ECOLOGICAL NOTES ON THE MUSSELS OF WINONA, PIKE, AND CENTER LAKES OF KOSCIUSKO COUNTY, INDIANA.[1]

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The Mussels of Winona Lake.

During the summer of 1902 I became convinced that the mussel fauna of Winona lake had a definite distribution, which would repay careful study. I proposed, should circumstances permit, to study this distribution and the conditions which control it. The opportunity came the following summer and with the aid of Mr. James Simonton, who had become interested in the problem, the study was undertaken.

We examined the bottom from four inches to four feet by wading, from four to seven feet with a clam rake, from seven to eighty-six feet with an iron dredge.

The species found were determined by comparison with shells that had been named by Call, Simpson, and Baker. The nomenclature is that used by Call in in his "Catalogue of the Mollusca of Indiana," which was published in the Indiana Geological Report for 1899. They were: *Unio luteolus* Lamarck, *Unio subrostratus* Say, *Unio glans* Lea, *Unio fabalis* Lea, *Unio rubiginosus* Lea, *Anodonta grandis* Say, *Anodonta edentula* Say, and *Margaritana marginata* Say.

Winona is a deep kettle-hole lake. In general, the beaches are composed of sand and gravel, which shade off with varying rapidity into marly sand, then into sandy marl, then into coarse white marl, and finally into the soft dark mud that covers the bottom in all the deeper parts of the lake. The bottom steadily grows softer as the proportion of dark mud increases. So soft does it become that a small sounding-lead sinks into it of its own weight from six to twelve inches. However, in some places, especially the southwest side of the large lake and in nearly all

[1] Contribution from the Zoölogical Laboratory of Indiana University, No. 75.

parts of the small one, the shallow part of the beach is formed of muck which shades off into marl without the presence of any sand or gravel.

In general, it may be said that the mussel zone extends from the shore-line to where the bottom changes to very soft mud. This region is covered by from four inches to nine feet of water, although in some places the mud comes to within a few feet of the water's edge, while in others the sandy and gravelly bottom runs out into twenty-two feet of water.

A. grandis is found just on the outer edge of the sandy and gravelly banks, while *A. edentula* appears most abundantly a little farther out. A few specimens of both species were taken closer inshore, *grandis* being sometimes found on sandy bottom, *edentula*, however, invariably upon soft bottom. Neither (healthy forms) was taken on hard sand or gravel. *U. gibbus* has been taken upon sandy and gravelly bottom in from four feet out. *U. fabalis* appears in about the same region, except that it goes out on the soft bottom as far as edentula. *U. subrostratus* appears on the outer edge of the sandy and gravelly banks in about four feet of water, and also further inshore where the bottom is soft. *U. luteolus* is the most variable, the most widely distributed, and the most abundant of all the species in the lake. It varies from a moderately thin, light straw-colored shell, marked by radiating greenish lines, to an extremely heavy, almost black form. The gradations of form, color, and size are shown in Figs. 9–19 in the plate. The straw-colored variety is found in from four inches to twenty-two feet of water. It is, however, dominant inshore, in weed patches (*Potamogeton* and *Ceratophyllum*), and on chara-covered bottoms. The dark variety occupies the same region but is dominant upon sandy and gravelly bottom in from three and one half to twenty-two feet of water. The intergrading forms cover the same territory as the straw-colored and dark varieties but cannot be said to be dominant anywhere. *U. rubiginosus* occupies about the same habitat dominated by the dark form of *U. luteolus*, except that it was not found in water deeper than ten feet. *M. marginata* was found so infrequently (only six times) that we could tell little of its distribution. The

specimens found were taken on sand and gravel and white marl bottoms in from four to twenty-two feet.

