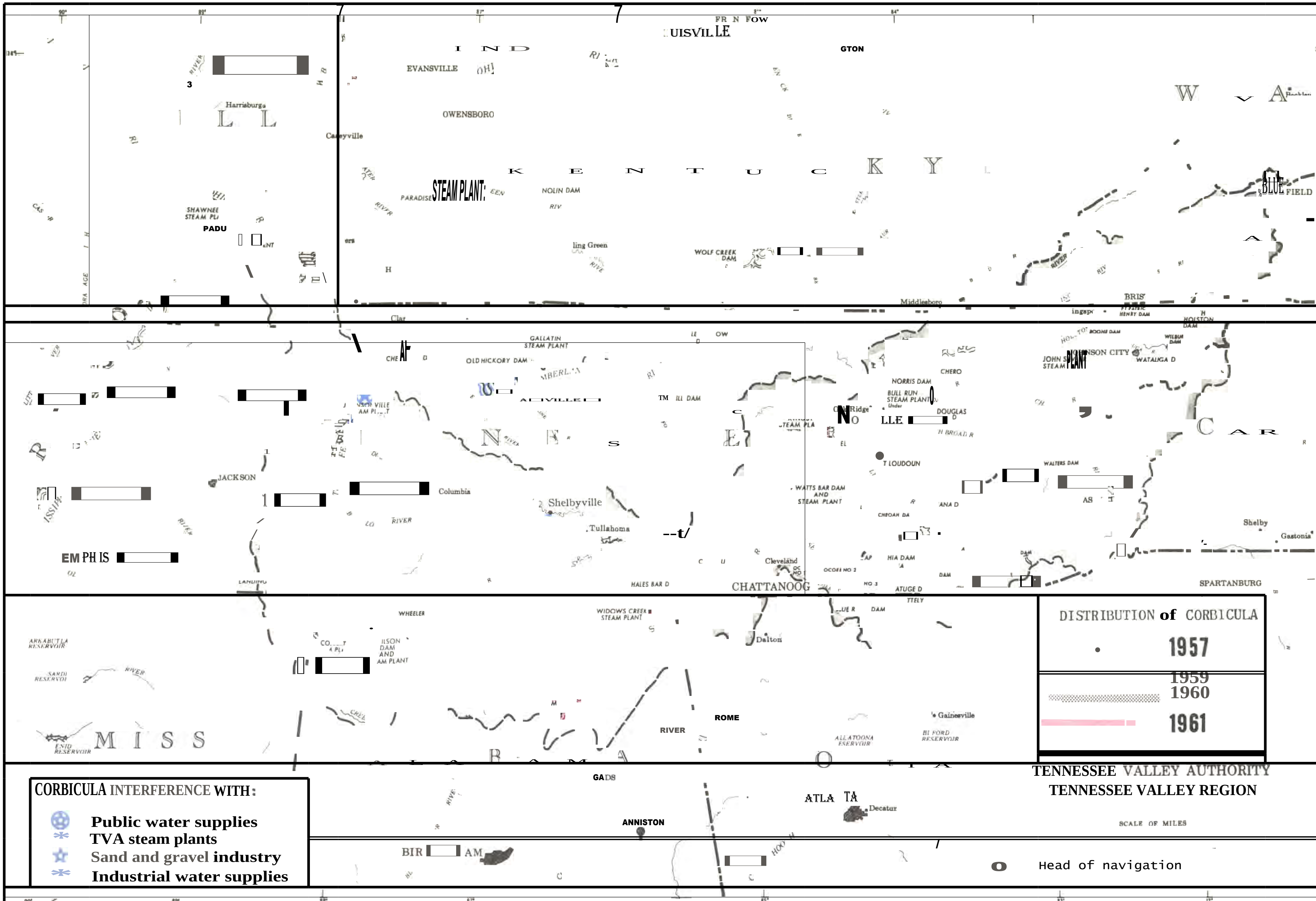
FURTHER STUDIES ON THE INTRODUCED ASIATIC CLAM CORBICULA IN TENNESSEE

TENNESSEE STREAM POLLUTION CONTROL BOARD

TENNESSEE DEPARTMENT OF PUBLIC HEALTH

1963


DISTRIBUTION of CORBICULA
1957
1959
1960
1961
TENNESSEE VALLEY AUTHORITY
TENNESSEE VALLEY REGION
SCALE OF MILES
CORBICULA INTERFERENCE WITH:
Public water supplies
TVA steam plants
Sand and gravel industry
Industrial water supplies
Head of navigation
EVANSVILLE
OWENSBORO
Harrisburg
Caseyville
SHAWNEE STEAM PLANT
PADU
PARADISE
STEAM PLANT
NOLIN DAM
WOLF CREEK DAM
Middlesboro
BLUEFIELD
K E N T U C K Y
GALLATIN STEAM PLANT
OLD HICKORY DAM
JACKSON
Columbia
Shelbyville
Tullahoma
NORRIS DAM
BULL RUN STEAM PLANT
CHEROKEE
DOUGLAS
WATTS BAR DAM AND STEAM PLANT
JOHNSONVILLE STEAM PLANT
WATAUGA D
FT LOUDOUN
WALTERS DAM
Shelby
Gastonia
SPARTANBURG
Cleveland
CHATTANOOGA
HALES BAR D
WHEELER
WIDOWS CREEK STEAM PLANT
WILSON DAM AND STEAM PLANT
Dalton
ARKABUTLA RESERVOIR
SARDIS RESERVOIR
ENID RESERVOIR
M I S S
ROME
RIVER
Gainesville
ALLATOONA RESERVOIR
BUFORD RESERVOIR
ANNISTON
Decatur

FURTHER STUDIES ON THE INTRODUCED ASTATIC CLAM (CORBICULA) IN TENNESSEE

by
Ralph M. Sinclair, Principal Biologist
and
Billy G. Isom, Principal Biologist

Tennessee Stream Pollution Control Board
Tennessee Department of Public Health
November 1963

STATE OF TENNESSEE
STREAM POLLUTION CONTROL BOARD
CORDELL HULL BUILDING
NASHVILLE **37219**

November 18, 1963

Dr. R. H. Hutcheson, Chairman
Tennessee Stream Pollution Control Board
Cordell Hull Building
Nashville, Tennessee 37219

Dear Dr. Hutcheson:

The Asiatic Clam, which first appeared in the Ohio River Basin in 1957, has since spread over this drainage basin at a phenomenal rate. The establishment of this clam as a dominant species in a variety of aquatic habitats has been equally as phenomenal as the rapid dispersal in subdrainage basins such as the Cumberland, Duck, and Elk Rivers.

The true identity of the introduced clam in this basin was established by our biologists during a study of the bottom fauna of Kentucky Lake in October, 1959.

The initial report (81) on this clam was entitled, "A Preliminary Report on the Asiatic Clam." Since then the biological staff of the Board has carried out a program designed to increase our knowledge of the clam by continuing studies on distribution, taxonomy and variation, life history, ecology, mollusc predators, etc. To these areas, a study of control was begun with static bioassays being conducted on various life history stages.

The clams have now become a real nuisance to sand and gravel operations, industry, steam plants, and at least one municipal water treatment plant

It is a matter of regret that no remedial measures are at hand for the relief of the sand and gravel industry, however, industrial and municipal water treatment plants should be able to cope with this pest by following the recommendations in this report.

Very truly yours,

S. Leary Jones
Executive Secretary

SLJ:RMS:pam

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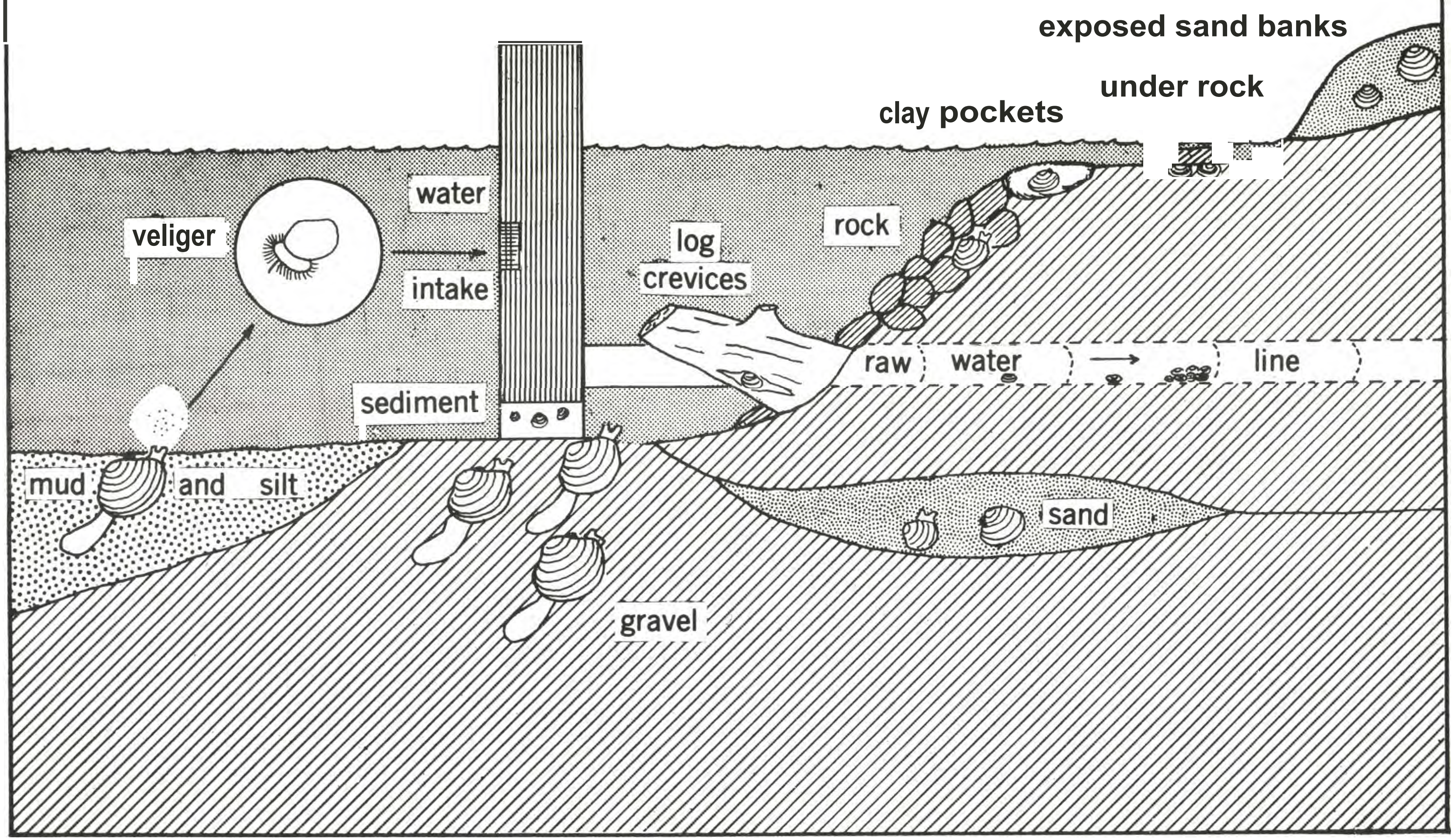
ABSTRACT

The introduced Asiatic Clam (Corbicula) was first taken in the Western Hemisphere from the north bank of the Columbia River in 1938. By 1957 it began to spread into the Ohio River Basin and is now found over virtually the entire Tennessee River and Lower Cumberland Basins Populations from scattered locations in the Ohio Basin and comparative populations from California and Arizona, were examined for the purpose of working out the life history details, the pertinent taxonomy, and control measures.

All specimens examined from the Ohio River Basin belong to one species based on sexuality and life history, and are placed in the synonomy of C. manillensis together with C. leana, C. javanica, and C. vicina.

The application of chlorine has been found to be effective as an in-plant control measure when used during the spawning season.

ECOLOGIC ASSOCIATION OF CORBICULA



FURTHER STUDIES ON THE INTRODUCED ASIATIC CLAM <u>(CORBICULA)</u> IN TENNESSEE

Ralph M. Sinclair and Billy G. Isom

INTRODUCTION

The Asiatic Clam (*Corbicula*) was first taken in this hemisphere in 1938 from the north bank of the Columbia River in the State of Washington (26). By 1948 (33) they were found widely distributed in California and by 1956 were taken in an irrigation canal in Phoenix, Arizona (15). In 1959 Dr. W. M. Ingram summarized the available literature and nuisance problems (36) and added 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 to the growing list of localities. The clam had definitely been established as a nuisance, as early as 1953, in irrigation systems in the Coachella Valley of California (36). Clams were reported as clogging pumps at (Tennessee Valley Authority) steam plants in 1960. Earlier records revealed difficulties at the TVA Shawnee Steam Plant on the Ohio River in 1957, apparently caused by *Corbicula* (Map 1).

On October 21, 1959, *Corbicula* was collected on the Tennessee River (Kentucky Lake) below Pickwick Dam in Hardin County, Tennessee (80). By 1962 they had reached Fort Loudoun Reservoir on the upper Tennessee River, the upper Duck River, Richland Creek in the Elk River Basin, and Old Hickory Reservoir on the Cumberland River (Map 1). Recent records are from as far up the Ohio River as Cincinnati; Mobile, Alabama; the Green River in Kentucky; New Orleans; and the Withlacoochee River, in Southwest Florida. The rapid spread, filling of a variety of habitats as a dominant species, and an accelerated buildup of population numbers, has been truly phenomenal.

Their threat to water supplies and sand and gravel operations shows no sign of abatement.

DESCRIPTION

(See Table 3, Plates 7, 12. and 13)

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 (fig 142) belong to the family Sphaeriidae whereas Corbicula belongs to a separate family, the Corbiculidae. Both belong to the Superfamily Sphaeriacea. The other bivalve molluscs found in Tennessee belong to the order Eulamellibranchia, which includes the families Unionidae (figs 145-148) and Margaritiferidae commonly known as mussels. The Unionid mussels are the largest of these groups and several species (including the "Pigtoe" fig. 148) are still being harvested for the pearl button trade, but mainly for export to Japan for use as nuclei in the cultured pearl industry.

This clam has been confused with the Sphaeriids and with the mussels, being called "baby mussels". The similarity is only superficial as a closer examination of the shell will show. The best field character for rapid identification, by those unacquainted with this shell, would be the lateral teeth and cardinal teeth (fig. 136). The cardinal teeth number three in each valve The lateral teeth number two on each side in the right valve, one on each side in the left valve, and are serrated.

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 usually absent from the umbones due to erosion on older specimens (fig. 134). The largest specimens collected (43 mm) showed severe erosion of the umbones (fig. 48). This again is a character which depends on environment. 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, and as mentioned by Ingram (36), this could reduce the life span of the clam. The interior of the shells is lined with a polished layer sometimes white or colored purple, which characteristically shows through the eroded umbones on the exterior of the shell The polished interior is variously referred to as non-nacreous or porcelaneous. The nacreous layer or "mother-of-pearl" is characteristic of the mussels, The nacreous layer is composed of certain organic matter and calcium carbonate. The Tennessee specimens have a hard polished layer below the pallial line, whereas the section above this line is not so highly polished.

The young shell is patterned with a characteristic dark stripe on the anterior part of the shell, 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 (fig. 180).

Size and Form (See Plates 1-6)

The largest specimens of the Tennessee River clam collected were 43 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	48
C. fluminea (=woodiana)	Canton	83
C. javanica	Java	50

Species	Locality	Length (in mm)
C. *fluminea* (?)	W. United States	55
C. *manillensis*	Philippines	38
C. *sandai*	Japan	38
C. *subsulcata*	Formosa	83

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. *Corbicula* sandai (fig 137) is a peculiar form of *Corbicula,* the umbones being high and prominent. Cahn (6) reports that the young shell has the shape of an isosceles triangle, but it becomes wedge shaped as the clam reaches maturity. The posterior and anterior margins of leana (figs. 60-73) are almost symetrical with the umbo forming a rounded projection. *Corbicula japonica* (figs. 74-87) 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.* The mature shell of *fluminea* (from Bonneville Dam, Oregon, (37-41), 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; 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 umbones are low. As it reaches maturity it becomes distinctly trigonal (figs. 96-99).

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 (fig. 100), further up the Tennessee River, are somewhat different in shape, being more elongate. The Cumberland River specimens taken in gravel were comparable with the lower Tennessee River populations.

As Kuroda points out, "The outline of shell, however, is unreliable, because it is modified as the shell grows to large and it is remarkably affected by the environments." (46),

Cahn reports that *Corbicula sandai* was transplanted from one lake to a smaller one, in Japan, and as a result the species changed from the original triangular to round due to the environment. The clams also did not propogate and their flavor was inferior to that of the original stock (7).

Pilsbry also comments on the great variety of shell shapes to be found in local populations of the same species (64).

A trigonal and oval form of *Corbicula radiata* have been found at the same locality which is a further indication that such variation is a common characteristic of the genus (65).

The shell characters which have been used in the past to errect species will be discussed more completely under Identification and Variation.

Hinge Teeth Reversal

The Sphaeriid clams have the same arrangement of lateral teeth of the hinge line as Corbicula, two pairs of laterals in the right valve and two single laterals in the left. The arrangement of the cardinal teeth of the hinge line differs in the two groups; Sphaeriids having two cardinals in the left valve, and one in the right, and Corbicula usually having three in both valves. Complete reversal of the hinge line teeth does occur in Sphaeriids. A more common arrangement in individuals with reversal of hinge teeth according to Herrington is the reversal of the laterals e.g. two posterior laterals and one anterior lateral in the right valve (29).

Eggleton and Davis found a reversal rate of 12.1 per cent in a large number of Ohio Sphaeriids examined, and of these reversals 40,5 per cent had the posterior lateral reversed (16). The posterior lateral reversal was predominant in the Muskingum system.

Hinge teeth reversals (laterals) and anomalies (cardinals) were particularly noticeable in a sample of Corbicula from Phoenix, Arizona. Out of a series of ten, of the low umbone (purple color within) form, three had the posterior laterals reversed, and three had a different arrangement of the cardinals. In the high umbone (cream color within) form five out of the fifteen displayed an abnormal cardinal tooth pattern.

A series of six Corbicula from Newman Wasteway of the Delta Mendota Canal, Newman, California had two with abnormal anterior laterals and two with abnormal cardinals. Out of thirty-five from Bethel Island, California two had the anterior cardinal missing.

A great number of Corbicula from Trotters Ferry were examined and of these one had the posterior two-thirds of the anterior laterals reversed. All Kentucky Lake specimens examined thus far have had the normal cardinal tooth pattern, which includes three in each valve. A partial reversal, the posterior laterals only, is clearly shown in a specimen of C. sandai (fig. 137)

Age and Growth Studies

Age and growth studies have not been made on the Tennessee clams. Two techniques have been used successfully in aging mussels and clams. One, is a study based on length frequency. At least one species of Corbicula has been studied using this technique (96). Clarke applied this technique to Dreissena with good results for ages up to three years (9).

The study of annual growth marks on the shell has been widely used to determine age and growth in mussels (59, 84).

The Tennessee clams do not, consistently, show pronounced annuli. One shell showing these annuli was estimated to reach 29 mm by the fourth year. Corbicula leana in Japan attains a length of 10 mm the first year and 20 mm at two years (32).

Clams from the Tuolumne River in Oregon were estimated to be in their seventh summer at 50 mm (36).

A third possibility for aging these clams would be a closer study of the posterior adductor muscle scar. These exhibit what appear to be regular annual increments.

The maximum size recorded for Trotters Ferry Corbicula is 43 mm (October 1962). These should be in their fifth summer according to calculations, based on size and the earliest records for Kentucky Lake.

Color and Pattern Development
(See figs. 173-176 and 180)

The typical color and pattern of this clam develop with age, tending to intensify with maturity and gradually becoming darker and obscure as the shell reaches a larger size.

The new dissoconch of the early benthic clam (one mm and under) is cream color and without pattern. At two mm the shell is ivory without and cream colored within, with a chestnut colored central ray.

As the shell approaches five mm the periostracum takes on a polished tan appearance.

The eight mm shell is olive green with little indication of the lunule and escutcheon. The shell is prominantly marked within, being three rayed (chestnut color) and cream colored, with no trace of purple.

By ten mm the shell is beginning to show the lunule and escutcheon, Within, the three rays are still prominent, but the middle ray is becoming suffused with purple,

The fourteen mm shell no longer exhibits the rays within, but remnants remain as definite chestnut markings at the ventral ends of the lateral teeth. The umbone cavity is purple, the umbones appear purple externally due to the erosion of the periostracum.

As the shell attains thirty-five mm the only remnants of the juvenile rays are chestnut (tinged with purple) colored patches, at the ventral end of the lateral teeth. This color continues on the ventral margin of the posterior lateral teeth. The inside may be cream colored with a tinge of violet, but is generally violet above the pallial line and purple below the line,

The periostracum changes from olive yellow to brownish yellow being dark brown or black at the umbone with dark patches on the lower part of the shell. Some are uniformly dark brown or black. In nearly all, the periostracum is highly polished and the regular concentric sculpture is prominent.

As pointed out by Turner, color patterns of molluscs used as a specific diagnostic character, must be considered with caution. The color can be influenced by environmental factors and nutrition (92).

