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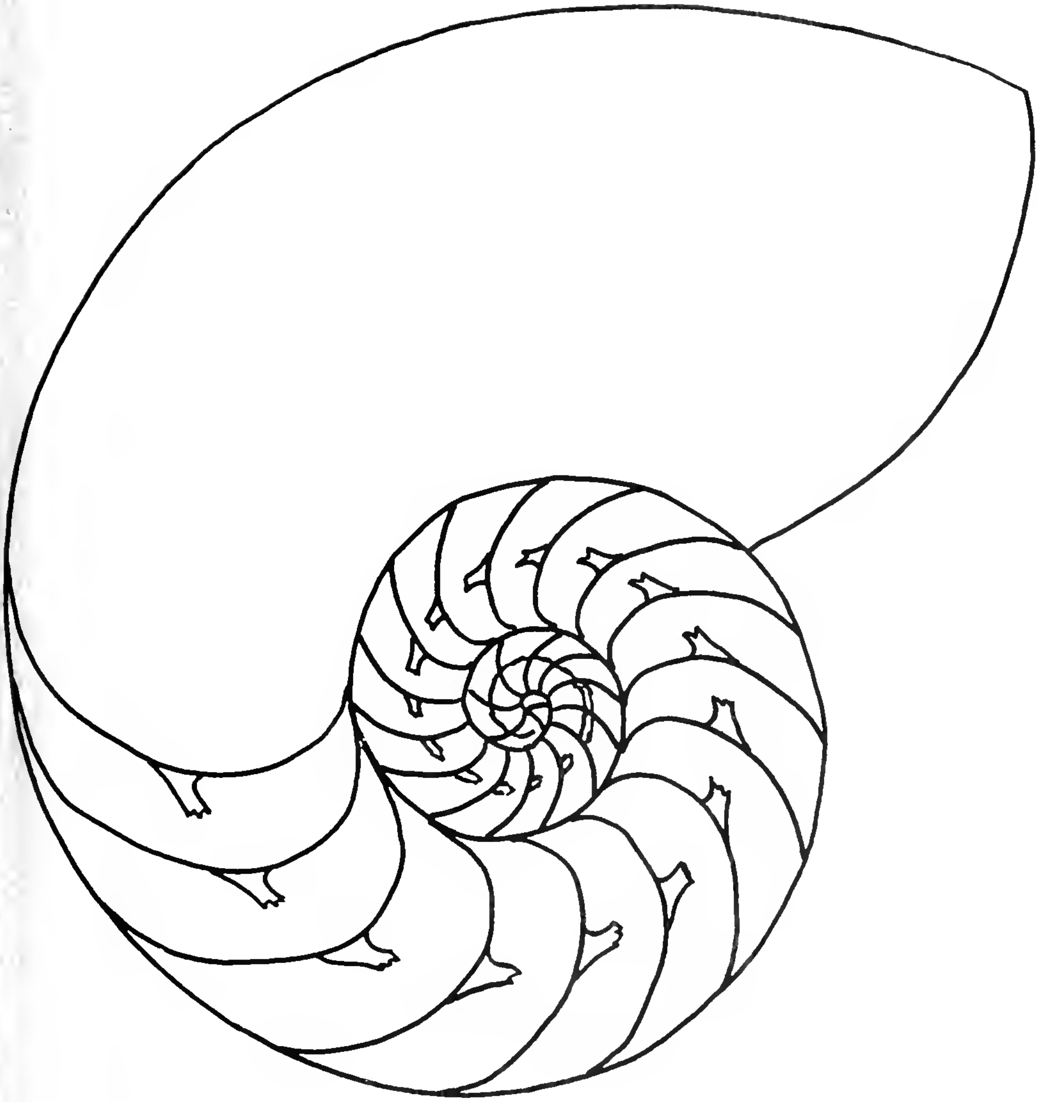

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PUBLICATIONS RECEIVED

Houbrick, Richard, S. 1978 (Dec. 15). The Family Cerithiidae in the Indo-Pacific. Part 1: The Genera *Rhinoclavis, Pseudovertagus* and *Clavocerithium. Monographs of Marine Mollusca,* No. 1, pp. 1-130, 98 pls. 3 in color. Taxonomic revision, biology, anatomy, phylogeny and geographical distribution of 47 living and fossil species. American Malacologists, Inc. $17.50, postage paid.

Chatfield, June E. 1978. *Welsh Seashells.* 44 pp., 90 figs. (20 in color. Paperback. National Museum of Wales, Cathays Park, Cardiff, U.K, CF1 3NP. Remit U.S. $3.00 or £ 1.50 sterling. An excellent little guide with 90 common shore species.

Goryachen, V. N. 1978. Gastropod Mollusks of the genus *Neptunea* Röding of the Bering Sea. 90 pp., 25 pls. Science Press, Moscow (in Russian)

The Pariah, no. 4, Sept. 1978. Edited by Jerry G. Walls. 8 pp. Contains review of Harpidae (J. G. Walls), note on *Cypraea thomasi* (P. W. Clover) and remarks on *Conus patae* (J. G. Walls). Available for 50 cents, P.O. Box 12, Hightstown, N.J. 08520.

Popenoe, W. P. and R. M. Kleinpell. 1978. Age and Stratigraphic Significance for Lyellian Correlation of the Fauna of the Vigo Formation, Luzon, Philippines. *Occ. Papers California Acad. Sci.*, no. 129, pp. 1-173, 18 pls., 1 table.

Saul, Louella R. 1978. The North Pacific Cretaceous Trigoniid Genus *Yaadia.* Univ. Calif. Publ. in Geol. Sci., vol. 119: 1-65, 12 pls. $7.25. Excellent account.

Zhengzhi, Doug. 1976. On Three New Species of the Genus *Octopus* from the Chinese Waters. *Studia Marina Sinica*, no. 11, pp. 211-215. (*O. nanhaiensis, O. striolatus* and *O. guangdongensis* new species).

Zhengzhi, Doug. 1978. On the Geographical Distribution of the Cephalopods in the Chinese Waters. *Oceanologia et Limnologia Sinica,* vol. 9, no. 1, pp. 108-116

Wu, Shi-Kuei and Nancy Brandauer. 1978. *Natural History Inventory of Colorado.* 2. The Bivalvia of Colorado. Univ. Colorado Museum, Boulder, CO 80309. 60 pp. 87 figs., keys.

Giese, Arthur C. and John S. Pease, (editors). 1977. *Reproduction of Marine Invertebrates.* Vol. 4, **Molluscs:** Gastropods and Cephalopods. 369 pp. Academic Press, 111 Fifth Ave., N.Y., NY 10003. Hardback, $38.00. An excellent, well-illustrated and well-documented account by competent workers. Includes recent reviews of reproduction on Prosobranchia (H. H. Webber), Opisthobranchia (R. D. Beeman); estuarine Basommatophora (A. J. Berry); *Nautilus* (Norine Haven); Squids (J. M. Arnold and L. D. Williams-Arnold); and Octopoda (M. J. and J. Wells).

NEWS

A.M.U. - W.S.M. Joint Meeting

Symposium on the Life Histories of Mollusks

Papers on any aspect of molluscan life histories will be considered for presentation at a symposium to be held during the joint meeting of the Western Society of Malacologists and the American Malacological Union in Corpus Christi, Texas, 5 - 11 August 1979. Presentations should be concerned with an aspect of the reproduction, development, growth, or population dynamics of mollusks. Theoretical papers on the evolution of life history traits of mollusks are also invited. Opportunity for publication of abstracts or full length versions of papers presented at the symposium will be provided. Further information and a Call for Papers is available from:

David R. Lindberg
Invertebrate Zoology
California Academy of Sciences
Golden Gate Park
San Francisco, CA 94118

UNITAS MALACOLOGICA

The international society of professional malacologists (formerly the Unitas Malacologica Europaea) is now open to all scientists interested in living or fossil mollusks. The President is Dr. Jean M. Gaillard, Museum d'Histoire Naturelle, 55 rue de Buffon, F-75005 Paris, France, to whom readers should write concerning the next and Seventh International Malacological Congress. These meetings will be held August 31 (registration) to September 6, 1980, on the Mediterranean coast of France near the "Laboratoire Arago". Secretary of the Unitas Malacologica is Dr. Oliver E. Paget, Naturhistorisches Museum, Burgring 7, A-1014 Vienna, Austria.

SIX NEW LIVING SPECIES OF MURICACEAN GASTROPODS

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ABSTRACT

The following new species of gastropods referable to the Muricidae are described: Pteropurpura benderskyi *from West Africa;* Favartia guamensis *and* F. dorothyae *from the western Pacific, and* F. elatensis *from the Red Sea;* Murexiella mactanensis *from the western Pacific; and* Siphonochelus radwini *from the western Atlantic. A recently described species,* Murexiella martini *Shikama, 1977, from the western Pacific, is illustrated and a supplementary description is given.* Dermomurex neglecta *(Habe and Kosuge, 1971), from the western Pacific, is illustrated and a translation of the original description is provided.*

At the time George E. Radwin and the junior author were preparing the text for "Murex Shells of the World, An Illustrated Guide to the Muricidae" (Radwin and D'Attilio, 1976), a number of taxa were recognized by them as new species. Fifteen of these species were described in an appendix to their book. Although they intended to describe elsewhere several other taxa that were received after the text of the book was completed in mid-1971, the tragic and untimely death of Dr. Radwin in 1977 terminated their joint venture.

At the request of the junior author, the senior author has joined him in the preparation of the present report, which was based in part on preliminary notes prepared jointly by D'Attilio and Radwin for two of the taxa described herein. The new taxa are classified largely according to the system followed by Radwin and D'Attilio (1976).

ACKNOWLEDGMENTS

We are grateful to the following collectors for the loan and/or donation of specimens: Israel Bendersky, L. J. Bibbey, Albert E. Deynzer, Francis Fernandez, Dorothy and Robert Janowsky, Leo Kempczenski, Don Pisor, and Eugenia Wright. Dr. Joseph Rosewater of the Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution and Dr. H. K. Mienis of the Zoological Museum, Hebrew University of Jerusalem lent additional material. Dr. Emily H. Vokes of the Department of Geology, Tulane University, provided data and the photographs used to illustrate figures 17 and 18. Masao Tabakotani of Bronxville, New York, generously contributed a translation of Japanese text. William E. Old, Jr. and G. Robert Adlington of the American Museum of Natural History kindly provided respectively, technical assistance and the photography.

INSTITUTIONAL ABBREVIATIONS:

AMNH = American Museum of Natural History, New York, New York
HUJ = Zoological Museum, Hebrew University of Jerusalem, Israel
NMNH = National Museum of Natural History, Washington, D.C.
SDMNH = San Diego Museum of Natural History, San Diego, California

FAMILY Muricidae

SUBFAMILY Muricinae

Genus *Dermomurex* Monterosato, 1890

Type species: *Murex scalarinus* Bivona-Bernardi, 1832 (= *M. scalaroides* Blainville, 1829), by original designation.

Dermomurex neglecta (Habe and Kosuge, 1971)

Figs. 17, 18

"*Description*: Shell distinguished by its varices, five in number, in each whorl. They are broad and somewhat prosocline at the shoulder to suture position. Whorls between varices are sculptured by numerous fine spiral striae so that it looks almost smooth. Siphonal fasciole is outstanding and umbilicus is open. Shell white with slight yellowish tinge in color."

"This species is distinguished for the shape and varices. Actually two specimens are known, both caught in South China Sea and brought back to the port of Kaohsiung, Taiwan." (Translation of the Japanese text, courtesy of M. Tabakotani.)

Measurements: Holotype, length 22.5 mm, width 11.2 mm; specimen illustrated herein, length 20 mm, width 11.00 mm. (Wright collection).

Type locality: "South China Sea", *fide* Habe and Kosuge (1971, page 7). Here restricted to off Bohol Island, Philippines.

Material examined: 1 specimen, off Balicason, Bohol Island, Philippines, in 366 meters, Eugenia Wright collection.

Remarks: At the suggestion of Dr. Emily H. Vokes, we have presented here a translation of the description of this poorly known western Pacific taxon, together with photographs of a specimen from the Philippines (figures 17, 18), which along with another one, had been sent to her for identification. Although this species was originally described as *Phyllocoma neglecta* by Habe and Kosuge (1971, p. 7, text figure), it is referable to the genus *Dermomurex* and is the first Recent record of the genus (*sensu stricto*) in the Indo-Pacific. Vokes (1975, p. 129) cited this record based on the Philippine specimens which were thought to represent an undescribed species. She pointed out (1975, *op. cit.*) that the specimens lack apertural denticulations on the outer lip, in contrast to the previously known representatives of *Dermomurex (sensu stricto)*. According to Dr. Vokes (*in litt.*) the present species is a probable descendent of *Dermomurex acuticostatus* (Wanner and Hahn, 1935, p. 254, pl. 19, figs. 8-10) from the Miocene of Java.

SUBFAMILY Ocenebrinae

Genus *Pteropurpura* Jousseaume, 1880

Type species: *Murex macropterus* Deshayes, 1839, by original designation.

Pteropurpura benderskyi, n. sp.

Figs. 1, 2, 19

Description: Shell small for genus, attaining 23 mm. in length, trigonally fusiform in appearance. Spire acute and high, with $1\frac{1}{2}$ polished, brown nuclear whorls, followed by 5 convex, postnuclear whorls; suture distinct, not strongly impressed. Body whorl moderate in size. Aperture ovate, with peristome entire and mostly erect, except for the posterior portion of left side in the parietal region. Siphonal canal broad, sealed (except at the recurved, tapering distal end), moderate in length and accommodating the siphonal fasciole. Body whorl with three winged varices; each varix with webbing between prominent spine-points. A medial costate ridge and two less prominent flanking costae intervene between each pair of consecutive varices. Spiral sculpture of numerous primary and secondary cords extending over body and siphonal canal. Primary cords strongest on dorsal surfaces of the spines. Spine at shoulder margin longest; body with a less prominent spine medially placed and with a minor spine at the base of body whorl and on the upper portion of siphonal canal. Leading, or ventral sides, of varical spines weakly open; last varix with leading edge sculptured with fine, low undulating lamellae and with some growth lines raised at intervals to give a somewhat scabrous texture to the surface. Shell tan to dark-brown, paler on the varical surfaces; aperture off-white and porcelaneous. Operculum: The morphology is typically ocenebrinean, as described by Radwin and D'Attilio (1976, p. 111).

Radula: Radular dentition is similar in morphological characters to those of the type species of *Pteropurpura*, *P. macroptera* (Deshayes, 1839); consult the radular illustrations of the Deshayes' taxon (Radwin and D'Attilio, 1976, p. 131, fig. 81) with the basal and frontal views of a rachidian and a frontal view of a lateral tooth of the present species (figure 19 herein).

Measurements: Holotype, length 23 mm, width, including varices 13.9 mm; smallest paratype (SD MNH no. 72626), 17.7 mm in length.

FIGS. **1** *and* **2**, Pteropurpura benderskyi *n. sp., holotype, AMNH 183819, ×3.* **3** *and* **4**, Favartia dorothyae *n. sp., holotype, AMNH 183821, ×3.* **5** *and* **6**, Favartia rosea *Habe, 1961, Janowsky collection, trawled in Kii Channel, Wakayama Prefecture, Japan, in 146 meters, ×3.* **7** *and* **8**, Favartia mactanensis *n. sp., holotype, AMNH 187186, ×3.* **9** *and* **10**, Murexiella martini *Shikama, 1977, SDMNH 72627, Bohol Island, Philippines, ×2. (Stated enlargements are an approximation)*


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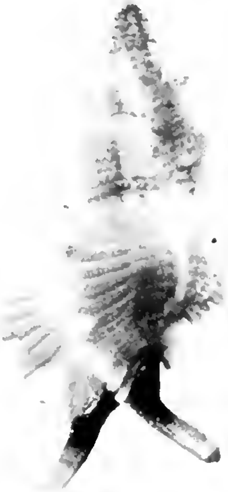
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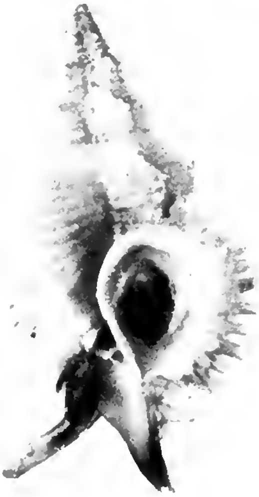
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Type locality: Off Luanda, Angola, Africa, dredged in 50 meters, sandy bottom, July 15, 1977, Francis Fernandez collector.

Material examined: Holotype AMNH 183819, from type locality, 1 paratype SDMNH 72626, ex Bendersky collection, and 1 paratype, Janowsky collection, both from off Luanda, Angola, dredged in 80 meters, February 10, 1977.

Remarks: Until the discovery of this new species, only one living representative of this genus was known to occur in the Atlantic Ocean. The other living *Pteropurpura* are found in the northern Pacific, with three in northwestern waters (largely off southeastern Japan) and with five in northeastern waters off California and northwestern Mexico (see Radwin and D'Attilio, 1976, pp. 129 to 133). The present species (figures 1, 2) differs from *P. bequaerti* (Clench and Pérez Farfante, pl. 21, figs. 1, 2, 1945), which ranges from North Carolina to the Dry Tortugas, in several characteristics (see comparative data in table 1). The two taxa clearly represent twin species, or cognates, separated by the present expanse of deep water of the Atlantic Basin.

SUBFAMILY Muricopsinae

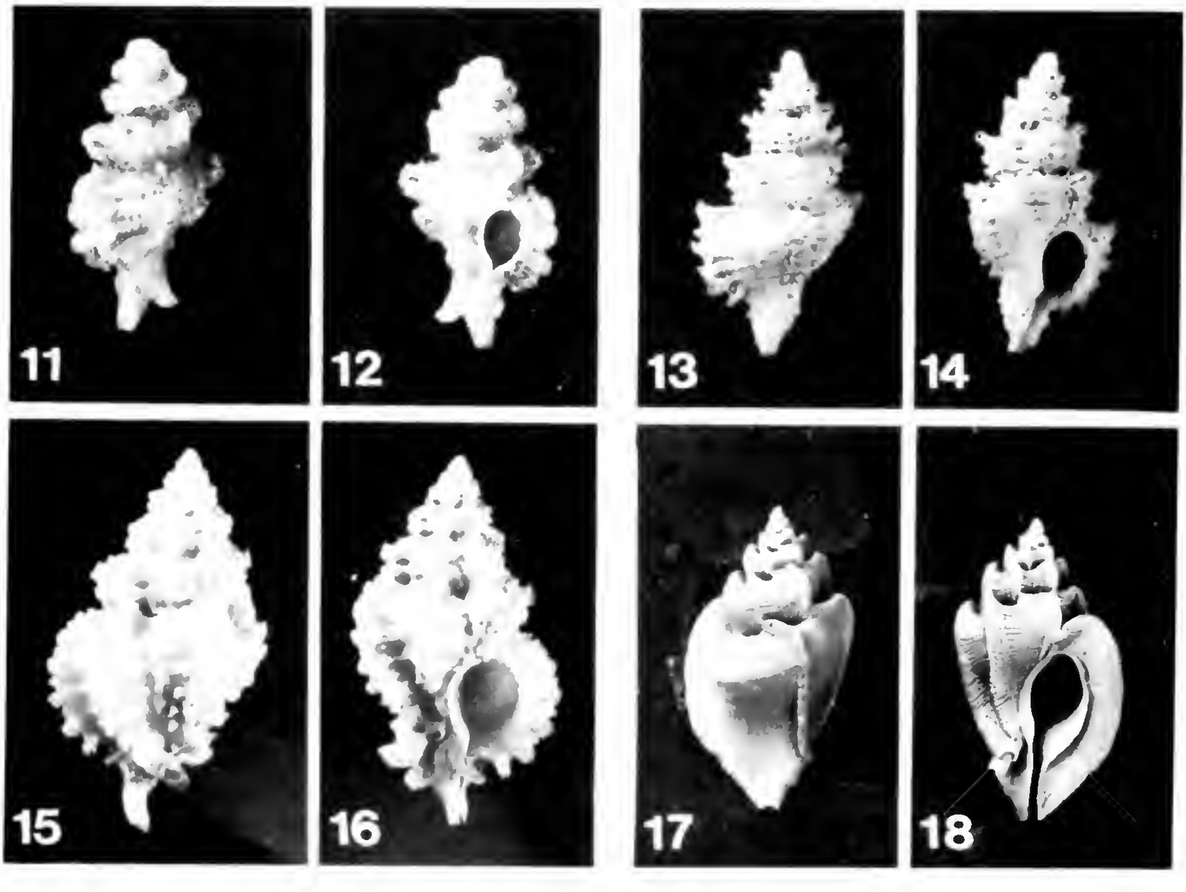
Genus *Favartia* Jousseaume, 1880

Type species: *Murex brevieulus* Sowerby, 1834, by original designation.

Favartia guamensis n. sp.

Figs. 11, 12

Description: Shell small, attaining 8 mm in length, fusiform. Characterized by strong rugose



FIGS. **11** *and* **12**, Favartia guamensis *n. sp., holotype, SDMNH 72625,* ×5. **13** *and* **14**, Favartia elatensis *n. sp., paratype, SDMNH 63254a,* ×5. **15** *and* **16**, Favartia dorothyae *n. sp., paratype, AMNH 183822,* ×3. **17** *and* **18**, Dermomurex neglecta *(Habe and Kosuge, 1971), Wright collection, off Bohol Island, Philippines,* ×2. *(Stated enlargements are an approximation)*

TABLE 1. *Comparative diagnostic characters of* Pteropurpura bequaerti *and* Pt. benderskyi

	Pteropurpura bequaerti	*Pt. benderskyi*, n. sp.
Maximum size	42 mm	23 mm
Numbers of whorls	6 to 7	5 (or more ?)
Outer lip	crenulated	not noticeably crenulated
Varices	blade-like	spine-like projections
Axial sculpture	a single, low knob	medial costae and 2 less prominent flanking costae.
Spiral sculpture	terminates in toothlike points on varical margins	varical margins extended into 4 broad-based, spiny terminations, with scabrous lamellae on ventral surface.
Color	gray-white; tip of siphonal canal suffused with purple-brown.	tan to dark-brown, paler on ventral surface

sculpture. Protoconch low, smooth with $1\frac{1}{2}$ whorls; followed by 5 convex whorls; suture deep but obscured at varices; spire well elevated. Aperture ovate; peristome weakly erect; anal sulcus deep, constricted in front into a closed channel. Siphonal canal with rostrate fasciole, broader above, tapering distally, slightly recurved with a narrow sinuous opening. Shell with 5 strong, spiral cords, squarish in cross-section and with an additional cord on the canal; cords crossed by strongly elevated fimbriae; fimbriations extend into the interspaces. Spiral cords with a strong central groove, crossed by fine lines, and with fimbriae forming strong, canopy-like scales; scales further interrupted axially by 5 to 8 fine grooves; scales scalloped on terminal edge. Varical flanges elevated and terminally wavy; early whorls with 6 varices; body whorl with 4 varices. Color of shell deep orange-red, ranging to yellow in the four specimens examined.

Measurements: Holotype, 7.5 mm in length; largest paratype, 7.7 mm in length; smallest paratype, 6.6 mm (Pisor collection).

Type locality: Off Orote Cliffs, Guam, Marianas Islands, in 18 to 21 meters under large boulders, 5-1-1977, Leo Kempczenski collector.

Material examined: Holotype, SDMNH no. 72625; 1 paratype, Leo Kempczenski collection and 1 paratype, AMNH no. 183820, all collected by Leo Kempczenski from type locality; 1 paratype from type locality, Don Pisor collection; 1 paratype from coral rubble, in 18 meters, SCUBA diving, 1977, A. Deynzer collection.

Remarks: The small size of the present species (figures 11, 12), complemented by the development of elaborate sculpture, the elongated body, and the rich coloring serve to distinguish this taxon from any of its congeners.

Favartia dorothyae, n. sp.

Figs. 3, 4, 15, 16

Description: Shell small for genus, attaining 9 mm in length, broadly fusiform; spire elevated but small in proportion to body whorl; protoconch of $1\frac{1}{2}$ whorls; post-nuclear whorls 6 in number; suture distinct. Body whorl obese, with a small ovate aperture; anal sulcus weakly-developed. Lower half of inner lip erect, adherent above; outer lip crenulated and sculptured within by 7 long lirae. Anterior end of columella ornamented by a small tooth. Siphonal canal broad above, tapering and distally recurved; siphonal fasciole rostrate. Body whorl with 5 major cords and with one major cord on canal; each cord subdivided by 4 or 5 incised lines. Three secondary cords situated above the major cord at shoulder. A secondary cord present on the body whorl below the second and third cords. A major cord appears on the canal with secondary cords above and below it. Additional minor spiral cords present on the body as well as over the shoulder. Five varices form the axial sculpture. Starting at each varical margin, the cords ascend to the strongly developed varix where they terminate and are recurved distally. The leading side of each varix bears 7 or 8 fimbriae which develop into scaly sculpture over the whorls. The shell color ranging from warm-white to carmine with the early whorls golden-hued; characteristically with the columella, the dorsal and ventral sides of the canal, and the base of the body whorl are all strongly colored a rosy pink.

Measurements: Holotype 15.9 mm in length, width 9.6 mm; smallest paratype (lacking a mature siphonal canal) 13.7 mm (AMNH 183822); largest paratype, 16.2 mm (SDMNH no. 72624).

Type locality: Off Punta Engaño, Mactan Island, Philippines, in about 30 meters, (obtained in tangle or gill nets), 1977, ex Dorothy and Robert Janowsky collection.

Material examined: Holotype AMNH 183821 (figures 3, 4), and three paratypes AMNH 183822, 1 paratype SDMNH 72624 (figures 15, 16, AMNH 183822a); 3 paratypes, Janowsky collection; 1 paratype Leo Kempczenski collection; all from the type locality. Three specimens, Panglao, Bohol Island, Philippines, in trap, 1977-1978, A. Deynzer collection.

Remarks: This species (figures 3, 4, 15, 16) with its distinct apertural coloration and delicate frostlike sculpture may be easily distinguished from the following congeners: *F. marjorae* (Melvill and Standen, 1903), to which it bears some resemblance, by comparison with a photograph of the holotype in Radwin and D'Attilio, 1976, fig. 95, p. 150. *F. marjorae*, which has a less swollen body and a higher spire, is grey in color and occurs in the Persian Gulf. *F. balteata* (Sowerby, 1841) from the western Pacific has a more strongly sculptured shell, with well-developed black squarrose varices, and has a brown shell with a red aperture. *F. salmonea* (Melvill and Standen, 1899) has a comparatively higher spire, possesses a decided gap between the body cords and those on the canal, and is pale reddish orange, darkest at the varices. It has not been reported from the northern area of the western Pacific. *F. rosea* Habe, 1961, (herein illustrated, figures 5, 6), from southeastern Japan, has a larger (23 mm), fleshy orange to yellow colored shell, with the varical areas conspicuously more rounded (swollen), and the surface not noticeably scabrous.

Favartia elatensis n. sp.

Figs. 13, 14

Description: Shell small for genus, attaining 8 mm in length, fusiform; spire high; protoconch 1½ rounded whorls, followed by 5 post-nuclear whorls; suture distinct. Aperture ovate, outer lip strongly undulate reflecting the dorsal sculpture; inner lip adherent; anal sulcus broad and simple; canal moderately long, narrowly open, tapering, weakly recurved, siphonal fasciole moderately developed. Axial sculpture strong with growth lines developing into widely spaced lamellae; vaulted scales formed by expansion of lamellae over the spiral cords. Six varices on post-nuclear whorls of spire; four on body whorl. Varices crossing at shoulder diagonally onto contiguous whorl. Spiral sculpture of 6 squarish and knobby cords on body whorl, with one cord, on the canal; cords grooved spirally, but dividing somewhat irregularly into unequal widths, to form unequal scaly ornamentation. Cords at the varical margins expanded into lobes; final varix with a recurved margin. Varical areas of shoulder extending into lobes with vaulted edge on leading side. Shell color uniformly fleshy white.

Measurements: Holotype 7.8 mm in length, 3.9 mm in width; largest paratype, 7.9 mm in length (SDMNH no. 63254a, figures 14, 15); smallest paratype (immature) 4.2 mm (HUJ no. 10.202/8).

Type locality: Elat, Gulf of Elat, Israel, 29°32′-29°31′ N., 36°58′-36°59′ E., in 190 meters from grab sample, October 8, 1965.

Material examined: Holotype and 7 paratypes HUJ 10.202/8 from the type locality; 2 paratypes SDMNH 63254, ex HUJ 10.202/RS-18, Elat, Gulf of Elat, 29°32′-29°31′ N., 36°58′-36°59′ E., in 190 meters; 1 paratype AMNH 183823, ex HUJ 10.204/1, Elat, Gulf of Elat, 29°31′-29°32′ N., 34°58′-36°59′ E., in 250 meters, October 8, 1965; 8 paratypes, HUJ 10.203/9 Elat, Gulf of Elat, 29°31′-29°32′ N., 34°58′-34°59′ E., in 80 meters.

Remarks: The presence of squarely-formed spiral cords terminating in lobed projections, and the relatively small size of the shell (figures 13,

14) serve to distinguish this species from others in the genus. This species is presently known only from the Gulf of Elat. Although Recent *Favartia* are not recorded in the Mediterranean, some Indo-Pacific species with shells larger than that of *F. elatensis* occur intertidally or in shallow depths elsewhere in the Red Sea.

Genus *Murexiella* Clench and Farfante, 1945

Type species: *Murex hidalgoi* Crosse, 1869, by original designation.

Murexiella mactanensis n. sp.

Figs. 7, 8

Description: Shell medium-sized for genus, attaining 22 mm in length; biconically fusiform; spire elevated, with 5 convex whorls; protoconch dense white and with suture impressed. Aperture broadly ovate; peristome erect, more weakly elevated on the left posterior side; margin of outer apertural lip wavy, with the 5 undulations reflecting the presence of the external cords; anal sulcus weak; siphonal canal moderately long, narrowly open; tapering tube-like and strongly recurved; siphonal fasciole strong, spaced some distance from body sculpture. Axial sculpture of 5 erect varices terminating distally as open spines of moderate height; final varix set-back from aperture, bent back and with the leading side richly scabrous; scabrous lamellae on leading side of all varices to the margin of each varix; intervarical area with weaker lamellae or with lamellae developing into scales. Spire with 6 varices, the varices more weakly erect crossing the shoulder diagonally and continuing on to the varix of preceeding whorl. Body whorl with 5 spiral cords; cords nearly erect on varices and terminate as upturned spines. Spines at shoulder longest; the first two paired, followed by the remaining 3; spines open, marginally not ornamented and on the final varix broadest distally with the edges recurved on the leading side; spines subdivided lengthwise by incised lines into 2 or 3 unequal areas. Minor cords situated between large ones, with a gap between the last cord on the body and the spinal cord on the canal. Shoulders ornamented, notably on the final varix, with a short lobe having 3 or 4 pointed spines. Shell color: on the holotype, the spire, intervarical areas, and fasciole flesh-pink, darkest towards the apex; varical areas white, especially terminally; aperture white. In the paratypes, the amount of the flesh-pink coloration varies in intensity and location on the shells.

Measurements: Holotype 21.7 mm in length, width (including spines) 14.3 mm; smallest specimen (4 post-nuclear whorls; Pisor collection), length 12.9 mm.

Type locality: Off Punta Engaño, Mactan Island, Philippines, in about 30 meters (obtained in tangle or gill nets), 1977, ex Dorothy and Robert Janowsky collection.

Material examined: Holotype AMNH no. 187186 (figures 7, 8); 1 paratype Panglao, Bohol Island, Philippines, in about 180 meters, 1977, Albert Deynzer collection; 1 paratype SDMNH 73800 (ex Pisor collection) and 1 paratype Don Pisor collection, both Bohol Straits, Philippines, in about 50 meters.

Remarks: The present species, characterized by having the 5 varices terminating in simple, unornamented spines, may be assigned to *Murexiella (sensu stricto)*, based on the typological genus-group concept of *Murexiella* Clench and Pérez Farfante, 1945 (see Radwin and D'Attilio, 1976, p. 155-161). Several western Pacific species were assigned by Ponder (1972) to *Murexiella*, which he regarded as a subgenus of *Favartia*. These other taxa differ from the new species by their closer relationship to *Favartia (sensu stricto)*. Comparison can be made with the Indo-Pacific species *F. salmonea* (Melvill and Standen, 1899) and *F. rosea* (rather *roorwindei*) Ponder, 1972, in which the body whorl and sculpture are somewhat similar. They lack, however, well-developed spines with connecting webbing, characters that serve to distinguish taxa referable to *Murexiella (sensu stricto)*. This new species, together with the one following, brings to two the number of distinctive *Murexiella* recognized recently in the central Philippines.

Murexiella martini Shikama, 1977

Figs. 9, 10

Supplemental description: A slender fusiform shell, attaining 28 mm in height (holotype); spire

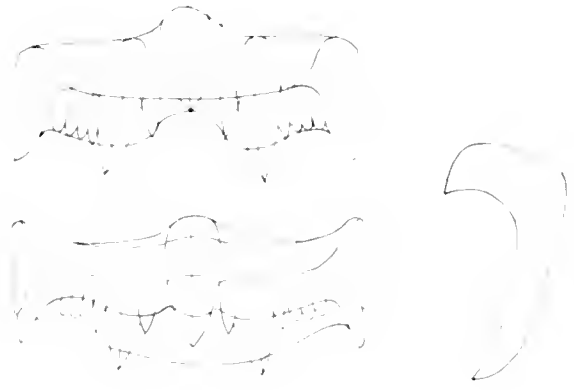


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FIG. 19. Pteropurpura benderskyi *n. sp., radular dentition (drawings by Anthony D'Attilio); greatly enlarged.*

well-elevated, with a protoconch of $1\frac{1}{4}$ whorls, followed by 6 post-nuclear whorls; body whorl large, strongly spined at shoulder; suture impressed. Aperture ovate, peristome entire and strongly elevated; sulcus shallow and broad; outer lip with 4 extended, lobe-like crenulations reflecting the dorsal spiral sculpture. Siphonal canal narrowly open, broad above, strongly recurved, tapering axially and tube-like distally, with fasciole formed by terminations of the two previous canals. Body whorl with 3 spinose varices; varical margins thick, erect and continuing nearly midway to the intervarical area; basal varix crossing the shoulder diagonally and extending to the previous whorl. Four strong spiral cords, one at shoulder separated by a gap from the group of 3 below; cords terminating in long moderately open spines at the varices; spine at the shoulder longest, those below about $\frac{1}{2}$ as long; cords subdivided by 3 to 5 incised lines. Spines connected by a flangelike web ornamented with a scabrous lamellate surface on the leading side; varical webbing with one small, medial cord and with a weakly defined cord on either side of the central cord. Scaly lamellae on entire surface of the shell, exclusive of the canal, and with most prominent lamellar development on the raised cords and spines. Shell pale-brown ochre, lighter dorsally on the cords and spines, darker brown on the open inner surface of the cords and on the varical margins; aperture and peristome translucent whitish. Color somewhat variable among the 10 specimens examined.

Measurements: Largest specimen examined 26.6 mm in length, width (excluding spines) 9.5 mm; smallest specimen (lacking mature siphonal canal) 18 mm in length, width (excluding spines) 7.6 mm, Bibbey collection.

Type locality: Off Cebu Island, Philippines.

Type depository: Personal collection of Dr. Tokio Shikama, Yokohama, Japan.

Material examined: Figured specimen SDMNH no. 72627 (figures 9, 10) and 1 other specimen, Bohol Island, Philippines, Leo Kempczenski collection; 3 specimens from off Punta Engaño, Mactan Island, Philippines Islands, Janowsky collection; 1 specimen, Mactan Channel, Philippines, in tangle-trawl, Bibbey collection; 1 specimen AMNH no. 183818, from Samar Island, Philippines, ex Bibbey collection; 2 specimens, Panglao, Bohol Island, Philippines, in trap, 1977-1978, Deynzer collection.

Remarks: This distinctive western Pacific species (Shikama, 1977, p. 15, pl. 2, figs. 10a, 10b) is characterized by the relatively small size of the body whorl, the slightly extended spire, the lengthy spines, and prominent webbing (figures 9, 10). It was compared by Shikama (1977, p. 15) to several unrelated long-spined species: *Chicoreus damicornis* (Hedley, 1903), *C. axicornis* (Lamarck, 1822), and *Murex longicornis* Dunker, 1864.

SUBFAMILY Typhinae

Genus *Siphonochelus* Jousseame, 1880

Type species: *Typhis arcnatus* [sic] Hinds, 1844 (=*T. arcuatus* Hinds, 1843), by orignal designation.

Siphonochelus radwini n. sp.

Figs 20, 21

Description: Shell small for genus, attaining 5 mm (holotype immature, lacking perhaps one body whorl), fusiform; spire acute, of $1\frac{1}{4}$ bulbous nuclear whorls, followed by 3 weakly angulate postnuclear whorls; suture impressed. Body whorl large, fusoid; aperture small, ovate with an entire and erect peristome. Anal sulcus apparently lacking, but with a moderately long anal tube, arising at the rounded, poorly defined margin of shoulder

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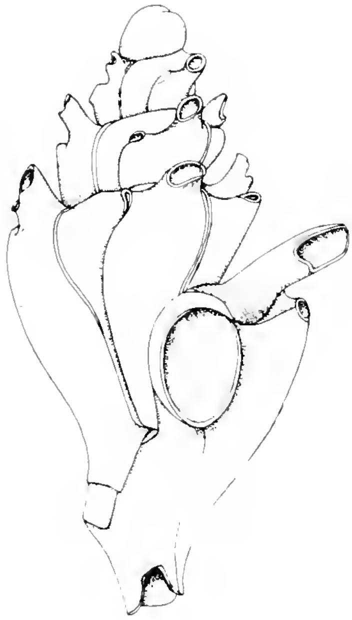

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FIGS. **20** *and* **21.** Siphonochelus radwini *n. sp., holotype, NMNH 323198 (drawings by Anthony D'Attilio): greatly enlarged (natural size = 5.0 mm. in length)*

in each varical interspace, and more closely placed to the earlier of the two varices. Proximal portion of each tube on the body swollen and axially depressed on the left side below the shoulder margin. A minor swelling produced on the leading side of each tube, terminating as a fold at the margin of the shoulder. Distal portion of tubes generally short, slanted, and irregular in cross-section. Last tube largest, weakly bent to the right, and the only one remaining open. Body whorl with 4 varices; each varical margin with a slight axial thickening corresponding to a former outer apertural lip. With increasing whorl size, position of each tube slightly ahead (in the direction of growth) of the corresponding tube on the preceeding whorl. Siphonal canal broad, moderately short, tapering, closed, bent to the right and dorsally recurved. Shell dull-white; aperture polished white.

Measurements: Holotype (figure 20, 21), length 5.0 mm, width 2.5 mm.

Type locality: Off Cabo Catoche, Yucatan, Mexico, dredged in 46 meters, USBF Sta. 2361.

Material studied: Holotype NMNH 323198.

Remarks: We have followed the genus-group concept of Radwin and D'Attilio (1976, pp. 198-200) in assigning this new species to *Siphonochelus*, the first record of a living representative of this genus from the New World. Additional living species of *Siphonochelus* are recorded by these authors from the western Pacific and from off the Cape of Good Hope. It should be noted, however, that Radwin and D'Attilio (1976) rejected the previous assignment by several authors of western Atlantic species to *Siphonochelus* (e.g.: Keen, 1944; Gertman, 1969; and Bayer, 1971); see also Penna-Neme and Leme (1978) for their use of *Siphonochelus* for an eastern American species.

Although this taxon is based on a unique, apparently immature specimen, its distinctive morphology, together with its occurrence in the Western Hemisphere, has led us to describe it.

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SCAPHELLA CONTOYENSIS,
A NEW VOLUTID (GASTROPODA) FROM EAST MEXICO

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ABSTRACT

Scaphella contoyensis, *a new species from the Yucatan Channel, Mexico, is described and compared with related volutid species of the New World subfamily Scaphellinae.*

During the past decade, several examples of a large, thin-shelled volute have been obtained by shrimpers in depths ranging from about 70 to 180 meters in the Yucatan Channel, mostly in the vicinity of Contoy Light, off Cabo Catoche, Yucatan, Mexico. These specimens are somewhat reminiscent of Australian species of *Ericusa* and *Cymbiolista* in size and coloration, but they lack the spinose ornamentation that characterizes the latter Indo-Pacific forms.

Specimens of the new species were generously donated to us by Donna and Riley Black and Elsie Malone of Ft. Myers, Florida, and Dr. William J. Clench of Dorchester, Massachusetts. Gene Everson of Ft. Lauderdale, Florida, kindly lent a specimen from his collection and donated the soft parts. These specimens form the basis for the present report. Additional specimens, all taken by dredging in the Yucatan Channel, are preserved in the following private collections: Christine S. Goddard of Ft. Myers Beach, Florida, 1 specimen, in 46 meters, March 1968. Barbara and Thomas McGinn of Cutoff, Louisiana, 8 specimens (2 of which are now in the collection of the American Museum of Natural History), in 132 to 183 meters, February 1970, (1 specimen), March, 1972 (6 specimens), 1975 (1 specimen); Elsie Malone of Ft. Myers, Florida, 1 specimen in 90 meters, *ex* Carmel and Wassy Frank collection; Carmel and Wassy Frank, Ft. Myers, Florida, 2 specimens (*teste* Elsie Malone); and Ernie Ryckman, of Key West, Florida, 1 specimen. We are grateful to these collectors for providing data and photographs of their specimens.

Drs. Frederick M. Bayer and Joseph Rosewater of the National Museum of Natural History also contributed data, and the latter lent us the holotypic specimen of *Scaphella evelina* Bayer. Our colleague, G. Robert Adlington, photographed the specimens illustrated in this paper.

TAXONOMIC PLACEMENT

Bayer (1971, pp. 200-221) succintly reviewed the pertinent literature pertaining to the classification of the western Atlantic species of Volutidae (*q.v.*, Clench, 1946, 1953; Clench and Turner, 1964, 1970; Olsson, 1965; Pilsbry and Olsson, 1953, 1954, and Weaver and duPont, 1970). We concur with Bayer's conclusion that the classification of the family is ". . . still a difficult matter," as the genus-group assignment of the *Scaphella* described herein proved to be perplexing because of conflicting data. We must, however, comment on Bayer's (1971, p. 195) placement of the genus *Teramachia* Kuroda, 1931, in the family Turbinellidae, based largely on shell characters in the absence to him of information on the radula. Anthony D'Attilio (*in litt.*) has pointed out to us that the radular characters of *T. tibiaeformis* Kuroda, 1931, the type species of *Teramachia*, as illustrated by Habe (1952, p. 132, fig. 12), are typically volutid. This genus is, therefore, referable to the subfamily Calliotectinae Pilsbry and Olsson, 1954, on the basis of radular and opercular morphology (*c. f.*, Weaver and duPont; 1970, p. 177, fig. 11b, for an illustration of the operculum).

In the most recent reviews of the subfamily Scaphellinae, Bayer (1971, pp. 209-216) and Weaver and duPont (1970, pp. 140-145) recognized the genus *Scaphella* as a polytypic taxon to include, in addition to the nominate subgenus, the subgenera: *Clenchina* Pilsbry and Olsson, 1953 (type species by original designation: *Voluta dohrni* Sowerby, 1903, = *S. gouldiana* (Dall, 1887), *fide* Abbott, 1974, p. 244) and *Aurinia* H. and A. Adams, 1853 (type species by original designation: *Volutia dubia* Broderip, 1827). The subgeneric units were separated by these authors largely on the basis of minor differences in the radular morphology, as defined by Pilsbry and Olsson (1954) in their "Systems of the Volutidae". According to Bayer (1971, p. 209, and fig. 63), the type species of *Scaphella (sensu stricto)*, *Voluta junonia* Lamarck, 1804, has ". . .a single long, concave cusp and no small basal denticles."; *S. (Clenchina) dohrni* has ". . . a shorter, more pointed, concave cusp flanked by minute accessory cusps."; and *S. (Aurinia) dubia*, together with the genus *Volutifusus* Conrad, 1863, has ". . .a well-developed lateral cusp on each side of the main, central cusp." Bayer concluded that the simple Y-shaped teeth of *S. junonia* had resulted from progressive reduction of the side-denticles from the well-developed tricuspid teeth of *Aurinia* and he suggested that these distinctions would be found to be of minor taxonomic significance, when more radular data became known. The radular morphology of the new species of *Scaphella* described herein serves to support Bayer's thesis, because the teeth lack basal denticles (fig. 7), in contrast to the denticled teeth of *S. evelina* Bayer (1971, fig. 63), which we believe to be the closest known relative of *S. contoyensis*, n. sp. (see remarks below).

In addition to the supposed radular differences, *Scaphella (sensu stricto)* and *Scaphella (Clenchina)* have been distinguished by trivial conchological characters, including the possession by the latter of less-solid shells than those of *S. junonia* (Weaver and duPont, 1970, p. 140). The basic similarity of the shell morphology, together with the minor differences of the radular characters, however, suggests to us that the genus-group taxon *Clenchina* is of questionable taxonomic value and our new species, together with *S. evelina*, should be assigned to *Scaphella (sensu stricto)*.

FAMILY Volutidae

SUBFAMILY Scaphellinae

Genus *Scaphella* Swainson, 1832

Type species: *Voluta junonia* Lamarck, 1804, by subsequent designation, Herrmannsen, 1848, p. 423.

Scaphella contoyensis, n. sp.

Figures 1-7

Description: Shell fusiform, large (attaining 170+ mm in length), with 6 whorls. Protoconch large and smooth, consisting of about 2 whorls. The first three post-nuclear whorls are thicker and more solid than the fragile body whorl, which is thin and inflated in mature individuals. The first 2 post-nuclear whorls sculptured with fine intersecting spiral and axial cords that give a weakly cancellate appearance to the surface (figure 5). Surface sculpture of the third post-nuclear whorl, especially posteriorly near the suture, is microscopically cancellate, but the sculpture is scarcely perceptible and the surface becomes macroscopically smooth on the body whorl. Spire short, not acutely angled; suture well-defined, moderately impressed. Aperture elongate-elliptical; outer lip thin and the parietal wall thinly glazed. Anal sulcus narrow and constricted posteriorly; siphonal canal broadly extended. Columella slightly arched, with two plications extending within the aperture. Periostracum tannish yellow and exceedingly thin.

Color of nuclear whorls is uniformly tannish brown; ground color of second and third post-nuclear whorls buff, overlaid with two spiral rows of irregular, elongated, chestnut-brown spots; ground color of third post-nuclear whorl and body whorl is a darker buff, with interspersed spiral bands of chestnut-brown streaks, which are lighter than the earlier chestnut-brown spots. In mature specimens, the interior edge of the outer lip (figure 3) has a continuous band of dark brown and the aperture is glossy, tannish-yellow to apricot.

Softparts: Length of foot, after preservation in alcohol, 78 mm; color-base whitish, with irregular dark markings that are preserved as black blotches (figure 6). *Radula:* Reduced to simple Y-shaped rachidian teeth lacking basal denticles (figure 7). An operculum is lacking.

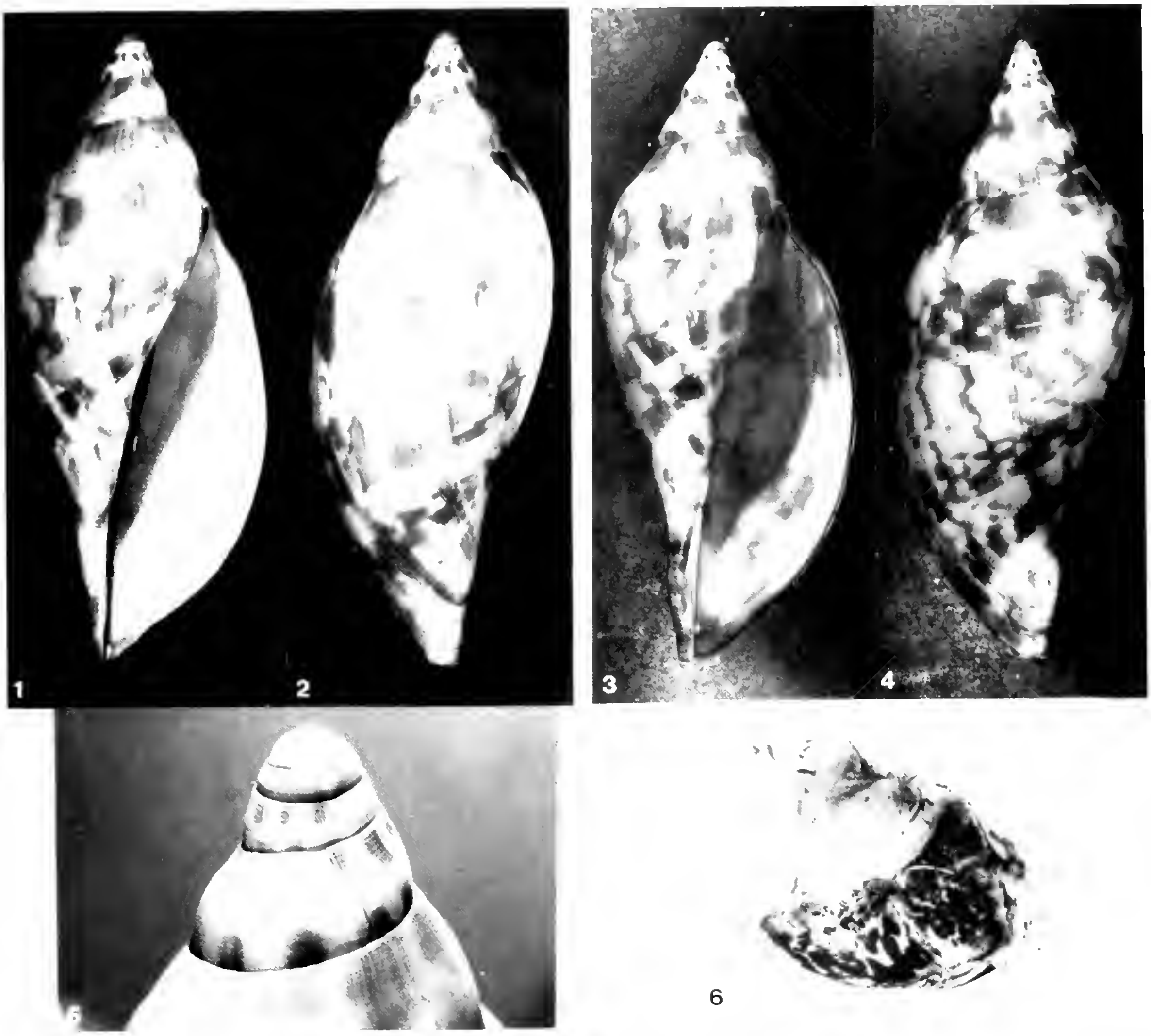
Measurements: Holotype 173 mm in length, 67.3 mm in width; figured male paratype, length, 70 mm in width (Everson collection); smallest specimen, immature, with three post-nuclear whorls, 56.5 mm in length (McGinn collection). Slender female specimen, 166 mm in length, 58.5 mm in width (AMNH collection, ex McGinn and Clench).

Type locality: Northwest of Contoy Light, Yucatan Channel, Mexico, dredged in 159 meters, September 1973, by Donna and Riley Black.

Type specimens: Holotype, AMNH 187180 (figures 1, 2, 5); paratype (figures 3, 4), northwest of Contoy Light, off Yucatan, Mexico, dredged in 73 meters, March 1978, Gene Everson collection. Paratype AMNH 182250, trawled off Punta Francisca, Yucatan, Mexico, in 183 meters, March 1972, ex McGinn collection.

Known range: Yucatan Channel, off Cabo Catoche, in 73 to 160 meters, and off Punta Francisca, in 183 meters, Yucatan, Mexico.

Remarks: Scaphella contoyensis n. sp. appears to be most closely related to *Scaphella evelina* Bayer (1971, p. 213-216, figs. 63c, 64), a species described from off eastern Panama and Colombia, in depths of 137 to 611 meters. Bayer's taxon differs from the present species by the possession of an acute spire, in the development of much stronger cancellate sculpture and a less flaring outer lip, and by the presence of a less distinctive and apparently inconsistent color pattern, as well as by the radular characters discussed above.



FIGS. 1-6 Scaphella contoyensis *n. sp.* **1, 2** *holotype, AMNH 187180, X½.* **1,** *Apertural view, note immature outer lip;* **2,** *Dorsal view.* **3, 4,** *Paratype, Everson collection, X½.* **3,** *Apertural view, note mature outer lip with dark colored band on interior edge of the outer lip.* **4,** *Dorsal view.* **5,** *Enlargement of the apical region of the holotype, showing weak cancellate sculpture, X2.* **6,** *Body of the paratype specimen illustrated in figs. 2, 3, X½; soft parts contracted by preservation in alcohol and sans the liver.*

The development of cancellate sculpture in this subfamily varies considerably among the species-group taxa and within some populations of these taxa. Of the extinct species that are most closely related to *S. junonia,* the early post-nuclear whorls are weakly to moderately cancellate in *S. trenholmii* (Tuomey and Holmes, 1856) from the Miocene and *S. floridana* (Heilprin, 1887) from the Pliocene. In the Miocene species, *S. precursor* Gardner, 1948, however, post-nuclear whorls are strongly sculptured and a spiral row of regularly spaced nodules are found immediately below the sutures on the earlier whorls and the body whorl; the postsutural nodules become obsolete and replaced by wavy spiral cords and prominent axial ribs on the remainder of the body whorl in mature specimens. In the living species, weak to moderate cancellate sculpture occurs on the second and third post-nuclear whorls of some individuals of *S. junonia* and *S. gouldiana* (especially in the forms named, *S. robusta* (Dall, 1889) and *S. marionae* (Pilsbry and Olsson, 1953), some ex-

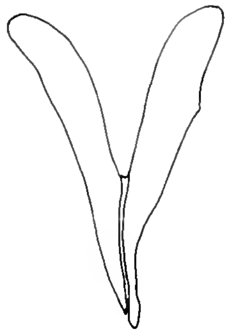


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FIG. 7. *The outline of a rachidian tooth of* Scaphella *contoyensis n. sp., greatly enlarged.*

amples of which possess nodular spiral bands on the earlier whorls.). All of the specimens of *S. contoyensis* n. sp. and *S. evelina* that we have examined have cancellate sculpture on the early whorls and near the suture on the body whorl. In the case of the former species, this sculpture is essentially microscopic, whereas in the latter species it is easily seen by the naked eye.

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A BIOGRAPHY OF ANDREW GARRETT, EARLY NATURALIST OF POLYNESIA: PART I*

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Andrew Garrett was an American explorer, naturalist and artist who specialized in malacology and ichthyology. He gathered and studied forms of many other invertebrates, such as corals and echinoderms, and made careful drawings of them. He also collected specimens of insects, birds, plants, and a few anthropological artifacts, some of which are doubtlessly resting anonymously in museums or private collections. He also described and drew watercolors of several dozen species of shells and several hundred fish, many of which are as yet unpublished.

Garrett lived and worked in various areas of the Pacific Ocean from the Hawaiian Islands to Fiji, the Marshall Islands, the Gilberts, Samoa, Tonga, the Cook Islands and the Society group. From 1856 to the early 1870's, his most productive years, he spent much of his time as a collector for Professor Louis Agassiz of Harvard College and in the latter part of this period, from 1873-5, served in the same capacity for the zoological and anthropological museum of the J. C. Godeffroy trading firm of Hamburg, Germany. In the last fifteen years of his life, while located permanently in French Polynesia, he added to his own vast collection of shells, part of which he occasionally sold and exchanged. He wrote twenty-one scientific papers which were published in journals in both America and Europe. One of the monuments of his zealous work were the 470 species of fishes which he gathered, described and drew in color for the important text edited by Dr. Albert C. L. G. Gunther. The Godeffroy Museum published the book, the first two volumes of which appeared from 1873 to 1875, and the final volume of which was issued in 1909, twenty years after Garrett's death. This production remained for forty years one of the most authoritative publications on fishes of Oceania.[1]

Unfortunately the name of Andrew Garrett is virtually forgotten, except by a few experts. Much of Garrett's important pioneer efforts in the field of marine biology were published by other authors, so that due credit was not always given him. Only one brief obituary was printed simultaneously in several scientific journals in America and England a few months after his death. A short outline of some of his accomplishments was included in the *National Cyclopaedia of American Biography* for the year 1899 (vol. 2, p. 162), but not in succeeding editions or in similar compilations or in histories of science. For many years his name and accomplishments were omitted from print. However, in

FIG. 1. *Andrew Garrett (1823-1887). Photograph probably taken in Hawaii about 1863. Original in the Museum of Comparative Zoology, Harvard College, Mass.*

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* Part 2: Catalogue of Molluscan Species and Bibliography of Andrew Garrett by William J. Clench will follow in the next issue of *The Nautilus*. Manuscripts submitted November 16, 1977.

the last twenty-five years there have been several short articles about him, one a brief chapter in a historical treatise on early scientific collecting in the Pacific.[2] A factor which may account for the eclipse of Garrett's reputation after his death was the nonexistence of diaries or personal papers. In the letters from him which do exist, he seldom mentions particulars of his private life. Furthermore, his specimens and drawings are widely scattered throughout the world with no inventory of his scientific collections ever having been made. Because of his colorful life and amazing travels there were many stories and possibly apocryphal tales. According to one story, Garrett had a mistress established on each of the islands where he periodically visited who made scientific collections for him in his absence. Another story concerns a queen of a remote locality where he was staying who induced her subjects to seize a barrel of his collecting alcohol. He had intended it to last for a year of collecting but it was consumed in one evening's drunken orgy. There has been no way of substantiating these tales as they were passed down by word of mouth. Furthermore, owing to gaps in our information as to Garrett's whereabouts it is unlikely that a definitive biography of him will ever be written. However, the present account is an attempt to present a resumé of the information that can be documented.

Early Life

This pioneer and largely self-trained naturalist was born in Albany, N. Y., on April 9, 1823. He was the third son of fourteen children and spent part of his early youth near Middlebury, Vermont. His father, Francis Garrett, was a native of Canada; his mother, born Joanna Campanaux, was a native of Belgium, and of good education. She spoke several languages. After Andrew left home at the early age of eleven, his family moved to Albany, N. Y.[3]

Early in his life young Garrett showed evidence of both independence and scientific curiosity. When he was eight years old he left home without warning to visit a museum one hundred miles away, and, then, having successfully completed his mission, returned safely. When only eleven he was apprenticed to learn the trade of an iron molder. At sixteen he abandoned this vocation and went to sea as a sailor for a period of three years. During that time, according to his own account, he touched at "nearly all the West Indian Islands, the Cape Verde Islands, off the African coast, as well as the Azores and Brazil and several Southern States." Reminiscing on this exploit several years later, he wrote, "I now went to work at my trade again, spending my leisure time studying the plants and shells. Still, my love of seeing new countries was not in the least abated so I travelled and worked (1842-1846) in various parts of the Northern, Middle and Western States."[4]

After these wanderings Andrew determined to go abroad again. Meanwhile, he had not neglected his interest in natural history, for it was during this time of roving that he lingered briefly in Boston, spending happy hours in the museum of the Boston Society of Natural History. "I wandered about the suburbs of the city with Bigelow's *Flora Bostoniensis* in my hand, studying plants. Having travelled in 23 States of the Union, I concluded to go abroad again."[4]

Pursuing his ambitions Andrew found himself on June 7, 1846, signed up as a crew member of a whaling vessel in New Bedford, Massachusetts. It was the bark *Edward*, bound for the Pacific.[5] Somewhere in the early course of this voyage, Garrett shipped over to another whaler, the *Eliza L. B. Jenney*, which had left Fairhaven, Massachusetts, on November 30, 1846. It was from this vessel on May 22, 1847, that Garrett stepped ashore at the busy port of Honolulu. The place caught his fancy, and he wrote some years later that he was so much pleased with its appearance that he made up his mind to settle there.[6] This, indeed, was the goal he achieved five years later.

Within a day or two of Garrett's arrival, an American missionary, the Reverend S. C. Damon paid a visit to the *Jenney*. Damon was the editor of the weekly journal, *The Friend*, dedicated to the spread of religion among seafaring men. Used to boisterous sailors who passed through the Hawaiian Islands, the minister was charmed by the inquisitive young man who was an amateur scientist. Such a vivid impression did Garrett make upon the older man that eleven years afterwards, Damon wrote: "We recollect to have accompanied him to the forecastle, and beheld with delight the collection of shells which he had already made. In reply to the question, 'Why did you ship before the mast?' he answered, 'In order to study conchology.' "[6]

That extended sea voyage marked a highlight in the life of the young sailor not only because of a variety of adventures but also the experiences he gained in exotic and faraway localities. These included the Marianas, the Bonins, the Ryukyu or Liu Chiu Islands, as well as China, the Philippines, and some Australian and East Indian ports.

When Garrett returned with his vessel on May 15, 1851, to its home port of Fairhaven, adjacent to New Bedford, he must have gained some satisfaction as the yield in sperm whale oil from this voyage amounted to 2,570 barrels. That was roughly the equivalent of $20,000. Although Garrett was only a foremast hand on a whaling ship his share must have been considered a profitable return for the times. But even more important to him were the twenty packing cases of shell specimens which he had assidiously collected during the long voyage. He himself mentioned this success six years after the incident when he was corresponding with his Boston patron, James M. Barnard. The sailor-naturalist took pains to mention that the proprietor of a shell store on State Street in Boston had bought the shells as well as some of the skins of birds, specimens of fishes and crustacea which he had collected.[4]

Ashore in Boston in the spring of 1851, he seemed uncertain of what his future held. He was twenty-eight and he had behind him a rather rough and wandering life. But he was also becoming more and more engaged in the study of natural history. The idea of sojourning somewhere in the Pacific Ocean and perhaps spending his life there must have been in his thoughts. Even six years before when his whaling ship had touched at Honolulu, he wrote he had been so pleased that, "I was determined to settle there".[4] During the next year or so after his return he travelled "through most of the States" as he expressed it, perhaps working as an iron molder. Finally, he left California, touching briefly at Rio de Janeiro and from that port finally headed for the Sandwich Islands, then also known as the Kingdom of Hawaii. He arrived in Honolulu sometime in the spring of 1852, and shortly thereafter made his temporary abode on the larger island of Hawaii. He remained there, except for various collecting trips in other parts of the Pacific, until 1863.

In the Hawaiian Islands

Why Garrett selected Hilo to be his headquarters will probably never be known. Of course, it was one of the three Sandwich Island ports preferred by the captains of the whaling ships from the 1830's until the time of the Civil War, when the whaling industry greatly diminished.

In 1850 the total population of the five islands of the Kingdom of Hawaii was only 84,165 in contrast to the approximately 840,000 living there today. The number of foreigners was only 1,962, a little over 2%. These persons were missionaries, traders, plantation owners, and others, some of whom had married Hawaiians and occupied government positions. Others were members of the diplomatic corps. King Kamehameha III was in the twenty-seventh year of his reign.[7]

Garrett was an ardent shell collector when he arrived in Hawaii in 1852 but he lacked scientific training. Doubtless, it was his association with a few skilled amateur naturalists which influenced his future career and raised the level of his interests above those of the mere collector. But, being somewhat quiet and shy he did not befriend these persons at once. His acquaintance and friendship with the avocational scientists of the Islands seems to have come about gradually.

Above all, it must have been the richness of nature in Hawaii which aroused and stimulated the spirit of inquiry. At first he seems to have been drifting along without any set purpose. We do not know whether or not he had some occupation or how he supported himself at this time. However, in the fall he received a letter from Dr. Wesley Newcomb, an American physician and naturalist who had come to the Islands for his health. Newcomb established a private medical practice and eventually became government Health Officer, devoting himself on the side to his hobby of conchology. His first scientific paper on land shells entitled "New *Achatinella*" was published by the New York Lyceum of Natural History in 1853. It is known that Garrett collected for Newcomb and within a year the doctor was proposing to name a new species of shell in honor of his friend, writing, "It would afford me much pleasure to embalm your name not your person, to have it associated with a fine, new species from Hawaii. When this is fixed, it descends through all coming time."[8]

At this time in Honolulu there was considerable interest in collecting shells, both local specimens and those from foreign shores. The comings and goings of sea captains and sailors, traders and missionaries probably had stimulated this traffic. The great abundance of tree snails with their bright colors, gathered by the native Hawaiians, was another form of trade. There was even a shell store in Honolulu from about 1852 to 1858, maintained by Dominique Frick, who had once been the French consular agent.[9]

We know that Newcomb left for the United States in March, 1855, but we do not know much about Garrett's association with other naturalists, except that he was collecting and had access to a limited amount of literature and at the same time was teaching himself to draw and paint. It may have been due to loneliness but also due to his aspirations of becoming a professional collector that Garrett on January 29, 1855, wrote a letter to one of the most distinguished scientists of his day. He addressed it to Prof. Louis Agassiz who had recently arrived in the United States as lecturer at Harvard and who, anxious to build up a core of collectors throughout the world, had issued some printed literature soliciting contributions. Garrett included sample drawings of fishes and some invertebrates, explaining he would continue to make sketches... "so that in the event of your observing any new species, or such as you would like specimens of, you can inform me. . . I do not make any pretensions to a knowledge of Ichthyology. . . yet will endeavor to write a description of each." He continued that he would be glad to exchange specimens in any branches of natural history and desired in return either specimens of shells new to him or copies of such books as Storer's *Fishes of Massachusetts* or of Dr. Gould's books on shells.[10] Although the financial resources of Harvard University were at a low ebb, a very fortunate arrangement was made through Agassiz's Boston friend, the merchant and shell collector, James M. Barnard.

By September, 1856, almost seventeen months later, Garrett received a reply to his inquiry to Professor Agassiz. It was from Mr. Barnard, written on the professor's behalf, inviting young Garrett to become a zoological collector on a permanent basis. Garrett replied that he was most happy to do so as he had no regular employment and was on the point of returning to the United States. In his letter of acceptance, he concluded to charge $400 per year which would cover all of his traveling expenses, food, hiring of assistants, his own salary and would further enable him to go on various ships to remote islands.[11]

The impetus furnished by Louis Agassiz for him to apply and improve his already self-acquired scientific techniques of observing, collecting and recording came to Garrett at what seems an appropriate time. On December 1, 1856, at Hilo he shipped aboard the whaleship, *Lydia*, whose master was John W. Leonard. Considering the territory covered in the voyage which included the Society Islands and some of the Marquesas Islands, the vessel was away from Hawaii for the surprisingly short span of three months. The voyage was highly successful from the point of view of the variety and number of specimens gathered, but a tragic event came later. After the reshipment of the collections to another vessel, the *John Gilpin*, the latter vessel was wrecked on its return to the United States in November, 1857, and its cargo lost, which included considerable but not all the material destined for Harvard.[12] It happened there were duplicates retained by Garrett and some of the fish pictures were already in the possession of Captain Leonard who eventually reached home safely.

Recently, through the courtesy of Barbara Johnson of Princeton, an interesting letter from Leonard to his wife, Lydia, has come to light. It provides confirmation that the American naturalist was making fish pictures specifically for Captain Leonard. In part, Leonard said, "Since I wrote last we have passed through several stirring adventures (new). We have been at Fannings Island, and Mitui, one of the lower archipelagos. And, also at the Island of Huehine [sic] where we have gathered a splendid lot of shells and fishes. We have a naturalist (Garrett) as Passenger with us which makes it very pleasant. And he is painting a fine lot of Fish for me and collecting a beautiful lot of shells. So I shall have a fine Colection [sic] when I get Home."[13] Of course, the principal benefactor was Harvard College and its museum of natural history. Later, most of this material was described and pictured in the publication of the Godeffroy Museum of Hamburg.

We have in this statement Leonard's corroboration of the fact that part of this was the same collection of watercolor drawings, all drawn by Garrett, which survived in the family of John Leonard's descendants. They are now the property of the author of this article. A further item of interest is that the Leonard set contains a Garrett picture of a beautiful wrasse fish of the family Labridae which the artist-scientist named *Julis leonardianum* undoubtedly in honor of his whaler friend.

A few months after Garrett returned from his voyage to Hawaii, he received a four-page letter in the handwriting of Professor Agassiz, addressed to John M. Barnard but intended for the naturalist-employee. It has significance, for it served as a guide for proper collecting and scientific observation. A total of three such letters from Agassiz composed for Garrett's benefit still exist and are preserved in the library of the Bishop Museum in Honolulu. The first one, dated August 28, 1857, explains:

"The principal merit of collections of objects of nature is not desired in our days from the accidental circumstances that they may contain new species but from the opportunity they afford of elucidating natural laws. The collector ought, therefore to have his attention constantly turned to this important end and must on that account collect in a particular way. . .[14]

He went on to explain that large quantities of specimens of one species in all sizes should be obtained as they all afford the means of ascertaining the range of different species. He added that the slightest difference between specimens of adjoining localities should be taken into account. Even in the case of adjoining islands "or opposite shores of the same island specimens must be collected of everything. . . It is thus ascertained that the different groups of Islands of the Pacific may be inhabited by distinct representatives but identity must be made out by direct comparison and can neither be assumed or denied before hand".

Meanwhile, the instructions Garrett had received for collecting and his own zeal compelled him to adopt and use more precise methods. Through a letter to Barnard, written after the trip on the *Lydia*, he reported on his field collecting. He explained that he made it a point to gather those specimens which did not often occur. "When searching along the coast I have to take pencil and paper, an assortment of small jars, boxes and calabashes which my native boys carry. And when I find anything I which to preserve I first note the depth of water, kind of bottom, its mode of locomotion and colors while alive. And I find it necessary to preserve them in water while carrying them about so that their delicate parts will remain perfect until I can place them in alcohol." He said that he found it essential to make rough sketches of many objects in order to give a clear idea of their markings. He, also, added that he had his own catalogue of the crustaceans in which he recorded everything relative to each species which he found.[15] It so happened that at the time Garrett mentioned his misgivings as a scientific field worker, Professor Agassiz had time to examine some of the young worker's drawings. In an undated letter to J. M. Barnard, probably written in the fall of 1857, he said "I have been much pleased with the drawings as well as the descriptions of Mr. Garrett. They will be invaluable material to clear up the Natural History of the Pacific Ocean but I would warn him not to be hasty in publishing them."[16]

Relationship with William Harper Pease

William Harper Pease (1824-1871), surveyor and conchologist, reached Hawaii when he was twenty-five years old. He had travelled in Mexico with General Scott's army and had made extensive collections there of birds, insects and other fauna for the Academy of Natural Sciences of Philadelphia. Even at that early age, he had already published the first of his scientific papers which totalled 82 articles by the time of his death. Pease chose to be in Hawaii for reasons of health, reaching there in 1849 and residing in Honolulu until his demise in 1871. In a short time he became an important man with interests enabling him to travel through the islands. He worked as a land surveyor, and held the position of Assessor of the City of Honolulu as well as being Commissioner of Water Rights. But, preeminently he was a scientist. Like Garrett he was a self-taught naturalist but by the time they met, Pease had acquired the disciplines of scientific research and was an inveterate collector. Pease helped Garrett not only by engaging him as his principal collector but allowing his friend to use his conchological and scientific books, instructing him in method of research and in other ways. It is very fortunate that there was such a person available to Garrett for his guidance and stimulation, and as the two first met in 1857, in a sense Pease took the place of Newcomb who left the Islands in 1856, and had formerly been the young collector's friend and mentor.

