaria	18	21	39
Quadrula metanevra	7	8	15
Quadrula pustulosa	24	14	38
Quadrula quadrula	78	89	167
Tritogonia verrucosa	13	7	20
Others	14	16	30
Totals	185	184	369

males, 2 females; *Fusconaia ebenus* (Lea), 1 male, 3 females; *Fusconaia undata* (Barnes), 5 males, 5 females; *Plethobasus cyphyus* (Rafinesque), 1 male, 1 female.

It is not practicable to attempt identification of the sex of fresh-water mussels without aid of a compound microscope. In this study, sex was determined by inserting a hypodermic needle through the incurrent siphon and into the gonad, withdrawing a small amount of gonadal tissue, and examining it under a compound microscope. The differences between the male and female tissues were obvious, and it is believed that unionid mussels can be sexed in this manner with complete confidence. So far as could be determined, this method for sex determination had no deleterious effects on any of the species studied.

Sexually mature males and females of *Q. quadrula*, collected in March, were studied histologically to determine whether there were concurrent areas of active and inactive gametogenesis within a single individual. The complete foot, along with the inner and outer gills were excised, cut midsagittally, and the central and peripheral areas compared by studying stained histological sections from the various midsagittal areas. The gills were fixed in Bouin's fluid (15) and preserved in 70% ethanol. Serial sections, 6 microns thick, were prepared and stained with Heidenhain's iron-haematoxylin and orange G.

Breeding seasons were determined by correlating the degree of gametogenic development in the gonads of both sexes with the presence or absence of eggs in the water tubes or marsupia of the females. A female was considered gravid if the gills had become modified into a marsupium and contained eggs. In determining the extents of the breeding seasons, the condition of the development of the ova was considered the best indicator, and the next best indicator was the condition of the male gonad. In some species, such as *O. olivaria* and *L. ovata ventricosa*, the marsupium is very pronounced whereas in *Q. quadrula* the appearance of the marsupium is not typical even though it may contain eggs. In that species, the eggs are in the inner and outer gills, and the water tubes had to be examined at various times of the year to determine the extent of the breeding season.

Relative Abundance and Distribution of Unionid Mussels

Although no attempt was made toward a revision of unionid mussels, it is important here to provide a brief account of the various attempts to delineate the systematics of those animals. The first attempt was that of Stein (26) and was followed by several preliminary lists by Call (4, 5, 6), who presented generalized geographic distributions for the aquatic forms known to occur within the boundaries of Indiana. In addition to these preliminary studies of Call, a rather superficial list of endemic species was published by Simpson (25).

The first detailed study of the unionid fauna of Indiana was Call's *Descriptive Illustrated Catalogue of the Mollusca of Indiana* (7), which included detailed descriptions and excellent drawings of each species known to exist in the state at that time. Blatchley and Daniels (3) provided a supplement to Call's catalogue adding a number of species, mostly gastropods. Daniels (11, 12) provided up-to-date checklists of the molluscan fauna of Indiana.

The most recent comprehensive study of the unionid fauna of Indiana is Goodrich and van der Schalie's (14) *Revision of the Mollusca of Indiana.* The latter paper was used in this study for species identification.

TABLE 2. *Distribution and abundance of unionid mussels in the Wabash, White, and East Fork of the White rivers of Indiana based on 99 collections in 1966 and 1967. R, rare; —, not present; C, common; A, abundant. Upper Wabash River: Delphi to Terre Haute, Indiana; Middle Wabash River: Terre Haute to Mount Carmel, Illinois; Lower Wabash River: Mount Carmel to Ohio River (22).*

