A PRELIMINARY REPORT ON THE INTRODUCED ASIATIC CLAM CORBICULA

IN TENNESSEE

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March 1, 1961

Dr. R. H. Hutcheson, Chairman
Tennessee Stream Pollution Control Board
Cordell Hull Building
Nashville 3, Tennessee

Dear Dr. Hutcheson:

The Asiatic Clam (Corbicula) is now found in Tennessee waters. This would be of biological interest only except that the presence and apparent rapid increase in number of clams has a bearing on water quality from the nuisance standpoint. This Clam has been found in the condensers of industrial and power plant water supplies and has damaged sand and gravel operations.

Our biologists found the Asiatic Clam in the Kentucky Lake of the Tennessee River in October, 1959, while collecting other biological data. Large numbers were found again in Kentucky Lake during July, 1960. The Clam also has been found in the lower part of the Cumberland River.

The Asiatic Clam is quite distinct in appearance. Outstanding is the heavy shell which has heavily sculptured, concentric ridges, or growth rings. The shells have a yellow-green color and reach a size of about 1.25 inches across. These characteristics should make this small clam readily recognizable.

This preliminary report was compiled to disseminate our present knowledge relative to the problem. It is hoped that it will be of use to those presently confronted with the problem as well as stimulate additional work and research by others. Therefore, additional information, comments and constructive criticisms will be welcomed by this department.

Very truly yours,

S. Leary Jones, Director
Stream Pollution Control

SLJ/aem

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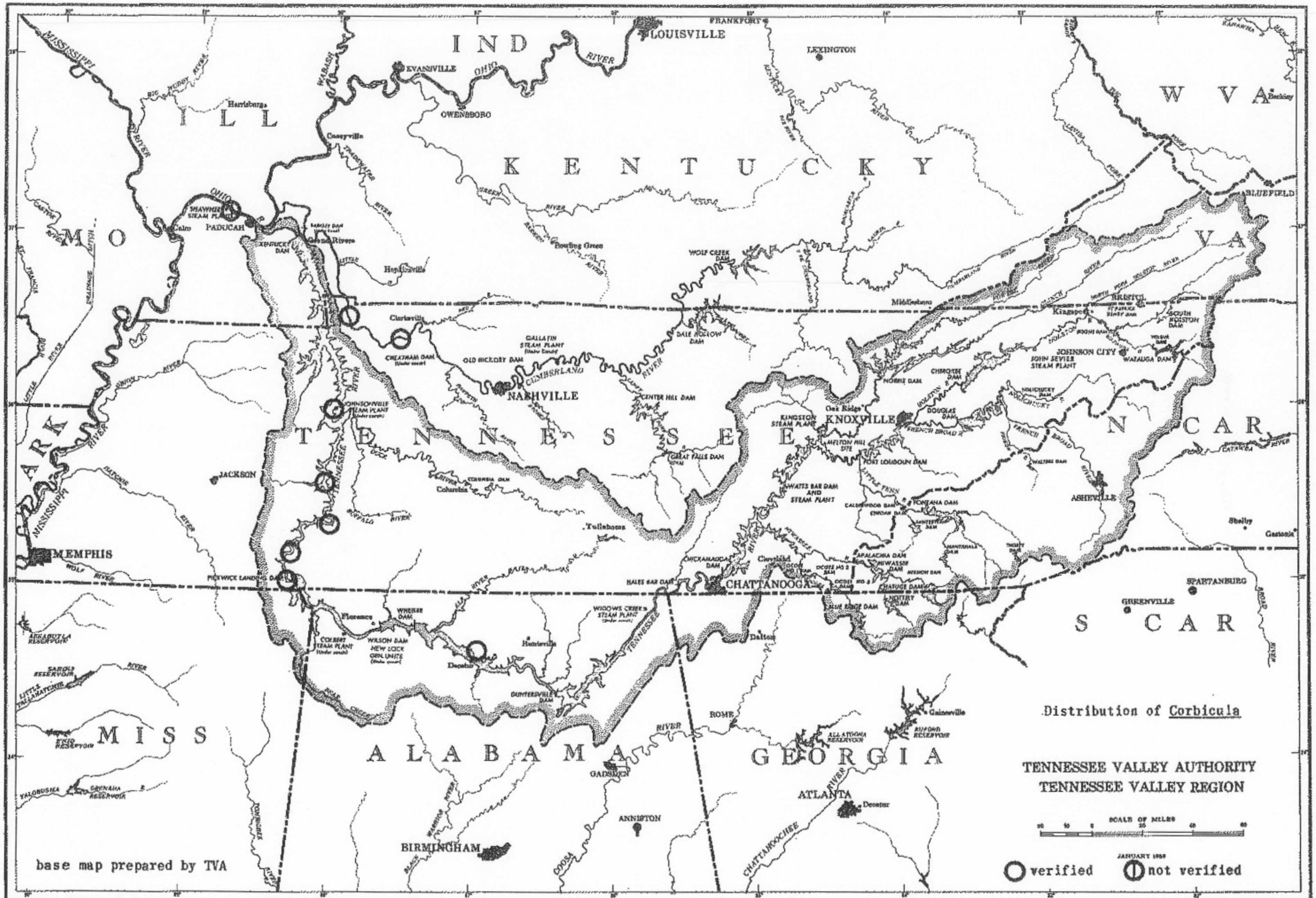

MAPS AND SURVEYS BRANCH

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A PRELIMINARY REPORT ON THE INTRODUCED ASIATIC CLAM (CORBICULA) IN TENNESSEE

INTRODUCTION

The introduced Asiatic Clam, Corbicula fluminea (Muller), was first observed in this country in 1938 in California (1). By 1948 (2) they were found in the Columbia River in Pacific County, Washington. By 1956 they turned up in an irrigation canal in Phoenix, Arizona (1). In 1959 Dr. W. M. Ingram summarized the available literature and nuisance problems (3). Lake Meade on the Colorado River; the water supplies of Phoenix, Arizona; Oregon and Washington sides of the Columbia River at Bonneville; and the Snake River on the Washington-Idaho border were added to the growing list of localities (3).

On October 21, 1959, they were collected on the Tennessee River below Pickwick Dam in Hardin County, Tennessee (5).

The clam has definitely been established as a nuisance, as early as 1953, in irrigation systems in the Coachella Valley of California (3). The clam was reported as clogging pumps at TVA steam plants in 1960 (6). Earlier records revealed difficulties at the Shawnee Steam Plant on the Ohio River in 1957. This was apparently caused by Corbicula.

The clams are evidently here to stay and are a growing threat to water quality from a nuisance standpoint.

DESCRIPTION

The Asiatic Clam is a bivalve mollusc belonging to the class Pelecypoda. It belongs to the same order, Heterodonta, as the Sphaeriid clams. The Sphaeriid clams belong to the family Sphaeriidae; whereas Corbicula belongs to a separate family, the Corbiculidae. The other bivalve molluscs, mussels, found in Tennessee belong to the order Eulamellibranchia, which includes the families Unionidae and Margaritiferidae. The mussels are the largest of these groups and are still being harvested for the pearl button trade and for export to Japan for use as "seeds" in the cultured pearl industry.

Corbicula would not be easily confused with the mussels, even juvenile forms. They could be easily confused with the Sphaeriid clams. They have, at least in one instance, been identified as Sphaeriids in one recent report. They will probably still masquerade under this group until the fact is better known.

Although these two groups are similar superficially, they are quite distinct in characters of the shell and breeding habits, etc. The best field character for rapid identification, by those unacquainted with this shell, would be the lateral teeth and cardinal teeth. The cardinal teeth number three in each valve. The lateral teeth number two on each side in the right valve and one on each side in the left valve.