For six years despite the various absences of Garrett on collecting trips, they saw each other fairly frequently. After the summer of 1863, Garrett left Hawaii never to return before Pease's death in 1871, but they kept up a faithful correspondence. A group of letters from Pease to Garrett written during the whole period of their friendship (1857-1871) survives in Honolulu's Bishop Museum. Excerpts from them are given in the series of articles by Karl W. Green published in 1960,[17] and others were quoted in the biography of Pease by Dr. E. Allison Kay.[9] The relations of these two men was friendly, although Pease took almost a paternalistic attitude toward Garrett. There was a difficult side for Garrett. It is true that, in a sense, he was an employee of the other man, but in some ways Pease seems to have taken advantage of Garrett's abilities and efforts. The latter worked hard and laboriously. He collected amid the most trying and dangerous conditions. He scrupulously described and drew pictures of many of the specimens gathered, particularly the fishes. In the case of fishes and shells he suggested the scientific names. But despite all this, he lived in the shadow of Pease while the more articulate writer and more assertive man earned the glory.

Collecting in the Kingsmill Islands

Was it restlessness or a desire to form collections from lesser known areas that goaded Garrett to make so many scientific forays? We sense that the business arrangement with the museum at Harvard as well as the enthusiasm of both Professor Louis Agassiz and the Boston businessman James M. Barnard, must have been the stimulants to these persistent travels.

Hawaii was a focal point from which trading schooners and whaling ships, served as a means of transportation. One of the latter was the brig, *Morning Star*, operated by the Board of Missions to convey American missionaries and their trained Hawaiian assistants to the various, far-flung island stations.[18] These mission voyages were financed by sums of money raised, largely by New England school children. Garrett explained that he had made reasonable arrangements as a passanger aboard the *Morning Star* paying $1.50 per day while he stayed on board, with an additional charge for his package of specimens. A plan developed so that he could sail directly to one of the islands and stay there collecting for three months.[19]

Our conchologist carried complete provisions as well as articles of trade to last him at least four months. The materials included cutlery, edge tools, beads, calico cloth and even 400 board feet of lumber with which to build wooden boxes for the return of his specimens. The brig, *Morning Star*, left Hawaii on August 11, 1859, but due to adverse winds and currents took longer for the trip to the South Pacific than would ordinarily be the case. Finally, after a voyage of three weeks from Honolulu, the two-masted vessel reached its destination on September 9th. This was Apiang, one of the northern islands of what are now known as the Gilberts in Micronesia. It must have been a strange, remote place, being flat and palm-covered coral rock. It was about fifteen miles square and had a total of not over 300 to 400 inhabitants, living in small, scattered villages. While the Rev. and Mrs. Hiram Bingham, who ran the mission, lived near their thatched church a scant distance away, Garrett established himself in a rather flimsy, borrowed dwelling. With the limited help of his servant Temawa, the naturalist busied himself in making extensive collections. To do this he daily waded for long hours over the inner and outer platforms of the nearby lagoons. He also exchanged small bits of his trade goods for selected specimens of fish, shells, echinoderms, and other forms of aquatic life. Several dozen natives crowded around him almost every hour of the day, causing him endless misery. This slowed down his work of preparing specimens, making drawings and jotting down notes. Their repeated attempts to steal his belongings made him worry that they might seize and drink the precious preserving alcohol, so that he frequently worked into the late hours of the night when his unwelcome guests were not around. After some days of deceiving the natives about the alcohol, they detected its smell. They would have taken it from him had he not convinced them that it was poisonous type of substance. Another nuisance he had to bear were visits by inhabitants of other islands. All of them demanded to see and handle what they called his "wonders". These were a mechanical music box, a magnifier with mirror, and the "plates" or pictures of natural history subjects which he had brought with him or had done on the spot. Although his companions demanded that he buy all their zoological specimens they brought to him in large quantities, he found it judicious to acquire only a few representative ones from each lot so as not to discourage the vendors from continuing to collect for him. Lacking a knowledge of the language, he was compelled to use pantomime combined with mixed words of Hawaiian and English, but seemed to succeed fairly well in communicating. Unfortunately, at frequent intervals he was ill with fever or other complaints and when attempting to rest, found: "a pair of black eyes glistening at every crevice in sides of the house." Sometimes, due to the crowds of noisy visitors, forty or fifty in a group, he had to close up his house and take long walks to get away from the tumult.[19]

From time to time the busy collector had some contact with the ruler, King Tekaiia. This person did not seem to be a real monarch. Garrett described him as a large, corpulent man whose only clothing was a rough mat of leaves wrapped around his loins. He lacked the respect of his subjects who seemed to ignore his authority. When one day several unfamiliar natives arrived from the nearby Island of Maraki, Garrett noticed that they were "bringing with them several Kanaka heads. They stated that there had been a battle... and the heads were those of some of their friends who had been slain and they had cut them offf and fled to prevent them (the heads) from falling into the hands of the enemy." One detects a note of reprovement in our traveler's remarks on his observations of the Micronesian Christian converts. They often dozed during the sermons of the missionaries or plucked and ate the lice from each other's heads while attending church. He was further shocked when one day in passing the council house he was overcome by the stench from a putrid corpse. It was the body of an elderly and venerated chief whose funeral services extended over several days.

Despite the hard times and vicissitudes which the naturalist had to endure, one realizes from his journal how enthusiastic and excited he became when he encountered new species of shells and fish. On its return from Apiang with Garrett and his booty aboard, his ship stopped at Ebon Island where he acquired additional specimens. When he arrived back in Hawaii on January 11, 1860, he must have had considerable satisfaction in the success of the expedition. A record of the importance of the venture is also incorporated in the official report of the Harvard Museum quoting Agassiz on the acquisitions from the Pacific Ocean, which stated, "the total number of specimens of fishes amounts to five thousand, comprising 1,000 different species, the most important of which are from the Kingsmill and Society Islands, collected by Mr. Garrett"[20] Despite this account it is quite likely there was an error in the report as the collections noted probably included shells and other organisms in addition to fishes.

Second Visit to the Society Islands

It is unfortunate that there is such scant information about Garrett's second visit to the Society Islands which took place from 1860 to 1863. The Society Islands offered ample opportunities for new discoveries, despite the collections of Captain

James Cook's associates, Lesson, Hugh Cuming, and others. Commenting on the early work of these scientists, Garrett, writing some twenty years later in his own research article, remarked "During the years 1860-1863 I made a much more thorough exploration (of land shells) than any of my predecessors, and by searching in nearly every valley of the group, discovered 50 new species. . ."[21] He left Hawaii for Tahiti and the other islands in May, 1860.[22] The manner of life of the natives there had probably not changed appreciably since his visit of three years previously when he observed, ". . conditions being there the same as at the Sandwich (Hawaiian) islands in the form of indolence, drunkeness, and the most loathsome diseases which he felt were rapidly decimating the population. I cannot perceive as they have improved an iota in there moral or physical condition notwithstanding 40 years of missionary labor and intercourse with foreigners."[23]

More importantly, he wrote of the marked similarity in the marine fauna in French Polynesia in comparison with that in the Sandwich Islands. Though the natives of each island group spoke a different language, they used the same name for the same objects common to both areas. He noted that residents of Boston, New York and Baltimore had two or three names for the same natural species. Still he found natives living 2,000 miles away from one another speaking almost a different tongue but using the same name for the same species of fish. "All Polynesian Islanders have with very few exceptions a distinct name for every kind of animal, plant and mineral, no matter how small and obscure the object is." He concluded by saying "They as a mass have a better knowledge of the natural productions of the islands than the mass of people in the United States".[23]

Although we have so little information about Garrett on this particular Society Island sojourn, we do find a reflection of his interests in the letters Pease wrote him and which he so carefully kept. On September 2, 1860, Pease wrote proposing their collaboration on a series of popular natural history publications which would contain lithographs of the watercolor drawings as well as printed descriptions of the more common fishes, shells and plants. "My opinion is the most effectual mode is to publish a small pamphlet in numbers, similar to those of Professor Adams, 'Contributions to Conchology'. I think I shall issue one before you return." Pease went on to explain that the publication would contain "your descriptions of fishes and a portion of the descriptions of shells I have forwarded to Cumings."[24] It is quite likely that a series of 30 handwritten sheets of descriptions of fishes and shells of both Hawaii and the Society Islands in Garrett's handwriting with borders drawn around them, each with a watercolor drawing, are part of the group previously mentioned as now owned by the author were intended for the pamphlet. Unfortunately, the projected publication never appeared as far as is known.

In the Central Pacific (1863-69)

Apparently Garrett returned from his Society Island explorations about July, 1863. The months that followed were crucial ones as he decided to abandon his base in Hawaii and go off on even more extensive voyages. In welcoming him back to Honolulu, the Rev. Samuel C. Damon, reporting enthusiastically of the naturalist's accomplishments, wrote ". . . he has visited every island and every valley and reef of every island, collecting specimens of shells, fishes and every variety of animal and insect. The extent of his collections may be indicated by the fact he has used three hundred gallons of alcohol in preserving the specimens. He has collected 400 different species of fishes. Each one of these is beautifully painted from life. Some of his drawings which we examined are executed with great skill and taste. The number of these specimens which were forwarded from the Society Islands would not fall below ten thousand."[22]

With his long journey behind him and with his collections shipped away, he had to put off the blandishments of his friend Pease. The latter was insisting that he remain and help with his projected commitments for publication. In fact, Pease at this time was writing several papers on land shells probably based in part on Garrett's collections. Eight papers appeared, chiefly on this topic, with Pease's name attached in the Proceedings of the Zoological Society of London between 1864 and 1865.[9]

Garrett, making preparations for his next extended voyage, received a letter dated October from his San Francisco agent, Sam Hubbard. He had purchased for him a supply of alcohol, a music box with which to entertain the natives, a magnetic machine (which may have been a surveying instrument), and a series of other articles. The most expensive item was a complete wet plate photographic apparatus which included a camera, plates and chemicals. It cost $376.76, an enormous sum, considering that Garrett's yearly salary was only $400.

Another important activity for Garrett in his 1863 stay in Hawaii was identifying both shells and fishes for the California Academy of Sciences. That institution had made him a corresponding member in 1856 and its *Proceedings* in 1857 had carried his article on marine shells, probably his first scientific contribution to be printed.[2] That same organization, hearing of his new expedition, sent him twenty gallons of preserving alcohol which they said was to be used "according to your best judgment, taking sufficient of it to reimburse yourself."[2]

Meanwhile, in August, Damon, in the same letter referred to, outlined the extensive South Sea Islands voyage the conchologist was planning. It would include the Marquesas Islands, the Navigators (Samoa), Friendly (Cook) and the Fiji Island groups. This would be a period of no less than five or six years which he would devote to new explorations. Damon added, ". . .he is perfecting himself in the photographic art, as he will go prepared to take views of natural scenery, animals and the inhabitants of those remote regions. Hereafter, his researches will embrace a wider range than they have hitherto done.[22]

Late in 1863 Garrett got off but we have only a vague knowledge of his specific locations in the next six years. He chose for his collecting grounds two main areas 2,000 miles and more south of his former haunts in the Hawaiian Islands. These were, first, the Tuamotu Islands, a large archipelago, stretching from 140° to 150° West Latitude and situated east of the Society Islands. He seems to have been there for most of 1864 and 1865 but we have no records of the precise places of his collecting. For the second part of his travels, he was in the Cook Islands, Western Samoa and, then for a good part of 1867 to 1869 he moved about the Cook Islands.

Garrett was not only doing his usual collecting but was also taking photographs of the native people. We have already noted his purchase of a camera and the necessary equipment. On January 20, 1864, not long after his departure from the Hawaiian Islands, Pease wrote to him ". . . Not a day passes without my dreaming of your fortune and success. I have imagined the missionaries might decide that your photographs were a useless article of furniture and discourage the natives from patronizing you, and then again I think I see you surrounded by a crowd of natives, dancing and shouting with the pictures. I shall be anxious to receive your first letter."[25]

During the period 1863 to 1866, according to a recent writer, Pease continued to sponsor Garrett's trips at least in part and continued to act as his agent in Honolulu. Garrett sent Pease descriptions of his living specimens and drawings of shells and nudibranchs for inclusion in the numerous papers Pease was writing.[9]

It cannot be accurately determined when Garrett ceased his activities on behalf of Harvard's musuem but it was sometime around 1863. Agassiz was having financial troubles at this time. Another factor could have been unfavorable circumstances brought on by the Civil War or other reasons which might have terminated James M. Barnard's annual payment of his salary. Certainly, the slacking off of American vessels engaged in the whaling industry all over the world may have been a contributing cause. Some of these vessels had been acquired by the Federal Government to be taken south and sunk to block up shipping in southern coastal ports, while others which were already at sea at the outbreak of hostilities were captured or destroyed by the Confederate Navy.

Garrett and the Godeffroy Museum

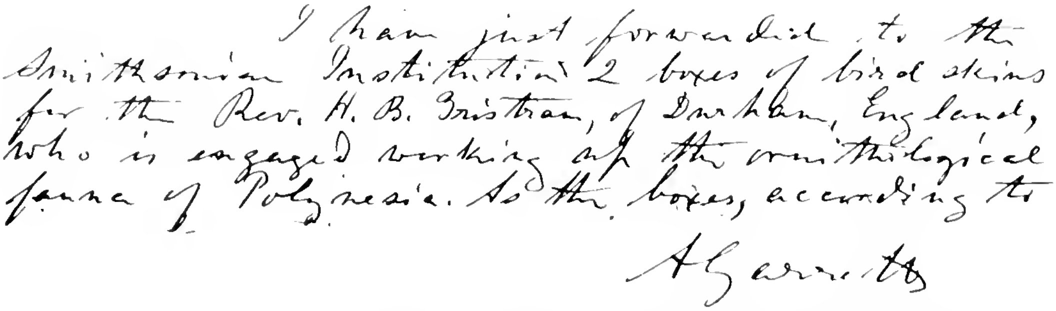
These circumstances may well have helped bring about Garrett's affiliation with another organization. Ever since the early 19th century an important shipping and trading company of Hamburg had operated vessels between Germany and South America's west coast. This was the firm of J.

C. Godeffroy and Son, which after having successfully managed a fleet of cargo-carrying passenger ships to South America, Australia and California, found its business cut off after 1855. In that year one of its representatives, August Unshelm, had been following orders seeking out business possibilities of trade for native products in such Pacific islands as the Carolines, the navigators (Samoa), the Friendly (Cook Islands) and the Fiji Islands. As a permanent headquarters and trading station for the whole area the firm purchased land at Apia, Samoa. For the next twelve years this grew into an impressive establishment with its own plantations of coconuts and cotton and a trading center serving several large clusters of remote islands. By 1864, a new Godeffroy employee, young Theodore Weber, took over as head of the business at Apia. He acquired more land and directed the production of copra which after its arrival in Europe was processed into candles and soap.[2]

Meanwhile, back in Hamburg, Johann Caesar Godeffroy, head of the firm, had a museum to house exhibits of rare material of the Pacific Islands in the fields of anthropology and zoology, He had hired a young Swiss zoologist, Dr. Edward Graeffe, to set up and display the collections which were being supplied by the captains of his twenty different vessels then travelling back and forth between Hamburg and Oceania. They had special instructions to secure natural history specimens and native artifacts. A year later, J. D. E. Schmelz, a qualified scientist, became custodian when Godeffroy sent Dr. Graeffe out to Samoa and Tahiti on a ten year assignment as collector for the new institution. Simultaneously, the Musuem sent a small band of collector-scientists into the field. Garrett became one of these about two years later.[26]

By 1866 Garrett was established in Samoa and busy collecting on the Islands of Upolo and Savaii. His name had been known previously in Hamburg, as some of the shells he gathered were sold to the Hamburg government museum in 1862. About this time at Apia he came into the good graces of the Godeffroy representative, Weber, and in 1866 the American had obtained passage on the company's ship the *Alfred* which transported him to the Fijis. The agent reported this in a letter to his employer sent from Samoa August 17, 1866, requesting that Garrett be permanently engaged. Godeffroy approved this recommendation and authorized Garrett to gather zoological specimens. Godeffroy promised to send the needed supplies for collecting and preserving. Garrett was to receive five hundred Chilean pesos for the first year, as well as free passage in the company ships and to be treated "always in the kindest way possible." In return for the payment and ship accommodations, the scientist was to provide a selection of his specimens for the company museum.[27]

It is particularly unfortunate that no detailed account of Garrett's activities in the Fiji Islands survives. Because of unstable political conditions of the country and the presence of savage cannibals he worked under extremely difficult conditions. Undoubtedly, he was befriended by a few American and English missionaries. The kingdom had for several years carried a heavy financial debt to the United States incurred when the home of the American consul had been destroyed by a mob. Fiji had even sought to be taken over as a protectorate



I have just forwarded to the Smithsonian Institution 2 boxes of bird skins for the Rev. H. B. Tristram, of Durham, England, who is engaged working up the ornithological fauna of Polynesia. As the boxes, according to

A Garrett

FIG 2. *A sample of Andrew Garrett's handwriting and signature from an 1887 letter written Hauhine Island, Society Islands to W. D. Hartman of West Chester, Pa. Original in the Smithsonian Institution.*

first by Great Britain and then by the American government but both offers had been refused. Finally, a Confederacy of Independent Kingdoms had been established in 1865.[28] In 1868, when Garrett was there, a Polynesian Company had been formed to pay U. S. claims against King Cakobau in exchange for concessions. Looking back on his three year experience in that amazing cluster of 800 little-explored islands, Garrett wrote in a letter nine years later "... in the Viti (Fiji) group I had several narrow escapes both from the natives and from drowning. They killed several whites, including a Missionary while I was there. The latter, together with several native teachers, were served up at one of their cannibal feasts. Shortly after I left the group there were a number of white residents killed by the savages, showing what risks the shell collector experiences when searching these regions."[29]

However, there is proof of Garrett's success in his collecting activities in the Fiji Islands. The sales catalogue of the Museum Godeffroy notes: "In regard to further research we advise that Andrew Garrett, well-known through his collection for Professor Agassiz and the fact that he has made the South Sea Islands his main task, has for some time extended his efforts on our behalf. The first shipment consisting mostly of animals of the Viti Islands has just arrived here. It consists of many interesting species such as amphibians, fish, crustaceans and a few polyps, worms as well as insects."[30]

But despite there somewhat pleasing results, a real tragedy occurred when a large portion of his final collections were destroyed in a shipwreck. Writing over two years later from Tahiti Garrett described his loss: "... When taking my departure after two years hard work I suffered a shipwreck and lost all my books on conchology, all my dried plants, Insects, Bird Skins, part of my Shells, Notes and Drawings and a series of Portraits of Natives which I had photographed. Fortunately, most of my shells had been shipped to Samoa in another vessel." He concluded by saying that from what he had saved from the wreck and what he had previously shipped to Samoa, I find about 1500 species of Viti (Fiji) shells and probably lost one or two hundred more.[31]

Last Years on Huahine (1870–1887)

After 1870 Garret spent his remaining years in the Society Islands. He had established a home there, having made several stops on previous voyages. One should not be surprised that he chose the attractive island of Huahine, ninety miles northwest of Tahiti, as his permanent home. It is a volcanic island of approximately ten square miles in area with twin mountain peaks, one of them rising over 2300 feet above the sea. His own description, written after his first encounter early in 1858 while a passenger aboard Captain John Leonard's whaleship, *Lydia*, says "The Island, in fact, consists of several islets which are separated by narrow channels. They present a bold and mountainous aspect, and are clothed in the most luxurious verdure from the water's edge to the summits. . . A short distance back there arises an amphitheatre of hills and mountains which are covered either with tall, rank grass or dense dark forests, and, the whole coast consists of a dense mass of fruit and splendid flowering trees, all combining to form one of the most delightful tropical scenes I ever witnessed."[4]

Although we find some evidence that he travelled (probably by small sailing canoe) among the nearby islands of Raiatea and Moorea, and may have made occasional business trips for mail and supplies to Papeete, the capital and chief seaport, he had much to occupy him at home. He was busy making up selected sets of his duplicate shells and either selling or exchanging them with collectors in Australia, England, France and the United States. This work which involved comparison of shell identifications led to extensive correspondence with both amateur and professional conchologists including R. E. C. Stearns of San Francisco, Berlin H. Wright of Penn Yan, New York, Rev. E. R. Beadle and George W. Tryon of Philadelphia, and various others. He maintained a steady correspondence with Dr. W. D. Hartmen of West Chester, Pennsylvania, and some of these letters from Garrett to the latter individual from 1874 to 1887 survive in the Carnegie Museum, Pittsburgh, Pa. In the middle seventies and early eighties a total of eighteen of Garrett's Scientific papers were published in the *Journal of the Academy of Natural Sciences of*

Philadelphia, the *Journal de Conchyliologie* in Paris, and other scientific periodicals.

During the first two years on Huahine (1870-1872) he must have devoted considerable time and energy to finishing and perfecting the descriptions of the collected specimens and the watercolor drawings of 476 different species of fishes from Hawaii, the Society Islands and the Fijis. Johann Caesar Godeffroy received this material in 1872 and thought so highly of it that he had the project edited and prepared by the celebrated ichythyologist of the British Museum, Dr. Albert C. L. Gunther. These comprised volumes 1 and 2 of the prodigious work, "Andrew Garrett's Fische der Sundsee", published in Hamburg as part of the *Journal of the Museum Godeffroy*. Unfortunately, the dissolution of the business of J. C. Godeffroy and Son in 1879 delayed further publication. But the final volume, No. 3 was issued in 1909. This work remained the ultimate authority on the fishes of the Pacific Ocean for almost forty years.[32]

Little has come to light of Garrett's private life but we know he was legally married to a woman named Otari. One account states she was a Samoan[2] and another informant, Alvin Seale, wrote after a visit to Garrett's home at Huahine on January 1, 1903 that Garrett's wife was the daughter of a high chief of the Island. It is not known whether or not they had any children, although the author made investigations of records on this topic on his two visits to Huahine and Tahiti in 1961 and 1974. He did find the site of Garrett's dwelling which was a short distance from the village of Fare. Mr. Seale describes it as "a neat little frame house, very comfortable and situated in a nice garden". It was on the edge of a bay and in sight of the ocean.[33]

In 1878 Garrett contemplated going to New Caledonia where he had a friend, [probably Rossiter] and also to the Solomon Islands. Instead he wrote Dr. Hartman of reports he had received of massacres of the whites by natives. "... Not having the slightest ambition to become a martyr in the name of Science, I think it will be the wisest course to postpone my visit to those savage islands."[34]

Fortunately this remarkable man did not suffer the kind of death he had feared in the far off cannibal islands but in a sense his passing was no less tragic as he died of a lingering case of cancer. On June 25, 1887 he wrote his friend Hartman in distant Pennsylvania: "As regards myself I have bad news to write and think this probably will be my last letter directed to you. I have been troubled some time back with a diseased mouth. The French doctors in Tahiti call it a very bad cancer and it has developed too far to be successfully treated by surgical operation. In fact, it has been so bad and painful that life is a burden and for some time I have been unable to work in my collection... I may possibly linger along for several months. I am too weak to write much, so I will thank you over and over again for your past kindness to me..."[35]

Garrett died on November 1, 1887, and is buried in the missionary cemetery under a large tamanu tree at the edge of the village of Fare. The grave, with an inscribed marker, surrounded by a small, iron fence, still survives and is kept in good repair at the expense of the French government.

It was fortunate that the English minister, Rev. Ebenezer V. Cooper, Garrett's neighbor, wrote a brief but fairly accurate obituary. It was published with a bibliography a few months after the scientist's death in four different conchological magazines, namely "The Conchologist's Exchange", "The West American Scientist", "The Journal of Conchology" (London) and "Science".[3]

The Personality of Andrew Garrett

What few descriptions we have of this now almost forgotten explorer-naturalist give us an impression of a sincere and gifted personality. Garrett was serious, intelligent, and blessed with prodigious energy and drive. Many times he had been in great danger and must have had unusual physical endurance, having been exposed at several times to shipwreck, tropical diseases, and extreme fatigue. One of the most striking of his characteristics was his ability to overcome the handicaps of very limted formal education. His missionary friend, the Reverend Ebenezer Cooper wrote, "He was self-taught in every sense of the word and his ability and achievements were wonderful and striking."[3] He advanced himself in reading and he so practiced himself in writing that he eventually acquired a commendable and vigorous prose style. His artistic ability, very crude at first, with persistent effort enabled him to draw not only with scientific precision but with aesthetic quality as well. As for languages, he could speak Polynesian, at least the Hawaiian form of it, and probably could use some French because of its commercial and social usage in the Society Islands where he spent one third of his life.

In appearance, he was a lank, partially bald man even in his early thirties, and had deep cavernous eyes to judge from the only portrait known to exist which he sent to Agassiz at the time he was engaged as a collector by the Museum of Comparative Zoology at Harvard. He was slim, apparently of medium height with slightly stooped shoulders, side whiskers and a full beard. He looked older than his true age and might have passed as a down-at-the-heels missionary or even an intellectual beachcomer. One person who knew him well remarked, "He was very unpretentious and no one from casual observation would imagine him to be a savant. . . Outside, his own special study of Conchology, he was deeply read in kindred subjects and no brand of natural history seems to have been overlooked." In his later life he possessed a good working library of books and pamphlets in his specialty and these books are now preserved in the Bishop Museum in Honolulu.

Although a shy man and apparently not endowed with an exuberant personality, he instilled quiet admiration and even warmth in his close friends. Dr. Wesley Newcomb was so pleased with him that he promised to name a new species of shell in his honor. One of his closest friends, William Harper Pease, in innumerable letters bemoaned his long absences which often lasted for years at a time. His staunch supporter, the missionary Damon, was constantly praising him and his rare qualities. One of Garrett's defects seems to have been his poor luck in business affairs and, perhaps, his over confidence in individuals whom he trusted who took advantage of him in failing to pay their debts. At times, he seemed to lack normal assertiveness.

Encomiums on the accuracy of his scientific work have come from a number of sources including Agassiz, Pease, Gunther, and more modern scientists such as Herbert H. Smith, Alvin Seale, Spencer Tinker and others. Especially noteworthy were the statements of the authority on *Partula* tree snails of Polynesia and Melanesia, Dr. Henry E. Crampton, Professor of Zoology in Columbia University. Crampton made at least five expeditions over a period of 18 years to many of the islands where Garrett had collected forty or fifty years earlier. Crampton wrote, "But, above all others, the name of Garrett stands out prominently. . . the rich fruits of his masterly studies are the shells described mainly by Pease and the precise descriptions of their habitats specified with an exemplary minuteness his own notable monograph. . . It is this work of Garrett's that forms a solid basis for comparison of the present intrinsic and distributional characteristics of Polynesian species in their conditions and situations. . ."[36] The same appraisal has been given by Dr. William J. Clench who said that Garrett deserves great credit because he recognized the hyperspecific localities and realized the value of numerous species from a variety of regions. He perceived the changes made in a species by changes in topography.[37]

One man, a contemporary from another profession but thoroughly familiar with Garrett's field work, Rev. Samuel C. Damon, was prophetic when in 1863 he wrote: ". . .we are bold to assert that there are but a few men in the world whose labors are intrinsically of more value to natural history. Take for example, his late exploration of the Society Islands. It is undoubtedly more important than that of any English, French or American exploring expedition which ever visited these islands. . . We are confident no explorer is more worthy of their notice, or has contributed more largely to widen the sphere of science and knowledge."[22]

Acknowledgments

The author is especially indebted to his late cousins, Francelia and Aurilla Leonard of Fairhaven, Massachusetts, who gave him a set of over 250 watercolors and drawings of fishes and shells made by Andrew Garrett. Many scientists and museum workers assisted in his forty-six-year researches, especially William J. Clench of

Harvard University; the late E. W. Gudger of the American Museum of Natural History; the late Henry E. Crampton of Barnard College; Peter Buck, Margaret Titcomb, Yoshio Kondo, Edward Bryan and Donald M. Mitchell, all of the B. P. Bishop Museum; Ruth E. Lee and Ann Blum, Museum of Comparative Zoology, Harvard; Spencer M. Tinker of the Waikiki Aquarium; Albert Panning of the Hamburg Zoologischen Staatsinstituts; Barbara Johnson of Princeton, New Jersey; Yosihiko Sinoto of Huahine and Aurora Natua of the Papeete Museum; and, for assistance for 1961 travel expenses, the Explorers Club of New York and the Frank M. Chapman Memorial Fund of the American Museum of Natural History. Dean Amadon, R. Tucker Abbott and many others gave of their time and assistance, for which I am very grateful.

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THE NEMERTEAN, *MALACOBDELLA GROSSA*, IN THE OCEAN QUAHOG, *ARCTICA ISLANDICA* (BIVALVIA)

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ABSTRACT

The commensal relationship between the marine bivalve, Arctica islandica, *and the nemertean* Malacobdella grossa *along the Atlantic coast of North America has not heretofore been reported, although it has been documented in European specimens. A single* M. grossa *was found living in a small Ocean Quahog dredged from offshore New Jersey. In addition, the nemertean occurred in the venerid clam,* Pitar morrhuana, *from the same locality with a frequency of 28%. Examination of numerous specimens of* A. islandica *for* M. grossa *with negative results suggests this occurrence is atypical.*

The commensal nemertean, *Malacobdella grossa* (Müller), ranges widely along the North American Atlantic coast where several species of bivalves are known to serve as hosts. Coe (1943) cites *Mercenaria mercenaria, Mya arenaria,* and *Crassostrea virginica* as known hosts of this commensal. Porter (1962) added *Mercenaria campechiensis* to this list, and Ropes discovered *M. grossa* in the Morrhua Venus, *Pitar morrhuana.* The aforementioned species are among seventeen bivalves known to serve as hosts for the genus *Malacobdella* and fourteen for *M. grossa* (Ropes, 1967).

While Coe (1943) lists *Arctica islandica* as a host of *Malacobdella grossa* in European waters, Ropes (1967) points out that in the western Atlantic *M. grossa* is not known from either *Arctica islandica* or *Spisula solidissima,* two widely distributed and abundant Middle Atlantic coast bivalves (Merrill and Ropes, 1969). This is unusual, since *Malacobdella* occurs in two other species of *Spisula (S. sachalinensis* from Japan and *S. stultorum* from Europe). Brunberg (1964), in reporting on nemerteans from Danish waters, says *Malacobdella grossa* was commonly collected in the mantle cavity of *Cyprina* (now *Arctica*) *islandica* in the areas investigated, i.e., the Gullmarfjord, the neighborhood of Frederikshavn and Laesø, in the northern Øresund. Nevertheless, Ropes (1967) reports examining thousands of surf clams and numerous ocean quahogs from the Atlantic coast with negative results.

METHODS

Specimens of *Arctica islandica* were obtained on 27 June 1977 by a commercial clamming vessel fishing with a hydraulic clam dredge at a location (~73°40′W and 40°15′N) approximately 32 kilometers offshore from Asbury Park, New Jersey, in water 30 meters in depth. Several specimens of *Pitar morrhuana* were caught with

FIG. 1. *Arrows show the nemertean,* Malacobdella grossa *attached to the mantle of the Ocean Quahog,* Arctica islandica *after removing the left valve and visceral mass. Scale at right has centimeter divisions.*

the ocean quahogs in the same dredge hauls. Twenty ocean quahogs of various sizes and 18 specimens of *P. morrhuana* were randomly selected from the dredge hauls, opened in the laboratory, and examined. Shell lengths were measured and the soft body tissues searched for other organisms. When the single nemertean, *Malacobdella grossa*, was discovered in an individual *Arctica islandica*, it was identified, measured, photographed, and preserved.

RESULTS

A single specimen of *Arctica islandica* contained the commensal nemertean *Malacobdella grossa* living in its mantle cavity (Fig. 1). The clam, a smaller individual than those normally caught, had a shell-length of 55 mm. The nemertean was easily recognized by the presence of a ventral, rear sucker found attached to the mantle of the clam. In a relaxed live state it measured 21 mm in length. Of the eighteen specimens of *Pitar morrhuana* collected from the same dredge haul, five contained individuals of *M. grossa* for an incidence of infection of 28%. Shell-lengths of the *Pitar* specimens ranged from 39 mm to 58 mm and averaged 44 mm while *M. grossa* occurred in individuals ranging from 41 mm to 58 mm. The worms ranged between 20 and 28 mm in length and each host contained only a single nemertean.

DISCUSSION

The single occurrence of *Malacobdella grossa* in an individual of *Arctica islandica* is apparently very rare for the Atlantic coast of the United States and Canada. Though Brunberg (1964) found ocean quahogs commonly hosting *M. grossa* in Danish waters, no incident of this relationship has ever been reported on this side of the Atlantic. Ropes (1967, *personal communication*) has examined numerous specimens of *Arctica* without finding any evidence of infection by *M. grossa*. In addition, I have opened almost one thousand specimens of *Arctica islandica* and *Spisula solidissima* for various research purposes without encountering another nemertean.

The single infected clam was smaller than those usually caught by commercial clamming apparatus and hence smaller than those usually examined. It was similar in size to the infected individuals of *Pitar morrhuana* collected in the same dredge haul. Nevertheless, numerous comparably-sized *Arctica* have been examined with negative results. Examination of hundreds of specimens of both surf clams and ocean quahogs for *M. grossa* has, except for this one incident, yielded negative results. The evidence supports Ropes' (1967) conclusion that *Malacobdella grossa* does not normally associate with either *Spisula solidissima* or *Arctica islandica* along the Atlantic coast of North America.

ACKNOWLEDGMENTS

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DEPTH DISTRIBUTION OF THREE GASTROPODS IN NEW MISSION BAY, LAKE MICHIGAN

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ABSTRACT

SCUBA was used in August, 1974, to determine the depth-distribution of snails at two localities in New Mission Bay, a small inlet of Grand Traverse Bay, Lake Michigan. Five 0.5m² samples were collected at 20 ft intervals along each of 6 depth contours at both localities (5, 10, 15, 20, 25, 30 ft and 10, 12.5, 15, 20, 25, 30 ft). At the 2 localities Gyraulus parvus *(Say) attained peak densities of 2.4/m² and 28.4/m² on small pebbles at 10 ft depths. These densities represent 60% and 92% of the* Gyraulus *collected at the two localities. Most* Marstonia decepta *(Baker) (*Amnicola lustrica *of Pilsbry) and* Valvata tricarinata *(Say) were collected from sand-silt substrates. Both* M. decepta *and* V. tricarinata *reached their maximum densities at the 10 ft depth at one locality (164.8/m² and 29.6/m², respectively), and at the 12.5 ft depth at the other (152.4/m² and 49.2/m², respectively). These densities represent 60% and 54% of the* M. decepta *and 37% and 30% of the* V. tricarinata *specimens collected from the two localities.*

Most studies of Great Lakes' macrobenthos have understandably been large scale dredging operations dealing primarily with profundal organisims (Eggleton, 1936, 1937; Merna, 1960; Powers and Robertson, 1965; Robertson and Alley, 1966; Henson, 1966) or with specimens collected from the upper littoral zone and beach drift (Goodrich, 1932; Heard, 1962a, 1962b; Henson and Herrington, 1965). Beach drift specimens, of course, tell us very little of the preferred habitat, and a number of papers have demonstrated problems with the reliability and efficiency of several types of bottom samplers (Beeton, Carr, and Hiltunen, 1965; Milbrink and Wiederholm, 1973). Others have shown, however, that, visibility permitting, SCUBA-assisted studies can provide direct, quantitative collections from a wide variety of substrates (Cvancara, 1972; Harmon, 1972; Clampitt, 1973, 1974). This paper reports on a SCUBA study of the depth distribution of 3 littoral gastropod species at 2 discrete localities in New Mission Bay, a small inlet on the western side of Grand Traverse Bay, Lake Michigan (Fig. 1).

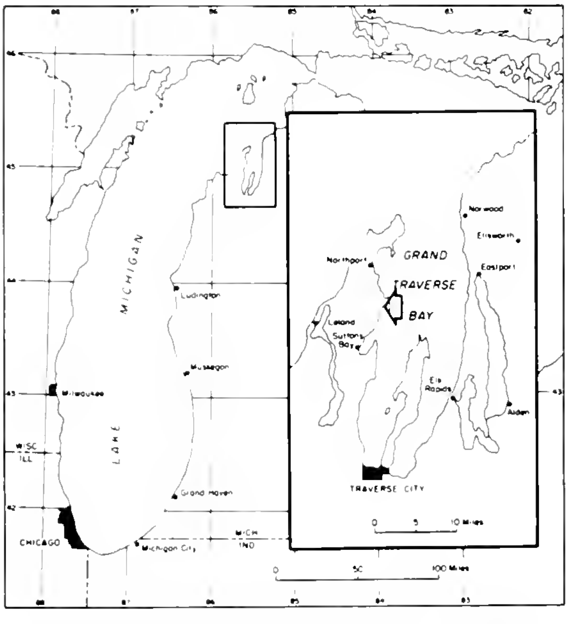

FIG. 1 *Location of New Mission Bay (arrow in inset).*

New Mission Bay narrows irregularly from a maximum width at its mouth of about 2.3 km, due North for a distance of approximately 1.7 km (Fig. 2). A paved road circumscribes the bay within a few hundred meters at all points. Between the road and the bay, mixed coniferous-deciduous woods dominate along the east shore and alternate with cleared land on the west and

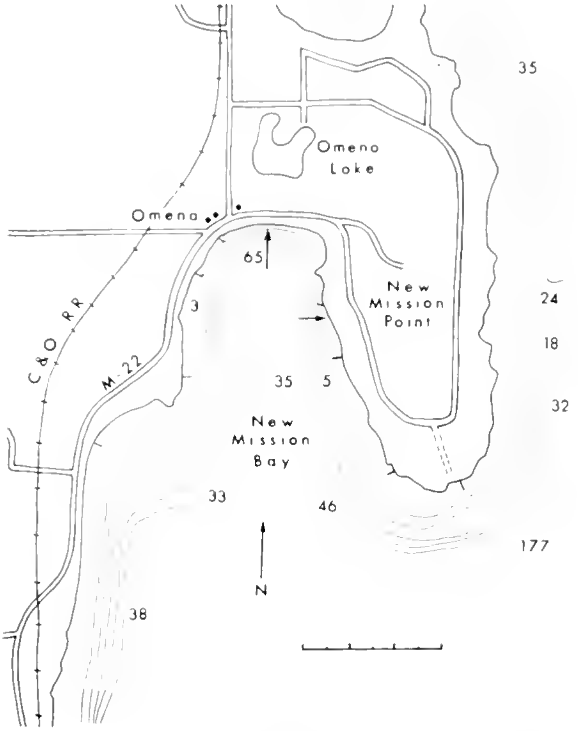

FIG. 2. *Contour map of New Mission Bay showing positions of Omena Beach and Omena-Traverse Yacht Club collecting localities (adapted from U.S. Army Corps of Engineers Chart L.S. 706) Scale = 500 ft/unit, Contour Interval = 6 ft.*

north shores. The very small town of Omena with its marina and public beach rests at the bay's Northwest corner while a few cottages, permanent residences and a yacht club are scattered among the trees along the east shore. The bottom-slopes are very gradual on both sides at the outer end of the bay. On the western side of the inner half of the bay, however, the bottom-slope is at first very gradual and then drops off abruptly. While there are local differences discussed below, the northern and northeastern bottom-slopes deepen rather regularly. Within New Mission Bay, only one region in the northwest corner is known to exceed 60 ft in depth (Fig. 2). Temperature measurements of 21° C down to 30 ft and 20° C at 40 ft were recorded in the northeastern part of the bay on August 17, 1974. These correspond well with Lauff's (1957) data for this region of Grand Traverse Bay. Lauff's report also provides a Secchi disk transparency measurement of 9-10 m and notes that surface currents pass the mouth of New Mission Bay in a WSW direction at this time of year.

MATERIALS AND METHODS

SCUBA was used to study the depth distribution of snails along two "transects" in New Mission Bay (Fig. 2). One, designated "Omena Beach" (O.B.), runs south from a point about 100 yds east of the public beach at the northern end of the Bay. Here the bottom-slope increases gradually in depth to about 15 ft and then drops off rapidly to depths greater than 60 ft. The predominantly sandy bottom gradually becomes overlain by a thin layer of colloidal organic sediment as the depth increases. The second transect, "Omena-Traverse Yacht Club" (Y.C.), extends west from the east shore about 50 yds. south of the yacht club. The bottom here is strewn with large boulders at the edge and increases rapidly in depth to about 10 ft where the substrate becomes sandy and the slope levels off for 100-150 ft. Here the organic content of the substrate increases as the depth increases rapidly to more than 45 feet. Macrophytes were essentially nonexistant at both study areas.

Each transect consisted of six 100 foot lines marked at 20 ft intervals and placed approximately parallel to shore along depth contours. These were established at depths every 5 feet out to 30 feet at Omena Beach, and 10 ft, 12.5 ft, 15 ft, 20 ft, 25 ft, and 30 ft off the Yacht Club. Depths were determined using a calibrated line tied to a float and were checked using diver's depth gauges. A sand-filled "Hula-Hoop" was sequentially placed at the center of each 20 ft section establishing a constant sample area (0.48m^2). Hand-picked snails were placed into prelabeled "zip-lock" type plastic bags. Thirty snail samples were thus collected directly from each of the two study areas.

RESULTS

The following mollusks, in order of decreasing maximum density ($\overline{X}$ m^2), were collected from the two localities: *Marstonia decepta* (Baker) (*Amnicola lustrica* of Pilsbry) (164.8), *Valvata tricarinata* (Say) (49.2), *Gyraulus parvus* (Say) (28.4), *Physa* sp. (3.6), *Pisidium* sp. (2.4), *Cincin-*

TABLE 1. *Depth Distribution of Snails near Omena Beach. Data are mean densities ($\overline{X}/m^2$) of 5 samples ($n=5$) at each depth, with Standard Error (SE) in parentheses; % of the species population at each depth, % of the snail community at each depth represented by each species.*

Species	Depth (ft)	Density ($\bar{X}/m^2$) (SE)	% Species	% Community
G. parvus (Say)	5.0	0.0	0.0	0.0
	10.0	2.4 (1.3)	60.0	1.2
	15.0	0.0	0.0	0.0
	20.0	0.8 (0.7)	20.0	3.6
	25.0	0.8 (0.4)	20.0	1.5
	30.0	0.0	0.0	0.0
M. decepta (Baker) (= A. lustrica Pilsbry)	5.0	7.6 (1.3)	2.8	40.4
	10.0	164.8 (14.4)	59.8	83.7
	15.0	44.4 (5.2)	16.1	68.1
	20.0	18.0 (2.0)	6.5	80.3
	25.0	38.0 (14.4)	13.8	72.5
	30.0	2.8 (1.3)	1.0	87.5
V. tricarinata (Say)	5.0	11.2 (1.7)	14.1	59.6
	10.0	29.6 (3.7)	37.4	15.1
	15.0	20.8 (7.6)	26.3	31.9
	20.0	3.6 (1.6)	4.5	16.1
	25.0	13.6 (7.3)	17.2	26.0
	30.0	0.4 (0.4)	0.5	12.5

natia cincinnatiensis (Anthony) (2.0), *Goniobasis livescens* (Menke) (1.2), *Lymnaea decampi* (Streng) (0.8), *Lampsilis radiata siliquoidea* (Barnes) (0.2), *Anodonta grandis* (Say) (0.1). Due to the substantial differences in relative abundance, only the data for the first three species are presented (Tables 1, 2, Figures 3-6) in any detail.

Gyraulus parvus, rarest of the three most prominent species, was most commonly found on the sand-gravel substrates at 10 ft in both localities. Densities of $2.4/m^2$ and $28.4/m^2$ represent 60% and 92.2% of the specimens collected at O.B. and Y.C., respectively (Tables 1, 2). Thus, at 10 ft, *Gyraulus* represented only about 1% of the 3-species community at O.B., but as much as 30% of that community at Y.C. The distribution of *Marstonia decepta* at Omena Beach (Table 1, Fig. 3) appears bimodal, with a major peak at 10 ft of $164.8/m^2$ and a minor one of $38/m^2$ at 25 ft. At the Yacht Club locality (Table 2, Fig. 4), however,

TABLE 2. *Depth Distribution of Snails near Omena-Traverse Yacht Club. Data are mean densities ($\overline{X}/m^2$) of 5 samples ($n=5$) at each depth, with Standard Error (SE) in parentheses; % of the species-population at each depth, % of the snail community at each depth represented by each species.*

Species	Depth (ft)	Density ($\bar{X}/m^2$) (SE)	% Species	% Community
G. parvus (Say)	10.0	28.4 (7.8)	92.2	30.2
	12.5	0.4 (0.4)	1.3	0.2
	15.0	0.4 (0.4)	1.3	0.5
	20.0	0.8 (0.7)	2.6	1.6
	25.0	0.4 (0.4)	1.3	1.1
	30.0	0.4 (0.4)	1.3	2.4
M. decepta (Baker) (=A. lustrica Pilsbry)	10.0	60.4 (6.1)	21.3	64.3
	12.5	152.4 (11.7)	53.7	75.4
	15.0	46.8 (12.1)	16.5	61.0
	20.0	11.2 (2.2)	4.0	22.4
	25.0	8.8 (2.7)	3.1	24.2
	30.0	4.0 (1.8)	1.4	23.8
V. tricarinata (Say)	10.0	5.2 (0.9)	3.2	5.5
	12.5	49.2 (6.8)	30.5	24.4
	15.0	29.6 (4.8)	18.3	38.5
	20.0	38.0 (4.6)	23.5	76.0
	25.0	27.2 (6.9)	16.8	74.7
	30.0	12.4 (4.4)	7.7	73.8

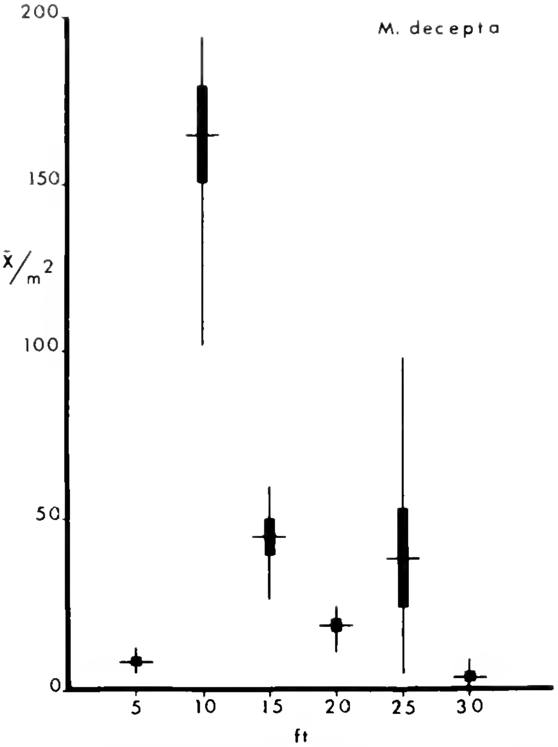

FIG. 3. *Depth distribution of* Marstonia decepta *at Omena Beach. Horizontal Line* = $\bar{X}$ *m²; Vertical Bar* = ± *1 Standard Error; Vertical Line* = *Range of density among 5 samples at each depth.*

Marstonia shows a definitely unimodal distribution with a maximum density of 152.4/m² at 12.5 ft. These maximum densities represent nearly 60% of the Omena Beach specimens and almost 54% of the Yacht Club specimens taken from the 6 depths at each locality. *Marstonia* was obviously the dominant member of the molluscan communities of the 5 deeper stations (68-87%) at O.B. (Table 1) and of the 3 shallower stations (61-75%) at Yacht Club (Table 2).

Valvata tricarinata appears to demonstrate bimodal distributions at both localities, but with distinct maxima in each case. At Omena Beach (Table 1, Fig. 5), *Valvata* reached its peak density of 29.6/m² at 10 ft. After decreasing rapidly from 20.8/m² at 15 ft to 3.6/m² at 20 ft, *Valvata* increased again to 13.6/m² at 25 ft. A similar, but less dramatic bimodal distribution was found at the Yacht Club site (Table 2, Fig. 6). Here, the maximum density (49.2/m²) occured at 12.5 ft. This declined to 29.6/m² at 15 ft and increased again to 38.0/m² at 20 ft. The maximum densities represent only about 37% of the specimens collected at Omena Beach and less than 31% of the specimens taken at the Yacht Club site. *Valvata* was the dominant member of the communities of the 5 ft station at Omena Beach (Table 1) and of the 3 deeper stations off the Yacht Club site. (Table 2).

DISCUSSION

The paucity of similar studies prevents the direct comparison of these data with those of others and the causes for the demonstrated stratification can only be surmised. Since all stations were within the elipimnion, the chemistry of these environments would be expected to be rather homogeneous. Physico-chemical differences in the benthic microhabitats, if they exist, may therefore be assumed to be the direct result of substrate-biota interactions. Harman (1972), reporting on mollusks from three central New York lakes, suggested that definite relationships

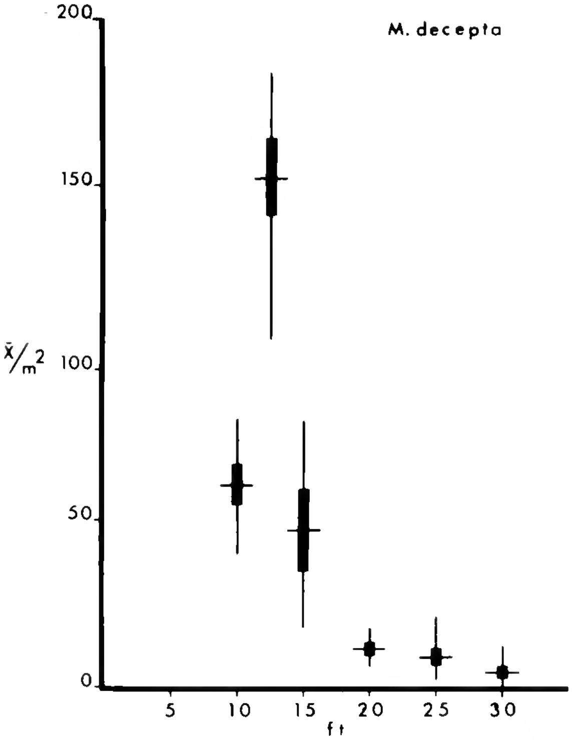

FIG. 4. *Depth distribution of* Marstonia decepta *at Omena-Traverse Yacht Club.*

exist between mollusk distribution and substrate patterns. The substrates of all our stations fall into one of his five broad types: "Littoral silt and detritus - fine organic and inorganic materials." According to Harman, this is the preferred substrate of only one of our three species, namely *Valvata tricarinata*. The other two species, *Gyraulus parvus* and *Mastonia decepta* are said to prefer "Autochthonous organic matter - aquatic plants and their decaying remains."

Of 121 collections of *Gyraulus parvus* by Harman (1972), 94 were from substrates of autochthonous organic matter, while only 9 were from littoral silt and detritus. Considering that there were no aquatic macrophytes near any of the stations we studied, it is perhaps surprising the *Gyraulus* were found to represent as much as 30% of the molluscan community at the 10 ft depth of the Yacht Club locality. This was, however, the only station in which *Gyraulus* was at all common. As indicated above, *Gyraulus* was frequently collected from small pebbles rather than from the more abundant sand and flocculent organic sediments. This may reflect the requirement of a more stable substrate usually available in the form of higher aquatic plants in these snails' preferred habitats.

Three observations suggest that major components of the niches of *Marstonia decepta* and *Valvata tricarinata* overlap: (1) the occurrence of both species at all our collecting stations; (2) the co-occurrence of the peak densities of these two species at 10 ft (O.B.) and 12.5 ft (Y.C.) indicating the preferred conditions for both species; (3) the co-occurrence of secondary density peaks at the 25 ft depth at O.B. That *Marstonia* is better adapted to the conditions in New Mission Bay is indicated by the fact that it was the dominant species in 8 of the 12 communities studied. Since a higher percentage of the *Marstonia* specimens were collected at the 10 ft (60%) and 12.5 ft (54%) depths, we might infer that this species has a stronger preference for (i.e., is better adapted to the) conditions at these depths than is *Valvata* (37% & 31%). At neither location did *Valvata* (15% & 24%) dominate the communities of these depths. At Omena Beach, *Valvata* dominated only the 5 ft depth, while *Marstonia* dominated all 5 greater depths. Off the Yacht Club however, *Marstonia* donated all three shallower depths, while *Valvata* was obviously the dominant member of the three deeper communities. Thus it seems that *Marstonia* is not only generally better adapted to the New Mission Bay conditions, but specifically best adapted to those at the 10-12.5 ft depths. *Valvata*, on the other hand, seems less specialized, but better able to take advantage of the

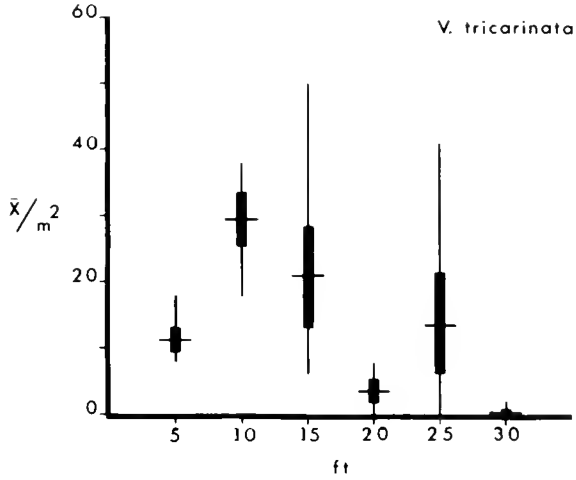

FIG. 5. *Depth distribution of* Valvata tricarinata *at Omena Beach.*

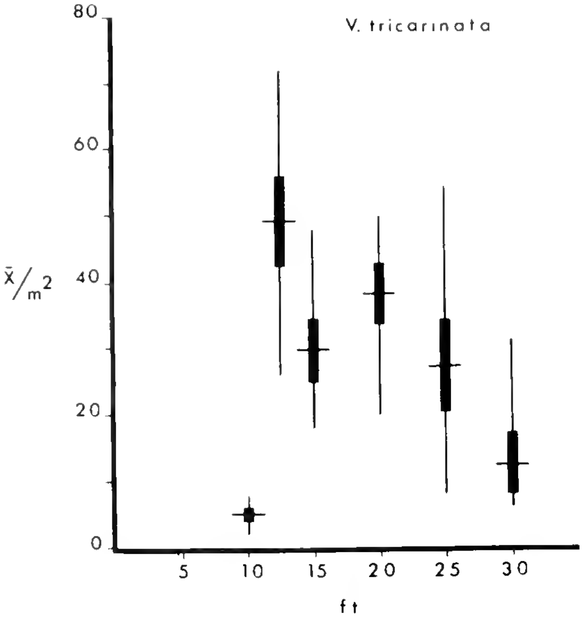

FIG. 6. *Depth distribution of* Valvata tricarinata *at Omena-Traverse Yacht Club.*

marginal habitats where *Marstonia* densities are low (5 ft - O.B.; 20, 25, 30 ft - Y.C.). Thus *Marstonia decepta* often outnumbers *Valvata tricarinata* in a littoral silt and detritus habitat. This directly contradicts Harman's (1972) statements as to the substrate preferences of these two species, and demonstrates the care which must be observed when attempting to apply the findings of those working on inland lakes in contrast to those dealing with the ecology of the Great Lakes.

ACKNOWLEDGMENTS

The authors express their deepest appreciation to Dr. Lee H. Somars, Director, Underwater Technology Laboratory and the Michigan Sea Grant Program for providing technical assistance, as well as the compressed air required for 200 man-hours of underwater work carried out during this study. The cooperation of the Omena-Traverse Yacht Club is also gratefully acknowledged. In addition, the assistance of our research assistant, Gregory Panos, III, and student assistants John Kerr and Larry Stevens was essential to the completion of the underwater sampling. This research was supported by a grant from the University of Michigan-Flint Faculty Research and Special Projects Committee.

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ARION SUBFUSCUS IN SOUTHEASTERN MICHIGAN

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The North American distribution of the introduced European slug, *Arion subfuscus* (Draparnaud), has been described by Chichester and Getz (1968, 1969), Getz and Chichester (1971) and Getz (1974). In general, the species occurs throughout northeastern United States and southeastern Canada, in the vicinity of Washington, D. C., and in the Kipawa Reserve in eastern Canada. The latter record represents the furthest westward locality previously known for the species. A recent discovery of *A. subfuscus* in Ann Arbor and Allen Park, Michigan, is therefore worthy of note. It extends the known range of the species to include the Great Lakes region.

Specimens of the species were first found by the senior author in her yard located within the city limits of Ann Arbor. Subsequent investigations revealed the species to be present in some, but not all, adjacent yards, as well as in Allen Park, a suburb of Detroit. It has not been reported elsewhere in the Ann Arbor or Detroit area, however. All individuals collected were bright orange and resemble Color Form Three as described by Chichester and Getz (1969).

The Blanchard's yard contains extensive uncultivated planting of native and introduced species of herbaceous plants, shrubs and trees. *Arion fasciatus* (Nilsson) has been present in the yard for years, but *A. subfuscus* was first noticed in 1973. It is not known how the species became established in Ann Arbor; most dispersal of European slugs apparently occurs during transport of nursery stock (Chichester and Getz, 1969). In all regions except Michigan and Washington, D. C., *A. subfuscus* occurs in natural woodland habitats as well as in association with human habitation. Chichester and Getz (1969) have predicted that *A. subfuscus* will become established in natural habitats throughout most of North Central United States and South Central Canada.

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THE ASIATIC CLAM, *CORBICULA MANILENSIS*, FROM TWO RESERVOIRS IN EASTERN TEXAS.

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Specimens of the Asiatic Clam, *Corbicula manilensis* (Philippi), were collected on several dates during 1977 from Lake of the Pines Reservoir in the Big Cypress River Basin, Texas, and from Murvaul Reservoir in the Sabine River Basin, Texas. The species has not been previously reported from either reservoir. Specimen at Lake of the Pines Reservoir were collected approximately one kilometer from the dam at a depth of less than one meter, on substrates of sand, fine gravel and very hard packed red clay. Collections at Murvaul Reservoir were made approximately 100 meters from the dam in a substrate of sand, at water depths also not greater than one meter. While the population densities of the clam were great in both reservoirs, the largest numbers were found at a depth of approximately one meter during the summer months, and at the water's edge during the winter months.

The mean values for physico-chemical parameters determined during 1977 (Table 1.) indicate both reservoirs have good water quality, and the fertility of both bodies of water are classed as mesotrophic. Preserved specimen have been deposited in the Invertebrate collection at Stephen F. Austin State University.

TABLE 1. *Mean values for physico-chemical parameters recorded for Lake of the Pines and Murvaul Reservoirs during 1977*

	NO_3^--N (PPM)	$PO_4^{\equiv}$ (PPM)	O_2 (PPM)	NH_3-N (PPM)	Cl^- (PPM)	Turbidity (NTU)	$SO_4^{=}$ (PPM)	Ca^{++} (PPM)
Murvaul	0.10	0.09	7.4	0.42	23.1	8.7	19.5	4.1
Lake of the Pines	0.04	0.44	6.5	0.51	19.2	1.9	22.8	9.4

EVIDENCE FOR TIDALLY CORRELATED FEEDING RHYTHMS IN THE EASTERN MUD SNAIL, *ILYANASSA OBSOLETA*

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ABSTRACT

The occurrence of the crystalline style in an intertidal population of the mud snail, Ilyanassa obsoleta, *was found to be correlated with the stage of the tide. At low tide when the snails were exposed almost no individuals sampled possessed styles, while during high tide when the snails were covered almost all individuals sampled possessed styles. The presence or absence of a style occurred concomitantly with the presence or absence of food in the digestive tract. These observations suggest that* I. obsoleta *individuals can possess cyclical, discontinuous feeding rhythms, similar to those that have been observed in intertidal bivalves and one other gastropod species.*

The digestive processes of certain intertidal bivalve species and the marine pulmonate gastropod, *Amphibola crenata*, from New Zealand, have been shown to be cyclical and correlated with the state of the tide (Morton 1956; Morton 1971, 1973 1975a, 1975b, 1977; Bernard 1973; Langton and Gabbott 1974). In particular, the studies on intertidal bivalves have shown that the crystalline style dissolves when the animals are exposed at low tide and reforms when they are subsequently inundated. Although the mud snail, *Ilyanassa obsoleta* (Say), is a member of the typically carnivorous, rachiglossan Gastropoda, it is primarily a deposit feeder (Scheltema 1964). As an adaptation to this mode of foraging, *I. obsoleta* possesses a crystalline style which aids in the digestion of microflora inhabiting the ingested substrate (Brown 1969). This note presents evidence for the cyclical dissolution and reformation of the crystalline styles belonging to members of an intertidal population of *I. obsoleta* in southeast Georgia.

MATERIALS AND METHODS

On November 18 and 19, 1977, *I. obsoleta* individuals were collected during various tidal stages in a slough located on the eastern side of Sapelo Island, Georgia. Approximately the same tidal level of the shore was sampled at each sampling period. The maximum depth of water during subtidal sampling periods was 30 cm.

Sampling was done by placing a line, marked at one meter intervals, parallel to the shore line. At randomly selected intervals 10 × 10 cm, square quadrats were inserted into the substrate. All of the snails, buried or on the surface, were removed from each quadrat sampled. Enough quadrats were sampled so that the total number of snails collected at each sampling period exceeded 50. Fifty snails were immediately selected at random from the main sample. Each specimen was processed in the field according to the following protocol: 1) shell length was determined, 2) snail was carefully removed from its shell by fracturing the shell with a portable vise, 3) style sac was opened with fine forceps and the presence or absence of a style was noted, 4) snail was placed in vial containing acid Bouin's fix-

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Contribution No. 380 from the University of Georgia Marine Institute.

ative. The total time from collection to final processing did not exceed 45 minutes. The contents of the digestive tracts of preserved snails were determined later in the laboratory.

RESULTS AND DISCUSSION

Figure 1 shows that the occurrence of the crystalline style in the study population is definitely correlated with the tidal cycle. Diel variations in temperature and light do not appear to modify this correlation. Air temperatures ranged from 24°C in the daytime to 12°C just before sunrise while water temperatures varied between 19° - 15°C. The lengths of the snails sampled ranged from 17-21 mm, indicating that the population under investigation comprised only mature adults (Scheltema 1964).

The presence of the crystalline style in *I. obsoleta* is correlated with the type of food eaten (Brown 1969). The style is absent in snails feeding actively on the flesh of animals while it is invariably present in those snails ingesting sandy or muddy substratum. In this study all of the snails with styles had mud present throughout their digestive tracts while the caecae and style sacs of the snails which did not possess styles were devoid of any type of food. In some of the latter snails, mud was found in the posterior portions of the intestine and the rectum.

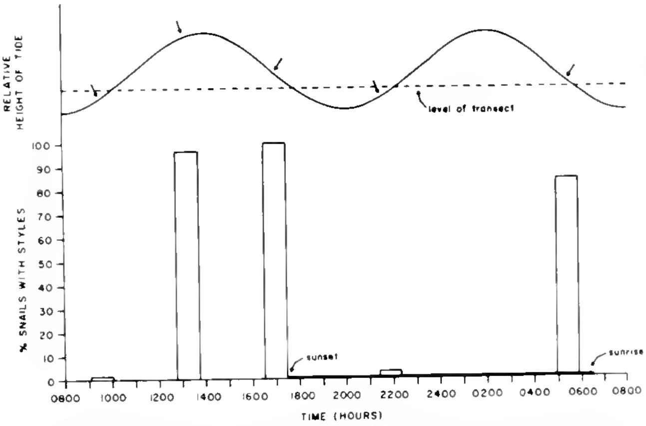

FIG. 1. *Occurrence of the crystalline style in an intertidal population of* Ilyanassa obsoleta. *Upper curve represents tidal cycle with horizontal line indicating position of sampling transect relative to tide. Arrows indicate time sample taken.*

Thus the correlation of the occurrence of the crystalline style with the tidal cycle in the population investigated appears to reflect cyclical, discontinuous feeding activities similar to those noted previously for bivalves and the mud-dwelling, marine pulmonate, *Amphibola crenata*. The results of the present study complement those showing that the locomotor activity of *I. obsoleta* is maximum during periods of high tide and minimum during periods of low tide (Stephens, Sandeen and Webb 1953).

While this study was restricted to a single population of mud snails and one sampling date, it does show that *I. obsoleta* individuals can possess discontinuous feeding rhythms correlated with the tidal cycle. Further work needs to be done on the seasonal variability of foraging rhythms (Morton 1975b, 1977) as well as the effects of substrate type, resource density and size of individual on feeding patterns.

It is interesting to note that the feeding cycle of the marine pulmonate, *Amphibola crenata*, is qualitatively different from that of *I. obsoleta*. While the latter restricts its feeding activities to periods when it is covered by the tide, *Amphibola* forages primarily during low tide or high tides occurring at night (Morton 1975b). These differences may reflect different adaptations to predation by visually orienting predators which follow the incoming tide (e. g. crabs and fish). The lack of operculum may make it adaptive for *Amphibola* to bury in the substrate when aquatic visual predators are most active (high tide during the day).

Ilyanassa, on the other hand, possesses both a durable shell and an operculum. These attributes might provide sufficient protection from predation to allow the snail to forage when aquatic predators are active. The factors limiting the foraging activity of *Ilyanassa* to periods when they are covered with water may be desiccation stress (Schaefer, Levin and Milch 1968; Schaefer, Milch and Levin 1968) or the need to ingest a substrate with a sufficiently high moisture content to facilitate digestion.

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FOOD SOURCES FOR *ANACHIS AVARA* (COLUMBELLIDAE) AND A DISCUSSION OF FEEDING IN THE FAMILY

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ABSTRACT

Length measurements were made on individuals of Anachis avara *maintained in the laboratory on carrion, epibiota from seagrass blades, organics in the sediment, and on organics from a flow-through seawater system as a control. Snails grew 52% as much on epibiota as on carrion, and showed some growth with sediment or water column organics as their food. Epibiota are probably a significant source of food for* A. avara *in the field.*

References regarding feeding in columbellid gastropods show varied and sometimes contradictory results (Puffer and Emerson 1953; Moore, 1961; Marcus and Marcus, 1962; Bandel, 1974). This paper reports differences in growth for *Anachis avara* (Say) on three separate food sources, and reviews the available literature on columbellid feeding.

METHODS

Two hundred and forty *Anachis avara* were collected from a turtle grass, *Thalassia testudinum* (König), flat at Bear Cut, Miami,

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Florida, during June, 1975. These individuals were measured and placed in eight 19-liter aquaria with running salt water. Two replicates were maintained with carrion (C), turtle grass with its epibiota (E), and particulate organic matter and detritus in sediment (D), as food sources, with the slight supply of particulate organic matter in the flow-through water used as control (W). No attempt was made to measure the amount of food provided or the amount of organic matter entering with the running water. It was assumed that the 120 grass blades and the 4 cms. of sediment in the separate pairs of aquaria provided the relative amounts of their associated foods available in the habitat. The turtle grass and sediment were changed weekly. Carrion was provided twice weekly for six-hour periods, and all eight aquaria were cleaned thoroughly at weekly intervals. The length of each snail was measured to the nearest 0.01 mm with vernier calipers every fourteen days for a period of six weeks. Differences between mean sizes were tested by a two-level nested ANOVA at the 0.05 alpha level and by the Student-Newman-Keuls non-parametric test (Sokal and Rohlf, 1969).

RESULTS

Table 1 shows no difference in mean lengths of the snails in the eight aquaria at the beginning of the experiment. After 28 days, three separate groupings by mean size were recognizable. Snails which were fed carrion grew the most; those fed grass blade epibiota grew next best; and those fed sediment organics and detritus grew the least, the latter being grouped with the snails from the control aquaria. The differences in size which occurred are shown in Figure 1. Significant results from this experiment are that: 1) growth occurred in all tanks, including the controls where the only food source was particulate organic matter entering through the flow-through seawater system; 2) snails feeding on the epibiota from the grass blades grew 52% of the amount that snails feeding on carrion did. Depending on relative availability of epibiota and carrion in the field, this latter result suggests that these epibiota are an important food source for *A. avara* in seagrass habitats.

TABLE 1. *Mean length (mm) of* Anachis avara *and results of a Student-Newman-Keuls analysis of feeding. The food types connected by each bar contain snails of the same statistical mean length.*

Time (days)	Length (mm)							
	E2	E1	W2	W1	D2	D1	C2	C1
0	5.17	5.15	5.10	4.98	4.96	4.86	4.81	4.73
	C2	C1	E1	E2	D1	W1	W2	D2
14	6.85	6.40	6.13	6.03	5.56	5.27	5.15	5.09
	C2	C1	E1	E2	D1	D2	W1	W2
28	8.29	8.06	7.23	7.19	6.06	5.68	5.61	5.25
	C2	C1	E1	E2	W1	D1	W2	D2
42	9.61	9.50	7.68	7.61	5.81	5.76	5.27	*

C = carrion; E = epibiota; D = detritus; W = organics from seawater (controls); * = no data; 1 & 2 = replicates of each food type.

DISCUSSION

Several food sources are available to *Anachis avara* at Bear Cut. Many of the mean 3291 seagrass blades per m² are encrusted with various kinds of epibiota (Humm, 1964; Meyers *et al.*, 1965; and personal observations). These epibiota include polychaetes, hydroids, tunicates, sponges, bryoza, and protozoa, as well as diatoms, blue-greens and several species of red, green, and brown macroalgae. No attempt was made to differentiate between epifauna and epiflora as food sources for *Anachis avara*. Carrion, such as dead spider crabs, fish, and the large bivalve, *Atrina rigida*, was visibly entrapped in the sediment. Particulate organics and detritus were also present in the habitat substratum.

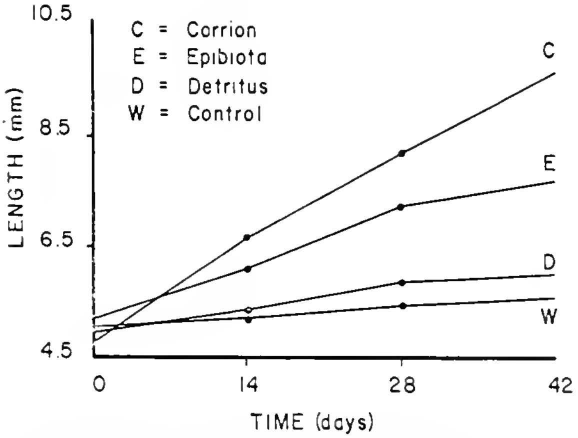

FIG. 1. *Mean lengths (mm) of* Anachis avara *for two replicates of each of three food types and a control*

The amounts and availability of the different food sources of *Anachis avara* at Bear Cut probably differ. *A. avara* is the only abundant sizeable gastropod grazer at Bear Cut, aside from the micromollusks, *Bittium varium*, *Tricolia affinis*, and several species of *Caecum*. Only occasional individuals of other columbellid species or other gastropods such as *Turbo castaneus* or *Astraea americana* were collected. Therefore, although some overlap in food choice may exist between *A. avara* and species from other phyla, such as caridean shrimp, competition for the epibiota is not thought to be intense. The high productivity and continuous presence of epibiota, and the probable low competition for this fauna and flora, make this source of food highly available to *A. avara*.