	Wabash River			White River	
Species	Upper	Middle	Lower	Main Stream	East Fork
Subfamily Anodontinae					
Alasmidonta marginata	R	—	—	—	—
Anodonta grandis	—	—	R	—	—
Anodontoides ferussacianus	R	—	—	—	—
Lasmigona complanata	C	C	C	C	C
Lasmigona compressa	R	—	—	—	—
Lasmigona costata	R	R	—	—	—
Strophitus rugosus	C	—	—	—	—
Subfamily Lampsilinae					
*Actinonaias carinata**	A	A	C	C	C
Cyprogenia irrorata	—	R	—	—	—
Lampsilis anodontoides	C	C	C	—	—
Lampsilis ovata ventricosa	C	C	C	C	C
Leptodea fragilis	C	C	C	C	C
Leptodea laevissima	—	—	R	—	—
Obliquaria reflexa	R	R	R	R	C
*Obovaria olivaria**	A	A	A	C	C
Obovaria subrotunda	R	—	—	—	R
Proptera alata	C	C	C	C	C
Truncilla truncata	R	R	R	R	R
Subfamily Unioninae					
*Amblema costata**	C	C	C	C	A
Cyclonaias tuberculata	—	—	—	—	R
Elliptio crassidens	—	—	—	—	C
*Fusconaia ebenus**	R	R	R	C	C
*Fusconaia undata**	R	R	—	R	C
*Megalonaias gigantea**	R	C	—	R	C
Plethobasus cyphyus	R	—	—	—	R
Pleurobema cordatum	—	—	—	—	R
*Quadrula metanevra**	R	R	R	R	R
*Quadrula pustulosa**	A	A	A	A	A
*Quadrula quadrula**	A	A	A	A	A
*Tritogonia verrucosa**	C	C	C	—	—

* The 10 species of greatest commercial value.

The distribution, relative abundance, and locations of collections are shown in Table 2 (22). The species are arranged in alphabetic order under three subfamilies. Many species taken were of little or no commercial value, but their occurrence is listed. Particular emphasis is placed on 10 species of known commercial value (Table 2).

All species collected in this study were listed by Goodrich and van der Schalie (14) and most were described and illustrated by Call (7). However, some rare and less abundant species listed by those authors, such as *Amblema peruviana* (Lamarck), were not encountered here, and some, once common in Indiana rivers, such as *Elliptio dilatatus* (Rafinesque) and *Quadrula cylindrica* (Say), were in evidence only through isolated dead shells. Those two species apparently have been extirpated from the study area within the last two decades. Other species, such as *Pleurobema cordatum* (Rafinesque), *Cyclonaias tuberculata* (Rafinesque), *Cyprogenia irrorata* (Lea), and *Obovaria subrotunda* (Rafinesque) are much less abundant and have much more restricted patterns of distribution than those recorded by Goodrich and van der Schalie (14). No species encountered in this study exhibited wider ranges of distribution since the earlier studies, and most species appeared much less abundant. Only two species, *Q. pustulosa* and *Q. quadrula*, were as abundant or more abundant than indicated by earlier authors.

Such information indicates a definite trend toward restriction in range and reduction in absolute abundance of most unionid mussels in the Wabash and White rivers. Although some species may have been extirpated from the areas under investigation there may still be limited populations in other parts of the drainage system. If there are, hopefully the populations in the mainstreams of the Wabash and White rivers may be re-established when conditions permit.

This pattern of reduction and elimination of unionid mussel populations may be attributed to two principal factors: 1) the disturbance and destruction of mussel beds through overexploitation for commercial purposes; and 2) deterioration of the environment as suitable habitat for mussels through increasing burdens of pollution.

The devastating effects of industrial and organic pollutants on unionid mussels were first pointed out by Ortmann (23) in his report on the effects of such pollution in the Allegheny, Monongahela, and Ohio rivers in western Pennsylvania. Ten years later, Forbes and Richardson (13) noted a direct correlation between increasing levels of pollution and decreasing ranges and numbers of mollusks in the Illinois River. More appropriate to the present work was the study by Baker (1) in which he reported in detail the elimination of all mussels from certain areas of the Big Vermillion River, a tributary to the Wabash River, by heavy loads of municipal organic wastes. More recently, Wurtz (30) stated that unionid mussels were quite intolerant to pollution of any kind and reported unequivocally that freshwater mussels disappear quickly from streams carrying moderately heavy burdens of pollutants.

Polluted streams exhibit remarkable patterns of recovery downstream from sources of pollution or following the abatement of pollution

(1, 16, 18, 19). Perhaps the first detailed description of the biological recovery of a river system downstream from a source of pollution was that of Kolkwitz and Marsson (17) who reported on the changes in the species composition of aquatic communities, and pointed out that the abundance and diversity of organisms increased as the effects of pollution diminished.