The brown stripes which mark the escutcheon and the lunule (fig. 180) are very prominent on the young Trotters Ferry Corbicula, and according to Kuroda may be diagnostic (46). Marshall noted that the narrow, radiating, reddish or chestnut colored lines on, Uruguayan, Cyanocyclas may or may not be present in specimens of the same species (52). He also called attention to the fact that they seemed to be in the periostracum, but were in fact in the calcareous portion of the shell, and are seen through the periostracum. This same thing is true of Tennessee Corbicula

Pilsbry and Bequaert also note that the purple beak ray may be present or absent in Corbicula radiata from the Belgian Congo (65). Some of these also had a brownish ray marking the escutcheon. The Tennessee Corbicula frequently exhibit this dark beak ray in the juvenile stage.

The periostracum of fluminea varies from brownish black to jet black (70). The Bonneville Dam specimens 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 C. japonica are yellowish brown. With age and maturity the shell becomes glossy black, usually with a radial pattern (7).

Kuroda concluded that the coloration of the interior of the valves, the yellow and brown colors of the periostracum, and the black rays on the young shell were of important diagnostic value in species identification, but the yellow and black color on the surface had no practical value since it was modified as the shell grew (46).

According to Kuroda the shells of Corbicula show much variation in shape as well as in color depending upon the environment and also the age of the shell (46). Those in discolored water with a mud substrate tend to be small with a dark shell. Those found in clear water and in sandy substrate tend to have large and colorful shells. The extremes as well as variations between these two types are nothing more than ecotypes. Unfortunately many of these have been described as species.

Kuroda divides the Japanese Corbicula into two groups: (A) japonica, and (B) leana. C. japonica was found in brackish water but rarely with the marine species. The young shell in this group was amber-brown, shiny, and rayed. The young were white within, becoming violet with age. The older shells were shiny and solid black, The nymph was white with fine irregular granulations (46)

The leana group was characterized as follows: the young shell was pale bluish, yellow, or straw color and without rays. The old shell varied from dark amber brown to orange brown or black. Some had cloud shaped black spots on the surface The shell tended to be rough and without luster, The inner shell was violet, with the section below the pallial line deep violet. The nymphs were rough and corrugated,

REPRODUCTION AND LIFE HISTORY

(See Plate 9)

The members of the family Corbiculidae include both incubatory and non-incubatory species. The eggs, which are fertilized within the gills, are either incubated within the interlamellar space of the inner gills (larviparous type) or discharged as conglutinates of eggs each with its individual gelatinous envelope (oviparous type). Those which retain eggs within the gills incubate them through the trochophore stage and discharge them as advanced veligers. Morton states that it appears that all freshwater bivalves incubate the eggs excepting Dreissena (58). The life histories of Corbicula have evidently been little studied Among those which are incubatory are leana and manillensis. C japonica is non-incubatory.

Miyazaki divided the Japanese Corbicula into three groups according to habitat and sexuality as follows (see Table 1)

> "Small bivalves of the genus Corbicula are widely used for human food in Japan, with some medical meaning, thus, they have some commercial importance and in some cases they are the object of cultivation being transplanted to the place where they are not found,
>
> Their habitat is either fresh or brackish water, The chief purpose of the present study is to elucidate their reproduction which shows different types according to ecological conditions.
>
> Twelve species occurring from the North, Hokkaido, to the South, Formosa, may be grouped in view of their habitats and sexuality into 3 categories as follows
>
> Group I Fresh-water - Monoecious - incubatory - non-swimming larva.
> Group II Fresh-water - Dioecious - non-incubatory - non-swimming larva
> Group III Brackish-water - Dioecious - non-incubatory - swimming larva
>
> Here mainly the description of the first group presented by C. leana Prime is given In the species, which is incubatory in its habit, inner gill-lamellae are differentiated structually for marsupial purpose Tts early larva is furnished with a velum which, being useless for swimming, is much better in its development compared with that of such as Sphaerium
>
> Post-larva with D-shaped shell when compared with the same stage of marine bivalves shows more advanced condition in its general organization, that is, the said larva of the present species is already furnished with well developed functional gill, foot and byssus thread, The larva has no stage of parasitic life," (56).

Group II is represented by sandai and Group III is represented by japonica. Although fluminea is generally regarded as a freshwater species, it has been found in brackish water and its life history would place it in Group III of Miyazaki.

Mandahl-Barth (99) found Corbicula africana to be incubatory, each inner gill containing from 500 to 1000 eggs or embryos The veligers within the gills were

200 microns long. In these respects this species is similar to Corbicula manillensis. Mandahl-Barth was of the opinion that Corbicula africana cunningtoni (Smith) could as easily be referred to the racial cycle of C. fluminalis since it is a transitional form between the latter and africana.

A closer study of the life cycle etc of these forms could well prove all the African forms to be the species fluminalis

The development of all species of Corbicula s s. and Corbiculina will likely prove to be similar regardless of whether or not they incubate the eggs The eggs which are fertilized by the sperm within the suprabranchial ducts or inner gills develops typical cleavage stages (fig 149) The ciliated ring of the trochophore (figs. 150-152) develops with its flagellum The trochophore passes into the veliger stage (figs. 153-157) as the shell gland produces the prodissoconch and the ciliated ring develops into the low lobed velum During this stage the developing labial palps, gills, dissoconch, adductor muscles, heart. foot, and gut can be observed through the almost transparent dissoconch This type of development is in marked contrast to the fresh-water mussels, the majority of which discharge glochidial larvae into the water, When fish (or Necturus in one instance) contact the glochidium it fastens, .is encysted, and develops as an obligatory, temporary, parasite After passing this stage the juvenile mussel drops off and attaches to an appropriate substrate by a long hyaline thread (byssus) which forms a holdfast at the end The glochidia can be picked up in plankton samples, however, they are not true plankters as are most of the marine bivalve larvae

Sexuality

In contrast to the Unionidae (mussels) which are with few exceptions dioecious and the Sphaeriidae (pea shell or finger nail clams) which are monoecious and hermaphroditic, the Corbiculid clams may be monoecious or dioecious according to the species.

Corbicula leana and manillensis are monoecious C. japonica, fluminea, and sandai are dioecious The clams found, thus far, in Tennessee have been demonstrated to be monoecious on the basis of numerous gonad smears made on countless specimens in varying sizes, Histological sections (fig [illegible] and 172) a'so demonstrated their monoecious character They could also be self fertilizing as are some Sphaeriids.

Sexual Maturity

The Tennessee River clam reaches sexual maturity during its first year at a length of 6,5 mm The Tulla, C. manillensis (figs 103-106), reaches sexual maturity at from 10.3 to 175 mm (96) Not enough clams have yet been dissected to determine the minimum size, nor average size at sexual maturity The fact that this c'am is monoecious, incubatory, and precocious in reaching sexual maturity certainly increases its potential as a pest species, invader, and serious competitor to aquatic communities, Spawning

The time during which the eggs (oviparous species) or veligers (larviparous species) are discharged has been called the spawning season. This has been determined for the following species

C. species - July to November (Tennessee)
C species - March to ? (Phoenix, Arizona)
C leana - June to October (Japan)
C. sandai - April, May, and June (Japan)
C manillensis - January to July (Philippines)
C fluminea - June to September (Taiwan)
C. japonica - June to August (Japan)

The spawning season of Dreissena in England is from May to September, and controls for it are instituted during this period Once the precise limits of spawning are established for the clam in this river basin, realistic controls can be instituted. These limits may be established simply by making routine plankton counts on the water involved Some plankton data from U. S Public Health Service water quality stations (National Water Quality Network Program) should become valueable in determining spawning seasons

Plants which are experiencing or anticipating clam problems should make plankton analyses on their water supply. Results of such analyses may be used for a more efficient program of clam control.

Ovulation and Fertilization

The ova (fig. 163) pass from the reproductive ducts, where fertilization probably takes place, into the suprabranchial chambers, thence, into the water tubes (fig. 161) of the inner pair of gills. According to Villadolid and Rosario (96)

> "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 70 to 160 microns at widest diameter." (manillensis, see appendix).

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.

Developing ova of clams from the Tennessee River have been examined in sections (fig. 171) and also in smears They are in the same size range as those of manillensis Mature ova within the gills of a Newman, California specimen were identical with the conglutinates of eggs discharged into the culture of a group of Newman adults. Both of these were surrounded by spermatozoa (fig. 149) as in Cahn's (7) figure of Venerupsis semidecussata (p. 16, fig 3). The gelatinous envelope surrounding each egg was well developed. The egg, which reaches an average diameter of 200 micra has a prominent nucleus and nucleolus.

The ones that were discharged into the culture developed rapidly, and a high percentage were normal. It is not known whether these were aborted or whether development can take place either way

Cahn, reporting on Miyazaki, stated that the development of larvae of Mactra sulcataria and the percentage of abnormalities varied inversely with temperature (7, 56).

Only two figures of spermatozoa of Corbicula have been located, one by Cahn (7) of leana (p. 80, fig 32) and the other of manillensis by Villadolid and Rosario (96, see appendix). The length of a spermatozoon from leana is shown as approximately 17 micra, but the size of manillensis is not indicated The two are radically different. The spermatozoon of leana according to Cahn is typically with a bean shaped head piece approximately two micra and a 15 micra flagellum (7) Flagella are not shown in the figure of manillensis which is tear shaped with a long tail piece. The morphology of the spermatozoon of manillensis; Newman, California; sandai, Phoenix, Arizona; and Ohio River Valley Corbicula are remarkably similar The length (excluding flagella) averages approximately 19 micra The spermatozoa of these latter two are unique in that two flagella are present which are approximately 45 micra, nearly twice as long as the body The spermatozoon appears to be flat and capable of a spiral forward motion, with a movement of the flagella

The spermatozoa develop in the acini which make up the male gonad (fig 172). The developing spermatozoa within the acini are closely packed with the tail to the center forming a sphere (fig 170) The flagella are free at the surface of the sphere, giving the mass a ciliated appearance The possibility of sperm dimorphism has not been recorded in Corbicula

Larval Stage The Marsupial Trochophore (figs 150-152)

The egg undergoing cleavage is heavily ciliated and rotates within the envelope After reaching the entoblast stage the ciliated ring becomes prominent, the larvae become elongated, developing a flagellum at the elongated pole. Inner gills of Corbicula, taken from the Tennessee River at Chattanooga on September 4, 1962, were heavily charged with trochophores 161 by 161 micra

Larval Stage The Marsupial Veliger (figs 153-157)

This larval stage derives its name from a prominent structure, the velum, which is heavily ciliated. The shell gland forms the dissoconch which is the larval shell, During this early veliger stage the larvae are quite active. The velum is well developed and is capable of being withdrawn into the shell Although many mollusc larvae use this as an organ of locomotion, this is apparently not so in the case of the Tennessee clams The velum functions in feeding, the cilia setting up a current of water, bringing food to the mouth The advanced veligers (approximately 200 to 220 micra) are discharged from the inner gills via the suprabranchial ducts and out the anal siphon into the surrounding water

Dreissena polymorpha is reported to swim with the velum upward near the surface of the water, but will retract the velum and sink at the slightest disturbance

This free swimming stage continues for about a week, during which time the foot develops and the larva can crawl about on the bottom (43)

Veligers in varying stages taken from the Tennessee River in plankton hauls, and also from cultures of the adult clams were never observed to swim with the velum. The Mendota veligers which developed both from incubated eggs as well as from eggs discharged into the surrounding water were not observed to use the velum as a swimming organ.

As the velum reaches its greatest development, the veligers (approximately 220 micra) are discharged by the adults.

Larval Stage: The Planktotrophic Veliger (figs. 153-157)

Although the veligers become a part of the plankton, they are not true plankters. The velum functions in ciliary feeding, the long velar cilia propelling the food toward the mouth, The time spent in this stage is thought to be relatively short, thus they are short term planktotrophic larvae or meroplankters. During this period the foot develops and the velum and the apical swim plate become reduced. The velum of Tennessee Corbicula is well developed yet there is no evidence of the velum being used to maintain its position in the plankton.

The apical swim plate, though well developed, was not used for swimming. A Japanese species of Clam (Andara) uses the apical swim plate for swimming during the veliger stage, and evidently does not use the velum for this purpose (7).

Larval Stage: The Benthic Veliger (fig, 158)

The period during which the veliger larvae drop out of the plankton and take up bottom life is not as critical as may be supposed, This stage (fig. 158) is marked by a highly developed foot with a statocyst necessary for equilibrium. The heavily ciliated foot is thrust out in rapid movements, anchors and retracts, bringing forward. Efforts to dislodge the larvae, when the foot was attached to glass substrates, by strong jets of water from a micro pipet was usually unsuccessful on the first try. The older ones may have a byssal gland but this could not be detected at this stage. A mucilage or other adhesive device was present at the distal end of the foot to provide an effective attachment, Matteson (53) observed that the foot of the newly dropped immature young of Elliptio complanatus seemed to possess these adhesive qualities.

Some veliger larvae utilize the byssal pit, at the tip of the foot, as a "sucker", and are thus able to move about over the bottom in search of a suitable substrate on which to attach the byssus. Benthic veliger larvae of Corbicula move about very rapidly, lying on one valve, the foot extending characteristically at a right angle to the hinge line, and moving in the direction of the foot thrust. The prodissoconch shows concentric growth lines as well as radial striae.

Late Larval Stage (fig 159)

The sculpture of the adult shell appears by the time the young clam reaches

0.9 mm, and brown pigment appears on the periostracum by the time 1,5 mm is reached. The young clams may be attached by the byssus at this time A series collected at the margin of Kentucky Lake (New Johnsonville), in August, 1962, was attached to rocks by the byssus These ranged in size from 1.5 mm to 4,8 mm Thus far, very few byssus attached ones have been found.

ECOLOGY

Substrate

Corbicula fluminea has been reported from substrates of sand or mud or a combination of the two in Formosa (36). Ingram gives the habitat as sand and mud in California (33). A preference for sandy substrate rather than silty ones was noticed in Formosa (35, 95). According to Filice (19) fluminea in San Francisco Bay prefers a sandy substrate, having an aversion to mud In Arizona they were found in sand in an irrigation canal (15) Corbicula sandai in Japan is reported to inhabit substrates composed of sand with an admixture of pebbles, with a marked distaste for muddy substrates (7), Corbicula leana is found on sandy bottoms and japonica on bottoms that are 70 per cent sand and mud in Japan (7). Corbicula manillensis was taken in abundance from "shallow strips of sandy banks" (96) The Tennessee River clams have been found in great numbers in gravel and rocks, especially in the Pickwick tailwater area, On the other hand great numbers have been found on a black clay substrate in shallow holes accommodating one or two large specimens, in the New Johnsonville section (Trotter's Ferry Landing), It is difficult at this point to say which type substrate is utilized most, the rock and gravel substrate possibly has the edge since it offers protection and prevents the clams from being washed downstream during high flow.

Bates noted "The highest per unit area concentration of individuals was observed in those areas having a sand-mud substrate; substrates of firmer nature yielded accordingly fewer individuals in apparent direct proportion". (4).

In view of the findings, of Scruggs and Bates, on the detrimental effects of impoundment on certain commercially valuable mussel species and their picture of possible slow extinction of these species, Corbicula will indeed have little competition in impounded water (77, 3)

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 clams collected in the summer of 1962 by the Tennessee Stream Pollution Control biologists were collected with the aid of a Petersen Dredge Also, some of the specimens collected in cooperation with the Academy of Natural Sciences of Philadelphia were collected with a Petersen Dredge. Collections from the Red, lower Duck, Buffalo Rivers, and Sycamore Creek were collected with a Petersen Dredge. Most of the collections from Pickwick Lake, Pickwick tailwater, and Kentucky Lake were made by hand, some were also taken with the Petersen on the latter two.

Vaas and Sachlan (101) found Corbicula javanica living in the mud in the shallow parts of Lake Tjiburuj in West Java This shallow lake has a soft black mud bottom without big stones.

Water Quality and Flow

Clams belonging to the genus Corbicula are typically fresh-water, but several species such as C. formosana and C japonica prefer brackish water (35, 56). Corbicula sandai requires at least a weak current, but it is found in fast flowing water as well In Japan C. leana is found in clear brooks and ponds.

These clams are exposed to intense fluctuation in water level in some Tennessee waters, For example in the Pickwick tailwater clams were abundant in moist gravel 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. Some specimens were collected from a TVA steam plant at New Johnsonville that were estimated to be at least four years old. They were collected from pipelines that are under pressure and flowing most of the time, Mr. Bill Turner, of the Tennessee Game & Fish Commission, collected over 50 Corbicula below Pickwick Dam. These were placed in water in a galvanized pail and left in an attic room for a month during the late fall of the year. At the end of this period, the water was foul with the decaying bodies of most of the clams, However, 18 specimens survived this rigorous treatment, which is an indication of their hardy nature.

The reaction of Corbicula to some common parameters of water quality will be followed with interest Thus far it has exhibited a tolerance to a number of environmental factors, Its reaction to high chlorides in the North Fork of the Holston River; copper and zinc in the Watauga River; chrome in Shoal Creek; and low dissolved oxygen tensions in streams receiving sewage should all prove to be interesting.

Temperature of the Cumberland and Tennessee Rivers offer a contrast, yet the clam has had little difficulty in becoming established in both.

Filice found that Corbicula was absent from stations below outfalls of domestic and industrial waste, and populations marginal to these outfalls were reduced (20) Filice also reported that Corbicula fluminea tolerated brackish water of the San Francisco Bay up a salinity of 5 o/oo, (19).

The nature of the substrate has a marked effect on some Corbicula, In California those found in sand are generally ovate; whereas, those in mud mav be trigonal (33). Kuroda reported that sandai changed from the original triangular to round, due to the influence of environment when it was transplanted (45). In Tennessee we have Iwo definite forms, one relatively round and only slightly trigonal, whereas the other form has a high umbo and is very definitely trigonal See section on variation for further discussion on this point.

Seasonal Activity

Mivazaki reports that sandai in Japan buries from two to six centimeters deep during the winter, re-appearing at the surface in late March or early April (56). It can be said that Corbicula from this area are active at all seasons, There is no indication that the clam, herein evaluated, buries itself during the colder months. Corbicula taken from the Cumberland River during extremely cold weather, on February 1, 1961, possessed the crystalline style. Some of the substrates from which Corbicula have been collected is of such a texture and density that it would be impossible for them to bury themselves. Where a sandy bottom is evident clams are often found several inches down, however, the texture of this material is such that you would expect vertical flow through it. They have been found as deep as two feet in the substrate.

Mortalities

Mass mortalities of Corbicula have been observed on three different occasions. The first was observed during the week of April 17, 1961 on the Tennessee River at Wolf Island (mi. 192.5). Large numbers of dead and moribund clams (up to 15 mm) were being washed ashore. Mr. Harry Stuart reported clam mortalities on the Cumberland River at mile 100 during this same period.

On August 30 and 31, 1962 the traveling screens at the Chattanooga Water Treatment Plant, on the Tennessee River, were clogged with the bodies of Corbicula. On September 4, an examination of the river revealed that large numbers of bodies were still moving down the Tennessee River. The cause of these die offs was never determined.

A remarkable thing about the bodies of these clams is their persistence in streams, which can be a problem as demonstrated at Chattanooga. The adductor muscles relax in the dying clams, the ligament forces the valves apart, and the body separates neatly from the shell. Gas produced by the bacterial decay of the tissues gives the body a buoyancy and it is carried downstream by the current.

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, possess the structure called the crystalline style. According to Pennak (61):

> "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."

Morton states that

> "After removal from water or cessation of feeding, especially where the style sac is open to the intestine, the whole style gradually dissolves, and some high tidal bivalves - such as Lasaea rubra - pass through a regular cycle, in which the style almost disappears when the tide is out and is later re-secreted". (58).

All Tennessee Corbicula specimens, regardless of locality, season, or condition, have exhibited a crystalline style. As stated elsewhere in this paper specimens taken from wet sand had a crystalline style. However it is assumed that the crystalline style in Corbicula is typically one of a Lamellibranch.

PARASITES.

Records of parasites from introduced Corbicula have not been located in the literature, nor have any been found in numerous examinations of living specimens of this clam. However van Benthem Jutting comments on heavy local infections of Echinostoma from humans eating raw or improperly cooked Corbicula in Java. (37). The Unionid mussels associated with Corbicula on Kentucky Lake have a fairly high incidence of infection with the common North American species of fresh-water fluke, Aspidogaster conchicola von Baer,

Raabe (75) studied the parasitic ciliates of Dreissena polymorpha from the Baltic Sea, Conchothirus acuminatus (Clap. Lachm.) and Hypocomagalma dreissenae Jar. Raabe. The papillose Allocreadiid fluke Megalonia ictaluri Surber utilizes the Sphaeriid clam Sphaerium transversum (Say) as intermediate host (8),

COMMON MOLLUSC PREDATORS

Sinclair and Isom reviewed the common mollusc predators. Some of that material is herein included and evaluated in light of new data (81).

Of 1,988 waterfowl killed during hunting seasons 1950-1954 on Reelfoot Lake, 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 bivalues utilized by these birds were fingernail clams, Musculium, Pisidium, and Sphaerium (76). 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. It was noted in the Reelfoot study that diving ducks' gizzards contained more animal material than did puddle ducks' gizzards (76); 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.

**Related in conversation.

To date we have no further evidence as relates to the utilization of the Asiatic Clam in Tennessee.

Other natural enemies include the flatworms which consume all sorts of material including young, fresh-water clams (61). 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. Dugesia continues to occur in tremendous numbers in the shallow water areas of Kentucky Lake (New Johnsonville).