Carrion is also available to *Anachis avara*, but it is also consumed by swimming crabs, *Callinectes sapidus* and *Callinectes ornatus*, juvenile spiny lobsters, *Panularus argus*, stomatopods, several species of fish and other faunal groups. I placed pieces of the bivalve, *Chione cancellata*, in the habitat and witnessed several *Callinectes* capture them prior to observable reaction by *A. avara*. Particulate organic matter from the seawater and sediment is also available; however, results of the laboratory experiment suggest this is only a minimal source of food.

Anachis avara probably feeds opportunistically, and this may be typical of many species of the family Columbellidae. In the laboratory, I have seen *Anachis avara* feed on moribund *Tagelus divisus*, a small gaping bivalve, but not on tightly-closed *Tellina texana* or *Macoma cerina*. Scheltema (1969) maintained *Anachis avara* on clam meat in the laboratory. Puffer and Emerson (1953) reported *Anachis avara semiplicata* from an oyster reef off central Texas as a herbivore. Moore (1961) suggested that *Anachis avara* from Port Aransas, Texas, preys on young oysters. Because *Anachis avara* does not extend from the Atlantic into the Gulf of Mexico (Scheltema, 1968; and Radwin, 1977), the species reported by Puffer and Emerson (1953) and Moore (1961) is probably *Anachis semiplicata* (Radwin, 1977; and Moore, *pers. com.*). However, the status of the western Gulf of Mexico species is not clear (Scheltema, 1968). Individuals of *Anachis semiplicata* from Sarasota, Florida, and of *Anachis avara* from Bear Cut lived and spawned in the laboratory on a diet of clam and fish meat.

Differences in foods reported for several columbellid species are partly the result of incomplete feeding investigations and secondary reports. Marcus and Marcus (1962) found algae in the gut of *Columbella mercatoria*. Bandel (1974) reported spawning for individuals of this species maintained in the laboratory on both algae and fish meat. I saw capsules produced in aquaria by individuals of this species that had been fed clam and fish meat exclusively. I also saw *Columbella rusticoides* spawn in the laboratory on the same clam and fish meat diet. Marcus and Marcus also found algae in the gut of this species. Miller (1974) stated that most columbellids are attracted to dead and/or injured prey, although members of the genus *Columbella* probably eat primarily plant material. The conclusion from Marcus and Marcus (1962) that the two above species of *Columbella* are solely herbivorous is not correct.

From a detailed study of the anatomy of eight columbellid species, Marcus and Marcus (1962) concluded that as a group the columbellids are general feeders. Marcus and Marcus (1962) found recognizable parts of polychaetes, crustacea, and colonial ascidians in the alimentary tract of six species of columbellids. Raeihle (1969) stated that newly hatched *Nitidella ocellata* (now *Mitrella ocellata* (see Abbott, 1974)) and an unidentified *Anachis* sp. fed on crushed *Mytilus edulis* spat. Bandel (1974) reported that *Nitidella laevigata* eats *Sargassum* as well as meat; that *Mitrella argus* and *Anachis obesa* eat hydroids but also feed on pieces of clam and fish meat; and that six other columbellid species feed on fresh meat in the laboratory. Spight (1976) mentioned that some columbellids feed on freshly killed crabs, limpets, and chitons in the laboratory. I have also maintained *Mitrella ocellata*, *Mitrella lunata*, and *Nitidella moleculina* in the laboratory on fresh meat from several species of fish and bivalves. Fretter and Graham (1962) point out that the superfamily Buccinacea is carrion-feeding, rather than predatory, as its members have lost the accessory salivary glands and boring organ necessary for that activity. In general, foods among the columbellids vary and it is probable that at least some species utilize varied plant and animal sources.

As no analysis was made of what *Thalassia* epibiota or sediment organics and/or detritus that *Anachis avara* fed on during the laboratory experiment, it cannot be concluded whether this species is carnivorous or omnivorous. Leathem and Maurer (1975) refer to this species as a carnivore, but they reach this conclusion from published references (Leathem, *pers. com.*). To my knowledge the results of a discrete test of whether *Anachis avara* is carnivorous or omnivorous have not been published. I conclude that *Anarchis avara* can obtain nutriment from other than carrion, particularly by grazing epibiota off turtle grass blades, but also from particulate organics in the sediment and from the water column. Where there is a plentiful source of food, I doubt that food is a limiting resource for this species in the seagrass flats near Miami, Florida.

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FIELD EVIDENCE THAT THE EASTERN MUD SNAIL, *ILYANASSA OBSOLETA*, INFLUENCES NEMATODE COMMUNITY STRUCTURE[1]

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ABSTRACT

Exclusion experiments conducted with the mud snail, Ilyanassa obsoleta *(Say), in nematode and benthic diatom communities showed that the areas devoid of snails had higher densities of both benthic diatoms and Pseudotheristid nematodes than the contiguous control area. We suggest that the increase in the diatom-eating* Pseudotheristus *sp. in the exclusion plot was a behavioral response to increased diatom densities, thus demonstrating an indirect trophic interaction between a molluscan macrofaunal herbivore and a nematode member of the meiofaunal community.*

The mud snail *Ilynassa obsoleta* (Say) is an ubiquitous organism in the intertidal region, ranging from the Gulf of St. Lawrence to northeastern Florida on the east coast of North America. It is an omnivorous depositfeeder, apparently subsisting almost entirely on ingested sand and mud and associated organisms (Brown, 1969). The animal has been the subject of many experimental and descriptive studies, but little work has been concerned with the influence of *I. obsoleta* on biological components of its environment. As a portion of a project to develop field methods for analysis of possible trophic links between faunal groups, we initiated a series of experiments on an intertidal salt marsh creekbank at Sapelo Island, Georgia. Results from these experiments indicate that when the eastern mud snail *Ilyanassa obsoleta* (Say) is excluded from an area, meiofaunal nematode populations respond to increases in diatom population and that this response is most probably a result of feeding behavior.

Wetzel (1976) demonstrated that *Ilyanassa obsoleta* (Say) can ingest and assimilate benthic diatoms. In addition, Pace (1977) has shown that if *I. obsoleta* (Say) is excluded from an area of the intertidal creekbank in the salt marsh, both chlorophyll *a* and ATP concentrations in the top centimeter of sediment show significant increases within twenty-four hours. After five days the concentrations of these substances increased significantly within the 2-5 cm layer of sediment. However, he did not determine the actual cause of these increases. Since up to 90% of total sediment ATP can be attributed to nematodes (Sikora *et al.*, 1977), it is possible that the difference in ATP concentrations observed by Pace (1977) reflected significant changes in the nematode community. We utilized similar exclusion techniques to obtain diatom blooms with the intent of studying numbers of individuals rather than lumped sums of chlorophyll *a* and ATP.

The study area was the same as used by Pace (1977). The intertidal sediment is 80% silt-clay. In July, the time of this experiment, the average density of *I. obsoleta* (Say) is 1500 m^{-2}. A one meter square area was enclosed with 1/4" (0.635 cm) hardware cloth 50 cm high and extending 3 cm into the sediment. Snails were removed from the enclosed area. One square meter contiguous with the experimental area was used as a control. Just after the water receded from the area, 3 cm^2 pieces of lens paper (double thickness) were placed in four randomly selected areas in both

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[1] Contribution No. 379 from the University of Georgia Marine Institute.

the experimental and control areas. Small cages were placed around the lens paper in the control area to prevent disturbance by snails during collection of the algae. These cages were in place only during collection of algae. After three hours the lens paper was collected and diatoms removed by a method similar to that of Eaton and Moss (1966). Briefly, lens papers were heated with sulfuric acid and potassium permanganate. They were then washed in distilled H_2O by centrifuging and decanting, transferred to vials and brought to constant volume of 3 ml. Four subsamples (2×10^{-4} ml) from each vial were counted using a hemacytometer. This method may overestimate numbers due to cell breakage and separation of valves (Eaton and Moss, 1966) but is necessary to determine the species composition of the samples.

A ten cc syringe was used to collect samples of the nematode population. It was assumed that nematodes near the surface of the sediment were more likely to be influenced by the diatom populations than those in deeper sediments. Therefore, only the top two centimeters of sediment were collected. Three samples, collected randomly from both the experimental and control areas, were fixed with formaldehyde (3% V/V). After twenty-four hours in the formaldehyde solution, samples were rinsed through a 45 μm mesh screen. Individuals retained on the screen were counted. After dehydration, glycerine slide mounts were prepared.

Data presented here are from samples obtained on day 1 and day 5 of the experiment. On both days the mean number of cells/cm² within the experimental area was greater than the control area (Table 1). ANOVA tests of mean number of diatom cells/cm² indicate that there were significant differences between the experimental and control areas and between days. The significant interaction term is due to the fact that the increase in cell concentration from day 1 to day 5 was greater in the experimental area than in the control area (Table 2.).

The patchy distribution of nematodes prevents any meaningful statistical analysis of the numbers of organisms obtained in the samples. However, on day 1 the average number of nematodes in all samples was 100. After five days the average number of individuals in the control area remained at 100. Average number of individuals within the experimental area had increased to 300.

TABLE 1 *Numbers of diatoms observed.*

	Experimental	*Control*
Day 1	2.93	0.67
Day 5	7.12	1.27

Mean number of cells/cm^2 $\times 10^6$

The change in species composition between day 1 and day 5 is of great interest. Initially, the nematode populations were composed of about fifteen different families (several undescribed species are represented), principally representing the Enoplida and Monhysterida orders. This diverse distribution remained in the control area. On day 5, 70% of the individuals from the experimental area were *Pseudotheristus* sp. This species represented only 19% of the population in the control area. The actual number of non-*Pseudotheristus* individuals remained stable in both the experimental and control. Thus, the increase in numbers of individuals in the experimental area was due entirely to the presence of *Pseudotheristus* sp.

Information on the generation time of free-living marine nematodes is scarce. Tietjen (1969) and Tietjen and Lee (1972, 1973) have reported minimum generation times of 22 days under optimal laboratory conditions. Hopper, Fell and Cefalu (1973) report generation times of 1-$\frac{3}{4}$ days to 112 days for six free-living nematode species cultured from decaying mangrove (*Rhizophora mangle*) leaves. Since the first egg cleavage requires from six to thirty-five hours (Hope, 1974), it seems unlikely that reproduction could account for the increase in numbers of adult individuals observed during the period of five days.

TABLE 2. *Analysis of variance of diatom numbers.*

	SS	*df*	*ms*	*F*	*P*
Treatment	106.45	3			
cage	263.12	1	263.12	47.92	<.001
days	91.93	1	91.93	16.65	<.005
interaction	51.41	1	51.41	9.38	<.001
Samples	65.92	12	5.49		

SS = sum of squares; df = degree of freedom; ms = mean square.

Seventy-five percent of the *Pseudotheristus* sp. contained diatoms within their guts. Individuals contained from two to twenty-two diatom frustules. In most cases chloroplasts were visible when the frustule was located in the anterior portion of the gut, but not in the posterior position. Diatoms were not found in the guts of any of the other species of nematodes in either the control or experimental area.

While it is possible that the difference in nematode density was because predation by the mud snails, two lines of evidence render this interpretation unlikely: dissection of over thirty *I. obsoleta* (Say) revealed no nematodes in their caecae and the change in nematode density was entirely due to increase in the *Pseudotheristus* sp. population. It is unlikely that *I. obsoleta* (Say) individuals exercise any selection over the type of material ingested from the substrate (Brown, 1969). Therefore, we suggest that the increase in *Pseudotheristus* sp. is a result of competitive release, thus demonstrating an indirect trophic interaction between the macrofaunal species *Ilyanassa obsoleta* (Say) and the meiofaunal species *Pseudotheristus* sp.

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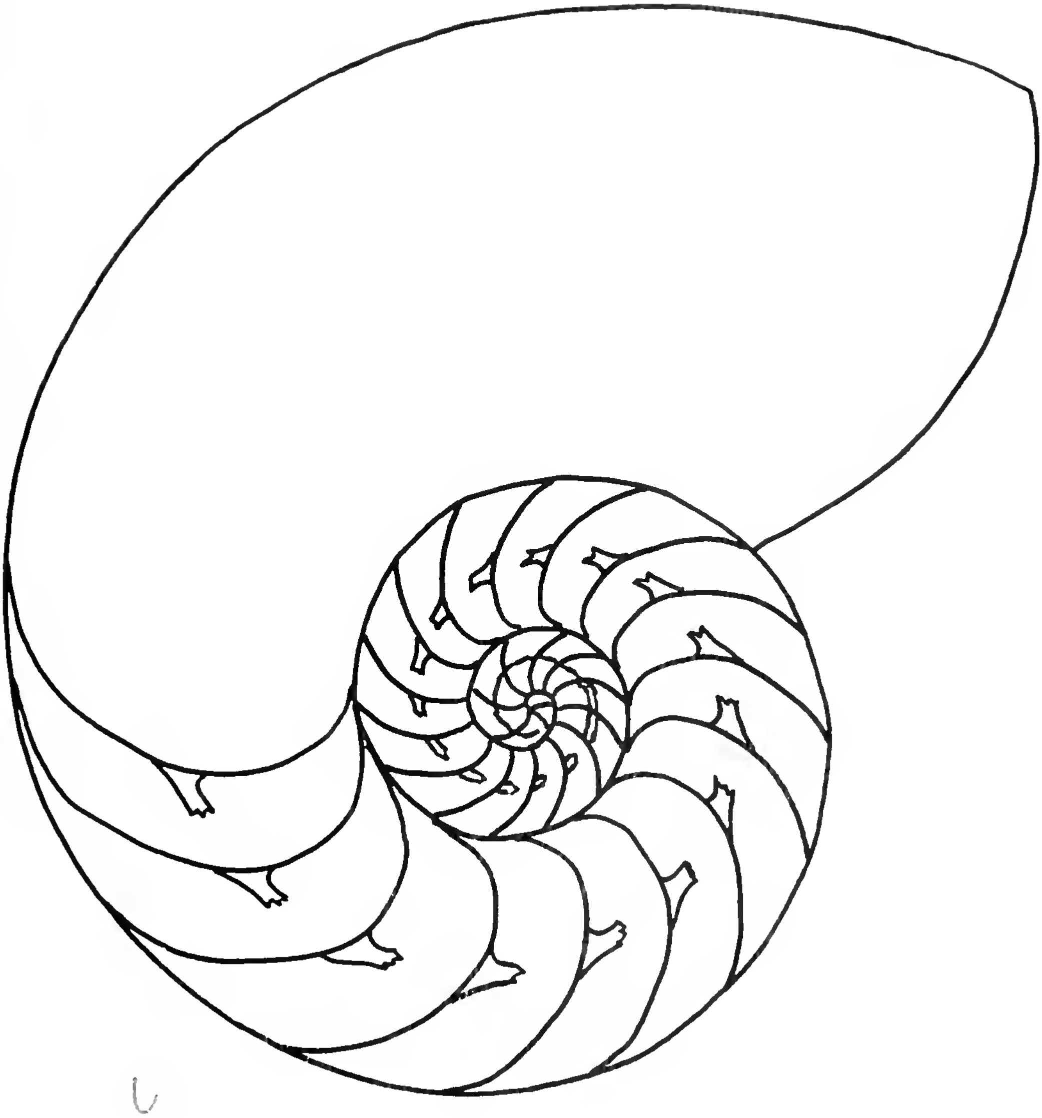

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(signed) R Tucker Abbott, Editor

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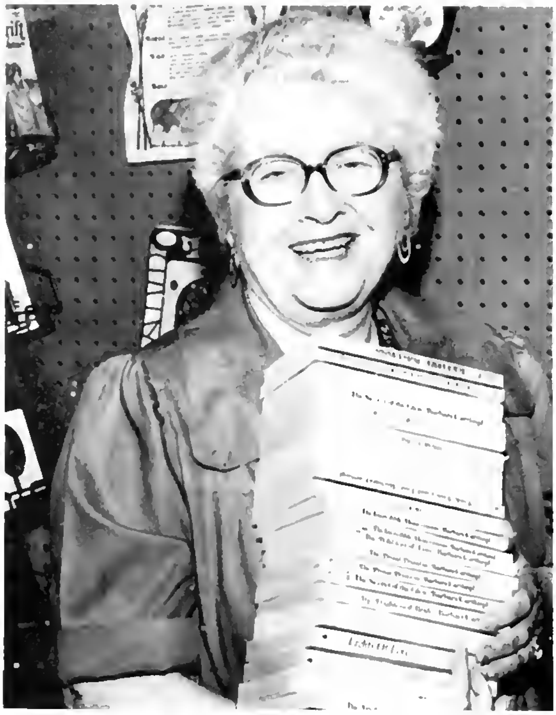

BERNADINE BARKER BAKER
Retiring Business Manager of *The Nautilus*

For nearly half a century Mrs. H. Burrington Baker, known to her friends as Bunny, has either collected shells, written about shells, or has been actively assisting scientists and editors in their malacological endeavors. Soon after she married the zoologist, and co-editor of *The Nautilus*, H. B. Baker in 1941, Bunny began proofing manuscripts and keeping the subscription records. Throughout the following 38 years her voluntary assistance has made the continuation of *The Nautilus* possible.

Mrs. Baker has been the fourth Business and Subscription Manager in the 93-year life of this journal. The first was its co-founder, William D. Averell (1853-1928) of Mt. Airy, Philadelphia, who served for the first three volumes from 1886 to 1890. The second was Charles W. Johnson (1863-1932) of Philadelphia and later of Boston who served from 1890 until his death in 1932 over a period of 42 volumes. The third was Horace Burrington Baker (1889-1971), of Havertown, Pa., who served from 1932 to 1958 when he then became senior editor. It was at this time during the 71st volume that Bunny became the fourth Business Manager and has served in that capacity for 20 years. Although retiring now, and still very active in the affairs of the Delaware County Memorial Hospital, Bunny is in excellent health and will continue to give sage advice and guidance to *The Nautilus*.

Bernadine Barker Baker was born October 1, 1906, in Quincy, Massachusetts, and received her A. B. degree in 1928 from Radcliffe College in Cambridge, Mass. She taught at Burdett College for three years, then was Financial Secretary at the Children's Museum in Boston where she first became interested in shells. With her co-worker Mildred Seymour (later MacCoy), Bunny ventured on an expedition with Harvard scientists in 1931 to the Everglades of Florida.

Mrs. Baker is a Life Member of the American Malacological Union, having joined as early as 1934, and served as its Treasurer from 1966 to 1972. She was Secretary of the Boston Malacological Club from 1935 to 1941, and is a charter member of both the Philadelphia and Wilmington Shell Clubs. Her interests have been mainly in marine mollusks. Her collection was donated to the Museum of Comparative Zoology, at Harvard, a few years ago. She published two scientific articles in *The Nautilus*, one in 1950 on the marine mollusks of St. Petersburg, and the other in 1951 on "Interesting Shells from the Delmarva Peninsula."

Bunny was engaged to her future husband at the 1941 A. M. U. meetings in Rockland, Maine, and appropriately they spent their honeymoon on shell-rich Sanibel Island, Florida. Until "H. B.'s" death in 1971, she assisted in *The Nautilus* matters, and raised two daughters, Elizabeth, now Mrs. Warren Brandkamp, and Abigail, now Mrs. John Kraljevich. She has four grandchildren. Her husband immortalized her name in malacological literature in 1942 by naming a new genus and new species of Mexican land snail, *Bunnya bernadinae*. For 17 years Bunny has been a volunteer worker at the Delaware County Memorial Hospital (see *Our Family*, vol. 5, no. 10, Aug. 1977), and she continues to assist in their Gift Shop. Among her hobbies are hooking rugs and collecting miniature bunnies. Bunny may still be reached by her friends at 11 Chelten Road, Havertown, PA, 19083. (R. T. Abbott).

ULTRASTRUCTURAL EFFECT OF CLEANING MOLLUSCAN SHELL WITH SODIUM HYPOCHLORITE (CLOROX)

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ABSTRACT

The corrosive effect of sodium hypochlorite (commercial clorox) on the ultrastructure of the organic components of the shell of the bivalve Mytilus edulis *Linné is described, and the detrimental results are related to cleaning of molluscan shells preparatory to storage in collections.*

INTRODUCTION

Sodium hypochlorite solutions have been employed routinely by shell collectors for some time to remove algal and other organic growths from the exterior of molluscan shells in preparation for storing them in collections (Abbott, 1954; Bales, 1974).

Commercial clorox, 5.25% sodium hypochlorite, available at most grocery stores, does not disfigure the mineral portions of shells, but does dissolve the organic matter. Soft molluscan and other tissues are dissolved rapidly (in a few seconds), while tough tissues, like molluscan periostracum and ligament, take considerably longer. Hamilton (1969), for example, was forced to treat valves of tellinid bivalves for as long as 30 to 60 days to completely remove the periostracum. Differential dissolution of organic matrix of shell by sodium hypochlorite has been used to good advantage by such investigators as Towe and Hamilton (1968), Mutvei (1970), and Carriker (1978) in the study of the fine structure of the units of molluscan shell.

The purpose of this note is to describe the effect of clorox on molluscan shell at ultrastructural magnifications, and to discuss these observations with reference to the procedures employed by shell collectors in cleaning shells.

METHODS

Shells of the bivalve *Mytilus edulis* Linné were employed for testing the effect of solutions of sodium hypochlorite. Rapidly growing specimens, approximately 6 cm in length, were collected in the vicinity of Woods Hole, Massachusetts. Valves, freshly cleaned of meats and washed in tap water, were shattered with a blow from a hammer. Pieces of shell, about 4 to 8 mm in longest dimension, were selected from the thick middle region of the valves. All major layers of shell were represented in each fragment: the exterior organic periostracum, the calcitic prismatic stratum, and the aragonitic nacreous layer next to the mantle (see Carriker, 1978, for review of the ultrastructure of the shell of this bivalve).

Several pieces of shell were placed in each of three small beakers, each beaker containing 30 ml of full strength commercial clorox (5.25% sodium hypochlorite). Beakers were covered, gently swirled by hand from time to time, and maintained at room temperature in a laboratory normally lighted with overhead fluorescent illumination. Shell pieces in beaker a) were immersed in clorox for 10 minutes, those in beaker b) for 30 minutes, and those in beaker c) for 40 hours. At the end of these periods, shell fragments were rinsed several times in cold tap water, drained on absorbent paper, and dried in a stream of warm air. Representative pieces from the three beakers were then mounted on 1 cm brass stubs with silver paint, dried in an oven at 60°C for a day, coated with gold in vacuum, and examined with a scanning electron microscope, using magnifications of 2000 to 6000 times at a voltage of 15 kv.

RESULTS

Ridges on the untreated surface of the periostracum of *Mytilus edulis* ranged in width from

1.4 to 2 µm (Fig. 1). This corrugated pattern was completely destroyed by treatment with clorox for 40 hours (Fig. 2), leaving cracked, buckled shreds of periostracum draping over the tops of tubercles of the thin mosaicostracal layer (Carriker, 1979) which binds the periostracum to the prismatic layer of the shell. Immersion of periostracum in clorox for shorter periods resulted in progressively less erosion of its surface.

Treatment of fractured surfaces of the prismatic layer of shell with clorox for 40 hours (Fig. 5) caused complete removal of the interpristmatic organic matrix (conchiolin) which surrounds each individual prism as an envelope and binds adjacent prisms to each other (compare with Fig. 3; prisms roughly 1 to 3 µm in major cross sectional dimension). The treatment also etched some of the intraprismatic organic matrix from the mineral crystals within the prisms, revealing the jagged edges of what appeared like mineral platelets. Treatment with clorox for 10 minutes (Fig. 4) resulted in the removal of only part of the interprismatic organic matrix.

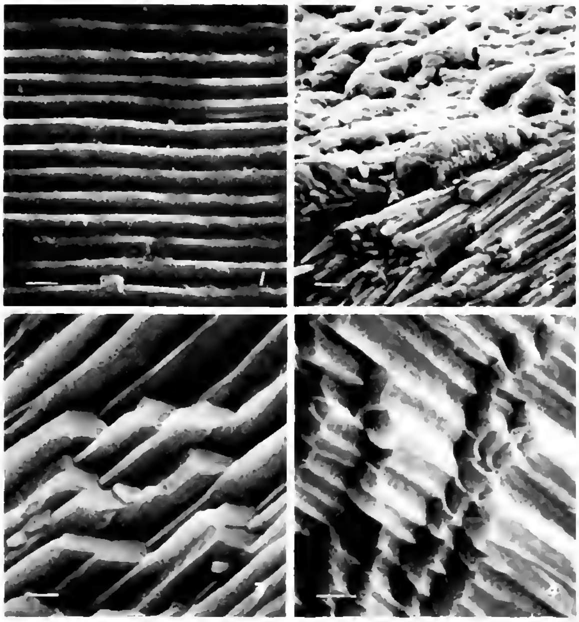

FIG. **1.** *Exterior of periostracum of* Mytilus edulis *near edge of valve illustrating normal, smoothly corrugated, untreated surface. Scanning electron micrograph. Scale bar = 2 µm.* **2,** *Exterior of periostracum after treatment with clorox for 40 hours. Periostracum was partially dissolved, and as it dried, cracked and warped. Scanning electron micrograph. Scale bar = 3 µm.* **3,** *Normal untreated fractured surface of prismatic layer of shell showing broken ends and sides of individual, closely fitting, anvil-shaped prisms. Scanning electron micrograph. Scale bar = 2 µm* **4,** *Fractured surface of prismatic layer of shell treated with clorox for 10 minutes. Most of interprismatic organic envelope was removed from each prism exposing pattern of mineral crystals beneath. Scanning electron micrograph. Scale bar = 2 µm.*

Exposure of the mantle surface of the nacre to clorox for 40 hours resulted in dissolution of the organic matrix which surrounds individual lamellae and cements them to each other (Fig. 7, compare with Fig. 6; lamellae roughly 5 to 10 µm in longest dimension). Removal of the matrix created a pattern of polygonal figures illustrated in the several terraces of lamellae exposed in Figure 7. A threefold enlargement of Figure 7 (Fig. 8) showed further that the clorox also solubilized some of the intracrystalline organic matrix within the lamellae, exposing what appeared like internal lath shaped substructures.

DISCUSSION

As other workers have discovered (Carriker, 1978, Hamilton, 1969; Mutvei, 1970; Towe and Hamilton, 1968), clorox is a highly efficient solubilizer of molluscan organic materials. Excessive use of full strength clorox in the cleaning of shells, however, can alter the ultrastructural nature of the shell surface, whereas when employed with discretion, the chemical is extremely useful in cleaning periostracal and ligamental surfaces of molluscan shells. Unpublished observations and the published work of others (Abbott, 1964; Bales, 1974) demonstrated that it is difficult to prescribe a given concentration or time for the use of clorox in cleaning the exterior surface of a particular species of shell. The age of the shell and previous exposure of the surface to weathering and to microbiological action are factors which increase the vulnerability of the surface to dissolution. Each specimen must thus be treated individually, and application of the chemical must be made initially for a brief period of time. For fragile specimens it is important to use clorox diluted five to twenty or more times with tap water. S. E. Siddall and R. A. Lutz (*personal communication*), for example, employ 2% alkalized (pH 9) clorox to dissolve the ligament of mussel larvae when examining the

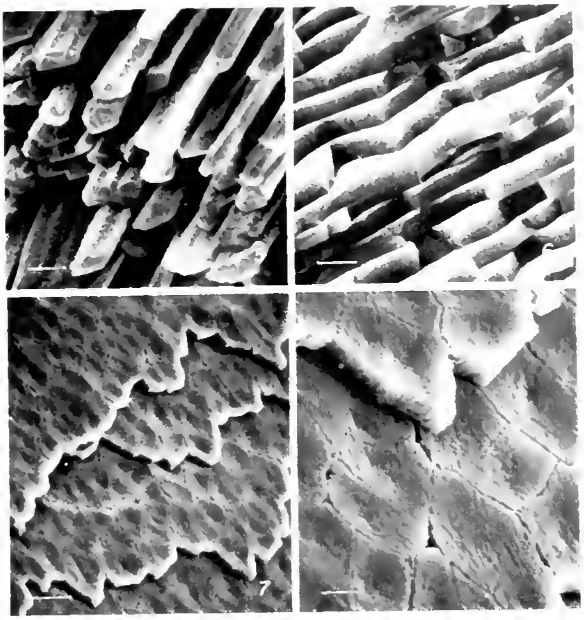

FIG 5. *Fractured surface of prismatic layer of shell treated with clorox for 40 hours. Interprismatic and some of intraprismatic organic matrix was solubilized, leaving conspicuous spaces among prism ends. Scanning electron micrograph. Scale bar = 2 μm.* **6,** *Normal, untreated, oblique, fractured surface of nacreous layer of shell showing terraces of brick-shaped lamellae. Scanning electron micrograph. Scale bar = 2 μm.* **7,** *Surface of nacreous layer of shell facing mantle treated with clorox for 40 hours. Organic matrix between adjacent lamellae was dissolved resulting in pattern of polygonal figures. Scanning electron micrograph. Scale bar = 6 μm.* **8,** *Same surface as in Fig. 7 magnified three times more. Dissolution of superficial organic matrix within lamellae revealed substructure of lamellae. Scanning electron micrograph. Scale bar = 2 μm.*

hinge structure. After initial immersion in clorox, careful rinsing in tap water, and drying, the surface of the specimen should be examined for effectiveness of removal of organic growths and for possible loss of sheen and color resulting from chemical deterioration of the surface. Guided by frequent visual examinations (preferably under a binocular microscope especially for small fragile specimens), the shell preparator can generally safely employ the required number of immersions in clorox to remove extraneous organic materials without objectionably altering the surface of the periostracum and ligament.

The organic matrix of the nacreous inner surface of valves, however, is much more vulnerable to dissolution by clorox than periostracum and ligament (see Fig. 7, 8). With the exception of fragments of flesh clinging to the muscle scars (myostracum), the nacreous surface is usually clean in freshly opened molluscs. It is thus necessary only to dissolve the organic matter on myostracal areas. This can be done without harming the nacre to any extent by carefully "applying" clorox only over the myostracal surfaces under a binocular microscope, observing the same precautions given in the previous paragraph for periostracal and ligamental surfaces.

Malacologists and conchologists often soak freshly collected shells in tap or seawater for a time to allow removal of muscle tissue from the myostraca by autolysis and bacterial decomposition. This treatment is effective in removing tissues, but caution must be observed as the treatment may also disfigure the nacreous surface as a result of the accumulation of acids in the water. If water must be used, it is safer to employ seawater because it possesses a considerably greater buffering capacity than does freshwater.

The observations reported in this paper suggest that caution should be exercised against over exposure to clorox in cleaning shells especially for permanent storage in study collections.

ACKNOWLEDGMENTS

Thanks are extended to Virginia Peters for collaboration in the scanning electron microscopy, to Walter S. Kay for preparing the final prints for publication and to R. Tucker Abbott for helpful comments on the manuscript. University of Delaware, College of Marine Studies Contribution Number 123.

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VARIATIONS IN THE LIMPET, *COLLISELLA OCHRACEA*, AND THE NORTHEASTERN PACIFIC DISTRIBUTION OF *NOTOACMEA TESTUDINALIS* (ACMAEIDAE)

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In August, 1975, I collected a series of small limpets, less than 10 mm in length, from the shells of the abalone, *Haliotis rufescens* Swainson, 1822, at a depth of 8 m off Kruse Ranch, Mendocino County, California (38°35′N). My initial efforts to identify the specimens using shell characters failed, so I examined radulae from several of the specimens. Radulae from other small limpets which had been obtained from shells of *Tegula pulligo* (Gmelin, 1791), collected in Monterey Bay, California (36°36′N), had previously been prepared. When compared to those of the Kruse Ranch specimens, the radulae proved to be very similar, although the shells of the two groups of specimens differed markedly in coloration and morphology.

As additional material was examined, radular characters initially thought to be unique to these two sets of specimens were also found to be present in *Collisella ochracea* (Dall, 1871). I now consider the limpets from *H. rufescens* and *T. pulligo* to be previously unreported forms of *C. ochracea*.

Subsequent to this, I encountered problems in attempting to establish the most northern distributional record for *C. ochracea*. Specimens identified as *C. ochracea* from western Alaska were not similar to southern specimens. After extensive examination and comparisons, these specimens were recognized as *Notoacmea testudinalis* (Müller, 1776), the presence of which in the eastern Pacific has been the subject of controversy.

This paper discusses and figures the various forms of *C. ochracea* and contains notes on the natural history of this species. Also included is a review of the presence of *N. testudinalis* in the eastern Pacific, with a discussion of its similarities to, and differences from, *C. ochracea*.

Abbreviations used in the text:

CAS - California Academy of Sciences, San Francisco, California.

CASG - Department of Geology, Cal. Acad. Sciences.

CASIZ - Department of Invertebrate Zoology, Cal. Acad. Sciences.

LACM - Los Angeles County Museum of Natural History, Los Angeles, California, Department of Malacology.

Collisella ochracea

Collisella ochracea is a little-known eastern Pacific species. Dall (1871: 249) described it from Monterey, California, as a variety of *Acmaea patina* Rathke, 1833 [now *Notoacmea scutum* (Rathke, 1833)], and it was treated as such by

Dall (1879; 1914; 1921), Pilsbry (1891), and Oldroyd (1927). A. R. Grant (1933) was the first worker to recognize *C. ochracea* as a distinct species and in a later thesis (Grant, 1938) correctly placed *Acmaea peramabilis* Dall, 1872, in synonymy. Observations by Grant (1938) of the radula of *C. ochracea* further demonstrated its distinctness. The radular strap was found to bear vestigial, marginal teeth (uncini), the presence of which assigned *C. ochracea* to the genus *Collisella* rather than to *Notoacmea*, the genus to which *N. scutum* belongs. Grant's treatment of *C. ochracea* was followed by the majority of subsequent workers, including Keen (1937), Burch (1946), Smith and Gordon (1948), Light, *et al.* (1955), Fritchman (1961), McLean (1966, 1969), and Carlton and Roth (1975). However, as recently as 1974, *C. ochracea* has again been erroneously listed as a variety of *N. scutum* (Abbott, 1974: 32).

In 1945 and 1946 Avery Ransome (Grant) Test published parts of her 1933 and 1938 theses. In the first paper the ecology of *C. ochracea* was discussed in a single paragraph in which she stated that the limpet occurs in the lower intertidal zone on rocks that are largely bare of macroscopic algae, appearing to be limited to this habitat by food (microscopic algae), the lack of competition, and permanent submergence. In the later paper (Test, 1946), *C. ochracea* was reported to be related to *Collisella pelta* (Rathke, 1833) based on a study of the radular characters. My own observations do not support this relationship nor is another evident at this time. Yonge (1962) included the species in his study of mantle cavity currents in acmaeids. McLean (1969: 17) reported that *C. ochracea* is one of the few acmaeid species occurring subtidally. McLean (*loc. cit.*) was also the first worker to refer to *C. ochracea* as being a common species. The range of *C. ochracea* is Captain's Bay, Unalaska Island, Alaska (53°03′N) to Isla Cedros, Baja California, Mexico (28°12′N).

The Forms of *Collisella ochracea*

Collisella ochracea is an eurytopic, polytypic species. It occurs on several different substrata and has shell color patterns and morphology that vary with the substratum occupied. One form occurs on the shells of trochid gastropods. A second variation occurs on encrusting coralline algae and two other forms occur in the low intertidal and subtidal zones. Only these last two were recognized and described by Grant (1933: 111).

Although each form is described separately below, several general characters are present on all specimens. The sculpture of *C. ochracea* consists of fine, non-bifurcating riblets. The riblets are consistently straight and evenly spaced. The aperture of *C. ochracea* may vary from circular (Fig. 2) to elongate (Fig. 4).

Solid and Tessellate Forms (Figs. 1-2)

Description: Shell of low to medium profile; apex in anterior third of shell length. Anterior and lateral slopes straight, posterior slope slightly convex. Solid form pale yellow to rose red. Tessellate form brown to gray, with symmetrical white markings, pattern finer at apex than at edge. White markings sometimes drawn out into bars at edge. Internal margin darker than intermediate or apical areas, sometimes streaked with white corresponding to external pattern. Intermediate and apical areas may be suffused with blue. Internal stain, when present in solid form, not covering apical area.

Remarks: As previously stated these two forms have been recognized since 1933 and they occur on smooth, bare rocks and reefs in the low intertidal and subtidal areas. McLean (1966: 77) stated that specimens are common to depths of 9 m, but are seldom collected below this.

Coralline Form (Fig. 3)

Description: Shell of low to medium profile; apex in anterior third of shell length. Anterior slope concave; posterior slope convex; lateral slopes straight. Aperture anteriorly narrowed. External color pattern of brown to red coalescing markings on a white background; pattern at apex finer than at edge. Apex erodes to white. Internal margin white, with markings corresponding to pattern at external edge; internal stain, when present, not extending into apical area. Shell translucent.

Remarks: This form occurs on intertidal and subtidal substrata encrusted with coralline algae of the genus *Lithothamnion*, including rocks, boulders, and the shells of *H. rufescens*. The concave anterior slope of this form distinguishes it from the other forms of this species. A form of *Collisella pelta* is also found on such surfaces, but it is readily distinguished from *C. ochracea* by its lack of fine riblets.

Epizoic Form (Fig. 4)

Description: Shell of medium profile; apex in anterior quarter of shell length. Anterior and lateral slopes straight; posterior slope slightly convex. Aperture elongate; lateral edges parallel. External color tan to reddish brown, generally mottled with white or with white markings. Solid forms occur. Apex erodes to white. Internal margin dark, with or without white markings corresponding to the external pattern which is visible through shell. Generally lacking internal stain.

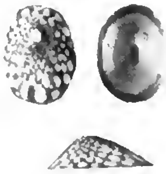
Remarks: This form occurs on the trochid gastropods *Tegula brunnea* (Philippi, 1848), *Tegula montereyi* (Kiener, 1850), and *Tegula pulligo* (Gmelin, 1791). The majority of my specimens have been collected from *T. pulligo* in the Monterey Bay area. This form of *C. ochracea* has been found on *T. brunnea* and *T. montereyi* in San Mateo County, California, and a single specimen of it was found at Bodega Bay, Marin County, California, on *T. brunnea*. Trochid gastropods are commonly utilized as substrata by acmaeid limpets. *Collisella asmi* (Middendorff, 1847) was considered to be the only epizoic limpet on *Tegula funebralis* (A. Adams, 1855). However, McLean (1966: 80) reported that *Collisella strigatella* (Carpenter, 1846) was also abundant on *T. funebralis* in the Monterey area, and Brewer (1975) reported six additional species of acmaeid limpets on *T. funebralis*. *T. funebralis* is a mid-intertidal species, and the limpets which occur on it are also found in the same intertidal zone. All three species of *Tegula* on which *C. ochracea* has been found are low intertidal and offshore kelp bed species (Carlton and Roth, 1975: 502-503) which corresponds to the habitat of *C. ochracea*.

Laminaria Form

After the manuscript was submitted to the editor a fifth form of *Collisella ochracea* was brought to my attention by M. G. Kellogg, Moss Landing Marine Laboratories, Moss Landing, CA. This additional form occurs on the stipes of the brown algae *Laminaria dentigera* and *Pterygophora californica*; both algae are typical habitats of *Collisella instabilis* (Gould, 1846). Both *C. instabilis* and the *C. ochracea* form have similar gross shell morphologies (*i.e.* elevated anterior and posterior shell margins), but differ in shell markings and sculpture. The *C. ochracea* form is brown with white markings similar to those of the tessellated form described above. *Collisella instabilis* is also brown but lacks the white markings although the apical area typically erodes to white. The sculpture of the *C. ochracea* form is as described above, with straight, raised riblets. The sculpture of *C. instabilis* consists of broadly-spaced grooves giving the appearance of obscure, flat ribs.

Figures 1-10 (see opposite page)
All figures actual size unless otherwise noted.

FIGS. 1-10. **1-4.** Collisella ochracea *(Dall)* **1,** *Tessellate form, California: San Mateo County; Pillar Point, CASIZ No. 003419* **2,** *Solid form, California, Mendocino County, Little River, 58717 CASG Type Collection;* **3,** *Coralline form, California: San Mateo County, Ano Nuevo Point, CASIZ No. 003396, × 2.* **4,** *Epizoic form, California: Monterey County, San Jose Creek Beach, on* Tegula pulligo *(Gmelin), CASIZ No. 003390, × 2.* **5-6.** *Radula of* Collisella ochracea *(Dall), California: Mendocino County; Kruse Ranch, CASIZ No. 003418, × 250.* **5,** *Radular tooth configuration, FLT = first lateral tooth; SLT = second lateral tooth; TLT = third lateral tooth, U = uncinus.* **6,** *Basal plate morphology; FLP = first lateral plate, SLP = second lateral plate; TLP = third lateral plate; VP = ventral plate, AP = anterior process; AS = anterior suture.* **7.** Collisella ochracea *(Dall), California: Santa Cruz County; Soquel Point, CASIZ No. 003393. Note shell color pattern change at apex. Enlargement × 7.* **8.** Notoacmea testudinalis *(Müller)* **8A,** *Alaska: Pribilof Islands, St. Paul Island, 58716 CASG Type Collection;* **8B,** *Alaska: Kenai Peninsula; Kachemak Bay, Cohen Island, LACM No. 73-20.* **9-10.** *Radula of* Notoacmea testudinalis *(Müller) Alaska: Pribilof Islands, St. Paul Island, St. Paul Village, LACM No. 73-24, × 200.* **9,** *Radular tooth configuration (see Fig. 5 for legend).* **10,** *Basal plate morphology (see Fig. 6 for legend).*



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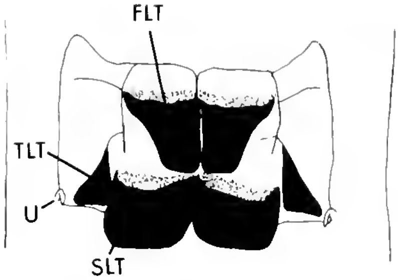

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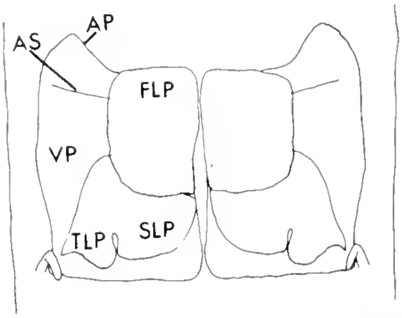

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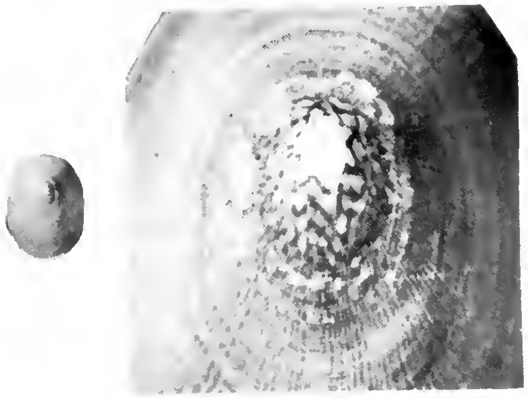

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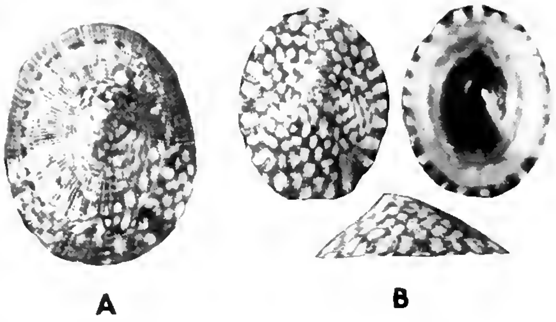
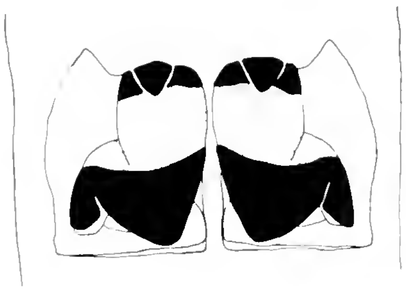
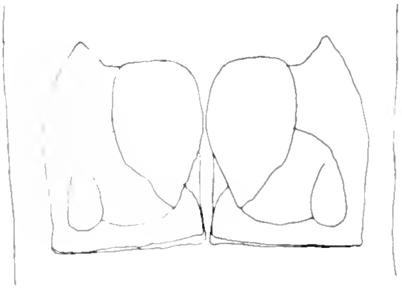


8



9



10

For explanations, see opposite page (Lindberg on Acmaeidae).

The Radula of *Collisella ochracea*

Although shell color varies significantly in this species, radular characters appear consistent.

Grant (1938: plt. 30, Fig. 2) figured the radular strap and basal plates of *C. ochracea*, but did not discuss or figure tooth configuration or morphology. She did mention the presence of elongated uncini. McLean (1966: 77) described the lateral teeth and basal plate morphology, and gave length/width ratios for the ribbon segments.

The radular tooth configuration of *C. ochracea* (Fig. 5) is typical of members of the genus. The first lateral teeth are close together on the anterior end of the segment and are rounded distally. The second laterals are posterior to the first laterals and are sub-rectangular, with broad straight cutting edges. The third laterals are oblique and are distal to the second laterals; they are wedge-shaped and smaller than the other laterals. The uncini are elongate and curve over the posterior corners of the ventral plates. The tips may be slightly broadened.

The basal plate morphology of the radula (Fig. 6) is also typical of members of the genus. The first lateral plates are sub-rectangular; the second lateral plates broad and posteriorly rounded; and the third lateral plates are separated from the second lateral plates by a strong partial suture. The third lateral plate is biformed, the inner section rounded distally and extends beyond the second lateral plate edge. The outer section is pointed distally and extends to the vicinity of the uncini. The ventral plates are clearly defined and bear both a strong anterior suture and process-the anterior process is difficult to see in radular mounts with closely spaced segments.

Natural History Notes

Specimens of *C. ochracea* of both sexes, some with shell lengths of less than 5 mm, have been found in a gravid state, and some of these from central California are known to have been collected in the months of February through August.

The bathymetric range of *C. ochracea* extends from the low intertidal (= 0.0 feet) to a little over 40 m. No submergence in the southern portion of the distribution of this species appears to occur, although Baja California specimens appear limited to areas of cold-water upwellings.

C. ochracea also occurs in the turbid water of San Francisco Bay, California (37°48′N) on the sides and bottoms of small rocks embedded in sand and gravel sediments and on fouled pilings in Monterey Harbor. The occurence of *C. ochracea* in such habitats is not surprising in view of Yonge's (1962) report that *C. ochracea* has a mantle current pattern similar to that of *Notoacmea testudinalis*, a species often found associated with sediment-laden water.

DISCUSSION

While the epizoic and coralline forms of *C. ochracea* are directly referable to particular substrata, the solid and tessellate forms appear to occur homogeneously in the intertidal and subtidal areas of central California. However, in a survey of over 400 specimens some geographic correlations of these forms were noted. Tesselate forms predominate in the southern part of the geographic distribution (south of 38°N) and decrease to the north; the solid forms predominate in the north and appear to decrease to the south (Table 1).

Some movement of individuals between substrata may exist. These movements are suggested by changes in shell morphology and shell color. Solid forms have been examined with the fine reticulate pattern of the coralline form visible at the apex (Fig. 7). The presence of the fine reticulate pattern may indicate movement from a coralline substratum to the exposed rock reefs, the typical habitat of solid forms. Changes in shell morphology and color have also been noted for *C. pelta* which may change substrata (McLean, 1966: 59).

Notoacmea testudinalis (Müller)

Although well-known on the east coast of North America (Abbott, 1974; Emerson and Jacobson, 1976), Arctic Canada and Europe (Macpherson, 1971), the presence of *Notoacmea testudinalis* in the northeastern Pacific has been

TABLE 1. *Geographical Distribution of Solid and Tesselate Forms of* Collisella ochracea *(Dall) in the Eastern Pacific*

DEGREES NORTH LATITUDE	SOLID FORM		TESSELLATE FORM		TOTAL # OF SPECIMENS
	# of specimens	% of specimens	# of specimens	% of specimens	
< 32	2	2	116	98	118
32-35	18	18	80	82	98
36-37	54	38	88	62	142
38-40	22	63	13	37	35
41-43	0	—	1	100	1
44-46	0	—	0	—	0
47-49	0	—	0	—	0
>49	12	92	1	8	13
$\sum$	108		299		407

the subject of considerable debate. Dall (1871) considered *N. testudinalis* to be readily discernable from *Acmaea patina* [= *Notoacmea scutum*] and to occupy a different habitat. In 1879, Dall reversed his position and regarded the two as varieties of a single species. Grant (1938) also considered the two to be of subspecific rank and to intergrade in the Alaskan Arctic. McLean (1966), Abbott (1974), and Emerson and Jacobson (1976) consider *N. testudinalis* to be limited to Atlantic and Canadian Arctic waters with a cognate, *N. scutum*, in the eastern Pacific. Moskalev (1964) considered *N. testudinalis* to be present in Arctic waters and to extend down the east coast of Asia.

After examining shells and radulae of specimens from Alaska and comparing these to Canadian Arctic, eastern Atlantic, and European specimens of *N. testudinalis*, I have concluded that *N. testudinalis* occurs in the northeast Pacific and that Dall's first account (1871) was correct as to the species habitat and distribution. Based on materials in the collections of the Los Angeles County Museum and the California Academy of Sciences, the west American distribution of this species in Alaska is from Point Barrow (71°22′N) (CASG #35056) to Goose Island, Icy Strait (58°13′N) (CASG #48915) and eastward to the Pribilof Islands (57°08′N, 170°15′W) (CASG #21975). In the eastern Pacific its habitat appears to be subtidal, although it occurs intertidally in the eastern Atlantic and Europe. Its subtidal habitat may contribute to its success in northern waters, as it occurs below the level of sea ice and low winter air temperatures. It has also been suggested that this species may migrate into the subtidal during the winter to avoid adverse conditions (Willcox, 1905: 327). In comparison, *N. scutum* is an intertidal species, not known to migrate and its northern distribution may be limited by sea ice and adverse winter weather. Therefore, in those areas where these two species' geographical distributions overlap (the Aleutians to Icy Strait, Alaska), *N. scutum* and *N. testudinalis* appear to be segregated by habitat.

The occurence of *N. testudinalis* in the eastern Pacific is similar to the distribution of *Collisella alveus* (Conrad, 1831) which occurs in both the North Pacific and the North Atlantic.

Arguments against the presence of both *N. scutum* and *N. testudinalis* as separate species in the eastern Pacific (Dall, 1879; Test, 1938) have been based on the presence of supposed intergrades (hybrids) in the Arctic. While the similarities of shell micro-structure and radular morphology suggest that speciation has been recent, I consider *N. testudinalis* and *N. scutum* sufficiently dissimilar to be considered specific.

Comparison of *Notoacmea testudinalis* and *Collisella ochracea*

Although the tessellate form of *C. ochracea* appears to be uncommon in the higher latitudes, it can be confused with *N. testudinalis* (*cf.* Figs. 1 and 8b). Both species have similar gross color patterns (Fig. 8), and in both, external sculpture consists of numerous, fine, non-bifurcating riblets.

As in most forms of *C. ochracea*, the internal stain of *N. testudinalis* does not cover the apex, and the external apex of both is white. However, the shell of *N. testudinalis* is larger and heavier than that of *C. ochracea*, and the internal stain is sharp and distinct; in *C. ochracea*, the stain is typically obscure or lacking.

As suggested by their generic allocations, *C. ochracea* and *N. testudinalis* differ in radular structure (Figs. 9-10). The radula of *C. ochracea* bears uncini; *N. testudinalis* lacks them. In *N. testudinalis* the first and second lateral teeth are elongate and pointed distally, rather than short and blunt as in *C. ochracea*. The basal plates of *N. testudinalis* differ from those of *C. ochracea* in that the third lateral plates are distinct and are located laterally from the second lateral plates. They are also lobate rather than biformed as in *C. ochracea*. The ventral plates of both species bear anterior processes.

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NEWS

Hans Bertsch has been appointed Curator of the Department of Marine Invertebrates at the San Diego Natural History Museum (P. O. Box 1390, San Diego, CA 92112). Dr. Bertsch was born in 1944 in St. Louis, Missouri, received his Ph. D. in 1976 from the University of California, Berkeley. He has published over 30 papers on opisthobranchs, and has had extensive field experience in Panama, Baja California, Hawaii and California. Dr. Bertsch was previously Assistant Professor in biology at the Chaminade University of Honolulu.

TROPICAL FAUNAL AFFINITIES OF OPISTHOBRANCHS FROM THE PANAMIC PROVINCE (EASTERN PACIFIC)

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ABSTRACT

This is a preliminary analysis of the distribution patterns of species of opisthobranchs (Gastropoda) in the eastern Pacific that are known to occur elsewhere in the tropics.

The opisthobranch fauna of the Panamic province (tropical West America) shares the greatest number of common species with the Californian temperate province (Bertsch, 1973a). Since 1970, various zoogeographic analyses of opisthobranch faunas from other marine provinces have been published (e.g., Franz, 1970, 1975; Thompson, 1976b, *et al.*).

Marcus (1977) enumerated the western Atlantic opisthobranchs, noting which species occur in other marine provinces. She lists species common to the Caribbean and tropical west American provinces and some amphi-Atlantic tropical forms. This extremely useful tabulation should be used with some reservation because certain species listed as "circumtropical" have not yet been reported from the Pacific coast of America (and hence are not universally circumtropical), and sources of the distributional data are at times unclear.

Emerson (1978) has compiled a list of the prosobranch gastropods and bivalves which are common to the Indo-Pacific and the eastern Pacific. This preliminary note is to compliment his study, so that a direct comparison can be made between the opisthobranchs and the prosobranchs. It is also intended to encourage further exchange of information on Panamic opisthobranchs. Only several tentative generalizations are presented because there is still much to be learned about the Panamic opisthobranch fauna.

Affinities

Table 1 summarizes the distribution patterns of species of opisthobranchs in the eastern Pacific that are known to occur elsewhere in the tropics. North-south range distributions (i.e., affinities with the temperate Californian and Peruvian provinces) are generally not included. Also omitted are the pelagic Thecosomata, a group with several circumtropical species.

Emerson (1978) and most of the writers he cites, have divided the Panamic province into 2 main portions: the offshore islands (Guadalupe, Revillagigedo, Clipperton, Cocos, and the Galápagos) and the continental shelf of west America (Gulf of California, Mexican and Central American coastline, and the Islas Tres Marias). The majority of Indo-Pacific prosobranch species occur in the eastern Pacific only on the offshore islands. By contrast, all of the opisthobranch species known from the eastern Pacific and any other tropical province occur on the mainland coast. Six species occur also at the Galápagos

TABLE 1. *Extra-provincial distributions of opisthobranch species occurring in the eastern Pacific. Numbers are species with that distributional pattern.*

	Cephalaspidea	Sacoglossa	Anaspidea	Notaspidea	Nudibranchia	Totals
Indo-Pacific	0	0	1	0	3	4
Circumtropical	0	1 (G)	5 (G)	1 (G)	4 (P)	11
Caribbean	0	1 (G)	0	2 (G)	5 (G)	8
Miscellaneous	0	1	0	0	3	4

G: One of the species (or the one species enumerated) occurs in the Galápagos Islands, in addition to being present on the mainland shelf of west America

P All four species are pelagic

Islands. No inter-provincial tropical species is presently known to occur only on the offshore islands. Of course, published records of opisthobranchs from these offshore sites are exceedingly scarce. Nevertheless, the occurrence of all these inter-provincial tropical species on the continental shelf is a very different pattern than that known for the prosobranchs.

So far as is known, there are no strictly Panamic forms which also occur in the Indo-Pacific province. Excluding the circumtropicals, species in common between these two provinces are apparently Indo-Pacific in origin.

The inter-provincial prosobranchs are primarily Indo-Pacific (48 species), with a very small number of circumtropical (tropicopolitan is Emerson's equivalent term) species (7). By contrast, there are 11 circumtropical and 4 Indo-Pacific species of opisthobranchs in the Panamic province.

Evolutionary relationships with species in other provinces (including generic-level affinities) have not been examined among the opisthobranchs. Although sister-species are well documented among prosobranch gastropods (Radwin, 1969), they have not been reported for the opisthobranchs. Such studies would yield vital information on the origins of the Panamic opisthobranch fauna, and would make substantial contributions to our knowledge of opisthobranch phylogeny and speciation and to current concepts of evolutionary zoogeography.

Ranges of the Individual Species

Four species of nudibranch occur circumtropically; they are all pelagic. These species are *Phylliroe bucephala* "Peron and Lesueur, 1810," *Cephalopyge trematoides* (Chun, 1889), *Fiona pinnata* (Eschscholtz in Rathke, 1831), and *Glaucus atlanticus* Forster, 1777.

Although some of the remaining species that comprise the data base for Table 1 may be able to swim periodically as adults, none are pelagic after metamorphosis from the veliger stage. In the following paragraphs, the distribution of each species in the Panamic province follows the locations in other zoogeographical provinces from which it has been reported.

Sacoglossa

Lobiger souverbii Fischer, 1856. Circumtropical (Baba, 1974). From tropical west America, southern Baja California (Isla San Jose and near Cabo San Lucas); Santa Cruz, Nayarit, mainland Mexico; Galápagos Islands (see Larson and Bertsch, 1974).

Polybranchia viride (Deshayes, 1857). Caribbean (Ev. Marcus and Hughes, 1974: 503-506). Gulf coast of Baja California; Nayarit, Mexico; Galápagos Islands (Bertsch and Smith, 1973; Ferreira and Bertsch, 1975).

Stiliger fuscatus (Gould, 1870). The distribution of this species is classed as one of the "Miscellaneous" types: north Atlantic coast of the United States; tip of South America; southeastern coast of Australia (Thompson, 1973: 210-213). Puerto Peñasco, Mexico, northern Gulf of California (Ferreira and Bertsch, 1975). This may be an introduced species (*sensu* Carlton, 1975: 17).

Anaspidea

Dolabella auricularia (Lightfoot, 1786). Indo-Pacific; Ecuador and Easter Island (Ev. Marcus and Er. Marcus, 1970: 191). Gulf coast of southern Baja California (Steinbeck and Ricketts, 1941: 171, 539-541; MacFarland, 1966: 32-37).

Aplysia dactylomela Rang, 1828. Circumtropical (Ev. Marcus and Er. Marcus, 1967: 38). Panama (Pilsbry, 1895: 88-89; Engel and Hummelinck, 1936: 6).

Aplysia juliana Quoy and Gaimard, 1832. Circumtropical. Northern Gulf of California (Puerto Peñasco, Sonora, Mexico) to Paita, Peru (Ev. Marcus and Er. Marcus, 1967: 155-159; Keen, 1971: 808).

Aplysia parvula Mörch, 1863. Circumtropical (Thompson, 1977: 110-112). Gulf of California (Lance, 1971: 60-63).

Dolabrifera dolabrifera (Rang, 1828). Circumtropical (Kay, 1964: 184-185). Northern Gulf of California to Panama (Bertsch, 1970a; Ferreira and Bertsch, 1975: 325); Galápagos Islands (Sphon and Mulliner, 1972: 149).

Stylocheilus longicauda (Quoy and Gaimard, 1824). Circumtropical (Ev. Marcus and Er. Marcus, 1967: 159-160). Gulf of California (Farmer, 1967; Bertsch, 1970b, and 1973b).

Notaspidea

Berthellina citrina (Rüppell and Leuckart, 1828). Circumtropical (Thompson, 1970: 190-192; 1976a: 167-169). Southern California; throughout the Gulf of California; Galápagos Islands (Bertsch, 1970b; Lee and Brophy, 1969; Sphon and Mulliner, 1972: 150).

Berthellina quadridens (Mörch, 1863). Caribbean (Thompson, 1977: 105-106). Panama Bay, Pacific coast (Ev. Marcus and Er. Marcus, 1967: 43-44).

Pleurobranchus areolatum (Mörch, 1863). Caribbean (Er. Marcus and Ev. Marcus, 1970: 55), south-central Atlantic (Ascension Island; Rosewater, 1975: 25), and west Africa (Edmunds, 1968: 85). Northern Gulf of California (Puerto Peñasco, Sonora, Mexico) to Panama; Galápagos Islands (Bertsch and Smith, 1973: 169).

Nudibranchia

Berghia major (Eliot, 1903) (includes *Baeolidia amakusana* Baba, 1937). Indo-Pacific (Edmunds, 1969: 467); Oahu, Hawaii (pers. obser., August 1977). Gulf of California (Farmer, 1966; Ferreira and Bertsch, 1975: 328-329).

Doriopsis viridis Pease, 1861. Indo-Pacific (Young, 1967: 160-161). Southern Gulf of California; known only from 1 specimen (Bertsch, 1971).

Spurilla alba (Risbec, 1928). Indo-Pacific (Edmunds, 1969: 465-466). Coast of mainland Mexico, from near Guaymas, Sonora, to Punta Mita, Nayarit (Sphon, 1971, 1978).

The four circumtropical nudibranchs are pelagic. They were treated in a previous section.

Cadlina evelinae Marcus, 1958. Caribbean: Brazil and Jamaica (Thompson, 1977: plt. 2; Ev. Marcus, 1977: 9). Pacific coast of Baja California; Gulf of California (Ev. Marcus and Er. Marcus, 1967: 168-170).

Dendrodoris krebsii (Mörch, 1863). Caribbean (Meyer, 1977: 304). Northern Gulf of California to Panama; Galápagos Islands (Bertsch, 1973b: 109; Meyer, 1977).

Phidiana lynceus Bergh, 1867. Caribbean (Edmunds, 1964: 16-18). Pacific coast of Panama Canal Zone (Ev. Marcus and Er. Marcus, 1967: 111-112).

Spurilla neapolitana (Delle Chiaje, 1823). Caribbean and Mediterranean (Ev. Marcus and Er. Marcus, 1967: 118-119). Gulf of California (Alex Kerstitch, *pers. comm.*).

Tayuva ketos Marcus and Marcus, 1967. Caribbean (different subspecies; Er. Marcus and Ev. Marcus, 1970: 65-66). Northern Gulf of California to Bahía de Banderas, Nayarit, Mexico (Ferreira and Bertsch, 1975: 327).

The remaining 3 species of nudibranchs have "Miscellaneous" distributions (i.e., they are not Panamic-Indo-Pacific, Panamic-circumtropical, nor Panamic-Caribbean).

Aeolidiella takanosimensis Baba, 1930. Japan (Baba, 1930); Mediterranean (Schmekel, 1968: 122-123); Oahu, Hawaii (pers. obser.; 1 specimen, Wailupe, 19 May 1977; 7 specimens, Earthwatch team members, Hauula, 14 June 1978). Southern California (Sphon, 1971); Bahía San Marte, Baja California del Sur, Mexico (Ferreira and Bertsch, 1975: 329). This is possibly an introduced species to Hawaii and the eastern Pacific.

Coryphellina rubrolineata O'Donoghue, 1929. Suez Canal, Australia, Japan, Brazil. San Agustin, Sonora, Mexico (Ev. Marcus and Er. Marcus, 1970: 210-211).

Limenandra nodosa Haefelfinger and Stamm, 1958. Mediterranean; Caribbean. Bahía Las Cruces, Baja California del Sur, Mexico (Bertsch, 1972).

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A NOTE ON THE DISTRIBUTION AND FOOD PREFERENCE OF *CADLINA LAEVIS* (NUDIBRANCHIA: CHROMODORIDAE)[1]

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ABSTRACT

The distribution and food preference of the nudibranch, Cadlina laevis *(Linnaeus, 1767) are discussed. This species has an amphiatlantic distribution from Cape Cod on the American coast to the Mediterranean on the European coast. It appears to feed on the soft, dendroceratid sponge,* Halisarca dujardini *Johnston.*

The dorid nudibranch *Cadlina laevis* (Linnaeus, 1767) has an amphiatlantic distribution. Lemche (1938) reported the distribution of *C. laevis* ". . . from the Gulf of Mexico, Greenland, several localities in the Arctic Sea, the Faroes, the Shetlands, the whole coast of Norway, southwards along the west coasts of Europe, and from the Mediterranean." The inclusion of the Gulf of Mexico in this list is probably an error since Franz (1970) reported the southern limit of this boreo-subarctic species to be Cape Cod, Massachusetts. There are no reports of *C. laevis* from the Gulf of Mexico in the recent literature. It is probable that Lemche meant the "Gulf of Maine" where this species does occur. While a student at Northeastern University, Boston, Massachusetts, I made field observations on this species at Eastport, Maine, in August and September of 1969 and 1970, and carried out laboratory studies at the Marine Science Institute at Nahant, Massachusetts.

FIELD OBSERVATIONS

C. laevis is found in the lower intertidal to subtidal regions of exposed rocky coastal areas. It was observed by me under rocks at approximately -3.0 feet below mean low water (MLW). The habitat consisted of boulders resting on bedrock around and under which small amounts of sandy mud were trapped. Some algal growth was present on the boulders. Other invertebrates, including brachiopods, colonial and solitary tunicates, and sponges, were also attached to the underside of these boulders. The unspiculated dendroceratid sponge, *Halisarca dujardini;* Johnston, was commonly found encrusting the undersides of these boulders. *C. laevis* was observed in close proximity to this sponge, being either within a small cleared area at the center

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of a *Halisarca* mat or at the edge of it. The anterior mantle of the nudibranch typically covered the edge of the sponge mat. When the nudibranch was removed a concavity in the edge of the sponge was seen. This concavity conformed to the size and shape of the anterior portion of the dorid. The nudibranch was only rarely found on rocks without the sponge.

LABORATORY OBSERVATIONS

Specimens of *C. laevis* were kept in laboratory aquaria for up to 10 months without any obvious food source. During this time the animals were observed to release fecal strands and to spawn. Animals dissected during this period had a brown material in the stomach. I believe this material was alagal slime from the sides of the aquaria on which the nudibranchs were able to maintain themselves. Eggs were deposited in early spring. The young hatched after approximately 2 months, but did not mature. When *Halisarca*-encrusted rocks were placed in the aquaria the nudibranchs were observed to feed on the sponge (M. P. Morse, *pers. comm.*).

DISCUSSION

Two of Swennen's (1961) three criteria for determining preferred food of nudibranchs were met in this study: (1) the animal was found in the field in close conjunction with the probable food; and (2) the animal fed on the probable food in the laboratory. The third criterion, the maintenance of the animal on the preferred food in the laboratory, was not met in this study.

There are, in addition to the above field and laboratory observations, morphological and anatomical indications that *C. laevis* feeds on soft sponges. The body is oval, with a broad foot and wide radula; the mouth lacks true mandibles. The digestive tract lacks a buccal pump, has a reduced caecum, and there is a reduction in the number of gland cells throughout the tract (Barbour, 1971). These modifications have been previously described for feeders of soft sponges by Forrest (1953) and by Thompson (1962).

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CATINELLA PARALLELA, A NEW SUCCINEIDAE (PULMONATA) FROM MIDWESTERN UNITED STATES

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ABSTRACT

Catinella parallela, *a new species of Succineidae, and its reproductive organs, chromosomes, shell and detailed habitats are described. The known geographic range extends from western Illinois to western Indiana, between 38°10′ - 40°50′N latitude. This species was taken from three types of habitats.*

In the course of my field studies on succineid gastropods in the midwestern states I have found a large, hitherto undescribed species.

Catinella parallela *n. sp.*

Description of Holotype: **Shell:** amber-colored, translucent, imperforate, elongate-ovate, composed of three and one-third inflated whorls separated by a deeply incised suture; height 10 mm, width 6.1 mm. A knoblike nuclear whorl tops the acute spire; whorls increase rapidly in size resulting in a tumid ultimate whorl; nuclear

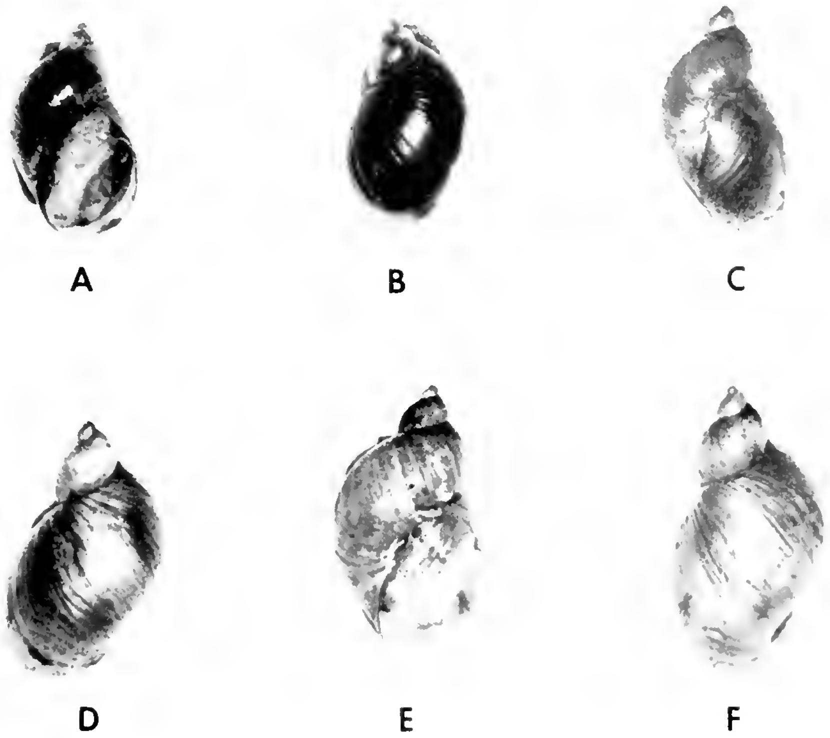

FIG. 1. A, B. *Holotype of* Catinella parallela, *n. sp (Height, 10 mm).* C. *Paratype of* Catinella parallela *n. sp., one-half mile N White River, Knox County, Indiana (Height 11.7 mm).* D. *Paratype of* Catinella parallela *n. sp., Pere Marquette State Park, Jersey County, Illinois (Height 12.0 mm)* E. F. *Paratype of* Catinella parallela *n. sp., New Hardin, Greene County, Illinois (Height 13.2 mm.)*

whorl finely granular; irregularly-spaced longitudinal striations, fine on the lower half of the nuclear whorl, increasing gradually, becoming coarser towards the aperture; ovate aperture occupies nearly seven-tenths of height of shell (Table 1). Sharply-edged peristome very fragile; very thin callus discernible on ultimate whorl above the aperture; amber-colored columella follows inner border of peristome and curves as it disappears into the ultimate whorl (Fig. 1, A).