Disruption of the stream bottom by mechanical means may be just as devastating to a mussel population as pollution. One of the methods for collecting mussels that is most destructive of the streambed is mechanical or hydraulic dredging. In the operation of such a dredge, about the uppermost 2 feet of stream bottom is lifted out of place, carried to a barge where the mussels are removed, and then dumped back into the river. In this operation, the stream bottom, with all its biotic communities, is completely discommoded. Any benthic organisms that survive must become re-established rather quickly or those segments of the stream ecosystem that depend on benthos for their livelihood will not survive.

Tongs, crowfoot bars, and other such equipment disturb the streambed to a limited extent, but they usually are used only in localities where they are known to be effective. At most, those tools disrupt small areas of bottom to a depth of a few inches, instead of upheaval of the entire streambed.

Perhaps the method least destructive to the stream bottom is handpicking. Here, the musseler simply walks along the stream bottom or swims over it and picks up whichever mussels he desires.

Numbers and Kinds of Mussels Collected

Data for the 20 species of mussels taken in at least 6 different collections are arranged according to method of collection in Table 3.

From the data in Table 3, it is obvious that about ⅓ (34.0%) of the total catch was made up of mapleleaf (*Quadrula quadrula*), one of the most highly sought-after commercial mussels for the cultured pearl industry. The mapleleaf was followed in order by the sandshell (*Obovaria olivaria*) which contributed 10.2% and the pimpleback (*Q. pustulosa*) with 9.0%. Thus, these three species made up 53.2% of the total catch. The remaining 7 of the 10 commercially important species listed earlier comprised another 23.9% of the catch, and all together the 10 species made up more than ¾ (77.1%) of all mussels taken during the study.

Of the 20 species listed in Table 3, several have shells that are too thin and fragile or are too highly colored to be of value as nuclei for cultured pearls. Others were taken in such small numbers that they could not be considered important in the commercial market. Only 15 of the 20 species were represented by more than 25 specimens.

The white heelsplitter, *Lasmigona complanata* (Barnes), is used sparingly in the cultured pearl industry, but has some commercial value

TABLE 3. *Numbers of individuals of the 20 species of the unionid mussels represented in six or more collections taken by crowfoot bar and by handpicking, together with the numbers of collections in which they occurred, from the Wabash and White rivers during 1966 and 1967. The averages are for the numbers of individuals per collection.*

	All Collections					
	Crowfoot Bar		Handpicking		Total	
Species	No.	Coll.	No.	Coll.	No.	Coll.
Lasmigona complanata	24	5	40	11	64	16
Lasmigona costata	1	1	5	5	6	6
Others*	12	11	3	2	15	13
Actinonaias carinata	88	21	21	6	109	27
Lampsilis anodontoides	36	6	1	1	37	7
Lampsilis ovata ventricosa	34	20	54	15	88	35
Leptodea fragilis	54	22	35	15	89	37
Obliquaria reflexa	10	6	3	2	13	8
Obovaria olivaria	162	35	32	10	194	45
Obovaria subrotunda	9	4	2	2	11	6
Proptera alata	9	7	14	6	23	13
Truncilla truncata	4	3	6	6	10	9
Others*	—	—	2	2	2	2
Amblema costata	41	15	63	10	104	25
Elliptio crassidens	35	3	22	3	57	6
Fusconaia ebenus	4	4	51	8	55	12
Fusconaia undata	8	6	13	7	21	13
Megalonaias gigantea	30	8	63	9	93	17
Quadrula metanevra	35	12	12	6	47	18
Quadrula pustulosa	88	25	84	14	172	39
Quadrula quadrula	359	39	288	17	647	56
Tritogonia verrucosa	27	12	—	—	27	12
Others*	6	2	16	12	22	14
Totals	1076	62	830	37	1906	99
Average	17.4		22.4		19.3	

* The total number of specimens for each of the species included in the category of "Others" are: *Alasmidonta marginata* (Say), 2 specimens; *Anodonta grandis* Say, 2; *Anodontoides ferussacianus* (Lea), 2; *Lasmigona compressa* (Lea), 4; *Strophitus rugosus* (Swainson), 5; *Cyprogenia irrorata*, 1; *Leptodea laevissima* (Lea), 1; *Cyclonaias tuberculata*, 3; *Plethobasus cyphyus*, 8; *Pleurobema cordatum*, 4; and 7 unidentified individuals.

because of its relative abundance. The shell is fairly heavy and the nacre is creamy white. The 64 specimens taken made up 3.4% of the total catch; however, most of those shells were collected by hand in the East Fork of the White River in water less than 6 feet deep.