The shell is ovate to trigonal in shape, inflated at the umbones, heavy, sculptured with concentric rings, and covered with a lustrous yellow-green periostracum. This outer covering or periostracum is absent from the umbones and the upper fourth of the shell on 16 mm specimens. The largest specimens collected (30 mm) showed severe erosion of the umbones (Figures 4, 6). The periostracum, as well as a layer of prismatic calcium carbonate, was dissolved away on this section of the shell. All of the larger specimens that were examined showed this condition. As mentioned by Ingram (3), this could limit the size attained. This would also reduce the life span of the clam. The interior of the shells is lined with a layer of nacre which has a polished appearance and is purple in color. This color characteristically shows through the eroded umbones on the exterior of the shell. The polished interior is variously referred to as "non-nacreous," "porcelaneous," and "nacreous." The nacreous layer or "mother-of-pearl" is characteristic of the mussels. The nacreous layer is composed of certain organic matter and calcium carbonate. Thus, there is some disagreement over the inner shell layer. Some of the Tennessee specimens have a hard polished "nacre" below the pallial line, whereas the section above this line appears to be nacreous but is not so highly polished.

The shell cannot be spoken of as patterned; however, the small and medium sized ones have a characteristic dark stripe on the anterior part of the shell (Fig. 1). This dark stripe marks the boundaries of the lunule. The same type of stripes are present on the posterior part of the shell and mark the limits of the escutcheon.

Growth

The dark shell bands have been used to determine age. In the Tuolomne River in Oregon, the 50 mm size was estimated to be reached in the seventh summer (3). Not all individuals have the prominent annuli or "rest marks." There is a consistency in the ones exhibiting these dark shell bands which indicates that it will be a reliable criteria for judging age and growth. Calculations made from the measurements of one shell indicate the following approximate values: first year, 6 mm; second year, 15 mm, an increment of 9 mm; third year, 21 mm, an increment of 6 mm; and fourth year, 29 mm, an increment of 8 mm. *Corbicula leana* attains a length of 10 mm the first year and 20 mm at two years (16).

Size and Form

The largest specimens of the Tennessee River clam which were taken were 30 mm in length. The size reached by some of the species in this genus are as follows:

Species	Locality	Length (in mm)
C. japonica	Japan	40
C. leana	Japan	43
C. fluminea	Canton	83
C. fluminea	W. United States	50
C. manillensis	Philippines	34
C. sandai	Japan	38

There is much variation in form in the genus Corbicula between species and species populations. There is also a change in shape from the juvenile to the adult form. Another factor to reckon with is a change in shape due to transplantation. Sandai is a peculiar form of Corbicula, the umbones being high and prominent. Cahn (12) reports that the young shell has the shape of an isosceles triangle, but it becomes wedge shaped as the clam reaches maturity. Leana has almost symetrical posterior and anterior margins with the umbo forming a rounded projection. Japonica is ovate, rounded anteriorly, and has a somewhat flattened posterior margin. The umbo form is rounded, not projecting like sandai. The ventral margin forms more nearly a straight line as compared with leana (12). The mature shell of fluminea (from Bonneville Dam, Oregon, and loaned through the courtesy of the U. S. National Museum) is rounded at both anterior and posterior margins and is ovate. The ventral margin is quite similar to japonica. The umbo forms a low, rounded projection, also like japonica. Viewed from either end, the shell has gently inflated umbones. The Pickwick shells (29 mm size group) are rounded anteriorly and flattened on the posterior margin; and compared to the Oregon shells, they are trigonal. The ventral margin is rounded, and the umbo forms a rounded projection not quite as exaggerated as in sandai. The umbones are greatly inflated.

The young clam found in the Tennessee River is elongate at 0.90 mm, and the umbone is low. As it reaches maturity, it becomes distinctly trigonal.

The shells from Pickwick Dam tailwater and New Johnsonville on Kentucky Lake (Tennessee River) are practically identical in form despite the fact that the former specimens were taken in rock and gravel and the latter in mud. The ones from Wheeler Lake, further up the Tennessee River, are somewhat different in shape, being more elongate. The Cumberland River specimens taken in gravel were also practically identical in form with the lower Tennessee River populations.

Color and Pattern

The typical color and pattern of this clam develop with age. The color and pattern tend to intensify with maturity, gradually becoming darker and obscure as the shell reaches a larger size. The immature clam, one mm and under, is cream color and without pattern. The five mm shell takes on the polished tan periostracum of the adult. By eight mm the periostracum becomes olive in color and highly polished. The pattern of the lunule and escutcheon also appear at this stage. At 22 mm the escutcheon is losing prominence, and at 30 mm both escutcheon and lunule are obscure.

The inner surfaces of the shell are deep purplish at the margins and beneath the umbones. By the time 30 mm is reached, the entire inner surface is suffused with light purple.

As pointed out by Turner (21), color patterns of mollusks, as a diagnostic specific character, must be considered with caution. The color can be influenced by environmental factors as well as nutrition patterns.

The periostracum of fluminea varies from brownish black to jet black (22). The Bonneville Dam specimens, mentioned above, were yellow brown to brownish black, becoming darker with age. The periostracum of sandai is orange yellow during juvenile stages but becomes a polished black with age and maturity. The young shell of leana is faintly yellowish green with an irregular brown pattern becoming glossy black with age and maturity. Young shells of japonica are yellowish brown. With age and maturity the shell becomes glossy black, usually with a radial pattern (12).

Identification and Variation

The Tennessee River clam has been identified as fluminea (5). When these clams are compared with the Oregon fluminea loaned by the U. S. National Museum, some variation is noticed. The Tennessee River clams are trigonal in shape, whereas the Oregon specimens are ovate. The growth rings are noticeably wider on the former. Some differences are to be expected since the shells are subject to pressures. In a personal communication to Mr. John Condor of the Tennessee Game and Fish Commission, Mr. Robert Personius indicates that Corbicula leana is also involved on the West Coast. It will be necessary to study in more detail the life histories of the clams involved. The examination of live specimens of some of the foreign species is planned so that these can be compared to the naturalized species, especially in regard to life history stages.

REPRODUCTION AND LIFE HISTORY

The fertilized eggs of fluminea develop and hatch in the adult clam. The adult releases the microscopic free-swimming larvae by the thousands (3). The larvae of leana are reported (8) to be incubated by the adult. The typical larval development of some molluscs is described by Davis (9) as follows:

> "Except in the Cephalopoda, the embryonic development of many forms result in the production and hatching from the egg of typical trochophore larvae, these in their general structure being indistinguishable from the trochophore larvae of the Annelida .... In other species the trochophore stage is passed within the egg membranes, and the larvae hatch at a later stage of development. On one side of the trochophore there develops a ...two-lobed shell gland, which soon secretes a ... bivalved larval shell. Meanwhile, around the mouth region there develops a two-lobed, heavily ciliated extension of the body wall, the velum, which is to be the post-trochophore larval locomotory organ. A foot develops as a protrusion between the mouth and the anus. In this manner the trochophore larva is transformed into a veliger larva. All or nearly all veliger larvae are planktonic, and the individuals maintain their position in the plankton mainly by the action of the velum, though this organ also has other functions, such as food getting. Veliger larvae of gastropods ... and of pelecypods ... are extremely characteristic plankters in marine environments, especially in relatively shallow areas near shore where the adults live in great abundance on the bottom. It must not be thought that all forms have planktonic veliger larvae. Many pass through the veliger stage within the egg, and hatch with purely adult characteristics."

This type of larval development is in contrast to the fresh-water mussels, the majority of which discharge glochidial larvae into the water. When fish contact the glochidium it fastens upon the fish, is encysted, and develops as an obligatory, temporary parasite. After passing this stage, the glochidium drops off and attaches to the substrate by a long, sticky thread called the byssus. Davis (9) remarks that, "the glochidium larvae cannot, however, be spoken of as having any real sort of planktonic existence."

Clark and Stein (10) quote Kofoid (11) as follows:

> "This group (Lamellibranchiata-Pelecypoda) is represented in the plankton by the larval stages or glochidia of the Unionidae (mussels) which form an important part of the bottom fauna of the stream and its tributaries."