Corbicula occur quite commonly in dissection of certain species of fish from Kentucky Lake, They have been found in the following fish species: the blue cat (Ictalarus furcatas LaSeur); the channel catfish, (Ictaluras punctatus Rafinesque); carp, (Cyprinus carpio Linnaeus); and the Redear sunfish (Lepomis microlopis Günther), see plate 14.

Sheepshead or fresh-water drum (Aplodinotus grunniens Rafinesque) are common in Kentucky Lake. It is well known that these fish have a common diet in the adult life, of molluscs, The small size of the Asiatic Clam, and its abundance, should place it as a prime food source for the drum.

It has been confirmed that fresh-water drum utilize Corbicula.

Ingram 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." (36).

Ictalarus furcatas and punctatus take the clam into the digestive system whole and digest the tissue out, excreting the shells. Corbicula excreted by carp were noted to be broken,

In the Philippines, 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 boschas Linn (96).

One dock operator reported that some individuals use Corbicula for bait in the Pickwick tailwater area of Kentucky Lake, Tennessee,

We plan to study further the utilization of the clam by fish and water fowl.

TRANS-OCEANIC AND TRANS-CONTINENTAL INTRODUCTIONS

(Maps 1 and 2)

The superfamilies Sphaeriacea and Dreissenacea have been widely scattered by introductions. The Sphaeriacea which includes the Corbiculidae and Sphaeriidae have

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many introduced species. Several species of the Sphaeriidae have been introduced from Europe into this country and at least one North American Sphaeriid has been introduced into England The introduction of Corbicula from Asia into North America rivals the spread of Dreissena across the Eurasian continent The Zebra Clam Dreissena polymorpha will very likely extend its range into North America

Pilsbry and Bequaert note that "Corbicula, generally spread in East Africa, appears to be in course of invading the West African fauna." (65).

Although speculations concerning the introduction of Corbicula have not been wanting, no documented evidence as to the nature of the introduction has been found.

Because of the variation in shell characters exhibited in the subgenus Corbiculina, it is impossible to place the exact origin of the species, Corbicula (Corbiculina) manillensis, introduced into the United States in the late 1930's. This species could have originally come from almost any section of the Orient. As already mentioned the shell characters of most ecophenotypes (recognized as species even by lumpers like Prashad) of Corbiculina can be matched by shells from locations from California to Tennessee.

In discussing the extensive distribution of the snail Melanoides tuberculata van Benthem Jutting (94) cites Martens explanation as follows:

> "In 1897 Martens (in Weber, Erg Reise Nied. Ost Indien, 4, p. 59) tried to explain the wide distribution of Melanoides tuberculata from North Africa to the Pacific Islands by assuming that this species, which is a common inhabitant of irrigated rice fields has been passively and unintentionally spread through human agency by inter-local, or even inter-continental transport of young rice plants."

According to Gregg Corbicula fluminea was introduced from Japan with seed oysters (19). The history of this seed oyster importation has been traced by Cahn, Ostreas gigas Thunberg, the most important food oyster in Japan is native to Japan and Korea and is known as the Giant Pacific Oyster in this country.

This species has been the subject of much effort in establishing commercial oyster beds on the Pacific Coast since 1902 - 1903. The dumping of a cargo of dead oysters led to the accidental discovery that the key to the transportation problem lay in shipping spat, not adult or semi-adult oysters. The spat or veligers were accidently attached to the shells of the adults, and only they survived the trip (6). According to Fitch there has been no substantial natural propagation of this species of oyster in California (18) Other introductions, which were the result of seed oyster export from Japan to the Pacific Coast of North Amer[4]ca, have been the oyster drill (Tritonalia japonica) and the Japanese Littleneck Clam (Tapes semidecussata). The latter could have been introduced in another way, but it is more likely that it too arrived as a veliger with the oyster spat (veligers)

Corbicula fluminea and leana are both fresh-water species, although Filice found that fluminea extended its range from fresh-water down the San Francisco Bay estuary to a salinity of 5 $^{0}/00$ (19) Yung found fluminea abundant in the Tanshui River, in Formosa, especially upstream, whereas formosana was only abundant at the convergance of the Tanshui and Keelung Rivers in brackish water (97). Although *fluminea* was most abundant upstream it was found at Yung's lower station at the junction of the two rivers where the maximum chloride reading was 11,800 ppm.

Of the three Japanese species of *Corbicula, japonica* is the only obligate brackish water form, Because of the confused taxonomy of this group a study of the dispersal and introduction of *Corbicula* will not be simple.

Although *fluminea* is not an associate of *Ostrea gigas* in brackish water it is entirely possible that the clam veligers were accidently introduced with oyster spat from Formosa at a time when Formosa was controlled by the Japanese. It is even less a possibility that *leana,* a typically fresh-water form, would have arrived with seed oyster shipments from Japan.

Corbicula japonica is found in brackish water at the mouth of rivers in Japan in Honshu, Kyushu and Shikoku. The greatest fishery (see appendix) for this species is in the mouth of the Tone-gawa, at Shiishiba, Chiba Prefecture of Honshu (7). This is the only brackish water *Corbicula* found in Japan, and it would have the greatest opportunity to become acclimatized on the West Coast in view of the intensive shipment of seed oysters and spat from Japan for over a half century. According to Fitch, the Pacific Oyster is raised commercially in most of the bays of California north of Morro Bay (18)

The Japanese Littleneck Clam is extremely common in San Francisco Bay being introduced around 1930 (18). This clam is widely distributed in Tokyo Bay, but the mouth of the Edo-gawa near Urayasu, Chiba Prefecture is the only good seeding bed for commercial use (7). *Corbicula japonica* is also present in this estuary and both it and the Littleneck Clam could have been imported as veligers with seed oysters

The shells from Trotter's Ferry (high umbone form) have been compared with those from Bethel Island (California), Phoenix, the Newman Wasteway, and Bonneville Dam, and have been found to be more nearly like the first This same shell typs is matched by *Corbicula javanica* (see 93, fig 14 a, b, p. 60) and *Corbicula fluminea* (see 70, fig. 7, p. 7) Unfortunately the Trotter's Ferry specimens have not attained as large a size as the Bethel Island specimens. The trend however is clearly recognizable. Both have the elongated posterior margin. The large Bethel Island *Corbicula* (figs, 1-7) are more like *japonica* (Cahn 7, p. 78, fig. 31) in shell characters than any other series examined. Unfortunately all of this series died before life history studies could be carried out, That these died is unusual in that *Corbicula* is very hardy It would be much more likely that *japonica* would be the San Francisco Bay species rather than fluminea. At any rate identification of some populations of this clam are in doubt.

The apparent absence of records for *Corbicula* in drainage areas between the Gila River in Arizona and the Ohio River is rather remarkable. This may be due to unreported specimens.

The tracing of a distribution pattern may be accomplished by a single age and growth study, which would establish the year in which the species was established at a particular locality.

DISTRIBUTION

Since the first published record of the Asiatic Clam in the Tennessee River a continuous record has been kept of its distribution (80). Sinclair and Isom followed this first paper with a more comprehensive analysis of the Asiatic Clam. It has been the opinion of the authors from, almost, the beginning that the Asiatic Clam would spread rapidly throughout the contiguous water courses of the area. Also, it was felt that the abundance of mussels encountered in marginal areas, at low water, would greatly enhance the possibility of spread by individuals collecting the clams for aquaria, etc.

The old standby that the "species" was spread by being carried on birds feet is of little value in the case of Asiatic Clam distribution. One of the biggest factors to be considered in explaining the Asiatic Clam's rapid distribution is the habits of the present day "water user". In the past a fisherman approached his favorite fishing area either by foot or by car. He fished a few hundred yards up or down the river from a given point. Today, most fishermen either own a boat and motor or rent them for use. With the larger impounded reservoirs fishermen often travel several miles by boat to reach their favorite fishing area If the fishermen uses live bait he of course transports minnows, etc. in a bucket of water, dipped-up at the point of departure. The clam being a part of the plankton in rapidly flowing waters would be easily transported in this way Often after a days fishing the live bait which is no used is transported home, placed in a spring branch or creek, thus infesting the branch or creek. For example fishermen from Nashville utilize TVA impoundments as far away as Pickwick Lake and tailwater and Kentucky Lake from 90 - 145 miles distance generally speaking. These are just a few plausible and highly likely distributional methods. Also, ballast and bilge water associated with river commerce and recreation is another factor to consider.

The sand and gravel yards have been examined and live <u>Corbicula</u> can be found readily, as these enterprises will readily testify. In the process of unloading gravel from barges the area around and downstream become infested We actually collected <u>Corbicula</u> immediately below a gravel unloading operation.

The Asiatic Clam has followed a general pattern of upstream migration, passive we believe, moving from the Ohio River up both the Tennessee and Cumberland Rivers (see Map 1) The present upstream record is at Fort Loudoun Dam on the Tennessee River mi. 602,3 which is near Knoxvil'e and the head of navigation. The uppermost record on the Cumberland River is just below Old Hickory Lock and Dam, Tennessee, which is some 100 miles below the head of navigation, however, there is only very limited commerce beyond Nashville It has recently been reported above Cincinnati (mi. 461.5) on the Ohio River (100).

Undoubtedly the Asiatic Clam has been distributed through these two primary navigation systems by river commerce However, the clam has not been spread exclusively by commercial enterprises as is evidenced by the records from the Duck River at Shelbyville, and the Richland Creek record below Pulaski, Tennessee Richland Creek is a tributary of the Elk River Tnvestigations in the summer of 1962 revealed no Asiatic Clams from the Elk, in Tennessee They should now enter through its Richland Creek tributary. The records on the lower Duck, Buffalo, and Red Rivers, and on Sycamore Creek, Tennessee were from areas that are inundated during periods of water storage. The Duck and Buffalo record sites are clearly evidenced as being streams at low water. The Red River and Sycamore Creek records are from localities that are probably influenced by backwater at all times.

It is worth while to look to the experience of the British and Europeans with the Zebra Mussel, Dreissena polymorpha (Pallas)* (figs. 143, 144) and its distribution for a better understanding of Corbicula distribution. Clarke states that: "One of the most startling facts about Dreissensia polymorpha is the way it overran Europe in a hundred years," (9). Pallas made the first discovery in 1769 at the mouth of the Volga River. In 1866 it had completed its extension into the hydrographic basins of France (90).

Between 1769 - 1866 it was spread through England and Germany....."it was supposed to have been carried into Germany by the pontoon trains during the wars of Napoleon, and became known as a German mollusk in 1814: as an English, toward 1824." (90),

Fischer's observation on the spread of D. polymorpha in Europe might well apply to the present rapid distribution of Corbicula in North America. "If," says Fischer, "this extension had occurred several centuries ago, it would have been impossible to ascertain the original locality of the species, except by reference to its ofssil remains: these show that it did not exist in the quarternaries of western Europe, but that it occurred in the chalk of the Stepps." (90)

Corbiculidae are common fossils in North America, Prime lists six genera of Corbiculidae from America. However, in reference to the genus Corbicula, Prime states that: "We do not find any living representatives of this genus on the northern portion of the continent, the most northern extremity to which it extends being Mazatlan". (72). These are now placed in the genus Cyanocyclas.

"Non-marine mollusca are one of the most common groups of fossils in Quarternary deposites, rivalling ostracods and microscopic plant remains in their frequency." (83).

A final note on the distribution of D. polymorpha. Tryon states that: D. polymorpha "is a native of the Aralo-Caspian Rivers," ...(90).

The spread of D. polymorpha through Eruope represents the extension of range over a virtual contigueous land mass. Corbicula, however, represents the successful adaption of an introduced species. As Bates points out: "Apparently little ecological resistance exists to prevent complete dominance of available mussel habitats by this species." (4),

CULTURE

Clams received from California and Arizona as well as those collected within the Tennessee Valley have been easily maintained in the laboratory in battery jars provided with aeration, Cultures have been successfully carried for months with the addition of plankton. The egg conglutinates (ovisacs) discharged by Newman California specimens were carried into the veliger stage Larvae discharged as veligers were not reared to the benthic stage due to predation by protozoa

*See Ellis pp. 65 & 66 or "Opinions and Declarations rendered by the International Commission on Zoological Nomenclature, 1955, 11, Part 1," (From Ellis).

The clams in the jars are forced to lie on one valve although they are able to move about by use of the foot and rest in a vertical position on either the lunule or escutcheon. The siphons are at times extended for a considerable distance. Occasionally the branchial siphon is moved about over the bottom of the jar or the valve of an adjacent clam. Normal siphoning and other movements are carried out when the clams are placed upside down resting either upon the lunule or escutcheon.

One lot received by air from Bethel Island failed to recover when placed in culture.

Mr. Chen in a letter informs us that the Corbicula in Taiwan are not easily maintained in the laboratory, thus hindering life history studies.

The ecology of the closely related brackish water clam (Polymesoda caroliniana) offers an interesting comparison. Andrews and Cook (2) found this clam on the James River in Virginia from nearly fresh water to salinities of about 15 parts per thousand. Polymesoda was found in three diverse habitats (1) in sedge-matted banks in small depressions, (2) in fine black silt under thick algal carpets, and (3) in riprap, between and under rocks.

Those kept in small bowls in the laboratory with little attention survived in spite of low oxygen and nearly dry substrates

CONTROL METHODS

The experience of the British and Europeans, with the Zebra Mussel, Dreissena polymorpha Pallas (fig. 143, 144) is of particular significance when viewing the relationship of the Asiatic Clam to present and future water treatment practices.

D. polymorpha like Corbicula can adapt to a wide range of habitats, D. polymorpha is unlike most other bivalves in its reproduction in that it does not incubate its eggs (58). D. polymorpha produces a free-swimming larval stage from eggs fertilized outside the body (9). Corbicula manillensis is hermaphroditic as well as incubatory The fact that D, polymorpha has this external development would seem to decrease its rate of successful reproduction, However, the observation of Wagner, who estimated a population density in Lake Balaton, Hungary at between 20,000 and 30,000 per square yard, tends to obliterate this view assuming this to be the primary requisite for fecundity. A total of only 10 specimens had been found two years prior to this (9).

In reviewing Clarke's paper it was noted that "The earliest, and perhaps the most sensational, record of trouble with Dreissensia polymorpha in water works was that at Hamburg by Kraepelin (1886)" (9). Tryon makes the statement in his Vol. 1, 1882: "In London they have caused trouble by growing in the water pipes, and in 1834 they appeared in Edinburg," In context this statement is part of a chronological sequence. This then would place the earliest nuisance, by D, polymorpha, back something over 52 years. (90).

More recent experiences with D, polymorpha are noteworthy, especially Clarke's statement in reference to the use of chlorine as a control for D polymorpha;

"Prechlorination has been found effective by the metropolitan water board; and at Great Yarmouth a 24-in. diameter main carrying raw water for 9 miles has been kept free of growth for four years and has apparently prevented pipes downstream becoming re-infested from the river. The dose used in this case was such as to leave no residual at the downstream end, usually 1.5 to 2 ppm. It should be mentioned, however, that Wilhelmi found larvae still alive after being in 10 ppm of chlorine for 1 hour (residual 7.5 ppm.)". Work at Yarmouth showed that "continuous dosing with 50 ppm flowing slowly through the main for upward of two weeks has shown itself to be a reliable method of removal." (9).

At present, the use of 1 to 0.5 parts per million chlorine, in the main feeding river water to the sedimentation reservoir, and a dose of 0.5 ppm to the main between the sedimentation reservoir and the treatment works only during the breeding period from May to September, keeps both mains quite free of mussels. Slug dosing has been tried by some waterworks and power stations but has not proved very successful as often large build-ups of organisms occur when the interval between doses becomes too long.* Thus it is readily calculated that chlorine treatment has proven effective over a span of fourteen years in the control of D. polymorpha.

Water treatment facility operators, in Tennessee, are asked to prechlorinate to the extent that the water will pass through the treatment process and on to the filter beds with at least 0.5 ppm chlorine residual and post-chlorination of 2 ppm with no less than 0,5 ppm residual chlorine at the most distant point in the distribution system.**

In experience of the British with D polymorpha Clarke states that "There is ample evidence that the larvae are held back by both rapid and slow sand filtration, but they do seem able to develop and live for a while in filtered water,"

With this knowledge of practice on D. polymorpha and with the present chlorine treatment of surface water in Tennessee water treatment facilities it seems highly unlikely that we will experience any undue nuisance from Corbicula in finished water.

The biggest nuisance to date and one that will continue will be in the use of water by industries, TVA, etc. Also, sand and gravel companies can expect the clam situation to intensify rather than improve as it relates to this industry.

With its apparent tolerance to great variety in habitat, including, substrate, temperature, etc. and in light of its tremendous reproductive capacity, Corbicula will undoubtedly become better known as a pest,

Practical Application of Chlorine

The successful application of chlorine is being used as a remedial measure in the control of Asiatic Clams in an industrial water supply at Chattanooga, Tennessee.

The clams were first noted in the sedimentation basin in the water treatment plant in March, 1961. Clam shells were also found in the condensers of refrigeration

*Personal communication with Mr. K. B. Clarke, December 1962.

**Only those facilities with surface streams or lakes as water sources are asked to follow this regimen, However, it should be pointed out that all plants do not follow this program of prechlorination.

***This seems a good point at which to institute such a program. Especially if the surface source from which a water system is obtaining its water is one from which Corbicula has been reported.

machines during annual overhaul (1961). These shells were thought to have passed through defective traveling screens at the river water pumping station? However, the subsequent breakdown of a large condenser due to fouling by clam shells evidenced that a problem existed.

Investigation of the raw water intake revealed a large quantity of Asiatic Clams.

They decided to introduce chlorine into the water system for control of the clams. Experimentation revealed that 1.0 ppm chlorine residual, in a flowing stream of river water, killed all of the test specimens within twelve days. On the basis of these tests they proposed to introduce chlorine through a grid distributor into each inlet flume at a rate to maintain 1.0 ppm chlorine residual at the pump discharge for a period of three weeks

They instituted this program in April, 1962 with reportedly, very satisfactory results, At present, it is felt that a three week treatment each year will be sufficient.

Other of this company's plants have completed similar treatment facilities in event they are needed.

A New Johnsonville Plant has also utilized chlorine as an effective molluscacide in the eradication of adult clams, in their water system. In addition to the treatment, for three weeks, with 1 ppm chlorine in residual, they have been using 1 ppm chlorine treatment one hour out of each 12 hours operation for the control of immature clams, however, they have not found this method to be effective for killing veligers,

Recommendations

The type treatment described above has proven effective in adult Asiatic Clams control. This treatment, as necessary, combined with screens of small pore size should prove very effective. The clams release the young from the gills when they are about 230 u (micra), (0.23 mm or .009 inch), in length. In order to strain out the veligers (young clams) micro-straining is necessary. Therefore, it is suggested that a relatively heavy gage, small mesh, non-corrosive wire or a non-corrosive, perforated metal, plate, cone, funnel, etc. be used as a screen for adult clams only. Occasional chlorination should control the veligers, thereby eliminating further nuisance.

Care should be taken not to return waste water to a receiving stream with a chlorine residual that would damage the downstream aquatic environment. In some cases the chlorine demand of the industrial process, waste, would rapidly dissipate 1 ppm residual chlorine. Tn any event the proper pollution control authority should be consulted before returning water with a chlorine residual to the receiving stream.

Past experiences do not recommend that a predator be sought for the control of Corbicula. In the case of impounded waters, flucuating water levels do not greatly effect Corbicula therefore this is not recommended as a special control measure. The

*Their water source is the Tennessee River at Chattanooga.

natural predators found in our streams do utilize the Corbicula, however, they will eradicate Corbicula. Ideally, a biological control would be preferred to a chemical control. But at this time the facts reveal that Corbicula is spreading rapidly throughout the contiguous waterways of the Ohio, and Gulf coast drainages. The ability of Corbicula to utilize all types of substrate and an apparent ability to adapt to varying water quality enhances its pest status.

Fourteen years of experience with chlorine in the control of D. polymorpha lends itself to consideration as a control for Corbicula.

More important perhaps is the experience of two industries and their successful eradication of adult Corbicula from their water systems, with the aid of chlorine.

As in the use of any pesticide, only competent personnel should be responsible for carrying out pest control programs. Every effort should be made to protect our aquatic environment yet be able to realize the maximum benefit from it as a resource.

The physiological activity of chlorine on bivalve molluscs has been studied by Galtsoff (24). His work dealt solely with oysters. Of particular interest was the ability of the oyster to protect itself against the irritating chlorine. Galtsoff observed that: "Oysters kept in chlorinated water secrete large quantities of mucus which is usually discharged as pseudo-feces from the mantle cavity;... In some of the 1945 experiments as much as 30 ml. of mucus, discharged by a single oyster, accumulated on the bottom of the tank in 24 hours. Mucus secreted by the mantle and the gills serves as a protective coating for delicate tissues of the tentacles, mantle, and gills, and absorbs chlorine before it comes in direct contact with the neuro-receptors. There is a considerable loss of chlorine when the water is passed through the oyster gills." (24). This data probably explains why some attempts to eliminate clams with chlorine under static conditions have been unsuccessful whereas continuous flow with lesser concentrations have been successful. Galtsoff's experimental treatments, in 1945, did not exceed 90 minutes. His primary intent was to study the effect of chlorine on the self-purifications of oysters, not to kill them, however, his methods would probably be very good for studying the physiological effect of chlorine on Asiatic Clams.