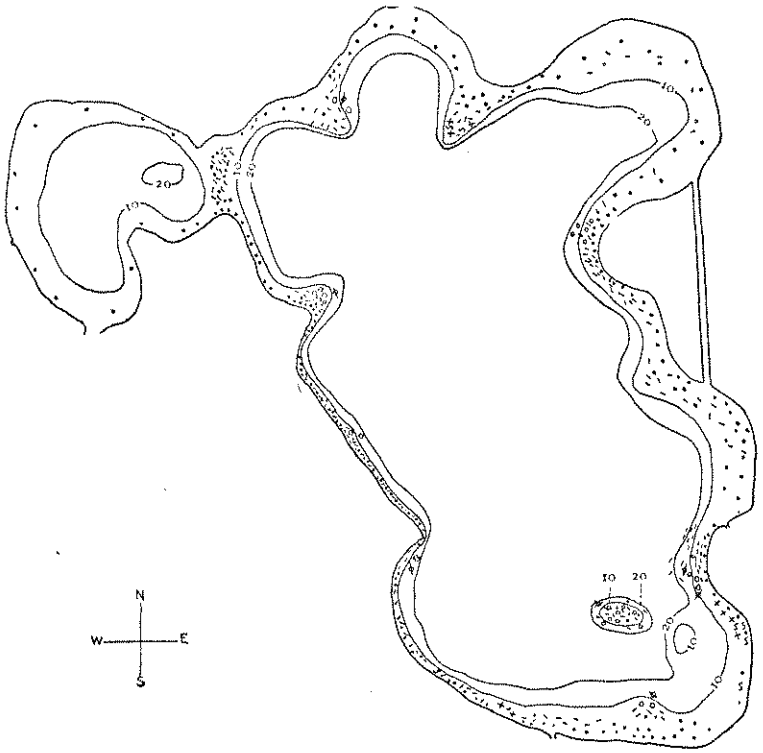


FIG. 1. Map of Winona Lake showing mussel beds. ● = *U. luteolus* — light variety; — = *U. luteolus* — dark variety; ○ = *A. grandis*; ϕ = *A. edentula*; | = *U. rubiginosus*; S = *U. subrostratus*.

There are a number of conditions which suggested themselves as possible explanations for this distribution — sex, light, temperature, food supply and oxygen, pressure, wave action, character of the bottom, and enemies. Sex cannot be important, for males and females are found together throughout the habitat; light can have but little to do with it, for mussels are absent in places in three feet of water and are abundant in others in fifteen feet, the difference in light being considerable. Further, the light over some of the immense beds in White River is no greater and perhaps even less than in twelve feet of lake water. That heat and cold have little effect, during the summer at least, is shown by

the fact that heavy beds were found in different temperatures, and by the fact that temperature variation in the mussel zone did not amount to more than two degrees; oxygen is not important, for the supply of oxygen throughout the mussel zone varies very little; pressure can have but little to do with it, for we found specimens on a sandy bottom in twenty-two feet of water, while on dark mud bottoms in ten feet none were taken in any case. Food supply cannot be effective, for it is about equally abundant throughout the zone. The food consists of diatoms and other low algæ forms and one-celled animals.

It seems to us that there are three factors which control the distribution of the mussels in Winona lake — wave action, character of the bottom, and enemies.

The first factor is active only in water less than three feet deep. As *U. luteolus* and *A. grandis* appear in this region they are subjected to this agency. Specimens of both *A. grandis* and the dark form of *U. luteolus* have been found washed ashore after a storm, and scores of these shells appear along the shore-line. Under similar conditions we have seen the light form of *U. luteolus* moving from the water's edge out into deeper parts. These facts point to the conclusion that the two first mentioned forms are, in general, prevented from occupying shallow water by wave action, but that the light form of *U. luteolus*, being very active and having a relatively thick shell, can well occupy this region. *U. glans*, *U. fabalis*, *U. subrostratus*, *U. rubiginosus*, *A. grandis* and *A. edentula*, if washed ashore would be unable to get back, and the shells of the last two would quickly be broken through by wave action. Those forms which occur in this region, especially those to which washing ashore is fatal, habitually bury themselves so deeply in the mud that only the siphonal tip of the shell projects and thus they are protected from the dragging action of the waves.