Some of the specimens collected from the Tennessee River below Pickwick Dam (July 1960), at the Perryville Bridge (November 1960), and the New Johnsonville area (July 1960) were incubating the larvae in the gills. The inner gill (posterior two-thirds) was packed with the veliger larval stage. These measure 0.22 mm wide by 0.20 mm high.

Sex

Corbicula fluminea has been reported to be dioecious as well as monoecious (3). Apparently, its exact status has not yet been determined. Other members of this genus have been established to be dioecious, sandai; and monoecious, leana and manillensis (8, 13). The Tennessee River clam is definitely monoecious. Dissections of large series of this clam have shown this to be the case.

Sexual Maturity

The Tennessee River clam reaches sexual maturity during its first year at a length of 6.5 mm. The Philippine clam, manillensis, reaches sexual maturity at from 10.3 mm to 17.5 mm in length (13). Not enough clams have yet been dissected to determine the minimum size at sexual maturity nor the average size. The fact that this clam becomes sexually mature and is self propagating as an individual will make control measures even more difficult.

Reproduction

Kawabata (4) states that sandai spawns in April, May, and June.

Corbicula leana has a spawning season from June to October (16). Corbicula manillensis has a spawning season from January to July in the Philippines (13). In Taiwan, Corbicula fluminea has a spawning season from June to September. The spawning season for the Tennessee River clam extends from at least July to November. There is an indication that an even longer spawning season is involved.

Ovulation and Fertilization (See Figures 10 and 11)

The ova pass from the reproductive ducts, where fertilization probably takes place, into the suprabranchial chambers, thence, into the water tubes of the inner pair of gills. According to Villadolid and Rosario (13):

> "The small, probably immature ova are hexagonal when still in the follicles. They measure from 20 to 60 microns in diameter. The large, probably mature ova appear to be pear shaped with a distinct nucleus and nucleolus. They measure from 70 to 160 microns at widest diameter." (manillensis)

The inner pair of gills becomes greatly distended, as a result of hundreds of developing larvae, and function as marsupia. Ova, from 50 to 120 microns in diameter, have been found both in the ovaries and inner gills of specimens taken on February 1, 1961, from the Cumberland River.

The spermatozoa of manillensis are shaped like a comma and are not constricted. Measurements were not given by Villadolid and Rosario (13). These are identical in outline and form with those taken in gonad smears from preserved specimens averaging 12 mm in length and taken from Pickwick Dam tailwater in July 1960. The spermatozoa of leana, as figured in Cahn (12), are kidney shaped with a long tail piece.

Larval Stages: The Trochophore (See Figure 12)

After fertilization, cleavage, and the formation of the entoblast, the larva develops cilia. This ciliated stage is known as the trochophore. Other major invertebrate groups, beside the Mollusks, which may possess a trochophore stage are the Crustacea and the Annelida. The great similarity in these three groups during the trochophore stage has led some to assume a common ancestor, the trochophore. There is much disagreement over this assumption. The ciliated trochophore develops within the inner gills which function as marsupia. The cilia move in a rythmic wave propelling it about when removed from the gills. The trochophore was found in large numbers in specimens 6.5 mm to 15 mm in lenght that were taken February 7, 1961, from the Cumberland River. The larvae are spherical with a row of cilia around the middle. They were from 15 to 21 microns in diameter.

Larval Stages: The Veliger (See Figures 13 and 14)

The veliger larval stage follows the trochophore stage. During the veliger stage, the prodissoconch is formed, which in some species is distinguishable from the larval shell which is quite brittle. The velum, the foot, and sometimes a byssus are noticeable features of the veliger. The velum, according to Davis (9), is used in locomotion as well as food getting. Miyazaki (8) states that young Corbicula leana have a velum, but it is useless as a swimming organ. His "D" stage veligers were 0.237 mm in length and 0.193 mm in height. These are incubated in the gills of the adult. The veligers which were tightly packed in nearly all the adults taken July 1960 from Pickwick Dam tailwater were indistinguishable from the veliger figured by Davis. These veligers measured 0.22 mm by 0.20 mm in close agreement with Miyazaki's "D" stage veliger of leana. His veligers had well-developed, functional gills; a foot; and a byssus. The veligers that we obtained were preserved and unsuitable for description other than measurements and shell description. The dissoconch or larval shell of the veliger was grannular and quite brittle. The veligers of the Tennessee River clam, mentioned below, did not use the velum for swimming.

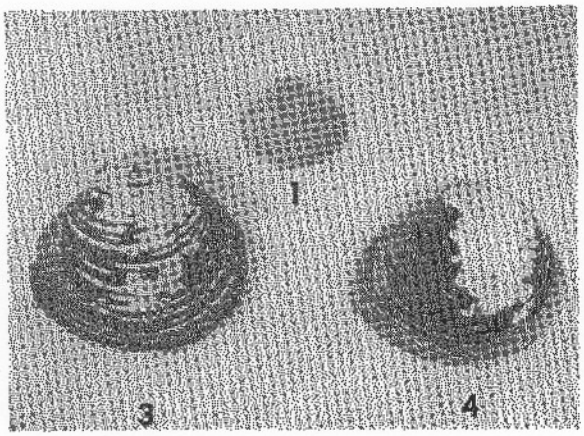
Post Marsupial Stage

The veliger of leana begins bottom life immediately after discharge from the adult. When it reaches a length of 1.5 mm, brown pigment appears on the

umbo (8). Adults collected from New Johnsonville on Kentucky Lake were placed in an aquarium. Larvae which were discharged into the water were isolated. They measured 0.22 mm by 0.20 mm and had a granular dissoconch like the veliger. By the time the larvae reach 0.90 mm, the characteristic growth rings have appeared.