Lasmigona costata (Rafinesque), the fluted shell, was rare in the collections and is of very little commercial value.

The mucket, *Actinonaias carinata*, was fourth in numerical abundance in our collections and made up 5.7% of the total catch. The shell of this species is commercially important and is of high quality in the manufacture of nuclei for cultured pearls.

The yellow sandshell, *Lampsilis anodontoides*, is not of commercial value because usually it does not have enough thick portion of the shell to warrant the expense of cutting it for nuclei.

Although the pocketbook, *Lampsilis ovata ventricosa*, and the floater, *Leptodea fragilis* (Rafinesque), comprised 4.5 and 4.7%, respectively, of the total catch, neither is important because of the quality of the shell. The pocketbook usually is pale green to brown in color and the shell of the floater is so fragile that it can easily be crushed between the fingers of one hand.

With the exception of *Obovaria olivaria*, all other members of the Lampsilinae were taken in such small numbers that they are not of commercial importance. The sandshell is one of the most highly sought-after shells and is relatively abundant, particularly in the Wabash River, where it consistently makes up a significant part of the commercial market.

The threeridge, *Amblema costata*, ranked fifth in the number of specimens collected in this study and made up 5.5% of the total catch. This mussel was common throughout the study area and was particularly abundant in the upper reaches of the East Fork of the White River. In that area, in contributes consistently to the commercial market.

Elliptio crassidens, the elephant's ear, is of no commercial value in the cultured pearl industry because of the purple color of its nacre.

Although the two representatives of the genus *Fusconaia*, *F. ebenus* and the pigtoe, *F. undata*, contributed only 2.9 and 1.1%, respectively, to the total catch in this study, they are highly desirable as shells in the cultured pearl industry. *Fusconaia ebenus* is particularly desirable and actually makes up a significant portion of the commercial market.

The largest freshwater mussel taken in the study was the washboard, *Megalonaias gigantea*. In this study it contributed 4.9% of the total catch and was particularly important in the East Fork of the White River. The washboard has a relatively high commercial value because of its size and thickness of the shell, but the quality of the nacre is not as desirable as that of some other shells.

The most important genus of freshwater unionids, so far as the contribution of its representatives to the cultured pearl industry is concerned, is *Quadrula*. In the Wabash River system, three members of the genus, the monkeyface, *Q. metanevra*, the pimpleback, *Q. pustulosa*, and the mapleleaf, *Q. quadrula*, contributed 45.4% to the total number of mussels taken during this study. These 3 shells, together with *Obovaria olivaria* and *Fusconia ebenus* are the 5 shells of greatest commercial value for pearl nuclei and they made up 56.7% of the total catch in this study. When these 5 shells are considered together with the other 5 of the 10 most important commercial species listed earlier, the contribution to the total number collected in this study was 77.1%. Thus, the 10 most sought after species are in aggregate the 10 most abundant species.

The only other species of commercial importance is the pistolgrip, *Tritogonia verrucosa*, which has a distribution limited almost entirely to the Wabash River upstream from Vincennes, Indiana. Although this shell contributed only 1.4% to the overall catch, in the area above Vincennes in 1966, it contributed 3.7%.

Comparisons of Catches in Different Localities

In the present study, it was assumed that the sites for collections by crowfoot bar and by handpicking were distributed randomly over the river systems investigated and that those methods of collection were non-selective in the kinds of mussels taken. Thus, the number and kinds of mussels in the collections should be a good indication of their distribution throughout the study area (Table 3). As is true of most animals in the world, the distribution of unionid mussels in the Wabash and White river systems was not uniform. Rather, some of the species were not taken in the Wabash River and others were not taken in the mainstream or the East Fork of the White River (Tables 2 and 3).