The character of the bottom applies throughout the mussel zone and is by far the most important factor. The bottom in the weed patches differs from that in the deeper parts of the lake in being less soft. The sandy and gravelly bottom affords firm foothold and allows the mussel to assume that position which enables it to get the best supply of food and oxygen, while the pure black mud allows it to sink so far as to be smothered.

In order to test the ability of the mussel to withstand these bottom conditions we made three wire clam baskets. One we lowered in twenty-five feet of water, another in thirty-five feet, and the other in eighty-five feet. The basket in twenty-five feet was placed on August fifth on a dark mud bottom. It contained thirteen *U. luteolus* and one *A. grandis*. On the tenth two of *U. luteolus*, dark variety, were dead; on the fifteenth one of *U. luteolus*, dark variety, was dead; on the seventeenth two of *U. luteolus*, dark variety, were dead and four were missing. The basket in thirty-five feet was placed on a sandy gray marl bottom on August ninth. It contained five *U. luteolus* of the light variety and one of the dark, and one *A. edentula*. On the fifteenth one *A. grandis* and one *U. rubiginosus* were added. On the twentieth one *U. luteolus* of the dark variety was dead; on the twenty-fourth five *U. luteolus* and one *U. rubiginosus* were found to have the gills badly choked with sediment, while the Anodontas were missing. The eighty-five feet basket was lowered on pure dark mud on the fifteenth of August. It contained seven *U. luteolus* of light and one of dark variety, two *A. edentula* and one *A. grandis*. On the twenty-first one *U. luteolus* of dark variety was dead; on the twenty-fourth seven *U. luteolus* and one *A. grandis* showed gills badly choked with sediment, while the two *A. edentula* were in better condition, showing very few patches of mud in their gills.

This experiment, incomplete as it is, serves to show two important facts—that the dark variety of *U. luteolus* resists the conditions of the gray marl far better than those of the fine black mud bottom, regardless of depth of water, for in the twenty-five feet basket on dark mud in five days two specimens, and in the eighty-five feet basket on dark mud in six days one specimen, were killed, while eleven days were required in the thirty-five feet basket on gray marl to destroy a single specimen; that the dark variety of *U. luteolus* is least resistant to these bottom conditions. It also indicates that the *Anodontas*, especially *A. edentula*, resist better than any other kind experimented with.

Naturally one should expect to find some difference in structure by which the mud is more thoroughly excluded in the more resistant species than in those which suffer more severely. There

is at least one such difference — the size of the shell in proportion to its weight. The Anodonta shells are very light, while those of the dark form of *U. luteolus* are very heavy in proportion to surface exposed. Many shells of the former, especially those of *A. edentula*, are easily crushed between the thumb and fingers, while those of the latter will frequently withstand the heavy blow of a hammer. The former is evidently fitted for a life on soft bottom, while the latter finds a most congenial situation on coarse sand or gravel beds. Between these two extremes the other species range, and indeed we find the main facts of their distribution explained by the status of this condition.

Accordingly *A. grandis* and *A. edentula* are found on the outer edge of the sandy marl banks, the *edentula* being better fitted to withstand the bottom conditions, even out in the edge of the dark mud. *U. glans* and *U. fabalis*, owing to lightness, are able to occupy about the same region. They are also found inshore in situations not subjected to wave action. *U. subrostratus*, having medium weight valves, appears on gravel and sand banks, in weed patches, and on chara-covered beds. *U. rubiginosus*, having very heavy valves, is confined to clear sand and gravel banks. The straw-colored form of *U. luteolus*, on account of its medium weight valves, is able to live on sand, gravel, in weed patches, and on chara-covered beds. Owing to the fact that so few specimens of *M. marginata* were found, we were unable to draw any conclusions as to its ecology.