Key to Figures 1-14

1. Left valve, Pickwick Dam Tailwater, actual size.
2. Left valve, Wheeler Reservoir, Alabama, actual size.
3. Right valve, Trotters Ferry, actual size.
4. Right valve, Pickwick Tailwater, actual size, showing severe erosion.
5. Right valve, Bonneville Dam, Oregon, actual size.
6. Left valve, Pickwick Tailwater, actual size.
7. Left valve, Pickwick Tailwater, actual size.
8. Right valve, Bonneville Dam, Oregon, actual size.
9. Left valve, Stewart County, Cumberland River, actual size.
10. Spermatazoa from Pickwick specimens, July 1960. (scale 20 microns)
11. Mature ovum from Cumberland River specimen, February 1961. (scale 120 microns)
12. Trochophore from Cumberland River specimen, February 1961. (scale 21 microns)
13. Veliger from marsupia of Pickwick specimen, July 1960. (scale 0.22 mm.)
14. Veliger from *manillensis* at age of extrusion, (after Villadolid and Rosario, very highly magnified).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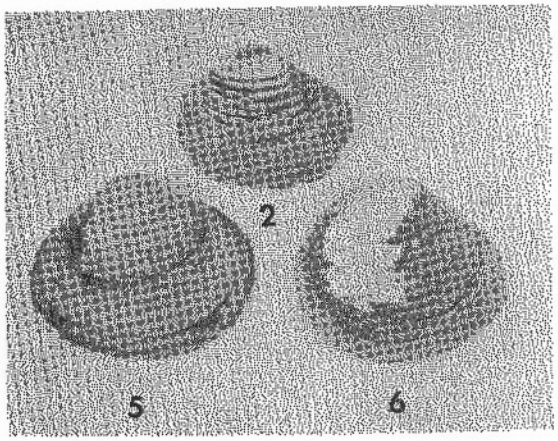
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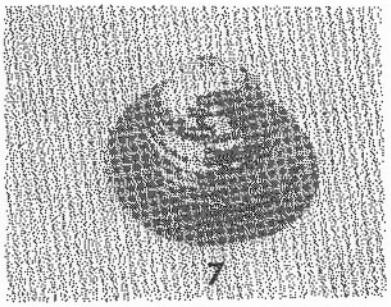
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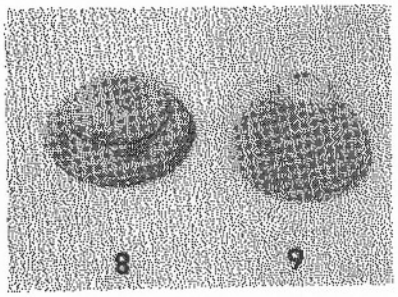
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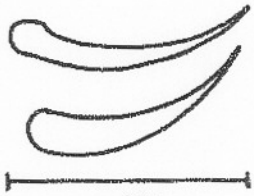
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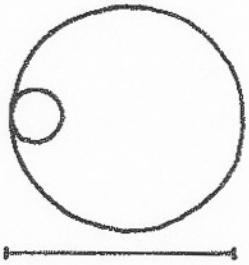
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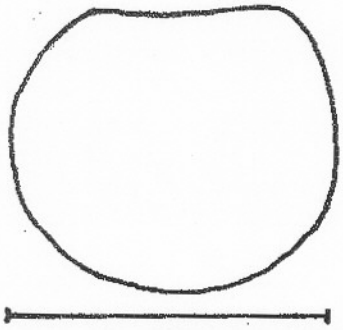
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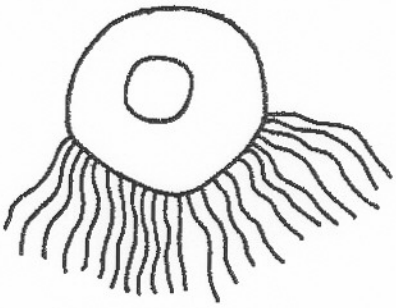
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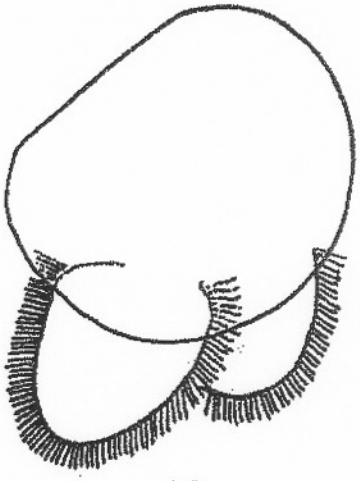
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ECOLOGY

Substrate

Corbicula fluminea has been reported from substrates of sand or mud or a combination of the two in Formosa (3). Ingram gives the habitat as sand and mud in California (2). A preference for sandy bottoms rather than silty ones was noticed in Formosa (3). In Arizona they were found in sand in an irrigation canal (1). Corbicula sandai in Japan is reported to inhabit substrates composed of sand with an admixture of pebbles, with a marked distaste for muddy substrates (12). Corbicula leana is found on sandy bottoms and japonica on bottoms that are 70 per cent sand and mud in Japan (12). Corbicula manillensis was taken in abundance from "shallow strips of sandy banks" (13). The Tennessee River clams have been found in greatest numbers in gravel and rocks. Some taken in the New Johnsonville section were in mud. Rock and gravel is preferred. In the section from Pickwick Dam to the Perryville Bridge (mi. 206.3 to 135.0), clams are found in great abundance in gravel, stones, and under small to large rocks. The "under rock" habitat seems to be unique. The Cumberland River clams were taken in gravel dredging operations. The Tennessee River clam is able to adapt to a wide variety of ecological conditions. The members of this genus are ordinarily found in sand or mud or a combination of the two. In the Philippines, Villadolid and Rosario (13) felt that manillensis did not occur at higher elevations in Molawin Creek, since the bed of the creek was made up of hard rocks and boulders. The clam at Pickwick Dam tailwater is quite common among the large rocks and boulders, being found beneath these and in the crevices as well.

Water Quality and Flow

Clams belonging to the genus Corbicula are typically fresh-water, but several species such as formosana and japonica prefer brackish water (3, 8). Sandai requires at least a weak current, but it is found in fast flowing water as well. Leana was found in Japan in clear brooks and ponds.

The Tennessee River clam is subject to much fluctuation in water levels. At Pickwick tailwater, the clam was abundant in moist gravel (with some sand) several feet back from the receding water level. Those examined from this habitat still possessed the crystalline style. They are able to resist extreme conditions for indefinite periods. Mr. Bill Turner, of the Tennessee Game and Fish Commission, collected over 50 Corbicula below Pickwick Dam. These were placed in a galvanized gallon pail in water and left in an attic for a month. At the end of this period, the water was foul with the decaying bodies of most of the clams. However, eighteen survived this rigorous treatment. This is another indication of their hardy nature.

The nature of the substrate has a marked effect on the clam. In California, those found in sand are generally ovate; whereas, those in mud may be trigonal (2). Kuroda (14) reported that sandai changed from the original triangular to round, due to the influence of environment when it was transplanted.

FOOD AND FEEDING

The Tennessee River clam feeds on phytoplankton, judging from dissections of the mature clams. How much it will compete with the native mussels remains to be seen. This clam, in common with the Unionid clams or mussels, possesses the structure called the crystalline style. According to Pennak (27):

> "The anterior part of the intestine of the Unionidae has a lateral diverticulum, or groove, containing the curious crystalline style. This is a cylindrical structure of a hyaline, milky, or brownish color and of a dense gelatinous consistency. During normal feeding activities, it is revolved on its long axis by the ciliary epithelium of the style sac. The anterior end of the style usually projects into the stomach where it rubs against a cartilage-like shield and is constantly being eroded away. This erosion liberates a polysaccharide-digesting enzyme and is thought to function also in separating food from foreign particles. The style disappears during periods of starvation but is regenerated as a response to ingestion. It is formed only slowly at low temperatures."

Future investigations of the feeding habits could well utilize a study of the crystalline style as a criteria of periods of feeding and periods of rest.

ASSOCIATED FAUNA

The benthic fauna associated with Corbicula in the Pickwick Dam tailwater has been discussed and listed in a previous paper. The principal invertebrates were colonial and sessile-attached, including sponges, bryozoans, and hydroids (5). Other benthic organisms found associated with Corbicula in large numbers were midge larvae of the family Tendipedidae, Trichoptera, and molluscs. The habitat presented to potamobenthic organisms below Pickwick Dam is unique. The tailwater below the dam is particularly subject to a controlled discharge. There is much variation in flow as well as in current. The organisms predominant in this assemblage of species are remarkably created for this particular habitat. Further downstream in the vicinity of New Johnsonville, the river takes on many characteristics of a lake due to the presence of Kentucky Dam. In this lower section there is also a fluctuation in water levels due to the annual schedule of draw down, etc. The section of the Cumberland River where Corbicula has been found is also subject to fluctuations in flow and level due to impoundments. The U. S. Corps of Engineers, Barkley Dam on the lower Cumberland, will create further profound faunal changes.

Colonial Sessile-Attached Associates

Bivalve molluscs furnish a specific "Kleinbiotopen" for several of the organisms making up this group. No valves of Corbicula have been observed, representing either live or relic, with sessile-attached invertebrates. Urnatella gracilis Leidy is commonly found on mussel shells. On Kentucky Lake this form was found on mussel shells as well as rocks in 1960. According to Pennak (27), this species is found only in the Meuse River in Belgium and in scattered localities in this country. Rogick (31) cites records for Pennsylvania, Ohio, Michigan, Indiana, Kentucky, Texas, Iowa, and Virginia. Records in the files of the Stream Pollution Control Board indicate that it is widely distributed in the Tennessee River system. Another bryozoan which has been found associated with mussel shells on Kentucky Lake is Pottsiella erecta (Potts) (Fig. 16). It was originally collected from southeastern Pennsylvania in 1884 and according to Pennak has never been found since except for a questionable Texas record. Rogick (31) gives the following records: Tacony Creek, Schuykill and Deleware Rivers, Pennsylvania; Lake Dallas, Texas; James River, Virginia; and Loosahatchie River, Tennessee. Pottsiella was found on rocks and on a relic valve of the Pigtoe Mussel, Fusconaia undata (Barnes) in 1960 on Kentucky Lake. Colonies were found at Eva, Harmon Creek, and New Johnsonville. Rogick (31) reports that it is photophilic and found on sponges and stones. The New Johnsonville specimens were examined in both a contracted and expanded condition. Some of the zooecia had lateral buds.