Among the 20 species mentioned in Table 3, only one, *Elliptio crassidens*, was not taken in the Wabash River at any time, and another, *Obliquaria reflexa*, was represented by a single female specimen taken on a crowfoot bar near Cayuga, Indiana, 24 August 1967. Conversely, *E. crassidens* was represented by 57 specimens collected by crowfoot bar and handpicking from the East Fork of the White River, and 12 specimens of *O. reflexa* were collected from the mainstream and East Fork of the White River in 1967. In that part of the White River system under study, 5 of the 20 species were not present in the collections from the main stem and 3 were not taken in the East Fork of the White River. However, of all of those species, only *Tritogonia verrucosa* is of commercial value.

It is also obvious from the data in Table 3 that some species are relatively much more abundant in one area than in another, whereas others may be fairly evenly distributed. Several species, *Actinonaias carinata*, *Obovaria olivaria*, *Quadrula metanevra*, *Q. quadrula*, and *Tritogonia verrucosa* apparently are much more common in the Wabash River than in the White River. By the same token, *Amblema costata*, *Fusconaia ebenus*, and *Megalonaias gigantea* appear to be more common in the White River. Only one of the 10 most commercially valuable species, *Quadrula pustulosa*, seems fairly evenly distributed over the study area.

Another datum that may give an indication of the distribution of mussels in the rivers investigated is the number of collections in which each kind of mussel occurred. Only four species, *Lampsilis ovata ventricosa*, *Obovaria olivaria*, *Quadrula metanevra*, and *Q. quadrula*, were taken by crowfoot bar and by handpicking from the Wabash River in both 1966 and 1967, and from the main stem and East Fork of the White River (Table 3). One other species, *Proptera alata* (Say), was taken by handpicking from each area and by crowfoot bar from the main stem and East Fork of the White River and from the Wabash River in 1966, but not in 1967. Similarily, *Truncilla truncata* Rafinesque, although rare, was collected in each of the areas.

For the entire study, 19 of the 20 species were represented in the 61 collections from the Wabash River, 17 were represented in the 27 collections from the East Fork of the White River, and 15 were taken in the 11 collections from the White River proper. Here, it should be pointed out that the 61 collections from the Wabash River were taken over a distance of about 330 miles, the 27 from the East Fork from about 110 miles of stream, and the 11 from the main stem of the White River from about 50 miles of stream, so that the intensity of sampling was about the same in each area.

In considering the occurrence of only the 10 species of greatest commercial value in all collections made during this study, only 1, *Q. quadrula*, was represented in more than half those collections. Four others, *O. olivaria*, *Q. pustulosa*, *A. carinata*, and *A. costata*, were represented in more than ¼, and each of the remaining 5 was represented in from 10 to 20% of all collections. In the Wabash River alone, 2 species, *Q. quadrula* and *O. olivaria* were represented in more than half the 61 collections, 5 were represented in from 20 to 35%, and 3 were present in less than 10% of the collections. In the main stem of the White River, where only 11 collections were made, no species was taken in more than four collections, and one, *T. verrucosa*, was not represented. In the East Fork of the White River, 2 species were present in more than half the 27 collections, 2 others were represented in more than ⅓, 3 others in more than ¼, 2 others in from 15 to 20%, and 1, *T. verrucosa*, was not represented. From these data it is apparent that *Q. quadrula* and *O. olivaria* are ubiquitous and that the other eight species, with the exception of *T. verrucosa*, are fairly widespread throughout the Wabash River system.

Comparisons of Catches in 1966 and 1967

During the course of this study, 10 one-mile sections of the Wabash River between Delphi (Mile 331) and Terre Haute (Mile 220), Indiana were sampled with a crowfoot bar during June or July 1966, and again in August 1967. All collections were made with the same equipment operated by the same personnel, and the data are believed comparable.