Body and Mantle Surfaces: Surface of head and body wall cream-colored, coarsely and irregularly tuberculate; pigmentation of dorsal body surface consists of bands of dark flecks extending from anterior end of head to junction of mantle and the body wall; mid-dorsally on head pigmentation forms a triangle, narrowing to a band between the superior (posterior) tentacles, dividing and continuing as a double band mid-dorsally the length of the body; the median triangle flanked on either side by a dark band, bending medially around the superior tentacles, paralleling the dorsal pair the length of the body; median triangle flanked on either side by a dark band which bends medially around the superior tentacle to parallel the mid-dorsal pair the length of the body; surface of both pairs of tentacles flecked; pigmentation of lateral body wall forming a broad horizontal band.

The genital aperture, about 0.5 mm in length, surrounded by a white lip, situated on anterior right-hand side of body. On either side a pedal groove, continuous from labial palp to posterior tip of body, separates foot from lateral body wall; pedal groove paralleled by a less pronounced suprapedal groove. Shallow, vertical grooves incise the suprapedal and pedal grooves, margin of foot and the broad pigmented band. These vertical grooves produce shallow scallops along the margin of the foot especially when the animal is in a somewhat contracted state. The sole of the foot is cream-colored and unpigmented.

The mantle collar is flecked overall. From anterior margin of mantle narrow bands of pigment, distinct near edge of collar, merge forming streaks over mantle surface. The kidney is outlined by a dark band.

Holotype: Catalogue no. FMNH 201444; Paratypes nos.: FMNH 201445, FMNH 201446, Molluscan Collection, Field Museum of Natural History, Chicago, Illinois. Additional paratypes are in the private collection of the author.

Description of Paratypes: **Shell:** (Fig. 1, C-F) Shells of mature snails, attaining a height of 15.2 mm, are comprised of 3 1/4 to 3 3/4 inflated whorls. Dimensions of the three largest shells, number of shells measured, and the median of each of the nine series measured, are recorded in Table 1. The range of the greatest height of the series of shells included in this study is from 10.2 to 15.2 mm, and the range of the greatest width is from 6.0 to 8.28 mm. The largest apertures of the shells of the nine series occupy from 65.8 to 72.0 percent of the entire height of the shell. Other dimensions and relative dimensions are to be noted in Table 1. The largest shells were taken from the flood plain of the Illinois River, New Hardin, Green County, Illinois (Field #269) on June 22, 1966. To date I have not found mature snails surviving beyond the month of July.

Reproductive Organs: (Fig. 2) The albumin gland (A, C - AG) triangular in form, composed of fine acini, is enclosed within a thin, transparent sheath. The elongate, subequally bilobed seminal vesicle (A, C - SV) is enclosed within a thin, transparent, pigmented sheath. The darkly pigmented hermaphroditic duct (A, C - HD) and the bilobed seminal vesicle join to form the fertilization sac (A, C - FS) from which diverge the oviduct (OD) and the sperm duct (SD) which leads into the prostate gland (PG). The oval prostate gland, enclosed by a thin, transparent, pigmented sheath, is composed of acini which are coarser than those of the albumin gland. The length of the prostate gland exceeds that of the albumin gland (A, C). As the vas deferens approaches the penis from the prostate gland it follows the penis along its dorsal surface. As it enters the distal end of the penis it enlarges to form the epiphallus (B, C - EP) which enters the unsheathed penis (P) terminally. The penis enlarges immediately into a cylindrical form. The penial appendage (B, C - PA) whose base is almost one-half the length of the penis, originates subterminally where the penis joins the genital atrium (B, C - GA). The appendage expands horizontally to equal about two-thirds of the

TABLE 1 *Dimensions of shells of* Catinella parallela, *n. sp. The measurements are of the three largest shells at each of the 9 series (6 localities) as indicated. In the 4th column of measurements are listed the ratios of the width of the shell over its height. In the last 3 columns are listed the ratios of the height of the aperture over the height of the shell, width of aperture over width of shell, width of aperture over height of aperture.*

	No. of Whorls	Height	Width	Width/ Height	Height of Aperture	Width of Aperture	H. Ap./ H. Shell	W. Ap./ W. Shell	W. Ap./ H. Ap.
Holotype	3 1/3	10.0 mm	6.1 mm	.61	6.7 mm	4.1 mm	.67	.67	.61
Type Locality	3 1/3	10.2	6.4	.62	7.4	4.5	.72	.70	.61
Field #458	3 1/3	9.5	5.6	.59	6.4	3.8	.67	.68	.59
Floodplain, Wabash R.,									
White Co., Illinois									
June 20, 1977									
Range (6 shells)	3 - 3 1/3	7.5 - 10.2	4.7-6.4	.56-.62	5.1-7.4	3.2-4.5	.66-.72	.67-.73	.59-.62
Median		9.5	5.6	.59	6.4	3.8	.67	.68	.59
Field #458	3 1/2	11.91	6.7	.563	7.89	5.51	.662	.822	.698
Floodplain, Wabash R.,	3 1/2	11.25	6.33	.563	7.27	5.00	.646	.790	.698
White Co., Illinois	3 1/3	11.15	7.00	.628	7.50	5.38	.623	.769	.717
June 5, 1976									
Range (12 shells)	3 - 3 1/2	6.3 - 11.91	3.61-7.0	.53-.628	3.94-7.89	2.78-5.51	.623-.711	.672-.869	.606-.717
Median		10.26	6.24	.573	6.86	4.42	.670	.798	.684
Field #461	3 1/2	14.29	7.44	.521	8.95	5.76	.626	.774	.644
One-half mi. N of	3 1/2	13.27	8.80	.663	8.50	5.74	.640	.652	.675
White River, Knox Co.,	3 1/2	13.04	7.85	.602	7.85	5.20	.602	.662	.662
Indiana									
June 6, 1976									
Range (8 shells)	3 1/3- 3 1/2	9.82- 14.29	6.28-9.80	.521-.663	6.53-8.95	4.48-5.76	.585-.678	.652-.80	.662-.735
Median		12.70	7.20	.640	7.56	5.44	.637	.713	.684
Field #461	3 1/2	10.6	6.0	.56	6.7	4.4	.63	.73	.65
One-half mi. N of	3 1/3	10.5	6.10	.58	6.8	4.5	.64	.73	.66
White River, Knox Co.,	3 1/3	9.9	5.7	.58	6.0	3.5	.61	.61	.58
Indiana									
June 21, 1977									
Range (28 shells)	3 1/4- 3 1/2	8.2-10.6	4.8-6.1	.49-.64	5.1-6.8	3.4-4.5	.56-.70	.60-.77	.56-.66
Median		9.5	5.6	.59	6.1	3.7	.64	.67	.61
Field #462	3 1/2	12.84 mm	7.25 mm	.565	7.83 mm	5.26 mm	.610	.726	.672
10 mi. N Vincennes,	3 1/2	10.00	6.09	.609	6.28	4.17	.628	.685	.664
Knox Co., Indiana	3 1/3	9.47	5.65	.597	5.78	3.95	.610	.699	.683
June 6, 1976									
Range (20 shells)	3 1/3- 3 1/2	3.89- 12.84	2.50-7.25	.474-.643	2.56-7.83	2.0-5.26	.528-.658	.641-.767	.576-.843
Median		8.03	4.75	.597	4.81	3.27	.577	.688	.684
Field #187	3 1/2	12.4	7.5	.60	8.6	5.4	.69	.72	.62
Pere Marquette State	3 1/3	12.2	7.0	.57	7.8	4.6	.64	.65	.59
Park, Jersey Co.,	3 1/2	11.7	6.7	.57	7.5	4.3	.64	.64	.57
Illinois									
June 15, 1954									
Range (7 shells)	2 3/4- 3 1/2	8.9- 12.4	5.1-7.5	.56-.61	6.2-8.6	3.7-5.4	.60-.69	.64-.72	.57-.66
Median		11.6	6.7	.57	7.5	4.6	.65	.70	.60
Field #269	3 3/4	13.23	8.20	.620	8.65	5.61	.654	.684	.649
New Hardin,	3 1/2	13.05	7.80	.598	8.60	5.68	.659	.728	.660
Greene Co., Illinois	4	13.00	7.74	.595	8.30	5.00	.638	.646	.602
July 11, 1964									
Range (23 shells)	3 1/3- 4	10.10- 13.23	5.60-8.20	.518-.645	6.22-8.65	4.36-5.68	.606-.711	.631-.841	.602-.723
Median		11.60	6.95	.60	7.59	4.91	.653	.701	.652
Field #269	3 1/2	15.20	8.28	.545	9.60	6.40	.632	.773	.667
New Hardin,	3 1/2	13.15	7.35	.559	8.55	5.95	.650	.810	.696
Greene Co., Illinois	3 1/2	12.82	7.40	.577	8.20	5.17	.640	.699	.630
June 22, 1966									
Range (9 shells)	3 1/3- 3 1/2	10.50- 15.30	6.05-8.28	.527-.630	6.95-9.60	5.05-6.80	.618-.689	.699-.863	.630-.777
Median		12.70	7.22	.576	8.20	5.36	.640	.810	.696
Field #445	3 1/3	12.15	6.85	.564	7.50	4.47	.617	.653	.596
0.8 mi. S Nutwood,	3 1/3	11.51	6.6	.573	8.0	4.92	.695	.745	.615
Jersey Co., Illinois	3 1/3	11.45	7.0	.611	7.50	4.52	.657	.646	.603
June 1, 1975									
Range (14 shells)	3 1/3- 3 1/2	8.42- 12.15	5.08-7.00	.566-.641	5.20-8.0	3.55-4.92	.610-.708	.646-.80	.596-.72
Median		10.5	6.12	.603	6.95	4.45	.657	.742	.648

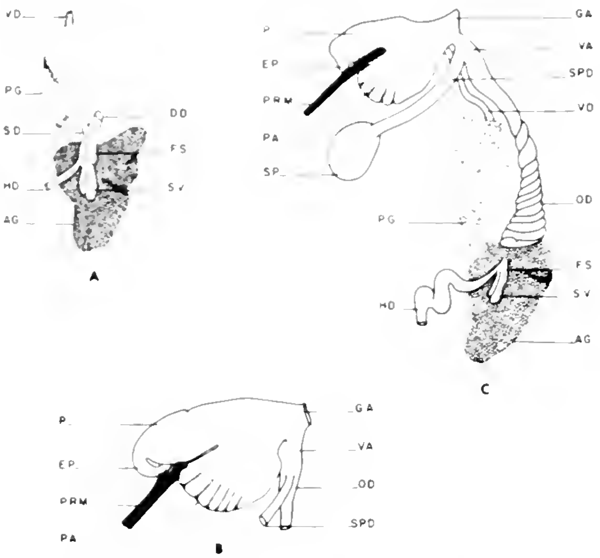

FIG. 2. *Reproductive organs of* Catinella parallela *n. sp.* AG, *albumin gland;* EP, *epiphallus;* FS, *fertilization sac;* GA, *genital atrium;* HD, *hermaphroditic duct;* OD, *oviduct;* P, *penis;* PA, *penial appendage;* PG, *prostate gland;* PRM, *penial retractor muscle;* SD, *sperm duct;* SP, *spermatheca;* SPD, *spermathecal duct;* SV, *seminal vesicle;* VA, *vagina;* VD, *vas deferens.*

length of the penis — the expanded portion parallels the penis (A, C). The vertical dimension of the appendage is almost twice that of the body of the penis. The internal walls of the penis and of the appendage are folded forming very prominent ridges projecting into the lumen. The internal foldings of the appendage can be noticed externally by markings as indicated (B, C). Fibers of the broad, stout penial retractor muscle insert mainly onto the base of the penial appendage; lesser fibers insert onto the penis and onto the epiphallus (B, C - PRM).

The globular spermatheca (Fig. 2, C - SP) is connected to the vagina by a stout spermathecal duct (SPD) which enlarges as it approaches and enters the vagina. The short vagina expands as it opens into the genital atrium (B - GA).

The Radula: Radulae of seven paratypes of three localities were stained and mounted. The number of rows of teeth occurring on the radulae examined range from 84 - 90 (Table 2). There are few teeth to a row on the anterior-most rows; the number increases rapidly posteriorly.

The number of marginals and laterals of representative rows of the seven radulae are recorded in Table 2. Although there is an individual variation of the radulae and also of the rows of teeth of a radula, the ratio of marginals to laterals is approximately 1:1 Such a ratio is characteristic of the genus as noted by Quick to be true of *Catinella (Succinea) arenaria* ("B.-Ch.") (Quick, 1933, Fig. 4, p. 296).

The structural details of the individual teeth resemble those of the genus as described for European species by Quick (ibid). The characteristics of the teeth are described below and illustrated in Fig. 3, A. The central tooth (C) bears a broad basal plate having a posterior, serrated margin flanked on either side by a rounded boss. The pointed mesocone extends downward to about the lower third of the basal plate. A short, pointed ectocone flanks the mesocone on either side.

The laterals (L-L) have a large, pointed mesocone which, like that of the central tooth, extends downward to about the lower third of the basal plate. A small, pointed endocone is present. The singly pointed ectocone is sometimes divided into two cusps; this is especially true of the more lateral teeth.

The marginals (L-M) smaller than the laterals, have a basal plate which is broader than long; this is especially true of the outermost marginals (Fig. 3). The small endocone is pointed; the pointed mesocone extends to the base of the basal

TABLE 2. *Formulae of representative rows of teeth of* Catinella parallela *new species.*

Station	Slide	No. of Rows of Teeth	Row	M - L - C - L - M
Field No. 445 Jersey County, Illinois	A	86	47	15 - 17 - 1 - 12 - 13
			50	13 - 12 - 1 - 12 - 13
			62	14 - 11 - 1 - 12 - 13
			63	15 - 10 - 1 - 11 - 13
Field No. 269 East Hardin, Illinois	A	87	21	10 - 13 - 1 - 16 - 7
			36	11 - 13 - 1 - 14 - 9
	B	88	22	14 - 10 - 1 - 11 - 10
			46	15 - 9 - 1 - 10 - 12
	C	88	47	13 - 10 - 1 - 11 - 12
	D	89	29	10 - 12 - 1 - 12 - 12
			34	13 - 12 - 1 - 14 - 11
Field No. 461 Knox County, Indiana	A	84	45	11 - 13 - 1 - 13 - 11
			53	11 - 13 - 1 - 10 - 12
			64	13 - 13 - 1 - 13 - 13
	B	88	54	14 - 13 - 1 - 14 - 14
			66	14 - 13 - 1 - 12 - 16

plate. The ectocone of the inner-most marginals is divided into two, while the outermost is divided into three cusps.

The basal plates of the marginals are short and broad which is a distinctive feature of the genus *Catinella* as observed by Quick (1933, Fig. 4). The basal plates of the marginals of the radula in the genus *Oxyloma* are long and tapering as reported of *Oxyloma (Succinea) pfeifferi* ("Rossm.") by Quick (ibid, Fig. 1). This feature of the radula was observed in other species of *Oxyloma* by Franzen (1963, Fig. 1; 1966, pp. 64-65; 1969, Fig. 1; 1973, Fig. 4). The basal plates of the marginals of the genus *Succinea* are intermediate in length (Quick, 1933, Figs. 2, 3; and Franzen, 1959, Fig. 3; 1971, Fig. 3).

The Jaw. The amber-colored jaw is illustrated in Fig. 3, B. Anteriorly the collar has a median fold flanked on either side by smaller lateral folds. Posteriorly the collar bears a broad, median indentation.

Chromosome Number. Ovotestes of *Catinella parallela* were squashed and stained with orcein. Examination of the stained chromosomes in meiotic metaphase revealed the haploid number of six. This small number is characteristic of the genus *Catinella* (Patterson, 1971, Table 1.). This contrasts with the haploid number of nineteen of several species of *Oxyloma: Oxyloma deprimida* Franzen (Franzen, 1973, Fig. 1, and p. 68); *O. retusa* (Lea), *O. haydeni* (W. G. Binney) and *O. salleana* (Pfeiffer) (Franzen, 1966, p. 67). The haploid chromosome number of eighteen is characteristic of *Succinea vaginacontorta* Lee (Franzen, 1971, p. 141) and other species of *Succinea* of continental USA. (Patterson, 1971, Table 1).

Geographic Distribution and Habitats. The known geographic range of *Catinella parallela* extends from the flood plain of the Illinois River in Greene and Jersey counties in western Illinois, across the state to the banks of the Wabash River in White County in eastern Illinois, and to Knox County in western Indiana. The eight localities where I have found *C. parallela* represent three types of ecological habitats, namely: (1) a wooded flood plain of a river; (2) a slough with stands of plants including *Typha* sp. (cattails), *Sagittaria latifolia* Willd. (arrowhead), *Eleocharis* sp. (spike rush), *Polygonum ineum* Muhl (water smartweed), *Rhus radicans* L. (poison ivy), and *Spartina* sp. (sawgrass); (3) roadside ditch supporting a stand of *Typha* sp.

Locality 1, Type Locality: Field No. D.S.F. 458; western edge of the flood plain of the west side of the Wabash River, below the bridge of Illinois Hwy. 14 (formerly U.S. Hwy 460), 7 miles E Crossville, White County, Illinois. The flood plain is a woodland of predominantly *Acer saccharinum* L. (silver maple), *Gleditsia triacanthos* L. (honey locust), and *Populus deltoides* Marsh (cottonwood). *Catinella parallela* lives on the shaded damp ground, on rotting wood, and on dead leaves on the ground.

Locality 2, Field No. D.S.F. 459; twelve miles E Princeton, Gibson County, Indiana, Indiana Hwy. 64, one-half mile E Wabash River, in a lowland wooded area of predominantly *Acer saccharinum* L. One individual of *Catinella parallela* was under a piece of cardboard in a small pile of rubbish.

Locality 3, Field No. D.S.F. 460; flood plain of the Patoka River, Patoka, Gibson County, Indiana, in a wooded area of predominantly *Acer saccharinum* L. and *Populus deltoides* Marsh. Two individuals of *Catinella parallela* were found on damp ground of an exposed area.

Locality 4, Field No. D.S.F. 461; one-half mile N White River, a roadside ditch and slough alongside Orville Road, west off of U.S. Hwy. 41, Knox County, Indiana. *Typha* sp. grows in the

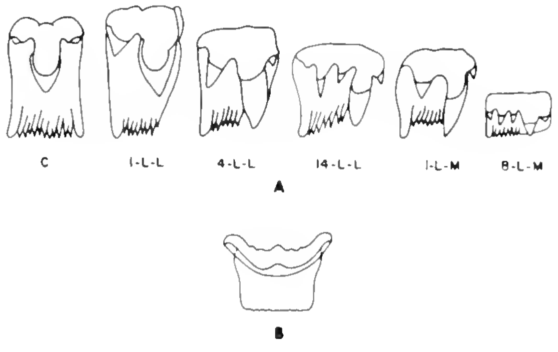

FIG. 3. A: *Respresentative radula teeth of* Catinella parallela *n. sp. C, central tooth; 1-L-L, 1st left lateral; 4-L-L, 4th left lateral; 14-L-L, 14th left lateral; 1-L-M, 1st left marginal; 8-L-M, 8th left marginal.* B: *A jaw of* Catinella parallela *n. sp*

water while *Sagittaria latifolia* Willd. and *Spartina* sp. grow in very wet ground. *Oxyloma salleana* (Pfeiffer) lives on the cattails and on dead vegetation floating on the water. *Catinella parallela* lives near the water's edge on the base of cattails, on the matting of dead vegetation and on bare spots on the wet ground shaded by sawgrass and leaf litter.

Locality 5. Field No. D.S.F. 467; ten miles N Vincenes, Knox County, Indiana, roadside ditch along U.S. Hwy. 41. Although at the time this site was visited the water was becoming polluted, *Typha* sp. was growing in the ditch and *Catinella parallela* was still living there.

Locality 6. Field No. D.S.F. 269; eastern bank of the Illinois River at New Hardin, Greene County, Illinois. On June 11, 1964, the ground was muddy from recent rains. The bank supported a thicket of *Salix* sp. (willows). *Oxyloma salleana* (Pfeiffer) lived on the muddy bank. *Catinella parallela* was found creeping on the wet ground, on surfaces of wet boards and other debris on the ground along the eastern edge of the flood plain away from the shore of the river. Since then, as a result of severe storms and flooding, the entire flood plain is littered with logs, branches and other debris. The habitats of the two succineid species are destroyed, at least temporarily.

Locality 7. Field No. D.S.F. 445; eight-tenths mile S Nutwood, or 2.4 miles S from the junction of Illinois Hwy. 100 and Illinois Hwy. 16, Jersey County, Illinois, on the west side of Illinois Hwy. 100. The habitat is a poorly drained slough. The bottom of the slough consists of fine, tan sand, and coarse, sandy reddish-tan loess from the deposit immediately to the east. The slough supports growths of *Typha* sp., *Eleocharis* sp., *Polygoneum ineum* Muhl and *Rhus radicans* L. Several small clumps of *Populus deltoides* Marsh and a thicket of *Cornus drummondi* C. A. Meyer are located within the slough. On June 1, 1975, a large population of *Oxyloma salleana* (Pfeiffer) lived on *Typha* sp. and on the wet ground at the base of the cattails. A well-established population of *Catinella parallela* lived on the eastern edge of the slough on wet, but not swampy, ground where the vegetation was less dense. One June 11, 1977, due to an abnormally low amount of rainfall during the spring months, there was no water in the slough but the ground was still damp. *O. salleana* was feeding on cattails and spike rish. However, a four-hour search netted only one individual of *C. parallela*. This might indicate that *C. parallela* is more readily affected by adverse conditions than is *O. salleana*.

Locality 8. Field No. D.S.F. 187; Pere Marquette State Park, Jersey County, Illinois, west side of Illinois Hwy. 100. The site is the east shore of a lake formed by a bow of the Illinois River. On June 15, 1954, *Oxyloma salleana* (Pfeiffer) and *Catinella parallela* were abundant on the wet ground and on wet boards lying on the bank. I have visited this site several times but have not found *C. parallela* since 1954, although *O. salleana* is still well-established.

Diagnostic Features. **Shell:** the elongate-ovate shell is comprised of 3¼ to 3½ tumid whorls. The height of the ovate aperture exceeds six-tenths of the height of the shell. Two examples of the latter are: (a) The height of the shell of the holotype is 10.0 mm and its aperture 6.7 mm in height; height of aperture / height of shell is .67. (b) The height of the largest shell of the series studied is 15.2 mm and its aperture 9.6 mm in height; height of aperture / height of shell is .632. The amber-colored columella forms the inner border of the peristome. A thin callus is discernible on the ultimate whorl above the aperture.

Penis and Penial Appendage: the base of the penial appendage equals almost half the length of the penis. The expanded appendage is positioned parallel to the penis. The vertical dimension of the appendage is almost twice the width of the body of the penis. The penial retractor muscle inserts mainly onto the base of the penial appendage and by means of lesser fibers onto the penis and the epiphallus.

The specific name *parallela* refers to the expanded penial appendage being parallel to the penis instead of right angle to the penis as is characteristic of other species in the genus *Catinella*.

Spermatheca: the globular spermatheca is connected to the vagina by a stout duct which enlarges as it approaches and enters the vagina.

Comparative Remarks: *Catinella parallela* probably more nearly resembles *C. texana* Hubricht than any other described species. The differences include: (a) Shell dimensions and ratios of dimensions. (1) The aperture of *C. parallela* is larger in proportion to the height of the shell than it is in *C. texana*. (2) The largest known shell of *C. parallela* is 15.2 mm in height. (b) The penial appendage of *C. parallela* is parallel to the penis whereas in *C. texana* the penial appendage is vertical in position, i.e. at right angle to the penis. (c) The penial retractor muscle of *C. parallela* inserts mainly onto the base of the penial appendage; lesser fibers insert onto the penis and onto the epiphallus. The penial retractor muscle of *C. texana* is "connected to the side of the penis near the middle" (Hubricht, 1961, p. 61). (e) The spermathecal duct of *C. parallela* is stout, of *C. texana* slender. (f) The seminal vesicle of *C. parallela* is pigmented but not as darkly as described of *C. texana* as being "strongly pigmented, almost black" (ibid).

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National Science Foundation Grants-in-Aid No's. NSF G18000 and NSF GB2715 provided laboratory equipment and supported, in part, the field studies. Dr. A. Byron Leonard read the manuscript and offered helpful suggestions.

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REDISCOVERY OF SOME PLEUROCERIDS (GASTROPODA) NEAR MUSCLE SHOALS, TENNESSEE RIVER, ALABAMA

Billy G. Isom[1], **Sally D. Dennis**[2] and **Charles Gooch**[1]

Lithasia verrucosa (Rafinesque, 1820), *Lithasia geniculata salebrosa* (Conrad, 1834), and *Pleurocera alveare* (Conrad, 1854) were rediscovered in May 1977 at Muscle Shoals, Alabama, below Wilson and Wheeler Dams on the Tennessee River.

The last records of *L. g. salebrosa* from the Tennessee River, of which the authors are aware, was reported by Goodrich (1934). Davis (1974) and Stein (1976) presumed that "pure *salebrosa* is probably extinct." However, their statements were apparently based on the literature and on material collected from the Duck River, but neither attempted to sample the original Tennessee River habitat of this species. *L. g. salebrosa* was found in the tailwater of Wilson Dam, the area from which Conrad collected the type specimens.

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[2] Tennessee Valley Authority, Forestry Building, Norris, Tennessee 37828

L. verrucosa was found in the Tennessee River at Florence, Alabama, along the south shore below U.S. Highway 72 bridge. It undoubtedly occurs elsewhere in the river, but its total distribution is not now known. Historically, this species was found in large rivers and large tributaries such as the Ohio, Tennessee, Wabash; Black, and Spring Rivers in Arkansas (Goodrich, 1940); Cypress and Flint River tributaries of the Tennessee River in Alabama; the Nolichucky River in Tennessee (Davis, 1974); and other streams. Sinclair (1969) indicated that *L. verrucosa* was limited to areas below Kentucky and Pickwick Dams in the Tennessee River.

P. alveare was found just below Wheeler Dam on limestone bluff outcrops, generally in water to three meters deep. Sinclair (1969) assumed this species was killed off by impoundment, while Stein (1976) indicated that status of "other" populations was unknown. Historically this species was limited, in the Tennessee River, to the shoals near Florence, Alabama, and to a number of local tributaries, particularly Cypress Creek (Goodrich, 1934a, 1934b, 1940, 1941).

These snails were collected by scuba divers. Collection by scuba divers is a very effective technique for sampling rocky substrates, which are difficult to sample effectively with conventional grab samplers. We expect to develop additional data on these species through the coming months. We particularly wish to thank W. Jeffrey Pardue and Jimmy G. Walden for their participation in this project.

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A NEW *VERTIGO* (PULMONATA: PUPILLIDAE) FROM THE OZARKIAN UPLIFT

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ABSTRACT

A new species of pupillid, Vertigo meramecensis, *is described from Crawford County, Missouri. It is most similar to* Vertigo gouldi *and is the sixth Recent* Vertigo *reported from the Northern Ozark Plateau. The type locality along Huzzah Creek would be flooded periodically if the proposed dam on the Meramec River is completed.*

On 12 June 1976 five other people and I were exploring some wooded limestone bluffs in Crawford County, Missouri. The site was south of Huzzah Creek, a few miles south of where it joins Courtois Creek which flows into the Meramec River nearby. This area lies at the northern edge of the Ozarkian Uplift (or Ozark Mountains), a large plateau covering parts of four states. A representative collection of land snails, including a new species of *Vertigo*, was made just after dark. The evening was warm and muggy; and snails were common, actively browsing in the plant cover on the bluff face. The tiny *Vertigo*, found alive, was first seen by Meg LaVal, who was using a headlamp to search the mosses and lichens on the limestone bluff.

Malacologists have long found the Ozarks to contain an interesting and diverse snail fauna. As the literature survey in Reeder and Miles (1976) points out, though, collecting has been spotty with only a few areas at all well known. It is not surprising to note that since Pilsbry (1948), only Hubricht (1964, 1972) mentions any *Vertigo* from southern Missouri.

Vertigo meramecensis, n. sp.

Figs. 1a, b; 3b

Description of Holotype: Shell (Fig. 1a) oblong, tapering with five well-rounded whorls, perforate: 1.86 mm long and 1.15 mm wide, H/D = 1.82. Shell surface (especially middle whorls) strongly, but irregularly striate with embryonic whorls smooth. Shell translucent, chestnut in color; lip darker than shell and reflexed with only a slight constriction. Penultimate whorl bears a crest (Fig. 1b) which separates the lip from a broad depression external to the palatal teeth and extends to just above the middle of the whorl. Aperture (Fig. 3b) one third shell length, angular, slightly higher than wide. Tooth formula 1-2-2; subcolumellar weakly developed; all teeth, white, situated near the lip edge with lower palatal slightly more recessed than the upper; parietal in line with the lower palatal.

Paratypes: Sixteen specimens. Adults (n = 10) have a reflexed lip and range in length from 1.72 mm to 2.01 mm ($\bar{x}$ = 1.83 ± 0.01) and in width from 1.05 mm to 1.20 mm ($\bar{x}$ = 1.10 ± 0.01). Half of the adults lack a subcolumellar lamella altogether. The lower palatal is more recessed from the lip edge and longer than the upper palatal. The lower palatal is variable in length; three specimens have the long, slightly curved lower palatal shown in Fig. 3b while the fold is knob-like in the holotype. This character may depend on the maturity of the animals.

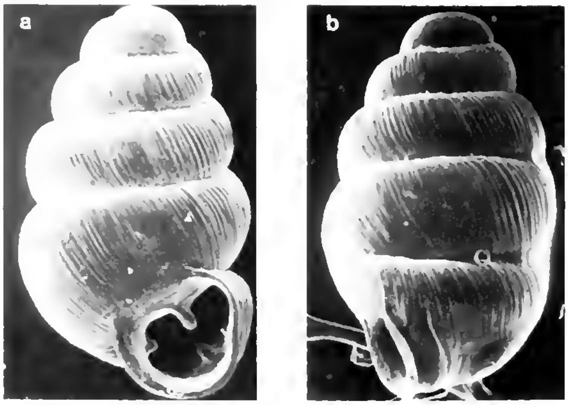

FIG 1a. Vertigo meramecensis *Van Devender, new species. Holotype (UMMZ 247640) 1.86 mm Crawford Co., Missouri.* **b.** *Paratype (UMMZ 247641) 1.87 mm*

Etymology: From the Meramec River drainage where the species was collected and the proposed Meramec Dam which would periodically flood the type locality (*pers. comm.* Dr. R. K. LaVal, Missouri Department of Conservation).

Types: Holotype, Museum of Zoology, University of Michigan 247640; 13 paratypes in the Museum of Zoology, University of Michigan 247641; 2 in the Field Museum of Natural History and the collection of the author.

Type Locality: Wooded limestone bluffs above Huzzah Creek, 13.8 km E of Steelville, Crawford County, Missouri (USGS Berryman 15′ NWSW-SWNWNE Sec 24, T38N, R3W).

Discussion: Vertigo meramecensis belongs in the genus *Vertigo* because of its small size, red-brown color, and moderately well-developed teeth. Pilsbry (1948: 943-1000) discussed the shell characters of *Vertigo* and placed most species in the subgenus *Vertigo (sensu stricto)*. He divided the subgenus into seven species groups whose component species vary so widely and overlap so greatly that Pilsbry himself was unable to construct a key to them. The new species shares some characters with at least two species groups, the *Vertigo modesta* group and the *Vertigo gouldi* group, but seems closest to the *Vertigo gouldi* group. Pilsbry (1948) and Hubricht (1964, 1972) report eight species of *Vertigo* from the northern Ozarks. Of these, two are placed in the *Vertigo gouldi* species group - *V. gouldi gouldi* and *V. hubrichti*, which was described as a subspecies of *V. gouldi* and is known only from fossil material.

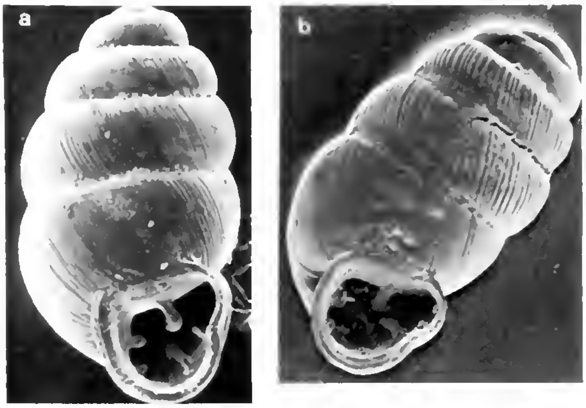

FIG. 2a, Vertigo gouldi gouldi *(Binney) (UMMZ 42321). 1.9 mm. Cumberland Co., Maine.* **b,** Vertigo hubrichti *Pilsbry Paratype (ANSP 160362) 2.03 mm. St. Louis Co., Missouri.*

Vertigo meramecensis resembles the species and subspecies in the *V. gouldi* group in that it has a distinctly striate shell, averages less than 2 mm long and displays about 5 moderately well-developed, white teeth. Unlike the majority of members in the species group, it lacks an angular lamella and its parietal lamella is directly in line with the lower palatal fold.

Comparisons with the Ozarkian members of the *V. gouldi* group are in order. *Vertigo meramecensis* at least superficially resembles the illustration in Pilsbry (1948:973, Fig. 521) of the fossil *V. hubrichti*. Examination of four paratypes of *Vertigo gouldi hubrichti* (ANSP 160362, Fig. 2b), however, shows that *V. meramecensis* has a smaller, more tapered and more distinctly striate shell. While the lower palatal fold of *V. hubrichti* (Fig. 3a) is situated very deeply in the mouth of the shell like *V. gouldi paradoxa* and *V. nylanderi*, the palatals of *V. meramecensis* (Fig. 3b) are close to the lip edge with lower fold only slightly more recessed than the upper. The parietal of *V. hubrichti* points toward the upper rather than the lower palatal fold. The sculpture of *Vertigo meramecensis* is heavier and more irregular than in *Vertigo gouldi gouldi* (Fig. 2a) and *V. meramecensis* with smaller teeth has a more open aperture than *V. gouldi*. The parietal tooth especially is less massive and straighter than in *V. gouldi* (Fig. 3c) whose parietal points between its palatal folds.

Of the *Vertigo* species known from outside the Ozarks, *V. meramecensis* most closely resembles the illustrations of *Vertigo gouldi cristata* from Eastern Canada (Pilsbry 1948:967-4,5). Comparisons with a series of shells from Southern Ontario (UMMZ 180213) show that *V. meramecensis* has heavier teeth, a more nearly square aperture, a darker (redder) color and a weaker crest than *cristata*. *Vertigo meramecensis* sometimes has the subcolumellar (basal) lamella that never occurs in *V. g. cristata*.

Land snails collected with *Vertigo meramecensis* include *Anguispira alternata* (1), *Glphyalinia indentata* (2), *Mesodon thyroidus* (1), *Mesodon zaletus* (18), *Triodopsis fosteri* (39), and *Triodopsis albolabris* (5).

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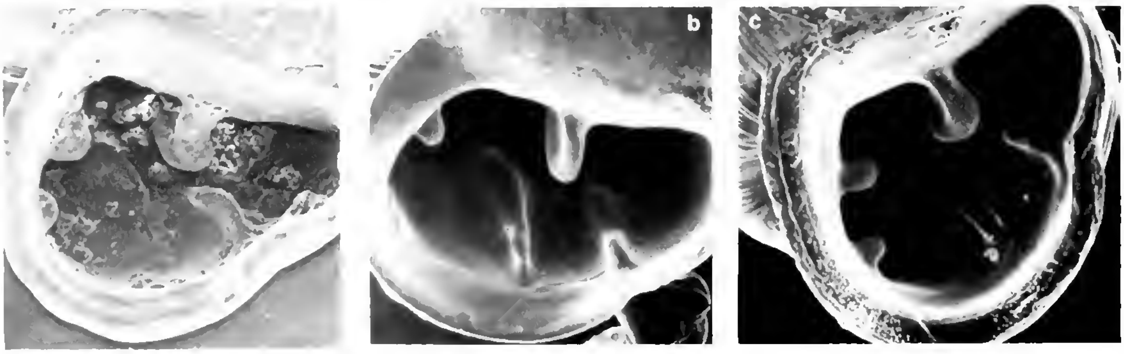

FIG. 3a, Vertigo hubrichti *Pilsbry Paratype (ANSP 160362) Enlargement of aperture, c. 155 ×.* **b,** Vertigo meramecensis *Van Devender, new species Paratype (UMMZ 247641) Aperture with subcolumellar lamella, c. 145 ×.* **c,** Vertigo gouldi gouldi *(Binney) (UMMZ 42321) Enlargement of aperture, c. 145 ×.*

Dr. J. B. Burch (both UMMZ) and Dr. George M. Davis (ANSP) kindly let me examine and take micrographs of material in their care. I want to thank Meg and Richard LaVal and Richard W. Fullington who read early drafts of the manuscript. Special thanks to R. W. Van Devender, Leslie Hubricht, and J. B. Burch who each in his own way encouraged me to write this paper.

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OBSERVATIONS ON THE FINGERNAIL CLAM, *MUSCULIUM PARTUMEIUM* (PISIDIIDAE), AND ITS ASSOCIATION WITH THE INTRODUCED ASIATIC CLAM, *CORBICULA FLUMINEA*

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ABSTRACT

In the cooling water system at the ERDA Savannah River Plant, the introduced Asiatic clam, Corbicula fluminea, *is inhabiting the floor of the sedimentation basin and is contributing to fouling problems. A second species of bivalves, the fingernail clam,* Musculium partumeium, *permanently inhabits the wall of the basin by means of a byssal-like attachment. The possibility of spatial competition between these two bivalves is discussed with emphasis on observations on reproduction. It is concluded that because of physiological adaptability* M. partumeium *can coexist with* Corbicula.

The Asiatic clam, *Corbicula fluminea* (Müller)[1], was first reported in the United States in 1938 in the Columbia River of Washington State (Ingram, 1959). By 1963, *Corbicula* had spread into the Mississippi and Gulf of Mexico Drainage, as evidenced by the Ohio River and Tennessee River discoveries (Sinclair and Ingram, 1961; Keup *et al.*, 1963). Sinclair (1971) excluded the Atlantic Slope region from the known range of *Corbicula* until Sickel (1973) reported that the exotic clam had probably been introduced to the Altamaha River of the Southern Atlantic Slope region of Georgia in 1968 or 1969. Fuller and Powell (1973) reported *Corbicula* in the Savannah River and Delaware River. Diaz (1974) found *Corbicula* in the James River, Virginia, and more recently, Rodgers *et al.*, (1977) reported *Corbicula* in the New River, Virginia.

During the course of its range extension, *Corbicula* has caused a dramatic increase in water use interference. Ingram (1959) reported *Corbicula* fouling problems in California, as did

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[1] This species is called *Corbicula manilensis* Philippi by many workers, but we prefer to use the earlier name, *fluminea* (Müller).

Sinclair (1964) in Tennessee. After the introduction of *Corbicula* in the Savannah River, a similar fouling problem developed at the United States Energy Research and Development Administration's (ERDA) Savannah River Plant. Openings in a plate from a non-reactor cooling process were clogged with adult *Corbicula* shells, thus restricting water flow (Tilly, 1976; *personal communication*).

Fouling caused by the *Corbicula* invasion is not the only concern of investigators. The possibility of a drastic impact on other bivalves has been of great concern to biologists. Sickel (1973) observed that where *Corbicula* were most dense in the Altamaha River, Georgia, there were no unionids, although the habitat appeared suitable. Gardner *et al.* (1976) determined that the invasion of *Corbicula* in the Altamaha River had been accompanied by a drastic decline in the populations of other bivalves (Pisidiidae and some Unionidae).

During *Corbicula* fouling studies at the ERDA Savannah River Plant, a sedimentation basin of a water treatment plant was found to contain two dominant species of bivalves. One of the species was *Corbicula fluminea* (Müller), the other species was *Musculium partumeium* (Say). Earlier studies had shown that the *Corbicula* invasion had had an impact upon other bivalves. This study deals with the association between *M. partumeium* and *Corbicula*.

Description of Study Area

The study area is located within the designated 400 area of the U.S. Energy Research and Development Administration's (ERDA) Savannah River Plant. A water intake structure is located on the Savannah River from which water is pumped through a closed pipe to the 400 area water treatment plant. Water is first received at the plant in a sedimentation basin. From this point, a portion of the water receives additional treatment for extensive use in the 400 area. The larger portion of incoming water receives little treatment and is used as cooling water in a non-reactor cooling process. It was in this cooling process that *Corbicula* fouling was first observed. A subsequent investigation lead to the discovery that the sedimentation basin had become a permanent habitat for freshwater clam populations of both *Corbicula* and *M. partumeium*.

The sedimentation basin consists of concrete bottom and walls. The bottom of the basin is covered with an extensive amount of mud, silt, and sand from the settling process. Due to the sediment buildup, the depth of the basin ranges from 4 to 8 feet with an average depth of 5 feet. An excellent substrate has developed for macroinvertebrates, since the basin has not been cleaned in at least eight years. Water remains at a fixed level in the basin throughout the year, thus allowing some organisms to inhabit the concrete walls of the basin. It was decided that since fouling problems had originated in the sedimentation basin, specimens would be collected from that area.

Additional sampling was attempted in the Savannah River adjacent to the Savannah River Plant property. Water fluctuation resulting from the Clark Hill Reservoir Hydroelectric Plant made river access difficult, and therefore sampling was abandoned.

Materials and Methods

Qualitative samples were taken monthly from the 400 area sedimentation basin from January, 1976, through July, 1976, including a semi-monthly sample in June, 1976. Samples of *Corbicula* were obtained by scooping the clams from the bottom of the basin with a commercial clam shovel. Samples were collected from the walls of the basin with a plankton net (25 micron). The net was lowered to the substrate-water interface beside the wall and then drawn up the side of the wall toward the water surface. An effort was made to take approximately the same amount of material each time since careful quantitative measurement was not possible. Samples were placed in styrofoam coolers containing aerated river water and returned to the laboratory for careful sorting so that the young would not be overlooked.

Numerous gross dissections were made under a binocular scope and many observations were made upon young and transparent specimens under a compound microscope. A sub-sample of 30 of the fingernail clams, *M. partumeium*, was taken from each of the April, May and June collections for determination of approximate brood sizes for identification purposes. The left and right inner demibranches of the gills were excised from each parent, and enclosed larvae were counted and measured for length with the aid of an ocular micrometer. Unfortunately, because of the nature of the collecting method employed, it was impossible to determine whether some or all of the extramarsupial larvae had been prematurely born or aborted, with the result that the number of incubating larvae found upon dissection may have been misleadingly low. Determinations were made to approximate size classes for developmental stages of *M. partumeium* larvae.

During August, 1976 the study was abruptly halted when collections indicated that a complete kill of both species of clams had occurred. Post-chlorination facilities at the water treatment plant had become inoperable, leading to emergency pre-chlorination of water prior to its entry in the sedimentation basin. Malfunction of the pre-chlorination equipment allowed excessive levels of chlorine to enter the basin for a period of several days, thus resulting in the kill.

A collection of *Corbicula* was made in the Savannah River on August 26, 1976 to check for gravidity. An attempt was made to collect *M. partumeium*, but none were found. Since *Corbicula* in the Savannah River were incubating young, qualitative and quantitative samples were collected from the sedimentation basin in January and April, 1977, to determine if repopulation was occurring through recruitment from the Savannah River. The qualitative samples were collected from the wall of the basin as described previously. Quantitative samples of the bottom material were made with a standard Ekman dredge. All of these collections were preserved immediately in 70 percent ethanol and returned to the laboratory. Clams were identified and counted, and some specimens were measured for length (anterior to posterior) with an ocular micrometer.

Results and Discussion

Taxonomy

The superfamily Corbiculacea Gray, 1847 is represented in North America by 37 species of the family Pisidiidae Gray, 1857 (formerly Sphaeriidae, Jeffreys, 1862), and by one introduced species *(Corbicula fluminea)* of the cosmopolitan family Corbiculidae (Burch, 1975). The Pisidiidae contain the five genera *Sphaerium, Musculium, Pisidium, Byssanodonta,* and *Eupera.* Baker (1927) divided the family into two subfamilies, based on the characters of the siphons. Heard (1965) later found enough differences to warrant three separate subfamilies, distinguishable on the basis of the nature of their siphonal arrangement and development of their embryos. The subfamilies are *Sphaeriinae,* containing the genera *Sphaerium* and *Musculium; Pisidiinae,* containing the genus *Pisidium;* and *Euperinae,* containing the genus *Eupera* (Burch, 1975).

In North America there are eight species of *Sphaerium* and four species of *Musculium* (Burch, 1975). One of the characteristics used to justify the validity of *Musculium* as a genus was the presence of a calyculus or "cap" at the umbone. Sterki (1909) found, however, that in most species of *Musculium,* specimens are found with slightly or noncalyculate beaks and that calyculate beaks are found occasionally in specimens of *Pisidium* and *Sphaerium.* Herrington (1962) suggested that calyculi have little taxonomic value because he, too, witnessed their occurrence in groups other than *Musculium.* He concluded *Musculium* to be a synonym, or at most a subgenus, of *Sphaerium* because of the lack of significant diagnostic shell characteristics to distinguish the two. When Gale (1972) determined that arrested growth caused the formation of a calyculus, he further questioned the taxonomic importance of this character. Studies on calyculate and uncalyculate forms of *Musculium securis* (Prime) by Mackie and Qadri (1974) indicated that calyculism is a predictable feature, and that the so-called "caps" of *Sphaerium* species are probably "pseudocalyculae". True calyculae are separated from adult valves by a sulcus, but "pseudocalyculae" are separated by an annulus. The calyculate character is of significance in identifying different generations in *Musculium* populations.

More recently, Heard (1977) has indicated that *Musculium* is a valid genus on the basis of several life history aspects. He concluded that: (1) proportionately more species of *Musculium* can inhabit temporary ponds than species of *Sphaerium;* (2) the extra-marsupial larvae of all known species lack eggs and sperm, which are found in the larvae in most species of *Sphaerium;* (3) all known species of this group show a higher fecundity, in terms of total numbers of young produced, than do most species of *Sphaerium;* (4) its species in general appear to have a shorter life cycle (30-70 days) than do *Sphaerium* spp. (4-8 months); (5) individuals of this group may have a shorter life span than do those of most species of *Sphaerium;* and (6) the two siphons in *Musculium* are fused together in their basal halves only, whereas, those in *Sphaerium* are fused together for their entire length. In addition, the shelled larvae in the gills of all *Musculium* species and *Sphaerium corneum* and *Sphaerium occidentale* are anchored by a byssal thread to a common stalk. Heard (1977) further noted that *S. corneum* and *S. occidentale* occupy a comparatively intermediate position between the two genera, sharing a number of features of both groups (see Table 1). These two species have traditionally been placed in *Sphaerium,* either because of their lack of calyculated beaks or because of the degree of siphon fusion.

From observations on anatomy, expected habitat, and life history of the pisidiids, and upon comparison with features presented in Table 1 and the preceding discussion, the clam inhabiting the sedimentation basin was determined to be of the genus *Musculium.* Although characters of soft anatomy are used in taxonomy of the Corbiculacea, especially in the classification to the generic level, all taxa can be identified by characters of the shells, and such shell characteristics are particularly important in distinguishing the species (Burch, 1975). Considering characters of the shell, habitat, and range, the pisidiid in this study was identified as *Musculium partumeium* (Say). A description of the key shell characteristics follows:

> Hinge of smooth lateral teeth; beaks of shell located centrally or anterior of center; shell with two cardinal teeth in one valve, and one in the opposing valve; shell sculptured with fine striae; adult shell small, less than 8 mm in length; posterior end nearly at right angles to the dorsal margin; anterior ventral margin of shell slopes upward, but only slightly; surface glossy (Burch, 1975).

TABLE 1. *Comparison of* Sphaerium corneum, Sphaerium occidentale, *other* Sphaerium, *and* Musculium *(Heard, 1977).*

Feature	S. corneum	S. occidentale	Sphaerium	Musculium
Siphon fusion				
entire	+	+	+	
partial				+
Standing water				
permanent	+		+	+
temporary		+		+
Mature gametes in extra marsupial larvae	+		+	
Functional byssus in late larvae	+	+		+
Number of F_1 per sac				
few	+		+	
many		+		+
Size of newborn				
small		+		+
large	+		+	

F_1 - a collective designation given for all incubating young regardless of stage of development.

M. partumeium is distributed throughout the United States and in southern Canada from New Brunswick to Saskatchewan (Herrington, 1962). Its habitat includes mud bottoms in small lakes, ponds, and swamps, and lotic situations. Clarke (1973) also found its habitat to include muddy parts of large lakes in the Canadian Interior Basin, as well as vernal ponds. Baker (1928) found it in black mud in shallow water of stable and temporary ponds.

Little will be included here concerning the taxonomy of *Corbicula fluminea* in this study. Sinclair and Isom (1963) have documented this subject fully in an earlier report. *Corbicula* from the 400 area sedimentation basin and the Savannah River was easily identified by the presence of three cardinal teeth per valve, the serrated lateral teeth, and the ribbed appearance of the shell (Sinclair and Isom, 1963). *Corbicula manilensis* Philippi is considered by us to be a synonym.

Attachment in M. partumeium (Say).

Identifications performed on the qualitative samples collected from the wall of the 400 area basin during the January through June 1976 collections, revealed that a population of the fingernail clam, *M. partumeium*, was inhabiting the wall of the sedimentation basin. From on-site visual examination of the samples, it appeared that the clams were actually attached to the wall and not burrowed under the thin layer of oligochaetes on the wall. Live specimens, after being sorted from oligochaetes and debris and being placed in glass aquaria in the laboratory, could readily climb the vertical walls of the container and attach to the glass. The foot of the clam is used in climbing but once the clam is on the vertical surface, threadlike filaments allow the clam's valves to remain closed while the clam is freely suspended from the side of the glass. Shell lengths of the *M. partumeium* encountered on the wall and observed in the laboratory ranged from 1.2 mm to 6.2 mm.

In describing the subfamily Sphaeriinae, Monk (1928) noted that the foot is anchored by means of an expansion of the anterior tip and ventral side. Adhesion is facilitated by a mucus secretion from the mucus glands of the foot. He noted that the mucus secretion is an important means of anchoring the foot, and that young specimens could climb vertical surfaces by this aid alone. Monk (1928) added that the byssal gland is vestigial in Sphaeriinae. The gland is much larger in the embryo, but the duct that supplies the gland is already occluded in embryos 1 mm or less in length. In contrast, Baker (1928) stated that while the adults usually bury themselves in the bottom, the young may be very active, crawling over plants and even suspending themselves from plants by byssal threads, thus suggesting a functional byssal gland.

When Heard (1965) divided the Pisidiidae into three subfamilies, he stated that *Euperinae* possess a functional byssal gland, whereas *Sphaeriinae (Sphaerium* and *Musculium)* and *Pisidiinae* did not. *Byssanodonta*, another pisidiid, limited in distribution to South America, is known to have a functional byssal gland. More recently, Heard (1977) has reported that a functional larval byssus occurs in all North American species of *Musculium*, *Sphaerium occidentale* (Prime), and *Sphaerium corneum* (Linnaeus). The byssus is evident in the shelled larvae (prodissoconch and extra-marsupial development stages) and is believed to function in the prevention of precocious birth (abortion) until the larval gonads sexually mature (Heard, 1977). Mackie *et. al.*, (1974a) described the structure of the larval byssus of *Musculium securis* (Prime) as consisting of a byssal stalk that originates in the foot of the prodissoconch larvae and a byssal bulb that inserts on the descending lamella of the inner gill of the parent. In this study, dissection of gills of *M. partumeium* collected from the sedimentation basin revealed the presence of the byssal stalk and byssal bulb on prodissoconch and some extra-marsupial larvae.

In reviewing the significance of the byssus in bivalves, Yonge (1962) stated that in cases where the byssus is retained for permanent attachment of the adult, it also functions in early life when the foot is still active as an organ of temporary attachment. By this means, the young bivalve climbs vertical surfaces. He added that, in general, wherever a functional byssal apparatus is present it is obviously related to a change in habit from infaunal to epifaunal life. Yonge (1962) concluded that the presence of a byssal apparatus in the adult represents the persistence of a post-larval organ, i.e., that the animals possessing it are in this respect neotenous.

The functional larval byssus, the epifaunal habitat of the clams on the basin wall as well as the record of vertical attachment, all suggest a functional byssus in adult *M. partumeium*. Whether the byssal-like attachment by thread derives from a functional byssus or by mucus secretions from the foot is uncertain. However, *M. partumeium* does have a method of attachment allowing it to inhabit the wall of a basin throughout its lifetime.

Notes on Reproduction.

During the course of this study, some observations on reproduction in *M. partumeium* were made, mainly for the purpose of identification of the species but also to note any major changes in reproductive habit associated with byssal-like attachment to the wall of the sedimentation basin. Observations on reproduction in *Corbicula* were included.

Like all Sphaeriinae, *M. partumeium* is monoecious and ovoviviparous; it is self-fertilizing internally (Thomas, 1959). Fertilized eggs are retained and incubated within the body of the parent, and development of the embryos takes place in the marsupial or brood sacs formed by the inner (anterior) gills. Gilmore (1917) and Mackie *et al.*, (1974b) have described the structure and development of such brood sacs in certain species of Sphaeriinae. In his division of the Pisidiidae into 3 subfamilies, Heard (1965) used as a distinguishing characteristic the fact that in *Sphaeriinae* the embryos develop in several thin-walled longitudinal sacs in each anterior gill, each sac containing one or more embryos.

Observations on samples collected from the sedimentation basin during January through July, 1976, and January and April, 1977, revealed that some *M. partumeium* were brooding extra-marsupial larvae in the gills during each collection. A peak in number of young ranging in size from 1.3-2.0 mm was evident in the June 10, 1976 sample and the January, 1976 and 1977 samples. All clams collected were not size classed, but the January and June peaks in number of young were visually evident during field collection and laboratory examination.

Gilmore (1917) and Foster (1932) reported that reproduction in *Sphaerium* goes on throughout the year, with a preponderance of young at certain times of the year. Mackie *et al.*, (1976a) found that births occurred throughout the year in a population of *M. securis* collected from a permanent aquatic habitat in Canada. They concluded from size classes dominating the summer collections and from newborn dominating the winter population that birth periods occurred in early summer and late summer-early autumn in the permanent habitat. Thomas (1959, 1963, 1965) studied a population of *M. partumeium* in a temporary pond and found that the production of the first young was seen in June when the pond had filled in March. Standing water disappeared from the pond in late June, leaving primarily young individuals which maintained the clam population over the winter. Mackie *et al.*, (1976b) concluded from studies on *M. securis* that intrapopulation variations in reproduction are more pronounced in temporary than in permanent aquatic habitats and that reproductive habits may be adaptively modified. Heard (1977) suggested that fertilization and birth can occur at any time in an animal, but, because of relative synchronization of individuals, a population can display seasonal, peak periods of those activities.

Dissections of the inner gills of adult *M. partumeium* during this study revealed that four developmental stages of incubating young (F_1) occurred. These four stages, each arising from a different time of fertilization, have been described by Heard (1977) and Mackie and Huggins (1976) as follows: embryos which include all developmental stages between the zygote and completed gastrula; fetal larvae which include all developmental stages between the gastrula and the beginning of the formation of the shell; prodissoconch larvae which include all developmental stages of shelled larvae while within brood sacs; and extra-marsupial larvae which are those that have escaped from the brood sacs and lie free in the interlamellar space prior to birth or are byssally attached to the demibranch. Figure 1 shows these four developmental stages in *M. partumeium* determined by numerous gill dissections of adults. General size distinctions were made between F_1 of the four stages of development. The

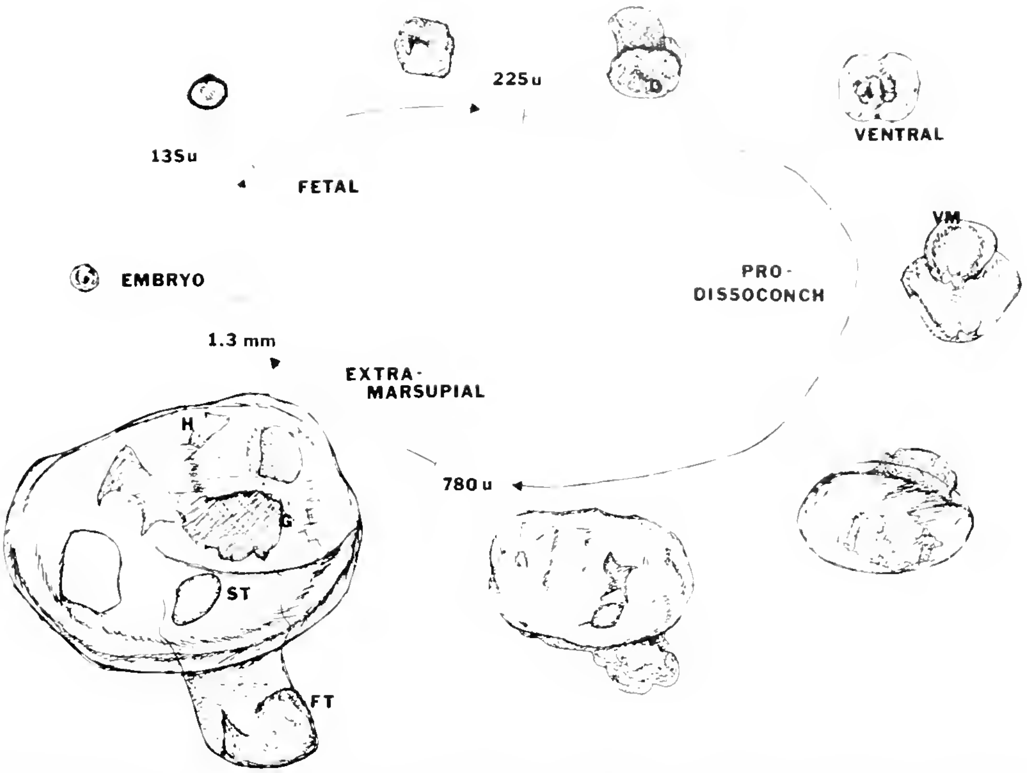

FIG. 1. *Life history of* Musculium partumeium *(Say). Note the four developmental stages and respective size classes. Symbols are identified as follows:* **d**, *dissoconch;* **st**, *statocyst,* **ft**, *foot;* **vm**, *visceral mass;* **g**, *gills,* **h**, *heart.*

specific duration of incubation of each of the four developmental stages is unknown for *Sphaerium* and *Musculium* (Heard, 1977).

Observations of dissections of live specimens indicated that fetal larvae show ciliary action similar to that shown by the trochophores of *Corbicula.* Trochophore and veliger stages are suppressed in *M. partumeium,* however. The prodissoconch larvae exhibit direct development with continued shell formation until the visceral mass is completely enclosed. Internal development takes place throughout this period. The visceral mass is moved about in the region of the foot while development continues. The extra-marsupial larvae show advanced internal structure similar to adults. The newly released clams appear to be miniatures of the adult.

The largest extra-marsupial larvae found in dissections of *M. partumeium* were 1.40 mm. Heard (1977) found the largest in his studies to be 1.22 mm. Thomas (1959) determined a mean birth length for *M. partumeium* in a temporary pond to be 1.6 mm, as compared to 1.44 mm in the laboratory. The smallest to be successfully raised was one which measured 1.25 mm in length. During the June and January sample collections of this study when young production was high, the major size class ranged from 1.3-2.1 mm.

The smallest specimen of *M. partumeium* examined that contained any developmental stage of larvae was measured at 2.58 mm in length. Only embryos were present in the brood sac. Thomas (1959) reported that ovary and testis are present at birth in *M. partumeium,* but neither organ contains mature reproductive cells. The mean length of the newborn was 1.6 mm, and the smallest developing adult that contained gametes was 2.1 mm long. Mackie *et al.,* (1976b) found gametogenesis first apparent in adult *M. securis* of length 2.00-2.50 mm. They reported simultaneous maturation of gametes as did Thomas (1959) for *M. partumeium.* Heard (1977) stated that extra-marsupial larvae of most *Sphaerium* already contain eggs and sperm, whereas gametes are not present in *S. occidentale* and *Musculium* after birth.

Unfortunately because of the method by which samples were obtained, accurate brood sizes could not be determined for *M. partumeium*. The true brood sizes might have been larger than any found in this study, since the methodology could have led to abortion of extra-marsupial larvae. From general observations, it was evident that brood sizes were large, with values ranging from 2 to 33. These data were considered sufficient for identification purposes. Gilmore (1917) listed between 10 and 20 as the brood size for *M. partumeium*, whereas Thomas (1959) reported a range of 2 to 30 and a mean of 10 for the same species. Heard (1977) found as many as 14 F_1 per brood sac and from 1 to 5 sacs in *M. partumeium*. When dissected, older adult *M. partumeium* contained a greater number of F_1 than younger adults. An increase in generative performance with age has been reported by Thomas (1959) and Heard (1977) for *M. partumeium* and by Mackie *et al.*, (1976b) for *M. securis*.

The life history of *Corbicula* has been described by Sinclair and Isom (1963). *Corbicula* from the Savannah River and the 400 area sedimentation basin show similar developmental stages. Of major importance is the fact that *Corbicula* young are released as planktotrophic veligers or benthic veligers at a size of approximately 0.22 mm. The importance of this will be discussed later.

Samples of *Corbicula* collected January-July, 1976, from the sedimentation basin and August 25, 1976, from the Savannah River were examined for gravidity. Specimens inspected in May and early June were incubating veligers in the gill. Not until August 25, 1976, were *Corbicula* again found to be gravid. The sample from the Savannah River, taken adjacent to the 400 area water intake, showed *Corbicula* to be incubating trochophore larvae at that time.

The findings of this study on the reproductive period confirm reports in the literature. Sickel (1976) examined plankton samples for *Corbicula* larvae in the Altamaha River in Georgia. He found larvae present in the water column throughout the year, except for the month of March, with a peak density in May. Aldridge and McMahon (1976) reported that *Corbicula* have two generations per year, a spring reproductive period extending from mid-April to late July and a fall reproductive period extending from late August to late November. They found *Corbicula* from Lake Arlington, Texas, with individual daily fecundities of 387.0 veligers/clam and 319.8 veligers/clam for the spring and fall reproductive periods, respectively.

Repopulation of the Study Area Basin.

Qualitative samples collected from the wall of the sedimentation basin and quantitative samples collected from the floor of the basin in January and April, 1977 were taken to determine the extent of repopulation of the basin following the August, 1976, extermination. In January, 1977, the wall sample indicated that *M. partumeium* was repopulating the basin. The sample consisted of 619 *M. partumeium* but also 11 *Corbicula*. Sizes of *M. partumeium* ranged from 1.26 mm to 6.27 mm long, with a preponderance of 1.3-2.0 mm long young. The *Corbicula* ranged in length from 1.61 mm to 5.0 mm. An examination of the bottom material collected during January, 1977, showed *M. partumeium* concentrations of 1834/m² as compared to 856/m² of *Corbicula*. More numerous in both species were young clams in the 1.3-2.0 mm length class. Some specimens of both species attained lengths as great as 8.0 mm.

The results of the April, 1977 sample collections differed dramatically from the January findings. A similar sampling effort was made in the April sample collection from the basin wall as was made in the January collection. Results showed 3277 *M. partumeium* in the collection as compared to 2 *Corbicula*. The *Corbicula* were 2.0 mm and 2.1 mm long, while the *M. partumeium* showed a complete range of size classes. Examination of the April bottom sample revealed *M. partumeium* concentrations of 1320/m², but *Corbicula* concentrations had increased to 8200/m². *Corbicula* ranged in length from 0.87 to 13.9 mm with a large number of clams between 1.0 mm and 7.0 mm. Various sizes of *M. partumeium* were collected in the sample, but the greatest number were 4.0 mm to 6.0 mm in length.

The results of the January and April, 1977 sample collections indicated that repopulation of the sedimentation basin was well underway. Since newly released *M. partumeium* are usually at least 1.25 mm long, it would seem that recruitment from the river may span a wide distribution of sizes. Results of the variety of size classes present in the January and April, 1977 samples would tend to support this belief. In recent impingement and entrainment studies at the Savannah River Plant, it has been determined that not only *Corbicula* veligers but also benthic larvae and juveniles are recruited in the water intakes (Tilly, 1976; *personal communication*). *Corbicula* are well-established in the Savannah River near the study area. *M. partumeium* have not been collected from the river, although the vast Savannah River swamp would seem to be an ideal habitat for this clam. Lack of collection has probably resulted from the inability to put a boat in the river at high water and the inaccessibility of the swamp when one does get a boat in the river at low water.

The majority of the younger clams present in the January, 1977 sample were probably recruited directly from the river, although some might have been born in the basin from gravid clams recruited in the Fall. *M. partumeium* up to 8.0 mm in length were present in the January sample, as well as some *Corbicula* of the same size. Sinclair and Isom (1963) found *Corbicula* to be sexually mature at a length of 6.5 mm. Some reproduction in *Corbicula* may have been underway by the time of the April, 1977 collection, since a large number of 1.0-3.0 mm long clams were present, as well as a large number of 4.0-8.0 mm long *Corbicula*. *M. partumeium* appeared to be prepared for an early summer reproductive period, since most clams ranged in size from 4.0-6.0 mm long.

Interactions of M. partumeium with Corbicula.

From a comparison of the results of the January, 1977 collection and the April, 1977 collections, the number of *Corbicula* increased dramatically on the floor of the basin while the number of *M. partumeium* decreased somewhat. During the same period in which the *Corbicula* population increased on the floor of the basin, the population of *M. partumeium* increased dramatically on the wall of the basin.

The number of *Corbicula* collected from the wall of the basin in January, 1977, was 11. In the April, 1977, collection from the wall, when it appeared that a much larger population of *M. partumeium* was present, only 2 *Corbicula* were found. During the January through July, 1976 sample collections, no *Corbicula* specimens were found in the established population of *M. partumeium* on the wall of the basin.

M. partumeium and *Corbicula* are able to coexist in the basin. The byssal-like attachment of *M. partumeium* may give this species a competitive advantage on the basin wall. Such an adaptation resulting in a competitive advantage is supported by the data of Heard (1977) which indicate that a functional larval byssus in *S. occidentale* and *M. partumeium* is an adaptation for temporary habitats.

Several interactions, such as food or space, may make it advantageous for *M. partumeium* to inhabit the wall of the basin by attachment. Spatial competition is a likely possibility considering the confines of the basin. Sickel (1973) reported that in the Altamaha River, Georgia, no unionids were present where *Corbicula* were most dense, although the habitat appeared suitable. He stated that it was unlikely to be spatial competition since the size of *Corbicula* and its density did not appear to be great enough to exclude the much larger unionids. Sickel (1976) later reported that *Corbicula* may be excluding the juvenile unionids which may eventually result in the loss of endemic species of clams. This competitive interaction would be more closely representative of the situation with *M. partumeium*. *Corbicula* in the sedimentation basin and the Savannah River ranged in maximum size from 25 mm to 35 mm long. In comparison, *M. partumeium* collected from the basin reached a maximum size of 8.0 mm in length.

There also may be spatial competition for the wall habitat of the basin. From earlier discussions, it was shown that *Corbicula* were present in very few numbers in January and April, 1977 sample collections and not present at all in

January-July, 1976 sample collections although the wall of the basin was well populated with *M. partumeium*. Although *Corbicula* is known to have a functional byssus (Sinclair and Isom, 1963), the size at which the clam is released from the gills of the adult would place it at a definite disadvantage. As mentioned earlier in the text, the veligers of *Corbicula* measure approximately 0.22 mm when released. In comparison, *M. partumeium* measures approximately 1.3 mm in length or larger when released from the gills (Figure 1) which would seem to give this clam a competitive advantage over the *Corbicula* larvae for the wall habitat, in this case, the preferred habitat for *M. partumeium*.

Heard (1977), in evaluating fecundity in terms of current ecological theory, determined that *Musculium* and *S. occidentale* are "r-strategists" in ephemeral habitats, devoting more energy to reproduction. In contrast, other *Sphaerium* and *Pisidium* in perennial habitats are "k-strategists," expending greater energy on such non-reproductive activities as maintenance.

Corbicula is an introduced species to the United States and shows characteristics of both an "r-strategist" and a "k-strategist." The "r-strategies" employed by *Corbicula* include early reproductive maturity and high fecundity. The "k-strategies" include producing young that have a greater survival probability, a long life span, and energy for competition. It appears that *M. partumeium*, normally an "r-strategist" in ephemeral habitats, may exhibit more "k-strategies" in the permanent aquatic habitat of the basin and thus may be using more of the available energy for competition. Heard (1977) reported that where *Pisidium* and *Sphaerium* both exist in the littoral zone of lakes, the range of the "r-strategist" *Pisidium* extended into the profundal zone, because of interactions with the more competitive *Sphaerium*.

CONCLUSIONS

Musculium partumeium has retained some larval form of byssal-like attachment throughout its lifetime which enables it to inhabit the wall of the 400 area sedimentation basin. It is not known whether the attachment originates from a functional byssus or from mucus secretions of the foot.

Some interaction or competition may exist between *M. partumeium* and *Corbicula*. Spatial competition is considered highly probable because of the size differences between adult *Corbicula* and adult *M. partumeium*. With the much larger size, adult *Corbicula* may inhabit the preferred habitat of the basin floor. In a like manner, *M. partumeium* may spatially out-compete young *Corbicula* for the habitat of the basin wall, since both species are capable of byssal attachment. Newly released *M. partumeium* are much larger than the *Corbicula* veligers and therefore may occupy the wall habitat, in this case, the preferred habitat for *M. partumeium*.

Observations on *M. partumeium* collected from the basin wall did not reveal any major changes in reproductive habits. It would be extremely difficult to document any minor variation in reproductive habits, since such habits are adaptively modified by changes in environment or habitat.

It is concluded that the adaptability of *M. partumeium* may have made it possible for the clam to coexist in the sedimentation basin with *Corbicula*. Those species capable of inhabiting temporary habitats may possess the adaptability necessary to withstand the *Corbicula* invasion.

ACKNOWLEDGMENTS

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Recent Death

Akibumi Teramachi, an amateur conchologist, artist, and well-known Japanese shell collector died in Kyoto, Japan, at the age of 80, on December 6, 1978. At the age of 24 he developed tuberculosis and went to Wakayama Prefecture for his health. There he became an avid shell collector, and published his first two papers on conchology in the *Venus,* vol. 2, in 1930. Two genera, *Teramachia* and *Akibumia,* and several species of mollusks were named after him, especially by Kuroda and Habe. *Cypraea katsuae* was named after his wife. Some of the types in his collection were sold from time to time, and the holotype, for instance, of *Teramachia tibiaeformis* Kuroda, is now in the Academy of Natural Sciences of Philadelphia.