Mollusc Associates

The mollusc associates of Corbicula on the Tennessee River have been listed by Sinclair and Ingram (5). Molluscs found in this section of the Tennessee

River have been listed in several papers, including Dr. J.P.E. Morrison (32) and Dr. Van der Schalie (7). The mollusc species collected with Corbicula in dredging operations on the Cumberland River in Stewart County were Quadrula quadrula Rafinesque and Elliptio crassidens (Lamarck).

Zooplankton

Samples collected during July 1960 below Pickwick Dam contained large numbers of the remarkable Leptodora kindtii (Focke) (Fig. 15). This transparent cladoceran is common in lakes of the northern United States and northward. It is one of the largest cladocerans (which includes Daphnia) reaching a length of 18 mm. Leptodora is limnetic and nocturnal.

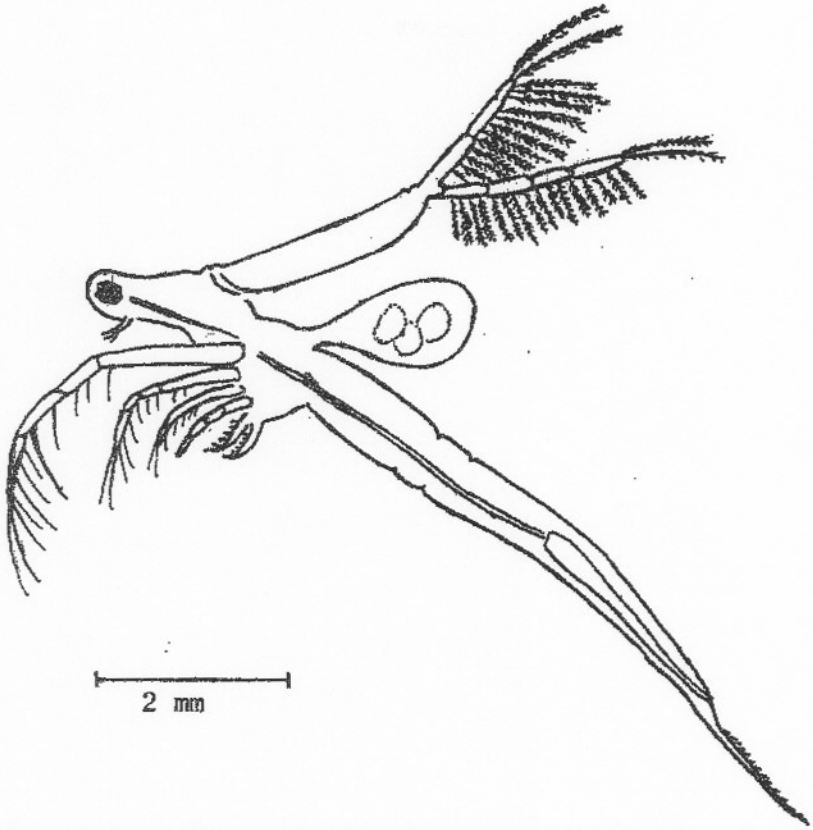

Figure 15. Leptodora kindtii (Focke) after Birge

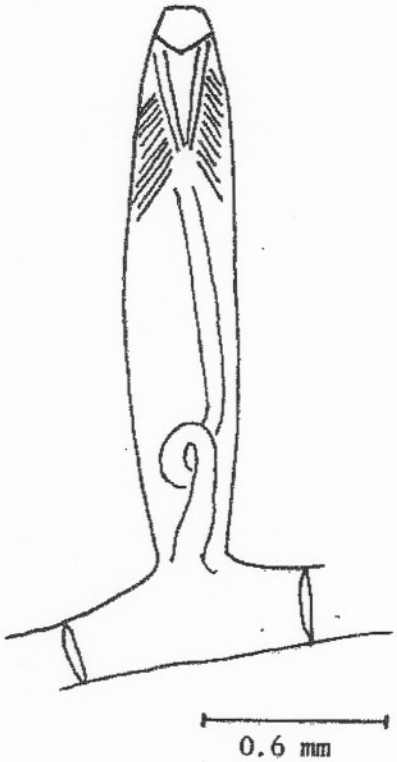

Figure 16. Pottsiella erecta (Potts). New Johnsonville, Kentucky Lake (contracted)

COMMON MOLLUSC PREDATORS

In planning an over-all study of the Asiatic Clam, it is of particular interest and value to evaluate the common mollusc predators with which it will come in contact in its new environment.

Of 1,988 waterfowl killed during hunting seasons 1950-1954 on Reelfoot Lake, Tennessee, clams were found in 189 specimens. These made up 1.37 per cent of the total food consumed by these birds as determined from the analysis of their gizzard contents. The principal bivalves utilized by these birds were fingernail clams, Musculium, Pisidium, and Sphaerium (18). The adaptibility of the Asiatic Clam enhances the possibility of its replacing the Sphaeridae in the Tennessee River system or at least being a serious competitor. It was related to the authors by Mr. Calvin Barstow**, that in the vicinity of New Johnsonville, Tennessee, on Kentucky Lake, that more ducks have been observed in the mud flats than has been previously noted in prior years. Mr. Barstow plans to obtain data during the 1961-62 duck hunting season that may show that ducks are inhabiting the mud flat areas because of the available food supply in terms of the Asiatic Clam. It was noted in the Reelfoot study that diving ducks' gizzards contained more animal material than did puddle ducks' gizzards (18); however, with the extensive mud flats on Kentucky Lake and the apparent adaptability of the Asiatic Clam, it is quite possible that, under these conditions, puddle ducks will utilize the Asiatic Clam, due to its abundance and ready availability.

Yocum and Keller (19), in their California study of waterfowl food habits, found that of seventy food items Pelecypoda (unidentified clams) were third in order of frequency of occurrence with a per cent of volume rate of 6.1 per cent. This percentage represents an index of the importance of this food in the local waterfowl population. This percentage utilization of clams is significantly larger than that reported from Reelfoot Lake and probably represents the greater availability of this item in the California habitat.

Ingram (3) states that: "Some specimens now in the U. S. National Museum were taken from the stomach of a Sturgeon that was caught in the Columbia River, near Bonneville Dam in 1950."

Other natural enemies include the flatworms which consume all sorts of material including young, fresh-water clams (17). Relative to this, when making our biological investigation in Kentucky Lake, it was observed that Dugesia tigrina inhabitated almost every stone and piece of debris, in great abundance. The presence of Corbicula may explain why the large population of Dugesia tigrina exists on Kentucky Lake. The Asiatic Clam is abundant in habitats where the Dugesia exists; however, it is not limited to the marginal area, as the Dugesia is.

Sheepshead or drum (Aplodinotus grunniens) is common in Kentucky Lake. It is well known that these fish have a common diet in the adult life, of mollusc (17). It was observed during the 1960 surveys on Kentucky Lake that commercial harvesting of mussels is common; therefore, the drum already have an available food supply and are not dependent on the Asiatic Clam by any means. But the small size of the Asiatic Clam, and its abundance, place it as a prime food source for the drum.