BIOASSAY

Bioassay with Bayer 73

Bayer 73 (2-hydroxy-5, 2' dichloro-4' nitro-benzanilide, Bayer Chemical Company, Germany) has been widely used as a molluscacide in the tropics to kill snails carrying cercariae which cause Bilharziasis.

This chemical has been used in bioassays with fish, snails, and clams (including adult and planktonic stages). The results to date are as follows.

Fish

Fingerling Bluegills (Lepomis macrochirus Raginesque) were obtained from the state fish hatchery at Springfield, Tennessee, Ten fish were used in each of ten liters concentrations. Aged tap water was used both to acclimatize the fish and to serve as a diluent for the Bayer 73. The 24 hour TLm was 0.18 mg/L.

Clams

The two stages of clams chosen for use were the more resistant adults, and less resistant veligers (the planktotrophic veliger).

Planktotrophic Stage

The young clams that are discharged from the parent are carried with the plankton in the current. They have a thin shell, (average app. 230 u in length), which does not vet show the characteristic concentric sculpture. These were obtained from plankton hauls taken below Pickwick Dam November 20, 1962 and acclimatized for a period of five days in culture bowls. Transfers were made by pipette using a binocular dissecting microscope, five clams were added to each concentration. Cessation of heart beat and ciliary movement of the gills was used as the criterion of death. This was observed using a magnification of 90X.

Only the acute toxicity, to this stage, is pertinent so observations were limited to a 24 hour period. The 3.2, 1.0, and 0.56 mg/L concentrations produced the same immediate symptoms, the foot extended and general paralysis. This was noticed within six minutes at the highest concentration. All specimens were dead by 35 minutes in the highest concentration and by 105 minutes in the 0.56 mg/L concentration. The next two concentrations used were 0.24 mg/L and 0.10 mg/L. At the end of twenty-four hours the former contained only two live clams, whereas all survived at the lowest concentration, a TLm of 0.17 mg/L.

Adult Clams

The clams chosen for testing were collected from Kentucky Lake October 31, 1962 and acclimatized for three weeks in the same dilution water used in the above tests. The clams used were uniform in size and averaged 35 mm in length. Concentrations of 3.2, 1.0 and 0.56 mg/L produced a general paralysis in these specimens The clams projected both siphons and foot and then clamped the valves tight on the extended parts during the first twenty-four hours. This position remained until death, By 48 hours all were dead.

Snails

Two Pleurocera canaliculata and two Lithasia geniculata were used in several concentrations. The Pleurocera were collected with the adult Corbicula and acclimatized along with these. The Lithasia were collected from the Duck River October 26, 1962 and acclimatized with the Corbicula, The Baver 73 concentrations had the same effect on the snails as the adult clams, that is the foot and body were thrust out of the shell to remain this way until death.

All specimen of both species were dead, in the 0.56 mg/L concentration by 48 hours. Tn the 0.24 mg/L concentration only one specimen of Pleurocera remained alive at the end of 48 hours.

Conclusions

Based on this data, Bayer 73 could be field tested in an industrial plant at a dosage of 0.5 mg/L. It would have to be restricted, however, to a system having a closed circuit, and not escaping to ground or surface water because of its toxicity to fish, etc. Of course, its toxicity would prohibit its use in treatment of water being used in food processing fur human consumption.

Chlorine

Planktotrophic veligers (approximately 230 micra), from cultures of Trotter's Ferry specimens, were used in this bioassay. This stage was chosen because of its sensitivity and the necessity of controlling larval clams that gain access to water systems.

A solution of sodium hypochlorite was used to make a 50 ppm chlorine stock concentration

Veligers reacted to two ppm chlorine by withdrawing their foot immediately, without extending it again. All five tested were still showing weak ciliary movement within the shell at the end of five hours. At 50 ppm chlorine all five veligers tested were dead within ten minutes. The point of death was taken as complete cessation of all ciliary movement.

Veliger larvae of Dreissena polymorpha have been successfully controlled at the Great Yarmouth water treatment plant in England by a continuous dose of 0.5 ppm chlorine to the main between the sedimentation reservoir and the treatment works dur'ng the spawning season (personal communication from K. B. Clarke).

THE SAND AND GRAVEL INDUSTRY

The chief economic problem posed by Corbicula has been centered in the sand and gravel industr (see map on inside of front cover). There are close to twelve of these industries operating on the Cumberland and Tennessee Rivers. According to the estimate made by one sand and gravel executive annual production of these plants amounts to several million dollars

The clam has been of considerable nuisance of these companies. The presence of these clams in river gravel deposits naturally places them in the line of production of aggregate. Mechanical separation is almost impossible. Clams do not exceed the one per cent limit specified for gravel. The problem lies in their response to being poured with concrete aggregate The move toward the surface leaving a void.

As one sand and gravel company executive put it, seeing moving concrete can be unnerving.

It is to be regretted that no solution has been found concerning this problem. However, the purpose of this paper was to provide basic data on the life history of the clam, and offer some solution to operators of water treatment plants who will surely be faced with this problem.

UTILIZATION

Economically the introduced Corbicula is considered a liability. There are, however, several areas in which the clam could be utilized such as; index organisms in pollution studies, a local food source, fish bait, and transplantation for culture.

Native bivalves have been successfully used by Nelson (59) for detection of Strontium-90 contamination in the aquatic environment He found that the

> "Analysis of data derived from the specific ctivity of Sr" in shells (Unionidae) showed that Sr released to the Tennessee River system remained in solution and that concentrations to a distance of 500 miles from the release site can be predicted on the basis of dilution of contaminated White Oak Creek water by a contaminated Clinch Tennessee River water."

Corbicula might also provide data on zinc and/or copper pollution, since bivalves are known to accumulate these.

Hayashi (104)attempted to use Corbicula sandai to detect sulphur compounds in a river receiving rayon wastes etc Pao-Shu (106) found that oysters from the polluted Kaohsiung Bay (Formosa) contained 1,180 mg/kg copper compared to ordinary oysters at 5.6 mg/kg copper.

Tsuda et al (91) in a pollutional study of the Yodogawa River in Japan found Corbicula leana was found at a lower station which according to the biotic index was the least polluted of lower stations. Hayashi (103)found that C sandai began to disappear from the river side of Otsu City (Seta River) in Japan around 1935,

Ingram (35) discussed the various uses bivalves might have in biological assessment of stream pollution, Some of the disadvantages in the use of the Unionidae, both in chemical analyses and in interpretation of benthic samples in relation to stream pollution, are inherent in sampling methods Changes in water level coupled with migratory movements of the Unionidae offer problems which are not always recognized in reports on molluscan fauna, Tryon's (90) statement about difficulties in collecting Unionids is a classic:

> "Species inhabit all kinds of bottoms, pebbly, sandy, muddy, and gravelly. Some species even prefer narrow crevices in the rocky bottoms of streams, as the U. punctatus in the Cumberland River, and U. fascians in Powell River. The collector who is unwilling through fear of snakes, colds, or rheumatism, to don an old suit and 'wade in', or strip and dive if necessary, will do well to quit talking about collecting Unionidae. In many cases they

> will be found packed so closely in rocky or gravelly bottoms, as to enable one to soon take out bushels of them; they are thus plentiful in the Ohio, Clinch, Holston, and Tennessee Rivers."

The introduced clam is much easier to collect, because of its lack of habitat discrimination.

The possibilities of a commercial harvest for food has not been explored. At least the clam populations could support a non-commercial harvest for local use. *Corbicula* clams are considered a delicacy in the Orient.

The species which has developed in the United States might serve as a stock for introduction or development of a local fisheries in foreign waters.

Out of a total of 84,000 tons of fish and shellfish reported in 1962 inland-water landings in Japan, 28,776 tons were mainly from a good harvest of fresh-water clams from the Tone River estuary in Chiba Prefecture (102). The species was not mentioned but most probably was *Corbicula japonica.*

According to Cahn (7):

> "The most intensive fishing for this species (*Corbicula japonica*) occurs in the mouth of the Tone-gawa at Shiishiba, Chiba Prefecture. Here two methods are used; both involving the same gear, which consists of an iron rake, a basket, and a bamboo pole (fig. 33). In one method the dredge is held by hand at the stern of the boat and the boat is moved by means of a 100-meter loop attached to a winch and fixed to a pole planted in the bottom. In the second method two dredges are held by hand at the stern of the boat, and the boat is moved by means of a "water sail" measuring three by three meters. This sail is of canvas or other material, with a weighted frame below and a bamboo pole above to act as a float, Submerged, it drifts with the current, pulling the boat slowly along. The direction and speed is controlled by a dragging anchor."

The plate Cahn refers to above is an appendix to this report. (see p. 66).

IDENTIFICATION AND VARIATION

The genus *Corbicula* was recognized first in 1772 as *Tellina,* and since then has contained many names, now placed in the synonmy. By 1882 as many as 150 species were recognized. Prashad (70) listed 64 synonyms alone for *Corbicula fluminea*. The generic name has also been subject to much change, before being stabilized in 1811 as *Corbicula.*

The genus exhibits an interesting growth pattern which is also influenced by environmental factors. The species are notoriously variable in shell characters.

Local populations of a given species may appear to be distinctly different in shell outline and color. This phenomenon has been noticed by a number of investigators (Kuroda, Jutting) and outlined in detail by Prashad (70). The same species differ in these characters not only at a given locality but from one locality to another. As an example of this the Phoenix, Arizona specimens are identical with the Tennessee River species in life history etc, but quite different in shell characters, which have been so widely used as criteria. Using the old criteria of shell characters, no less than four varieties are present at Phoenix. This does not take into account shells of different sizes (age groups), as growth factors are involved here, the four varieties not being tracable to ontogeny.

It is possible, but very improbable, that more than one species is involved in the above mentioned five varieties (four from Phoenix, and one from Tennessee). One may take many series of freshwater Corbicula from Oregon, California, Arizona, and Tennessee and match nearly every species of freshwater Corbicula named!

The history of taxonomic studies on Corbicula is inextricably linked to these factors. Müller who named the genotype fluminea in 1774 gave the locality as "In arena fluviali Chinae", but the shells generally accepted as his cotypes are labeled "East Indies or China". During the years 1860 to 1878 Temple Prime described many species, basing these upon generally recognized shell characters. Investigators of his day gave little attention to specific locality, the anatomy of the soft parts, life cycle, and habitat. Although, Prime recognized some of the characters as being variable it was not until 1907 that Pilsbry pointed out the difficulty in defining species of Corbicula as follows:

> "Specific differences in Corbicula are not strongly developed, though a great deal of local differentiation is evidently in progress, so that one can almost say that every lot gathered has its own minor perculiarities. In this multitude of forms differing by slight, often hardly definable, characters, it is difficult to define conventional species."

Prashad in 1929 enlarged upon this, yet hesitated to place certain names in the synonomy. Kuroda in 1936 recognized this problem and gave specific recognition to only four species:

> "Many works were published and the numerous specific names were proposed for the Japanese Corbicula although it is very hard to define distinctly these species, since they show a number of local variations which are evidently in progress. No adequate account is given by any previous author for the problem, then the writer intended to group the Japanese species by the accurate examination of numerous specimens from various localities of Japan with his profound experiences. In my opinion the surface sculpture of the valves and the nymph of the hinge and the coloration of the interior of valves are regarded to be important criteria of specific diagnosis in Corbicula. The yellow and brown colors are worth to distinguish the species, but the yellow or black color on the surface has no practical value, because

> it is modified as the shell grows to large, the black rays on the young shell are also one of the important characters for the specific diagnosis. The outline of shell, however, is unreliable, because it is modified usually as the shell grows to large and it is remarkably affected by the environments."

In describing Corbicula sadoensis Pilsbry (62) states:

> "It fills me with sadness to add another Corbicula to the Japanese fauna, but these specimens cannot without violence be referred to any of those known."

Pilsbry referred to the many Chinese species described by Heude as an attempt to name every local form:

> ". . . a task I believe to be practically impossible, and if accomplished the result would be absolutely useless to any other zoologist from the impossibility of again recognizing the form." (64).

Fortunately the museum of Comparative Zoology of Cambridge, Massachusetts, contains types of most of Heude's species of Corbicula described in 1880 and illustrated with fine color plates (98).

Van Benthem Jutting (93) in 1953 defined this growth pattern for the Javanese Corbicula and illustrated two growth stages (gracilis and ducalis) which she correctly assigns to the species javanica.

Although Corbicula is readily separated as a genus by shell and anatomical characters, the species within the genus are poorly defined. Reliance on shell characters alone has produced an infinite number of synonyms. These species have been variously arranged by each authority with very little satisfaction. More recent workers, who were quick to point out the inadequacy of shell characters, nevertheless used these in separating the species. Until studies on anatomy and life history are made, the so-called species will be continually re-arranged with even less satisfaction. The use of shell characters alone produced nearly 20 species of Corbicula in Japan. By life history and ecologic studies these have successfully been reduced to three species, leana, sandai, and japonica. A fourth form awajiensis falls into the leana group. This same type of treatment should be extended to the genus Corbicula in the remaining part of its distribution.

Excluding Corbicula (Cyrenodonax) formosana Dall, the bulk of the species of Corbicula easily fall into three polymorph species (fluminea, manillensis and fluminalis) and one species (sandai) which apparently has arisen from the fluminea group. The distinguishing external characters are of limited value in separating these three, and it remained for Dall in 1903 to recognize that one group which he named as the subgenus Corbiculina had an entirely different life cycle than that of Corbicula s. s. Although he was correct in this, the shell characters he used for Corbiculina (smaller and more delicate) has not proven to apply to all species. Miyazaki, Oyama and Hirase and Taki place fluminea in the subgenus Corbicula s.s. and leana in the subgenus Corbiculina on the basis of reproductive and life history characters.

Relationships between the brackish water species of the genus Corbicula are not well defined. Dr. van Benthem Jutting comments on the process of conversion among fresh-water molluscs from marine to non-marine conditions, as follows:

> "In the opinion of various malacologists the bivalve family Corbiculidae forms a similar instance. It is true that many Malaysian Islands are inhabited by a number of Corbicula-species, yet there are no true marine ancestors from which they could be the descendents. Only the genera Polymesoda and Batissa belonging to the same family, live in brackish water, and in spite of their incorporation in the same family they are not direct relatives of Corbicula." (94).

The majority of the species of the genus Corbicula are restricted to fresh water. The brackish water species: lutea, luteola, and subsulcata are remarkably similar in shell characters. The life history details of these three should also prove to be similar and could well prove them to be in reality one species. It appears that the genus has brackish water forms only in the eastern section of its former range. Prashad (70) was of the opinion that the brackish water species, the lutea group and subsulcata had developed from a common ancestral type. The brackish water species are generally characterized by their method of reproduction and life history. These characters, dioeciousness, non-incubation of trochophores, and free-swimming veliger place them with other brackish and marine bivalves.

The reverse is generally true of the fresh-water species of Corbicula which are monoecious, incubatory, and have non-swimming veligers. Morton (58) mentions that all fresh-water bivalves appear to incubate the eggs, with the exception of Dreissenia, which has free-swimming veligers. Corbicula sandai of Japan is an exception to this in that it is non-incubatory. It is also dioecious and has non-swimming veligers.

The fresh-water species are remarkably tolerant and according to Prashad (70):

> "Species with very wide ranges of distribution and living in different types of habitats, varying from small ponds, pools, lakes, and sluggish streams to rapid running hill torrents with varying quantities of aquatic vegetation and mud in suspension and with different types of bottoms, differ greatly in form, texture, sculpture, and color of shells."

Corbicula sandai is apparently an exception in that it is restricted to the Lake Biwa system in Japan and requires a weak current.

The great variety of forms now found in the United States could be placed according to shell characters under many species, but the inescapable conclusion is that only one species has been introduced.

Although this introduced species has been generally identified as Corbicula fluminea, its sexuality and life history is not the same.

Dr. Habe, an authority on Japanese shells, has examined a large series of shells of the introduced species and concludes that it is not C. fluminea, though belonging to that group, and may come from China or the Philippines.

Dr. van Benthem Jutting, an authority on Indonesian shells, has also examined representative series from the United States and found them within the range of variation of Corbicula avanica Mousson.

The life history of the introduced clam in the Tennessee River is identical with manillensis. A series from the Pasig River (drains Laguana de Bay, figs. 103-106) is almost identical in shell characters with the Tennessee River clam.

Prashad (70) noted that manillensis was closely related to fluminea, but Talavera and Faustino (80) relegated it to the synonomy of fluminea. They could not justify its retention as a valid name for geographical reasons alone. But in fact manillensis belongs to the Corbiculina group I complex.

Corbicula fluminea and fluminalis both have the most widespread distribution of any species in the genus. Their distribution is almost continuous from Asia Minor to the Ussuri Basin in south eastern Russia. The former occupies the eastern half and the latter the western half. Forms intermediate between the two separate them in India. The possibility exists that the two may in reality be conspecific having a wide range very similar to Melanoides tuberculata Muller (see map 2, p. 253 Pilsbry and Bequaert, 65). Apparently little is known concerning the biology of fluminalis.

As a result of these problems the study of speciation within this group has made little progress.

Prashad (70) made a real contribution to a more stable nomenclature of this group by pointing out the difference that exists between what he calls "young", "half-grown", "still older", and "adult shells". Earlier workers had simply failed to take this into account by naming every intermediate growth stage as a new species. There is a good possibility that Dall's subgenus Cyrenodonax of which formosana is the only species will prove to be only the young stage of Corbicula (Cyrenobatissa) subsulcata. Both have the same life history characters and are found in the mouth of the Tansui River on Formosa. The smaller stages of subsulcata have not been described. In view of the fact that at least one species of Corbicula becomes sexually mature and produces young at a size of 10 mm, the terms young and adult ambiguously refer to growth and longevity rather than maturation. The age limits of Corbicula have not yet been determined, but some of the Unionid mussels have been recorded to be as old as 40 years. Prashad (70) places woodiana in the synonomy of fluminea, and according to him:

> . but the connecting forms, which I figure on plate VII, leave no doubt that C. woodiana is only the adult of C. fluminea."

Suzuki and Oyama (85) placed this species with subsulcata in the subgenus Cyrenobatissa

> "Hier noch einige neue Ansichten; Batissa steht Corbicula sehr nahe und wenn auch die beiden

typischen Formen leicht einzuteilen scheinen, ist doch die Gruppe der sogenannten Batissa (z. B. B. triquetra, B. obtusa usw.) von grossen sogenannten Corbicula-Arten (z. B. C. subsulcata, C. woodiana usw.) kaum verschieden. Für diese Gruppe, die in der Mitte zwischen Corbicula und Batissa steht, schlagen wir eine neue Section Cyrenobatissa vor."

The shells of both woodiana and subsulcata in the 45 to 83 mm size group are identical. (See 70, Prashad fig. 10, plate VII; 73, Prime, fig. 59, p. 227; and 87, Tan fig. 4 and 6). The maximum size recorded for both subsulcata in the estuary of the Tansui River and woodiana from Canton, China is 83 mm. The maximum size recorded both for C. fluminea in Korea and C. japonica in Japan is 40 mm. The subgenus Corbiculina (leana, manillensis, javanica, and vicina group) reaches a size of from 36 to 50 mm. According to Ingram (36) the maximum size reached by Corbicula in the Tuolumne River in California is around 50 mm.

While there seems to be no problem with the correct placing of the name C. fluminea, the nomenclature of the C. leana-vicina species is more involved. With only the shell characters associated with names prior to Miyazaki's work (56) the problem becomes acute, particularly with the latter group.

Müller's fluminea is generally accepted as being identical with fluminea of Miyazaki (56), Suzuki and Oyama (85), and Oyama (60); although this association cannot be proven since no shell characters can separate the two most closely related sections of Corbicula s. s. eg. Section Corbiculina (vicina etc) and Section Corbicula s. s. (fluminea etc).

In view of the long continued usage of fluminea it would probably be wise to retain the name in association with Oyama's (60) classification.

The Corbiculina section presents even greater difficulty since association with a particular name has not been consistent. Müller's fluviatilis is available and tototypes have been selected which are within the range of distribution and variation of this section. Again in the absence of any life history or anatomical characters a definite association with fluviatilis cannot be made. Apparently the earliest name available is C. manillensis Philippi 1841. The name is definitely associated with section Corbiculina in reproductive and anatomical characters. The following abbreviated synonymy is suggested:

Family Corbiculidae.
Genus Corbicula Suzuki and Oyama, 1943.
Subgenus Corbicula s.s. Suzuki and Oyama, 1943.
Section Corbiculina Suzuki and Oyama, 1943.

Corbicula manillensis Philippi

1841 Cyrena manillensis, Philippi, Zeitschr. Malakozool., p. 162.
1849 Cyrena orientalis var. javanica, Mousson, Land & Sussw. Moll. Java, p. 86.
1864 Corbicula venustula, Prime, ALNHNY, p. 73.
1880 Corbicula vicina, Heude, Conch. Fluv. Nanking et Chine Centrale.
1884 Corbicula leana, Prime, ALNHNY, p. 68.

1929 Corbicula fluminea (in part), Prashad, Mem. Ind. Museum.
1929 Corbicula manillensis, Prashad, Ibid, p. 51.
1938 Corbicula leana, C. awajiensis, C. producta and C. papyracea (not colorata), Kuroda, Venus 8:35.
1943 Corbicula vicina and papyracea, Oyama, Venus 12: 155-156.