REDISCOVERY OF A PRESUMED EXTINCT RIVER MUSSEL, *DYSNOMIA SULCATA* (UNIONIDAE)

Billy G. Isom[1], Charles Gooch[1], and Sally D. Dennis[2]

Several commercial mussel boats were sighted on the Cumberland River in July 1976. A visit was made to the area on September 1, 1976, to determine the species of mussels being taken commercially. Among the species found were several specimens of one that had been presumed extinct (Stansbery, 1970) or reduced to a single river system (Stansbery, 1971). The species was later taken live near Cumberland River at mile 296.8, the same general area in which the mussel boats had been working. This species is believed to be confined to this portion of the Cumberland River in Tennessee.

Lea (1829) described the species as "Shell subelliptical, inequilateral, ventricose, slightly marginate; valves thick; beaks nearly terminal; cardinal and lateral teeth large, and double in both valves; nacre purple." The type locality was listed by Lea as Ohio in his plate 8, fig. 12.

Dysnomia sulcata (Lea, 1829) was reported to exist in the Cumberland River by Wilson and Clark (1914), who commented on its distribution: "Although this species seems to be pretty well distributed along a considerable stretch of river, we obtained only occasional examples here and there along the shore . . . It can probably be procured in large numbers during low water."

"It is common enough to be pretty well known to the clammers, who call it 'peewee' on account of its small size, or 'cat's-claw' because of the peculiar clawlike structure on the marsupial expansion of the female."

Ortmann (1925) provided good locality records for *D. sulcata*. However, he considered the species an "immigrant" in both the Cumberland and Tennessee Rivers, its principal distribution centered clearly in the Ohio and Wabash Rivers.

Neal and Allen (1964) reported finding only one specimen during their study of the mussels of the upper Cumberland River. This specimen was found at Neeleys Ford near Burkesville, Kentucky.

Stansbery (1970) stated that "The big river *D. s. sulcata* form having a purple nacre may be extinct, but the white-nacred *D. s. perobliquus* is still occasionally found in streams tributary to western Lake Erie or Lake St. Clair." However, Stansbery (1971) stated that *D. sulcata* was reduced to a single river system, the Green River in Kentucky.

Lack of recent locality records for this species may result from limited amount of collecting being done in big rivers, especially the Cumberland River. The last comprehensive study of the middle and lower Cumberland River was by Wilson and Clark (1914).

We wish to thank Steven A. Ahlstedt for his assistance in this project.

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A REVIEW OF THE SYSTEMATICS OF *CYLICHNELLA* GABB (OPISTHOBRANCHIA: SCAPHANDRIDAE)

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ABSTRACT

A morphological study was made of six species of the genus Cylichnella *Gabb, 1873.* Cylichnella oryza *was studied anatomically for the first time. Comparison of the information obtained in this study with that in the literature suggests that* Utriculastra *Thiele, 1925, should be regarded as a junior synonym of* Cylichnella. C. canaliculata *and* C. inculta, *while similar in form, are distinct species.* C. cerealis *is maintained as a valid species while* C. eximia *is suppressed as a junior synonym of* C. culcitella.

INTRODUCTION

The recent works of Marcus (1974, 1977), Rudman (1971, 1973), Bouchet (1975) have dealt extensively with the comparative morphology of members of the Cephalaspidea. Many species possess shells which are similar in form yet have dramatically divergent internal morphology. The systematics of the Cephalaspidea has been more clearly defined as a result of these studies.

Two genera of the Scaphandridae, *Cylichnella* Gabb, 1873 and *Utriculastra* Thiele, 1925, have different shell types. *Cylichnella* has an involuted spire while *Utriculastra* possesses a projecting apex of varying prominence (Marcus, 1958; Marcus, 1977). Marcus (1977) noted that the gizzard and radula of members of both genera are virtually identical but differentiated the genera on the basis of several other criteria. Marcus (1977) described two subgenera, *U. (Utriculastra)* and *U. (Tornastra)*. My preliminary examinations suggest that a more detailed analysis of the status of *Cylichnella* and *Utriculastra* is warranted. The work of Marcus (1977) supplied an excellent analysis of *Utriculastra* and its component subgenera and species and provides the basis of comparison for the work presented in this paper.

I would like to thank Dr. Ruth Turner of Harvard University for her encouragement and for her critical comments, Dr. Eveline Marcus of the University of São Paulo, Brazil for her suggestions and enthusiasm, Dr. M. Patricia Morse of Northeastern University, Mr. Kee Muschenheim of Yale University and Mr. Gale Sphon of the Los Angeles County Museum for providing specimens. I would particularly like to thank Dr. Larry Harris of the University of the New Hampshire for his guidance and friendship and for his help in collecting specimens in Nova Scotia.

MATERIALS AND METHODS

Three specimens of *Cylichnella cerealis* (Gould, 1852) were collected from Bodega Harbor, Bodega Bay, California (lat. 38°18′N.; long. 123°03′ W.) on June 17, 1976. Numerous specimens of *C. inculta* (Gould, 1856) were collected from Morro Bay, California (lat. 35°20′ N.; long. 120°50′ W.) on July 17, 1976. *C. canaliculata* (Say, 1826) was collected on August 17, 19, 26, 1977 from several localities in Nova Scotia and New Brunswick, and on September 3, 1977 from Pt. Judith, Rhode Island (lat. 41°24′ N.; long. 72°30′ W.) Additional specimens of *C. canaliculata* from Long Island Sound were provided by Mr. Kee Muschenheim. Several specimens of *C. culcitella* (Gould, 1852) from San Miguel Island, California, (lat. 35°59′ N.; 120°25′ W.) were loaned by the Los Angeles County Museum. Three specimens of *C. bidentata* (Orbigny, 1841) from the Eveline Marcus collection were made available by the Department of Mollusks, Museum of Comparative Zoology, Harvard University. Numerous specimens of *C. oryza* (Totten, 1835), dredged from Long Island Sound, were provided by Mr. Kee Muschenheim.

Specimens were observed alive whenever possible and were dissected for morphological comparison. Several (circa 5-10) individuals of each species were dissected to determine intra as well as interspecific variation. The anatomy of the shell, postero-lateral extension of the mantle, radula, jaw, gizzard plates, nervous system and reproductive system was studied for each species.

Cylichnella Gabb, 1873

type species: *Bulla bidentata* Orbigny, 1841

1. *C. canaliculata* (Say, 1826)

Specimens collected from three different localities in New Brunswick and Nova Scotia exhibited different shell characteristics. Specimens from Parlee Beach, Shediac, N. B. (lat. 46°12′ N.; long. 64°30′ W.) an open sandy beach on the Northumberland Strait, have a spire which is elongate and clean; those from Pictou Harbor, N. S., (lat. 45°40′ N.; long. 62°45′ W.) a quiet area of mixed fine sand and mud have an elongate spire which is covered with sand and mud; and the spires of all specimens (100) from Bras d'Or Lake, N. S., (lat. 46°05′ N.; long. 60°48′ W.) a large calm estuary, are almost completely eroded. The shell ranges from 3.5 to 6.0 mm in length. In all cases the periostracum is thin and transparent. The postero-lateral elaboration of the mantle edge is short.

The radular formula in five specimens ranges from 12-15 × 1. 1. 1. The jaws are cuticular and possess platelets as depicted by Marcus (1977). The gizzard plates of *C. canaliculata* are similar to that described by Marcus (1977) with a wide heart shaped dorsal plate and two narrow sub-equal latero-ventral plates. In six specimens observed the large gizzard plates ranged in length from .85 to 1.0 mm while the lateral plates ranged from .95 to 1.25 mm in length.

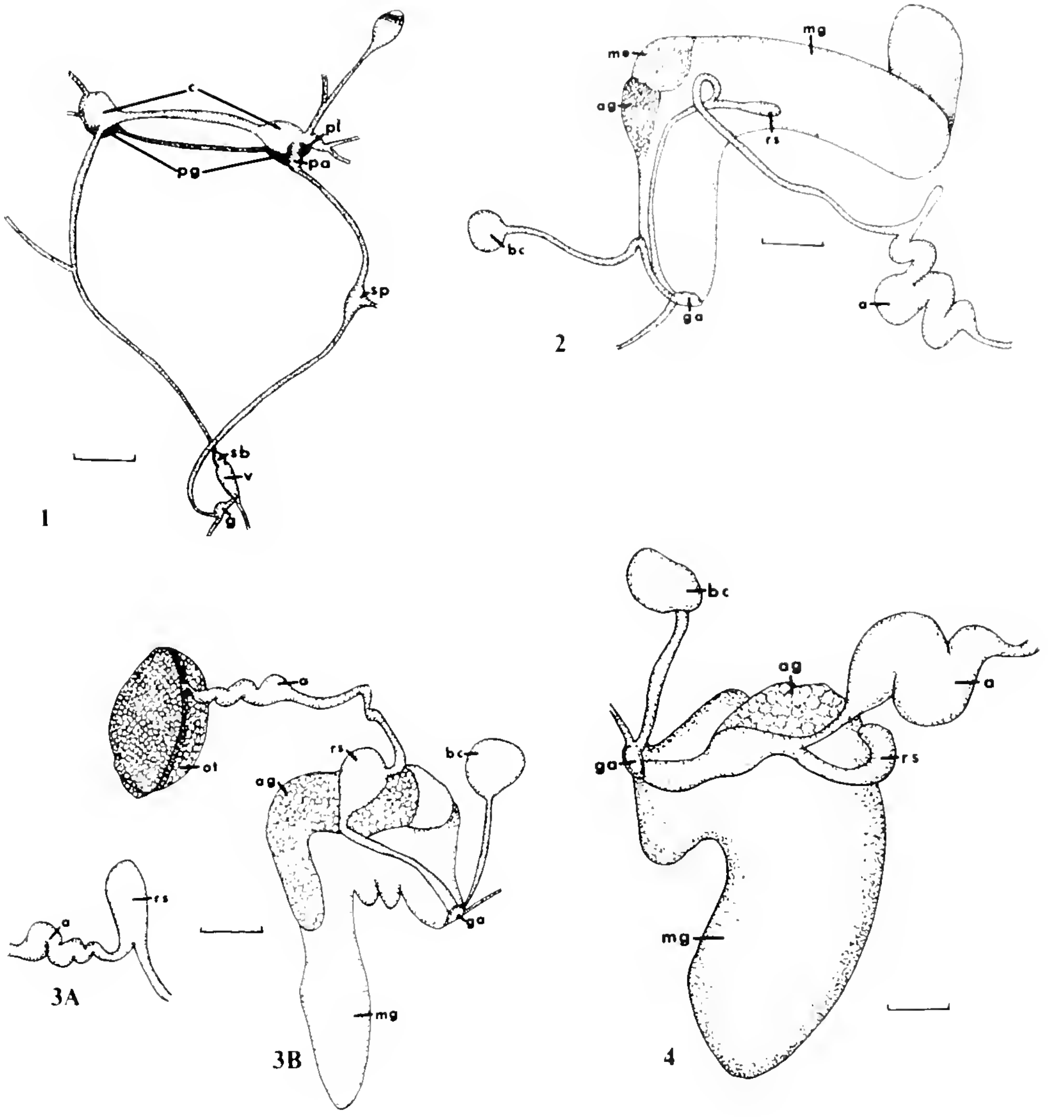
The nervous system (Fig. 1) consists of two large cerebral and two large pedal ganglia. The cerebral and pedal commissures are approximately equal in length. The left and right pleural ganglia are small and connect to the cerebal and pedal ganglia. Immediately posterior to the right pleural ganglion lies the right parietal ganglion. From there the right visceral nerve runs posteriorly to the supraintestinal ganglion which is situated at the level of the mid-portion of the gizzard. At the dorsal surface of the ganglion the short osphradial nerve connects with the vestigial osphradium. Near its posterior limit the right visceral nerve crosses the left visceral nerve dorsally and loops anteriorly to the small genital ganglion. From the genital ganglion emanates the genital nerve and the left visceral nerve. After a moderate distance the left visceral nerve gives rise to the closely associated visceral and sub-intestinal ganglia. Midway between the left pleural ganglion and the sub-intestinal ganglion the left visceral nerve gives rise to the pallial nerve. At this juncture the visceral nerve is slightly thickened yet does not form a distinct pallial ganglion.

The reproductive system of *C. canaliculata* (Fig. 2) consists of a series of diffuse lobes of the ovotestis which are interdigitated with the digestive gland. The narrow pre-ampullary duct is short and widens into an ampulla consisting of numerous convolutions. The ampulla narrows into an elongate and relatively straight post-ampullary duct. A semiserial receptaculum seminis (terminology following Edmunds, 1970) enters the post-ampullary duct which continues distally to the common genital atrium. Also entering the common atrium are the large female accessory organs, the albumen and mucus glands. The duct of the spherical bursa copulatrix also enters the common atrium at this point. From the gonopore an open seminal groove runs anteriorly to the protrusible cephalic penis.

2. *C. inculta* (Gould, 1856)

The shell of *C. inculta* has an elevated spire. The protoconch may be present or eroded. The periostracum is transparent. In the forty specimens studied the shell is 3.5 to 6.0 mm long. The postero-lateral margin of the mantle is produced into a short extension. The radular formula in four specimens varies from 18-20 × 1.1.1. The jaws are thin and cuticular and possess platelets as depicted by Marcus (1977). The gizzard is similar to that described by Marcus (1977). The dorsal plate is broad and heart shaped and ranges from .80-1.05 mm in length. The narrow paired gizzard plates are .95 to 1.10 mm in length.

The central nervous system and reproductive system are indistinguishable from those of *C. canaliculata* with the exception of the penis. In *C. inculta* the prostate is thick and elongate while in *C. canaliculata* it is much thinner and shorter.



FIGS. 1-4. Cylichnella canaliculata *(Say)* 1, *central nervous system (scale 1.0 mm).* 2, *reproductive system (scale 0.5 mm).* 3, Cylichnella culcitella *(Gould) (scale 1.0)* 3a, *receptaculum seminis.* 3b, *entire reproductive system.* 4, Cylichnella bidentata *(Orbigny) (scale 0.2 mm), reproductive system.*

Legend to Lettering

a-ampulla
ag-albumen gland
bc-bursa copulatrix
c-cerebral ganglia
g-genital ganglion
ga-genital aperture
me-membrane gland
mg-mucus gland
ot-ovotestis
p-penis
pa-parietal ganglion
pl-pleural ganglion
pr-prostate
rs-receptaculum seminis
sb-subintestinal ganglion
sp-supraintestinal ganglion
v-visceral ganglion

3. *C. culcitella* (Gould, 1852)

The shell is 9.5 to 15.0 mm in length in the 20 specimens observed. The spire is slightly to moderately elevated. The periostracum is transparent-brown with numerous spiral striations. The length of the postero-lateral mantle extension varies from moderate to extremely long. It recurves to the right side of the animal and extends ventrally to the ventral surface of the body whorl.

In *C. culcitella* there are 23, 24 and 28 pairs of lateral teeth in three individuals observed. In the specimen with 24 pairs of lateral teeth there is a row of 14 small, rectangular rachidian teeth, while rachidians are entirely absent in the other two individuals from the same collection. There are 55 to 66 denticles along the entire margin of the lateral teeth. The jaws consist of a thin membranous cuticle without platelets. In four specimens observed the small unequal gizzard plate is laterally flattened and is 1.6 to 2.9 mm long. The large subequal gizzard plates are 2.4 to 4.9 mm long.

The reproductive system of *C. culcitella* is similar to that of *C. canaliculata* except that the receptaculum seminis is serial in one specimen (Fig. 3b) and semi-serial in two other specimens (Fig. 3a). The penis and prostate in three specimens observed is similar to that described by Marcus (1977) and ranges from 7 to 13 mm in length.

4. *C. cerealis* (Gould, 1852)

The shell is 6.5 to 11.0 mm in length and has a moderately elevated spire. The periostracum is transparent with brown spiral striations of varying prominence. The postero-lateral extension of the mantle is elongate and recurves to the left along the dorsal surface of the body whorl.

The radula in the three specimens observed consists of 17, 19 and 21 pairs of lateral teeth. In no case is there any trace of rachidian teeth. The jaws are thin and membranous without platelets. In the four specimens observed the small, uneven gizzard plate is dorso-ventrally flattened and 1.0 to 1.5 mm long. The large subequal plates are 1.5 to 2.5 mm long.

The nervous system is identical to that described for *C. canaliculata*.

The reproductive system is the same as in *C. canaliculata* except that the receptaculum seminis in one specimen is serial and semi-serial in another, as in *C. culcitella*. In the three specimens studied the penis consists of an elongate, thickened prostate and a conical papilla which lacks papillations. The penis ranges from 8 to 12 mm in length.

5. *Cylichnella bidentata* (Orbigny, 1841)

The shell is elongate and cylindrical with a bulloid apex. In the three specimens studied the shell is 2.8 to 3.1 mm long and 1.4 to 1.6 mm wide. The periostracum is thin and transparent without striations. The postero-lateral extension of the mantle is of a moderate length.

The radular formula in two specimens dissected consists of 14 and 15 × 1.1.1. The jaws are thickened at the anterior edge but lack any platelets. The gizzard consists of a wide heart shaped dorsal plate which in two individuals ranges from .55 to 1.0 mm in length. The narrow paired plates range from 0.6 to 1.0 mm in length.

The nervous system and the reproductive system (Fig. 4) are not significantly different from that of *Cylichnella canaliculata*. The penis is identical to that described by Marcus (1958).

6. *C. oryza* (Totten, 1835)

The shell (Fig. 5) is orbicular with a depressed bulloid apex. The preserved animals vary in length from 1.4 to 2.8 mm and 0.7 to 2.0 mm in width. The postero-lateral extension of the mantle is extremely short.

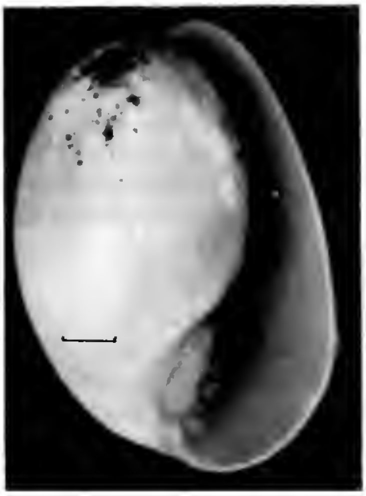
In the two specimens examined the radula (Fig. 6) has a formula of 16-17 × 1.1.1. There are 10 to 16 denticles on the inner margin of the laterals. The jaws consist of a thin chitinous cuticle which lacks platelets. The gizzard (Fig. 7) consists of a large heart shaped dorsal plate and two smaller, subequal ventro-lateral plates. The dorsal plate in the one specimen examined is 1.35 mm long and .97 mm wide. The two subequal plates are 1.25 mm and 1.22 mm in length and .51 mm and .50 mm wide, respectively.

The central nervous system (Fig. 8) appears to be entirely euthyneurous as the right visceral nerve does not cross the left visceral nerve. The relationships of the ganglia are similar to those of *C. canaliculata* except that the visceral nerves are shortened.

The reproductive system of *C. oryza* (Fig. 9, 10) closely resembles that of *C. canaliculata*. The only difference is that the receptaculum seminis is spherical with an elongate duct in both specimens dissected. The penis consists of a wide prostate which narrows anteriorly for most of its length. The penial papilla is broad without any armature or papillae.

DISCUSSION

The morphological similarities between the species described is striking. Marcus (1977, p. 17) noted that the radular teeth and gizzard plates of *Cylichnella canaliculata (as Utriculastra)* and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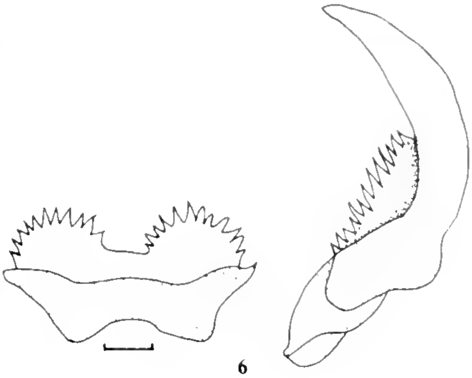
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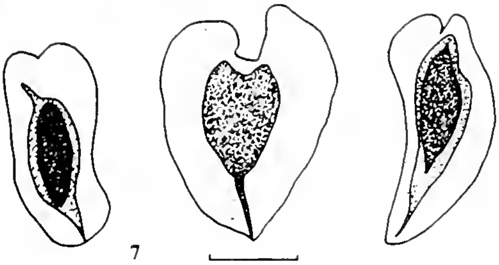
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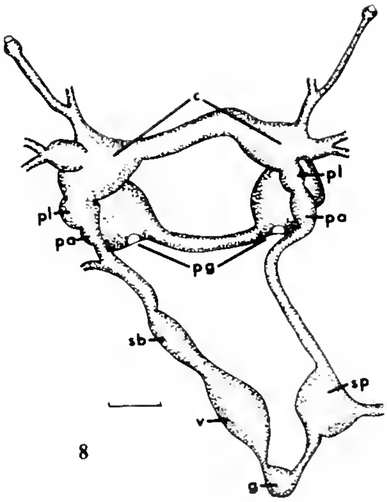

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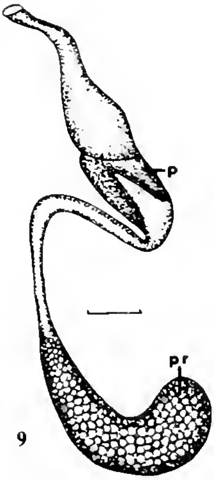

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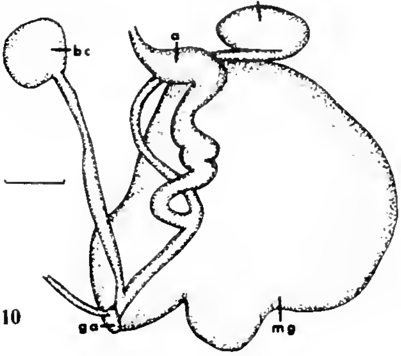

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FIGS. 5-10. Cylichnella oryza *(Totten)*. **5**, *shell (scale 0.3 mm)*. **6**, *radular teeth (scale 10 mμ)*. **7**, *gizzard plates (scale 0.5 mm)*. **8**, *central nervous system (scale 0.3)*. **9**, *penis and prostate (scale 0.1 mm)* **10**, *reproductive system (scale 0.25 mm)*.

Cylichnella bidentata were identical yet stated that "the depressed apex (of the shell), the shape of the head shield, posterior adherence and the male organ are different in both forms and justify generic separation." A detailed examination of these differences is required.

The presence of a bulloid shell in *Cylichnella* versus an elevated spire in *Utriculastra* appears to be a useful character for generic separation. However, if one examines the shells of species which Marcus considered as members of *Utriculastra* one encounters a wide range of form. *C. rolleri* (Marcus, 1977) generally has an extremely elongate spire (unpublished data) while in *C. eximia* the spire is scarcely elevated (Marcus, 1977). Most other species are somewhat intermediate between these two in spire elevation.

The shape of the head shield in *C. canaliculata*, when fully extended, is rectangular and more elongate than shown by Marcus (1977, Fig. 23). The posterior lobes of the head shield are rounded in *C. canaliculata* whereas they are acutely pointed in *C. bidentata*. The lobes of *C. rolleri*, however, are elongate and acute as in *C. bidentata*. I am unable to discern any consistent difference in the shape of the head shield between species considered as *Cylichnella* and *Utriculastra* by Marcus (1977).

It appears to me that the "posterior adherence" (Marcus, 1958) of *Cylichnella bidentata* is homologous with the "cloacal tentacle" (Marcus, 1977) found in *C. cerealis*, *C. culcitella* and *Tornatina conspicua*. I prefer the term posterior extension of the mantle. *Cylichnella oryza* lacks any noticeable extension of the mantle while in *C. inculta* and *C. canaliculata* it is extremely short. In specimens of *C. cerealis* from Bodega Harbor the extension was as highly elaborated as in *Tornatina conspicua*. The length of the extension varies in specimens of *C. culcitella* from San Miguel Island. There seems to be no consistent difference between *Cylichnella* and *Utriculastra* with respect to this character.

The final character on which Marcus (1977) based her separation of *Cylichnella* and *Utriculastra* was the structure of the penis. The papilla of *C. bidentata* bears a row of papillae along its margin (Marcus, 1958, present study). In *C. culcitella* the penis contains similar papillations (Marcus, 1977). The penis of *C. inculta*, *C. canaliculata* and *C. oryza* lacks any papillations. Marcus (1974) has shown that some species of *Scaphander* posses papillations on the penial papilla while others lack them entirely. Similarly, Rudman (1974) has shown that *Aglaja ocelligera* has a penial papilla with numerous papillations while other members of the genus have a naked penis. There seems to be little basis for separation of *Cylichnella* and *Utriculastra* with regard to the penis.

The nervous systems of all species of *Cylichnella* in this study were virtually identical with the exception of *C. oryza* which is completely euthyneurous yet has the same configuration of ganglia. Though all other species observed in this study, including *C. bidentata*, differ slightly from *C. oryza* their differences are not regarded as having taxonomic importance.

In the examination of the reproductive systems of the six species observed in this study the most substantial difference occurred within the species, *C. culcitella* and *C. cerealis*. In both species the receptaculum seminis may be either serial or semiserial. Since the greatest difference observed is of an intraspecific nature there is no basis for separating genera.

When the observed species of *Cylichnella* are compared there is no characteristic which clearly differentiates them at the supraspecific level. The differences in the radula and gizzard of Marcus' two subgenera *Utriculastra*. *U. (Utriculastra)* and *U. (Tornastra)*, are more substantial than those between *U. (Utriculastra)* and *Cylichnella*. I feel that the taxa *Cylichnella* and *Utriculastra* form a natural, monophyletic genus and should be regarded as *Cylinchnella* Gabb, 1873, on the basis of priority. *Utriculastra* is regarded as the junior synonym.

Marcus (1977) described two subgenera of *Utriculastra*, *U. (Utriculastra)* and *U. (Tornastra)*. *U. (Utriculastra)* is characterized by having a deltoid unpaired gizzard plate while *U. (Tornastra)* has a round unpaired plate. However, the vast majority of morphological characteristics (e.g. shell, radula, nervous and reproductive systems) are virtually identical between species placed in both subgenera. In *Philine*, the monotypic genus of the closely allied Philinidae, the shape of the gizzard plates varies considerably or may be absent but no subgeneric separation is made. I feel that the separation of *Cylichnella* is not useful as it appears to form a natural generic taxon. I therefore also supress *Tornastra* as a junior synonym of *Cylichnella* Gabb, 1872.

The large number of synonyms of *Cylichnella canaliculata* attests to the taxonomic confusion regarding this species. Wells and Wells (1962) examined numerous specimens of *Cylichnella* from North Carolina. They maintained that two species were present, *Retusa canaliculata* and *Acteocina candei*. Although closely allied, the species were placed in separate genera, as the absence of a radula in *Retusa obtusa*, the type species of *Retusa*, had not been verified. Subsequent study has confirmed that a radula is wanting in *Retusa obtusa* (personal observation) and that it is inappropriate to place *C. canaliculata* in *Retusa*. Wells and Wells regarded the two species as being distinct on the following bases: slight conchological differences, the presence of more numerous denticles on the rachidian and lateral teeth of the radula in *C. candei* and an offshore distribution of *C. candei* with an estuarine, inshore distribution in *C. canaliculata*. Wells and Wells described an entirely contained developmental pattern for *C. canaliculata*. Franz (1971) examined the developmental biology of *C. canaliculata* from Connecticut and determined that the species exhibits a plankotrophic pattern. He offered several possible explanations for this discrepancy. My observations of an estuarine population in Pictou Harbor, Nova Scotia, confirm that the species has planktotrophic development. Marcus (1977) discussed the criteria used to separate the two species and suggested that intermediates in conchological and radular morphology are common. She also noted that these characteristics cannot be correlated with estuarine or offshore distribution and that *C. candei* should be regarded as a junior synonym of *C. canaliculata*. My observations of *C. canaliculata* are entirely supportive of Marcus' findings.

Cylichnella canaliculata is morphologically very similar to *C. inculta*. *C. canaliculata* has 12 to 15 rows of radular teeth while *C. inculta* has 17 to 20 rows. The large dorsal gizzard plate of *C. inculta* is broader than in *C. canaliculata* and also contains a proportionately larger thickened central portion. The penis of *C. inculta* contains a thicker and longer prostate than that of *C. canaliculata*. While these differences are minor they do appear to be consistent and warrant specific separation.

Marcus (1977) stated that *C. cerealis* was distinct from *C. eximia* and *C. culcitella*. The material from Bodega Harbor supports this contention. The unpaired gizzard plate is dorso-ventrally flattened rather than laterally compressed. The lateral teeth in *C. cerealis* possess 20 to 37 denticles compared to 40 reported for *C. eximia* and 55 to 66 for *C. culcitella*. Dall's (1922) contention that *C. cerealis* are young *C. culcitella* is refuted since all specimens collected at Bodega Harbor were sexually mature and were collected with egg masses.

The separation of *C. eximia* and *C. culcitella* seems more difficult. Marcus (1977) stated that they were distinguished by their radular teeth, penis and gizzard, yet described the radula of *C. culcitella* as corresponding "to that of eximia". The gizzard plates depicted for *C. culcitella* are slightly more oval than those of *C. eximia* (Marcus, 1977, figs. 57, 68, 69, 70, 74) yet specimens from San Miguel Island showed similar variation. The penis and prostate was 20 mm long in *C. eximia* and 3 mm long in *C. culcitella* in specimens of approximately equal length. Specimens studied in this paper had penis and prostate lengths of 7, 9 and 13 mm. Due to the intermediate length of the penis along with similar morphology of the other systems the two species are here considered as synonymous with *C. culcitella* (Gould, 1852) having priority.

Based on the anatomical work I have undertaken I propose the following taxonomic arrangement:

Genus **Cylichnella** Gabb, 1873

Cylichnella Gabb, 1873: 273. (type species: *Bulla bidentata* Orbigny, 1841)

Utriculastra Thiele, 1925: 235. (type species: *Volvaria canaliculata* Say, 1826)

Tornastra Marcus, 1977: 5. (type species: *Bulla eximia* Baird, 1863)

Cylichnella bidentata (Orbigny, 1841)

Bulla bidentata Orbigny, 1841.
Cylichnella bidentata (Orbigny, 1841) Gabb, 1873

Cylichnella canaliculata (Say, 1826)

Volvaria canaliculata Say, 1826.
Bulla candei Orbigny, 1841.

Utriculus canaliculatus (Say, 1826) Watson, 1886.
Tornatina canaliculata (Say, 1826) Pilsbry, 1895.
Tornatina candei (Orbigny, 1841) Pilsbry, 1895.
Retusa (Utriculastra) canaliculata (Say, 1826) Thiele, 1925
Actaeocina candei (Orbigny, 1841) Carcelles, 1944
Acteocina canaliculata (Say, 1826) Perry and Schwengel, 1955.
Retusa candei (Orbigny, 1841) Abbott, 1958.
Acteocina candei (Orbigny, 1841) Wells and Wells, 1962.
Utriculastra (Utriculastra) canaliculata (Say, 1826) Marcus, 1977.

Cylichnella inculta (Gould, 1856)

Tornatina inculta Gould, 1856
Utriculastra (Utriculastra) inculta (Gould, 1856) Marcus, 1977.

Cylichnella cerealis (Gould, 1852)

Bulla cerealis Gould, 1852.
Utriculastra (Tornastra) cerealis (Gould, 1852) Marcus, 1977

Cylichnella culcitella (Gould, 1852)

Bulla culcitella Gould, 1852.
Bullina eximia Baird, 1863
Utriculastra (Tornastra) culcitella (Gould, 1852) Marcus, 1977.
Utriculastra (Tornastra) eximia (Baird, 1863) Marcus, 1977

Cylichnella oryza (Totten, 1835)

Bulla oryza Totten, 1835.
Cylichnella oryza (Totten, 1835) Marcus, 1958.

Cylichnella knockeri (E. A. Smith, 1872)

Tornatina knockeri Smith, 1872.
Utriculastra (Tornastra) knockeri (E. A. Smith, 1872) Marcus, 1977.

Cylichnella rolleri (Marcus, 1977)

Utriculastra (Tornastra) rolleri Marcus, 1977.

Other species possibly belong in the genus *Cylichnella* (Marcus, 1958: 8; Marcus, 1977:6) but cannot be assigned with certainty until they have been studied morphologically.

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NEWS

Malacological Archives Moved

The main archives for the American Malacological Union have now been removed from the Delaware Museum of Natural History and placed in more convenient and accessible quarters in the Department of Malacology, Academy of Natural Sciences of Philadelphia, 19th and The Parkway, Philadelphia, PA 19103 (stewardship is in the hands of Dr. George M. Davis; phone 1-215-299-1132).

The archives contain documents, correspondence, photographs and information on about 1500 professional and amateur American malacologists, and are available for examination by serious students of historical malacology. New material, especially of historical value, is most welcome at the new center, and will be properly curated and preserved.

SHELL SPINULES OF THE BIVALVE *LYONSIA HYALINA*[1]

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ABSTRACT

Small, conical projections of the periostracum cover the outer shell surfaces of the bivalve Lyonsia hyalina *Conrad. These radially arranged spinules help entangle a mucoid secretion produced by mantle glands and aid in the retention of sand grains which adhere to the shell. The sand-cover helps stabilize the bivalve in the substratum and may lend some protection to its thin shell.*

Many members of the bivalve family Lyonsiidae have the curious habit of attaching sand grains to the outside of their shells. Of the three genera of this family, *Lyonsia* is typically found partially buried with at least some portion of its shell covered with adhering sediment. *Entodesma*, a rock-crevice nestler, and *Mytilimeria*, found embedded within compound tunicates, will attach some sediment to their shells if grown within a sand substratum (Yonge, 1952). The ability of *Lyonsia* to glue sand to its valves was previously attributed to a minutely fringed (Morris, 1973; Emerson and Jacobson, 1976) or sticky (Yonge, 1952) periostracum. Prezant (1979) showed that small, multicellular glands which line the mantle edge of *L. hyalina* secrete a mucoid product over the periostracum, and it is this which is responsible for adhesion of sand.

The superfamily Pandoracea has many infaunal genera, including *Lyonsia*, which are described as having "granular" shell surfaces. The granulations or spinulations increase shell surface area and help stabilize the bivalve within the substratum (Aller, 1974). The small spines of *Lyonsia* are often obscured by adhering sand, and are thus not exposed to the substratum to aid in stabilization. This investigation was thus designed to examine the role of these minute projections relative to the attachment of sediment to the shell of *L. hyalina*.

Methods

Lyonsia hyalina were collected from Delaware Bay from a muddy-sand substratum at a depth of about 15 meters. Shells were gently cleared of most adhering sand grains with a fine camel's hair brush. Valves were carefully opened and the animal removed. Shells were then rinsed in distilled water, and some were dipped in 0.53% sodium hypochlorite (10% commercial Clorox) and some in 20% 1 N hydrochloric acid for 30 seconds, and again rinsed in distilled water. Valves were then dried for 48 hours in a 60°C oven. Dry shells were fractured, and fragments were mounted on scanning electron microscope stubs with silver paint, coated with gold, and examined on a Cambridge scanning electron microscope.

Results

The nacreous shell of *Lyonsia hyalina* is thin and fragile but has a well developed periostracum with numerous periostracal striations which radiate from the umbones. A surface view at low magnification of a partially cleaned shell (Fig. 1) reveals the prominent striations and minute spines which run parallel to the radial sculpturing. There are 7 to 8 columns of these spinules between each pair of periostracal striations. Mucus, secreted by mantle glands (Prezant, 1979), forms a tight web along the radial striations (Fig. 2) and is further entangled by the small spines.

The exceedingly small spinules are truncated at their tips (Figs. 3 and 4), and average 5.5 μm in height and 7.5 μm in width at their base in a

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[1] University of Delaware, College of Marine Studies Contribution No. 131.

bivalve 11 mm long. The base of each spinule is sunken into a slight depression of the underlying supporting shell (Fig. 3). The spinules, which are highly regimented in distribution (Fig. 5), average a distance of 15 μm from one to another in either direction. In the Cloroxed specimen (Fig. 6), the spinules have been partially dissolved, especially peripherally suggesting an organic component. The surface of the periostracum in the treated specimen appears pitted (Fig. 6). Treatment in dilute hydrochloric acid further reduces the spinules, suggesting a calcareous portion. The latter occurs primarily in the central region of the spinule. This may indicate that the spinule is composed principally of an aragonitic core surrounded by periostracum.

Adhesion of foreign particles to the shell is aided by the large number of truncated spinules which help entangle the mucoid secretion generated by the mantle glands. The viscous mucus is laid down above, but in conjunction with, the periostracum.

Discussion

Unlike the spinules of *Laternula flexuosa*, another member of the Pandoracea, those of *Lyonsia* are not "prefabricated" in the mantle (Aller, 1974), but are laid down along with the rather thin periostracum. This being the case, the spinules are calcified periostracal components as defined recently by Carter (1978). Allen and Turner (1974) discussed several Verticordiids possessing mantle glands, which attach sediment to their shells, and have calcareous spinules which may be preformed. Aller (1974) considered attachment of external particles to the shell a supplementation, using "prefabricated" extraneous components in place of naturally "prefabricated" spines. The latter author viewed such supplementation, whether foreign or natural, as a consistent theme within the Pandoracea.

The external adhesive properties of valves of most Lyonsiids produces greater surface resistance through attachment of sand grains, and thereby greater stability within the substratum. The sand cover of *Lyonsia hyalina*, and most likely all other species of *Lyonsia*, may act secondarily as an armor protecting the thin shell, and sediment adhering around the otherwise exposed siphonal region may act as a defensive barrier or camouflage.

ACKNOWLEDGMENTS

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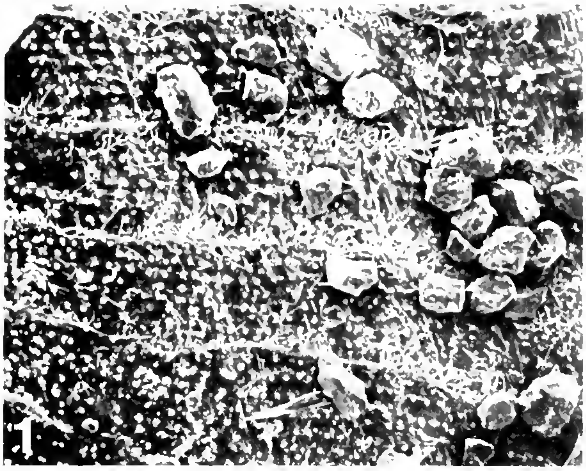
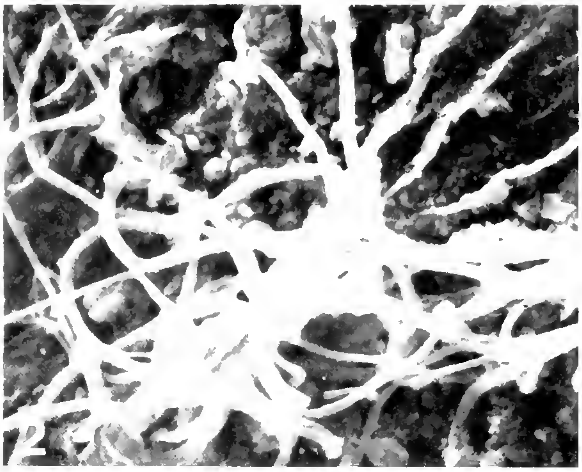
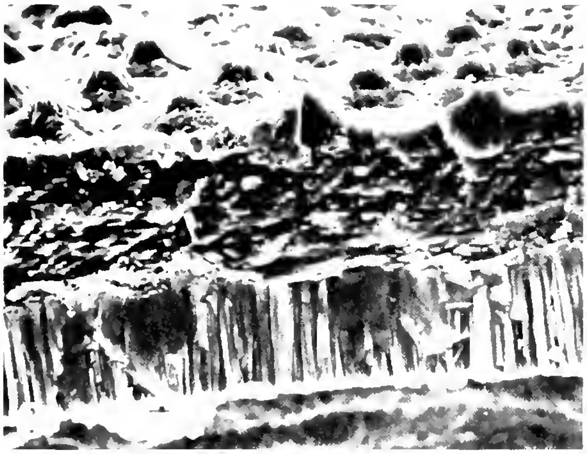
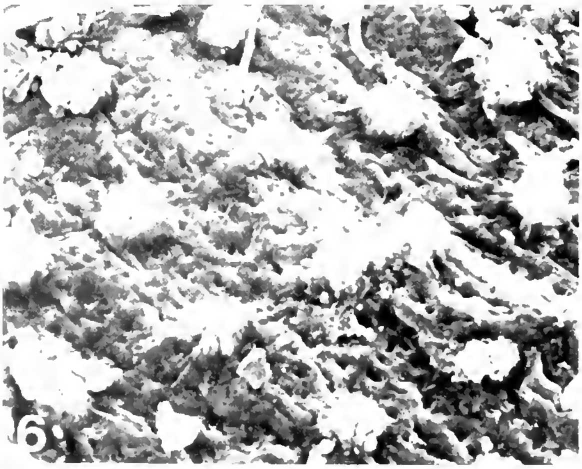
FIGS. 1-6 **1,** *Surface view of a partially cleaned shell of* Lyonsia hyalina. *Several sand grains remain adhered to the mucoid coat which covers much of the periostracum. The prominent radial striations of the periostracum and the small spinules which run parallel to them are evident. 25×* **2,** *Magnified view of the strand-like mucoid secretion which forms a webbed pattern along the radial striations of the periostracum. 650×* **3,** *A fractured section through the shell of* L. hyalina *revealing the truncated nature of the periostracal spinules. The underlying nacre and myostracum are also evident. 260×.* **4,** *Magnified view of a fractured spinule showing its confluence with the periostracum. 3700×* **5,** *An oblique surface view of the periostracum showing alignment of the spinules. 1000×* **6,** *Following treatment in sodium hypochlorite the spinules were dissolved revealing their organic nature. This micrograph also shows the pitted outer surface of the shell after removal of the mucoid coat. 1200×.*









Explanation on opposite page (Shell Spinules of the Bivalve, Lyonsia hyalina)

A BIOGRAPHY OF ANDREW GARRETT, EARLY NATURALIST OF POLYNESIA: PART 2* CATALOGUE OF MOLLUSCAN SPECIES AND BIBLIOGRAPHY

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The Andrew Garrett Shell Collection

The Garrett collection of land and marine shells, together with Garrett's conchological library and a few manuscripts, but not his journal, were purchased by the Bishop Museum in Honolulu, Hawaii, some time prior to 1899. Exact data concerning this purchase are lacking. Apparently, the items were not in the museum in 1893, when the natural history portion of the "Preliminary catalogue" was printed, for under marine shells only the Baldwin collection and some specimens from the Government Collection were mentioned, but they may have arrived a year or more before 1899, when the first mention of the collection is made in printed records of the museum. Dr. Wm. T. Brigham had had time to have the specimens mounted on pasteboard blocks and labels printed before then.

In the Spring of 1899, Dr. Wm. H. Dall, of the U. S. National Museum, was employed by the Museum Trustees, upon recommendation of the Director (Dr. Brigham) to come to the Bishop Museum and examine the collection. He arrived August 16, and spent two months making his study and correcting the nomenclature. His report is published in the Report of the Director for 1899 (Occasional Papers, **1**(2): 10-13). Dall estimated that the collection contained about 25,000 specimens, representing between 8,000 and 9,000 species, about one-fourth of them land shells, all neatly mounted and with printed labels, and largely with localities, at least to island groups.

Andrew Garrett's shell collection was one of the most complete for Pacific areas of that period. It formed the basis for many early descriptions of species, and contains a number of type specimens or at least cotype or paratype specimens of species described by W. Harper Pease and other conchologists of the period. Dr. Dall states that he simply "corrected" the names of the specimens.

It is unfortunate that we do not have more exact information concerning the acquisition of these early collections. For reasons best known to himself, Dr. Brigham made only meager record of early accessions. A search of Trustees records was made by Dr. Yoshio Kondo at the time he wrote a memorial to Dr. C. Montague Cooke, Jr., and he states that he found no information concerning the purchase of the Garrett Collection.

Prepared by E. H. Bryan, Jr.

History of the Andrew Garrett Collection 1888-1972

Andrew Garrett died in Huahine, Society Islands, Nov. 1, 1887. His private collection of shells went on sale.

February 18, 1893: Charles R. Bishop, in Washington, D.C., wrote to Trustee Hyde [Bishop Estate Letters in, Book 4, pp. 56-58], notifying him that he had "authorized Mr. Dorence Atwater to buy the Garrat [sic] collection of shells etc. at $5,000 if found to be in good order and complete . . ."

May-October, 1893: Andrew Garrett collection received by the Bishop Museum. This date is deduced from Brigham's correspondence between March and December, 1893, listing the Museum's needs to the Trustees.

1894-1899: Collection was catalogued by Brigham (1894) and specimens were mounted, with printed labels, on cardboard.

August, 1899: Wm H. Dall studied A. Garrett collection. See BPBM Director's Annual Report for 1899 (Occas. Papers **1**(2): 10-13).

1900 ff.: Garrett collection was in the [exhibit] cases of BPBM (Director's Annual Report for 1900, p. 8; "A Handbook for Visitors . . ." by Brigham, 1903).

1905: Garrett Collection was partly relabelled in accordance with Dr. Dall's identification, and was rearranged to accord with the new system of taxonomic arrangement. (Director's Report for 1905, p. 260).

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*Part 1 on the life of Garrett, by W. Stephen Thomas, appeared in the previous number of *The Nautilus*, vol. 93, no. 1, pp. 15-28.

1927: Garrett's land Shells were removed from the showcases in Polynesian Hall to the [Malacology] laboratory. (C. M. Cooke, Jr., annual report to Director for 1927).

1930: Mrs. J. G. McAllister copied "Garrett's original catalog into the Museum catalog . . ." (C. M. Cooke, Jr., Annual Report for 1930). [Mrs. McAllister did not, however, number the specimens with the corresponding catalog numbers; catalog numbers are 01-8694.]

1930-1970: Garrett's specimens were rearranged, re-identified, re-surveyed, re-exhibited, etc., by various workers in malacology.

1972 onward: Attempts are being made to locate possible types and to designate them as lectotypes by A. Kay and D. Fellows. We also hope to completely determine the circumstances by which the Museum acquired the collection.

Prepared by: Danielle B. Fellows
11 December 1972

Geographic Names

All of the type localities of Andrew Garrett were given along with the original descriptions. Certain of these names have changed with the passage of time and are listed below:

Austral Islands are now Tubuai Islands.

Cook's Islands are now Cook Islands.

Kiva — This locality in the Fiji Islands has not been located. It has been suggested that this name may have been an error for "Kioa", a small island at the eastern end of Vanua Levu and northwest of Taviuni but Garrett had mentioned this locality several times as "Kioa shore reefs". It is possible that the name Kiva has since disappeared. The name Kiuva or Kiura has been suggested as well (about central on the coast at the eastern end of Viti Levu).

Paumotu, Panmotu and Paumotus Seas or Islands are now Tuamotu Islands.

Tivinni — is Taviuni or Taveuni Island.

Viti Islands are Fiji Islands.

Abbreviations

AJC — American Journal of Conchology
ANSP — Academy of Natural Sciences of Philadelphia
BPBM — Bernice P. Bishop Museum
BSMF — Bulletin Society Malac. France
JANSP — Journal Academy Natural Sciences Philadelphia
JC — Journal of Conchology
PANSP — Proceedings Academy Natural Sciences Philadelphia
PCANS — Proceedings California Academy Natural Sciences
PCAS — Proceedings California Academy Sciences
PZS — Proceedings Zoological Society London

Garrett included several manuscript names of W. H. Pease in the synonymy of other species by Pease. In a few cases, Garrett described the species with the original names. The credit for these species go to Garrett as he described them as well as added the figures.

Pease, like many others during these early years of descriptive zoology, sent as gifts or exchange a great deal of material with manuscript names, much of which was never described. Specimens under these names are in many institutions, both here and abroad, and Garrett's work will have solved many of these nomenclature problems for future workers.

abbreviata, Cithara, 1873, PANSP, p. 223, pl. 3, fig. 41 (Paumotus Isles).

acuticostata, "Mousson" Garrett, *Partula*, 1884, JANSP, (2) 9:30, pl. 2, fig. 13 a-b (Raiatea Island, Society Islands).

adusta, Partula, 1884, JANSP, (2) 9:79 [A manuscript name in the synonymy of *Partula varia* Broderip.]

affinis, Gibbula, 1872, PCAS, 4:201, (Viti and Samoa Islands).

affinis, Nanina, 1887, BSMF, 4:4 [nomen nudum], (Isle Faiwata, Marquises at 2000 feet). [Is *Microcystis subvenosa* Ancey.]

affinis, Rissoina, 1873, PANSP, p. 212, pl. 2, fig. 10 (Viti Isles).

affinis, Tornatellina, 1879, PANSP, p. 23, [not fig.] (Rurutu Id., Austral Islands).

albopunctatus, Goniobranchus, 1879, PANSP, p. 31, (Huahine, Society Islands). [Is *Glossodoris* Ehrenberg 1831.]

alternata, Engina, 1872, PCAS, 4:203, (Samoa and Viti Islands).

amanda, Odostomia, 1873, PANSP, p. 225, pl. 3, fig. 47, (Viti Islands).

anceyana, Pitys, 1887, BSMF, 4:19, (I. le Dominique, Isles Marquises). [*Pitys* Beck 1837, [nomen nudum]], is *Diaglyptus* Pilsbry 1893.

angustivolata, Microcystis, 1884, JANSP, (2) 9:20, pl. 2, fig. 34, a-b, (Moorea Island, Society Islands).

anthracina, *Nassa*, 1873, PANSP, p. 229, pl. 3, fig. 57, (Viti Isles).

assawaensis, *Nanina*, 1887, PZS, p. 169, (Naviti Island, Assawa Group, Viti Islands).

assimilis, *Mitra*, 1873, PZS, p. 841 [not fig.] (Rarotonga, Samoa, and Viti Islands).

assimilis, *Trochomorpha*, 1884, JANSP, (2) **9**:27, pl. 3, fig. 44 (Huahine Island, Society Islands).

arenacea, *Truncatella*, 1887, PZS, p. 301 [not fig.] (Vanua Levu [Island], Viti Islands).

bicolor, *Partula*, 1884, JANSP, (2) **9**:79, [A manuscript name in the synonymy of *Partula varia* Broderip].

bicolor, *Turricula*, 1880, JC, **3**:38, [not fig.] (Samoa and Paumotu Islands).

boraborensis, *Pitys*, 1884, JANSP, (2) **9**:32, pl. 2, fig. 18, a-b, (Borabora Island, Society Islands).

bythinellaeformis, *Atropis*, 1884, JANSP, (2) **9**:98, pl. 3, fig. 73, (Tahiti and Moorea Islands, Society Islands).

bythinaeformis, *"Mousson" Garrett*, *Omphalotropis*, 1887, PZS, p. 310 [not fig.] (Vanua Balavo, Windward Islands, Viti Islands).

caelata, *Clathurella*, 1873, PANSP, p. 220, pl. 2, fig. 34, (Viti Isles).

caelata, *Vitrinella*, 1873, PANSP, p. 214, pl. 2, fig. 16, (Kiva Island, Viti Isles).

canalis, *Pitys*, 1872, AJC, **7**:227, pl. 19, fig. 17, (Rarotonga Island, Cook's Isles). Lectotype (by Solem) in ANSP 47752.

castanea, *Turricula*, 1880, JC, **3**:42, [not fig.] (Samoa and Viti Islands).

cavernula, *Pitys*, 1872, AJC, **7**:226, pl. 19, fig. 16 (Rarotonga Id., Cook's Isles [Cook Ids.]). [Tryon had changed this name to *Helix subcavernula* in error — non *cavernula* Hombron and Jacquinot 1841; Garrett had described his species in the genus *Pitys* and not *Helix*.]

consanguineus, *Melampus*, 1887, PZS, p. 287 [not fig.] (Vanua Levu Island, Viti Islands).

consobrina, *Pitys*, 1884, JANSP, (2) **9**:31, pl. 2, fig. 17, a-c (Huahine Island, Society Islands).

consobrina, *Plecotrema*, 1873, PANSP, p. 236, pl. 3, fig. 69, (Viti Isles).

contigua, *Microcystis*, 1887, BSMF, **4**:6 (Iile Dominique, Isles Marquises).

costata, *Adeorbis*, 1856 [1857], PCANS, **1**:103 (Hawaii [Island], Hawaiian Islands).

costatogranosa, *Rissoina*, 1873, PANSP, p. 211, pl. 2, fig. 7, (Viti Islands).

costulatum, *Caecum*, 1873, PZS, p. 789, (Kioa Island, Viti Islands).

crassilabrum, *Bulimus*, 1872, AJC, **7**:233, pl. 18, fig. 5, (Vanua Levu Id. Viti Isles).

crassilabrum, *Rissoa*, 1856 [1857], PCANS, **1**:102 [not fig.] (Hilo, Hawaii Id., Hawaiian Islands).

crebristriatus, *Melampus*, 1887, PZS, p. 289 [not fig.] (north coast of Vanua Levu [Island], Viti Islands).

crenilabris, *Cheletropis*, 1873, PANSP, p. 215, pl. 2, fig. 18, (Paumotus Islands) [Tryon puts *Cheletropis* in the synonomy of *Sinusigera* d'Orb. These are pelagic larvae of a marine gastropod. Garrett's figure, however, does not show any outer lip embayments. [WJC].

cretacea, *Endodonta*, 1884, JANSP, (2) **9**:41, pl. 2, fig. 27, a-b (Borabora Island, Society Islands).

crispa, *Mitra (Costellaria)*, 1872, PCANS, **4**:201 (Samoa and Viti Islands).

crystallina, *Odostomia*, 1873, PANSP, p. 226, pl. 3, fig. 49 (Viti Isles).

crystallina, *?Rissoa*, 1873, PANSP, p. 216, pl. 2, fig. 24 (Kiva Island, Viti Isles).

curta, *Omphalotropis*, 1879, PANSP, p. 28, [not fig.] (Rurutu Id., Austral Islands).

cuspidata, *Odostomia*, 1873, PANSP, p. 228, pl. 3, fig. 54 (Viti Isles).

daedalea, *Clathurella*, 1873, PANSP, p. 219, pl. 2, fig. 33 (Viti Isles).

debilis, *Rissoina*, 1873, PANSP, p. 212, pl. 2, fig. 9 (Viti Isles).

decorticata, *Pitys*, 1872, AJC, **7**:228, pl. 19, fig. 19 (Rarotonga Id., Cook's Isles, [Cook Ids.]). Lectotype (by Solem) in ANSP 47754.

degagei, *Pitys*, 1879, PANSP, p. 18 [not fig.] (Rurutu Id., Austral Islands).

degagei, *Succinea*, 1879, PANSP, p. 26 [not fig.] (Rurutu Id., Austral Islands).

densecostata, *Odostomia*, 1873, PANSP, p. 223, pl. 3, fig. 42 (Samoa and Viti Isles).

densestriata, *Odostomia*, 1873, PANSP, p. 224, pl. 3, fig. 44 (Viti Isles and Samoa).

discoidiae, *Microcystis*, 1881, JANSP, (2) **8**:409 [error for *M. discordice* Garrett].

discordice, *Microcystis*, 1881, JANSP, (2) **8**:383 [not fig.] (Cook's Islands).

eburnea, *Mitra*, 1880, JC, **3**:15 [not fig.] (Paumotu Islands).

eburnostoma, *Mitra*, 1880, JC, **3**:15, [not fig.] (Paumotu Islands).

exigua, *Murex*, 1856 [1857], PCANS, **1**:102 [not fig.] (Pure* shallow Pools; on the rocky coasts of Hawaii).

exquisita, *Thala*, 1872, PCANS, **4**:202 [not fig.], (Paumotu Islands).

exquisita, *Mitra*, 1872 [April 1893], PZS, p. 842 [not fig.], (Paumotu, Tahiti, Cook's Islands, Samoa and Viti Islands).

exilis, *Odostomia*, 1873, PANSP, p. 223, pl. 3, fig. 43 (Viti Isles).

fenestrata, *Fissurella*, 1872, PCANS, **4**:204 [not fig.], (Viti and Samoa Islands).

festiva, *Turricula*, 1880, JC, **3**:46 [not fig.] (Viti Islands).

ficta, *Endodonta*, 1884, JANSP, (2) **9**:41 [Nomen nudum, originally listed in the Schmeltz, Cat. Mus. Godeffroy **5**:223 and renamed *E. cretacea* Garrett, q.v.]

filaris, *Cantharus*, 1872, PCANS, **4**:202 [not fig.], (Samoa and Viti Islands).

flexicostata, *Turricula*, 1880, JC, **3**:46 [not fig.] (Paumotu and Viti Islands).

foveolata, *Fissurella*, 1872, PCANS, **4**:203 [not fig.] (Viti and Samoa Islands).

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*Pure may have meant Puna but the word in Hawaiian does not mean "shallow pools". Data from Dr. Lee Moettler of the B. P. Bishop Museum.

fratercula, Mitra, 1872, [April, 1873], PZS, p. 842 [not fig.] (Tahiti, Rarotonga, Samoa and Viti Islands).

fusconigra, Turricula, 1880, JC, **3**:47 [not fig.] (Kioa shore reefs, Viti Islands).

fusiformis, Daphnella, 1873, PANSP, p. 229, pl. 3, fig. 58 (Paumotus Isles).

gibbosa, Engina, 1872, PCANS, **4**:203 (Viti and Samoa Islands).

godeffroyana, Nanina, 1872, AJC, **7**:223, pl. 19, fig. 9 (Interior of the N. E. part of Vanna Levu, Viti Isles).

geomeaensis, Helicina, 1893, PANSP, p. 233, pl. 3, fig. 63 (Gomea Island, Viti Isles).

gracilis, Rissoina, 1873, PANSP, p. 211, pl. 2, fig. 8 (Viti and Society Isles).

granum, Truncatella, 1872, AJC, **7**:225 [not fig.] (N. E. end of Tavinni Id., Viti Isles).

gregaria, Libera, 1884, JANSP, (2) **9**:36, pl. 2, fig. 6, a-b (Moorea Island, Society Islands).

guanensis, Bulimus, 1872, AJC, **7**:235, pl. 18, fig. 8 (Guan Isl., Viti Isles).

gummea, Trochonanina, 1887, BSMF, **4**:14 (Iile Nuka-Hiva, Iles Marqueses).

harveyensis, Pitys, 1872, AJC, **7**:228, pl. 19, fig. 20 (Rarotonga Id., Cook's Isles [Cook Ids.]). Lectotype (by Solem) in ANSP 47756.

hirsuta, Plecotrema, 1872, AJC, **7**:219, pl. 19, fig. 2 (Viti Islands).

holosericea, Neritina, 1872, AJC, **7**:219, pl. 19, fig. 1 (Vanna Lavu, Viti Islands).

horrida, Rissoina, 1873, PANSP, p. 210, pl. 2, fig. 5 (Viti Islands).

hoyti, Bulimus, 1872, AJC, **7**:234, pl. 18, fig. 7 (Vanna Levu Id., Viti Isles).

hoyti, Nanina, 1872, AJC, **7**:221, pl. 19, fig. 6 (Tavinni Id., Viti Isles).

hoyti, Turricula, 1880, JC, **3**:47 [not fig.] (Viti Islands).

huaheinensis, Partula, 1884, JANSP, (2) **9**:78 [A manuscript name in the synonymy of *Partula varia* Broderip].

humeralis, Mitra, 1880, JC, **3**:18 [not fig.] (Anaa Island, Paumotu Islands).

hyalina, ?Rissoa, 1873, PANSP, p. 217, pl. 2, fig. 25 (Samoa, Viti and Paumotus Isles).

hyalinus, Obeliscus, 1893, PANSP, p. 228, pl. 3, fig. 56 (Paumotus and Society Isles).

imperforata, "Pease" Garrett, Partula, 1884, JANSP, (2) **9**:54, pl. 3, fig. 53 (Toloa and Hapai Valleys, west coast of Raiatea [Island] Society Islands).

incisa, Turricula, 1880, JC, **3**:63 [not fig.] (Kioa shore reefs, Viti Islands).

incisus, Melampus, 1887, PZS, p. 289 [not fig.] (Vanua Levu [Island] Viti Islands).

infrastricta, Rissoa, 1873, PANSP, p. 215, pl. 2, fig. 21 (Kiva Island, Viti Isles).

infrasulcata, Clathurella, 1873, PANSP, p. 220, pl. 2, fig. 35 (Viti Isles).

instricta, Turricula, 1880, JC, **3**:48 [not fig.] (Viti Islands).

irregularis, Patula, 1887, PZS, p. 179 [not fig.] (Viti Levu, Viti Islands). Lectotype (by Solem) in BPBM 7982.

kantavuensis, Trochomorpha, 1887, PZS, p. 177 [not fig.] (Kantava Island, Viti Islands).

kivaensis, Nanina, 1873, PANSP, p. 237, pl. 3, fig. 71 (Kiva Island, Viti Isles).

koroensis, Bulimus, 1872, AJC, **7**:236, pl. 18, fig. 9 (Koro Isl., Viti Isles).

laevicostata, Turricula, 1880, JC, **3**:50 [not fig.] (Paumotu Islands).

lamellicosta, Patula, 1884, JANSP, (2) **9**:30, pl. 2, fig. 11, a-b (Tahiti Island, Society Islands). Lectotype (by Solem) BPBM 2841.

lenta, Microcystis, 1887, BSMF, **4**:5 (I. le Dominique, I. les Marquises).

layardiana, Omphalotropis, 1887, PZS, p. 310 [not fig.] (Vanua Balavo [Mbalavu], Windward Islands [Fiji Islands]).

lentiginosa, Pythia, 1872, AJC, **7**:220, pl. 19, fig. 4 (Tavinni Id. Viti Isles).

Libera, 1881, JANSP, (2) 8:390 [no type species indicated].

liricincta, Vitrinella, 1873, PANSP, p. 213, pl. 2, fig. 14 (Kiva Island, Viti Isles).

littorinaeformis, ?Rissoa, 1873, PANSP, p. 215, pl. 2, fig. 18 (Kiva Island, Viti Isles).

lutea, Odostomia, 1873, PANSP, p. 226, pl. 3, fig. 50 (Viti Isles).

luteofusca, Mitra, 1872 [1873], PZS, p. 842 [not fig.] (Rarotonga, Cook's Islands).

marquesana, Pitys, 1887, BSMF, **4**:18 [not fig.] (Nuka-Hiva, I. les Marqueses).

marquesana, Succinea, 1887, BSMF, **4**:37 [not fig.] (I. le Dominique, I. les Marqueses).

maupiensis, Pitys, 1872, PCAS, **4**:204 [not fig.] (Mautipi Island, Society Islands).

maupiensis, Pitys, 1873, PANSP, p. 233, pl. 3, fig. 64 (Maupiti Island, Society Isles).

melanostoma, Cithara, 1873, PANSP, p. 222, pl. 2, fig. 40 (Kiva Island, Viti Isles).

melanostoma, Persa, 1872, AJC, **7**:224, pl. 19, fig. 11 (Viti Isles).

merzianoides, Helix (Trochomorpha), 1872, PANSP, p. 237, pl. 3, fig. 72 (Vanna Levu Island, Viti Isles).

micans, Tornatellina, 1879, PANSP, p. 23 [not fig.] (Rurutu Id., Austral Islands).

millecostata, Rissoina, 1873, PANSP, p. 210, pl. 2, fig. 3 (Viti Islands).

millegrana, Daphnella, 1873, PANSP, p. 230, pl. 3, fig. 59 (Paumotus Isles).

minor, Hipponix (Amalthea), 1856 [1857], PCANS, **1**:103 [not fig.] (Hawaii [Island], Hawaiian Islands).

minutissima, Drillia, 1873, PANSP, p. 218, pl. 2, fig. 30 (Viti Isles.)

modicella, Turricula, 1880, JC, **3**:53 [not fig.] (Paumotu Islands).

monticola, Helicina, 1887, BSMF, **4**:42 (I. le Dominique, I les Marqueses). [Nomen nudum, is *Helicina versilis* Ancey]

mooreana, Zonites, 1884, JANSP, (2) **9**:23, pl. 2, fig. 28, a-b (Moorea Island, Society Islands).

multicostata, Rissoa, 1856 [1857], PCANS, **1**:103 [not fig.] (Hilo, Hawaii Id., Hawaiian Islands).

multilamellata, Pitys, 1872, AJC, **7:**230, pl. 19, fig. 25 (Rarotonga Id., Cook's Isles [Cook Ids.]).

multilineata, Turbo, 1856 [1857], PCANS, **1:**102, [not fig.] (Hilo Bay, Hawaii Id., Hawaiian Islands).

multistriata, Nanina, 1887, BSMF, **4:**12 (I. le Taiwata, I. les Marqueses) [Nomen nudum.]

newcombianum, Succinea, 1856 [1857], PCANS, **1:**103 [not fig.] (District of Waimea [Oahu Id.] Hawaiian Islands).

nigricans, Turricula, 1880, JC, **3:**47 [Nomen nudum, is *Turricula fusconigra* Garrett.]

nodosa, Vitrinella, 1873, PANSP, p. 214, pl. 2, fig. 17 (Viti Isles).

obeliscus, Odostomia, 1873, PANSP, p. 226, pl. 3, fig. 51 (Viti Isles).

obesa, Atropis, 1884, JANSP, (2) **9:**99, pl. 3, fig. 72 (northwest part of Tahiti [Island], Society Islands).

obesa, Clathurella, 1873, PANSP, p. 221, pl. 2, fig. 36 (Viti Isles).

ochrostoma, Bulimus, 1872, AJC, **7:**232, pl. 18, fig. 3 (Tavinni Island, Viti Islands).

octolamellata, Pitys, 1887, BSMF, **4:**18 [not fig.] (I. le Dominique, I. les Marqueses).

oryza, Odostomia, 1873, PANSP, p. 224, pl. 3, fig. 45 (Kiva Island, Viti Isles).

oryza, Rissoina, 1873, PANSP, p. 210, pl. 2, fig. 4 (Kiva Island, Viti Islands).

otareae, Nanina, 1872, AJC, **7:**222, pl. 19, fig. 8 (Natawa Bay, Vanna Levu [Fiji Islands]).

otareae, Pitys, 1872, AJC, **7:**228, pl. 19, fig. 21 (Rarotonga Id., Cook's Isles [Cook Ids.]). Lectotype (by Solem) ANSP 47755.

paludosus, Ophicardelus, 1872, AJC, **7:**220, pl. 19, fig. 3 (Viti Islands).

papillosa, Drillia, 1873, PANSP, p. 218, pl. 2, fig. 29 (Viti Islands).

paumotuensis, Scissurella, 1873, PZS, p. 878 [not fig.] (Paumotu Islands).

peaseana, Tornatellina, 1884, JANSP, (2) **9:**83, pl. 2, fig. 19 (Moorea Island, Society Islands).

peasei, Turricula, 1880, JC, **3:**57 [not fig.] (Viti Islands).

perorata, Pythia, 1872, AJC, **7:**221, pl. 19, fig. 5 (Viti Isles).

perplexa, Partula, 1884, JANSP, (2) **9:**79. [Nomen nudum, in the synonymy of *Partula varia* Broderip, in Garrett.]

perplexa, Tornatellina, 1879, PANSP, p. 24 [not fig.] (Rurutu Id., Austral Islands).

picea, Endodonta fabrefacta var., 1884, JANSP, (2) **9:**39, [not fig.] (W. side of Raiatea Island, Society Islands).

picturata, Navicella, 1872, AJC, **7:**224, pl. 19, fig. 13 (Vanna Levu, Viti Isles).

pinguis, Clathurella, 1873, PANSP, p. 221, pl. 2, fig. 38 (Samoa and Viti Isles).

pinguis, Partula, 1884, JANSP, (2) **9:**77 [not fig.] (mountain ravines at the head of Vaioara Valley, Raiatea Id., Society Islands). ["It certainly = *rustica*" [Garrett]. A manuscript name in the synonymy of *Partula rustica* Pease.]

planoconus 'Mousson' Garrett, *Trochomorpha,* 1887, PZS, p. 174 (Ono Island, Viti Islands). [This was a ms. name by Mousson, which Garrett described.]

planospira, Patula, JANSP, (2) 8:388 [not fig.] (Rarotonga Island, Cook's Islands). Lectotype (by Solem) in Zool. Mus. Univ. Zürich.

pohliana, Helicina, 1887, PZS, p. 313 [not fig.] (Viti Levu [Fiji Islands]).

prasina, Gibbula, 1872, PCANS, **4:**202 [not fig.] (Viti Islands).

propinqua, Mitra, 1880, JC, **3:**22 [not fig.] (Society Islands).

propinqua, Turricula, 1880, JC, **3:**58 [not fig.] (Viti Islands).

proxima, Pitys, 1872, AJC, **7:**230, pl. 19, fig. 24 (Rarotonga Id., Cook's Isles [Cook Ids.]). Lectotype (by Solem) in ANSP 47700.

pulchra, Odostomia, 1873, PANSP, p. 225, pl. 3, fig. 48 (Viti Isles).

pulchra, Turricula, 1880, JC, **3:**56 [not fig.] (Viti and Samoa Islands).

pulchella, Clathurella, 1873, PANSP, p. 219, pl. 2, fig. 32 (Viti Isles).

punctifera, Clathurella, 1873, PANSP, p. 222, pl. 2, fig. 39 (Society, Samoa and Viti Isles).

punctifera, Microcystis, 1879, PANSP, p. 17, [not fig.] (Rurutu Id., Austral Islands).

punctiperforata, Pitys, 1884, JANSP, (2) **9:**32, pl. 2, fig. 16, a-c (Moorea Island, Society Islands).

pura, Microcystis, 1887, BSMF, **4:**5 [not fig.] (I. le Dominique, I. les Marqueses).

pura, Vitrinella, 1873, PANSP, p. 213, pl. 2, fig. 13 (Kiva Island, Viti Isles).

pusilla, Drillia, 1873, PANSP, p. 219, pl. 2, fig. 31 (Viti Isles, Cook's Isles, Paumotus Isles).

pygmaea, Volvaria (Volvarina), 1873, PANSP, p. 217, pl. 2, fig. 27 (Viti Isles).

quadricarinata, Separatista, 1873, PZS, p. 878 [not fig.] (Paumotu Islands).

radiata 'Pease', Partula, 1884, JANSP, (2) **9:**74, pl. 3, fig. 45 (Hamoa Valley, east coast of Raiatea Island, Society Islands).

raiatensis, Helicina, 1884, JANSP, (2) **9:**106, pl. 3, fig. 69, a-b (Raiatea [Island], Society Islands).

raiatensis, Partula, 1884, JANSP, (2) **9:**54. [Nomen nudum, in the synonymy of *Partula imperforata* "Pease" Garrett, q.v.]

rambiensis, Bulimus, 1872, AJC, **7:**233, pl. 18, fig. 4 (Rambi Id., Viti Isles).

recedens, Libera, 1884, JANSP, (2) **9:**36, pl. 2, fig. 7 (Moorea Island, Society Islands).

reticulata, Pleurotoma (Mangelia), 1856 [1857], PCANS, **1:**102 [not fig.] (Hilo Bay, Hawaii, Hawaiian Islands).