**Related in conversation

Carr (20) reports the food habits of the common map turtle (Graptemys geographica) (Le Sueur). Of particular interest is the map turtle's preference for large bodies of water, especially lakes. As a predator, it has a marked preference for molluscs. Carr, in reference to Garman's work in 1890 on this species, states that, "In all specimens examined by Garman in Illinois, the food was exclusively molluscan -- in the young consisting of Valvata tricarinata and other thin-shelled species, and in the adult, of larger, thicker-shelled forms." (20) He further summarizes the literature relative to food habits of map turtles and includes food items found by other writers which are: crayfish, snails, aquatic insects, fish, carrion, water mites, clams, and plants. He gives Lagler's summary of analysis of contents of stomachs and colons of map turtles. In this table summary we find that clams' frequency of occurrence is 8.3 per cent and constitutes 1.3 per cent of the total volume analyzed from the stomachs. In the colon clams had 37.5 per cent frequency of occurrence and constituted 12.5 per cent of the total composition by volume.

We do not have population measures or estimates of occurrence on the map turtles of the Tennessee River. According to Dr. Glenn Gentry, Chief of Fish Management, Tennessee Game and Fish Commission, map turtles are abundant on Kentucky Lake. Dr. Gentry has published a number of papers on Herptology, including a paper entitled, "Annotated Check List of the Amphibians and Reptiles of Tennessee" (1955), (29).

Muskrats are also enemies of mussels, although they are ranked by Coker as energy converters of the first order (17). They would be of little consideration as predators in this instance.

In Asia, man is a common consumer of Asiatic Clams. Ingram (3), in his paper, reveals that in Formosa, families of the Taipei municipality harvest the Asiatic Clam for a living; some of the harvest is sold alive, some dried, and the small ones are used for feeding ducks. On the Keelung River in the vicinity of Taipei, ducks forage for clams.

In the Phillipines, Corbicula manillensis Philippi ("Tulla") were found to constitute part of the diet of food fishes found in Laguna de Bay. Also in this area, fishermen use the meat of this clam as bait in hook and line fishing. In the Laguna de Bay area, Corbicula manillensis is used extensively as food for domesticated ducks, Anas Bascher Linn (13).

"The tulla is used also for food by the native inhabitants, expecially by the laboring class. In some places in Laguna de Bay regions, the shells are burned for the manufacture of commercial air-slaked lime." (13)

There is no published data available to confirm that any of the above predators of molluscs are preying on the Asiatic Clams in Tennessee, but the above information does outline the ecological possibilities and implications.

The utilization of Corbicula in Tennessee has been only briefly encountered. In a deep water fish population study on Kentucky Lake, Tennessee, mile 96.7, the junior author examined intestinal contents of some catfish: the blue cat, Ictalurus furcatus (Le Suer); and probably the channel catfish, Ictalurus punctatus Rafinesque. This aforementioned examination revealed an extensive utilization of the Asiatic Clam as a food source. The clams were taken into the digestive system whole and the tissue digested out. The shells were left intact and expanded, as is typical of these clams; when they are killed and subsequently relaxed, they expand partially

and remain in this condition. The shells were about 5 mm in length and smaller (no measurements were made in the field). The fish examined weighed approximately one-fourth kg each. All fish taken during the population study were measured, weighed, and identified by the fisheries biologist. We plan to study further the utilization of the clams by fish and waterfowl. Since we can closely approximate the date which the Asiatic Clam was introduced to the area, it offers an excellent opportunity to study its succession in the food habits of the resident fish population.

Cahn (12), in his interesting work on "Clam Culture in Japan," gives us an insight into the possibilities of utilizing Corbicula fluminea as a source of food. The following will probably be of interest to the gourmet.

Corbicula sandai Reinhardt is of very good eating quality when taken from sandy or sandy-pebbled areas. "The meat of this species has the best flavor just before spawning ..."

Corbicula leana Prime is either eaten fresh or canned. "The shell is frequently used for making shell toys or is made into fertilizer ..."

Corbicula japonica Prime is of best quality when taken in winter. "The Japanese believe that soup made from the meat of this species is an effective remedy for jaundice ..."

THE NUISANCE ASPECTS AND DISTRIBUTION

One of the most important and most interesting aspects of the Asiatic Clam is its involvement in water supplies. In the following statements, one can see the past, present, and potential nuisance of the Asiatic Clam in industrial, agricultural, and municipal water supplies.

Ingram (3)* gives us a good account of the Asiatic Clam as a potential pest in California water supplies and its distribution in California, Washington, Arizona, and Oregon.

Ingram and Bartsch (15) give additional information on Corbicula fluminea Muller and list their distribution as Arizona, California, Idaho, Oregon, and Washington.

Sinclair and Ingram (5) further our knowledge on the distribution of Corbicula fluminea in a paper which relates its occurrence in the Tennessee River below Pickwick Dam on Kentucky Lake at miles 206.7, 205.3, and 203.3.

In our effort to ascertain the extent to which the Asian Clam had appeared in Tennessee and adjoining areas, we contacted Mr. M.A. Churchill, Chief, Stream Pollution Control Staff of the Tennessee Valley Authority. He kindly furnished us further information, which was very much appreciated, on the distribution of the Asiatic Clam, as it relates to the pest activity of Corbicula in some TVA steam plants.

The TVA has experienced considerable nuisance by the Asiatic Clam at Johnsonville Steam Plant, Kentucky Lake (mi. 100.5), Colbert Steam Plant on Pickwick Lake (mi. 245) during 1960, and the Shawnee Steam Plant at Paducah, Kentucky, on the Ohio River (mi. 94.6) during the summer of 1957. They have experienced no serious difficulties but have had a large number of small cooling-water pipes to become sluggish with clams at all of the stations. They reported taking "two wheelbarrow loads from the number seven condenser inlet water box. They had plugged the inlets on about half of the tubes." Most of the clams were small and "ranged from about 1/2 to 7/8 inch in size."

They found some clams throughout the raw water service and the fire protection systems.

At present, "the only control measure instituted is flushing the lines at regular intervals." He does not state the degree of success. They plan to chlorinate the water as a control measure since it is the only "practical approach to the problem at this time."

In a personal inquiry by the senior author to Dr. Dee Dundee, Department of Biology, Louisiana State University in New Orleans and Dr. Dundee's subsequent reply, Dr. Dundee relates the incidence of a sand and gravel company in Decatur, Alabama, with Corbicula. They had some problems with Corbicula "relating to the setting of their cement." This closely resembles the difficulty that a sand and gravel company in Nashville, Tennessee, had with the Corbicula. In conversation with a

*Refer to this paper for nuisance activity of C. fluminea in California.

representative of the company, it was related that in pouring a strip of concrete the numerous Corbicula in the gravel used migrated to the surface. It seems that the constituents of the concrete either irritate the clam, or it naturally migrates to the surface and of course creates a nuisance.

The authors have in their possession Corbicula taken by this gravel company from the Cumberland River at mile 109.8. The company had to abandon operations near Palmyra, Tennessee, on the Cumberland River because Corbicula were so numerous. This finding of Corbicula constitutes a new and easternmost record for its distribution. Although it was known that the clams existed on the Cumberland River prior to February 1, 1961, this is the date on which the first official collection was made. A few days earlier by telephone, this nuisance aspect had been reported. Examination of these specimens revealed that they were at least two years old. This record will probably be short lived since the Corbicula already occur in the Ohio River.

Specimens from Wheeler Reservoir, Alabama, sent by Mr. John T. Gallaher and collected during 1960 were examined.

To summarize the distribution then, specimens have been collected from Alabama, Tennessee*, and a reported nuisance by Corbicula at Shawnee Steam Plant on the Ohio River at Paducah, Kentucky.

Contrary to our view, clams of the genus Corbicula are looked upon as essential to the economy in certain areas of Asia. It may be due to the fact that they have been introduced into a new habitat that contributes or is responsible for its nuisance activity in the United States. From 62 to 204 clams were found "per square foot of clam bed" in Laguna de Bay March 1929 to February 1930 (13). At "Molawin Creek" May 1929, August 1929, and January 1930, "the average number of clams per square meter of clam bed" ranged from 45 at station 9 to 235 at station 1 (13). These figures indicate that the clams exist in these areas as densely as they do in the habitat to which they have been introduced. From the information now available in this report, it does not follow that the Asiatic Clam is detrimental to its faunal associates, in its new habitat, but is a nuisance only in municipal, industrial, and agricultural water supplies. Also, in sand and gravel operations it can definitely be considered a nuisance.