In 1966, 297 specimens referable to 21 species were taken from the 10 collecting sites (Table 4), whereas in 1967, only 56 mussels referable to 11 species were collected. This amounts to a reduction in numbers of specimens of 81% and a reduction in the diversity of species of 48%. The only instance in which more individuals were collected in a single station in 1967 than in 1966, was at Wabash River Mile 253-252, where 24 individuals were taken the second year as compared with 19 the first. Mussels referable to 9 species were taken during the 2-year period, of which 7 were collected in 1966 and 6 in 1967. The numbers of individuals of each species taken in 1966 were: *Lasmigona complanata*, 8; *Lampsilis anodontoides*, 2; *Proptera alata*, 2; *Obovaria olivaria*, 2;

TABLE 4. *Collections of mussels from each of 10 1-mile sections taken with a crowfoot bar in 1966 and 1967, showing the numbers of mussels and numbers of species taken in each collection.*

	1966		1967	
River Mile	No. of Specimens	No. of Species	No. of Specimens	No. of Species
320-319	50	12	22	9
311-310	42	7	2	1
294-293	45	8	1	1
285-284	19	5	2	1
281-280	7	2	—	—
271-270	27	9	2	2
259-258	39	7	—	—
253-252	19	7	24	6
239-238	3	2	—	—
230-229	46	10	3	2
Totals	297	21	56	11

Quadrula pustulosa, 1; *Q. quadrula*, 3; and *Tritogonia verrucosa*, 1. In 1967, the numbers were: *Actinonaias carinata*, 4; *Obliquaria reflexa*, 1; *O. olivaria*, 6; Q. *pustulosa*, 1; *Q. quadrula*, 11; and *T. verrucosa*, 1. An analysis of these catches indicates that the mussels taken in 1967 had a much higher commercial value than those taken in 1966; of the 10 commercially important mussels listed earlier, there were 23 taken in 1967 and only 7 taken in 1966. The reasons for these differences in the locality under discussion are not readily apparent. In the light of the data from the other nine localities where collections were made both years, it seems most likely that the chance of a crowfoot hook coming in contact with a particular mussel was very important in the makeup of that part of the study. Still, the consistently low catches in 1967 in the other 9 localities indicates that the overall populations of mussels in the upper Wabash River had declined rather spectacularly.

The numbers of individuals of each species taken each year in all 10 collections are listed in Table 5. Of the 22 species listed, 21 were taken in 1966 and 11 were taken in 1967. A single specimen represented the total catch for each of 8 species in 1966, and there were 5 species represented by a single individual in 1967. Although 9 of the 10 commercially desirable species listed earlier were taken in 1966 compared with 6 such species in 1967, the percentages of the total catch made up by those species for the 2 years was about the same. However, the actual drop in the numbers of such highly desirable species as *A. carinata* and *Q. quadrula* cannot be regarded lightly. This is even more impressive when it is considered that all of the specimens of *Q. quadrula* collected in 1967 were taken in the single collection at Mile 253-252.

TABLE 5. *Numbers of each species of mussels collected by crowfoot bar from the same 10 one-mile sections of the Wabash River in 1966 and 1967 (see Table 4 for location of collecting sites).*

Species	No. Taken in 1966	No. Taken in 1967
Alasmidonta marginata	1	—
Anodontoides terussacianus	1	—
Lasmigona complanata	8	2
Lasmigona compressa	1	1
Strophitus rugosus	5	—
Actinonaias carinata	43	9
Lampsilis anodontoides	2	—
Lampsilis ovata ventricosa	9	4
Leptodea fragilis	16	1
Obliquaria reflexa	—	1
Obovaria olivaria	44	15
Obovaria subrotunda	3	—
Proptera alata	5	—
Truncilla truncata	1	—
Amblema costata	1	1
Fusconaia ebenus	1	—
Fusconaia undata	1	—
Plethobasus cyphyus	1	—
Quadrula metanevra	15	—
Quadrula pustulosa	24	4
Quadrula quadrula	110	17
Tritogonia verrucosa	5	1
Totals	297	56

Only two species, *O. olivaria* and *Q. quadrula,* were represented in each of the 10 collections in 1966, whereas *O. olivaria* was represented in 5 of the 1967 collections and *Q. quadrula* was represented in 4. Seven other species were represented in 4 or more collections in 1966, but only 2 species other than those mentioned above were represented in more than a single sample. The lack of representation in more than a single collection in 1967 lends credence to the decline in species diversity as well as actual abundance of mussels during the period under consideration.