Rissopsis, 1873, PANSP, p. 228, type species *Rissopsis typica* Garrett, (monotypic).

rudis, Pitys, 1872, AJC, **7:**227, pl. 19, fig. 18 (Rarotonga Id., Cook's Isles [Cook Ids.]). Lectotype (by Solem) in ANSP 47701.

rugatus, Bulimus, 1872, AJC, **7:**234, pl. 18, fig. 6 (Vanna Levu Id., Viti Isles).

rurutuensis, Patula, 1879, PANSP, p. 18 [not fig.] (Rurutu Id., Austral Islands).

rusticus, Melampus, 1887, PZS, p. 289 [not fig.] (Viti Islands and on Tonga and Samoa Islands)

scaba, Rissoina, 1873, PANSP, vol. 25, p. 211, pl. 2, fig. 6 (Viti Islands).

scalpta, Microcystis, 1884, JANSP, (2) **9:**21, pl. 2, fig. 30, a-b (Tahaa Island, Society Islands).

schmeltziana, Zonites, 1887, PZS, p. 173 (Malolo Island, Viti Islands). [Is in the genus *Orpiella.*]

scripta, Bulla, 1856 [1857], PCANS, **1**:103 [not fig.] (Hilo, [Hawaii Id.], Hawaiian Islands.)

sculptilis, Rissoina, 1873, PANSP, p. 209, pl. 2, fig. 2 (Viti Islands).

sculptilis, Vitrinella, 1873, PANSP, p. 214, pl. 2, fig. 15 (north coast of Natawa Bay, Vanna Levu, Viti Isles).

semilineata, Clathurella, 1873, PANSP, p. 221, pl. 2, fig. 37 (Samoa and Viti Isles).

simulans, Helicina, 1884, JANSP, (2) **9**:105, pl. 3, fig. 66, a-b (Tahiti [Island], Society Islands).

spiripuncta, Mitra, 1880, JC, **3**:27 [not fig.] (Koro reefs, Viti Islands).

stearnseana, Microcystis, 1887, PZS, p. 171 [not fig.] (Viti Islands).

stellaris, Separatista, 1873, PZS, p. 879, (Samoa and Viti Islands).

striata, Gibbula, 1872, PCAS, **4**:201 [not fig.] (Viti and Samoa Islands).

striatella, Purpura, 1856, [1857], PCANS, **1**:102 [not fig.] (Island of Hawaii, Hawaiian Islands).

striatula, Trochus, (Margarita), 1856 [1857], PCANS, **1**:102 (Hawaii [Island] Hawaiian Islands).

strictus, "Mousson" Garrett, Ostodes, 1887, PZS, p. 306 [not fig.] [See Clench 1949, B. P. Bishop Museum, Bull 196, p. 21, fig. (Holotype 8a)]. (Vatu Lele Island, ex museum Godeffroy) [Fiji Islands.]

subconula, Trochonanina, 1887, BSMF, **4**:13 (I. le Dominique, I. les Marqueses).

subexcrescens, Microcystis, 1881, JANSP, (2) **8**:381, (Rarotonga, Cook Islands). [Nomen nudum.]

subglobosa, Succinea, 1884, JANSP, (2) **9**:88, pl. 2, fig. 3 (Tahiti [Island] Society Islands).

subglobosus, Pedipes, 1873, PANSP, p. 236, pl. 3, fig. 70 (Tanthala Island, Viti Isles).

subrufa "Pease" Garrett, Helicina, 1884, JANSP, (2) **9**:104, pl. 3, fig. 68, a-b (Raiatea and Borabora [Islands] Society Islands).

subrugosa, Trochonanina, 1884, JANSP, (2) **9**:22, pl. 2, fig. 38, a-d (Tahiti and Moorea [Islands]).

subtexturata, Mitra, 1880, JC, **3**:26 [not fig.] (Raiatea Island, Society Islands).

subtilis, Pitys, 1884, JANSP, (2) **9**:31, pl. 2, fig. 15, a-c (Huaheine Island, Society Islands).

sulcata, Odostomia, 1873, PANSP, p. 224, pl. 3, fig. 46 (Viti Isles).

supracostata, Rissoina, 1873, PANSP, p. 209, pl. 2, fig. 1 (Viti Isles).

suturalis, "Pease" Garrett, Partula, 1884, JANSP, (2) **9**:63, pl. 3, fig. 77 (Haamene Valley, east coast of Tahaa [Island], Society Islands).

tahitensis, Mitra, 1880, JC, **3**:30 [not fig.] (Tahiti Island, Society Islands).

tahitensis, Trochonanina, 1884, JANSP, (2) **9**:23, pl. 2, fig. 39, a-c (Tahiti Island, Society Islands).

taneae, Pitys, 1872, PCAS, **4**:204 [not fig.] (Maupiti Island, Society Islands).

taneae, Pitys, 1873, PANSP, p. 234, pl. 3, fig. 65 (Maupiti Island, Society Isles).

tavinniensis, Helix, 1872, AJC, **7**:223, pl. 19, fig. 10 (Tavinni Id., Viti Isles).

tenella, Nanina, 1872, AJC, **7**:222, pl 19, fig. 7, (Kioa Id., Viti Isles).

tenuicostata, Pitys, 1872, AJC, **7**:229, pl. 19, fig. 23 (Rarotonga Id., Cook's Isles [Cook's Ids.]). Lectotype (by Solem) in ANSP 17702.

terebra, Rissoina, 1873, PANSP, p. 212, pl. 2, fig. 11 (Viti and Samoa Islands).

tessellata, Daphnella, 1873, PANSP, p. 330, pl. 3, fig. 61 (Paumotus Isles).

thalia, Partula, 1884, JANSP, (2) **9**:69, pl. 3, fig. 16 (Huaru Valley, west coast of Raiatea Island, Society Islands).

themis, Trochomorpha, 1887, PZS, p. 177 (new name for *Trochomorpha ludersi* Mousson 1870, non Pfeiffer 1855).

tryoni, Goniodoris, 1873, PANSP, p. 232, pl. 4 (Society Islands).

truncata, Rissoa, 1873, PANSP, p. 217, pl. 2, fig. 26 (Kiva Island, Viti Isles).

tumuloides, Pitys, 1872, AJC, **7**:225, pl. 19, fig. 15, (Rarotonga Id., Cook's Isles [Cook Ids.]).

turrita, Pleotrema, 1873, PANSP, p. 235, pl. 3, fig. 68 (N. E. end of Tavinni [Taveuni Island] Viti Isles).

turrita, Rissoina, 1873, PANSP, p. 213, pl. 2, fig. 12 (Society Islands).

typica, Rissopsis, 1873, PANSP, p. 228, pl. 3, fig. 55 (Viti and Samoa Isles).

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unilineata, Odostomia, 1873, PANSP, p. 227, pl. 3, fig. 53 (Viti Isles).

unilineata, Turricula, 1880, JC, **3**:60 [not fig.] (Viti Islands).

ventricosa, Turricula, 1880, JC, **3**:55 [not fig.] (Samoa and Viti Islands). [Nomen nudum]. [Is *T. porphyretica* Reeve.]

venusta, Rissoa, 1873, PANSP, p. 216, pl. 2, fig. 23 (Viti Isles).

vidualoides, Drillia, 1873, PANSP, p. 217, pl. 2, fig. 28, (Viti Isles)

violacea, Thala, 1872, PCAS, **4**:202 (Samoa and Viti Islands).

virginea, "Pease" Garrett, Partula, 1884, JANSP, (2) **9**:61, pl. 3, fig. 54 (Vaipiti Valley, west coast of Tahaa [Island] Society Islands).

vitiana, Paludinella, 1872, AJC, **7**:224, pl. 19, fig. 12 (Viti Isles).

vitiense, Caecum, 1873, PZS, p. 879 (Kioa Island, Viti Islands).

vitiensis, Assiminea, 1872, AJC, **7**:225, pl. 19, fig. 14 (Viti Isles).

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vitiensis, Pupina, 1873, PANSP, p. 233, pl. 3, fig. 62 (Gomea Island, Viti Isles).

vitrea, Daphnella, 1873, PANSP, p. 230, pl. 3, fig. 60 (Paumotus Isles).

vitrea, Odostomia, 1873, PANSP, p. 227, pl. 3, fig. 52 (Viti Isles).

vitrea, ?Rissoa, 1873, PANSP, p. 215, pl. 2, fig. 19 (Kiva Island, Viti Isles).

woapoensis, Pitys, 1887, BSMF, **4**:17, (I. le Woapo, I. les Marqueses).

youngi, Pitys, 1872, AJC, **7**:229, pl. 19, fig. 22 (Rarotonga Id., Cook's Isles [Cook Ids.]). Lectotype (by Solem) in ANSP 47703.

zebra, Strigatella, 1880, JC, **3**:35 [not fig.] (Viti and Samoa Islands).

zebrina, Mitra. 1872 [1873] PZS, p. 812, [not fig.] (Paumotu, Tahiti, Cook's [Islands], Samoa, Viti Islands)

zebrina, Pitys, 1873, PANSP, p. 234, pl. 3, fig. 66 (Rarotonga Island, Cook's Isles).

Additional Names by William Harper Pease

These names were inadvertently omitted by W. J. Clench (1975), *Nemouria,* no. 16, Delaware Museum of Natural History.

approximata Pease, *Partula,* 1884, JANSP, (2) **9**:75 [nomen nudum]. [Is *P. vittata* Pease. It was listed earlier by Gloyne in the Journal of Conchology, **1**:338, May, 1878].

microstoma Pease, *Partula,* 1884, JANSP, (2) **9**:74 [nomen nudum]. [Is *P. radiata* "Pease" Garrett, *q.v.*]

fratercula Pease, Helix, 1867, AJC, **3**:104. [New name for *Helix sculptilis* Pease, 1865, non Bland 1858.]

oualanensis "Pease" Tryon, *Melania,* 1866, AJC, **2**:299, pl. 20, fig. 4 (Oualan I. [now Kusaie Island, Caroline Islands.]) [A manuscript name by Pease but never described by him.]

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THE CAECIDAE (GASTROPODA: RISSOACEA) OF WATER ISLAND, U. S. VIRGIN ISLANDS, WITH A NEW SPECIES.

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ABSTRACT

Eleven shallow-water species of Caecum, *from the marine sediment around Water Island, are described according to their microsculpture as observed under the scanning electron microscope. One new species,* Caecum donmoorei, *which was found in Sprat Bay, Water Island, is also described.*

In 1973, a study was made of the shallow marine carbonate sediment around Water Island, the fourth largest island in the U. S. Virgin Islands group. A total of 56 samples of approximately 100 grams each was collected around the island at sites which were exposed to differing amounts of wave-energy. A total of 618 *Caecidae* was picked from the samples and their distribution around the island was plotted according to the number of specimens found (Fig. 1).

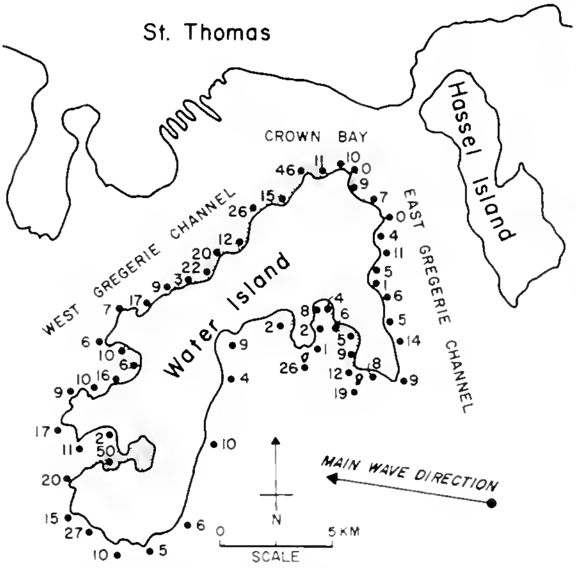
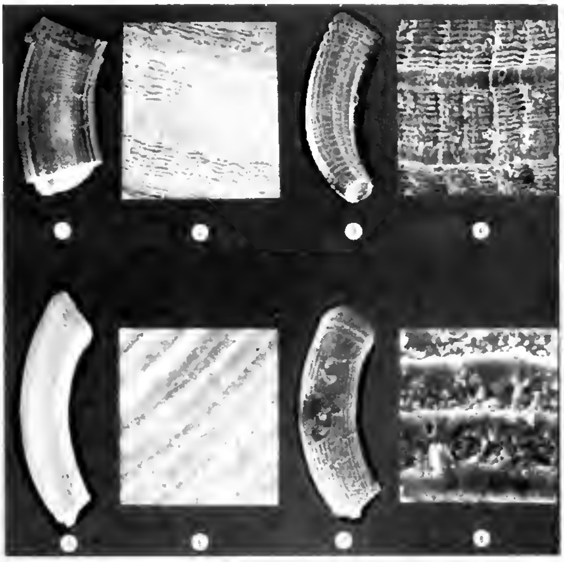


FIG. 1a. *Distribution of the number of specimens collected around Water Island, U. S. Virgin Islands. Stippled areas are grassbed, low wave-energy areas.*



FIGS. 1-8. **1,** C. breve *Folin* ×*15;* **2,** C. breve *Folin* ×*120,* **3,** C. imbricatum *Carpenter* ×*15;* **4,** C. imbricatum *Carpenter* ×*120;* **5,** C. tenuicostatum *Folin* ×*30;* **6,** C. tenuicostatum *Folin* ×*215;* **7,** C. tenuicostatum *Folin* ×*15;* **8,** C. tenuicostatum *Folin* ×*240.*

Compared with samples from Bahia Honda in the Florida Keys, where up to 212 specimens per sample occur, there are few specimens in this area. This may be due to the geographical location of the Virgin Islands and the prevailing east-west current. This current results in the specimens being representative of the local standing crop only. It is interesting to note that not a single specimen of *Caecum insularum* Moore, originally found on the sister island of St. John (Moore, 1970), was present in Water Island samples.

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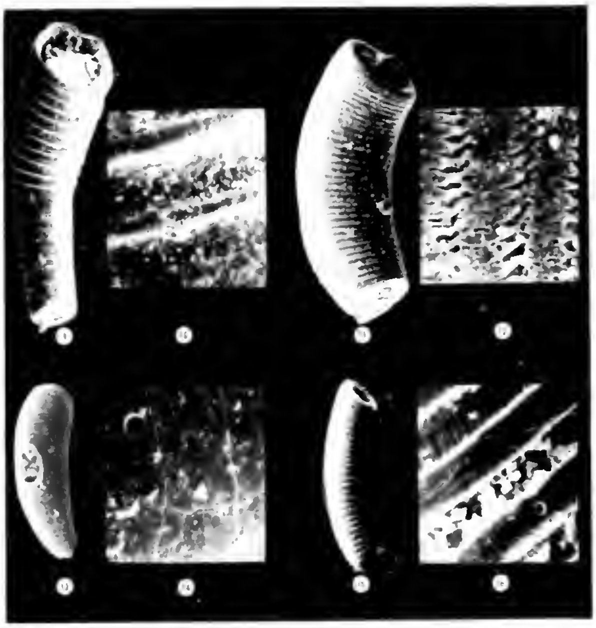
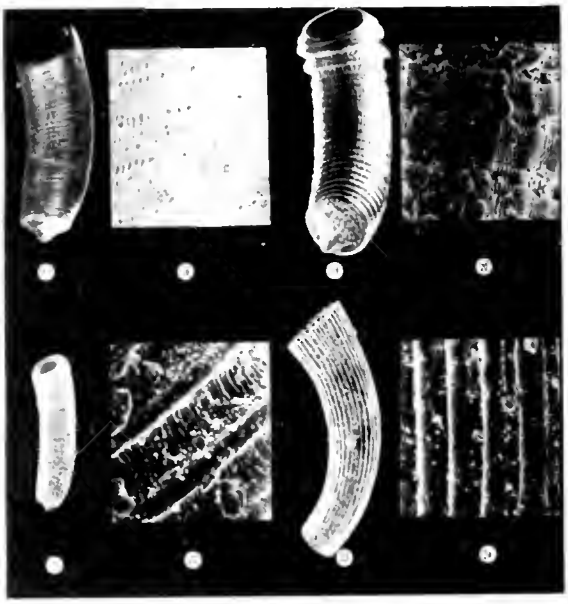


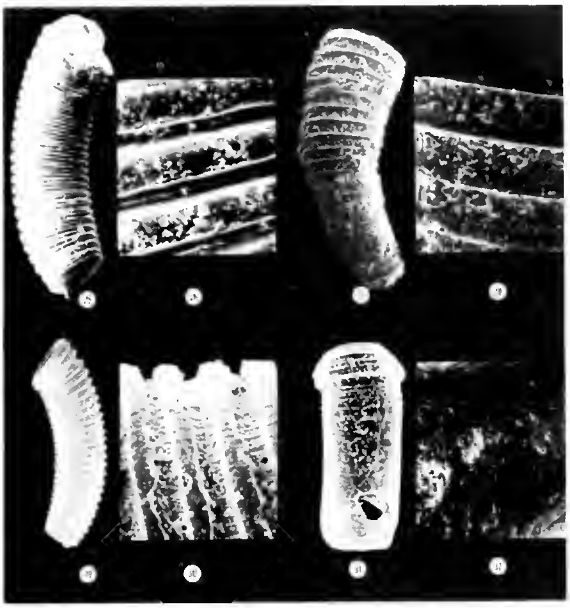
FIGS. 9-16. **9,** C. regulare *Carpenter ×25;* **10,** C. regulare *Carpenter ×175;* **11,** C. textile *Folin ×35;* **12,** C. textile *Folin ×340;* **13,** C. cornucopiae *Carpenter ×15;* **14,** C. cornucopiae *Carpenter ×240;* **15,** C. gurgulio *Carpenter ×20;* **16,** C. gurgulio *Carpenter ×160.*

The distribution of the 618 specimens (Fig. 1) shows no discriminate pattern, other than the low count for the eastern side of the island. This small number of specimens might be attributed to the local water current through Gregerie Channel, which would move the specimens to a lower energy area. The dominant species in the grass-beds, low-energy areas, were *Caecum cornucopiae* Carpenter (Figs. 13 and 14) and *C. nitidum* Stimpson. Distinguishing between these two species is rather difficult, but *C. nitidum* tends to be larger with a more oblique aperture in the adult stage. The row of dark spots sometimes seen on *C. cornucopiae* by Moore (1972) was not apparent in the specimens from the grassbeds and only seen on two specimens from a reef area in a southside bay. In the reef, or medium wave-energy areas, the most abundant species was *C. regulare* Carpenter (Figs. 25, 26, 27 and 28). *C. breve* Folin (Figs. 1 and 2), *C. lineicinctum* Folin (Figs. 31 and 32), and *C. floridanum* Stimpson (Figs. 19 and 20) were also found in these areas. The dominant species in the rocky, high wave-energy areas on the southern side of the island was *C. imbricatum* Carpenter (Figs. 3 and 4). A rare species, *C. tenuicostatum* Folin (Figs. 5, 6, 7, 8, 23 and 24) was also found in these areas. Some of the specimens of *C. tenuicostatum* appear under the SEM to have longitudinal ribs which are smoother and less raised on one side, giving an appearance of wavelike ribs moving clockwise looking down from the aperture.

One species common to all areas is *C. textile* Folin (Figs. 11 and 12). Some specimens of *C. textile* (Figs. 17 and 18) appear under the light microscope as having a raised interspace between the annular ridges, giving an almost smooth appearance, while the SEM reveals that the longitudinal striae on the ridges are continued through the interspace and are joined to those on the adjacent ridges (Fig. 18). Another species, also common to all wave-energy environments, is *C. regulare* Carpenter and its close relative, *C. gurgulio* Carpenter (Figs. 15 and 16). The sculpture of *C. regulare*, as revealed by the SEM, shows an absence of striae between the well-raised, flat-topped annular ridges (Fig. 26). This can also be seen in the specimen described by



FIGS 17-24. **17,** C. textile *Folin ×30;* **18,** C. textile *Folin ×210;* **19,** C. floridanum *Stimpson ×20;* **20,** C. floridanum *Stimpson ×145;* **21,** C. donmoorei *n.s. paratype ×10;* **22,** C. donmoorei *n.s. paratype ×140.* **23,** C. tenuicostatum *Folin Second stage ×20;* **24,** C. tenuicostatum *Folin ×140.*



FIGS. 25-32. **25,** C. regulare *Carpenter* ×*10;* **26,** C. regulare *Carpenter* ×*210;* **27,** C. regulare *Carpenter Second stage plus part of third stage* ×*25;* **28,** C. regulare *Carpenter* ×*175;* **29,** C. donmoorei *n.s. holotype* ×*20;* **30,** C. donmoorei *n.s. holotype* ×*120;* **31,** C. lineicinctum *Folin* ×*20;* **32,** C. lineicinctum *Folin* ×*80.*

Moore (1972). *C. gurgulio* is very similar in appearance, but is smaller, has less curvature, and low, flat-topped, closely set ribbing with striae present only between the ribs (Fig. 16).

Caecum donmoorei, n. sp.

Description: Shell tapered with slight curvature; 27 annular ribs well-spaced, raised, rounded-topped (Fig. 31); primary striae in interspace thick; secondary striae thin; all striae continue over surface of ribs (Fig. 32); Septum slightly convex, bearing broad, weak mucro angled to right; two small circular ribs around circular aperture; no varix; color white in holotype, some specimens tinged brown near aperture; length 1.4 mm.

Remarks: This species has round-topped and striated ribs as opposed to the smooth, flat-topped ribs of *C. regulare*. It differs from *C. gurgulio* which has rounded, robust, but not so raised, ribs which are small, smooth, and bear no striae. There is also no similarity to *C. tornatum* Verrill and Bush which has strong ribs and a very strong mucro and appears to be confined to Bermuda. The most distinguishing feature of *C. donmoorei*, which appears to justify the naming of a new species, is the round-topped striae-covered ribs. This species is named after Dr. D. R. Moore, a leader in the field of the study of the *Caecidae*.

Type-locality: Holotype: In 5 m of water in Sprat Bay, Water Island, USVI. Four paratypes were found in Ruyter Bay and Elephant Bay at similar water depths and of low wave-energy.

Types: Holotype deposited in 1977 in the Delaware Museum of Natural History #119521. Paratypes were placed in the collection at the Florida Bureau of Geology, Tallahassee, #12909.

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DISCOVERY OF LIVING BIVALVED GASTROPODS IN THE FLORIDA KEYS

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The first living bivalved gastropod was observed by Kawaguti just twenty years ago (Kawaguti and Baba, 1959). A year later, in October 1960, Kawaguti visited Miami in an effort to find these animals in the western Atlantic. He was unsuccessful, but shortly after Edmunds (1962) reported a species from Jamaica. This species was described as *Berthelinia caribbea* Edmunds, 1963. *B. caribbea* was reported from Puerto Rico by Warmke (1966), and later from Panama and Brazil (Meeder and Moore, 1972).

The search for *B. caribbea* in United States waters was unsuccessful for many years; then one of us (MFM) collected eight live specimens in the Florida Keys on 14 July 1978. They were collected in sea wall scrapings from a canal off Tavernier Creek, Plantation Key. After being observed alive, they were preserved in alcohol. Four of these were donated to the School of Marine Science, University of Miami.

This is the first living species of the family Juliidae to be reported from Florida. A fossil species, *Julia floridana* Dall, 1898, was described (as a pelecypod) from the Oligocene of northwestern Florida along the Chipola River. The genus *Julia* is presently found living in the central and western Indo-Pacific, and is known from two fossil species in the western Atlantic area. *Berthelinia caribbea* is not likely to be found as a fossil, however, as it is extremely thin-shelled.

B. caribbea is now known from the Florida Keys, Jamaica, Puerto Rico, Panama, and Brazil. It appears to have planktonic larvae, and should be found at many more localities in the Tropical Atlantic.

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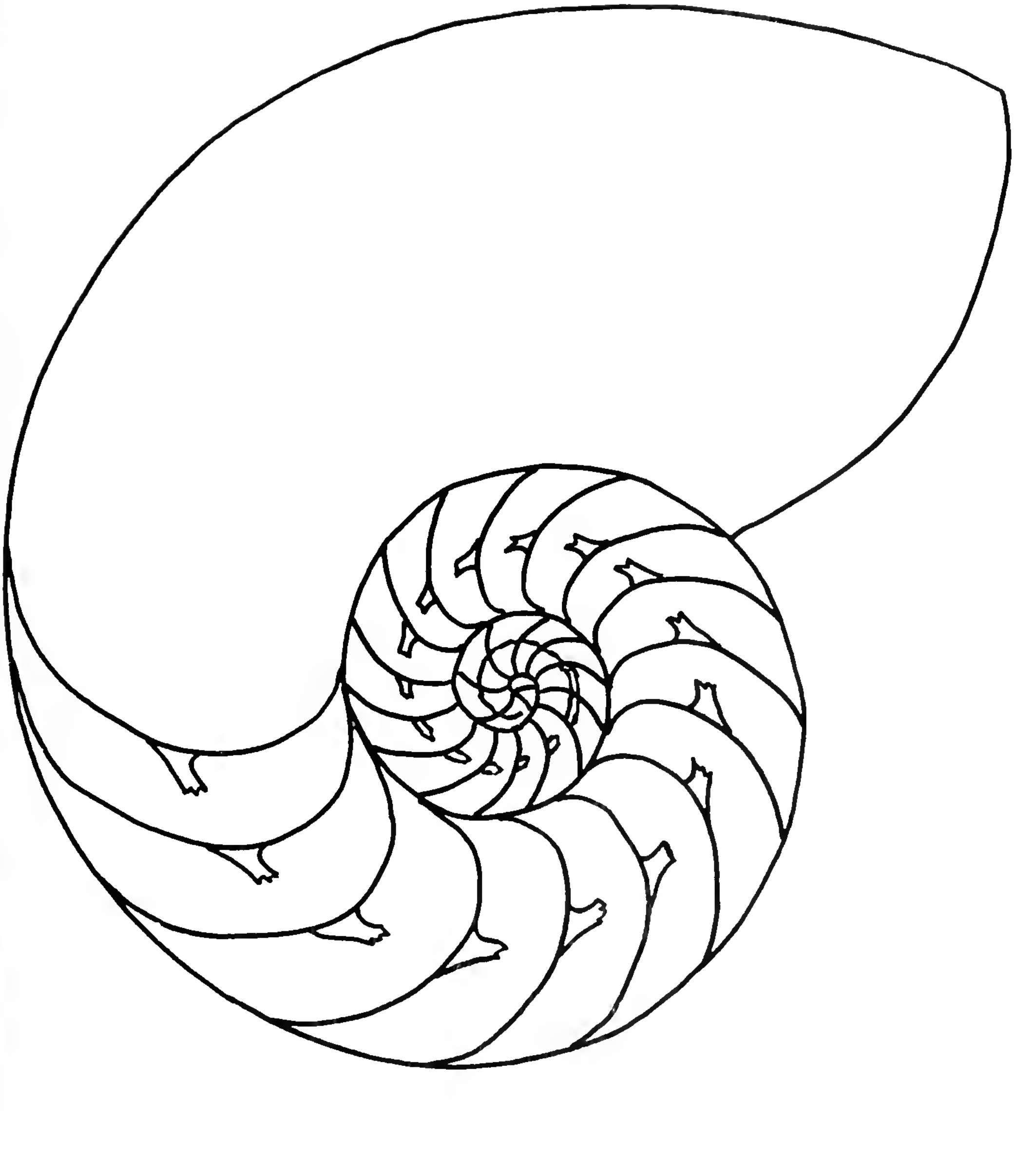

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BIOLOGICAL ASPECTS OF THE CALICO SCALLOP, *ARGOPECTEN GIBBUS*, DETERMINED BY SPAT MONITORING[1]

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ABSTRACT

Biological information on the calico scallop, Argopecten gibbus, *was collected using spat traps as monitoring devices on the Cape Canaveral grounds off the Florida east coast from March 1970 to October 1971. The shells of young scallops (spat) differ in shape and color from those of adult scallops. Spat and, by deduction, the larval scallops, occurred at five sampling locations off Cape Canaveral in depths of 9 to 24 m; spat were most abundant at the 18 m site. There was no evidence that scallop larvae survived in estuarine waters in the Cape Canaveral area. Based on spat distribution, larvae were apparently distributed throughout the water column but were least abundant near the surface. Seasonally, spat were most abundant in the spring. Growth estimates show that young scallops can reach 1.5 mm shell height in 1 month from spawning, 17.0 mm in 2 months, and 28.0 mm in 3 months. Setting apparently occurred at a minimum size of 0.25 mm shell height and spat showed strong byssal attachment up to at least 5.0 or 6.0 mm shell height. Spat may utilize filamentous host organisms, such as hydroids, for setting, perhaps before attachment to shell. Numerous invertebrates were associated with calico scallops in the traps, but calico scallops were generally dominant.*

Based on spat abundance, spawning of adults occurred during all seasons, but intensity was highest in spring (March through May) when bottom water temperatures associated with spawning scallops were probably about 18°C.

Recommendations for future spat monitoring are discussed.

The calico scallop, *Argopecten gibbus*, supports a small fishery off the southeastern United States. The scallop grounds are located off North Carolina, off the Florida east coast, and in the northeastern Gulf of Mexico (Figure 1). Abundance and distribution of scallops on the grounds are seasonally and annually variable, which has, in part, contributed to the slow development of the fishery. To recognize factors controlling the abundance and distribution of the calico scallop, the Bureau of Commercial Fisheries (now the National Marine Fisheries Service), Miami, Florida, conducted laboratory and field studies of the biology of this species from 1969 to 1971.

Biological information concerning certain marine invertebrates has been revealed by their habit of attaching to or "fouling" of submerged objects (Woods Hole Oceanographic Institution, 1952; Merrill, 1965). Artificial substrates, such as test surfaces or fouling panels, are used in biological monitoring because of the relative ease with which the unit of sampling effort can be standardized and controlled (Calder and Brehmer, 1967; Cory, 1967; Pequegnat and Pequegnat, 1968). Spat collecting devices, made of oyster shells or asbestos plates, are particularly useful in oyster biological studies that have direct application to the commercial fishery (Loosanoff, 1966; Shaw, 1967).

Scallops (family Pectinidae) attach to substrates by means of byssal threads. The first byssal attachment of young scallops after a planktonic existence is called "setting," and the

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[1] Contribution Number 79-37M, NOAA, National Marine Fisheries Service, Southeast Fisheries Center, Miami, FL 33149.

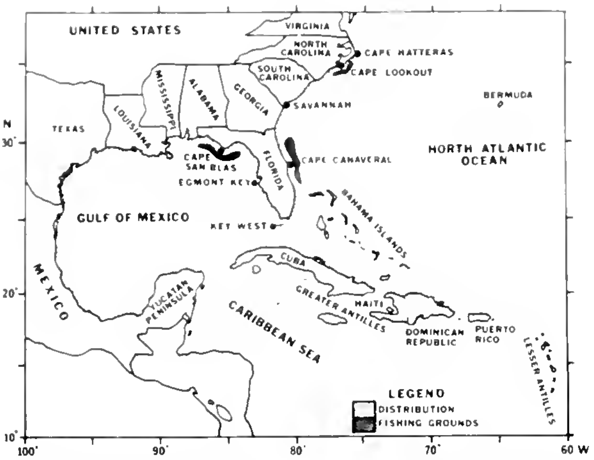

FIG. 1. *General distribution of the calico scallop and primary scallop fishing grounds. (Modified from Cummins, 1971; Allen and Costello, 1972)*

recently set scallops are called "spat." Setting was described for the bay scallop, *Pecten irradians* (now *Argopecten irradians*), by Belding (1910). Young scallops of various species will set on natural and artificial substrates (Belding, 1910; Woods Hole Oceanographic Institution, 1952; Merrill, 1965; Brown et al., 1967; Dow, 1969; Costlow, 1969; DePalma, 1969; Turner, Ebert, and Given, 1969 and Golikov and Scarlato, 1970.) Under natural conditions, calico scallop spat are generally found attached to mollusk shells, primarily the empty valves of calico scallops (Allen and Costello, 1972). Calico scallop spat have also attached to navigation buoys (Waller, 1969) and plastic peanut floats (Pequegnat, Gaille, and Pequegnat, 1967).

The setting habits of scallops suggested that calico scallop spat might be effectively sampled using artificial substrates as collecting devices. An effective spat collector, briefly described by Allen and Costello (1972), was developed by me in early 1970. Later spat monitoring, using this device, provided basic data concerning spat: description, distribution and abundance, age and growth, behavior, and associated organisms; and spawning of adults. In recent years, a similar spat collecting device has been used in a Japanese commercial scallop culture system (Dix, 1977).

METHODS

In preliminary field tests off Cape Canaveral, Florida (Figure 2), young calico scallops byssally attached to a variety to cultch materials in addition to calico scallop shells. Unlaid polyethylene line, which forms a filamentous tangle, was particularly effective as cultch. Comparison of cultch effectiveness was difficult because many of the larger spat dropped from the cultch as it was removed from the ocean. To minimize the loss of spat that may release attachment before or during the time spat collectors were retrieved, the cultch was contained within wire, plastic, or nylon mesh of appropriate size.

The standardized spat collector (designated "spat trap") used during most of this study consisted of a small, nylon mesh bag stuffed with a fixed quantity of unlaid polyethylene line (Figure 3). The nylon bag was 56.0 cm long and 30.5 cm wide, with mesh openings about 3.0 mm in diameter. Polyethylene line, diameter 9.4 mm and length 61.2 cm, was separated into individual filaments and placed in the bag, along with a plastic identification label. The bag was closed by means of a figure-eight knot tied in the bag at its midpoint. Excess bag material was drawn down over the knot and tied with nylon parachute cord, which also secured the spat trap to a vertical line at a selected position in the water column. These spat traps survived well in the marine environment, because their components did not decompose rapidly.

The spat traps filtered large quantities of water from currents which presumably carried the scallop larvae to the traps where the larvae set and grew. Young scallops inside the traps were permanently trapped when their size exceeded the 3.0 mm mesh openings. Probably few spat less than 3.0 mm shell height[2] were lost during recovery of the traps because spat in this size category show strong byssal attachment.

Preliminary comparative studies indicate that standard spat traps containing 61.2 cm of unlaid line caught more spat than mesh bags containing no line but stretched with wire to a size and shape similar to that of the standard traps. When the amount of line in the traps was increased to 183.6 cm, the numbers of spat caught increased, but their growth declined markedly. Furthermore, the tightly packed line apparently caused a high incidence of deformed valves and mortality among the larger spat. As noted by Merrill and

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[2] Shell height is a straight measurement of the greatest distance between the umbo and the ventral margin.

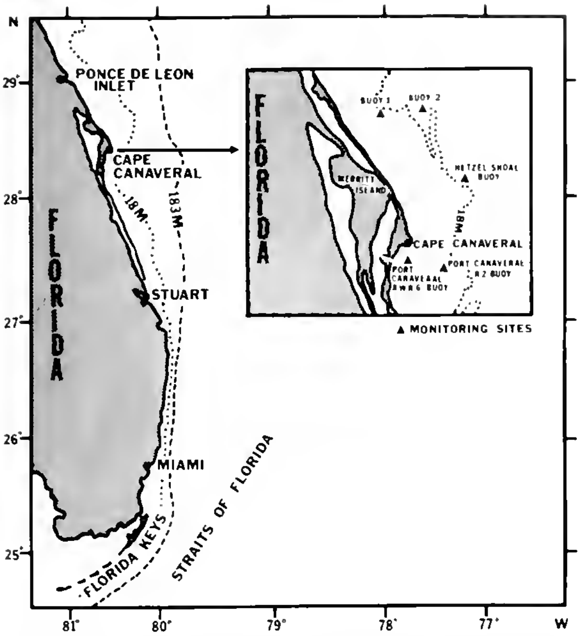

FIG. 2. *Calico scallop spat monitoring sites off Cape Canaveral and geographic locations along the east coast of Florida.*

Edwards (1975) for young sea scallops, *Placopecten magellanicus*, growing in fouling communities, "The mantle is apparently easily injured, and evidence of serious shell malformation was seen in situations where other organisms were in close approximation to the scallop." In the standard spat traps, no deformities occurred. Extensive mortality did occur in standard traps that were exposed for almost 4 months, but the causes are unknown. These traps contained potential predators (including starfish, crabs, and gastropod mollusks) and competitors (bivalve mollusks) that had apparently passed through the meshes as larvae and were themselves trapped. In addition, the meshes were clogged with silt.

Five sites to monitor calico scallop spat distribution and abundance were established off the Florida east coast near Cape Canaveral, in depths of 9 to 24 m (Table 1, Figure 2). U.S. Coast Guard navigation buoys or special service buoys marked each site and enabled location and recovery of the spat traps after exposure for extended periods of time. It was necessary to establish the sites inshore of the greatest adult scallop concentrations because of the absence of large, permanent buoys in the offshore waters. Adult scallops occurred near Buoys 1 and 2 but were rare or absent at the remaining three sites.

In use, the spat traps were attached to a spat monitoring array that was typically composed of an anchor, vertical line, stabilizing float and surface buoy. To facilitate recovery, the arrays were positioned within sight of the permanent buoy at each site. In some areas, where danger of propeller cutoff and theft was great, the surface buoy was retained underwater until released by a timed magnesium fuse shortly before scheduled recovery. For most of the comparative studies, two spat traps were located on the vertical line at positions 0.6 m and 6.0 m above the ocean bottom. For special purposes, additional traps were located 0.9 m below the water surface and elsewhere in the water column.

The preliminary, experimental spat collecting devices were first set out in March 1970. After refining techniques, standardized spat traps, useful for comparing abundance, were exposed for varying periods of time from July 1970 to October 1971. Scallops caught by both the preliminary and standardized traps were used in the growth study. The shortest exposure time was 11 days, and the longest, 117 days. Losses of arrays were common and were attributed to strong currents, entanglement with fishing gear, theft, and propeller cut-off. Most of the successful recoveries of arrays were at Buoys 1 and 2, the sites most remote from vessel traffic or fishing activities.

When the spat traps were recovered from the ocean, they were placed in fine-mesh nylon bags (mesh size about 0.75 mm) and preserved in 10% Formalin.[3] Although the spat apparently released byssal attachment upon contact with Formalin, the fine-mesh preserving bags retained spat as small as 0.75 mm shell height and helped maintain the integrity of each spat trap during the later flushing, freezing (for preservation), and thawing process.

The calico scallop spat (including empty shells) and associated organisms from each spat trap were sorted and counted. An unknown number of very small spat (less than 0.75 mm shell height) may have been washed through the fine-mesh preserving bag or overlooked by the sorters. Other species of scallops were caught in the traps

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[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

but constituted less than 1% of those large enough to be identified to species. The scallop spat were measured for shell height. Spat less than 1.0 mm shell height were measured to the nearest 0.25 mm, those from 1.0 to 5.0 mm to the nearest 0.5 mm, and those more than 5.0 mm to the nearest 1.0 mm. Scallops from 0.25 to 27.0 mm shell height were found in the trap samples. One trap, exposed for 35 days, contained 4,761 spat that ranged from 0.75 to 8.0 mm shell height.

Since the "catching effort" of the spat traps varied with exposure time, catch data were standardized by calculating the average number of spat caught per trap per day of exposure.

Thermographs recorded bottom temperatures at Buoys 1 and 2 during most of the study period, but there were intervals when no data were collected because of thermograph malfunction or loss.

Spat

Description

The calico scallop shell was described by Waller (1969). Shells of calico scallop spat collected in spat traps on the Cape Canaveral grounds (Figure 4) differed in shape and color from shells of adult scallops collected in the same area.

Shell height was usually greater than shell length[4] in spat 1.0 to 8.0 mm height. At about 9.0 mm shell height, shell length began to increase more rapidly than shell height, and from my additional observations of larger scallops, and those of Wells, Wells, and Gray (1964), this relationship apparently continued throughout life. In trawl-caught scallops, shell length did not begin to increase more rapidly than shell height until a shell height of about 30.0 mm was reached.

Table 1. Locations and depths of calico scallop spat monitoring sites off Cape Canaveral, Florida.

Buoy	Latitude and longitude	Distance from land	Depth
		(km)	(m)
Buoy 1	28° 48.5' N 80° 38.6' W	9	18
Buoy 2	28° 49.1' N 80° 29.0' W	22	22
Hetzel Shoal Buoy	28° 38.2' N 80° 21.0' W	22	24
Port Canaveral R2 Buoy	28° 22.9' N 80° 25.5' W	13	17
Port Canaveral RWR6 Buoy	28° 23.8' N 80° 32.2' W	6	9

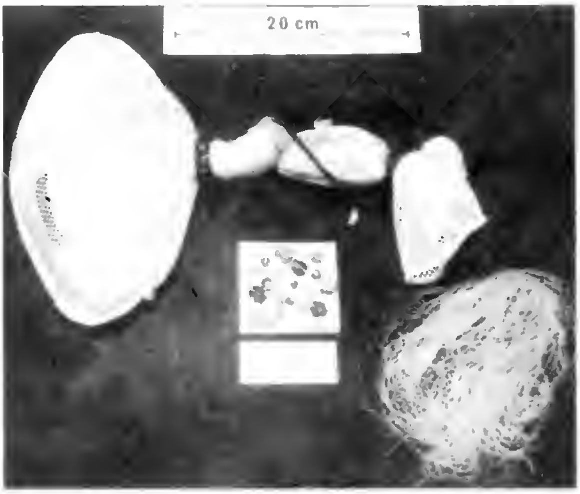

FIG. 3. *Spat trap, consisting of nylon mesh bag (top) and unlaid polyethylene line (bottom right). Calico scallop spat (center) exceed mesh openings in size. (From Allen and Costello, 1972).*

Length of the hinge line was about equal to shell length in spat 1.0 to 1.5 mm shell height. However, as shell height increased, hinge line length increased more slowly, so that at 8.0 mm shell height (approximately 8.0 mm shell length) hinge line length was 6.0 mm.

Spat less than about 10.0 mm shell height were noticeably compressed, or flattened, as compared with the strongly inflated adult scallops. For spat ranging from 3.5 to 8.0 mm shell height, depth[5] was only about 27 to 31% of shell height. As shell height increased, depth increased disproportionately. For spat 19.0 to 23.0 mm shell height, depth was about 37 to 46% of shell height, and for scallops 37.0 to 65.0 mm shell height (caught by bottom trawl), depth was about 54 to 64% of shell height.

There was a difference in convexity[6] between the left (upper) and right (lower) valves in spat from 1.5 mm up to at least 8.0 mm shell height. For spat 3.5 to 4.5 mm shell height, the left valve,

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[4] Shell length is a straight line measurement of the greatest distance between the anterior and posterior margins.

[5] Depth is the sum of the convexities (see footnote 6) of the left and right valves.

[6] Convexity is the maximum distance between the exterior surface of a valve and the measuring platform, measured along a line perpendicular to the measuring platform (Waller, 1969).

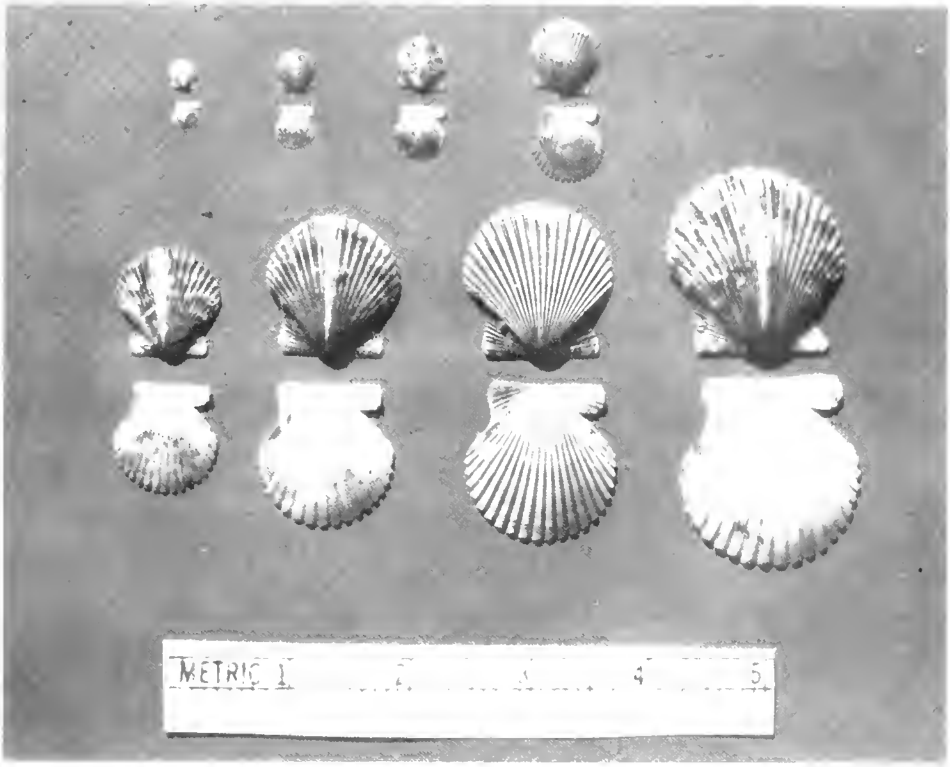

FIG. 4. *Calico scallop spat from 2.5 to 16.0 mm shell height. For each pair, left valve is on top and right valve is on bottom.*

strongly convex, accounted for 65 to 81% of the depth, while the right valve, weakly convex, accounted for only 18 to 34% of the depth. Convexity of the valves became more equal as shell height increased. Waller (1969), apparently discussing adult scallops, observed that the valves were "generally equiconvex to slightly left convex."

Spat ranging from 0.75 to 18.0 mm shell height had white, tan, violet, brown, red-brown, and orange-brown valves. Some mottling or banding occurred on spat as small as 2.0 mm shell height. Colors on the left valve were darker than those on the right valve, which was generally white or light tan. Colors on the left valve became darker and more intense as size increased. White and tan were common base colors on the left valve of spat 0.75 to 8.0 mm shell height, grading into brown and red-brown as size increased up to 18.0 mm shell height.

A fairly common characteristic of spat, particularly those from about 4.0 to 8.0 mm shell height, was a white streak bisecting the left valve, extending from near the umbo to the ventral margin and encompassing the width of a few ribs.

Distribution and Abundance

The general distribution of the calico scallop was summarized from several sources by Allen and Costello (1972), who stated that the range of this species ". . . extends from the northern side of the Greater Antilles and throughout the Gulf of Mexico to Bermuda and slightly north of Cape Hatteras." According to Allen and Costello (1972), "The greatest known abundance is located off the Florida east coast near Cape Kennedy [Cape Canaveral], with lesser concentrations near Cape Lookout, N. C., and in the northeastern Gulf of Mexico near Cape San Blas, Fla." Sporadic commercial concentrations also have been reported off Savannah, Georgia, and along the west coast of Florida, from off Egmont Key to Key West (Figure 1).

Although the calico scallop may consist of one population throughout its range, with planktonic larvae from stock in one area contributing to stock in another area, there is little evidence to support this theory. Oceanic currents probably determine the direction of transport of the larvae (Waller, 1969). Therefore, the Gulf Stream system, and associated countercurrents, may be important in larval distribution. Kirby-Smith (1970) suggested that part of the North Carolina calico scallop stock may result from larvae transported northward from the Cape Canaveral grounds by the Gulf Stream. The origin of the calico scallops on the Cape Canaveral grounds is unknown. These scallops may be either self-sustaining or partially dependent upon larvae transported from more distant spawning stocks, presumably (but not necessarily) located farther south than the lower end of the Cape Canaveral grounds near Stuart, Florida. Calico scallops occur in the Florida Keys (Waller, 1969), and these scallops may supply larvae to the Cape Canaveral grounds (Figure 2). This hypothesis, however, does not negate the fact that there is a large stock of spawning scallops on the Cape Canaveral grounds, and water circulation in the Cape Canaveral area might be expected to retain scallop larvae on the grounds until setting occurs, since surface currents off Cape Canaveral reverse direction to north or south with wind changes, and bottom currents converge toward the cape from offshore (Bumpus, 1973).

Calico scallop spat were caught in traps at all five study sites off Cape Canaveral (Table 2). This might be expected since the wide distribution of adult scallops on the Cape Canaveral grounds (Drummond, 1969) would presumably contribute to the wide distribution of larvae in this area. The intensity of spat setting (or survival) between sites was variable. Where comparisons between sites could be made, they showed spat to be most abundant, generally, at Buoy 1 and least abundant at Port Canaveral RWR6 Buoy. For example, traps exposed from May 25 to June 26, 1971 (35 days) caught 2,320 spat at Buoy 1 (9 km offshore, 18 m of water), 895 spat at Buoy 2 (22 km offshore, 22 m), and 21 spat at Port Canaveral RWR6 Buoy (6 km offshore, 9 m) (Table 2). Variability in setting between locations was also observed in the northeastern Gulf of Mexico, where calico scallop spat attached to biofouling

Table 2. Seasonal abundance of calico scallop spat at monitoring sites off Cape Canaveral, Florida, July 1970 to October 1971.

Spat Trap Exposure		Buoy 1		Buoy 2		Hetzel Shoal Buoy		Port Canaveral R2 Buoy		Port Canaveral RWR6 Buoy	
Period	Days	Total	Per day	Total	Per day	Total	Per day	Total	Per day	Total	Per day
		number of spat[1] per trap[2]									
7/21/70 - 8/26/70	35	227	6.5	--	--	--	--	--	--	--	--
8/26/70 - 11/11/70	76	39	0.5	--	--	27	0.4	77	1.0	--	--
11/11/70 - 1/24/71	74	134	1.8	139	1.9	--	--	--	--	--	--
1/06/71 - 1/24/71	18	--[3]	--	--	--	--	--	60	3.3	--	--
1/06/71 - 2/16/71	41	--	--	--	--	--	--	384	9.4	--	--
1/24/71 - 2/16/71	23	--	--	--	--	--	--	361	15.7	--	--
1/24/71 - 3/16/71	51	692	13.6	188	3.7	143	2.8	--	--	--	--
2/16/71 - 3/16/71	27	--	--	--	--	--	--	35	1.3	--	--
3/16/71 - 4/01/71	16	--	--	--	--	--	--	1	0.1	--	--
3/16/71 - 4/20/71	35	4,562	130.3	1,531	43.7	469	13.4	--	--	--	--
4/01/71 - 4/12/71	11	--	--	--	--	--	--	122	11.1	--	--
4/20/71 - 5/25/71	35	2,300	65.7	1,181	33.7	--	--	--	--	--	--
5/25/71 - 6/26/71	32	2,320	72.5	895	28.9	--	--	--	--	21	0.6
6/26/71 - 8/24/71	59	142	2.4	536	9.1	--	--	--	--	--	--
8/24/71 - 10/27/71	64	21	0.3	70	1.1	--	--	--	--	--	--

[1] Spat size ranged from 0.25 to 27.0 mm shell height.

[2] Spat traps were positioned about 0.6 m above ocean floor.

[3] Dashes indicate no data (i.e., trap was not exposed, or if exposed, not recovered).

Table 3. Vertical distribution of calico scallop spat at monitoring sites off Cape Canaveral, Florida, November 1970 to October 1971.

Spat trap exposure period	Buoy 1			Buoy 2		
	Surface	Intermediate	Bottom	Surface	Intermediate	Bottom
	number of spat per trap per day					
11/11/70 - 1/24/71	--[1]	1.2	1.8	--	2.2	1.9
1/24/71 - 3/16/71	--	1.0	13.6	--	0.7	3.7
3/16/71 - 4/20/71	--	110.5	130.3	--	44.4	43.7
4/20/71 - 5/25/71	0.5	136.0	65.7	0.3	75.9	33.7
5/25/71 - 6/26/71	--	41.7	72.5	--	26.5	28.9
6/26/71 - 8/24/71	--	2.2	2.4	--	15.2	9.1
8/24/71 - 10/27/71	--	1.3	0.3	--	1.2	1.1

[1] Dashes indicate no data.

Note: Surface traps were positioned about 0.9 m below ocean surface, intermediate traps 6.0 m above ocean floor, and bottom traps 0.6 m above ocean floor.

arrays more abundantly at sites 19 km offshore than at sites 4 or 41 km offshore (Pequegnat and Pequegnat, 1968).

The usual distribution of adult calico scallops indicates that the larvae are restricted to open marine water. The larvae, however, sometimes enter estuarine waters, based on reported occurrences in semi-enclosed sounds of juveniles in North Carolina (Waller, 1969) and adults in Bermuda (Aurelia, 1970). There was no evidence that the larvae survived and set in estuarine waters in the Cape Canaveral area. Relatively few spat were caught at Port Canaveral RWR6 Buoy, the site closest to shore and to an estuarine inlet (Figure 2, Table 1). Furthermore, a year-long biofouling study at nearby Ponce de Leon Inlet produced three species of mollusks, but no scallops (Richards and Clapp, 1944).

Larval calico scallops are apparently distributed throughout the water column, since spat were found in traps positioned at the ocean surface, at intermediate depths, and near the bottom (Table 3). Similar vertical distribution of larvae was indicated by Pequegnat and Pequegnat (1968) who reported calico scallop spat from biofouling arrays distributed from surface to bottom in 46 m of water in the northeastern Gulf of Mexico. Off Cape Canaveral at Buoys 1 and 2, from April 20 to May 25, 1971, there were very few spat in the surface traps as compared with those in the intermediate and bottom traps. At each of these two sites, comparisons of intermediate and bottom catch rates between November 1970 and October 1971, showed that vertical distribution of spat was highly variable during certain exposure periods, indicating variations in larval abundance or spat survival between the intermediate depths and the bottom at these seasons (Table 3).

Calico scallop spat were caught year-round in traps off Cape Canaveral; at least a few spat were caught during every exposure period (Table 2). This suggests continuous recruitment of young scallops to the population on the grounds, although there may not be a simple relationship between setting success in the traps and success on natural substrate in the immediate area. For example, while the numbers of spat at Buoy 1 generally exceeded those at Buoy 2 (Table 2), trawl catches of adult scallops on the ocean floor at Buoy 2 greatly exceeded those at Buoy 1. The substrate at Buoy 1 consisted of sand and flat conglomerate rocks, while that at Buoy 2 was sand and live shell rubble.

There were distinct seasonal variations in spat abundance. At Buoy 1, between July 21, 1970 and October 27, 1971, catches ranged from 0.3 to 130.0 spat per trap per day. Based on catches at Buoy 1, where the data are most complete, and supplemented by data from Port Canaveral R2 Buoy, the great majority of spat were caught in traps exposed between January 6 and June 26, 1971, with peak numbers from March 16 to April 20, 1971. Relatively few spat were caught during the remainder of the year. A similar pattern of spat abundance occurred at Buoy 2 (Table 2).

Age and Growth

Age and growth of young calico scallops were estimated from the maximum sizes of spat caught in the spat traps at the end of each exposure period. For example, spat traps exposed for 35 days contained spat ranging from 0.25 to 10.0 mm shell height; the size composition from one trap is shown in Figure 5. Assuming no movement of spat into the traps after initial setting, the setting time of these scallops had to be within the 35-day exposure period. Under laboratory conditions, calico scallop larvae set 16 days after spawning, at about 0.25 mm shell height (Costello et al., 1973). Therefore, age of the 10.0 mm spat in the traps could not exceed 51 days (16 days from spawning to set, plus a maximum of 35 days in the traps.) In estimating growth, it was assumed that the largest spat in the traps (10.0 mm shell height) set on the first day of trap exposure. Evidence that spat set soon after the traps were exposed was based on the size ranges of spat in traps exposed for short periods of time. In one trap exposed for 11 days, many spat from 0.25 to 1.0 mm shell height were found. Since spat set at 0.25 mm shell height, it is reasonable to expect that the 1.0 mm spat set first, on or soon after the first day of trap exposure. While this assumption regarding time of spat setting may not be entirely correct for all situations, it is probably the best assumption that can be made based on the available data. If it is assumed that the largest spat set *after* the first day of trap exposure, then estimated growth would be more rapid than reported here.

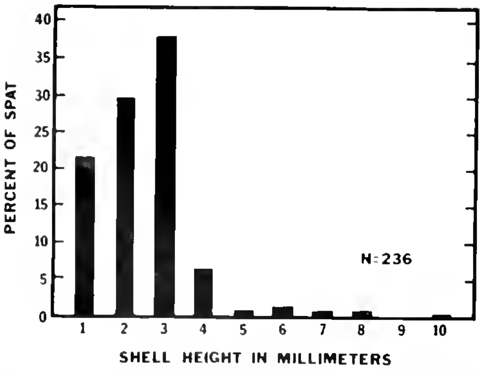

FIG. 5. *Size composition of calico scallop spat from spat trap exposed at Buoy 1 off Cape Canaveral, Florida, April 20 to May 25, 1971*

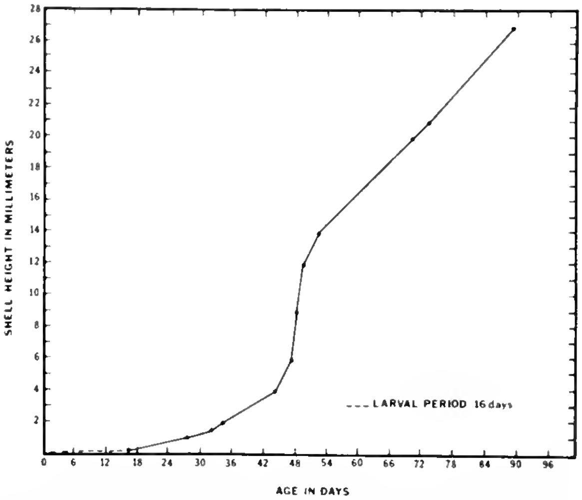

FIG. 6. *Estimated age and growth of calico scallop spat from spat traps exposed off Cape Canaveral, Florida, March 1970 to October 1971. Age is number of days from spawning to set (16) plus number of days of spat trap exposure.*

This method of estimating age as related to size was applied to the largest spat from each exposure period and the results are shown in Figure 6. Based on these data, calico scallops are capable of reaching approximate sizes of 1.5 mm shell height in 1 month from spawning, 17.0 mm in 2 months, and 28.0 mm in 3 months. This growth rate is compatible with results of preliminary studies of marked calico scallops on the Cape Canaveral grounds, reported by Miller and Hudson[7], which indicate that scallops reach 10 to 15 mm shell height in 6 to 8 months.

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[7] Miller, G. C. and J. H. Hudson. Age and growth of the calico scallop, *Argopecten gibbus*. Manuscript in preparation, National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, Miami, FL 33149.

Preliminary studies indicate that growth rate of spat in the traps is affected by location in the water column and, probably, by the density of spat. At Buoy 2, spat in a trap 0.6 m above the ocean bottom grew more rapidly than those in traps 6.0 m off the bottom and 0.9 m below the water surface. Similarly, Merrill and Posgay (1968) observed that juvenile sea scallops grew faster on the ocean bottom than on navigation buoys. Also at Buoy 2, in three traps located 0.6 m off the bottom and exposed for 72 days, the maximum size of spat in each trap decreased with increased number of spat per trap.

Behavior

Information concerning setting and byssal attachment of calico scallops in respect to size has been reported briefly. The larvae set at about 0.25 mm shell height in the laboratory (Costello *et al.*, 1973). Calico scallop spat have been reported by size and attachment as follows: 1 to 8 mm (presumably shell height) from plastic floats (Pequegnat, Gaille, and Pequegnat, 1967); 2.0 to 7.5 mm shell length, among epifauna on shells of living calico scallops (Wells, Wells, and Gray, 1964); and 3 to 5 mm shell length, attached to the shells of dead calico scallops, primarily (Commercial Fisheries Review, 1962).

The sea scallop showed a progressive loss of byssal attachment as size increased (Caddy, 1972). The calico scallop apparently behaves similarly, from observations on recovered spat traps. Off Cape Canaveral, setting apparently occurred at a minimum size of 0.25 mm shell height, since this was the minimum size of spat in the trap samples. Strong byssal attachment to the exteriors of the traps was shown by spat up to at least 5.0 or 6.0 mm shell height. Very few spat larger than 10.0 mm in height were found attached to the exteriors of the traps at recovery, although many spat larger than 10.0 mm were contained inside the traps where escape was impossible. This size difference suggests weakened byssal attachment by the larger spat, since most had apparently detached from the exteriors of the traps upon reaching 10.0 mm shell height or were dislodged during trap recovery. Calico scallops as large as 38 mm shell height occasionally were found attached to dead scallop shells in trawl catches on the Cape Canaveral grounds. From observations on calico scallops resting on the bottom, in Bermuda, Waller (1973) reported "The majority of the largest individuals [50 to 60 mm shell height] lie free, without byssal attachment, although many mature individuals attach a weak byssus to dead shell and coral fragments."

Associated Organisms

Setting, growth, and survival of scallops are positively influenced by certain sessile plants and animal which form a hospitable habitat. Young bay scallops attached to seagrass (Belding, 1910), algae (Marshall, 1960), and hydroids (Zahl, 1969). Young kelp scallops, *Leptopecten latiauratus* were found in the interstices of erect bryozoans (Brown et al., 1967) and attached to colonial invertebrates (particularly hydroids) and algae (Turner, Ebert, and Given, 1969). According to Dow (1969), young sea scallops first set on bryozoans that are attached to adult scallop shells and at a larger size, attached themselves directly to shells or bottom debris. Merrill and Edwards (1975) noted, however, that sea scallop spat will set "on sedentary branching plants and animals, or any other hard surface on or above the ocean floor which offers freedom of shell movement on all sides."

Before the inception of the calico scallop spat monitoring study, most calico scallop spat had been caught by trawl or dredge. Under these circumstances, spat as small as 3.0 mm shell length were found attached to the dead shells of calico scallops (Commercial Fisheries Review, 1962). Primary setting of very small calico scallop spat on filamentous plants or animals before attachment to mollusk shells was not reported. However, spat 2.0 to 7.5 mm shell length were among the epifauna attached to the shells of living calico scallops (Wells, Wells, and Gray, 1964). In addition, calico scallops 1 to 8 mm (presumably in shell height) were reported from plastic floats (Pequegnat, Gaille, and Pequegnat, 1967). Attachment, in the last two cases, was not necessarily directly to the shells or floats, but perhaps to the "pioneer" fouling organisms already affixed. Data presented by Pequegnat, Gaille, and Pequegnat (1967) indicated that calico scallop spat occurred in greater numbers on plastic floats exposed 8 and 12 weeks than on floats exposed 2 and 4 weeks, and that the floats

Table 4. Estimated spawning periods of calico scallops off Cape Canaveral, Florida, July 1970 to September 1971.

Spat trap exposure period[1]	Catch of spat	Minimum spat size	Estimated age of spat	Estimated spawning period
	(per day)	(mm)	(days)	
7/21/70 - 8/26/70	6.5	3.0	39	7/05/70 - 7/18/70
8/26/70 - 11/11/70	0.5	4.0	44	8/10/70 - 9/28/70
11/11/70 - 1/24/71	1.8	1.0	27	10/26/70 - 12/28/70
1/06/71 - 2/16/71	9.4	0.75	23	12/21/70 - 1/24/71
1/24/71 - 2/16/71	15.7	0.5	20	1/05/71 - 1/27/71
1/24/71 - 3/16/71	13.6	1.5	32	1/08/71 - 2/12/71
3/16/71 - 4/20/71	130.3	1.0	27	2/28/71 - 3/24/71
4/20/71 - 5/25/71	65.7	1.0	27	4/04/71 - 4/28/71
5/25/71 - 6/26/71	72.5	1.0	27	5/09/71 - 5/30/71
6/26/71 - 8/24/71	2.4	0.75	23	6/10/71 - 8/01/71
8/24/71 - 10/27/71	0.3	4.0	44	8/08/71 - 9/13/71

[1] Traps were located at Buoy 1 except for those exposed from 1/06/71 to 2/16/71 and 1/24/71 to 2/16/71, which were at Port Canaveral R2 Buoy. All traps were positioned about 0.6 m above the ocean floor.

acquired growths of hydroids before calico scallops became present.

During the present study, filamentous marine plants and animals were found attached to array lines and spat traps. On more than one occasion, small calico scallop spat 0.75 to 4.5 mm shell height (mostly 1.5 to 2.0 mm) were found among attached hydroids (unidentified). Attempts at sea to determine if spat were byssally attached to the hydroids, rather than directly to array lines or spat traps, were unsuccessful because of rough sea conditions, and live spat had detached before microscopic examination could be made. These observations suggest, however, that very small calico scallop spat may utilize filamentous host organisms for setting, perhaps before later attachment directly to shell. A cycle of dependence may be operating, since certain species of hydroids and erect bryozoans, which may host calico scallop spat, were reported by Wells, Wells, and Gray (1964) as common among epifauna attached to the shells of living calico scallops.

Most organisms in the spat traps apparently arrived as planktonic larvae and included numerous invertebrates (coelenterates, annelids, mollusks, echinoderms, crustaceans, and tunicates) and, rarely, fishes. Calico scallops were generally the dominant macroscopic animals in respect to biomass and, with the possible exception of amphipods, in numbers. Barnacles were common in the traps and were sometimes attached to calico scallop spat. At least some barnacles attach when calico scallops are young; a barnacle 2.0 mm diameter at its base was found attached to a spat 5.0 mm shell height.

Ecological succession in the spat traps may have been modified or hastened by the effect of the filamentous strands of polyethylene. Contents of one spat trap exposed for only 11 days indicated very rapid development of the biofouling community or assemblage. Included were 121 calico scallop spat 0.25 to 1.0 mm shell height, 125 gastropod mollusks, and 250 amphipods. There were less than 10 each of bivalve mollusks (other than calico scallops), isopods, copepods, mysids, crabs, and polychaetes.

ADULTS

Spawning

The abundance and size of calico scallop spat caught during successive trap exposure periods were used to estimate the season and intensity of adult spawning. The size of the smallest spat caught during each exposure period (Table 4) was related to age (Figure 6). For spat caught during each exposure period, spawning was estimated to have extended from 16 days before the trap was first exposed to the date the trap was recovered, less the age in days of the smallest spat caught. It was assumed that spat abundance primarily reflected seasonal spawning intensity, rather than variations in survival of larvae and spat. Estimated spawning periods from July 1970 to October 1971 are shown in Table 4. Spawning apparently occurred during all seasons, but intensity was greatest in the spring. Following low spawning intensity in July, and lower intensity from August into December, spawning increased in late December or January and peaked in March. High spawning intensity continued through April and May, followed by an abrupt decrease in June and low spawning intensity into September.

There is no direct evidence that spat setting on the Cape Canaveral grounds are entirely or partially the first generation progeny of scallops spawning in that area. However, the spawning pattern determined from seasonal distribution and abundance of spat in this study is similar to the spawning pattern determined from ovarian color changes of calico scallops on the Cape Canaveral grounds (Roe, Cummins, and Bullis, 1971; Miller, Allen, Costello, and Hudson[8]). Furthermore, as explained previously, water circulation in the Cape Canaveral area might be expected to retain scallop larvae on the grounds until setting occurs.

Spawning of calico scallops, similar to spawning of other bivalves, is influenced by water temperature changes. In the laboratory, spawning of ripe calico scallops was induced by raising water temperatures from about 20° to 25°C (Costello *et al.*, 1973), but these temperatures are not necessarily critical for spawning. In the natural environment off Cape Canaveral, daily mean temperatures of bottom water at Buoys 1 and 2 are available for most of the period from March 28, 1970 to August 24, 1971, and ranged (combined) from 16.3° to 26.9°C (Leming, 1979). During the period of apparent minimum spawning, August through November 1970, bottom temperatures at these sites ranged from 18.3° to 26.9°C, while during apparent maximum spawning, March through May 1971, temperatures fluctuated between 16.9° and 22.0°C. Temperatures at Buoys 1 and 2, however, were recorded in water 18 and 22 m deep, shoaler than the 28 to 65 m depths where most of the scallops occur off Cape Canaveral (Allen and Costello, 1972). Therefore, the temperatures at Buoys 1 and 2 often varied from those associated with the large concentrations of scallops in deeper water. On the shelf off Cape Canaveral there was a general onshore movement of 18°C bottom water beginning in March 1971 (Leming, 1979). This cold water passed over the concentrations of scallops expected to be mostly ripe during March, April, and May and perhaps triggered successive spawning.

DISCUSSION

The spat monitoring techniques used in this study were useful in determining certain preliminary information concerning the biology of the calico scallop. However, ecological succession and other alterations with time in an exposed spat trap provide a continually changing environment, affecting both spat setting and survival. In this low-priority study, the scheduling of trap exposure was governed by the availability of ship time. In future studies to measure seasonal abundance and distribution of spat, monitoring should be further standardized by scheduling trap exposure for relatively short time periods of uniform length and interval throughout the year. These refinements would also serve to more precisely fix spawning time and provide measures

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[8] Miller, G. C., D. M. Allen, T. J. Costello, and J. H. Hudson. Maturation of the calico scallop, *Argopecten gibbus*, determined by ovarian color changes. Manuscript in preparation, National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, Miami, FL 33149.

of early spat growth by season. Expansion of spat monitoring over wider areas, both on the Cape Canaveral grounds and on the Florida-Hatteras and West Florida shelves, would provide insight into the origin of the larvae and the relationship of varying water temperature regimes to spawning, setting, and survival.

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FACTORS INFLUENCING DISTRIBUTION OF MUSSELS IN THE BLANCO RIVER OF CENTRAL TEXAS

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ABSTRACT

Environmental parameters that influence the distribution of eight mussels in the Blanco River of Central Texas were studied. The effects of type of substrate, stream flow rate and physicochemical features on mussel distribution were evaluated, but emphasis was given to the role of organic enrichment of the river by a city sewage treatment plant. From tolerance tests to ammonia and low oxygen on five local mussels and from field studies, the following remarks can be made about mussel distribution in the Blanco River.

(1) Low dissolved oxygen levels (0 - 0.5 mg O_2 1^{-1}*) proved lethal to 47% of the mussels tested in seven days.*

(2) Levels of 5 mg $NH+_4$ - $NH_3 1^{-1}$ *(pH 7.8 to 8.0;* NH_3 - $N = 0.26$ *mg -1) were lethal to 40% of the mussels tested in seven days.*

(3) Corbicula manilensis *was more tolerant, and* Amblema p. plicata *less tolerant than the other mussels tested to elevated ammonia and low oxygen concentrations associated with sewage enrichment.*

(4) Even though the physicochemical parameters did not indicate stressful conditions on the days sampled, mussels of the Blanco River seemed to have been adversely effected by enrichment from the secondary sewage treatment plant of San Marcos. Fewer mussels were found downstream from the sewage plant than upstream, even where the river bottom, depth, and flow rates were similar.

INTRODUCTION

The use of freshwater mussels (Bivalvia) as aquatic indicators of ecological changes brought about by agriculture, mining practices, effluents from industrial and or domestic disposal plants has not been studied extensively. Freshwater mussels might be valuable indicators of both past and present ecological conditions of aquatic environments.