Although Oyama (85) recognized that vicina, leana, and awajiensis scarcely differed he did not place them in the synonomy

> "C. (Corbiculina) vicina Heude (Taf. 5, Abb. 6) steht zwischen den japanischen Arten, C, leana Prime und C. awajiensis kaum unterscheiden und die alte kaum von C. leana. Ich bin nicht in der Lage, die Frage über die Beziehung dieser drei Arten zu entscheiden."

There can no longer be any justification for the continued use of essentially geographic names for the polymorph species of Corbicula which is characterized as being monoecious, with modified inner gill lamellae for incubation of the young, with non-swimming veligers, and typically freshwater. This same introduced species which is now found over much of the United States is a vital demonstration of the danger of relying solely upon geographical and morphological shell characters for the diagnosis of Corbicula species,for our species exhibits nearly every one of the ecophenotypes described in Corbiculina.

According to McMichael and Iredale (50) there are 17 species of Corbiculina in Australia, named on the basis of morphological variation, which could be reduced to a few widespread species. Two of these australis and maroubra are figured by McMichael (49). Both appear to be within the range of variation exhibited by the United States species.

Taxonomic work on these clams has been based mainly upon shell characters.

Prime (72) in speaking of the pallial sinus notes that

> "This is a character derived from the soft parts, though the knowledge of it is conveyed to us by an examination of the shell."

Although he proposed to separate the American Corbicula from those from other regions on the basis of this character, he urged caution because:

> " .....it is possible that too much importance has been attached to this feature."

Prime (74) based his caution upon a paper by Fischer, on the anatomy of Corbicula largillierti. Fischer dissected alcoholic specimens of this species which possessed a rudimentary siphonal muscle. Prior to this the absence of a pallial sinus in Corbicula had indicated that the siphonal muscle was absent, and consequently there would be no siphons.

Marshall (51) states:

> "The two chief facts which have been discovered in the Corbiculidae since the time these molluscs were segregated into a family by themselves, lie in a discovery made by Prime and a later one made by Dall."

Prime's discovery was the observation on the absence of the pallial sinus in Corbicula from other regions. Dall observed that two species from Uruguay were viviparous. Marshall also observed two more species from Uruguay that were viviparous.

Although the pallial sinus is not well marked in the introduced Corbicula, they do have very well developed and retractile syphons. The high umboned series from Trotter's Ferry have a marked indentation in this area.

Kuroda's revision (46) was based primarily upon shell characters; the surface sculpture of the valves, the hinge of the nymph, valve interior color, yellow and brown colors on the surface, and the black rays on the young shell.

Other possibilities for separating the species would be sexuality, differences in spermatozoa, and early life history stages.

The occurrence of the incubatory and non-incubatory condition in a series of clams from Newman, California, introduce the possibility that this character may not be a constant with a given species. This series of clams presumably involved only one species.

In a very closely related family (Sphaeriidae) Heard (28) stated that:

> "There is some evidence at present which implies that life histories of sphaeriid clams are geographical (latitudinal) in nature and may eventually have to be discarded as a taxonomic criterion. Further life history data are required."

Materials

The majority of the anatomical and life history observations were made on specimens of Corbicula from the Tennessee River (102.4 river mile), Kentucky Lake, at Trotter's Ferry Landing on the west side of the river in Benton County, Tennessee. Observations on other populations are identified as to locality. All measurements referred to are in millimeters and apply to the greatest length of the shell.

(1) Tennessee River, Wheeler Reservoir, Alabama. 1960. Collected by John L. Gallagher.

(2) Fresh water canal. Phoenix, Arizona. October 1962. Collected by Dr. Gerald Cole.

(3) Newman Wasteway, Delta-Mendota Canal; Stanislaus County; Newman, California. November 1962. Collected by R. Nicklen

(4) Sacramento - San Joaquin Delta, app. 8 miles East of Antioch, California. November 14, 1962. Collected by W. A. Dahlstrom.

(5) Columbia River. Bonneville Dam. Oregon. 1950. Collected by I. Donaldson. (exchange from U.S.N.M.)

(6) Corbicula sandai. Lake Biwa. Shiga Prefecture, Japan.

(7) Corbicula leana. Yoshida Village, Shizuoka Prefecture, Japan.

(8) Corbicula japonica. Mouth of Edo River. Urayasu, Chiba Prefecture, No. 6 - 8. Presented by Dr. A. R. Cahn.

(9) Phoenix, Arizona Country Club. Collected February 27 and March 19, 1963 by George E. Harrington.

(10) Corbicula (Cyrenodonax) formosana Dall, Tansui, Formosa. MCZ 44756.

(11) Corbicula insularis Prime. Formosa MCZ Paratypes 175645. (fluminea)

(12) Corbicula bocourti Morelet. Haiphong, Tonkin North Vietnam. (listed as fluminea) MCZ 103356.

(13) Corbicula venustula Prime. Manila, Luzon, Philippines, MCZ Paratypes 187465. (manillensis)

(14) Corbicula elatior Van Martens. Kaschimpo, 5 miles N. of Kuchin West Coast of Korea. MCZ 172894. (japonica).

(15) Corbicula ducalis Prime. Lent Agoeng near Djarkta. (Java) Indonesia. (manillensis)

(16) Corbicula leana Prime. Kiso River. Japan. MCZ 19027. (manillensis)

(17) Corbicula japonica Prime. Tsu Ise Japan. MCZ 81223.

(18) Corbicula manillensis Philippi. Pasig River. Manila, Philippines, exchange from MCZ.

(19) Polymesoda caroliniana Bosc. Swan's Point Surry Co., Virginia. Cypress James River. April 20, 1947. Col. J. P. E. Morrisson.

Map two showing the world range of Corbicula was taken directly from Simpson with the red overlay modified from Pilsbry and Bequaert (65). Map one showing the distribution of Corbicula etc. in the Tennessee and Cumberland River Valleys has as base, a map prepared by TVA. Both are used by permission as cited in the acknowledgement.

All photographs of the shells (excepting the one of Dreissena) were taken directly from actual specimens by the Polaroid Land Camera using the Polaroid print copier The specimens were mounted on white cards, inserted into the back of the print copier, and the picture taken on film type 42. The advantage of this type of photography is that the resulting photographs are actual size and immediate results may be obtained with the proper contrast. The photographs as well as the specimens have not been retouched in any way. The exceptions to this are the photographs showing the interior of the valves of *Polymesoda.* The shells are marked on the pallial line and muscle scars to show these features. The photographs were carefully cut and mounted on white stock for comparison. All are reproduced actual size. All photographs were taken by the junior author. The maps, line drawings, and plates were done by the senior author.

Figure 143 is reproduced through the courtesy of the *Linnean Society* of *London,* and is from Ellis, A. E., British Fresh-water Bivalve Molluscs *(Synopses* of the *British Fauna* No. 13, 1962.). Figure 144 has been adapted from Tryon (59). The photographs used in Plate 14 are by Robert Moore, Tennessee Game and Fish Commission.

SUMMARY

Corbicula manillensis is now found in a variety of habitats in the Ohio River Basin. It has become firmly entrenched as a dominant species in the invertebrate fauna.

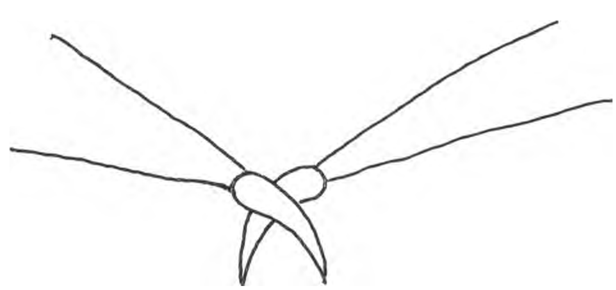
The shell varies, as in most *Corbicula* species, in color, pattern, size, and form depending on the environment. The maximum size reached thus far in Kentucky Lake is 43 mm.

The clam has been found to be monoecious and incubatory, the inner gill lamellae being modified as a marsupium. The larvae discharged as veligers are non-swimming, and may utilize a byssus for attachment. These details place it with *leana* rather than *fluminea.*

The short term planktotrophic larvae in the current are particularly apt to be carried into raw water intakes, clogging the system as the larvae attach and grow to adults.

Corbicula has become a nuisance in the Ohio River Valley by clogging industrial water lines in private industries and TVA steam plants. The bodies of these clams have also obstructed traveling screens at a municipal water supply plant.

Chlorination of raw water systems has been found effective. Critical times for control measures may easily be determined by periodic sampling and analyses of plankton in the raw water during and just prior to the spawning season.



CONCLUSIONS

1. The Tennessee River *Corbicula* exhibits two environmental forms with gradations between the two.

2. Only one species is involved, and there is only the remote possibility of a future second introduction of another species.

3. The Tennessee River Clam is assigned to group I *(Corbiculina)* on the basis of sexuality and life cycle.

4. The species introduced into the United States is placed in the synonomy of *Corbicula (Corbiculina) manillensis*, Philippi. 1841. along with C. *leana*, C. *vicina*, C. *fluminea* (in part), and C. *javanica*.

5. *Corbicula* will rapidly advance into all major streams in the Tennessee and Cumberland River Valleys, excepting some which are grossly different in water quality.

6. The veliger larvae (size 160 to 220 micra) are discharged into the water by the adult clam in large numbers.

7. The veliger larvae are short term planktotrophic, and non-swimming.

8. Plants dependent on surface streams and reservoirs for water supply will draw into their systems large numbers of veliger larvae during the spawning season, June to November.

9. The larvae drawn into such systems will be a continual nuisance unless remedial measures are taken.

10. Veligers lodging within a system may not be easily noticed until they reach a larger size, by continued growth inside the system.

11. The elimination of such infestations will be much more difficult after a build-up is allowed.

12. Continuous chlorination of raw water during the spawning season will be necessary to control this clam.

13. Substrate is not a limiting factor in the distribution of this species, however, firm substrates are not as productive as sand-mud substrates.

14. *Corbicula* has been able to manifest itself in many new drainage areas, with widely varying parameters of water quality.

15. Sufficient chlorine added to influent water to maintain a 1.0 ppm chlorine residual for a period of three weeks should eliminate clam infestations. This treatment may prove to be more effective if implemented during the latter part of the spawning season.

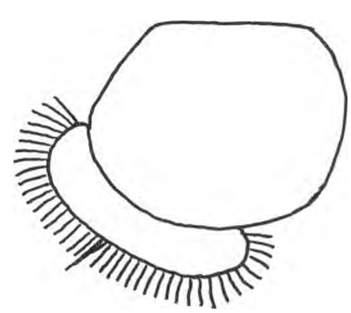
16. Water users that already have a problem with clams will have to remove dead shells by flushing or by mechanical means. Other water users should prepare for nuisance control.

RECOMMENDATIONS

1. Users of surface water supplies in Tennessee are faced with the possibility of drawing in tremendous numbers of veliger larvae during the summer months. The problem may be anticipated if plankton samples are taken periodically, beginning prior to the spawning season and more frequently during the spawning season. One gallon samples of the raw water should be concentrated by plankton net or centrifuge, and the concentrate examined in a Sedgwick-Rafter cell under the 10X objective of a microscope. Samples taken from various sections of a water system for plankton analysis should reveal the effectiveness of a control program.

2. Plankton techniques as outlined in detail in <u>Standard Methods</u> for the <u>Examination</u> of <u>Water</u> and <u>Wastewater</u> (1) are recommended.

3. Water which has been treated in clam control programs should be returned to the stream free of any molluscacide.



ACKNOWLEDGEMENTS

The following personnel of the Tennessee Department of Public Health were especially helpful: Messrs. S. Leary Jones, Director, and Harold N. Mullican, Chief Biologist, scheduled the time necessary to carry out the project. In addition Mr. Mullican collaborated in the collection of study material and in bioassay. Miss Patricia A. Mason, Secretary, typed the manuscript and final master sheets; Mr. Allie C. Farmer and his efficient staff made the plates and printed the report; Mrs. L. B. White, Librarian, secured published material; Mr. Harold T. Sansing, Junior Biologist, assisted in dredging and sample analyses; and Mr. O. D. Keaton, Chief Chemist, provided chemical analyses. Mr. David Choi, Division of Laboratories, translated several sections of some Japanese papers.

We extend thanks especially to Dr. A. R. Cahn who provided comparative specimens of Japanese Corbicula and gave assistance in Japanese references.

Drs. Tadashige Habe and Ichiro Miyazaki patiently answered innumerable questions concerning Japanese Corbicula. In addition Dr. Miyazaki provided a copy of an English synopsis of his important paper. Dr. Tokubei Kuroda generously shared his reprints on Corbicula.

The loan of literature and/or specimens were generously provided by Miss Virginia Orr; Drs. Harald A. Rehder, Joyce E. Rigby, A. E. Ellis, Gerald A. Cole, Wendell O. Gregg, J. D. Andrews, H. B. Baker, D. F. McMichael, A. Fuji, John E. Fitch, D. S. Dundee, Kazumasa Hayashi, Max R. Matteson, D. F. Yung, Deogracias V. Villadolid, C. B. Wurtz, D. W. Taylor, Gunnar Thorson, Olga Sebesty6n, H. B. Herrington, H. B. Orcutt, W. M. Ingram, W. S. S. van Benthem Jutting, B. W. Sparks, Ludwig Hasslein; Messrs. John L. Gallagher, Aurthur J. Innerfield, Walter A. Dahlstrom, Ray Don Estes, and L. J. M. Butot.

Dr. Faustino T. Orillo, Editor of the Philippine Agriculturist generously granted permission to reproduce the plate in Dr. Villadolid's paper. Mr. Paul H. Oehser, Chief of the Editorial and Publications Division, Smithsonian Institution gave permission to reproduce Simpsons map. We especially thank Mr. Sherrod East, Director of World War II Records, USNARS, for making Dr. Cahn's papers available; and Dr. Thomas C. Grady of the Linnean Society of London for granting permission to reproduce the figure of Dreissena.

Mr. Keith B. Clarke of the Great Yarmouth Water Treatment Plant was of invaluable assistance in providing practical data on the control of D. polymorpha. He also provided a translation of Korschelt's paper.

The continued aid of Dr. W. J. Clench in locating and loaning references and material from the Museum of Comparative Zoology is gratefully acknowledged.

Dr. Myra Keen answered innumberable questions; Mrs. E. W. Swint of the Joint University Libraries assisted in locating references; Mr. Mamoru Ishikawa generously translated sections of Kuroda's paper; Messrs. Calvin Barstow, Bill Turner, John Condor, and Dr. Glenn Gentry of the Tennessee Game and Fish Commission; Dr. Milo Churchill, Messrs. Ben Jaco, Jack Chance, and Harold Elmore of the Tennessee Valley Authority;

Mr. Harry Stuart of the Cumberland River Sand and Gravel Company; Mr. Chin-cheng Chen, National Taiwan University; and Dr. Katura Oyama; Dr. N. N. Akramowski; provided information essential to this report.

We wish to thank Mr. Yoshimichi Kozuka for his translation of Kuroda's revision and extended consultation on that paper.

The information provided by Messrs. Oscar Waldkirch, J. L. Bell, and H. Sargent of the E. I. duPont de Nemours Company was greatly appreciated.

This assistance is gratefully acknowledged by the authors.

Through the gracious cooperation of Mr. M. L. Roonwal, Director of the Zoological Survey of India and Mr. Will'am O. Baxter, American Consul General we were able to examine most of the comprehensive papers on Asiatic <u>Corbicula</u> by Prashad.

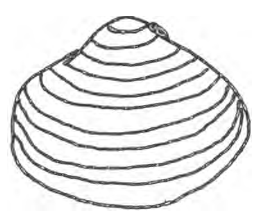


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Table 1

Observations on Corbicula by Miyazaki (37) *

Group	Species	Habitat	Sample Locality	Sexuality	Reproduction	Larvae
	C. leana		Central Japan			
	C producta	Fresh-water	Korea	Monoecious	Incubatory	Non-swimming
	C. awajiensis		Central Japan			
	C. insularis (1)(2)		Formosa			
TI	C sandai (3)	Fresh-water	Central Japan	Dioecious	Non-incubatory	Non-swimming
III	C japonica (3)(5)		Central Japan			
	C jap_ sadoensis		Hokkaido (Japan)			
	C elatior	Brackish	Korea	Dioecious	Non-incubatory	Free-swimming
	C fluminea		Formosa			
	C. maxima		Formosa			
	C (Cyrenodonax) formosana (4)		Formosa			

(1) Becomes brackish at flood tide
(2) Sexuality uncertain.
(3) Some specimens have radial color stripes on the surface of the shell
(4) All specimens have radial color stripes on the surface of the shell
(5) According to personal communication of Dr Miyazaki this species has been reported to invade fresh-water habitats in N Japan

* Translated by Dr. Ichiro Miyazaki.

Table 2

Correlation of Natural Groups Within the Subgenus <u>Corbicula</u> s.s. Oyama 1943

Subgenus Corbiculina Dall 1903	Subgenus Corbicula s.s Dall 1903
Group I, Miyazaki. 1936,	Group II, Mivazaki. 1936
Subgenus Corbicula s,s. Ovama. 1943	
manillensis Philippi. 1841	fluminea, Muller, 1774
(=vicina)	(=suifunensis)
(=leana) Ecophenotypes	(=felnouilliana)
(= avanica)	etc,
etc. Introduced in the United States	
fresh water generally monoecious incubatory development slower than marine bivalves size to 50 mm approximately	brackish water generally dioecious non-incubatory development as marine bivalves generally size to 40 mm approximately
Shell characters are of little value in separating these two species.	

Table 3

Variations in Corbicula Shell Characters

Corbiculina (=Miyazaki Group I) *

Outline - trigonal to ovate umbo located near median, anteriorly or posteriorly.

Posterior Margin - rounded, rostrate, or truncate

Shell Diameter - inflated to depressed

Umbo - elevated to low,

Valve thickness - thin (outer sculpture shows through inside of valve) to thick

Color of Porcelaneous Inner Shell - white, purple, salmon pink, with shades in between May be bicolored, the section below the pallial line being more intense in color.

Color of Periostracum - black, yellow, orange, brown, yellow green; shell sometimes bicolored due to earlier growth section being darker or lighter, dull or polished

Color Pattern of Outer Shell - purple beak ray present or absent, lunule and escutcheon prominent to poorly marked; when all three show on one valve it gives the appearance of being three rayed.

Cardinal Teeth - little variation,

Lateral Teeth - anterior right upper lateral deflected at anterior end or straight.

Nymph - regular corrugations, granular, or smooth.

Ligament - short to long,

Sculpture - heavy and widely spaced to fine and narrowly spaced

* All of these characters are to be found in different combinations in local populations of the Corbicula manillensis introduced into the United States. The many species of Corbicula (Corbiculina) are nothing more than ecophenotypes.