The muskrat is the principal enemy of the mussel ; around his house many mussel shells are found but no live mussels. Shells of all the species in the lake except the smaller ones appear there, those of the *Anodontas* being in much greater evidence than is proportionate to their total number. They do not appear so on first examination, for they are broken up by the animal and worn by the waves. The conditions on the sand banks beyond reach of wave action are very favorable for *Anodonta* life, except for the presence of the muskrat. They are absolutely absent from the water some distance from his home where we found Unios rather abundant. This points to the fact that the muskrat confines the *Anodonta* to the deeper water at the edge of sandy and gravelly banks.

It seems to us that the foregoing facts give basis for the following conclusions: the mussel zone lies mainly upon sandy and gravelly banks, and on the outer edge of the same; wave action and the muskrat determine the shoreward limit of the distribution, and the character of the bottom is the principal factor determining the outer boundary of the zone.

The Mussels of Pike and Center Lakes.[1]

My work in the summer of 1904 was carried on with the aid of Mrs. Headlee and was simply a continuation of that of the previous summer. We had two main objects in view in pursuing this study further; to determine which of the distributional forces discovered in Winona lake may be essential, that is, may apply to small fresh-water lakes in general; to ascertain by experiment the effect of black mud bottom conditions on mussel life, and what species are most resistant.

In pursuance of the first object we studied the mussel distribution in Pike and Center lakes and I shall devote the following paragraphs to a brief discussion of them.

In Center Lake we have Winona in miniature. Some new elements, however, enter in the form of sewage-like shore washings on the southeast side and the absence of *Potamogeton* patches and of heavy wave action.

In general, I may say that the mussels here are much fewer as compared with the number in Winona than the difference in the sizes of the lakes would warrant. There are two conditions here which may safely be regarded as at least partial explanations of this difference: the southeast shore, which once supported great numbers, has become unfavorable to mussel life through the accummulation of decaying vegetable and fecal matter; there is an enormous destruction by the small boy, who finds amusement in collecting mussels to throw or to cut open for pearls.

Such mussels as are found, all varieties of *U. lutcolus*, *U. subrostratus*, *U. rubiginosus* and *A. grandis*, appear in situations in

[1] Pike and Center are two small lakes within two miles of Lake Winona and at the very edge of the town of Warsaw, Indiana.

almost perfect agreement with those of Winona. There are, however, two noteworthy differences — very few mussels occur in water deeper than twelve feet, although our dredge scraped over gravel in seventeen feet; very few are to be found in water less than three feet deep. I have no explanation to offer for the first variation; the second is undoubtedly due to human agency.

The mussel zone in Center Lake, therefore, extends over gravel, sand, and white marl banks in from three to twelve feet of water. The deep-water edge is determined by the character of the bottom, modified locally, doubtless, by some as yet unknown factor, while the shoreward edge is determined by the ravages of small boys. Neither the muskrat nor the action of the waves is effective here for the first is not present and the second is not powerful enough. That the shoreward limitation is due to man is shown by the fact that only those individuals of the deep-burrowing species which best exemplify this tendency, are able to survive in the area from three feet to the water's edge. So rigid is this selection that we looked long and carefully before we found any mussels at all in this region. We found the light colored form of *U. luteolus*, *U. rubiginosus*, and *U. subrostratus*, and in every case the mussel was buried so deeply that only the extreme tip of the shell projected. Even this was frequently covered with a spongy growth, which still more effectually concealed it.

Pike Lake, in size, falls between Center and Winona and in depth it does not exceed the former. The bottom conditions resemble those of Winona and considerable diversity of beach obtains. All the species found there, except the Corbiculidæ, which we did not seek, were taken here. Everything seemed favorable for a large bivalve fauna, yet mussels are almost as scarce as in Center. I can give no complete explanation for this condition, although here, too, human agency is certainly a very important factor.