For the following reasons, mussels might be especially good as indicators of stream conditions.

(1) Unlike plankton or free swimming fauna, bivalves as benthic invertebrates usually remain in relatively fixed positions in streams (Weber 1973).

(2) Mussels can directly absorb nutrients, simple organic compounds (Churchill 1916) and various pollutants. Such pollutants might be pesticides, radioactive materials and heavy metals which often would show up in biologically magnified concentrations (Weber 1973; Butler 1965; Fuller 1974; Bedford *et al.* 1968; Mathis and Cummings 1973). Bivalves also indirectly reflect ecological conditions by taking up pollutants by feeding from the basic trophic levels or aquatic food chains (Fuller 1974).

(3) The freshwater mussels (Unionacea) have relatively long life cycles, up to 17 years and longer (Williams 1969; Bedford *et al.* 1968). Therefore, their community and population structures are accumulatively affected by environmental perturbations (Weber 1973).

(4) Unlike periodic chemical analyses, the benthic mussels are continuously exposed, except when buried, to the water conditions and might reflect variable or infrequent discharges of pollutants (Weber 1973).

Our present knowledge is insufficiently detailed, however, to define Unionaceae or Sphaeriidae (Pisidiidae) as pollutional indicators in chemical terms (Fuller 1974; Ingram 1967). A great deal of work needs to be done on identifying the reactions of bivalves to specific natural factors in the environment, and on the reactions of mollusks to pollutants (Butler 1965).

Recently, Neel and Allen (1964) noted the decimation of various mussel populations in the upper Cumberland Basin by coal mine acids, while Charles (1964) found that very heavy populations of mussels have been virtually destroyed by brine pollution from oil wells. Even potassium has been suggested to regulate the survival and distribution of freshwater mussels (Imlay 1973).

Because they concentrate certain pollutants otherwise not detectable in water or sediments, mussels have been utilized as indicators of pesticide and metal pollution (Bedford *et al.* 1968; Mathis and Cummings 1973). The bivalves concentrated both pesticides and metals in higher concentrations than was found in the surrounding water, but contained lower levels of most of these toxic compounds than occurred in sediments. Possibly the best utilization of freshwater mussels as indicators of stream conditions is as "indicators of the biological recovery zone" (Simons and Reed 1973).

The purpose of the current study was to explore the environmental parameters that influence distribution of mussels in the Blanco River. Special emphasis was given to the effects of organic enrichment of the river by a city sewage treatment plant. Tolerance tests to ammonia and low oxygen on five species of local mussels were conducted in the laboratory in an atempt to evaluate such enrichment.

STUDY AREA

The Blanco River is located at the headwaters of the Guadalupe River Basin in central Texas. The Blanco River flows over the Edwards Plateau and joins the San Marcos River approximately 4 km east of the perimeter of the plateau. The Edwards Plateau is composed of uplifted limestones that contribute to the natural calcareous hardness of the Blanco River. At the Kyle sampling station the mean annual flow for a 19 year sampling period was 4.3 m^3 sec^{-1} (U.S.G.S. 1976). At the Kyle gauging station, about 9 km upstream from the study area, no flow levels occurred in the summers of 1956, 1963, 1964 and twice in 1971 (U.S.G.S. 1976). Except during periods of flooding, the lower portion of the Blanco River is usually transparent enough for a visual analysis of the substrate.

The drainage basin of the Blanco River above the Kyle sampling station is 1,067 sq. km. and contains little arable land. Most of the basin is sparsely populated, and agriculture consists mainly of grazing with only limited crop farming on the rocky terrain. After the Blanco River leaves the plateau, the river traverses a more populated area where crop farming predominates.

Sampling areas on the Blanco River were located between 29°55′–29°51′ latitude and 97°55′–97°54′ longitude. The study area consisted of a 6 km stretch of the Blanco River located just upstream of the confluence of the San Marcos River (Fig. 1). A secondary sewage treatment effluent enters the Blanco River approximately 2 km downstream from the headwaters of the study area. The sewage effluent, except under very low flow conditions, is diluted naturally by a side channel of the river before it reaches the main stream. In the faster moving waters of the

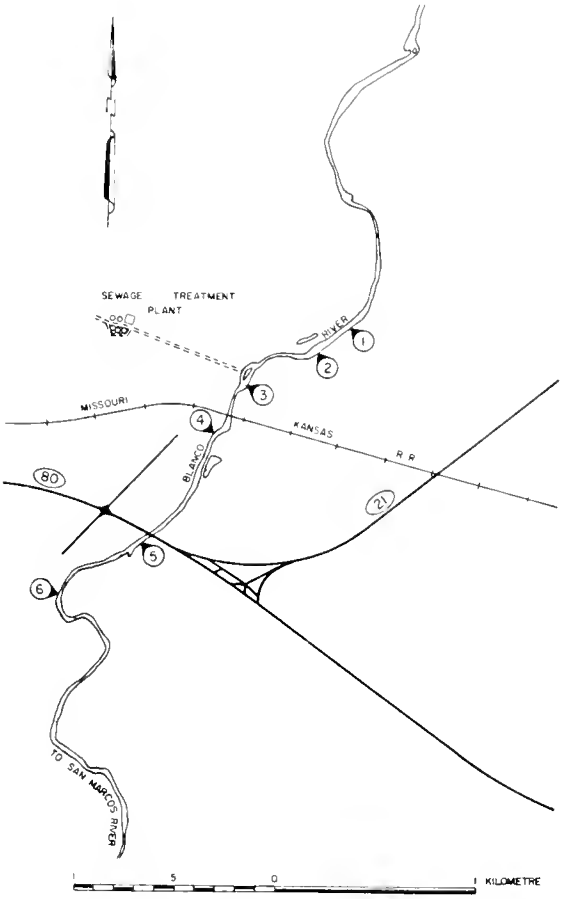

FIG. 1. *Location of sampling sites on the Blanco River, Texas.*

diluted side channel, toxicity study areas were established about 50 m before and after the point of entry of the sewage. Three sampling stations for physicochemical analyses of the river were located (1) about 50 m above (Station 3), (2) 200 meters (Station 4) and (3) 2 kilometers below (Station 6) the site where the sewage effluent enters the river (Fig. 1).

METHODS AND MATERIALS

Qualitative and Quantitative Determinations

Qualitative and quantitative mussel counts were performed at mid-day by visual inspection while wading or scuba diving in the deeper pools. The entire study area was quantitatively sampled for freshwater mussels. Three quantitative counts were made at stations above, and two quantitative counts below the sewage effluent (Fig. 1). Quantitative counts were made in 10 m^2 areas utilizing ten one meter transects. After identifying and recording the specimens, they were lifted from the substrate to prevent duplications. Only those individuals exposed or actively siphoning in the substrate were utilized in the quantitative determinations.

Mussel specimen identifications were made utilizing the taxonomic keys of Burch (1973), Murray (1962; 1968), Simpson (1913) and Strecker (1931). Identifications were checked and verified by Dr. H. D. Murray of Trinity University in San Antonio, Texas, and Dr. David Stansbery of Ohio State University in Columbus, Ohio. Specimen were deposited at Ohio State University (Collection Numbers OSUM: 1976: 352-361).

Tolerance Tests

Specimens utilized in the tolerance tests were collected in central Texas near the study area. The specimens were then placed in aerated aquaria for a minimum of five days for acclimation to laboratory conditions. During the period of acclimation and testing, the experimental and control specimens were not fed. Before being utilized in the toxicity tests each laboratory specimen was washed and scrubbed to remove adhering organisms. The ventral margins of the bivalves were notched with a triangular file so that the bivalves would be constantly exposed to the stressors. At least eight specimens of each species were utilized in the toxicity tests.

The chlorine content of the tap water used in the experiments ranged from 0.2 - 0.4 mg l^{-1} and was removed from the test waters by aeration or bubbling nitrogen. The total alkalinity of the water varied from 200 to 250 mg l^{-1} and depended upon the stressor(s) utilized. The total alkalinity of water from which the organisms were collected varied from 150 to 200 mg l^{-1}. The temperature of the experiments was ambient room temperature which was usually between 24°–26° C. The hydrogen ion concentration (pH) ranged between 7.8 and 8.2 during the laboratory experiments. At an average pH of 8.0 a solution containing ammonia ($NH+_4$ -NH_3) would consist of 94.7% ammonium ions and 5.3% ammonia gas (NH_3). In this manuscript the term ammonia refers to both the ionic and gaseous form, even though the gaseous ammonia is the toxic form.

At no time were more than four larger mussels used in a single experiment. The bivalves

Table 1. Substrate related distribution of freshwater mussels in the Blanco River.

Species	Stream Bottom					
	Boulder	Cobble	Gravel	Pebbles	Sand	Silt-mud
Amblema p. plicata	+	+++	+++	+++	++	+
Anodonta imbecillis	-	-	-	-	-	+
Corbicula manilensis	-	+	++	++	++	+
Cyrtonaias tampicoensis	-	-	++	++	+	+
Lampsilis a. anodontoides	-	-	+	+	+	+
Lampsilis bracteata	-	-	+	+	+	+
Quadrula petrina	+	+	++	++	++	+
Toxolasma texasensis	-	-	-	-	+	+

+++ = More than 5/m^2
++ = 1-5/m^2
\+ = Less than 1/m^2
\- = Not Found

Amblema p. plicata (Say, 1817), *Anodonta imbecillis* (Say, 1829), *Corbicula manilensis* (Philippi, 1841), *Cyrtonaias tampicoensis* (Lea, 1838), *Toxolasma texasensis* (Lea, 1857) (=*Carunculina parva texasensis*) were subjected to laboratory tolerance tests for 168 hours. Specimen were removed from the testing apparatus after failure to respond to physical stimuli by closure of the valves. Death was established when the mussels did not respond by attempted closure when their valves were partially pried apart.

Low oxygen tolerance tests (0 - 0.5 mg 0_2 1 $^{-1}$) were performed in a modified 8 liter desiccator with a regulated water flow of about 300 ml hr.$^{-1}$. A 16 liter reservoir of water was deoxygenated by bubbling prepurified nitrogen gas. The deoxygenated water was mixed with a magnetic stirrer and forced through the testing apparatus with low N_2 pressure. Water samples for chemical analyses were taken from the testing apparatus by removal and subsequent replacement of standard biochemical oxygen demand (BOD) bottles that were situated before and after the specimen container. By maintaining the flow at least 300 ml hr^{-1} the dissolved oxygen (DO) levels of the incoming and outflowing waters of the specimen container were similar.

In the combination high ammonia and low oxygen tolerance tests the water was deoxygenated first and ammonia then added to the above testing apparatus. In both the combination high ammonia-low oxygen and high ammonia tolerance tests, ammonia levels of 5 ± 0.5 mg 1^{-1} (NH^3 -N = 0.26 mg 1^{-1}) were obtained by the addition of ammonium bicabonate. Bunkhalter and Kaya (1977) estimated 0.25 mg NH^3-N1^{-1} to be the incipient lethal threshold concentration for rainbow trout fry.

High ammonia tolerance tests were performed in 8 liters of aerated tap water in covered aquaria. Samples for chemical analyses were made by removal and subsequent replacement of similar amounts of water from the aquaria.

The tolerance tests in the Blanco River were performed in a side channel which contained diluted sewage. The bivalves *Amblema p. plicata*, *Anodonta imbecillis*, *Corbicula manilensis* and *Cyrtonaias tampicoensis* were put under stress. The mussels were placed in cages of 1/4 inch square mesh screen which were partially buried in the gravel substrate. The controls were located 50 m above the point of entry of the sewage and were placed in a similar substrate. The side channel toxicity tests were performed for one month periods.

Statistical analyses of the toxicity studies were performed by single factor analysis of variance and after hypothesis rejection analyses were followed by the Student Newman Kuels tests for differences in population ranges (Zar 1974). The survival times in hours were used as the observations in the statistical tests. Since the maximum utilizable value for survival time was sometimes limited by the length of the toxicity test, interpretations of the above statistical analyses were conservative.

Physicochemical Analyses

Water samples were taken with 1 liter polyethylene bottles 0.3 m below the surface on sunny mid-day periods. Water temperature was taken at the same time 0.3 m below the surface in shaded areas. Chlorine levels were determined in the field. Stream velocities were measured with a U.S.G.S. Pigmy current meter. Chlorine levels were determined in the field, whereas samples for pH, alkalinity, DO, NH^+_4 -N, BOD_5 and total mercury were analyzed within forty-five minutes of collection in the laboratory. Samples for the determinations of Kjeldhal nitrogen, total dissolved phosphate-phosphorus, and potassium were stored at -20°C and analyses were conducted within three hours of collection. Chemical analyses of water were performed according to *Standard Methods for the Examination of Water and Wastewater* (A.P.H.A. 1975).

Sediment analyses were performed utilizing the modified Wentworth grade classification (Home and McIntyre, 1971 and Weber, 1973). The substrate was scooped into a container placed just downstream and analyzed using U.S. Standard sieves. Hydrogen ion concentrations were determined with a standardized Beckman Expandomatic pH meter. Total alkalinity analyses were performed by titration with 0.02N H_2SO_4 to a pH of 4.5. Dissolved oxygen determinations were performed utilizing the alkali-azide modification of the Winkler method. Ammonia nitrogen analyses were made by distillation of the ammonia into boric acid followed by nesslerization. Kjeldahl nitrogen determinations were made by sample digestion followed by distillation and nesslerization. Total dissolved phosphate-phosphorus samples were first filtered through 0.45 micron filters and then treated to persulfate digestion and the color developed by the ascorbic acid method. Chlorine levels were determined utilizing the orthotolidine colorimetric methods. Total mercury analyses were performed by the cold vapor technique using a mercury analyses system connected to an atomic absorption spectrophotometer. Total potassium ion determinations were made utilizing an atomic absorption spectrophotometer.

RESULTS

Qualitative Sampling and Species Distribution

Living specimens of eight species of freshwater mussels, and shells of *Anodonta g. grandis* (Say, 1829) and *Lampsilis anodontoides fallaciosa* (Smith, 1899), were collected in the Blanco River study area (Table 1).

The type of stream bottom and the corresponding flow patterns seemed to limit the distribution and perhaps the abundance of some of the species (Table 1). Local geologic formations (recent alluvium) and periodically high stream velocities created a bottom composed of a gravel-cobble substratum in the faster flowing portions of the stream. Only on the periphery of the larger pools where the current was slow was a mud-silt bottom found (Fig. 1). All species collected in the river were present, although sometimes sparsely, in mud-silt substrates.

Individuals having relatively heavy shells, such as *Quadrula petrina* and *Amblema p. plicata*, were the only species found in waters with average stream velocities of 1 m sec^{-1} or greater. In these waters the bottom was typically composed of cobbles with some boulders and gravel present. Although *Corbicula manilensis* has a relatively thick shell its small size probably limits it from occurring in the swiftest waters (Table 1).

Freshwater mussels with shells of intermediate thickness such as *Cyrtonaias tampicoensis, Lampsilis a. anodontoides* (Lea, 1834) and *Lampsilis bracteata* (Gould, 1855) generally were found in regions of intermediate stream velocities (0.5 - 1 m sec^{-1}) where the usual bottom composition was coarse and/or medium sized gravel. The very thin shelled *Anodonta imbecillis* and the small sized *Toxolasma texasensis* were restricted to areas with the finest types of substrate material (Table 1), and both were rarely found in the river.

Physicochemical Parameters

During the sampling period from July, 1976, to June, 1977, the minimum flow was 1.5 m^3 sec^{-1} and the maximum flow was about 112 m^3 sec^{-1} at the Kyle gauging station. Unlike previous years very low or no flow periods did not occur during the sampling year. Water temperatures varied from 11.5°C in January, 1977, to 31.0°C in August, 1976. Secchi disc transparency varied from 0.8 m to 2.1 m in the Blanco River. Generally, transparency increased during low flow periods and decreased during high flow periods.

The secondary sewage plant adjacent to the Blanco River usually received less than 30% of the total sewage load of San Marcos. The mean flow through the sewage treatment plant for the twelve month sampling period was 0.84 million gallons/day (mgd) with extremes of about 0.05 to 1.1 mgd.

For June, 1977, average effluent values for the treatment plants and the diluted sewage of the side channel are given in Table 2. Also for June the sewage enriched side channel of the Blanco River (Fig. 1) had a total flow of approximately 0.1 m^3 sec^{-1} of which about 20 - 50% was sewage effluent, depending upon the amount of effluent discharged. During the same period, the Blanco River received an average of 110 kg BOD_5 day^{-1}, 90 kg potassium day^{-1}, 50 kg of ammonia-N day^{-1} and 9 kg of total phosphate-phosphorus day^{-1} . The secondary treatment plant received waste from only the northeast portion of San Marcos.

Total mercury analyses for the sewage effluent and water samples from the Blanco River in March, 1977, were below detectable limits (less than one microgram l^{-1}). Chlorine also was not detectable (less than 0.1 mg l^{-1}) in the enriched side channel. Chemical parameters which were monitored at Stations 3, 4 and 6 (Fig. 1) are presented in Table 2. Where the sewage effluent entered the river, all parameters increased, except dissolved oxygen and pH. The largest increases occurred with ammonia and total dissolved phosphate which increased 300% and 100%, respectively. At the sampling station located 2 km downstream from the treatment plant (Site 6), all parameters were more similar to the uncontaminated waters above the sewage effluent. Only dissolved oxygen returned to its upstream (Site 3) concentration at the

Table 2. Water chemistry determinations for the sewage effluent and diluted sewage in Blanco River side channel.

Parameter (mg l^{-1})	Sewage effluent	Side channel (diluted sewage)
BOD_5	44.20	9.00
Chlorine	0.80	0.00
Dissolved oxygen	6.40	7.55
$NH_4^+ + NH_3$-N	18.40	6.80
pH (units)	7.65	7.85
Potassium	33.00	7.80
Total alkalinity	276.00	240.00
Total dissolved phosphate-phosphorus	3.30	1.70

Table 3. Water chemistry determinations for the Blanco River.

Parameter (mg l^{-1})	Twelve month average (range) Above (Site 3)	 Below (Sewage Plant)	 Downstream (Site 6)
BOD_5	1.2 (0.9 - 2.2)	1.8 (1.0 - 5.0)	1.6 (1.0 - 2.6)
Dissolved oxygen	8.97 (6.75 - 10.42)	8.79 (6.88 - 10.35)	8.97 (7.42 - 10.37)
$NH_4^+ + NH_3$-N	0.03 (0.01 - 0.05)	0.09 (0.01 - 0.27)	0.06 (0.01 - 0.14)
Organic - N	0.24 (0.09 - 0.36)	0.38 (0.09 - 0.63)	0.36 (0.08 - 0.49)
Potassium	2.06 (1.70 - 2.70)	2.27 (1.85 - 2.85)	2.48 (1.85 - 2.78)
pH (units)	7.88 (7.74 - 8.02)	7.87 (7.74 - 8.02)	7.89 (7.75 - 8.02)
Total alkalinity	193.00 (165 - 212)	197.00 (170 - 224)	196.00 (170 - 224)
Total dissolved phosphate-phosphorus	0.12 (0.04 - 0.26)	0.24 (0.05 - 0.49)	0.22 (0.04 - 0.72)

downstream station (Site 6). The nutrient levels of ammonia-N best indicated the enrichment of the sewage effluent upon the Blanco River (Table 3).

Tolerance Tests

The laboratory tolerance tests were chosen because they measured parameters that were potentially toxic to freshwater mussels and which may result from organic enrichment. Since the laboratory tests lasted only seven days, highly stressful conditions were needed for definitive results. Nevertheless, the concentrations chosen were environmentally realistic. During the laboratory tolerance tests, it was frequently observed that the more tolerant species had their shells tightly shut, while the least tolerant species usually continued siphoning or had their mantles exposed.

The exotic asiatic clam *(Corbicula manilensis)* demonstrated greatest survival to low oxygen conditions (Table 4). The native mussels, *Anodonta imbecillis* and *Toxolasma texasensis*, also had relatively high survival capacities to low dissolved oxygen, whereas *Cyrtonaias tampicoensis* and *Amblema p. plicata* had the lowest survival tolerances. *Amblema p. plicata* had a significantly lower survival tolerance to low dissolved oxygen (Table 5). Although the four other species exhibited large differences in their survival capacities (Table 4), they were not significantly different at 95% confidence limits (Table 5).

Toxolasma texasensis demonstrated the highest survival capacity during the aerated high ammonia tests (Table 6), whereas *Anodonta imbecillis* and *Amblema p. plicata* had the lowest tolerance to high ammonia concentrations. Due to their frequent gaping, snapping of valves and extrusion of glochidia when gravid, *Anodonta imbecillis* appeared to be the most stressed species. All species frequently secreted mucous at the beginning of the aerated ammonia experiments. The interspecific survival capacities were not statistically different at 95% confidence limits for the mussels in high ammonia (Table 5).

In the combination high ammonia—low oxygen tolerance tests, *Corbicula manilensis* again demonstrated the highest survivorship (Table 7). No apparent synergistic effects were detected in the combination high ammonia—low dissolved oxygen tests. Interspecifically, *Amblema p. plicata* had significantly lower survival tolerance and *Corbicula manilensis* had significantly higher tolerance as compared to most of the other species (Table 5).

Survival of the mussels, except *Corbicula manilensis* in the combination low oxygen—high ammonia tests, appeared to be related to the mussel's tolerance to one of the two most stressful parameters. Intraspecfic survival capacities in the laboratory tolerance tests were not significantly different at the 95% confidence limit.

The tolerance tests in diluted sewage again demonstrated that *Corbicula manilensis* had significantly higher survival capacities (Table 5 and 8). *Amblema p. plicata* had significantly lower tolerance to the diluted sewage, while *Crytonaias tampicoensis* and *Anodonta imbecillis* exhibited intermediate survival capacities that were not significantly different from each other.

The levels of potential toxicants in the sewage side channel are given in Table 2. Ammonia and possible potassium were found at potentially lethal concentrations. However, the measured daylight and nocturnal oxygen levels did not appear near the lethal range nor potentially stressful during the tolerance tests. Although low oxygen levels may not have been present in the sewage side channel (Table 2), the relative tolerance of the mussels was comparable to their survival capacities in the combination low oxygen—high ammonia tolerance tests (Tables 5, 7 and 8).

Quantitative Samples

Quantitative sampling sites were chosen in areas with similar substrates at mid-stream locations in both the slow and fast moving waters. The substrate composition shown in Table 9 is from faster moving waters (0.3 - 1.5 m deep), but even at the sampling stations in the slower moving waters (1 - 4 m deep) more than 90% of the substrate was composed of fine gravel or larger. All quantitative sampling sites were located in areas containing relatively high populations of freshwater mussels. Therefore, data presented in Table 10 is representative of the more dense mussel populations of the Blanco River. Marked differences were noted in the number of species and the populations of mussels above and below the point of entry of the sewage effluent (Table 10). Initially during the study period large numbers of mussels were found in the river immediately below the sewage effluent (Fig. 1). At the end of the study period in July, 1977, very few mussels were found alive at this site. The large numbers of mussels initially found in the uppermost portion of the enriched study area may have been transported by floods from a large bed of mussels found just upstream at Site 3 (Fig. 1).

Of the native species, *Amblema p. plicata* and *Quadrula petrina* were the most abundant. The asiatic clam *(Corbicula manilensis)* was not

Table 4. Percentage survival in low oxygen concentrations (0-0.5 mg O_2 l^{-1}).

Species (Number used)		55 hr	110 hr	165 hr
Amblema p. plicata	(8)	88	0	0
Anodonta imbecillis	(8)	100	88	75
Corbicula manilensis	(8)	100	89	89
Cyrtonaias tampicoensis	(8)	88	62	38
Toxolasma texasensis	(8)	100	88	62

Table 5. Statistical analyses of tolerance tests (SNK) for interspecific mean survival times.

Species	Tolerance Test Low O_2	High NH_3	Low O_2 + High NH_3	Diluted Sewage
1) *Amblema p. plicata*	-S(all)	NS	-S(3,4,5)	-S(all)
2) *Anodonta imbecillis*	+S(1)	NS	-S(3)	+S(1) -S(3)
3) *Corbicula manilensis*	+S(1)	NS	+S(1,2,5)	+S(all)
4) *Cyrtonaias tampicoensis*	+S(1)	NS	+S(1) -S(3)	+S(1) -S(3)
5) *Toxolasma texasensis*	+S(1)	NS	+S(1) -S(3)	--

S = Significantly different at 95% confidence interval (-S = lower; +S = higher).
NS = Not significantly different at 95% confidence interval.

noticeably present in the study area in the spring or summer of 1976. However, immature *Corbicula manilensis* were found about 7 km upstream of the study area in the spring of 1976. Immature specimens were first evident in the study area in the spring of 1977. *Corbicula manilensis* was found in much higher concentrations above the sewage effluent than given in Table 9. Densities of up to 50 m^{-2} of small individuals were found in the uncontaminated headwaters of the Blanco River side channel (Fig. 1). The highest numbers of *Corbicula manilensis* occurred in sand-fine gravel substrates. No living specimens of *Corbicula manilensis* were found below the entrance of the sewage effluent in the Blanco River.

DISCUSSION

From the previous records of Strecker (1931) all of the species collected in the present study, except the exotic asiatic clam *(Corbicula manilensis)*, have been present in the Guadalupe River drainage for many years. Since *Lampsilis bracteata* is still present in the Guadalupe and San Antonio River drainages, and *Quadrula aurea* (Lea, 1859) is also present in the Guadalupe River drainage, the continued existence of these species may not be threatened. Athearn (1970) has considered both *Lampsilis bracteata* and *Quadrula aurea* as rare and endangered in central Texas.

Some species of mussels are limited in their distribution by the type of stream bottom. For example, mussels of the genus *Anodonta* and *Leptodea fragilis* were only rarely found in rocky substrates (Murray and Leonard, 1962). In the Blanco River *Anodonta imbecillis* and other species with relatively thin, light weight shells did not occur in swift waters with coarse substrates. This might be due, in part, to their physical displacement and/or destruction by the shearing forces in faster waters.

Considering the rapid dissemination and population growth of *Corbicula manilensis*, their abundance in the upper half of the study area in 1977 was not suprising even though none were noted in 1976. Gardner *et al.* (1976) observed that the population of *Corbicula manilensis* in the Altamaha River (Georgia) increased from a minimum of 0 m^2 in 1971 to a maximum of 10,000 m^2 in 1974. *Corbicula manilensis* maintains a distinctive reproductive advantage over the usually dioecious, slow growing, glochidial-producing native freshwater mussels. *Corbicula* is monoecious, incubates its free-living larvae and is sexually mature in less than one year (Gardner *et al.* 1976).

The physicochemical parameters measured from July, 1976, to June, 1977, for the Blanco River were similar to those found from other parts of the Guadalupe River drainage (Hannan *et al.* 1973; Young *et al.* 1972). The large increases of ammonia-N (300%) below the point of entrance of the sewage effluent into the river suggested organic enrichment of the stream. Ammonia values often are a good index of changes in trophic status of streams that have been influenced by excessive enrichment by organic wastes (Ellis 1937).

Although pronounced changes in the water chemistry were found below the point of entrance of sewage effluent into the river, none of the parameters measured were at concentrations known to be toxic or harmful to freshwater mussels. Upon consideration of the sources of waste entering the secondary treatment plant, excessive pollution by heavy metals or pesticides was not likely. The lack of measurable flow in the Blanco River as reported by the Kyle gauging station during previous dry periods (U.S.G.S. 1976), however, could increase the levels of potential toxicants to concentrations equal to or greater than the levels found in the diluted sewage side channel. When the Blanco River stops flowing, as it does every few years, the sewage is not diluted when it enters the river and is then the primary source of water below the sewage plant.

The levels of ammonia-N, potassium and nocturnal dissolved oxygen could be potential hazards for the mussels during such low flow periods. Imlay (1973) found potassium levels of 11 ppm to be toxic in 36-52 days to 90% of the freshwater mussels tested, and for long term survival. Imlay (1973) postulated that potassium levels should be no higher than 4 to 10 mg l^{-1}. It is doubtful that potassium would be a problem in the Blanco River. In contrast, it is well known that nocturnal dissolved oxygen deficiencies also can be critical in determining stream distribution of organisms (Gaufin and Tarzwell 1952). Organically rich pools or slow moving waters in the Blanco River might experience extreme fluctuation in O_2 concentration, especially at the mud-water interface. Considering the levels of potential toxicants (ammonia, low O_2 and potassium) in the Blanco River, as demonstrated by their values in the diluted sewage side channel, ammonia is probably the most lethal stressor to mussels during the low flow periods.

The depletion of dissolved oxygen that results from sewage enrichment has been proposed as the principle stressor influencing molluscan survival (Ingram 1957). Ellis (1937) stated that juvenile mussels are very sensitive to low oxygen concentrations and that adults usually become quiescent

Table 6. Percentage survival in high ammonia (5 mg $NH_4^+ + NH_3$-N)

Species (Number used)		55 hr	110 hr	165 hr
Amblema p. plicata	(9)	78	56	33
Anodonta imbecillis	(9)	100	67	56
Corbicula manilensis	(14)	100	95	62
Cyrtonaias tampicoensis	(10)	100	100	70
Toxolasma texasensis	(10)	100	80	80

Table 7. Percentage survival in low oxygen and high ammonia ($0-0.5$ mg O_2 l^{-1} + 5 mg NH_4^++NH_3-N)

Species (Number Used)		55 hr	110 hr	165 hr
Amblema p. plicata	(8)	100	25	0
Anodonta imbecillis	(12)	80	60	40
Corbicula manilensis	(16)	100	93	93
Cyrtonaias tampicoensis	(10)	88	80	60
Toxolasma texasensis	(10)	90	80	20

when oxygen levels are at or below 20% saturation. However, mussels generally are more tolerant of low 0_2 levels than freshwater fishes. One of the more tolerant of the freshwater fishes, the carp, survives only a short time in water containing 0.71 mg 0_2 1^{-1}. In contrast, in the low 0_2 tolerance tests (0 - 0.5 mg 0_2 1^{-1}) about 53% of the mussels tested in this study survived for seven days (Table 4).

During the laboratory tolerance tests, the mussels that did not have their valves closed for extended periods were more senstive to stressors (NH_3 and/or low 0_2). A similar conclusion was made by Ellis (1937), who reported that if mussels failed to respond by shell closure to low dissolved oxygen, then they were more vulnerable to destruction by pollution. Extended gaping of the valves usually precluded death. In the laboratory tolerance tests when a mussel began to gap its valves, death would usually follow within several hours.

Mussels that were stressed usually siphoned less and had their valves closed for longer periods than the non-stressed specimens. Badman (1975) noted that under hypoxic conditions, *Elliptio dilatatus* and *Pleurobema coccineum* increased periods of valve closure and reduced filtration rates, whereas in contrast, Allen (1923) reported widening of the siphons and mantles to pass more water through the mussel (increased respiration)

Table 8. Percentage survival to diluted sewage in the Blanco River side channel.

Species (Number Used)		7 days	14 days	21 days	28 days
Amblema p. plicata	(16)	12	0	0	0
Anodonta imbecillis	(10)	70	20	0	0
Corbicula manilensis	(20)	100	65	50	50
Cyrtonaias tampicoensis	(11)	64	27	0	0

Table 9. Substrate composition of two typical collecting areas.

Type	U.S. Series No.	Size (mm)	Percent Composition Upstream	Percent Composition Downstream
Boulder	-	256	-	-
Cobble	-	64-256	49.10	20.90
Coarse gravel	-	32-64	11.50	26.10
Medium gravel	-	8-32	24.60	36.50
Fine gravel	8	2-8	12.30	13.00
Very coarse sand	18	1-2	1.80	1.50
Coarse sand	40	0.5-1	0.62	1.54
Medium sand	60	0.25-0.5	0.02	0.32
Fine sand	120	0.125-0.25	0.04	0.10

as a result of low oxygen levels. The various species may respond differently to environmental stressors.

The mussels most tolerant of low dissolved oxygen were collected from standing or slow moving waters. For example, the more tolerant *Anodonta imbecillis* and *Toxolasma texasensis* were taken from ponds or reservoirs, while the more sensitive *Amblema p. plicata* was collected in the fast moving waters of the Blanco River. At least for some mussels, tolerance to low dissolved oxygen levels might be correlated with distribution.

Insufficient dissolved oxygen was suggested by Isom (1971) as a cause for the decline of the endemic mussel fauna in Fort Loudoun Reservoir, Tennessee. Organic enrichment of the reservoir was apparently the causative agent.

Perhaps even the rapid colonization of aquatic habitats by *Corbicula manilensis* is due to their tolerance to stressful physicochemical conditions as well as their reproductive capabilities. Hable (1970) found that *Corbicula* was resistant to low oxygen levels and that the presence of *Anodonta imbecillis* and *Corbicula manilensis* in Fort Loudoun Reservoir, when they had not been previously detected in the Tennessee River, may have been due not only to their fecundity, but also to their relative high tolerance to low dissolved oxygen. As with *Corbicula manilensis*, *Anodonta imbecillis* is monoecious and has glochidia that may develop to maturity without a living host (Murray and Leonard 1962).

The lack of significant differences in survival capacities to elevated ammonia levels demonstrated that of the mussels tested, all are relatively sensitive to ammonia. In aerated aquaria, where the pH of the testing waters varied from 7.8 to 8.2 and was similar to the pH of the Blanco River, concentrations of 5 mg ammonia-N l^{-1} were lethal to 40% of the mussels tested in seven days (Table 6). The ammonium ion (NH_4^+) is not very toxic, but molecular NH_3 is highly toxic. The proportion of ammonia to ammonium ions greatly increases with decreasing hydrogen ion concentrations, and as reported by Ellis (1937), pH is an important factor in the toxicity of ammonium compounds to aquatic animals. For instance, Ellis (1937) found that for daphnia and gammarids, the toxicity of ammonium compounds increased 200% or more as pH increased from 7.4 to 8.0.

With concentrations of 6.8 mg ammonia-N l^{-1} (pH 7.85), the diluted sewage in the side channel contained ammonium levels which exceeded the experimental ammonium levels utilized in the laboratory. The concentrations of 18.4 mg ammonia-N l^{-1} in the sewage effluent would present potentially lethal levels if the effluent composed 20% or more of the total stream flow. Such conditions would exist in the Blanco River if the flow was reduced to about 0.1 m^3 sec^{-1} which would be 15 times lower than the minimum flow (1.5m^3 sec^{-1}) found for 1976-1977.

Over long periods, much lower concentrations of ammonia may be detrimental to mussels. Ellis (1937) found that 1.5 mg ammonia l^{-1} was the maximal concentration not indicative of organic pollution. In streams with pH values ranging from 7.4 to 8.5, ammonia levels of 2.5 mg l^{-1} would tend to be detrimental to many freshwater animals (Ellis 1937). Levels of ammonia-N probably should be kept below 1 ppm in all streams containing mussel populations.

Mussels are more sensitive to ammonia than the common goldfish, *Carassius auratus*, which Ellis (1937) listed as tolerant to 10 ppm ammonium carbonate (pH 7.7) for more than four days. Conversely, and as mentioned earlier, physiologically mussels are less sensitive to low dissolved oxygen levels than goldfish. However, a mussel's chances for survival when unfavorable conditions occur is reduced by their lack of mobility and confinement to the substratum. Maximum allowable ammonia-N levels in a fishery is 0.02 mg l^{-1} (Wellingham, 1973; NAS and NAE, 1972).

In general, laboratory tolerance tests demonstrated that *Corbicula manilensis* was the least, and *Amblema p. plicata* the most sensitive of the mussels (Table 5). However, not all *Amblema* can be called "sensitive". On the basis of their high densities in "conditionally polluted areas", Richardson (1928) postulated a species of *Amblema (A. rariplicata)* to be the least sensitive of the mussels sampled in the Illinois River.

Since specimens for this study were collected by handpicking, the youngest age classes of mussels were not observed. Mussels less than three years of age are commonly overlooked when handpicking (Van Cleave 1940). No information, therefore, was collected on mussel reproduction when exposed to the stressors or on larval tolerances. It is likely that individuals of the same species, but of different ages, have dissimilar tolerances to stream pollutants (Ellis

Table 10. Quantitative samples of the freshwater mussels of the Blanco River.

	Upstream ($\bar{x}/m^2$)			Downstream ($\bar{x}/m^2$)	
Species	Site 1	Site 2	Site 3	Site 5	Site 6
Amblema p. plicata	2.7	6.8	5.7	0.0	0.1
Corbicula manilensis	1.6	0.0	1.6	0.0	0.0
Cyrtonaias tampicoensis	0.0	0.6	0.0	0.0	0.0
Lampsilis a. anodontoides	0.1	0.0	0.0	0.0	0.0
Lampsilis bracteata	0.1	0.0	0.1	0.0	0.0
Quadrula petrina	0.2	0.5	1.3	0.0	0.1

1937). Pollution tolerance data, therefore, must be viewed with caution.

Based upon the results of this study the suggestion by Weber (1970) that *Corbicula* is less tolerant than *Anodonta imbecillis* to organic pollution may be incorrect.

Due to the intolerance of mussels to diluted sewage in the side channel and because the substrate and other physical factors below the effluent of the treatment plant of San Marcos are basically similar to those factors upstream, the decreased number of mussels downstream was probably due to organic enrichment (Fig. 10). The severity of sewage pollution would increase tremendously during low or no flow periods. No other explanation is available at present to account for the disproportionate lack of mussels below the entrance of the sewage effluent in the Blanco River.

Simons and Reed (1975) noted that the molluscan segment (mostly mussels) of the benthic community represented a more sensitive portion of the macrobenthos than did most insects in the North Anna River, Virginia. The point of full "biological recovery" of the North Anna River was assumed to have been where the mussel populations had been reestablished (Simons and Reed 1975).

As suggested by Ingram (1957) and from data presented here, mussels may have value as indicators of nonpolluted waters because their presence typically indicates high dissolved oxygen and associated chemical and physical conditions. For determination of the severity of water pollution reduced numbers of "clean water" species which were formerly present in the stream may be more important than an abundance of known pollution resistant forms (Richardson 1928).

The following concluding remarks can be made from the tolerance tests and field studies.

(1) Low dissolved oxygen levels (0 - 0.5 mg O_2 l^{-1}) proved lethal to 47% of the mussels tested in seven days.

(2) Levels of 5 mg NH_4^+-NH_3 l^{-1} (pH 7.8 to 8.0 were lethal to 10% of the mussels tested in seven days.

(3) Even in waters with dissolved oxygen levels not indicative of pollution, ammonia levels can be lethal to mussels.

(4) *Corbicula manilensis* is generally more tolerant and *Amblema p. plicata* less tolerant than the other mussels tested to stressors associated with sewage enrichment.

(5) Even though the physicochemical parameters did not indicate stressful conditions on the days sampled, mussels of the Blanco River seemed to have been adversely affected by enrichment from the secondary sewage treatment plant of San Marcos. Fewer mussels were found downstream from the sewage plant than upstream.

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ALLOCATION OF "*MARGINELLA*" *CORDEROI* CARCELLES, 1953 TO A NEW GENUS IN THE VOLUTE SUBFAMILY ODONTOCYMBIOLINAE (GASTROPODA)

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Marginella corderoi was described and illustrated by Carcelles (1953:10, pl. III, fig. 17, 18) as coming from places located in the South American Atlantic littoral, at the mouth of the Rio de la Plata. The description as well as the illustrations, left us with a certain doubt about the correct allocation of the species in the genus *Marginella*.

Subsequently we examined the holotype (M.A.C.N. "Bernardino Rivadavia" N° 24194) coming to the conclusion that what we really had was a Volutidae, without being able, though, to determine the genus for lack of knowledge of the soft parts. Rios (1970:112) also expressed his doubts about it, placing the generic name in quotation marks and stating that it did not look like a *Marginella*.

Recently we have obtained on the shore of the Brasilian State of Rio Grande Do Sul (33°17'S -50°34'W Operation CEDIP II, 10-20-72, in a thin muddy bottom) some specimens of the above mentioned species with its soft parts (Col. Malc. M.N.H.N. N° 8809). We then prepared the radula and verified that the species belonged to the subfamily Odontocymbiolinae (Clench & Turner, 1964: 170). The radula is formed by a single row of rachidian teeth and each one of them is made up of a basal plate forming a medium angle (Fig. 2) from which a long, narrow, curved, hook-shaped tricuspid emerges. This characteristic, the large protoconch and the proportionally short spire, allow us to place this species close to *Odontocymbiola* Clench & Turner, 1964.

Nevertheless, the details of the sculpture, axially ribbed, crossed by thinner spiral cords clearly separate it from this genus. However, this sculpture is a characteristic of *Miomelon philippiana* (Dall, 1890) type-species of the genus *Miomelon* (Dall, 1907:365). But the latter presents a high spire and very small protoconch with a rachidian tooth formed by a basal plate, roughly rectangular, and no angle in the middle portion (Pilsbry & Olsson 1954:pl. 27, fig. 10) (Stuardo & Villarroel, 1974:145, fig. 17); these features do not agree with the species of Carcelles.

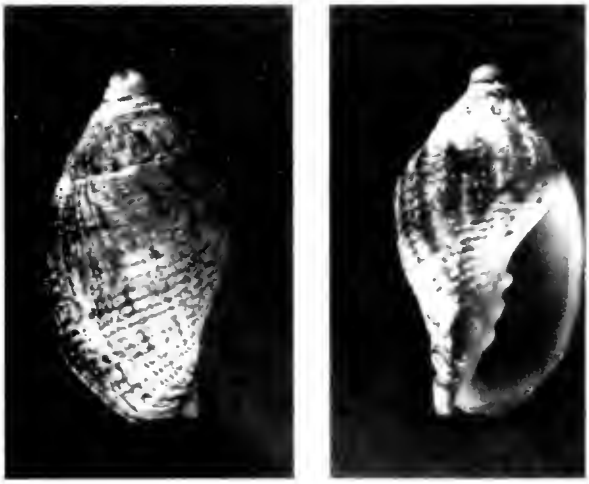

FIG. 1. Minicymbiola (new genus) corderoi *(Carcelles, 1953) Type of the genus. Paratype specimen No 3194. Malacological Collection, Museo Nacional de Historia Natural, Montevideo. 200 km west of Uruguay in 100 meters*

For the above reasons, we think that it would be convenient to establish a new genus for the species with the following diagnosis:

Minicymbiola *gen. nov.*

Type-Species: *Marginella corderoi* Carcelles, 1953

Diagnosis: Shell small within the subfamily. The largest specimen we know is 28 mm in length (N° 11.430 of the Collection Museo Oceanográfico de Rio Grande, Brazil) and it was obtained in Uruguayan waters 35°05'S and 52°40'W, 117 m in depth. Spire short; protoconch moderately large and dome-shaped. Axial sculpture formed by rounded ribs crossed by thinner spiral cords. Radula with arched basal plate forming an angle at its middle part and bearing three long, narrow and curved cusps. Periostracum and operculum are absent.

Distribution: At present, represented only by the type-species which is found in the South American Atlantic from the State of Paraná, Brazil, in the North, (Rios, 1970:112) to the Provincia of Buenos Aires, República Argentina, in the South.

Remarks: The subfamily Odontocymbiolinae, Clench & Turner, 1964, contains five genera: *Odontocymbiola* Clench & Turner, 1964; *Miomelon* Dall, 1907; *Tractolira* Dall, 1896; *Volutoconus* Crosse, 1871; and now *Minicymbiola*. The only known living species of Tractolira are from Pacific waters, off Central America, in abyssal depths. The protoconch forms an apical spur that characterizes them easily.

Volutoconus has four species restricted to Australian waters. In this genus the protoconch bears an apical spur, and other features are present that allow us to separate it from the genera known to South American waters (Atlantic or Pacific). A second species, represented only by the holotype up to now, from a locality between the Malvinas Islands and Magallanes, *Miomelon scoresbyana* Powell, 1951, possibly should be removed from this genus when its radula is known and placed in *Minicymbiola*. Its short spire, stump-shaped apex, and its sculpture consisting of very weak axial lines of growth (Weaver & du Pont, 1970: pl. 56, E.F.) similar to the ones found in *Odontocymbiola pescalia* Clench & Turner, 1964, or in young specimens of *Odontocymbiola magellanica* (Gmelin, 1791) indicate its affinity with *Odontocymbiola* and separate it from *Miomelon*.

Finally, we have the genus *Odontocymbiola* Clench & Turner, 1964, which contains four species living in South American Atlantic waters: *O. americana* (Reeve, 1856), *O. magellanica* (Gmelin, 1791), *O. pescalia* Clench & Turner, 1964 and *O. subnodosa* (Leach, 1814); the last one was included in the genus recently by Weaver & du Pont (1970:130) and by Castellanos (1970:2). The last three species present a characteristic unit that gives homogeneity to the group. This is not the case with *O. americana* (Reeve, 1856) also considered to be in the genus; but its smaller size, smooth exterior surface and rather sharp nodes separate it from the former ones. We should emphasize that Clench & Turner (1964: 129) stated that the characteristics of the shell of *O. americana* (Reeve, 1856) are closest to the ones of *Aulicina vespertilio* (Linné, 1758) from the West Pacific, but the radulae are different, placing the species in different subfamilies.

In short, it appears to be logical to include the new genus *Minicymbiola* in the subfamily Odontocymbiolinae based on the radular characteristics. Also it appears as a very distinct genus easily separated from *Odontocymbiola* by its small size and conspicuous axial sculpture and its spire. It is easily distinguished from *Miomelon* by its short spire, large and stump-shaped apex and by the conformation of the basal plate of the rachidian tooth.

The name *Minicymbiola corderoi* (Carcelles, 1953) should not be confused with another volute, *Provocator corderoi* Carcelles, 1947, an entirely different species.

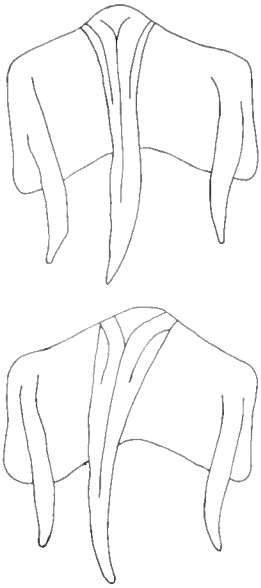

FIG. 2. *Two rachidian radulae of* Minicymbiola corderoi *(Carcelles, 1953), from a specimen off Rio Grande Do Sul, Brasil.*

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LOCALIZED EGG SHELL DISSOLUTION DURING DEVELOPMENT IN *STENOTREMA LEAI* (PULMONATA: POLYGYRIDAE)

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ABSTRACT

As the embryo of Stenotrema leai *(Binney) undergoes development, it first dissolves the calcite crystals in the outer part of the egg, not uniformly throughout the surface of the egg, but at a local area of the shell. Finally the rest of the egg shell calcium crystals are dissolved. This observation is at odds with previous explanations of egg shell dissolution only by lowering egg albumen pH. Now it seems that some larval organ is specifically applied against the egg shell and causes local calcium resorption in one area at a time. The two most likely organs which could be involved are the embryonic podocyst, which is a modification of the foot, or the mouth region.*

Recent work has clearly demonstrated that the egg shell of most land snails contains calcium carbonate crystals which the embryo utilizes for its own calcium needs during development (Tompa, 1975). Almost all the work pertaining to such embryonic calcium utilization has involved eggs which are said to be heavily calcified (Tompa, 1974), i. e., they have a brittle, hard calcium shell. In such a system, using the eggs of *Strophocheilus oblongus*, it has been shown that the egg fluid pH dramatically decreases and fluid calcium concentration concomitantly increases during development (Tompa, 1979). Because of this documentation, it appeared that all of the egg shell calcium must be dissolved at the same rate, equally all around the egg, since a pH decrease in the egg albumen fluid would cause erosion everywhere where it touches the egg shell. The present study deals with changes associated with development in the partly calcified egg of the land snail *Stenotrema leai* (Binney) (alias *monodon* (Rackett)). This study suggests that a pH change in the egg albumen is not sufficient by itself to explain the differential disappearance of calcite crystals in the outer egg layers in partly calcified eggs.

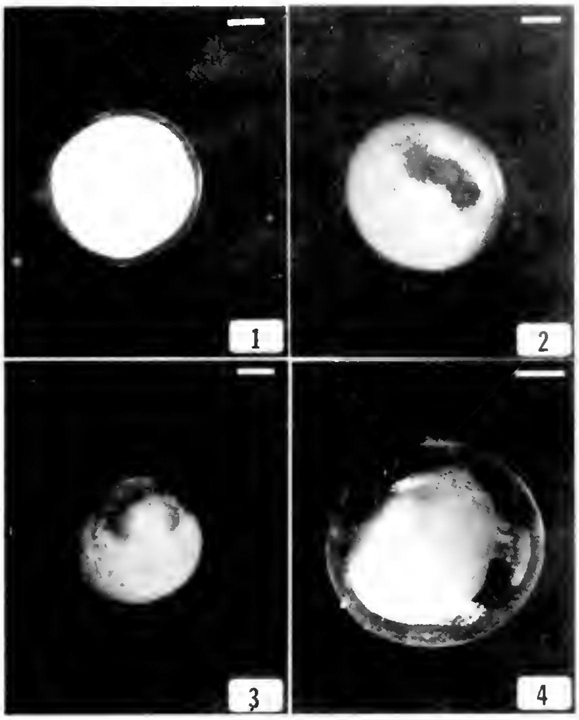
MATERIALS AND METHODS

Stenotrema leai snails were collected within the city limits of Ann Arbor, Michigan. They were brought into the laboratory, fed on a diet of carrots, chalk and filter paper, and were found to mate and breed successfully. Containers were checked for eggs every day; when found, they were immediately isolated and placed inside a small glass Petri dish containing ash-free filter paper moistened with deionized water. Close-up photographs were periodically made of the developing eggs.

RESULTS

A total of ten clutches were examined. The number of eggs per clutch was 2.06 ± 1.06, with each clutch ranging in size from 1-4 eggs. The average size of the eggs laid was 2.28 ± 0.14 × 2.29 ± .18 mm. Approximate time of hatching at 20°C was two weeks. The pictures illustrated in Figure 1 were taken from eggs of the same clutch, in increasing order of age, so that Figure 1 is a newly deposited egg, while Figure 4 is within a few days of hatching.

The most striking aspect of this developmental sequence is that the egg crystals are not dissolved uniformly around the embryo. Instead, certain areas of the shell are preferentially dissolved, often completely, before other parts of the calcite layer were involved. Figure 2 is an especially striking example of this phenomenon, where one small area of the egg shell has been completely denuded of calcite crystals while the rest seem intact. As indicated in Figure 4, most eggs lose their opacity by the time of hatching, and become transparent from loss of the crystal layers in the outer egg shell. This same type of localized calcite dissolution has been subsequently observed with



FIGS. 1-4 *Illustrate the appearance of progressively older eggs of* Stenotrema leai *during incubation at room temperature.* **1,** *is a freshly deposited egg;* **2,** *is older by several days and shows a single pronounced area of crystal dissolution;* **3,** *is older still, with a more extensive area of calcium carbonate erosion.* **4,** *is an egg only a few days from the time of hatching; here the embryo occupies most of the egg and only a very small amount of calcite crystal material is left. This, too, will disappear before final hatching. White scale bar in the upper right corner indicates 0.5 mm. All four eggs are from the same clutch; 4 is the maximum number of eggs found per clutch for this species in the laboratory.*

eggs of other partly calcified eggs, such as those of the pulmonates, *Varohadra yeppoonensis* from Australia and *Helicodiscus parallelus* from the northern United States.

DISCUSSION

The cause of such specific and localized calcite dissolution is not clear and conflicts with the previously held ideas that a general erosion of the egg shell crystals occurs during development. The present study suggests that while there may be a moderate degree of general crystal dissolution during development, limited areas are preferentially attacked and rapidly dissolved.

It has not been possible to associate the juxtaposition of any embryonic organ with the exact site of calcite disappearance. Especially in the earlier parts of development, the egg is opaque and the embryo is not visible. Presently, the best guess is that either 1) the embryonic foot organ called the podocyst (see Cather and Tompa, 1972) is applied to this area to dissolve calcium carbonate, or that 2) the mouth and its secretions are directly responsible. We know that immediately post-hatching, the neonate consumes all of the egg shell remnants available and may even rasp on the shells of other nearby eggs (numerous sources; personal observations with such snails as *Helix, Stenotrema, Anguispira,* etc.). On the other hand, it is also known that the podocyst, an embryonic organ modified from the foot, functions in taking up egg albumen (Cather and Tompa, 1972) and indeed it may have a calcium resorbing function as well, such as in the avian embryo's chorioallantois (Terepka *et al.*, 1969). This is all the more likely since the podocyst is often seen directly appressed to the inner egg shell surface for long periods of time. The podocyst is often so large in later development that it makes direct contact with 50% or more of the inner surface area of the egg shell. Therefore, either the podocyst or the larval mouth area takes part in egg shell calcite resorption. The embryo, of course, needs this calcium to build its first whorls of the body shell, the protoconch, so that it has a hard shell by the time of hatching (Tompa, 1975). No doubt, such a hard shell, into which the neonate can withdraw, has a direct and immediate selective advantage where micropredators abound; the calcitic egg shell is dissolved, then re-precipitated by the embryo as aragonite body shell crystals.

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GASTROPODS AS INDICATORS OF TROPHIC LAKE STAGES

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ABSTRACT

Field data associated with the 91 species and subspecies of boreal and arctic North American freshwater gastropods were analyzed. Most species and subspecies are eurytopic, but a few are entirely, or nearly, restricted to lakes of particular trophic levels. These are: Valvata sincera sincera *Say for oligotrophic lakes,* Fossaria decampi *(Streng) and* Stagnicola catascopium *(Say) for oligotrophic and mesotrophic lakes, and* Amnicola limosa *(Say),* Lymnaea stagnalis jugularis *(Say), and* Planorbula armigera *(Say) for eutrophic lakes.* Physa integra *Haldeman is frequently associated with mesotrophic lakes but also occurs in other habitats. The indicator species are illustrated and briefly described.*

The literature dealing with gastropods as indicators of water quality, especially in regard to water pollution, has been recently reviewed by Harman (1974). That paper includes a survey of existing knowledge (including new observations) about the tolerances of many species of gastropods to extremes of pH, alkalinity, total CO_2, dissolved 0_2, and temperature, and to industrial wastes and pesticides. The fundamental value of this approach is unquestioned, although as that author has also pointed out, most mollusks have broad tolerances for environmental perturbations and "almost every common species has been found in polluted environments" *(loc cit*, p. 302.)

The present study seeks to assess the possible utility of freshwater gastropods, not as pollution indicators, but as indicators of progressive trophic lake stages. It is based on the literature and on about 2000 freshwater field collections and associated observations made since 1950 throughout cool-temperate, boreal, and arctic North America (Clarke, 1973, 1980). Although the field experience has been fairly extensive, in most instances the trophic character of a lake was judged solely on qualitative observations. The conclusions presented here must therefore be considered provisional. Most freshwater species listed here are eurytopic or wide-ranging in habitat tolerance, but others are restricted to lakes in various stages of development.

Of course mollusks have biological requirements which affect their utility as indicator organisms. Since most pulmonates are confined to shallow water where access to the atmosphere is possible, they commonly occur near the water line or among emergent vegetation. Many, however, are apparently able to capture and use the oxygen released by plants during photosynthesis and in some the pulmonary cavity is filled with water and functions as a branchium or gill. Such adapted pulmonates, like prosobranchs, can thrive in the deep profundal zone of lakes. Although some species have been found in water with very low oxygen saturation levels (Harman, 1974), it is unlikely that any species is able to live for long periods in regions which periodically undergo prolonged and drastic reductions in dissolved oxygen, such as within the hypolimnia of many eutrophic lakes. Eggs of gastropods, in fact, are even more susceptible to low oxygen values.

Table 1 represents a preliminary attempt to tabulate the relative abundance, regional geographical distribution, and kinds of water bodies inhabited by the freshwater gastropods of northern North America. The species list is thought to be complete for Canada and virtually so for Alaska. Nearly all of the species found in New England and the states bordering Canada are also included, and some can serve as laketype indicators.

The attributes which a species should possess to be useful as an indicator of lake-stages are: wide geographical distribution, comparative abundance, relative stenotopy, and ease of identification. The table demonstrates that only a few of the 91 species and subspecies listed combine all

TABLE 1

Relative Abundance, Approximate Distributions, and Usual Habitats of the Freshwater Gastropoda of northern North America (1)

SPECIES	ABUND.	DISTRIBUTION		HABITAT			
		W of 95°	E of 95°	OLIGOTR	MESOTR	EUTROPH	VERNAL
Lymnaea atkaensis Dall	C	A T M		X X X			
Valvata sincera sincera Say	C	B M	B G	X X X	x x x		
Lymnaea stagnalis sanctaemariae Walker	R		B G	X X X	x x x		
Valvata perdepressa Walker	R		G	X X X	X X X		
Probythinella lacustris (Baker)	C	T B P	T B G	X X X	X X X		
Acroloxus coloradensis (Henderson)	R	M	B G	X X X	X X X		
Fossaria decampi (Streng)	C	T B M P	T B G	X X X	X X X		
Stagnicola castascopium catascopium (Say)	C	T B M P	T B G	X X X	X X X		
S. catascopium nasoni Baker	R		B G	X X X	X X X		
S. catascopium preblei (Dall)	P	T B	T B	X X X	X X X		
Stagnicola kennicotti Baker	R	A		X X X	X X X		
Helisoma corpulentum corpulentum (Say)	R		B G	X X X	X X X		
Valvata sincera helicoidea Dall	C	A T B M	A T B	X X X	X X X	X X X	
Valvata tricarinata (Say)	C	T B M P	T B G	X X X	X X X	X X X	
Physa propinqua Tryon	C	M		X X X	X X X	X X X	
Physa jennessi jennessi Dall	C	A T	A T	X X X	X X X	X X X	X X X
Physa heterostropha (Say)	C		G	X X X	X X X	X X X	X X X
Somatogyrus subglobosus (Say)	R		G	X	X X X		
Physa integra Haldeman	C		G	x	X X X	x x	
Cincinnatia cincinnatiensis (Anthony)	R	P	G		X X X		
Physa gyrina latchfordi (Baker)	R		B		X X X		
Helisoma corpulentum vermilionense Baker	R		B		X X X		
Valvata piscinalis (Müller)	I		G		X X X	X	
Goniobasis livescens (Menke)	C				X X X	X X	
Lithoglyphus virens (Lea)	R	M			X X X	X X	
Bulimus tentaculatus (L)	I		G		X X X	X X X	
Fossaria exigua (Lea)	C	P	T B G		X X X	X X X	
Physa jennessi athearni Clarke	R	M			X X X	X X X	
Physa columbiana Hemphill	C	M			X X X	X X X	
Physa lordi Baird	C	M			X X X	X X X	
Helisoma anceps anceps (Menke)	C	T B M P	T B G		X X X	X X X	
Helisoma anceps royalense (Walker)	C		B G		X X X	X X X	
Helisoma campanulatum campanulatum (Say)	C	B	T B G		X X X	X X X	
Helisoma campanulatum collinsi Baker	R		B G		X X X	X X X	
Ferrissia parallela (Haldeman)	C	B P	B G		X X X	X X X	
Stagnicola elodes (Say)	C	A T B M P	A T B G		X X X	X X X	X X X
Stagnicola proxima (Lea)	C	M			X X X	X X X	X X X
Valvata sincera ontariensis Baker	R		B		x x x	X X X	
Pseudosuccinia columella (Say)	C		G		x x x	X X X	
Bulimnea megasoma (Say)	R	B	B G		x x x	X X X	
Lymnaea stagnalis jugularis (Say)	[illegible]	T B M P	T B G		x x x	X X X	
Stagnicola arctica (Lea)	[illegible]	A T	A T		x x x	X X X	
Gyraulus deflectus (Say)	[illegible]	A T B M P	A T B G		x x x	X X X	
Helisoma trivolvis trivolvis (Say)	[illegible]		T B G		x x x	X X X	
Helisoma trivolvis subcrenatum (Carpenter)	[illegible]	T B M P			x x x	X X X	
Helisoma pilsbryi infracarinatum Baker	R	B P	B G		x x x	X X X	
Physa gyrina gyrina Say	[illegible]	T B M P	A T B		x x x	X X X	X X X
Gyraulus parvus (Say)	[illegible]	T B M P	A T B G		x x x	X X X	X X X
Promenetus exacuous exacuous (Say)	[illegible]	T B M P	T B G		x x x	X X X	X X X
Pleurocera acuta Rafinesque	[illegible]		G		x X	X X	
Juga plicifera (Lea)	R	M			X	X X	
Campeloma decisum (Say)	[illegible]	P	B G			X X X	
Viviparus georgianus (Lea)	I		G			X X X	
Cipangopaludina chinensis (Gray)	I	M	G			X X X	
Marstonia decepta (Baker)	R		B G			X X X	
Lyogyrus granum (Say)	R					X X X	
Amnicola walkeri Pilsbry	R		B G			X X X	
Amnicola limosa (Say)	C	B P	B G			X X X	
Fossaria ferruginia (Haldeman)	R	M				X X X	
Fossaria truncatula (Müller)	I	M				X X X	
Radix auricularia (L)	I	M				X X X	
Radix peregra (Müller)	I		B			X X X	
Acella haldemani (Binney)	R		G			X X X	
Armiger crista (L)	R	B M P	B G			X X X	
Promenetus exacuous megas (Dall)	C	B M P				X X X	
Menetus cooperi Baker	C	M P				X X X	
Planorbula armigera (Say)	C	B P	B G			X X X	
Helisoma trivolvis binneyi (Tryon)	R	B M				X X X	
Helisoma corpulentum whiteavesi Baker	R		B			X X X	
Physa concolor Haldeman	R	M				X X X	
Physa hordacea Lea	R	M				X X X	
Physa nuttalli Lea	R	M				X X X	
Laevapex fuscus (Adams)	R		B G			X X X	
Ferrissia fragilis (Tryon)	C	M	G			X X X	
Fossaria modicella (Say)	C	T B M P	T B G			X X X	X X X
Bakerilymnaea bulimoides (Lea)	C	M P				X X X	X X X
Bakerilymnaea dalli (Baker)	R	M P	G			X X X	X X X
Stagnicola reflexa (Say)	R	B M P	B G			X X X	X X X
Gyraulis vermicularis (Gould)	C	M				X X X	X X X
Promenetus umbilicatellus (Cockerell)	R	M P				X X X	X X X
Physa jennessi skinneri Taylor	C	T B M P	T B G			X X X	X X X
Aplexa hypnorum (L)	C	A T B M P	T B G			x x x	X X X
Planorbula campestris (Dawson)	C	B M P				x x x	X X X
Stagnicola caperata (Say)	C	P					X X X
Gyraulus circumstriatus (Tryon)	R	B M P	G				X X X
Stagnicola montanensis (Baker)	R	M			streams and springs		
Physa johnsoni Clench	R	M			streams and springs		
Ferrissia rivularis (Say)	C	B P	B G			rivers	
Lanx nuttalli (Haldeman)	R	M				rivers	
Pomatiopsis lapidaria (Say)	R		G			amphibious	
Fossaria parva (Lea)		T B M P	T [illegible] G			amphibious	

(1) [illegible]

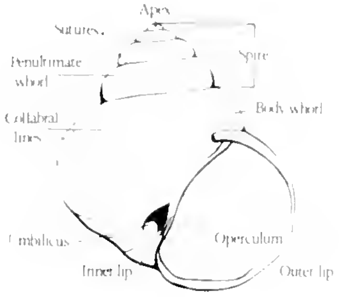

FIG. 1. *Parts of a gastropod shell.*

of these attributes. These are: (for oligotrophic, or early stage, lakes)[1] *Valvata sincera sincera* Say; (for both oligotrophic and mesotrophic lakes) *Fossaria decampi* (Streng) and *Stagnicola catascopium* (Say); and (for eutrophic, or old, advanced stage, lakes) *Amnicola limosa* (Say), *Lymnaea stagnalis jugularis* (Say), and *Planorbula armigera* (Say), among others. In southern Canada *Physa integra* Haldeman occurs most frequently in mesotrophic lakes and is therefore of some use as an indicator also, but it is not entirely restricted to such habitats. It is also worthwhile to note that *Stagnicola caperata* (Say) and *Gyraulus circumstriatus* (Tryon) are confined to vernal, or temporary, water bodies and that *Aplexa hypnorum* also ordinarily occurs only in vernal habitats.

The lake-stage indicator species are illustrated in Fig. 2 and briefly described below. This is for the benefit of those who are not familiar with mollusks but who wish to use them for lake classification. The structural features mentioned are illustrated in Figure 1. However, positive identification can only be achieved by consideration of all species which are similar to the indicator species. For additional references consult especially Baker (1928), Clarke (1973, 1980), Harman & Berg (1971), La Rocque (1966-70) and Taylor (1975).

Prosobranchia

Valvata sincera sincera Say (Valvatidae) (Fig. 2, A) is one of about six boreal North American species and subspecies of *Valvata*. It is up to 3.2 mm high and 5 mm wide, with four rounded whorls sculptured with widely-spaced collabral threads (8 or fewer per mm), and a round operculum with about 6 turns. It is similar to *Valvata sincera helicoidea* Dall but that subspecies is more northern, is larger (up to 7 mm wide) and has finer, more crowded, collabral threads (14 or more per mm).

Amnicola limosa (Say) (Hydrobiidae) (Fig. 2, B) is one of eight boreal North American species in the family. Most northern hydrobiids are less than 6 mm high, are higher than wide, and possess an ovate aperture and an ear-shaped operculum with fewer than three turns. (One species, *Lyogyrus granum*, has a round,

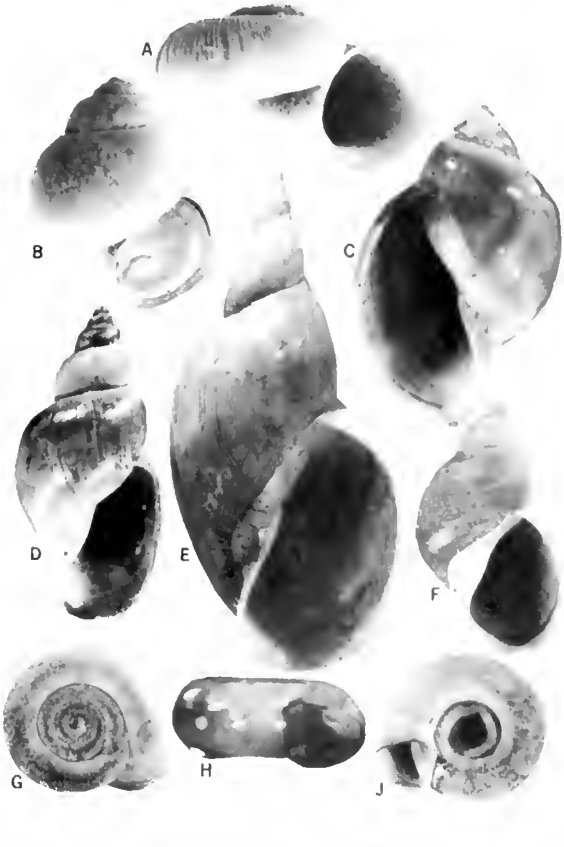

FIG. 2. *Trophic lake-stage indicator species of gastropods.* **A**, Valvata sincera sincera *(USNM 336464, width 4.6 mm)*; **B**, Amnicola limosa *(USNM 271099, height 4.2 mm)*; **C**, Physa integra *(NMC 3374, height 11.6 mm)*; **D**, Fossaria decampi *(NMC 39766, height 11.2 mm)*; **E**, Lymnaea stagnalis jugularis *(NMC 14749, height 61.1 mm)*; **F**, Stagnicola catascopium catascopium *(NMC 2197, height 18.7 mm)*; **G**, **J**, Planorbula armigera *(NMC 29319, width 6.3 mm)*. **H**, P. armigera *showing position of internal "teeth" (NMC 39345, width 4.7 mm). Abbreviations: USNM, Smithsonian Institution; NMC, National Museums of Canada.*

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[1] *Lymnaea atkaensis*, although known only from oligotrophic lakes, is restricted to Alaska and extreme northwestern Canada.

multispiral operculum). *A. limosa* is up to 4 1/2 mm high, 3 1/3 mm wide, with 4 1/2 convex whorls, and has a blunt (but not truncated) spire. It is often abundant on lily pads and other vegetation. *A. limosa* occurs throughout the eastern two-thirds of the United States and Canada south of the tree-line.

Pulmonata

Fossaria decampi (Streng) (Lymnaeidae) (Plate 1, figure D). The Lymnaeidae is a large family (26 Canadian species and subspecies) characterized by shells which are rather thin, high-spired, and dextral (i.e. coiled clockwise when viewed from above) and by the absence of an operculum. Nearly all *Fossaria* (6 species in Canada) are less than 12 mm long at the adult stage (5-6 whorls) and most are less than 8 mm. *F. decampi* (normally 4-8 mm long and about half as wide) may be recognized by its shouldered whorls, laterally flattened body whorl, elevated and reflected inner lip, and aperture which is narrowly arched above and broadly rounded below. It occurs in the Great Lakes-St. Lawrence drainage and north and west throughout the boreal forest region, principally in large lakes.

Stagnicola catascopium catascopium (Say) (Lymnaeidae) (Plate 1, figure F). Most *Stagnicola* (10 species and subspecies in Canada) are medium-sized (10-35 mm), variable, and have relatively strong shells. *S. catascopium catascopium* shows unusually great interpopulation variability. Most specimens are between 13 and 25 mm long, about 2/3 as wide, with a rather heavy shell, low spire, broad aperture, inflated whorls, deep suture, and thickened inner lip. It occurs across North America (except in northern British Columbia, Yukon Territory, and Alaska) south to about 40° north latitude.

Lymnaea stagnalis jugularis Say (Lymnaeidae) (Plate 1, figure E) (formerly *L. stagnalis appressa* Say) is larger (often 60 mm long), with height about double the width, up to 7 1/2 whorls, and thin-shelled. It has a long, narrow spire with concave sides and flatly rounded whorls and a bulbous body whorl. This common subspecies lives throughout nearly all of boreal and temperate Canada and the northern United States except for the extreme eastern portion, i.e. it is absent from most of New England, the Canadian Maritime Provinces, and northern Quebec.

Physa integra Haldeman (Physidae) (Plate 1, figure C). The Physidae (about 16 Canadian species and subspecies) have shells which are thin in most species, high-spired, and sinistral, i.e. coiled counterclockwise when viewed from above. They all lack an operculum and are small to medium-sized (7-26 mm high). *P. integra* is up about 15 mm high, 9 mm wide, with five whorls, and the shell is thicker and heavier than that of other northern species of *Physa*. The aperture is thickened within by a white ridge and many specimens have several whiteish collabral bands representing thickened lips formed during previous growth stages.