Plate 1 CALIFORNIA **CORBICULA**

Plate 2 ARIZONA CORBICULA

15 16 17 18 19 20

high umbo, coarse sculpture, white within

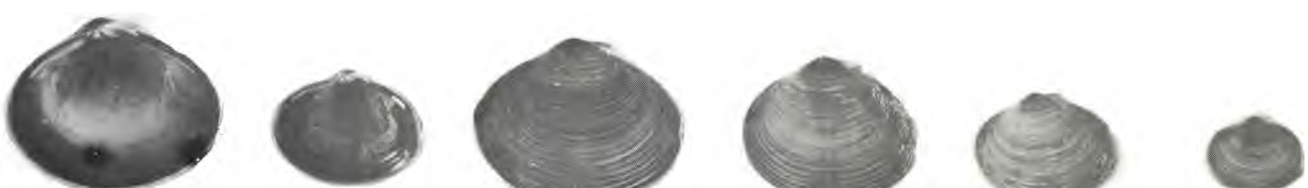
21 22 23 24 25

low umbo, fine sculpture, purple within

Phoenix (15-25) trigonal, thick shell

26 27 28 29 30

high umbo, coarse sculpture, white within



31 32 33 34 35 36

low umbo fine sculpture, purple within

Phoenix Country Club (26–36) ovate, thin shell

Plate 3 OREGON AND TENNESSEE **CORBICULA**

37 38 39 40 41

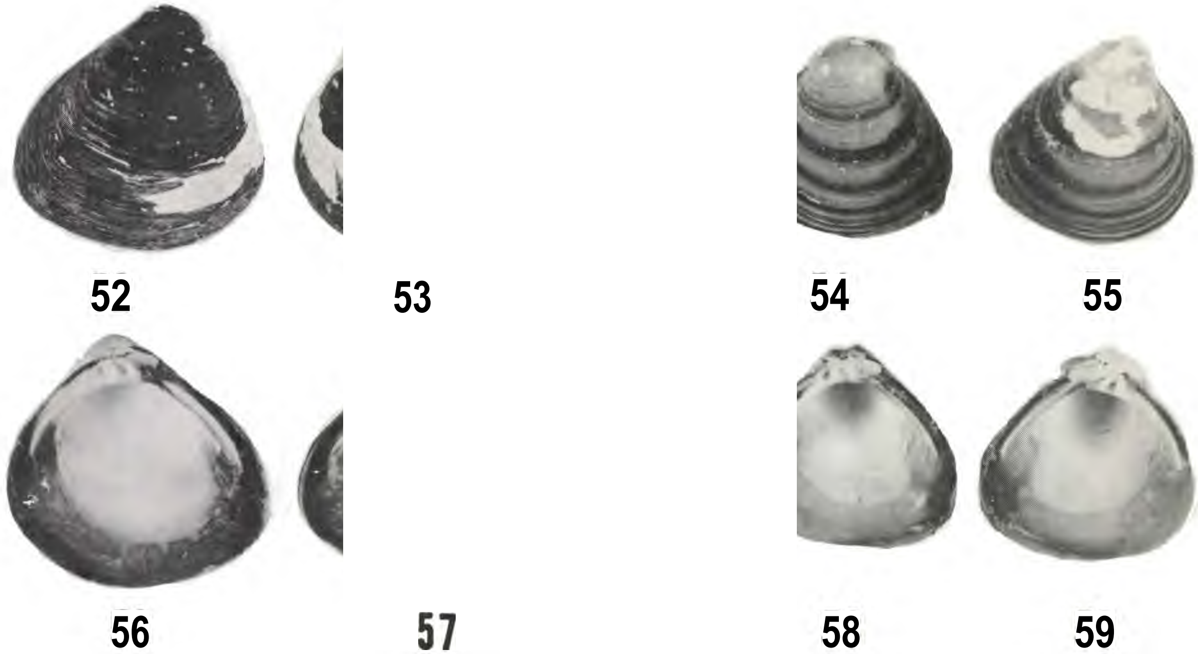
Oregon, Bonneville Dam (31—41)

42 43 44 45 46 47

48 49 50 51

Tennessee, Trotters Ferry (42-51)

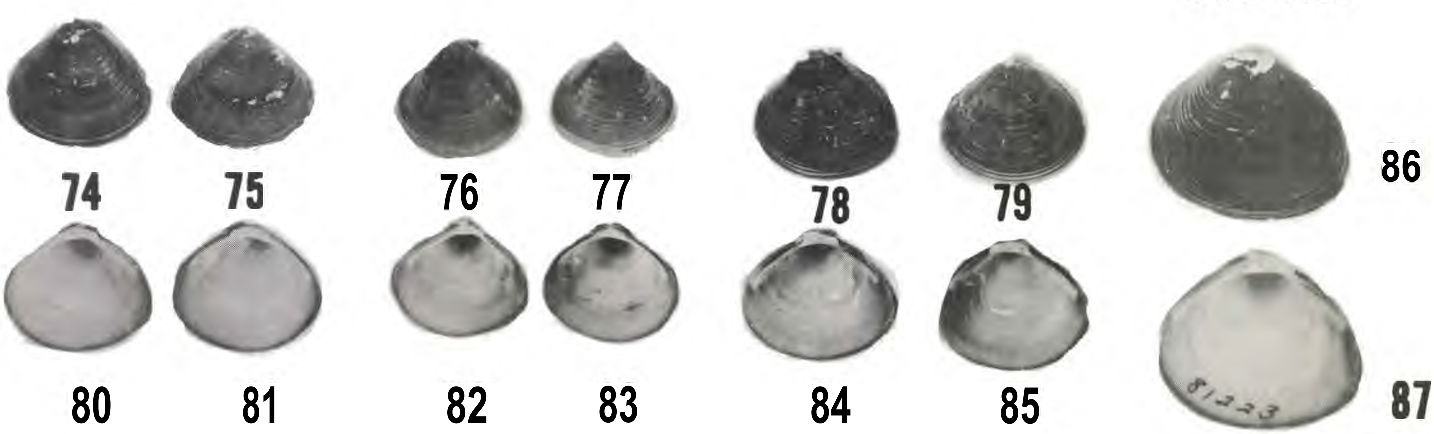
Plate 4 JAPANESE CORBICULA



Corbicula sandai Reinhardt. 1818. "Setashijimi" Lake Biwa. Shiga. Japan. (52-59)

Corbicula leana Prime. 1864. "Mashijimi". Yoshida. Shizuoka. [60–71] Kiso River 72–73

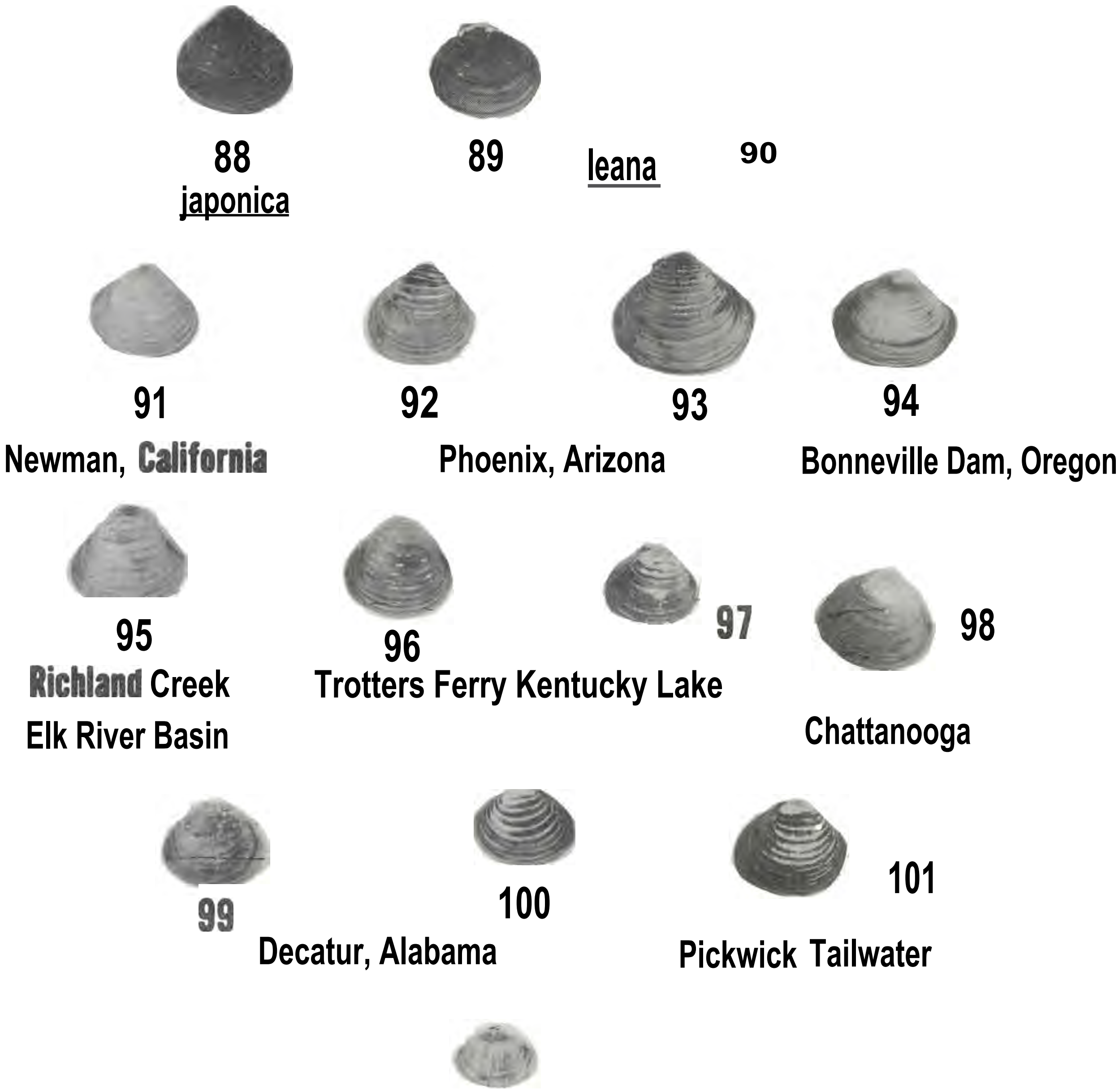
MCZ 19027



Corbicula japonica Prime. 1864. "Yamatoshijimi". Yedo River. Urayasu. Chiba [74–85].

Tsu Ise (86-81 MCZ 81223)

Plate 5 YOUNG CORBICULA



Sycamore Creek Embayment Cheatham Reservoir Cumberland River

(96-101 Tennessee River)

Plate 6 ASIATIC **CORBICULA**

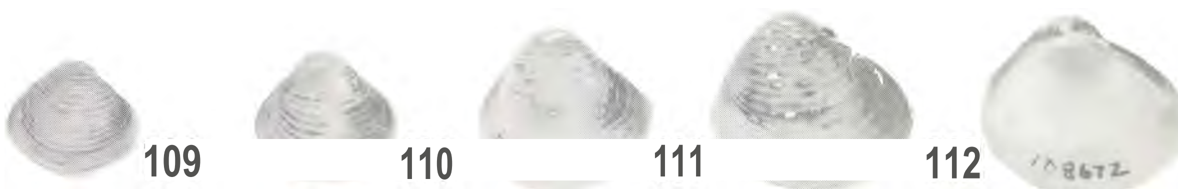
103 104 105 **106**

Corbicula manilensis Philippi. 1841. "Tulla". Pasig River. Manila. Luzon. Philippines.

MCZ 187465

107 108

Corbicula squalida Deshayes. 1854. Manila. Luzon. Philippines.paratype venustula Prime. 1864.



109 110 111 112 113

Corbicula ducalis Prime. 1862. **Lent** Agoeng. **Java.** (near Djakarta) MCZ **108672**

114 115 116 **117**

Corbicula elatior v. Martens. 1905. Kaschimpo. 5 m N Kuchin. W coast Korea. MCZ **172894**

Corbicula insularis Prime. 1861. Formosa. MCZ **175645** paratype

118 119 120 121 122 123

Corbicula bocourti Morelet. 1865. MCZ 103356. Haiphong. Viet—Nam.

Plate 7 SHELL CHARACTERS

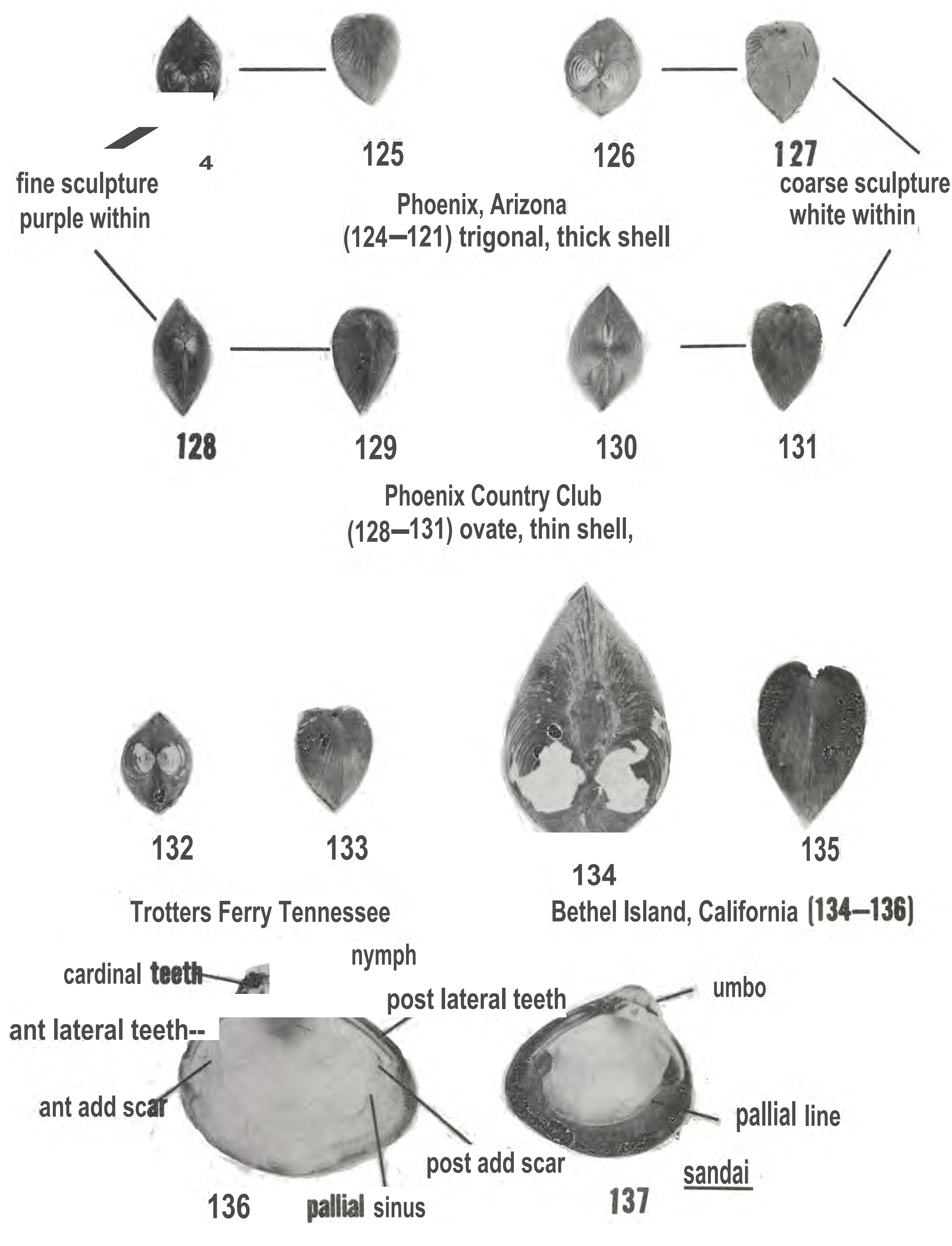
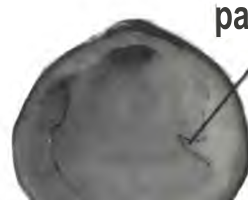


Plate 8 RELATED PELECYPODS

138

139



140

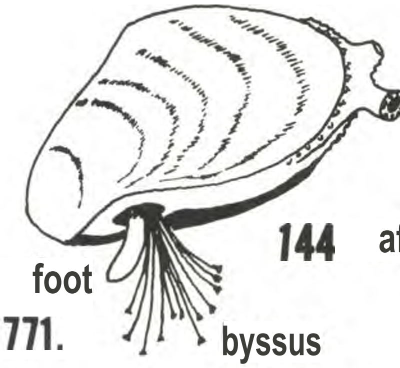
141

Polvmesoda caroliniana Bosc. 1807. James River,

142

Sphaerium fabale Prime. 1851. Browns Creek. Davidson County, Tennessee.

Oxford, England 143



144 after Tryon

Dreissena polymorpha Pallas. 1771.

145

Leptodea laevisima Lea. 1830.

146

Leptodea fragilis Rafinesque. 1820.

147

Anodonta imbecilis Say. 1829.

148

Pleurobema cordatum Rafinesque.1820.

145-148 Trotters Ferry. Kentucky Lake.

Plate 9 LIFE HISTORY OF CORBICULA IN TENNESSEE

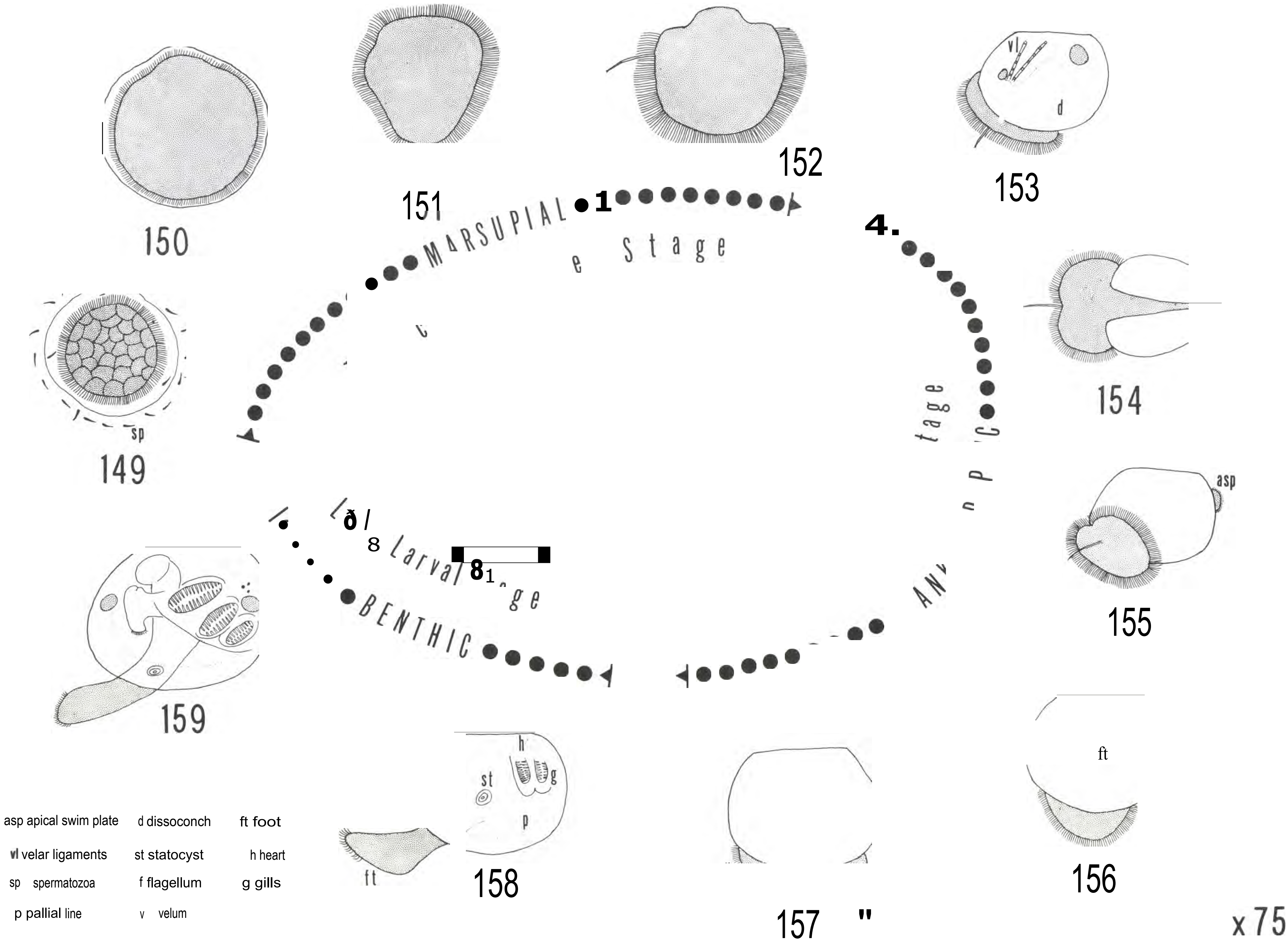
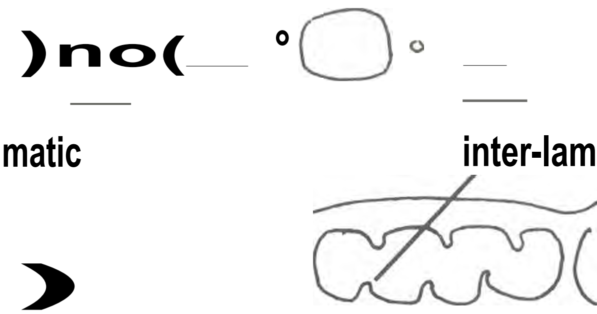


Plate 10 LIFE HISTORY DETAILS

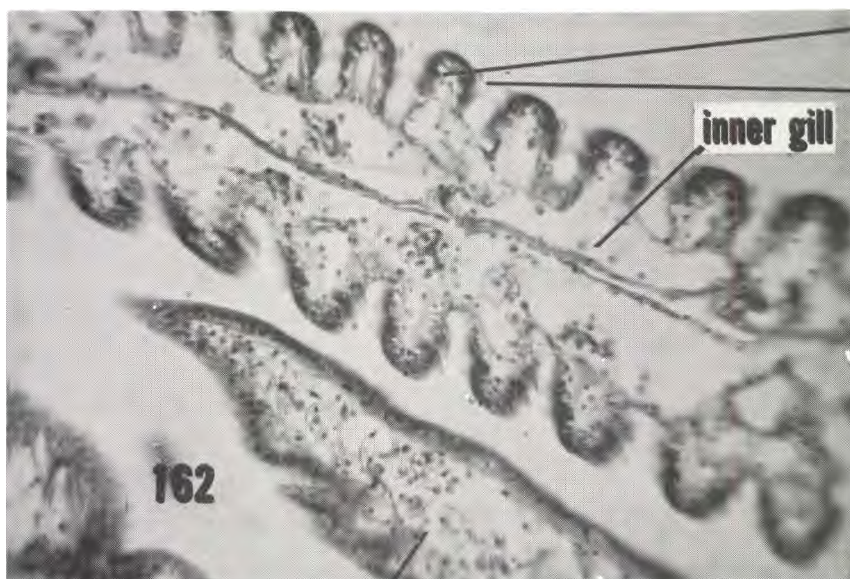
160

161

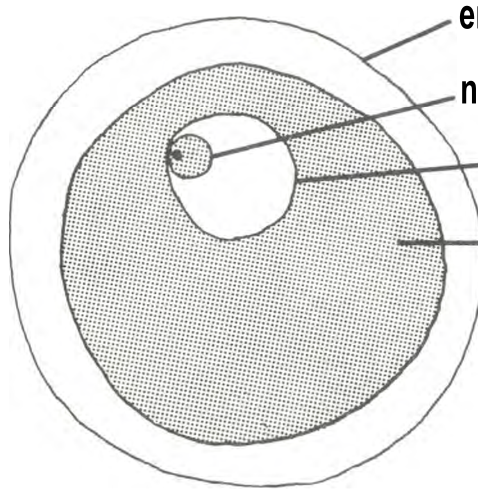


diagrammatic

Trotters Ferry (160-162) Tennessee



cross section



163 mature ovum (Phoenix)