The mussel zone extends from a depth of four feet to fifteen feet on the sandy and gravelly beaches; on gray marl beaches its shoreward edge extends into shallower water. The deep water edge is determined by the character of the bottom, the

shoreward edge by wave action, the muskrat, and human agency. Wave action would keep the clumsy and slow-moving forms out of the region from eighteen inches to the water's edge; the muskrat would keep mussels scarce about his house, as indeed he has; but neither nor both could keep them absent from favorable beds in from four feet to eighteen inches of water. This peculiarity of distribution is noticeable only on sandy and gravelly beaches, such as are frequented by bathers. We have seen these throwing mussels on shore and out into deep water and therefore believe this to be the cause of the dearth of mussels in these regions.

In Winona, Pike and Center lakes, mussels are most numerous on the sandy and gravelly beaches; they are scattered on gray marl; very rare on muck; and are not present at all on the fine black mud. They thrive best on gravelly and sandy beds, poorly on gray marl, and not at all on muck and fine black mud. The primary and essential factor in mussel distribution in these three lakes is the character of the bottom, while wave action, the muskrat, and human agency play varying and secondary parts.

Experiments.

The work done in 1903 seemed to show that bottom conditions are favorable or unfavorable as they do or do not allow the animal to assume his natural position and to project his siphons above the mud. When he cannot get his siphons above the mud, his gills become choked and death follows. The animal, therefore, which remains near enough the top of the mud to project his siphons is bound to be the most successful in resisting it. Any of the mussels can do this on sandy or gravelly bottoms, but where the bottom is composed largely of the fine black mud, only such forms as *U. fabalis*, *A. grandis* and *A. edentula* are able to sustain themselves. These shells are all light and the last two expose a large surface in proportion to weight.

We placed eight baskets in water from nine and one-half feet on sandy bottom to eighty-two feet on fine dark mud. Of these, two were lost within a week, one in four weeks, and one in eight weeks and three days. Four remained until the contents were taken out, killed, and examined. We further carried on an ex-

periment in a common wash-tub to which I shall refer in detail later.

In these experiments when a mussel was found, whose gills contained mud, we considered that he was the victim of bottom conditions. So far as our experience goes, the presence of mud in the gills is always followed by the death of the animal if he cannot free himself from the environment which is responsible for his mud-choked state. Beginning with the least successful, the following forms are given in the order in which they stood the bottom test, assuming that the more mud they contained, the less well had they withstood the soft bottom: The dark form of *U. luteolus*, *U. rubiginosus*, the medium form of *U. luteolus*, the light form of *U. luteolus*, *U. subrostratus*, *A. grandis* and *A. edentula*. *U. glans* and *U. fabilis* have not been listed because we were unable to obtain a sufficient number for investigation.

Since the mussels taken directly from the beds differed from those taken from the baskets placed on dark mud in that the latter showed from sixty to ninety per cent. of the total number choked with mud, the question might be raised, is not the presence of mud due to the animal being confined in a basket, where, perhaps, he cannot place himself most advantageously? The confining of the mussels in the baskets might operate unfavorably through crowding or through lack of soil in which to assume their normal position. The basket in all cases was made large enough to give each mussel more room than he would have on a crowded bed. It is true that on a hard bottom the basket would prevent the animal from burrowing in the soil, but on the soft bottom he would have from two to six inches of it. The baskets were weighted so that they would be forced down into the soft bottom. We set a basket on a gravelly sand bottom, but it was lost just before we would have killed and examined its contents. However, during the forty-five days of its submersion before its loss, none of the mussels died — a condition which obtained in but one of the baskets planted on mud, and this one was in but twenty feet of water where the bottom was not so soft as in the deeper parts. The mussels in the basket on gravelly sand were subjected to more injurious conditions by the basket itself than were those of the others, for the wire in this case could not sink

into the bottom enough to give them soil in which to right themselves.

We placed three specimens of each species experimented upon, except *U. rubiginosus*, in a tub, which had previously been two-thirds filled with fine dark mud from the deep area, and then filled up with water. This water was freshened by the use of *Elodea* and the occasional addition of clean water, which was so added as not to disturb the mud. After seventeen days all of *U. luteolus*, two of *U. subrostratus*, and one of *A. grandis* showed mud in gills, thus effectually demonstrating that the basket was not alone to blame for the general failure to withstand the fine black mud of the bottom.