Villadolid and Rosario (13) concluded from the facts that they collected on C. manillensis in Laguna de Bay that legislative measures would be necessary for the conservation of this bivalve. This reflects the magnitude of importance of this clam to the economy in the area studied.

Cahn (12) reports that in Japan Corbicula sandai is protected by law; there is a closed season in late spring on this species and a size limit prohibiting the taking of shells less than 1.5 centimeter on any occassion.

In closing this chapter, it may be stated that nowhere in the available literature was reference made to Corbicula as a pest or nuisance in Asia. However, in California and the West it has proved itself a nuisance for some years. It now is a pest in certain TVA steam plants in the Tennessee area and also in one industrial plant water supply at New Johnsonville, on the Tennessee River at

*See Table III for distribution of Corbicula fluminea on Kentucky Lake, Tennessee.

TABLE III

Corbicula fluminea Distribution on Kentucky Lake

Sta. No.	River Mile	July 1960[x]	October 1959[xx]	Frequency of Occurrence
1	206.3	x	XX	abundant
2	205.3	x	XX	abundant
3	203.3	x	XX	abundant
4	198.1	x	--	abundant
5	190.0	x	--	few, abundant on shore in November, 1960
6	157.8	x	--	abundant
7	135.0	x	--	abundant
8	111.0	x	--	*Corbicula* relic only
Observation Nov. 1960	101.5, at old Ferry landing	x	--	abundant
9A	101.0	--	--	none
9B	98.5	x	--	few
10	96.6	--	--	none
Observation Nov. 1960	96.7	x	--	few
11	89.0	--	--	none
12	78.4	--	--	*Corbicula* relics only
13	66.3	--	--	none

mile 98.5. A sand and gravel operation had to be moved on the Cumberland River due to this clam. The prospects are that this clam will extend its range rapidly due to the distribution by dredging operations and by curious individuals carrying them home from the river banks. Kentucky Lake is visited extensively as a resort and fishing area. Corbicula may be eventually controlled by its common enemies. It is not ecologically nor economically possible to eliminate it from its new habitat at the present time.

INTRODUCTION AND SPREAD

This clam could have easily been introduced from the disposal of aquaria contents (5). An inquiry to local dealers in aquaria supplies failed to disclose specimens. A further search of dealers in other localities might be enlightening. The introduction of fluminea in California has not yet been accounted for. It is likely that no one source will be incriminated for its introduction into the Ohio drainage.

The earliest available record as mentioned under distribution places the clam on the Ohio River near Paducah, Kentucky, in 1957. Indications are that the clam has migrated, with the help of man, in an upstream direction as far as Montgomery County, Tennessee, on the Cumberland River and as far as Decatur, Alabama, on the Tennessee River. The clam has had every opportunity to spread with navigation and dredging enterprises.

RELATIONSHIP OF MUSSEL SPECIES TO CARBONATE HARDNESS

Shoup (24) concluded from his work on Tennessee streams that the Gastropod population is relative to total alkalinity in that, "For the most part, the more alkaline streams yielded greater volumes of collections of each species present." In relating Shoup's findings to the Pelecypoda, we find that species and subspecies of Pelecypoda occurring in the Cumberland, Tennessee, and Duck Rivers may be related to total carbonate hardness (Table II).

TABLE II

Total Mussel Species & Subspecies		Average M.O. Alkalinity	Average Total Hardness	Type Excess Hardness
Cumberland River	83 (25)	87	99	Noncarbonate
Duck River	63 (26)	89	74 (28)*	No excess
Tennessee River	51 (7)	61	70	Noncarbonate

*Consult Standard Method for the Examination of Water and Wastewater, for hardness-alkalinity relationships. All the hardness in this instance is due to carbonate as differentiated from noncarbonate hardness.

TABLE I

Chemical Analysis

	pH	M.O. Alkalinity as ppm $CaCO_3$	Hardness as ppm $CaCO_3$	Ca as ppm $CaCO_3$
Dover**				
	7.7	88	170	108
	7.5	101	94	71
	7.3	103	56	54
	7.5	108	77	63
	7.9	102	135	114
	7.8	49	86	60
	7.5	60	77	60
Average	7.6	87	99	76
New Johnsonville*	7.8	84	96	48
	7.9	54	60	44
	8.4	61	64	42
	9.3	61	74	48
	9.3	47	58	37
Average	8.5	61	70	44
Bonneville, Oregon (23)				
Average		63 (40-78)	67 (55-81)	
Duck River***				
Average		89 (74-108)	74 (56-86)	

*Collected by monthly composite, August-December 1960, Tennessee River at New Johnsonville, Tennessee (mi. 99.6)

**Collected as grab samples, January 13, 1958-September 13, 1960, Cumberland River at Dover (mi. 88.4)

***Collected from 6/18 - 6/27/56, Average of 43 samples, taken at 22 stations from mi. 62.2 - 210.3.

The above information provided by the Chemistry Laboratory, Tennessee Department of Public Health, Stream Pollution Control Board; Mr. O. D. Keaton, Chief Chemist.

Data (23) completed on the Columbia River below Yakima River at Bonneville, Oregon, shows the average alkalinity mg/l for 43 samples taken in 1957-1958 to be 63, and the average hardness mg/l of 15 samples in 1958 to be 67. These averages are almost identical for the values of samples taken from the Tennessee River, Table I; whereas, the average values for the Cumberland and Duck River stations are higher.

MOLLUSCACIDES

It seems worthwhile at this point to summarize the work on mollusk control by chemical means. Ingram (3) is the only author that deals with the present knowledge of mollusk control as relates to Corbicula. The following is a summary of his information on clam control. Copper sulfate was effective at 750 ppm concentration with a 48-hour exposure time. It was found that chlorine gave a quicker kill; but he points out that both chlorine and copper sulfate in the high dosages required to kill clams will corrode iron structures and also the use of copper as delineated by USPHS (30), which is that copper as Cu should not exceed 3 ppm. Ingram states that, "In 1953, 2,500 ppm of a relatively inexpensive aromatic solvent was found to be effective and stated to be safe." Some control can be obtained with coal-tar naptha at 2,500 ppm.

Further study of the Asiatic Clam must be made in relation to the development of adequate controls. Desirable control must leave the water palatable and non-toxic both to humans and the aquatic environment.

It is hoped that this paper will stimulate further observation as to the distribution of Corbicula and in the development of control procedures.

CONCLUSIONS

Thus far, we have learned much valuable information concerning the Tennessee River clam. Research into the life history, ecology, and control of this clam is imperative. The clam is already a decided nuisance and a threat to water quality. A method of control must be found. The cost of such a program will not be light. As far as can be ascertained, the required research has not been planned nor has any real effort been carried out. It is expected that this clam will be found eventually in the Tennessee River and its major tributaries above Chattanooga. It is also expected to advance into the Duck and Elk Rivers as well. It is only a matter of time before it will come into conflict with water use at other industrial treatment plants, municipal treatment facilities, and irrigation facilities. The life history, with the larvae incubated within the gills of the hermaphroditic adult, of this particular species will prove to be less vulnerable to ordinary control methods.