Plate 11 LIFE HISTORY DETAILS

165

167

169

Trotters Ferry (169–172)

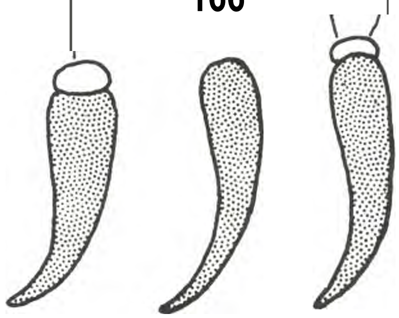
168

164

166

Pleurobema cordatum

(from 148)



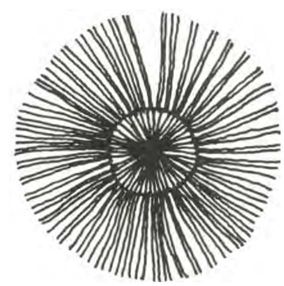
leana

Phoenix sandai

manilensis Trotters

Country Club

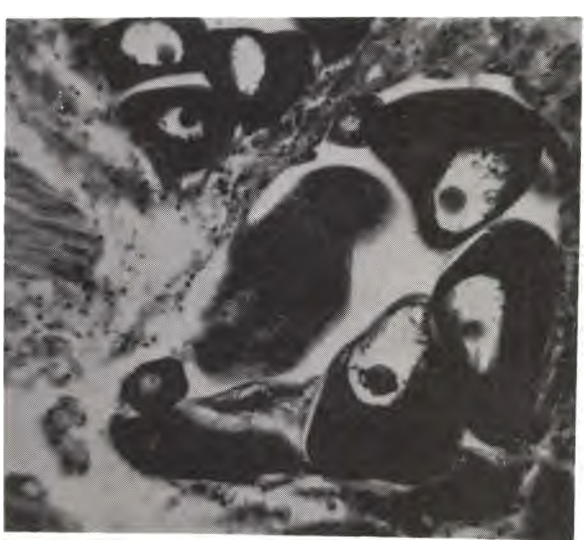
I 2000



170

500

spermatozeugma



171 cross section of of ova

250

172

cross section of acini containing sperm and

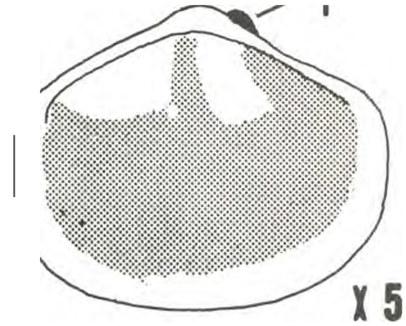
formation of spermatozeugma

Plate 12 MORPHOLOGY

173

174

175



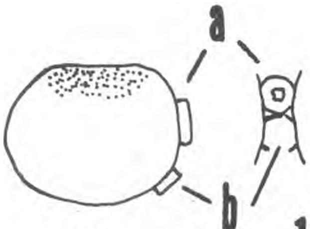
176

Inner shell pattern development

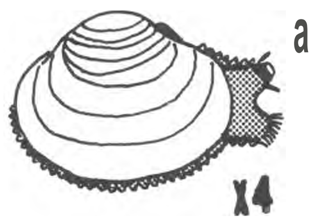
(Pickwick Tailwater)

Shelbyville, Duck River

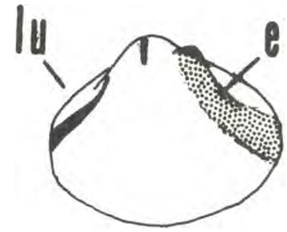
150



177 178



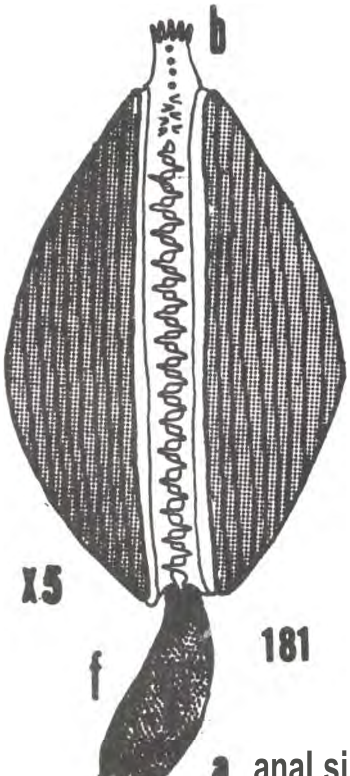
179



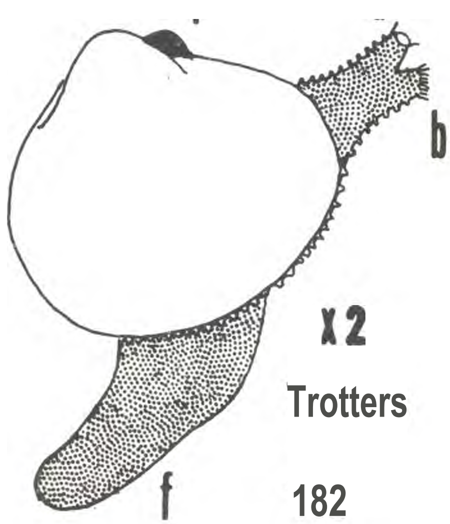
Newman

180 X 2

Siphon development

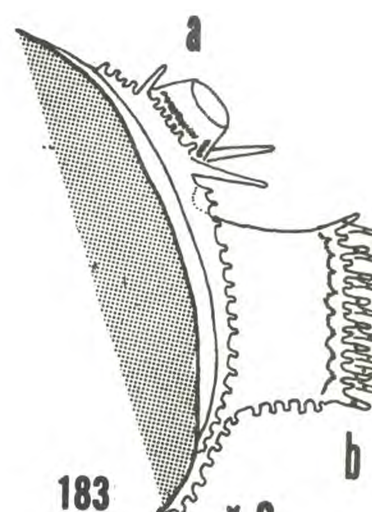


181



Trotters

182



183 X 8

a anaLsiphon b branchial siphon l ligament lu lunule e escutcheon f foot

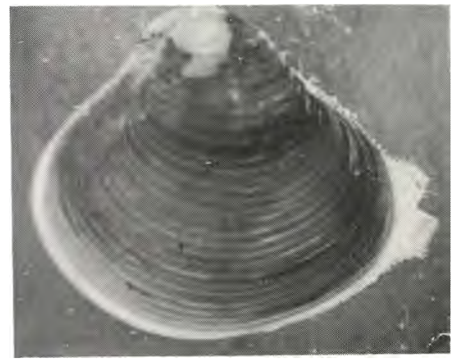
181, 183 Phoenix CC (31-36 series)

Plate 13 EXTERNAL MORPHOLOGY

184

185

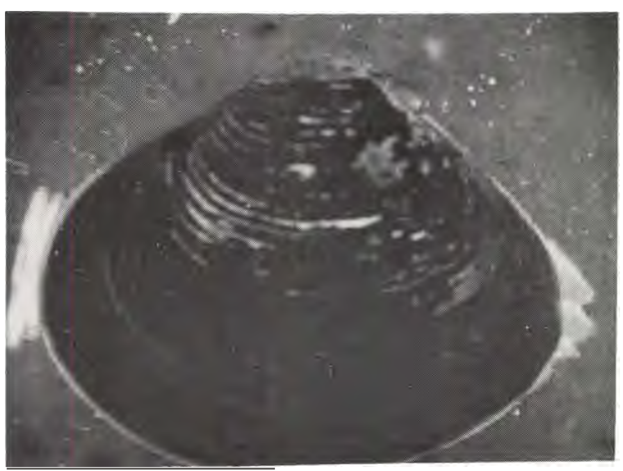
Phoenix , Arizona Country Club



186

Trotters Ferry

x 1.5

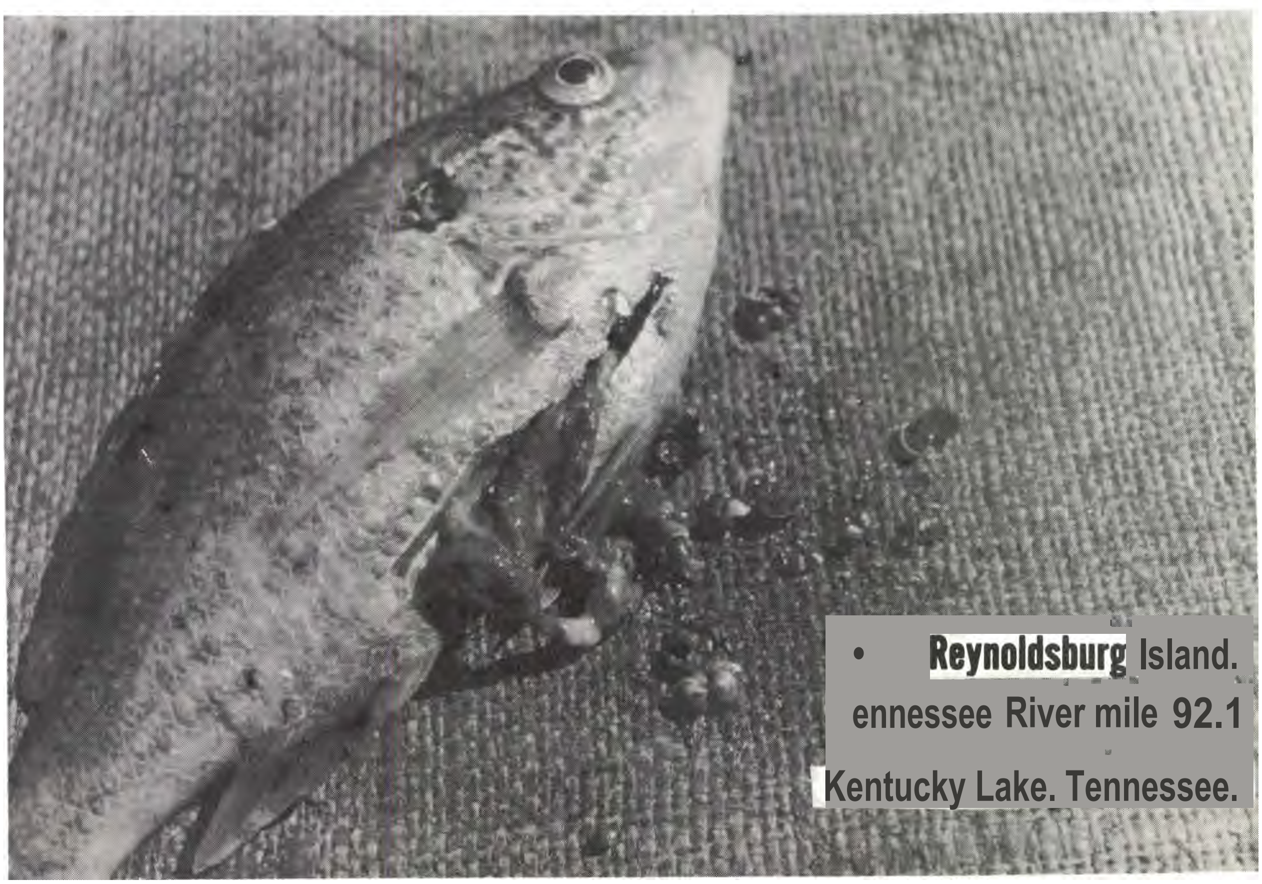


187

abnormal specimen from Newman, California with double branchial siphon

Plate 14 IMPORTANT MOLLUSC PREDATORS UTILIZING CORBICULA

188 Blue Catfish Ictalurus furcatus LeSueur

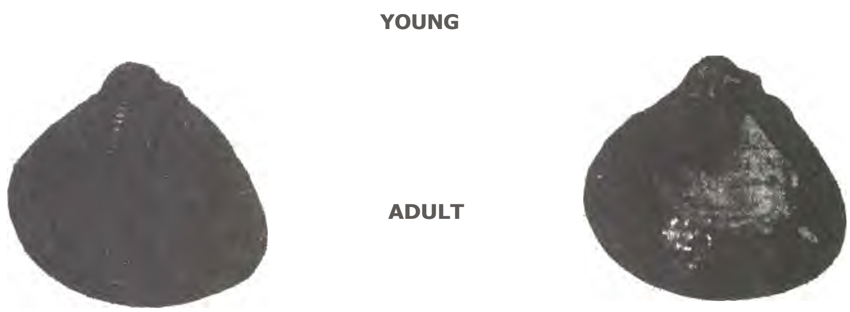


189 Redear Sunfish Lepomis microlophus Gunther 3/4 actual size

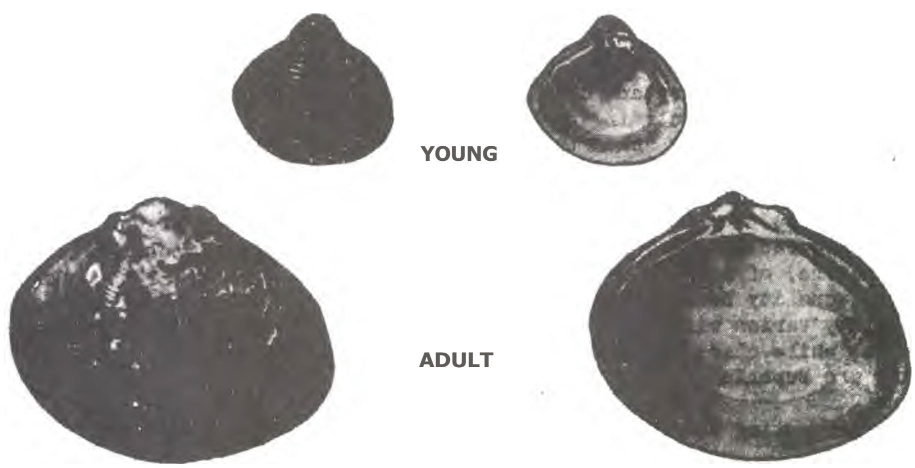
APPENDIX I

The following three 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, 103 pages; and were done by Messrs. Saburo Satouchi and Kitsayuki Kita. Cahn's report is comprehensive and gives life history details which have been useful in the preparation of this paper. In Cahn's report the titles of figure 32 and figure 9 were evidently transposed by accident.

TWO IMPORTANT SPECIES OF CORBIGULA



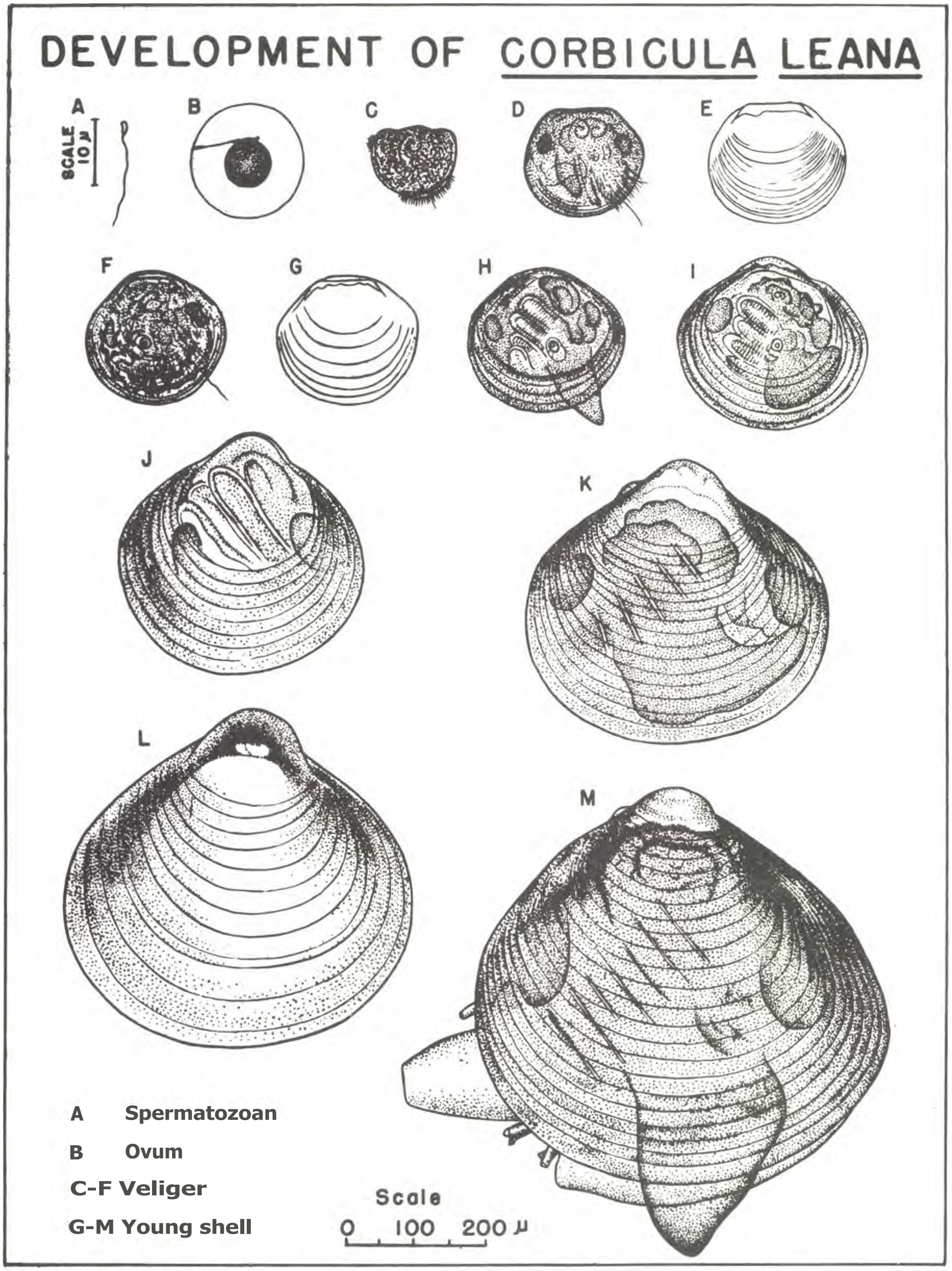
Corbicula sandai



Corbicula japonica

Scale
IN
2.5 CM

Figure 31


DEVELOPMENT OF CORBICULA LEANA
A
SCALE 10 μ
B
C
D
E
F
G
H
I
J
K
L
M
A Spermatozoan
B Ovum
C-F Veliger
G-M Young shell
Scale
0 100 200 μ

HARVESTING OF CORBICULA JAPONICA IN CHIBA PREFECTURE

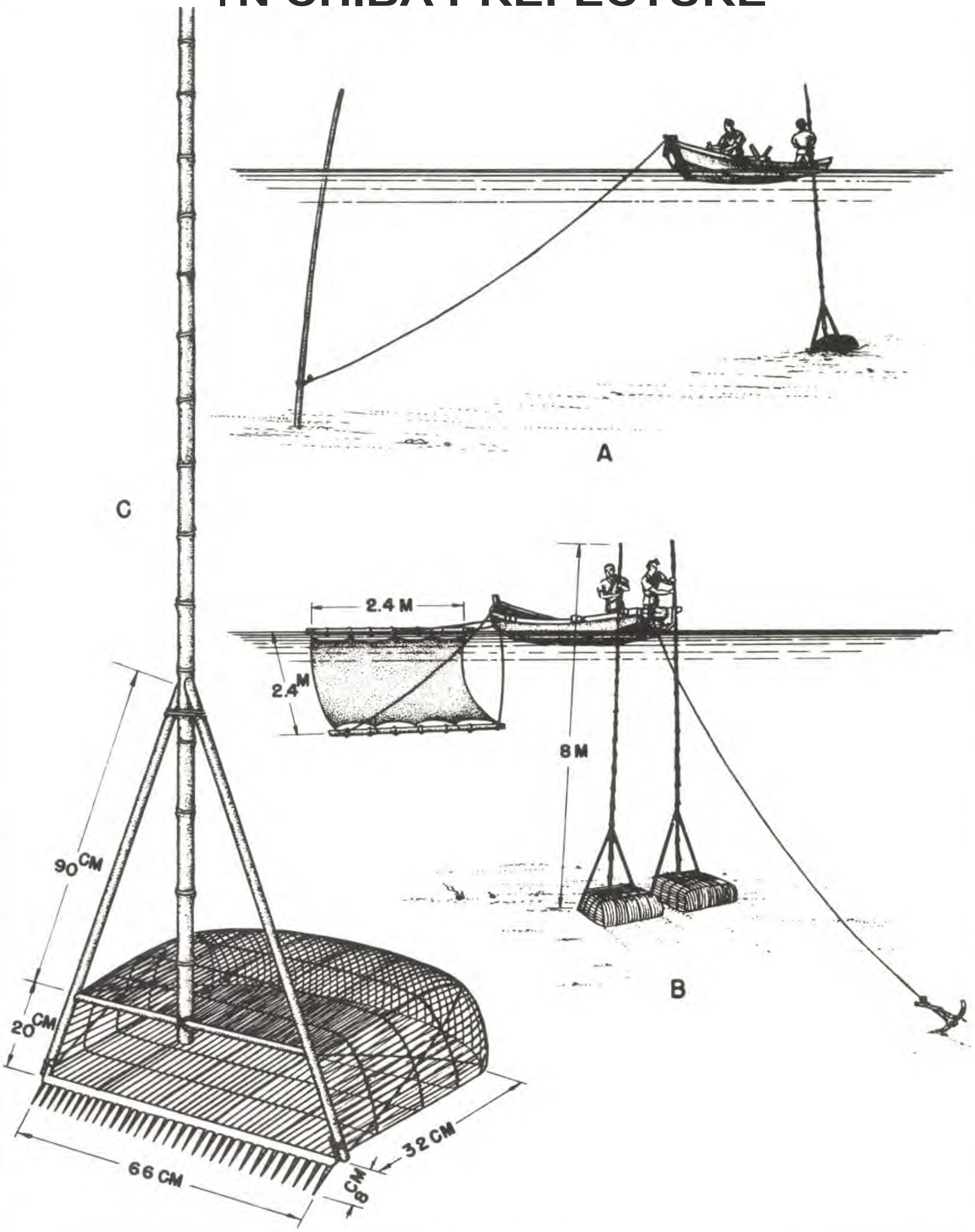


Figure 33

APPENDIX II

The following plate has been taken from Villadolid, Deogracias V. and Del Rosario, Fidel G. 1930. Some Studies on the Biology of Tulla (*Corbicula manillensis* Philippi), a Common Food Clam of Laguna De Bay and Its Tributaries, The *Philippine Agriculturist* XIX (6) 355-382.