The work of 1903 and 1904 shows conclusively that the mussels of Winona, Pike, and Center lakes cannot exist on the fine black mud bottom — they become choked with mud and apparently smother — and that the light weight forms and the forms exposing great surface in proportion to weight can rest on top of comparatively soft mud and can, therefore, live farthest out on the deep water edge of the bed. Because the mussels cannot occupy any region where the pure black mud is present, they are confined by it to isolated beds and narrow bands of shore-line.

I believe that the whole evidence of the distributional and experimental work of 1903 and 1904 points clearly to the character of the bottom as the great basal influence in the distribution of mussels in small lakes generally.

Additions to the Known Fauna.

We knew that various species of *Sphærium* had been taken in Turkey and Maxinkuckee lakes and therefore hoped to find more than the one thus far reported from Winona.

Mr. A. M. Banta told us of a small bivalve that he had discovered in an artificial lily-pond in the assembly grounds near the lake. It required but little effort to find it in the decaying vegetable matter in the bottom of this pond, but we did not take it in the lake. It is *Sphærium partumeium* Say. It has not been reported from this region before. The dead shells of *Sphærium striatinum* Lamarck occur in great numbers along the

shores of the lake and even in deep water but, in spite of considerable search, we found no live specimens. The shells of *Pisidium inequilaterale* Prime were also found, although less abundantly, but neither were live specimens of it taken. Neither of these has before been reported from this region and the latter, not from Indiana.

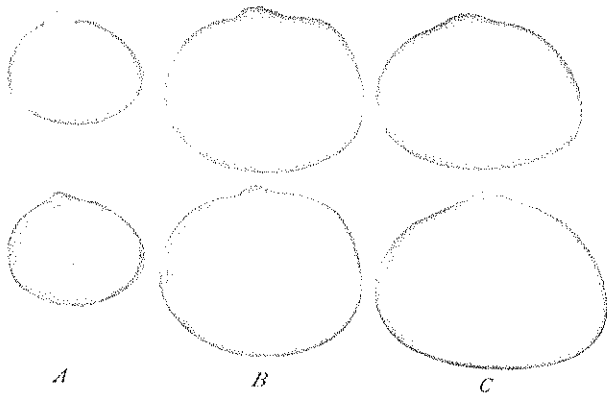


FIG. 2. *A*, left and right valves of *Pisidium inequilaterale* (dorso-ventral diameter of original is .19 in.); *B*, left and right valves of *Sphærium partumeium* (dorso-ventral diameter is .29 in.); *C*, left and right valves of *Sphærium striatinum* (dorso-ventral diameter of original left valve is .27 in., while that of the original right valve is .29 in.).

In conclusion, I wish to acknowledge my indebtedness to Prof. C. H. Eigenmann under whose direction this work was done, and to R. Ellsworth Call, who kindly identified the three last-mentioned species.

EXPLANATION OF PLATE XII.

FIG. 1. Right and left valves of *Unio fabalis*.

FIG. 2. Right and left valves of *Unio glans*.

FIG. 3. Right and left valves of *Unio subrostratus*.

FIG. 4. Right and left valves of *Unio rubiginosus*.

FIG. 5. Right and left valves of *Margaritana marginata*.

FIG. 6. Right and left valves of *Unio luteolus*.