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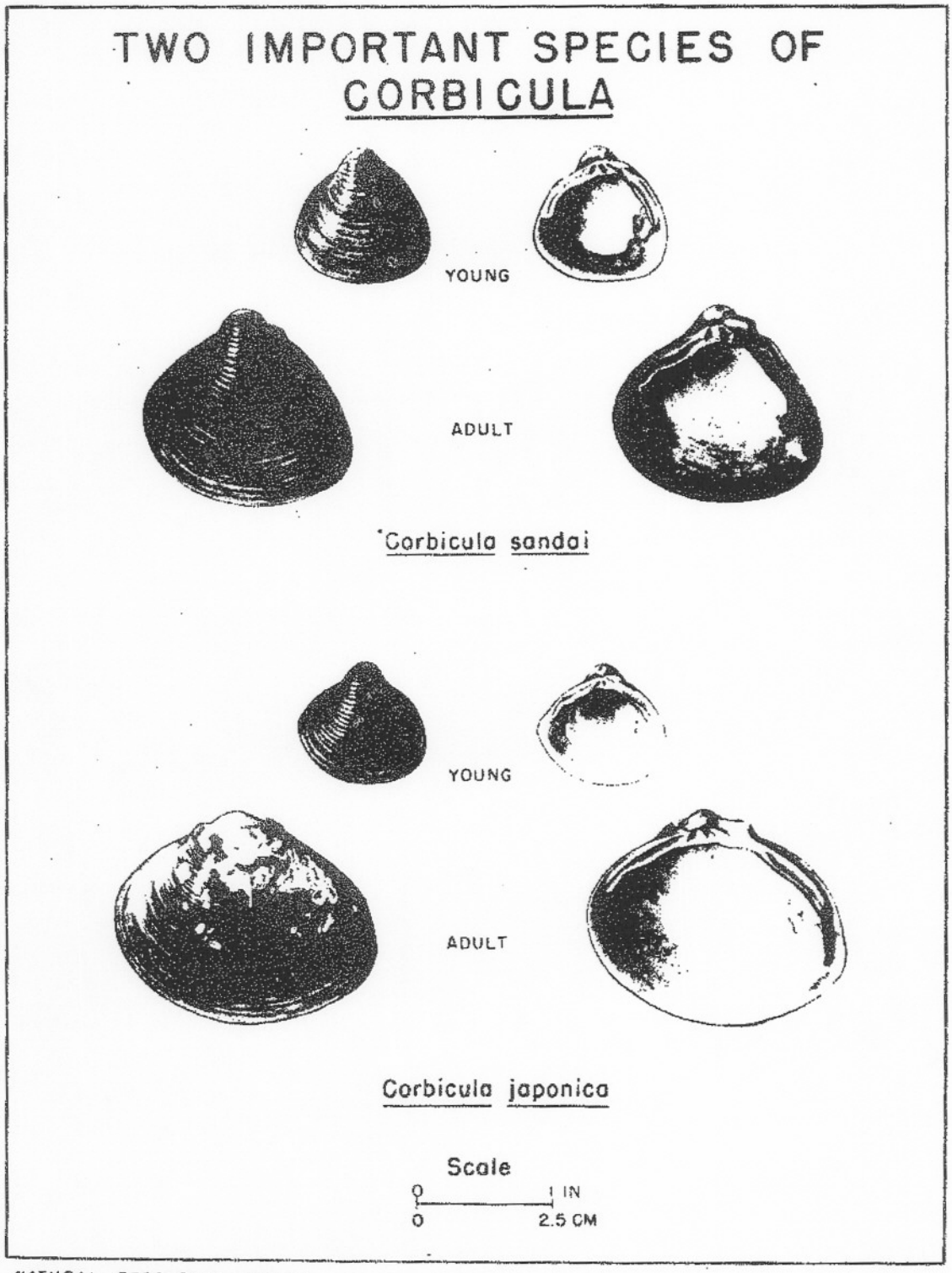
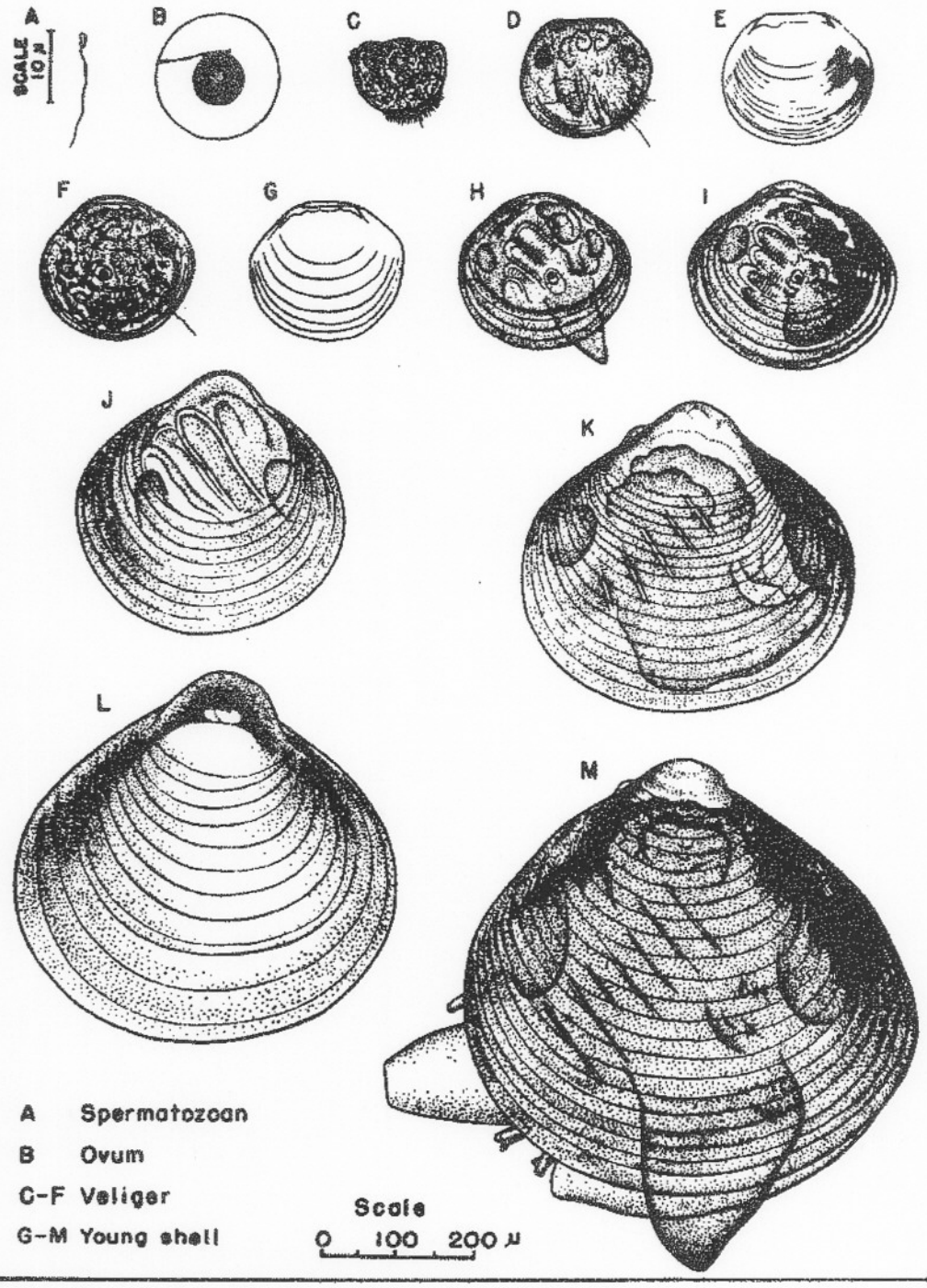
APPENDIX

The following two plates have been taken from Cahn, A. R. 1951. Clam Culture in Japan. Gen. Headquarters, Supreme Commander for the Allied Powers, Natural Resources Section. Report no. 146:1-103. These figures are the work of Messrs. Saburo Satouchi and Katsuyuki Kita. Cahn's report is quite comprehensive and gives details on life history which have been most useful in the preparation of this paper. The original figures in Cahn's report provide an interesting comparison; for this reason they are included in this report. In Cahn's report the titles of figure 32 and figure 9 have evidently been transposed.



NATURAL RESOURCES SECTION

Figure 31

DEVELOPMENT OF CORBICULA LEANA