The life history details as shown here are identical with C. *vicina,* C. *leana,* and the Ohio River Valley form generally listed as C. *fluminea,* thus placing *manillensis* in the *Corbiculina* group. All the above species of the subgenus *Corbiculina* are in this paper considered one species, and are here placed in synonomy under C. *manillensis,* the species illustrated.

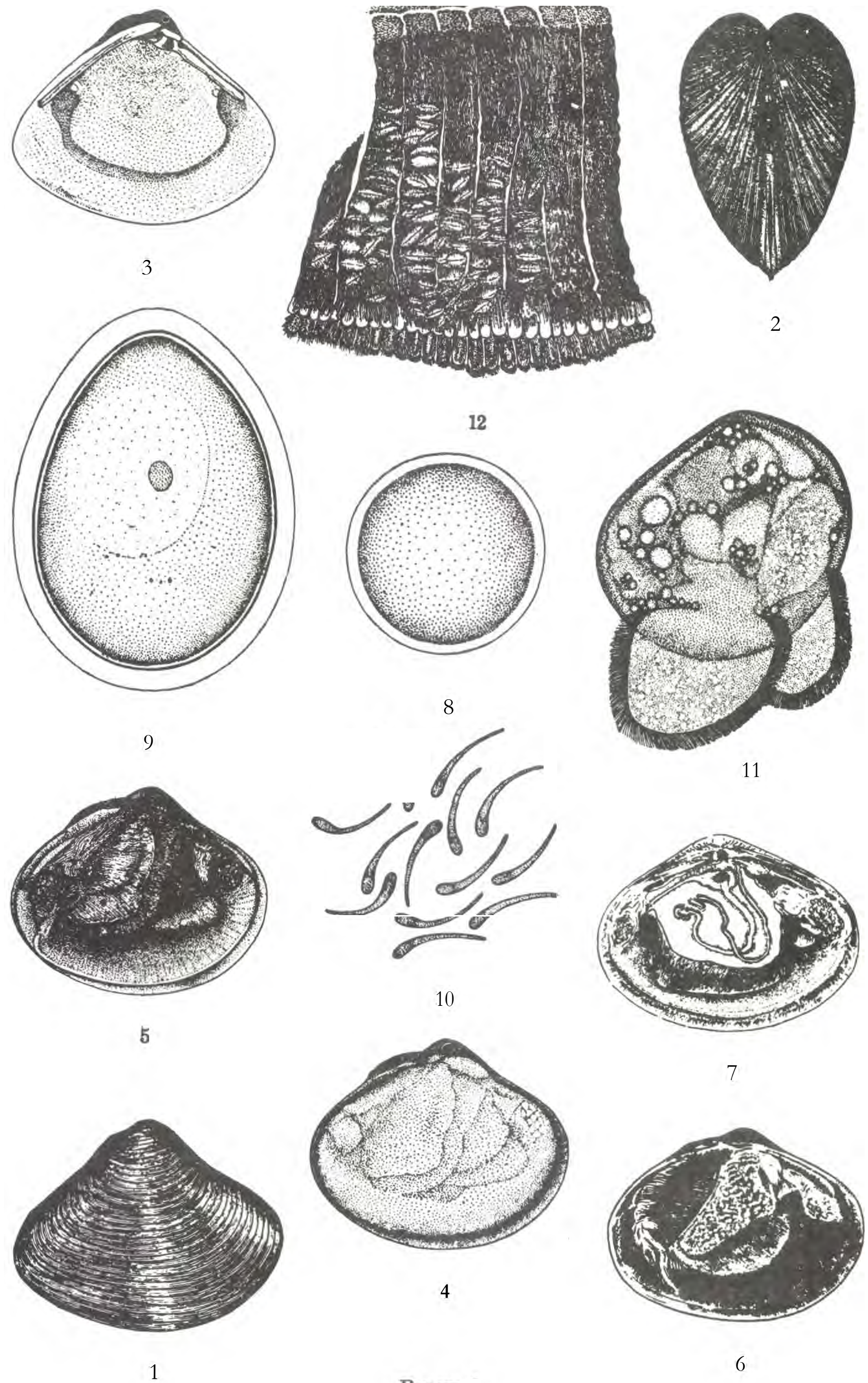


PLATE I

Corbicula manillensis Philippi. 1. left valve. 2. posterior end showing siphons. 3. right valve. 4. left valve removed to show mantle. 5. left valve and mantle removed. 6. left gills pushed back to show gonads. 7. dissection to show digestive system. 8. Immature ovum. 9. Mature ovum. 10. Spermatozoa. 11. Larva at age of extrusion. 12. Portion of inner gills showing nepionic shells. 1-7 are X2 and 8-12 are very highly magnified. Drawings by Daniel M. Buliag.

ADDENDA

Corbicula is rapidly extending its range into other U.S. river basins, including the Mobile River (Alabama); Florida rivers including the Apalachicola (Gadsen County), Withlacoochee (Citrus County), and the Chattahoochee; and the Mississippi River (New Orleans and Memphis). Migration on the Duck River (Tenn,) has been downstream from Shelbyville, where 69 individuals were taken in a three square foot bottom sample in October 1963. One year prior to this only four were taken. The clams had not become established in the Columbia area in October 1962, a year later a few small ones were found, but by May 1964 they literally covered the river intake of a large chemical company below Columbia. A few weeks later the company drained a raw water storage tank which had accumulated great numbers of small clams.

Examination of a series taken from the Apalachicola River (Gadsen County, Fla.) below Jim Woodruff Dam by Dr. W. H. Heard on May 20, 1964 r the inner gills packed with typical trochophores. These clams were monoecious and had the typical spermatozoon, Another series collected by Dr. Heard on August 10, 1964 from the Withlacoochee River (Inglis, Fla.; Citrus County) was examined for life history stages with negative results. The Withlacoochee series have low umbones are ovate, dark, and match Prashad's (70) figure 19 of plate VII. The ripalachicola series have high umbones are olive yellow, trigonal, and match Prashad's (70) figure 6 of plate VII. These two series are similar in some respects but distinct from all others examined, which accords with known variation of the species introduced into the U.S. Data received through TVA, indicate the clams have become a nuisance in a steam-electric generating plant in North-west Florida where they lodge in valve seats.

The Johnsonville TVA Steam Plant was still experiencing infestations of Corbicula in 1964, which were being controlled by "traps" on raw water lines and per ic flushing. Dismantling and manual cleaning in some sections of the plant system were still necessary. The presence of these clams in TVA reservoirs has had some beneficial res lts. Large populations of Redear Sunfish on Chickamauga Reservoir (Tenn.) have developed as a direct result of increased Corbicula populations. Stomach analyses revealed an almost exclusive diet of Corbicula (personal communication from Ray Hoffarth).

According to Erle Starley Gardner ("Poisoned Paradise", Sports Afield, May 1964, p. 140) a two to three man boat landed a daily average of 1,200 pounds of freshwater clams for a fish company in the California Delta area. Scoops with long handles were used to dredge the black peat mud for clams. The potential for economic use of Corbicula in Tennessee needs investigation.

Dundee, Dee S. and Walter J. Harman. 1963. Corbicula fluminea in Louisiana, Natuilus 77:30.

Fechtner, Frederick R, 1962. Corbicula fluminea (Müller) from the Ohio River, Nautilus 75:126.

Heard, William H. 1964. Corbicula fluminea in Florida, Nautilus 77:105-107

Horning, W. B and Lowell Keup. 1964. Decline of Asiatic Clam in Ohio River, Nautilus 78:29

Hubricht, Leslie. 1963 Corbicula fluminea in the Mobile River, Nautilus 77:31.

Ingram, W, M., Lowell Keup, and Croswell Henderson. 1964, Asiatic Clams at Parker, Arizona, Nautilus 77:121-124, Sinclair, Ralph M. 1964. Clam Pests in Tennessee Water Supplies. Jour. American Water Works Assoc. 56:592-599.

Stein, Ca 1 B. 1962. An Extension of the Known Range of the Asiatic Clam Corbicula fluminea (Müller) in the Ohio and Mississippi Rivers. Ohio Jour. Sci. 62:326-327

Thomas, N. A. and K. M. Mackenthun. 1964. Asiatic Clam Infestation of Charleston, West Virginia. Nautilus 78:28.

The mode of introduction of an Oriental Shrimp into San Francisco Bay and the role of sea water systems of large naval vessels is reported by Newman in a very interesting paper.

Newman, William A. 1963. On the Introduction of an Edible Oriental Shrimp (Caridea, Palaemonidae) to San Francisco Bay, Crustaceana 5:119-132.

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Soviet Literature on Dreissena Control

ere has recently been a significant increase in Soviet literature on Dreissena control, due to that clams migration and the advent of new hydraulic engineering installations. Layakhov mentions:

> "Despite the fact that during the past century Dreissena became widespread not only in the aquatoria of the European part of the Soviet Union but also in a considerable part of Western Europe, no thorough and radical method of control has been developed as yet, . .within a year after the construction of the Volgrad reservoir the quantity of young Dreissena on the rocky bottom of former Volga-river bed constituted in some cases as high as 10,000 specimens per square meter. Having achieved sexual maturity, which takes place on the second year of its life, Dreissena becomes within a short time one of the most important components of the reservoir fnnna,"

Zhadin in his book on freshwater biology in the USSR included a section on Dreissena, "Overgrowing of Hydroelectric Installations and Water Pipes and Its Control", and according to him

> "in the German Democratic Republic this mollusk is now damaging many water supply installations, especially in the Oder-Spree canal zone. In the USSR mass appearances of Dreissena bugensis were reported from many parts of the Volga, Don, and Dnieper basins The Dnieper Hydroelectric Power Station im, V. I, Lenin was damaged by overgrowths on the network; the Moscow water pipeline suffered similar damage for sometime. . .Chlorination entirely eradicated the Dreissena larvae from the purification installations of a Moscow water-supply station."

Other successful control measures used were heated water, electric current and ultrasound (22,000 kilocycles per second) Kirpichenko et al and Lyakhov found that periodic flushing with heated water (45-55 C) was an effective treatment for Dreissena growths in pipes. Such measures should prove equally successful with Corbicula,

Kirpichenko, M. Ya , V. P. Mikheev, and E. P. Stern. 1962. Control of Dreissena Fouling at Hydroelectric Power Stations. Elektr, Sta 5:30-32 Referat. Zhur. Biol. no. 24 Zh 406 Translation of Russian abstract.

Lyakhov, S. M. 1962. Protecting of Hydraulic Installations from Overgrowth of 'reissena. Prioroda 51:106-108. (OTS 63-2195).

Mikheyev, V. P. 1962, Distribution of Dreissee polymorpha Pallas on the Sructures of the Volga Hydroelectric Power Plant Imeni V. I. Lenin. Bull. Water Reserv. Biol. 12:32-33. (OTS 63-21761).

Zhadin, V. I. and S. V. Gerd, 1963. Fauna and Flora of the Rivers Lakes and Reservoirs of the USSR. Translation from the Russian, Smithsonian Institution and the National Science Foundation, OTS 63-11166. Office Technical Services, U. S. Dept. of Commerce, Washington, D, C.

The Spermatozoon of the introduced Corbicula conforms to Franzen's primitive type, with some modification, since the tail piece consists of two filaments. There is a remarkable resemblence between the spermatozoon of both the polychaete worm helgolandica and Corbicula (see Franzen, 1958, p. 4).

Franzen, Ake. 1956. Investigations into Spermiogenesis and Sperm Morphology among Invertebrates. 13 p. Thesis. Uppsala.

Franzen, Ake. 1958, On Sperm Morphology and Acrosome Filament Formation in some Annelida, Echiuroidea, and Tunicata. Zool. Bidrag. 33:1-28. Uppsala.

Japanese Studies

Further studies on Corbicula by Seno in the Tone River (Chiba Prefecture) have shown mixed populations of C. japonica and C. leana, distinguished on the basis of nymph structure, The former species was made up of three types, all having local names, another example of variation in Corbicula. A close study of these two species found in a mixed population grading from C. leana to C. japonica (and from fresh to brackish water) would be profitable, particularly when life history characters are evaluated, Hayashi's (27) paper, previously cited, has implication for an evaluation.

There is an important accumulation of Japanese literature ertinent to this study, but unfortunately translations are few. When Fr ish summaries have been included, they are usually too brief. Glude has pointed out the problems that exist in this regard. His recommendations, for an adequate translation program of pertinent Japanese literature in fisheries are worthy of serious consideration.

Glude, John B. 1964. A Survey of Japanese Research on Shellfisheries and Seaweeds, U.S. Fish and Wildlife Service Circular 168.

Seno, Jiro. 1953. Studies on Carl cula taken on the Downstream of the River Tone, I. Systematic Studies. Bull. Jap. Soc. Sci. Fish, 18:455-461 (English summary)

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Corbicula fluminalis

Further life history and ecological data on the related Corbicula fluminalis has been published by Kasymov:

> "Corbicula fluminalis inhabits in sand and slime-sand biotopes.. Corbicula feeds on detritus, bacteria, and algae. The life duration is five to six years On the third year of its life it comes to sexual maturity. The throwing out of its embryos happens at the water temperature 22-30° C on clean sand from the beginning

of July till the end of September every year. The number of embryos varies from 5,000 to 10,000 specimens. The 42° C water temperature is lethal for the species." (Translation from p. 17 by Nikolai N. Akramowski).

Dr. Akramowski (personal communication) comments that some specimens of Corbicula from Middle Asia are more similar to C. fluminea, although from the distributional view point they should be C. fluminalis. In a section of the Kura River in the Caspian Lowland C. fluminalis was found in silty places, especially a sandy bottom with a rough surface and silt-bound holes. A minimum temperature restriction in Transcauciasia was 0° C in January. In Iran C. fluminalis was recorded from irrigation canals at Isfahan by Biggs. Further data may prove C. fluminalis and C. manillensis synonomous.

Biggs, H. E. J. 1936. Collecting Molluscs on the Iranian Plateau, Nautilus 50:8-13,

*Deksbach, N. V. 1943. The Mollusc Corbicula fluminalis Müller in the Valley of the Murgab River. C. R. Acad. Sci. (Moscow N, S.) 40:33. (A new link in Asiatic distribution).

*Kasymov, A. G. 1963. Hydrofauna of Lower Kura River and of the Mingechaur Reservoir Baku, Acad. Sci. Azerbaijan S. S. R. Pub. House. (D. Sci. Theis. in Russian).

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Explanation of Figures

1-4, 8-12, 15, 17-21, 23-25, 27-29, 33-47, 53, 54, 57, 59, 60, 62, 64, 67, 69, 71, 72, 74, 76, 78, 81, 83, 85, 86, 88, 90, 91, 94, 100, 108-112, 114, 117-122, 137, 139, 141, 143-148, 177, 179, 180, 184-187. left valve.

5-7, 13, 14, 16, 22, 26, 30-32, 48-52, 55, 56, 58, 61, 63, 65, 66, 68, 70, 73, 75, 77, 79, 80, 82, 84, 87, 89, 92, 93, 95-99, 101-107, 113, 115, 116, 123, 136, 138, 140, 142, 173-176. right valve.

150 fertilization membrane still surrounds early trochophore.
152 late trochophore.
153 early veliger.
154 ventral view.
165 spermatozoon after Miyazaki.
166 spermatozoon after Villadolid and Rosario.
168 spermatozoon after Cahn.
178 branchial siphon still incomplete.
179 view from left valve.
180 left valve.
181 size of mantle border tentacles slightly exaggerated.
182 maximum extent of siphon protrusion observed.
184 thin shelled, high umbo, coarse sculpture, white within form.
185 thin shelled, low umbo, fine sculpture, purple within form,
186 high umbo form.
187 siphons halfway retracted.
189 several of the small clams show the violet beak ray in the original.

*Reference not seen.

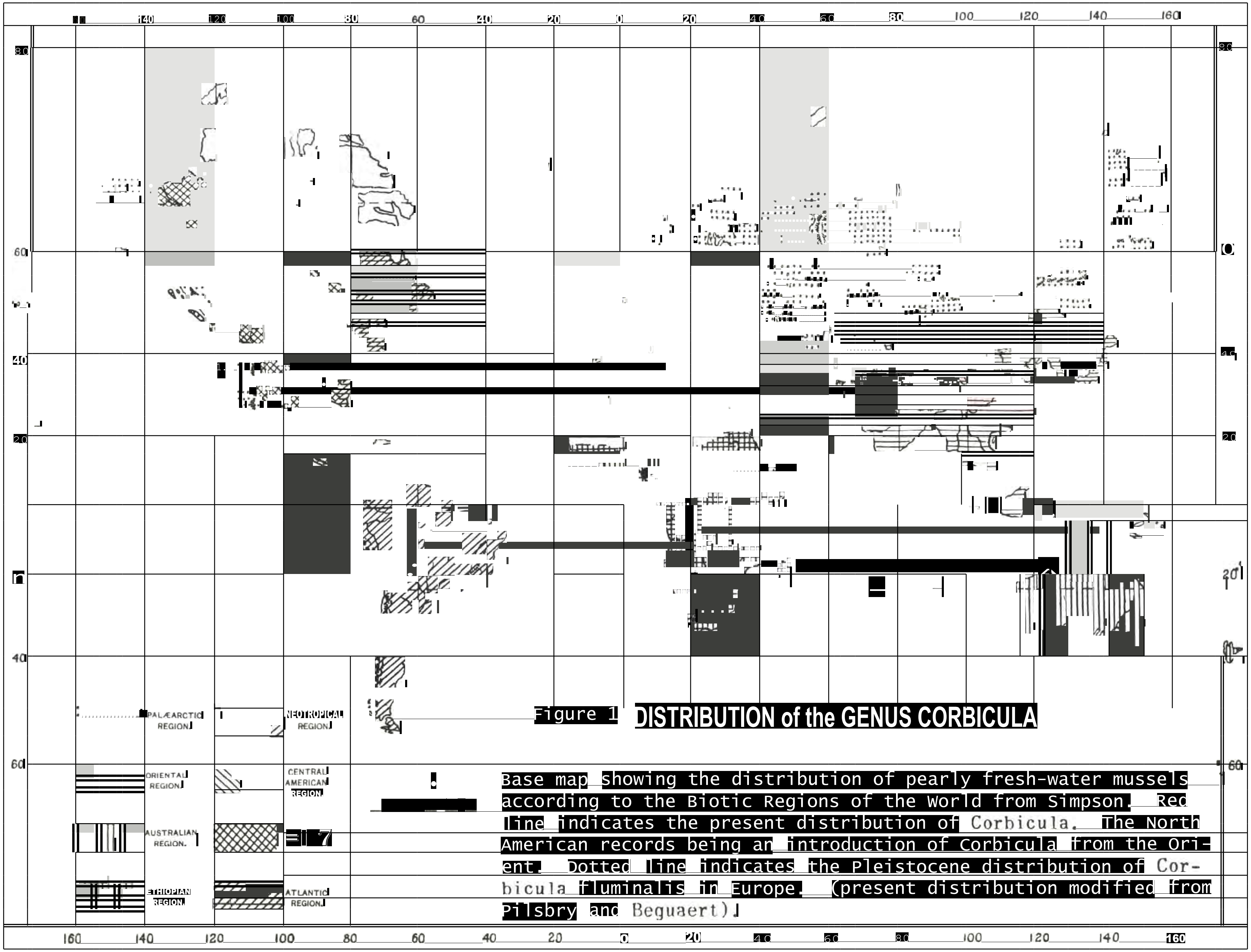

Figure 1 DISTRIBUTION of the GENUS CORBICULA

Base map showing the distribution of pearly fresh-water mussels according to the Biotic Regions of the World from Simpson. Red line indicates the present distribution of *Corbicula*. The North American records being an introduction of *Corbicula* from the Orient. Dotted line indicates the Pleistocene distribution of *Corbicula fluminalis* in Europe. (present distribution modified from Pilsbry and Bequaert).

MAP SHOWING THE DISTRIBUTION OF PEARLY FRESH-WATER MUSSELS