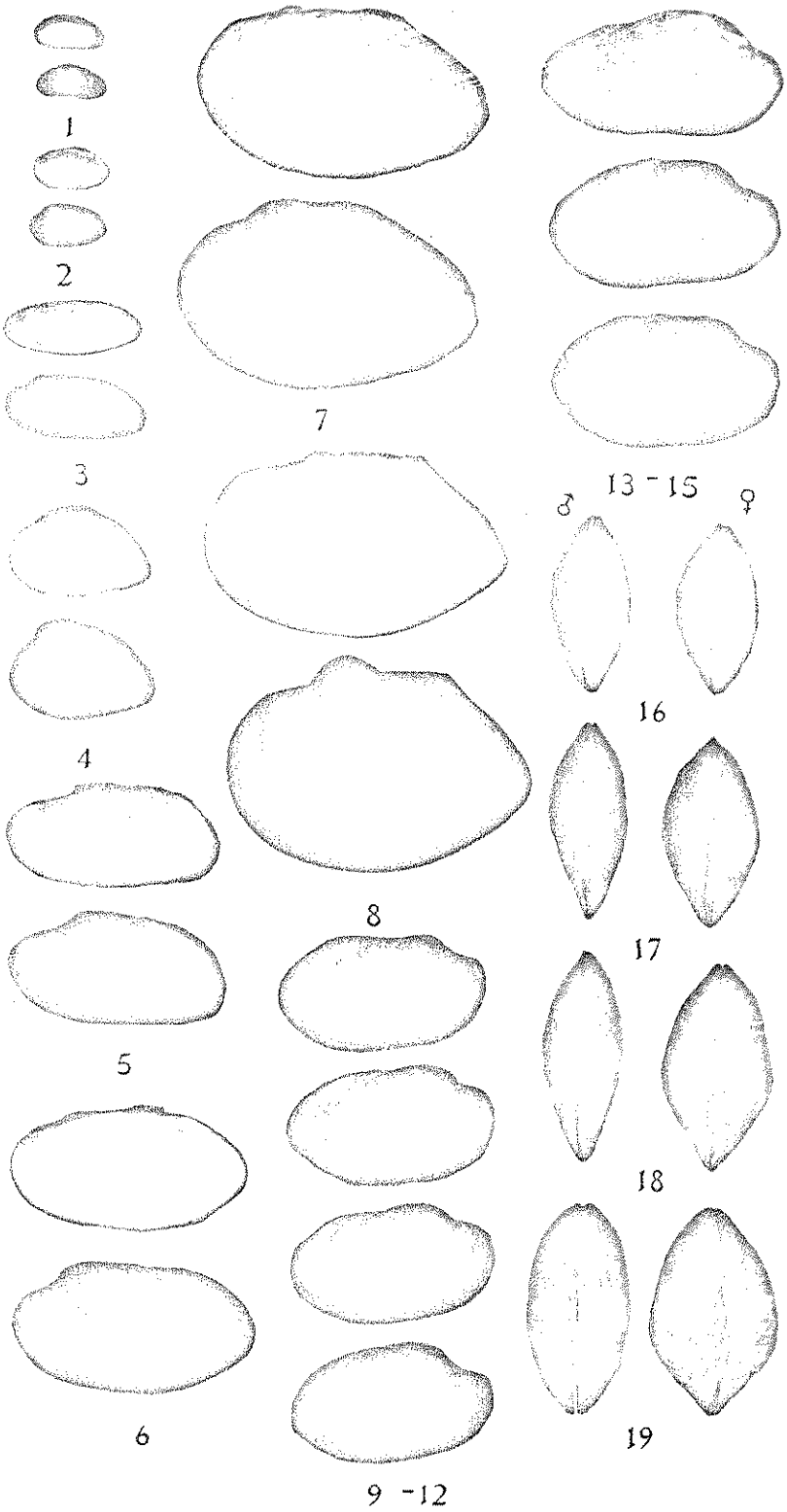
FIG. 7. Right and left valves of *Anodonta grandis*.

FIG. 8. Right and left valves of *Anodonta edentula*.

FIGS. 9–15. Side view of a series showing gradations in form, color, and size from the small light-colored variety to the large dark-colored variety of *Unio luteolus*.

FIGS. 16–19. Dorsal view of a series of *Unio luteolus* including both males and females and showing the gradations in form and size from the small light-colored to the large dark-colored variety.

Note. — The shell represented in FIG. 7 is 2.75 in. from dorsal to ventral surface and 4.5 in. from anterior to posterior end. The reduction of FIGS. 1–19 is the same as that of FIG. 7.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