In comparing the catches in 1966 with those in 1967, it is important to compare them with changes in the numbers of shells sold for use in the cultured pearl industry. In 1965, 2000 tons of Indiana shells were sold for use in Japan; in 1966, that number was 4200 tons; in 1967 it was 1080 tons; and in 1968 the total number probably did not exceed 250 tons. Using these data for comparison, the percentage drop between

1966 and 1967 was essentially the same as for our samples taken in the survey and there was another substantial drop between 1967 and 1968 for which we have no data.

It is important here to note, however, that in 1969 the commercial musselers have reported very large numbers of small mussels in the Wabash River, and from the estimated size of these young animals they must be in their second or third year of life. On examination, it was found that most of these small mussels were Asiatic clams.

Efficiency of Different Kinds of Gear

Only two methods for collecting mussels were used in this study, the crowfoot bar and handpicking with or without SCUBA gear. When a crowfoot bar is dragged over an area, only those mussels at the surface of the stream bottom with their valves open are capable of being caught. With diving or handpicking, each mussel seen or touched by the musseler is capable of being captured. Thus, it is obvious that the opportunities for collecting mussels by handpicking, including diving with or without auxiliary air supply, are much greater than with a crowfoot bar.

On 13 September 1966, in the Wabash River near Americus, Indiana, we roped off an area of stream bottom 10 feet wide and 170 feet long. That area was then dragged with a crowfoot bar, and a total of 8 mussels representing 3 species and weighing 8.4 lbs. was collected. Following the study with the crowfoot bar, 2 divers equipped with SCUBA gear covered the same marked-off area and picked up 220 mussels of legal size including 201 specimens of commercial value as follows: 8 *Actinonaias carinata*, 3 *Obovaria olivaria*, 13 *Amblema costata*, 7 *Quadrula metanevra*, 6 *Q. pustulosa*, and 164 *Q. quadrula* that weighed a total of 138.8 lbs. The other 19 specimens represented 4 species of no commercial value and weighed 8.7 lbs.

On the basis of the data in Table 3, where the average catch per drag of the crowfoot bar over a 1-mile section of river yielded 17.4 mussels and the average catch per collection by handpicking was 22.4 mussels, the difference does not seem great. It should be pointed out here that each collection with a crowfoot bar required 2 men more than 2 hours of work whereas the average time for the collections by handpicking was 2 men for less than 30 min. Thus, it is apparent that the latter method is more than four times as efficient on the basis of time alone.

Handpicking with the aid of an auxiliary air supply is so efficient that an entire mussel bed can be wiped out in a few hours. We know of 1 instance in which 3 men with auxiliary air supply collected more than 3000 lbs. of commercially valuable mussels from a single bed in less than 2 days. Of course, they collected only mussels of legal size and left the smaller individuals behind. That act did assure the survival of the population, but the growth rate of most thick-shelled mussels is slow; it requires about 4 or 5 years for a mapleleaf or threeridge mussel to attain the legal size of 2.5 inches. Still, by removing all the larger individuals, the reproductive capacity of the population is seriously impaired, and it may take another 4 or 5 years or even longer for the population to recover its reproductive potential.

Reproduction

The cell lineage in unionid mussels has been adequately described and illustrated by Lillie (20), and atypical spermatogenesis in mollusks has been reported by Coe and Turner (9) and Loosanoff (21). No attempt has been made in the present study to describe the details of meiosis in either the male or female mussel, but atypical spermatogenesis was demonstrated in *Quadrula quadrula* (2).

Atypical sperm cells develop from the same type of spermatogenic cells as normal sperm cells, but the atypical cells undergo several mitotic divisions while still surrounded by the original cytoplasm within the original cell membrane. The number of cells undergoing atypical spermatogenesis usually are much less numerous than those undergoing normal spermatogenesis, but there are occasions when the atypical cells outnumber the typical ones.

Spermatogenesis is a continuous process in *Q. quadrula*, the most active period being in the seasons immediately before and during spawning. In March and April, before the breeding season commences, spermatogenesis is active and continuous until late June.

In the ovary of *Q. quadrula*, the primordial wall becomes differentiated and the ovum is formed following the usual maturation divisions. The ovum moves from the lumen of the ovary through ducts to the suprabranchial chamber and down into the water tubes of the inner and outer gills. The spermatozoa move through ducts from the lumina of the acini to the suprabranchial chambers and cloacal chamber and out the excurrent siphon into the water. The sperm are drawn into the incurrent siphon of the female by respiratory action, and are carried through the mantle cavity to the gills where they enter the water tubes through the ostia.

Syngamy and cleavage take place in the water tubes and the gills become modified into a marsupium to accommodate the developing embryos. *Q. quadrula* is larviparous, the homolecithal ova are incubated within the interlamellar spaces of the modified gills. In about 2 to 4 weeks, glochidia are formed and discharged from the water tubes into the suprabranchial chambers, through the cloacal chamber, and out the excurrent siphon. Since glochidia are obligate temporary parasites of fishes, if they do not find a host fish within a few days they perish.

If there is a large or dense adult population of mussels or if there is a sparse population of suitable fishes to serve as hosts for the developing glochidia, the survival of young individuals is low. If, however, there is an adequate breeding population of mussels but they are scattered rather sparsely over a large area, the survival of glochidia will be high if enough suitable host fishes are present. Thus, if the legal-sized mussels are harvested after they have reproduced, any glochidia that survive the host-parasite relationship with fishes, will have a much better rate of survival but they will not be able to add to the harvestable crop for about 5 years.

According to Pennak (24), all members of the Subfamily Unioninae are short-term breeders and are gravid sometime between April and August; whereas, all members of the Subfamilies Anodontinae and Lampsilinae are long-term breeders among which fertilization takes place in mid or late summer and the embryos are carried until the next spring.

Among the species reported here (Table 1), only *Actinonaias carinata* and *Obovaria olivaria* belong to subfamilies other than the Unioninae. Histological studies of the gonads of 21 specimens of *Actinonaias carinata* indicated that the ovary was not in breeding condition until late July and continued in that condition until mid-October. Spermatogenesis became active during the late spring, but no mature sperm were encountered until late July. Thus, based on the relatively few specimens studied, it is apparent that fertilization could not have taken place much before August and could continue on through early October. No observations were made on the time of release of glochidia in this species, but the evidence at hand indicates that it is a long-term breeder.

In *O. olivaria*, the gonads of 39 specimens were examined in detail. Uncleaved but mature ova were observed in the ovaries of specimens sacrificed in August, and at that time the ovary appeared to be in typical breeding condition. Mature spermatozoa were present in the lumina in late July, indicating that active spermatogenesis was in progress. These conditions in the gonads of each sex persisted through September, typical for the long-term breeder. No observations were made on the release of glochidia.

All other species for which there were adequate samples for detailed study belong to the Unioninae and would be expected to be typically short-term breeders. In *Amblema costata*, the breeding seasons extend from early May to early July. The breeding season for *Megalonaias gigantea* extends from early June through August. The breeding seasons for the three species of *Quadrula* studied here extend through May, June, and July.

Of the 19 specimens of *Tritogonia verrucosa* reported here, there were 7 females and 12 males. Examination of the testes from specimens collected in July indicated that they were in prebreeding condition and specimens collected in November and early May contained mature sperm. The ovary of a specimen taken in November was in typical breeding condition. The walls of the primordium were thin, the vitelline membranes were well developed, amphinuclei were present, and the ova were crowded in the lumen. Ovaries from females collected in June and July were characteristically in prebreeding condition. Thus, it appears that *T. verrucosa*, although a member of the Unioninae, is a long-term breeder. However, more data will have to be gathered in order to establish the precise limits of the breeding season, and observations must be made on the time of release of glochidia.

The only evidence of sexual dimorphism among the mussels studied was in individuals of *T. verrucosa*. In that species, the valves of the females have long posterior extensions not present in the valves of the males. There is no evidence, based on this study, of any relationship between degree of obesity and maleness or femaleness.

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