Planorbula armigera Say (Planorbidae) (Plate 1, figure G-J). The Planorbidae (about 21 Canadian species and subspecies) have shells which are nearly all flatly-coiled, with the body whorl in about the same plane as the apex, lack an operculum, and may be small to quite large (3-32 mm in shell width). *P. armigera* is medium sized (about 8 mm wide, 3 mm high, 5 whorls) and has one (rarely two) set of 5, well-developed "teeth" well within the aperture. In most specimens these teeth may be seen by looking into the aperture but in some specimens they are visible only by use of transmitted light (as a dark, thickened area) or by chipping back about 1/4 of the body whorl. Only one other northern planorbid, the larger western species *P. campestris* (Dawson), has apertural teeth but each set contains 6 teeth and they occur only in juveniles. *P. armigera* lives throughout eastern and central North America from Georgia and Louisiana to New Brunswick, northern Ontario, and the vicinity of Great Slave Lake in Canada's Northwest Territories.

ACKNOWLEDGMENTS

C. O. Berg and R. S. Houbrick read the manuscript and provided useful suggestions, Ms. Cathy Lamb assisted in the laboratory, and Ms. Valerie Fulford prepared the diagrammatic drawing. The photographs were provided through the courtesy of the Smithsonian Institution and the National Museums of Canada. I am grateful for all of this assistance.

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A NEW SPECIES OF *AMNICOLA* FROM AN ARKANSAS CAVE (HYDROBIIDAE)

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ABSTRACT

A blind cave snail, Amnicola cora, *is described from Independence Co., Arkansas.*

Amnicola cora, new species

Figs. 1-3

Description: Shell small, broadly conic, wider than high, thin, subhyaline, pale-yellow; whorls 3.3, well-rounded the last whorl lightly appressed to the preceding whorl, sutures very deep, nuclear whorl slightly raised; umbilicus open, about one-fifth the diameter of the shell; aperture nearly round, peristome continuous, barely attached to the preceding whorl, lip thin, columellar margin not reflected or bent; sculpture of many fine spiral lines, operculum corneus, multispiral, with about 5 whorls.

Animal white and blind, without any trace of eyes; verge bifid, rather stout; central tooth of the radula with 11 denticles on the reflection, one moderately large mesocone and 5 ectocones on each side; lateral tooth with 11 denticles, one moderately large mesocone, 3 entocones, and 7 ectocones; marginal teeth with numerous small denticles.

Height 1.6 mm, diameter 2.0 mm, aperture height 1.0 mm, aperture width 0.9 mm, umbilicus diameter 0.4 mm, 3.3 whorls. Holotype.

Distribution: ARKANSAS: Independence County: stream in Foushee Case, 3 miles west of Locust Grove (Type Locality) (Norman & Jean Youngsteadt; Leslie Hubricht, collectors) holotype 193762, and paratypes 193763, Field Museum of Natural History, other paratypes 47584, 47585, collection of the author.

Remarks: Amnicola cora is most closely related to *A. stygia* Hubricht from cave streams in Perry Co., Missouri. It differs in being smaller, with more slowly expanding whorls, the shell is not as fragile, and the operculum is multispiral rather than paucispiral. It is named for the Attic goddess, Cora, Queen of Hades.

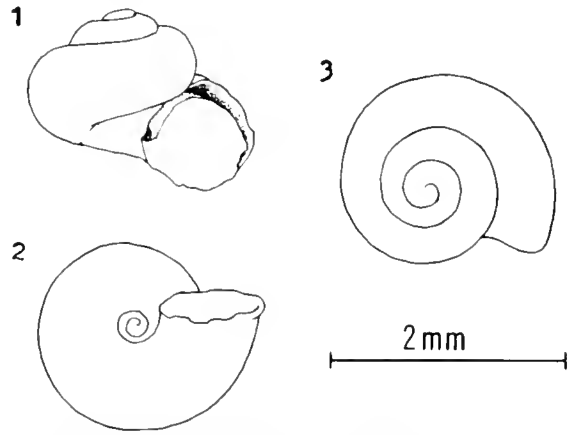

FIG. 1-3. Amnicola cora *Hubricht, holotype. Drawings courtesy of Elisabeth A. Leibman, Field Museum of Natural History.*

THE BEHAVIOR OF THREE SYMPATRIC SPECIES OF *CREPIDULA* (GASTROPODA: PROSOBRANCHIA) FROM THE ATLANTIC, WITH IMPLICATIONS FOR EVOLUTIONARY ECOLOGY

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ABSTRACT

In the course of a study of reproductive energetics, behavioral observations were made on Crepidula fornicata *(Linnaeus),* C. *plana* *Say, and* C. convexa *Say. Although* C. convexa *is intertidal,* C. fornicata *and* C. plana *rarely are.* C. fornicata *orients itself on convex, exposed surfaces with the anterior shell margin upward, if possible.* C. plana *is photonegative.* C. fornicata *and* C. convexa *juveniles appear at staggered intervals during the summer in New England.*

When brooding eggs, females of all three species are sedentary. However, all but the highly convex or twisted individuals are capable of some movement. C. convexa *is the most mobile. Only* C. fornicata *forms stacks of more than 3 individuals.*

Brooding is energetically costly for Crepidula*; both brood abortion and brood cannibalism occur. Eggs can also be delayed in hatching. Newly-hatched* C. convexa *graze using the radula; filter-feeding is probably not efficient at that stage.*

These behavioral patterns are discussed in terms of their survival advantages and niche differences of the three sympatric species.

There are three species of *Crepidula* found commonly along the eastern coast of the United States: *C. fornicata* (Linnaeus), *C. convexa* Say, and *C. plana* Say. The three share several generic characters of an ecological nature: they are primarily sedentary as adults, they must copulate in order to reproduce, they are protandrous, and they acquire food via filtration of water through the gills. Species differences include maximum size, shell convexity, shell muscle scar patterns, substrate preferences, and whether or not there is a planktonic larval stage (Hoagland, 1977b). The species can be collected together at many localities, including Woods Hole, Massachusetts.

In the course of a comparative study of the reproductive energetics of the three species (Hoagland, 1975), behavioral and physiological differences were identified that give each species unique niche dimensions (Hoagland, 1978; 1979). This paper adds further observations on orientation behavior, brood care, and feeding in *Crepidula*. After discussing each set of observations in turn, I will interpret the findings in the context of niche theory and evolutionary adaptations for the survival of individuals of each species.

STUDY SITES, METHODS

Individuals of all three species were observed in shallow water (less than 1 m) on shell and stone substrate resting on mud or sand bottom, at Vineyard Haven (Martha's Vineyard) and Woods Hole, Massachusetts. Some *C. fornicata* and *C. plana* were found attached to live horseshoe crabs *(Limulus polyphemus)*. Many *C. plana* and *C. convexa* were on gastropod shells occupied by hermit crabs, while *C. convexa* was abundant on live *Littorina littorea*. *C. fornicata* was also observed on stones in tide pools at Nahant, Massachusetts, and on *Mytilus edulis* attached to docks at Tiverton, Rhode Island.

Some specimens and their substrates were marked in the field by notching the shell and painting numbers on the substrate. Laboratory observations were made on specimens taken from the Woods Hole and Martha's Vineyard populations. Live specimens still attached to their original substrates, or made to attach to watch glasses, were maintained in flowing sea water tables at the Woods Hole Oceanographic Institution. The temperature was not controlled.

RESULTS: OBSERVATIONS

Microhabitat

Many ecologists describe *Crepidula* as intertidal. *C. convexa* occurs on shells of *Littorina littorea* and *Ilyanassa obsoleta*, snails that frequently exist intertidally. *C. convexa* may be found with a bone-dry shell, tightly affixed to an equally dry living snail, during the hottest summer days. Yet *C. convexa* has been dredged from a depth of 212 meters (Abbott, 1974).

However, *C. fornicata* and *C. plana* are uncommon above the mean low tide line. In Nahant, *C. fornicata* is found in upper tide pools, but only occasionally are specimens found out of water. In Woods Hole, the only specimens of *C. fornicata* or *C. plana* found out of water in three years of study were those deposited ashore by storms or by the buoyant alga, *Codium fragile*, which attaches to the shells of *C. fornicata* and floats the snails to the intertidal zone. Those *C. fornicata* and *C. plana* that attach to the undersides of horseshoe crabs or inside hermitcrab-occupied shells also find their way into the intertidal zone, but remain in a moist environment.

None of the *Crepidula* are commonly found on hard substrate in the rocky intertidal zone; this high energy environment is apparently not suited to their mode of life, which is much closer to the oyster than to either the limpet or the mussel. The preferred substrate of *C. fornicata* is a convex surface, not highly irregular. Specimens are rarely found on large boulders, but are common on fist-sized stones. The bottom sediments are usually mud rather than sand; the latter indicates an environment that is poor in organic material and probably in food for filter feeders. *C. fornicata* is known for forming large stacks, one animal atop the other (Figure 1). Occupying such a convex surface, a *C. fornicata* individual would be exposed to greater currents and less sedimentation than if it were located on a concave surface.

In the laboratory, young specimens of *C. fornicata* placed inside of finger bowls invariably climb up and over the edge of the bowl, to the convex exterior. The final orientation is nearly always as shown in Figure 2. The animal sits at an angle to the top of the bowl, with its anterior shell margin directed upward, near or flush with the rim of the bowl. Faeces and pseudofaeces are released from the anterior shell margin. Mobile *C. fornicata* also tend to move to the part of the tank with the most rapid water flow.

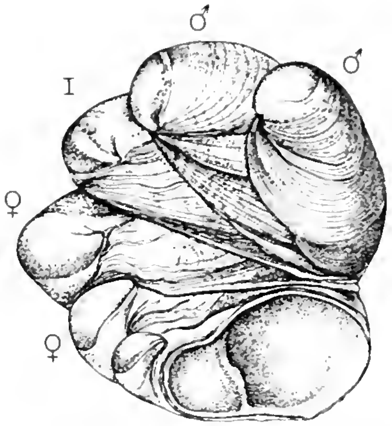

FIG. 1. *A stack of* Crepidula fornicata *in life position. Sexes of the individuals are indicated. I = intermediate.*

C. convexa has no preference for convex or concave surfaces, nor does it show precise orientation. It forms male-female pairs, but not stacks. It attaches to eelgrass blades as easily as to shells, bottles, or porcelain (Hoagland, 1977a).

C. plana prefers dark places and concave or flat surfaces, such as underneath rocks or inside large empty shells. It forms clusters of several males and juveniles on one female, but not

FIG. 2. *Preferred orientation of* Crepidula fornicata *on the outside of a glass fingerbowl. The anterior margin touches the rim of the bowl. The entire bowl was submerged in sea water.*

stacks. In the laboratory, *C. plana* juveniles display a photonegative response. Natural concave surfaces tend to be inner surfaces, so it is not clear if *C. plana* is selecting darkness or concavity or both.

All three species are sometimes found on the same piece of substrate, such as a stone or a dead shell. *C. plana* occupies the under- or inside of such a substrate, but the microhabitats of *C. fornicata* and *C. convexa* cannot be so easily distinguished. In Woods Hole in the years 1972-1974, the summer reproductive periods of *C. fornicata* and *C. convexa* did not coincide. *C. fornicata* spat settled in early June, followed by a "set" of barnacles; then *C. convexa* juveniles appeared in early July. Another wave of *C. fornicata* settled in August, and finally more *C. convexa* in early fall. This pattern serves to decrease competition among juveniles for substrate. Those individuals of both *C. fornicata* and *C. convexa* that settled intertidally disappeared within a few days. This indicates either mortality or removal to a less exposed microhabitat.

Mobility

The common knowledge among ecologists is that *Crepidula* species are largely sedentary. Yet *Crepidula* must copulate, and the substrates of *Crepidula* are spatially discontinuous; the snails cannot survive in the intervening sand or mud. *C. fornicata* and *C. plana* can disperse during the planktonic larval stage, but *C. convexa* lacks this stage. I investigated the mobility of the three species, to see how wide is their access to the substrate and to each other.

In the field, *C. fornicata* and *C. plana* adults are largely sedentary. Of 50 female *C. fornicata* marked in the tidepools of Nahant, 34 remained in place two years later. *C. plana* and *C. convexa* were more difficult to follow because their substrates moved. However, *C. convexa* adults were observed to travel within tidepools. Those living on eelgrass either had to move or perish, because the eelgrass died each winter. The greater mobility of *C. convexa*, and its greater propensity for attaching to living organisms, means that *C. convexa* is more likely to disperse as an adult than either of the other species. However, *C. convexa*, like all other *Crepidula*, is sedentary when out of water.

Laboratory observations confirmed the above impressions. Small individuals of all three species, including most *C. convexa*, can maneuver over abrupt discontinuities in substrate (e.g., from one stone to another), across a silty tank bottom, as long as there is a hard bottom underneath. Movement can be assessed by measuring trails left on the silty bottom. Adult *C. fornicata* and *C. plana* grow to fit the curvature of the substrate, and have difficulty moving. Highly arched or distorted specimens cannot move at all. Regardless of species, those brooding young do not move.

Both *C. fornicata* and *C. convexa* have a tendency to climb up (negative geotropism) and out of the water when placed in aquaria. They often sit above the water line, where they die. This tendency can be reduced by increasing aeration in the tanks. In fact, several times, young *C. fornicata* established themselves directly on top of an air stone. When aeration in the tanks was stopped, all but the brooding females and those attached to other highly arched shells moved upward.

The ability of the three species of *Crepidula* to regain their positions on a substrate, once dislodged, is very different. *C. convexa* can reattach within seconds, if both animal and substrate are wet. *C. convexa* has a very active and flexible foot, which allows an overturned animal to right itself. I have observed *C. convexa* floating upside-down on the surface film of the water until reaching the side of the tank, where it quickly attached.

Adult *C. fornicata* and *C. plana* may take 1 to 3 hours to attach firmly to a substrate. During that time, the specimens are vulnerable to crab predation. I demonstrated this vulnerability by placing several adult *Crepidula* loose on top of their former substrates, accompanied by 3 crabs, in an aquarium. All specimens of *Crepidula* were eaten.

The difference in ease of attachment between species is partly, but not completely, due to size. Small *C. fornicata* and *C. plana* can attach more effectively than larger ones, which often have irregularly-shaped apertures that can only fit against the substrate on which they grew. Still, small specimens of *C. convexa* were more resilient and active than their counterparts.

One cause for mobility in *Crepidula* is to enhance breeding success by ensuring copulation. In both field and laboratory, *C. convexa* and *C. plana* males were seen to wander from one female to another, although a single pairing of *C. convexa* in the lab lasted as long as 5 months. Some *C. fornicata* males also wander, but some spend their entire lives as males with one stack of females. Most biologists have assumed that stacking in *C. fornicata* is related to mating. Walne (1956) believed that the tendency to form stacks was not related to reproduction, but rather to the production of feeding currents. The strength of the excurrent flow of faeces and pseudofaeces may be augmented by the shape of the stack, as Walne supposed. No data exist on this point. An analogy might be made to oysters, which form clusters that serve to raise the animals from a muddy substrate, augmenting their ability to filter-feed. Yet in *Crepidula*, the stack is a breeding unit (Hoagland, 1978), and probably reduces the vulnerability of males to predation by reducing their need to be mobile. Because of the close proximity of the right anterior portions of the shells of a stack (Figure 1), the several males at the top can easily copulate with the several females at the bottom, with eight or more individuals in between. This leads to a promiscuous breeding system, as is also found in *C. convexa* and *C. plana*, but by means of an entirely different behavior pattern.

Brood Care

All female *Crepidula* brooding young are completely sedentary. Interesting problems for ecologists include just how much of a liability this is for a brooding female. How much energy is expended by a brooding female in caring for the eggs? Does brooding affect her own chances for survival?

I observed that females of all three species, but especially *C. fornicata*, often push the young out from under the shell when aeration is reduced, measurably lowering the oxygen tension in the aquarium. The same event occurs when the animals are kept in millipore-filtered sea water (starvation). In three of eight cases of low oxygen and two of six cases of starvation, the females died after expelling the eggs. Survival of females of equivalent size but not brooding eggs was better in all three experimental situations, but insufficient data were obtained for statistical analysis. The data suggest that there is a cost involved in brooding, and that a female might abort a brood, thereby increasing her longevity.

Egg masses released by females were kept in aerated but unfiltered sea water to see if they would hatch. Ciliated protozoans, bacteria, and nematodes infested most of the egg masses. If some of the eggs become inviable, the entire egg mass eventually was lost to the predators. However, 2 of 10 egg masses of *C. convexa* and 4 of 20 of *C. fornicata* did hatch. The young were normal in appearance. Therefore, release of the brood by a dying female could be of benefit to the young, especially if they were near hatching.

The role of the female in larval brooding thus appears to be related to oxygenation and cleaning of the larvae. Egg maintenance appears to require continuous circulation of water. A female without eggs reduces its filtration if the water contains no food, but one brooding eggs continues to filter at a high rate. This is one energy cost. The brood is maintained in the vicinity of her gills, which, in these filter-feeders, create strong currents flowing over the egg mass (Werner, 1951). The presence of the egg mass probably reduces the efficiency of the gills as respiratory and feeding structures; this is another cost of brooding.

Not only can individuals of *Crepidula* be induced to leave their broods, but they can sometimes be induced to produce eggs at abnormal seasons. In the laboratory, they can also retain broods over winter, but this has not been observed in nature, at least in New England where reproduction normally occurs only in summer. In New England waters, *Crepidula* do not develop broods until the temperature exceeds 10° C.

Specimens of *C. fornicata* collected at Martha's Vineyard in December 1972, were accidently left outside a water table, in a finger bowl, sometime between January 18 and February 1, 1973. The water warmed, and two females produced eggs. The females with broods were placed back in the water table, where the water temperature was 2 - 4° C. The egg masses finally hatched on April 1, 1973, at a temperature of 6° C. Another specimen dredged from Buzzard's Bay, at a time unrecorded, spawned in a water table on February 13, 1973, when the water temperature suddenly rose to 6° C. In the summer of 1972, 25 female *C. fornicata* were maintained at 9° C., to see if egg production could be delayed. None produced eggs at 9° during a three-month period, June to August, when *C. fornicata* is normally brooding.

Specimens taken from Martha's Vineyard in November, 1972, contained ripe gonads; specimens taken from the same locality in January, 1973, had spent gonads, although no reproduction was observed in the interim. The gonads are probably resorbed during winter under natural conditions.

Another question of interest is how long sperm can be stored within the seminal receptacle of the female. Coe (1953) claimed that sperm storage could last several months to a year. In my laboratory, females of *C. fornicata* known to have mated but isolated in early June continued to reproduce broods through September, but none reproduced the following spring. This may have been due to sub-optimal feeding in the laboratory. Orton (1952) suggested that an individual could store its own sperm while in the process of changing sex, thereby functioning as a self-fertilizing hermaphrodite, but his speculation was based on the circumstantial evidence of finding isolated females with broods.

Larval Cannibalism

It had been thought that *Crepidula* under normal circumstances did not provide the developing young with nurse cells (Fretter and Graham, 1962, p. 404-405). However, Gallardo (1977) has reported nurse cells for *Crepidula dilatata*, and Coe (1942), for *C. onyx*. Thorson (1940) said that some capsules of *C. walshi* contained large embryos, while other embryos in the same capsules disintegrated.

An examination of several hundred broods each of *C. fornicata* and *C. convexa* within 24 hours of collection in the field revealed that a high percentage (10% of *C. fornicata*; 23% of *C. convexa)* failed to develop. These embryos broke up and were ingested by other embryos once they had reached the stage of possessing feeding structures. If a normal embryo was artificially ruptured with a fine needle, surrounding larvae spinning around within the egg capsule drew cells from the damaged embryo into their gullets via a self-generated feeding current. Both species did this, but *C. convexa* appeared not to have the capability once the larvae had lost the velum. If the damaged larva is in the veliger stage, the velum is not eaten but persists within the egg capsule until the capsule ruptures at hatching.

This process probably explains the cases I have seen in *C. convexa* where some hatching egg capsules of a brood contain 8-10 uniform, average size young, whereas others contain 2-3 very large young. It explains Thorson's observation as well. The size at hatching is more uniform in *C. fornicata*, which releases its brood in the veliger stage.

Feeding

When the broods are released, *C. convexa* young immediately begin a benthic existence. In the laboratory, I observed one brood of newly hatched young moving over a glass substrate coated with bacteria and microscopic algae. The snails' heads swayed from side to side, clearing tracks of microorganisms and debris. Inspection under the dissecting microscope showed that the odontophores and radulas were working, and material was entering the guts of the animals. Putnam (1964) reported that *C. adunca* also uses its radula to graze when first emerging from the egg capsule. Microscopic examination of the gill filaments of newly hatched *C. convexa* proved them to be fewer in number than in adults and rather fat and club-shaped. It is doubtful that they could function efficiently as filtering devices at that stage. This is probably one reason that *Crepidula* retains a large, well-developed if unspecialized radula, despite the filter-feeding mode.

Another reason for retention of the radula (over evolutionary time) is that it is used to handle food packaged on the gills (Werner, 1951). I have observed adults of *C. fornicata* to reach around and grab mucous balls containing large particles rejected by the gills (pseudofaeces), which normally exit on the right side of the mantle cavity. Occasionally, these balls are re-ingested. This behavioral pattern was observed only in closed-system aquaria, where I assume food availability was low.

DISCUSSION

Evolutionary Adaptations

Although cause-and-effect relationships are difficult to determine in evolutionary biology, one can often guess the survival value of a particular behavior or morphological structure. In the case of *Crepidula*, it is clear that individual orientation is adaptive. In *C. fornicata*, it maximizes the chances of encountering others of the same species and maximizes feeding currents while minimizing fouling. In *C. plana*, an orientation opposite to *C. fornicata* with respect to light sacrifices availability of currents, but increases protection against large predators such as crabs and fish. In *C. convexa*, small size and foot flexibility allow much greater mobility, an obvious advantage in a species without planktonic larvae.

Brooding costs the female an as-yet undetermined amount of energy. The expulsion of the broods under conditions of stress benefits the female by saving energy, and may indirectly benefit the offspring, which would die if trapped under a dead female. In terms of evolutionary theory, this is the optimal strategy for an individual that has high risk of juvenile mortality, can produce numerous broods over its lifetime, and that increases in fecundity with age and size. The same strategy occurs in birds that abandon the nest under unfavorable conditions.

The survival advantage of brood cannibalism is even more obvious. This system prevents wastage of the energy that the female diverted into reproduction. Furthermore, nonviable embryos do not remain to decay and contaminate the brood. The "nurse cells" are not specially differentiated as such, but the effect is the same. Fretter and Graham (1962, p. 405) described the situation structurally: "In capsules in which embryos are not separated from one another but share a common supply of albumen, it seems likely that a healthy individual will automatically devour disintegrating tissues with the albumen which is used as food." In terms of evolution, this is a way of increasing offspring size, as an alternative to the female adding more yolk to all the eggs. The advantage of size to a young *Crepidula* is not known, but by analogy to other organisms, it probably provides an edge in survival.

Niche Theory

The three species of *Crepidula* from New England are the most divergent, morphologically and behaviorally, of those living in the Atlantic Ocean. The differences among sympatric species in microhabitat, mobility, and orientation preferences bring up questions about how they divide their resources (Schoener, 1974). Hoagland (1976) pointed out that in *Crepidula*, species with morphological and ecological parameters in common overlap only in the tropics where there is closer species packing. In rigorous environments such as the northwestern Atlantic, there are found the fewest species, with the greatest morphological and ecological distance between them. Important niche-discriminating parameters were identified as substrate type, light preference, depth preference, and a size factor, correlated with types of life history and types of predators.

Carpenter (1857) also demonstrated that the number of sympatric species of *Crepidula*, and the family Calyptraeidae as a whole, decreases dramatically with increasing latitude along the west coast of North America. Similarly, in the Atlantic, those from the northernmost part of the province have the most extreme differences in morphology.

Reproductive isolating mechanisms are an alternative to competition as an explanation for the observed differences between related species. However, the need for such mechanisms should increase in the tropics, and instead, this is the area with the most similar congeners. I conclude that the present distribution of *Crepidula* in the Northwestern Atlantic and the behavioral differences of sympatric species are indicative of divergence that occurred long ago and had the effect of decreasing competition.

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THE OCCURRENCE AND SPREAD OF *CORBICULA MANILENSIS* IN EAST-CENTRAL ALABAMA

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The introduction and spread of the Asiatic Clam, *Corbicula manilensis* (Philippi, 1841)[2], in the United States has been recorded by numerous authors (review in Sinclair, 1971; Sickel, 1973; Fuller and Powell, 1973; Diaz, 1974; Britton and Murphy, 1977). These papers generally include the type of substrate in which the animals were found; the range of size classes (often used to suggest the date of the introduction); some mention of the problems that this exotic bivalve will cause to human uses of the watercourse; and, occasionally, some hypothesis or comment as to how *Corbicula* might have been introduced into the system. Few of these papers detail the extent of the newly reported *Corbicula* population, a fact which could indicate a great deal about the introduction of this animal into the stream and its subsequent spread within the system.

Distributional data about previously unre-

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[2] In this paper I am following present usage by considering *C. manilensis* (Philippi, 1841) to be the name of the eastern North American corbiculid species. Morrison, however, believes that the vast majority of these populations are *C. leana* Prime, 1864 (J. P. E. Morrison, *personal communication*, 1977)

ported *Corbicula* populations were collected while studying the distribution patterns of unionids in east-central Alabama (Jenkinson, 1973; 1975). This study (conducted in 1972 and 1973) involved four small stream systems, all of which originate in central Lee County, Alabama. Two of these streams, Saugahatchee (Saw-ga-hach'-ee) and Uphapee (You-fap'-ee) creeks, flow west into the Tallapoosa River while the other two streams, Halawakee (Hal-a-wok'-ee) and Uchee (Ooch'-ee) creeks, flow east into the Chattahoochee River (Fig. 1). During the course of this study 2,646 unionids and 76 voucher specimens of *Corbicula* were collected from 47 productive sites on these four streams. Additional collections have also been made in adjacent small streams and in the two rivers.

The resulting distribution pattern for *Corbicula* is illustrated in Figure 1. *Corbicula* is abundant in both the Tallapoosa and Chattahoochee rivers (although I had not found it in the Tallapoosa River in 1968), however, *Corbicula* is essentially absent from the tributary streams.

Uchee Creek Population

Two exceptions to this general distribution pattern were found to exist. One large and apparently well-established population of *Corbicula* was located in the lower half of Little Uchee Creek and in Uchee Creek only below the mouth of Little Uchee Creek. No *Corbicula* specimens were taken in any other part of this creek system although unionids were abundant in all of the permanent streams. The farthest upstream collection of *Corbicula* from Little Uchee Creek was taken at the base of a rapids and falls that mark the transition from Piedmont to Coastal Plain substrates. This was also the most upstream site where fishermen were noticed. Following the hypothesis advanced by Sickel (1973), it would be tempting to suggest that *Corbicula* was introduced into the Uchee Creek system at this site by fishermen. Unfortunately, I have no additional evidence to support such a hypothesis.

A similar distribution pattern for *Corbicula* has been reported from the Mesilla Valley of Texas and New Mexico (Metcalf, 1966). In that case *Corbicula* occurred in the main channel of West Drain but not in its tributaries or in any other adjacent tributary of the Rio Grande River. Metcalf suggested that the periodic drying up of

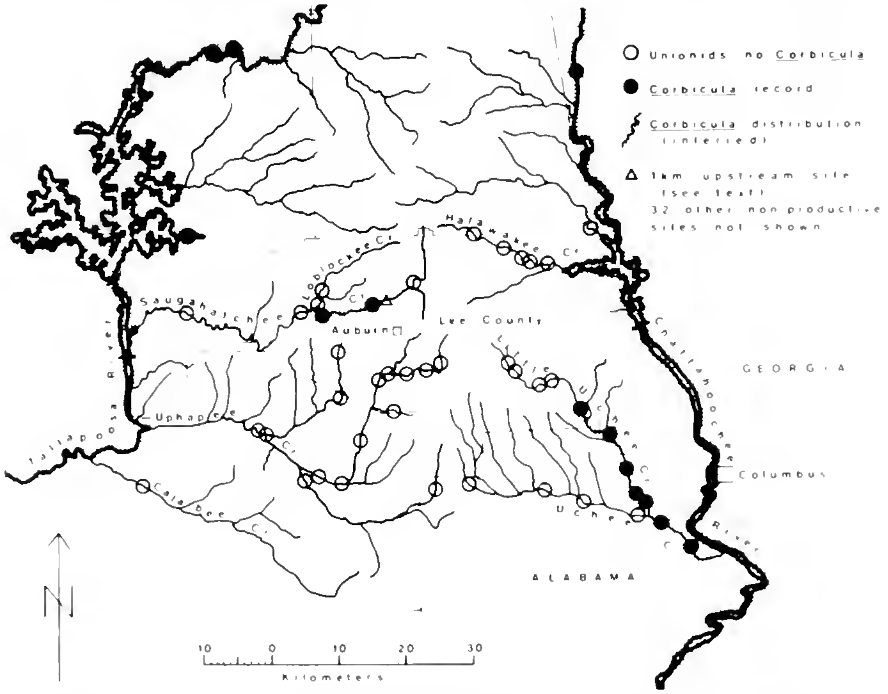

FIG. 1. *The known distribution of* Corbicula manilensis *(Philippi, 1841), in east-central Alabama. Most records date from 1972 and 1973; Saugahatchee Creek records above the mouth of Loblockee Creek date from 12 September 1976.*

the Rio Grande or some adverse environmental factors in the unpopulated drains might account for this pattern. Neither of these conditions seems to be operating in the Uchee Creek system; the larger streams always maintain some minimum flow, and any "adverse environmental factors" which might prevent colonization by *Corbicula* have not affected the thriving unionid populations.

Saugahatchee Creek Population

The Uchee Creek population was the only *Corbicula* population known from any of these creek systems until October 1973, when John C. Hurd collected one dead specimen of *Corbicula* in Saugahatchee Creek. This find was unexpected because Hurd had surveyed the aquatic mollusks of western Lee County in 1970-1971 and had found no living bivalves in the main stream of Saugahatchee Creek (Hurd, 1971). Hurd had concluded that unionids were unable to survive in Saugahatchee Creek because this stream carries the effluents of a large textile mill and a sewage treatment plant.

In addition to the mill and sewage effluents, Saugahatchee Creek also receives water from the experimental ponds of Auburn University Department of Fisheries and Applied Aquaculture. During the summer of 1972 a project was conducted in some of these ponds to determine if *Corbicula* could be used as a biological filter to reduce the plankton levels in commercial catfish ponds. At the end of that project the clay bottoms of the test ponds were screened in Saugahatchee Creek to separate out the *Corbicula* for counting and growth analysis. The dead specimen that Hurd collected some distance downstream during the following fall might have been an escape or a discard from this screening process. Regardless of the origin of this specimen, collections made in November 1973 indicated that living *Corbicula* did exist in Saugahatchee Creek at that time.

Starting with the collections made in November 1973, three sites on Saugahatchee Creek have been sampled at approximately 18-month intervals in an attempt to monitor the status of the *Corbicula* population in this stream. The most upstream of these sites is located approximately one kilometer above the experimental pond discharge and the area where the pond bottoms were screened. The midstream site is approximately one kilometer below the screening site and the downstream site is approximately nine kilometers further downstream. In addition to being visited in November 1973, all three sites were collected on 8 March 1975 and on 12 September 1976. On each occasion a hand seive was used to collect *Corbicula* specimens from sandy areas in the substrate. No special effort was made to collect particular size classes; what was desired was an essentially random sample of any living *Corbicula* population. The results of these collections and the lengths of the living *Corbicula* specimens obtained are shown in Figure 2.

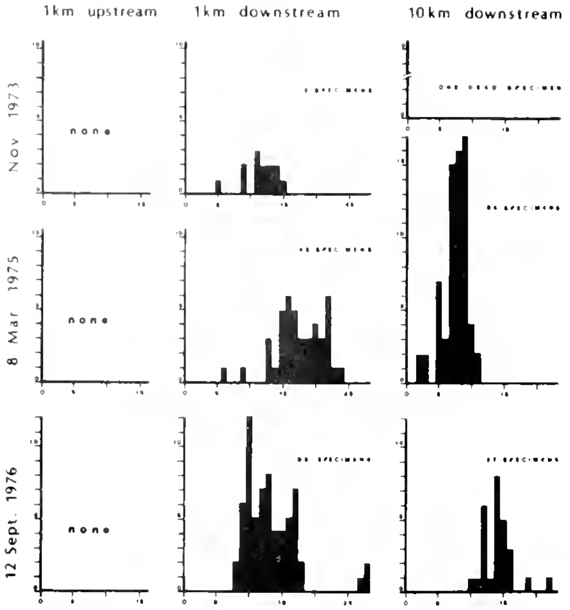

FIG 2. Corbicula *collection results from three sites on Saugahatchee Creek taken over a three-year period. Numbers along each ordinate refer to maximum shell length in millimeters; those along each abscissa refer to numbers of individuals with a given shell length.*

These collections document that during November 1973 a population of relatively small (<16mm) *Corbicula* existed in the creek only at the midstream collecting site. In March 1975 there were no *Corbicula* at the upstream site, the midstream population included some larger individuals (>20mm) and the downstream site was populated by many small animals (<12mm). By September 1976 both the mid- and downstream sites included animals with fairly broad ranges of shell lengths, the largest still occurring at the midstream site. No. *Corbicula* specimens had yet been found at the upstream site.

These results strongly suggest that *Corbicula* was introduced into Saugahatchee Creek within one kilometer of, and within a few months of, the screening of experimental *Corbicula* specimens by Auburn Fisheries personnel. These results document that *Corbicula* was able to survive and reproduce in a stream which, apparently because of pollution, is incapable of sustaining unionid populations. So far as the spread of this *Corbicula* population is concerned, these results indicate that an easily detectable population was established approximately ten kilometers downstream from the apparent site of introduction in more than 12, but less than 28 months. The population had not spread one kilometer upstream in approximately 48 months.

Current

The factors responsible for this apparent unidirectional colonization pattern are presently unknown, however, stream current is one environmental factor which could produce this kind of effect. According to Sinclair (1971) the North American corbiculid species passes through a non-swimming, pelagic, veliger larval stage. When these larvae are released, they apparently cannot swim against the current and all of them are carried downstream. The unidirectional effect of current alone, therefore, could explain the lack of upstream colonization in Saugahatchee Creek.

The unidirectional effect of current could also explain the "unusual" distribution patterns of the *Corbicula* populations in the Uchee Creek system and in Mesilla Valley. In both cases, if *Corbicula* had been introduced at an upstream site, the remainder of the distribution pattern coincides exactly with the areas where non-swimming planktonic larvae would be carried by current. In the Uchee Creek system current would adequately explain why no *Corbicula* specimens were found in Uchee Creek proper above the mouth of Little Uchee Creek, although unionids occur in both areas. In Mesilla Valley current alone could prevent an original population in West Drain from spreading into any tributary that maintained some minimum flow. This same reasoning could be used to explain why *Corbicula* does not occur in other east-central Alabama streams even though it is abundant in both the Tallapoosa and Chattahoochee rivers.

Although this proposed role of current in directing the spread of *Corbicula* populations would seem entirely logical and expected, I have found no mention of it in the extensive American literature concerning *Corbicula*. Other ideas have been advanced, however, to explain the occurrence of this invading organism in certain locations. One recently proposed hypothesis is that *Corbicula* sometimes becomes established because it is able to out-compete the native bivalves in areas that have been disturbed by man (Fuller and Imlay, 1976). While this hypothesis may fit some situations, especially with regard to sphaeriids (e.g. Gardner *et al.*, 1976), it does not seem to be operating in the relatively unaltered Uchee Creek system where unionids and *Coribula* occur together in large numbers. In addition, the information presented in the abstract by Fuller and Imlay appears to support this "current hypothesis" better than the "competition hypothesis" they propose.

Corbicula can no longer be considered to be an oddity only worthy of a casual distributional note. This organism is now a dominant member of many North American freshwater faunas, often much more abundant than any other mollusk. Since we know so little of the biology, ecology or taxonomy of this newly-established species, every piece of factual information which appears in the literature can only serve to increase our understanding of this animal. In addition to the theoretical material presented in this paper, I have attempted to detail the present distribution pattern of the *Corbicula* populations in east-central Alabama as completely as possible. It is my hope that future workers may be able to use these data in various ways to increase our general understanding of this no-longer alien mollusk.

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DESCRIPTIONS OF SIX NEW FORMS[1] OF FLORIDA TREE SNAILS, *LIGUUS FASCIATUS*

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In the spring of 1962 I found a group of snail hammocks in the southern Everglades of Florida that had never before been explored by *Liguus* collectors. One of these supports a polymorphic colony of *Liguus fasciatus* (Müller) that includes two new color forms.

In Pilsbry's (1946) classification of *Liguus fasciatus*, these new forms would be placed in the subspecies *testudineus* Pilsbry. Their closest relationship is with the form *castaneus*. I have called these two forms, or morphs, *humesi* and *framptoni*.

Four years earlier (1958) I had set out with a friend in his airboat in search of an especially beautiful form, *margoratus*, which a Seminole Indian, Smallpox Tommy, had shown me. We picked up Tommy at his camp three miles north of the Tamiami Trail. A lack of communication between the Indian and us, or his reluctance to take us there, prevented us from finding our *marmoratus*. The group of hammocks to which he took us contained instead a new form of the subspecies *testudineus*, namely *evergladesensis*.

The deplorable practice by collectors of transplanting the Florida tree snail, *Liguus fasciatus*, to hammocks already populated with other *Liguus* began before the turn of the last century and continues to this day. Collectors gathered choice specimens of this magnificent snail and put them in selected hammocks with the expectations of collecting them and their progeny before some other collector did. In 1917 I interviewed a Mr. Lincoln, a former Florida West Coast shell dealer. He was then in his late eighties and resided in a rest home in Ft. Myers, Florida. He told me that when he was a young man he transplanted some *Liguus* from Long Pine Key of the Lower Everglades to Big Pine Key in the Lower Florida Keys. Charles Torrey Simpson introduced them into his hammock in Lemon City (North Miami) so that he could more easily observe and study them. "In my bit of forest, into which I have carried many specimens from elsewhere - - -."

A great flurry of transplantation occurred immediately before the establishment of the

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[1] Latinized names for color forms, *forma*, varieties, or aberrations are useful to students of variation, but these infrasubspecific names, proposed after 1960, have no nomenclatural standing, and hence no priority over properly proposed specific or subspecific names, according to Articles 1 and 10b of the International Code Zool. Nomen. - Editor

Everglades National Park in 1947. Collectors rushed to the then-to-be Park and removed some of the more beautiful varieties and relocated them outside the Park in Pinecrest, Collier County, the East Coast Ridge and the Florida Keys. They hid them almost anywhere they thought the snails would not be found by other collectors. This distribution in no way hurt the Park colonies but the cumulative effect of all the introductions greatly affected the gene mix of once reasonably stable populations, so that now it would be next to impossible to work out the mystery of the distribution of these snails in southern Florida.

Liguus feed upon the minute lichens, fungi, sooty molds and algae that grow on the bark and leaves of trees, shrubs, etc. They use their radulae to scrape these foods and loose particles of bark from the hammock vegetation. Newly hatched snails begin feeding at the bases of trees and, during periods of wet weather, work their way to the tops of the trees, feeding as they go.

In the descriptions of the forms that follow, I have used the words large, medium size and subsolid in describing the size and solidity of shells. One should understand that the size and solidity of *Liguus* shells are determined to a lesser degree by heredity and to a greater degree by the amount and quality of the snail food found in a hammock. It follows, therefore, that when one describes the size and thickness of a *Liguus* shell, one describes to a greater degree the condition of the hammock as it relates to *Liguus* and to a lesser degree the inherant nature of the shell itself. For example: if one took, say, 45 newly hatched *graphicus* from one small colony, divided them equally into three lots and put one lot in a hammock with a maximum amount of food on the lysiloma and Jamaica dogwood trees; the second group in an identical hammock with a minimum of food; the third lot in a hammock forested principally with bustic and hackberry with optimum food, one would get three very different results. If one were to describe the size and solidity of each group at the end of the third year of activity, the descriptions would be approximately as follows:

First group - large size (up to 70 mm.), solid;
Second group - small size (up to 46 mm.), thin;
Third group - large size (up to 65 mm.), thin.

These facts were not understood by some describers of *Liguus* and it has caused confusion and difficulty in subsequent identifications of some forms of snails.

Liguus fasciatus humesi, *new form*

Figs. 5, 6

Description: Shell medium size (up to 55 mm. in length), moderately elongate, subsolid; texture lustrous in young shells to dull in old specimens; whorls not inflated, slightly convex; columella sinuate to straight, thin; palatal lip smooth, occasionally crenate at juncture of periostracal green lines, slightly thickened within.

Color: apex pink; columella and parietal wall invariably white except in thin shells where the color of the shell penetrates the very thin white callus which produces a slight pinkish effect; there is a narrow white to creamy brown sutural line; the third whorl is light-pink to brown and is marked with a few brown axial striae; the color of the fourth, fifth, sixth and last whorls is dark-brown to almost black, broken by irregular yellowish axial stripes (which are often zigzag) and blotches that often extend from suture to suture on the fourth, fifth and sixth whorls and from suture to the base of the shell on the last whorl; there is a narrow yellowish peripheral band that produces a dark band, broken by yellow axial flames and/or blotches, above and below the periphery. A small percentage of shells have a few spiral green lines above and/or below the periphery.

Type material: The form *humesi* is found only in an isolated group of hammocks of the southern Everglades. The holotype and paratypes were collected March, 1962. The holotype has been placed in the United States National Museum, Washington, D.C. It is a four-year-old shell; length 46 mm., width 23 mm., aperture width 23 mm., distance from suture to base of shell 21.5 mm. Paratypes have been placed in the United States National Museum, Washington, D.C., the Museum of Comparative Zoology, Harvard University, the Academy of Natural Sciences of Philadelphia, University of Florida, Gainesville, and the Everglades National Park Collection, Homestead, Florida.

A lot of 129 shells, collected without selection included the following forms:

castaneozonatus	101	78%
cingulatus	11	9%
humesi	9	7%
framptoni	5	4%
luteus	3	2%
	129	100%

The color form *humesi* differs from the form *castaneus* by always having a white columella and parietal wall and by the absence of the single or double peripheral bands.

In 1964 a group of *humesi* was introduced into a hammock containing no *Liguus*. Since then I have visited this hammock scores of times during the last 15 years and have not seen any of the other forms associated with it in its native habitat.

It is with great pleasure that I name this shell for one who has played a significant part in the history of *Liguus* in Florida, Mr. Ralph Humes, now of Leesburg, Florida, intimate friend, delightful snailing companion and dedicated conservationist. He donated his fine large *Liguus* collection to the Everglades National Park. He is the originator of the Park *Liguus* project on which he collaborated until he moved from Miami. Mr. Humes described the color form *wintei* and wrote a history of *Liguus* collecting in Florida.

Liguus fasciatus framptoni, *new form*

Figs. 7, 8

Description: Shell medium size, (up to 55 mm. in length), moderately elongate, subsolid; texture lustrous in young to dull in old shells; whorls not inflated, slightly convex above the periphery; columella sinuate to straight, thin; palatal lip smooth, occasionally crenate at juncture of periostracal green lines, slightly thickened within.

Color: apex pink with a minute brown spot on its summit; columella and parietal wall invariably pink or liver-colored; there is a narrow creamy brown sutural line; the third whorl is creamy brown, sometimes with faint narrow light brown axial streaks; the color of the fourth, fifth, sixth and seventh whorls is dark-brown, broken by irregular yellowish axial striae (which are often zigzag) and blotches that often extend from suture to suture on the fourth, fifth and sixth whorls and from the suture to the base of the shell on the last whorl; there is a narrow yellowish peripheral band that produces a dark band, (sometimes wanting on the last whorl) broken by yellow axial flames and/or blotches, above and below the periphery. A small percentage of shells have a few faint spiral green lines above and/or below the periphery. A brown or purplish sinuating line borders the parietal wall from termination of the suture to the tip of the columella. It is a parallel form to *humesi*, differing only in the light-brown coloration, the pink or liver-colored columella and parietal wall and the pink apex with the minute brown spot at the summit.

Type material: This color form is found with *humesi*, *castaneozonatus*, *cingulatus* and *luteus* in an isolated group of hammocks of the southern Everglades referred to above in the description of *humesi*. The holotype, a three-year-old shell, has been placed in the United States National Museum, Washington, D.C. Its length is 47 mm., width 23 mm., aperture width 12 mm., distance from suture to base of shell 21 mm. Paratypes have been placed in the United States National Museum, Washington, D.C., the Museum of Comparative Zoology, Harvard University, the Academy of Natural Sciences of Philadelphia, University of Florida, Gainesville, and the Everglades National Park Collection, Homestead, Florida.

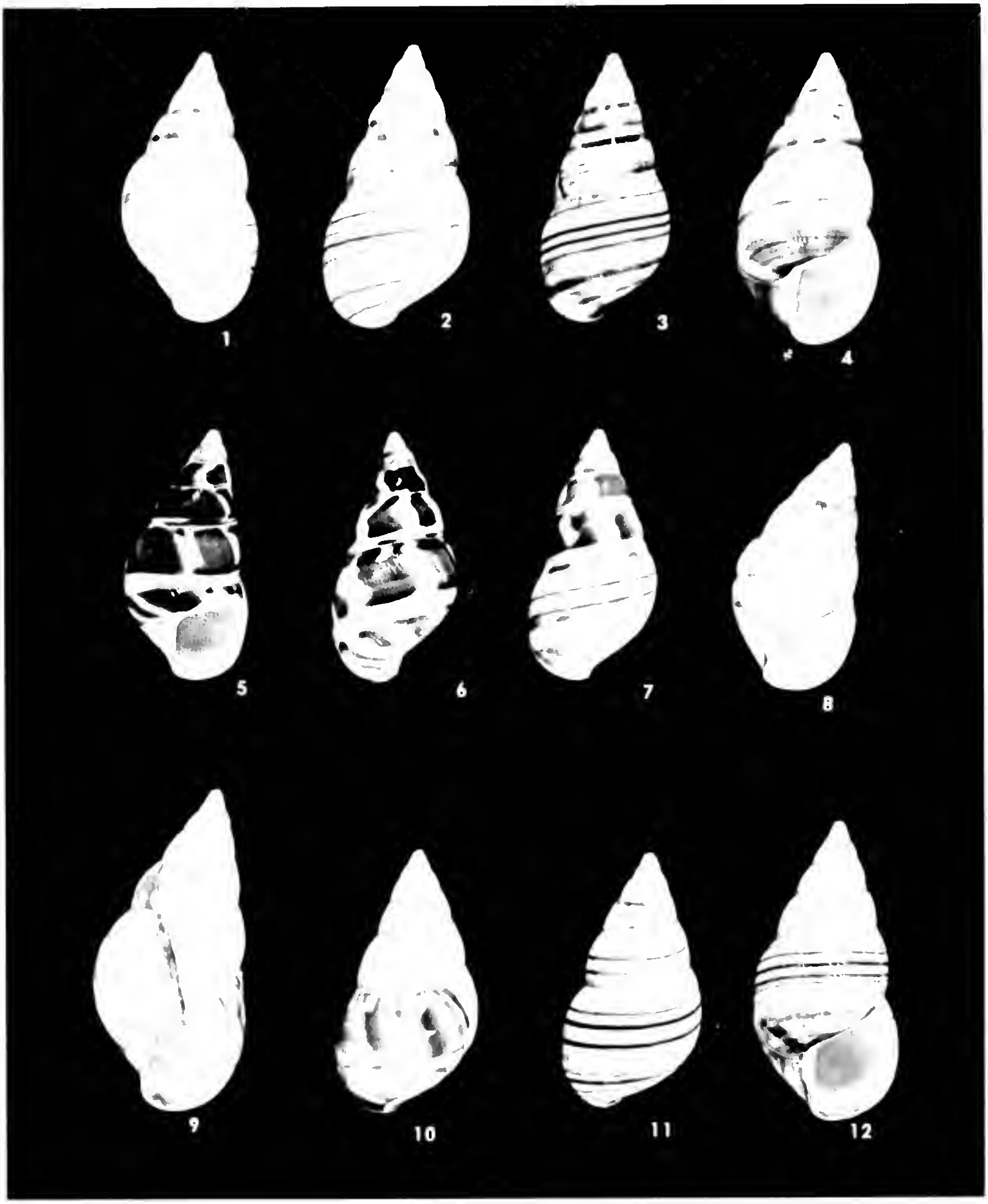
The offspring of a number of *framptoni* introduced several years ago into a hammock devoid of *Liguus* were predominately *framptoni*, some *humesi*, *luteus* and very rarely *castaneozonatus*.

I have named this form in honor of Henry G. Frampton (1902 - 1966), one of the early modern collectors of Florida *Liguus*, who contributed to the literature by describing the forms *splendidus*, *fuscoflammellus* and *elenchi*. His widow, Theodosia, presented his fine, large *Liguus* collection to the Museum of Comparative Zoology, Harvard University.

Liguus fasciatus evergladesensis, *new form*

Figs. 1, 2

Description: Shell medium size, moderately inflated, subsolid, texture matt or without much gloss; whorls convex, last whorl well rounded;



[illegible] 1, 2. [illegible] 3, 4. [illegible] 5, 6. [illegible] 7, 8. [illegible] 9, 10. [illegible] 11, 12. [illegible] sutures not very deep, well shouldered; columella usually thin, straight and simple, occasionally slightly sinuated; palatal lip smooth, slightly crenate at juncture of periostracal green lines, slightly thickened within.

Color: apex, columella and parietal wall invariably pink. Ground color is light-yellow. The antepenult whorl is marked by a broad smoky lavender band broken by yellow vertical flames or blotches. Above and below this band are narrow rufescent bands. On the penultimate and body whorls the broad band degenerates into alternating vertical smoky lavender and light-yellow flames. The two narrow bands become a series of comma-like blotches. The yellow ground color predominates. On the body whorl, the vertical flames are broken at the periphery by a very light-yellow band and or a lavender line. The columella is bordered by a narrow pink line. There is a narrow reddish brown basal line which is often reduced to a series of blotches. Almost all shells have from one to five spiral green lines above the periphery and from one to four below.

Type material: The type locality is one of a group of four or five hammocks about one mile west of Canal Levee 28 about six miles north of the 40-Mile Bend of the Tamiami Trail. The holotype has been placed in the United States National Museum, Washington, D.C. It is a three-year-old shell: length 48 mm., width 25 mm., aperture width 14 mm., distance from suture to base of shell 23 mm. Paratypes have been placed in the United States National Museum, Museum of Comparative Zoology, Harvard University, the Academy of Natural Sciences of Philadelphia, University of Florida at Gainesville and the Everglades National Park Collection, Homestead, Florida.

Comments: Form *evergladesensis*, in its first year superficially resembles *castaneus* but in later growth the juxtasutural bands are absent or reduced to a series of blotches. The columella and parietal wall are invariably pink whereas in most *castaneus* they are white. It is unique among Pinecrest and Collier County subspecies *testudineus*, being the only form having a full pink tip. I doubt if there is any close genetic relationship between *evergladesensis* and *castaneus*. Over 50 miles separate the two forms. The closest hammocks containing *castaneus* are those of the Long Pine Key area near Homestead. The form *evergladesensis* is found with *livingstoni*, the predominant form, and with the form *floridanus*. It is interesting that while they are found in a polymorphic population they breed true to form when isolated. Such populations introduced in two southern Everglades hammocks in 1961 have never produced any other forms.

Liguus fasciatus margaretae, *new form*

Figs. 3, 4

Description: Shell large (to 64 mm. in length), elongate; texture subsolid with a sheen but appears dull; body whorl convex, well-shouldered; penultimate whorl convex; the antepenult, fourth and third whorls flat; columella straight, not thin, slightly twisted, occasionally obliquely truncated; palatal lip slightly thickened within, usually crenate at juncture of periostracal green lines which are numerous and always present.

Color: columella and first two or three whorls of spire are white. There is a narrow suprasutural creamy yellow band and a subsutural mahogany-colored line. The fourth whorl is ivory-white broken by reddish brown subsutural spots that often develop into vertical striae that extend downward almost to the suture. The fifth, or antepenult whorl, has a broad bluish gray band broken by light-tan vertical flares that increasingly diffuse on the penultimate and body whorls and on the body whorl are overlaid with a blue-green wash above the reddish mahogany peripheral line and a wide darker green wash below the light-tan narrow band that lies immediately below the peripheral line. There is often a baby-blue line immediately above the peripheral line. An orange basal band borders the columella and it is bordered by a much darker band that extends from the base of the shell to approximately two-thirds the distance to the suture.

Type material: The type locality is a small hammock of the southern Everglades. The holotype is a mature, three-year-old shell, length 54.5 mm., width 26 mm., aperture width 13 mm., distance from suture to base of shell 22.5 mm. It has been place in the United States National Museum, Washington, D.C. Paratypes were also placed there and in the collections of the Everglades National Park, Homestead, Florida.

Museum of Comparative Zoology, Harvard University, Academy of Natural Sciences of Philadelphia and the University of Florida at Gainesville.

Comments: This race of snails descended from five snails that appeared in a hammock in which I had placed together *lucidovarius* from Pinecrest Hammock No. 11 and *clenchi* from Pinecrest Hammock No. 88. One of these shells had a so-called "jewel tip", or apex of pinkish brown. This population produced the two above-mentioned forms, *lossmanicus*, many intermediates and the five ancestors of *margaretae*.

The five snails were transferred to another hammock which had no snails. Two years later I returned and saw about 15 newly hatched snails (all of the white-tipped form), three white-tipped parents and the dead jewel-tipped shell. If this jewel-tipped snail died before it mated it could account for the white-tipped offspring.

One would expect to find the polymorphism of the first hammock to show itself in the snail population of the second hammock but this has not occurred. Since the introduction in July, 1969 all offspring have been *margaretae*.

The distinguishing characteristics of *margaretae* are the light blue-green wash over the body whorl and the spire pattern of *lucidovarius*. In recently collected shells the wash appears to be more blue than green but as the colors fade green predominates.

I name this shell for my wife whose patience and understanding made it possible for me to spend many thousands of hours in the field these 45 years since I first began snailing in 1934.

Liguus fasciatus beardi, *new form*

Figs. 11, 12

Description: Shell similar to that of *margaretae*, except for color and pattern. First whorl of spire pink, faintly tinged with brown at the summit. Next two or three whorls ivory-white or white, sometimes flecked with ochre. There are supra and subsutural light-brown lines which are darker, heavier and broken on the antepenult whorl. On the penultimate whorl this line sometimes appears as brownish spots. The overall *color* of the shell is grayish brown wash, broken at the periphery by a wide, lighter colored band which is dissected by a heavy, brown or mahogany line. There are usually four or five green lines above and about three or four brownish green ones below the periphery. The columella is white or nearly so. The parietal wall is light-purple. There is a brownish purple line bordering the parietal wall which extends from the suture to the tip of the columella. Bordering this line at the base of the shell is a lighter colored band sometimes bordered by a darker one.

Type material: The type locality is a small hammock of the southern Everglades near the type locality of *margaretae*. The holotype is an adult three-year-old shell: length 54 mm., width 26 mm., aperture width 14 mm., distance from suture to base of shell 24 mm. The holotype has been placed in the United States National Museum, Washington, D.C. Paratypes have been placed in the United States National Museum, the Everglades National Park Collection, Homestead, Florida, Museum of Comparative Zoology, Harvard University, Academy of Natural Sciences of Philadelphia and the University of Florida, Gainesville.

Comments: There is almost a total lack of vertical markings of any sort, except as described above. Occasionally a shell will have a trace of the blue-green wash of *margaretae* on the body whorl.

It gives me much pleasure to name this shell for Dan Beard, first superintendent of the Everglades National Park, whose foresight and encouragement made possible the introduction of rare and beautiful forms of *Liguus* into the Park where, hopefully, they will be saved for future generations of scientists to study and for Park visitors to observe and enjoy.

Liguus fasciatus kennethi, *new form*

Figs. 9,10

Description: Shell large (to 62 mm.), moderately elongate, subsolid to solid, somewhat lustrous to dull; whorls 7 - 7½, convex; columella heavy, straight but slightly twisted, obliquely truncated.

Color: first three whorls of the apex and columella ivory-white, parietal wall very light-flesh color. The ground color of the body whorl is yellow with an overlay of blotches, smears and vertical stripes of burnt umber and umber which fade with time to yellow-ochre. There is a very narrow yellowish cream subsutural line and a narrow (1 - 2 mm.) peripheral band of the same color, sometimes bordered above by a lavender line. As the colors fade, each year's markings become lighter so that in some old shells the whorls above the body whorl are almost white. A few specimens show on the body whorls some spiral bandings as in the form *floridanus*. Periostracal green lines seldom present and few in number. Growth-rest varices slightly expanded.

Type material: The type locality is a small hammock of the southern Everglades. The holotype is a four-year-old shell, length 59 mm., width 28 mm., aperture width 15.5 mm., distance from suture to base of shell 26 mm. The holotype has been placed in the collection of the United States National Museum, Washington, D.C. Paratypes have been placed in the United States National Museum, the Museum of Comparative Zoology, Harvard University, the Academy of Natural Sciences of Philadelphia, University of Florida, Gainesville, and the Everglades National Park Collection, Homestead, Florida.

Comments: The progenitors of *kennethi* first appeared in Pinecrest Hammock No. 13 into which Mr. Erwin C. Winte had comingled some introduced *Liguus* with the native population. Unfortunately, no records were kept and information as to the identity of the forms introduced is uncertain. Mr. Winte and I isolated five snails of this new form in a barren hammock. Later most of the progeny were transferred to another hammock. Since then, the two colonies have remained monomorphic. This phenomenon, plus the fact that *kennethi* shows no similarity to any of the forms of the original population leaves its geneology uncertain. Its overall shape and appearance indicate only mainland forms were involved but its somewhat glossy appearance in five and six-year-old specimens suggests the influence of a Florida Keys ancestor.

I name this snail for my son whose help in the exploration for suitable hammocks, collecting *Liguus* material and establishing it in the Everglades National Park contributed substantially to the success of the Park *Liguus* Project.

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CHICOREUS COSMANI, A NEW MURICID GASTROPOD FROM THE WEST INDIES

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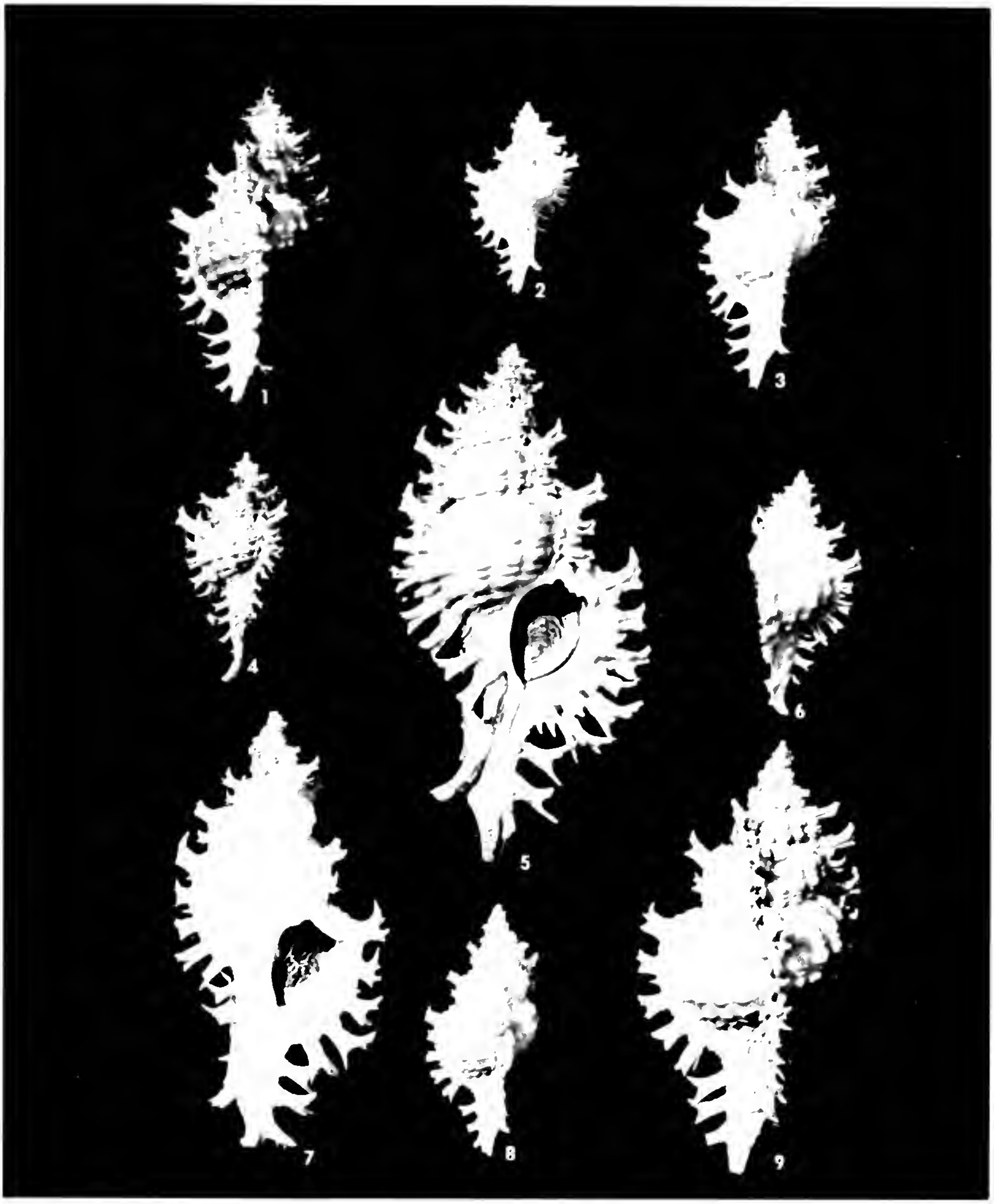
Despite the fact that the taxonomy of the family Muricidae has recently suffered under the hands of various conflicting interpretations (E. H. Vokes, 1971, Radwin and D'Attilio, 1976; Wagner and Abbott, 1978), new, apparently valid, taxa continue to come to light (Emerson and D'Attilio, 1979). Contributing to our knowledge of marine mollusks is a corps of enthusiastic SCUBA divers and ardent private shell collectors. An outstanding example are the collecting efforts of Mr. Dieter Cosman of Long Island, New York, who has personally collected and documented numerous outstanding conchological discoveries in the tropical Western Hemisphere.

Among Mr. Cosman's unusual discoveries is a colony of *Chicoreus* muricid snails from Jamaica representing a species which evidently has not been given a valid, scientific name. We take great pleasure in naming this new species after him.

Chicoreus cosmani *new species*

(Figs. 1-9)

Description: Shell moderate in size for the genus, attaining a length of 79 mm., trigonally



FIGS. 1-9. Chicoreus [illegible] [illegible] 5, [illegible] length; the other figures [illegible] Collected by [illegible]

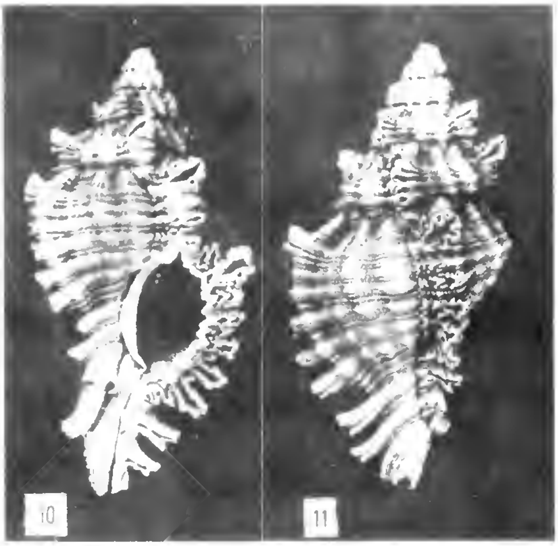
fusiform in shape. Spire acute, with an angle of 35 to 40°, and about 15 percent of the entire length of the shell. Nuclear whorls 1 1/2 glossy-smooth, convex, small but bulbous, whitish to tan, and with a well-indented suture, followed by 8 or 9 convex, well-sculptured, post-nuclear whorls. First few whorls with a cancellate sculpture between the varices. Suture finely impressed and slightly wavy. Aperture relatively small, about one-fourth the length of the entire shell, and with the peristome entire. Parietal wall glossy, slightly raised, and tinted with yellow, orange-brown or pinkish. Outer lip scalloped and bearing 10 to 12 minute, raised, white denticles. Siphonal canal moderately broad, nearly sealed, and slightly recurved dorsally and to the right at the distal end. Former siphonal canal half as large, tube-like, recurved to the left, and bearing on its surface a half-dozen axial, irregular, small cords. Last (and earlier) whorls with three varices, originating just behind the varix above it on the previous whorl. Each varix in the body whorl bears 8 short, bi- or tri-furcate, scaly, partially (or rarely entirely) closed fronds. Three of these fronds are on the right side of the siphonal canal. In the early whorls the top frond is usally twice the size of those below. Intervarical sculpture consists of 4, rarely 3, even-sized axial, low cords which are crossed by numerous finer, spiral cords, thus forming a pattern of low, rounded beads, or tiny knobs, all about the same size. Color of shell varies from a uniform brownish orange to a pale yellow orange, rarely white. Interior of aperture white, with an orange-stained columella. Operculum chitinous, light-brown, oval, unguiculate, with fine, scaly concentic growth lines.

Measurements (mm) —

length	*width (with spines)*	*no. whorls*	
79	40	10+	holotype, fig 5
67	33	9+	paratype, fig 7
38	21	7.5	paratype, fig. 6
29	17	8.0	paratype, fig. 3
25	15	7.0	paratype, fig. 2

Type locality: on pilings at the Reynolds Bauxite dock, Ocho Rios, north side of Jamaica. 10 to 15 feet. March 1967. Dieter Cosman, collector.

Types: The holotype (Fig. 5) has been deposited in the U. S. National Museum no. 783323. Paratypes are in the collection of Dieter Cosman, C. John Finlay, the Academy of Natural Sciences of Philadelphia, the Amer. Mus. Nat. Hist., Jerome Bijur, and the Delaware Museum of Natural History. Specimens have been reported as "very uncommon in about 35 feet at the Bogue Islands, Discovery Bay, Orange Bay and Bull Bay (south coast), Jamaica, in water as deep as 60 feet by Michael Humfrey (1975, p. 131, pl. 15, figs. 10, 10a). We have not seen these specimens. One paratype (Acad. Nat. Sci. Philadelphia no. 35419) worn in condition, was collected by Robert Swift in St. Thomas, Virgin Islands, in the 1860's.



FIGS. 10, 11 Chicoreus *species from Curacao resembling* cosmani. *29 mm. in length. Collected by Henk Bielderman, 1973. Constance Boone collection. Photos courtesy of Emily Vokes.*

Remarks: The *Chicoreus* complex in the Caribbean is complicated by the existence of a number of species, subspecies and local, isolated forms, so that the present status of our knowledge is still far from complete. We believe that *C. cosmani* is a valid species, closely related to *C. dilectus* (A. Adams, 1855), *brevifrons* (Lamarck, 1822), *spectrum* (Reeve, 1855) and *florifer* (Reeve, 1845). It differs markedly from those other species in having 3 or 4 axial rows of rounded beads between the varices, somewhat reminiscent of the sculpturing seen in *Bursa pileare* (Linnaeus). The other species usually have one large and one or two smaller knobs on the shoulder of the whorl. In *brevifrons* and *mergus* E. Vokes, 1974, the spire is much lower, the shell more quadrate, and the upper spine on the varix much larger and longer than those below. Closest to *cosmani* is the specimen from Curacao illustrated and identified by Ruth Fair (1976, pl. 6, figs. 73, 73a) as *Chicoreus pudoricolor* (Reeve, 1845). This may be a darkly striped, less beaded form of *cosmani*. The type and only known specimen of *pudoricolor* was returned to Denmark by Reeve, and has not been subsequently relocated. The original illustration and description suggests a species more like *corrugatus* (Sowerby, 1841) or a young *spectrum*. We consider *pudoricolor* a *species inquirenda*. The Indo-Pacific counterpart of *cosmani* is *akritos* Radwin and D'Attilio, 1976, from northern Australia.

ACKNOWLEDGMENTS

We would like to thank Dieter Cosman for his generosity in contributing the holotype to the U. S. National Museum, Smithsonian Institution, and Jerry Harasewych for his excellent photography, and Emily E. Vokes, Constance E. Boone and the Walter N. Carpenters for information and the loan of related species.

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POPULATION DYNAMICS AND ZONATION IN THE PERIWINKLE SNAIL, *LITTORINA ANGULIFERA*, OF THE TAMPA BAY, FLORIDA, REGION

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ABSTRACT

Seasonal changes in population density and size class distribution reflect the seasonal nature of reproduction in Littorina angulifera *in the Tampa Bay, Florida, area. The zonation pattern of adult snails and juveniles is described. Both extremely high tides and a* Gymnodinium breve *"Red Tide" bloom reduced the population density. The* Gymnodinium *bloom killed new recruits differentially and had a long-lasting effect on the population density. The data show that most new recruits reach spawning size 9 to 10 months after metamorphosis. Most adults do not survive to spawn after two years, as there is an approximate 70 percent yearly mortality.*

INTRODUCTION

This is our second report dealing with *Littorina angulifera* (Lamarck) in the Tampa Bay area. The first dealt with reproductive behavior and early development (Gallagher and Reid, 1974); this report characterizes the composition and zonation of a Tampa Bay population of *L. angulifera* and describes seasonal changes in it from October 1971 through May 1975. In addition, two unusual natural environmental stresses occurred during the course of the study. Excessively high tides three to five feet above normal (Simon, 1974), accompanied Hurricane Agnes in June 1972 and an extensive outbreak of "red tide" caused by blooms of the dinoflagellate, *Gymnodinium breve*, in the winter and spring 1974. Effects of these events are described and resultant changes compared with those in non-stress years.

Although various *Littorina* species have been investigated extensively, only Borkowski (1974) has studied seasonal population changes and growth in groups of littorines over a period of several years. Palant and Fishelson (1968) reported on the reproductive cycles and ecology of *L. punctata* and *L. neritoides* in the Mediterranean Sea, but seasonal changes in population density and size distribution were not considered. Lenderking (1954), in her work on the biology of *L. angulifera* in the Miami, Florida, area studied growth, reproduction and size distribution patterns, but data were sparse on small snails because they were difficult to detect in the mangrove habitat in which she worked. Population density studies were not done. Hayes (1929) and Moore (1937) investigated shell growth in *L. littorea*; Moore also reported on spawning, length of life and mortality in this snail. Bingham (1972) investigated the growth and ecology of *L. irrorata* but none of these studies investigated seasonal changes in snail populations as reported here. Much has been done also on zonation patterns of littorines by Smith and Newell (1954), Evans (1965), Bock and Johnson (1967) and Chow (1975) among others. In addition to studies involving only littorines, others have investigated desiccation, temperature and salinity changes, and behavior patterns in relation to observed zonation patterns of intertidal animals generally (Broekhuysen, 1939; Kensler, 1967; Markel, 1971; and Vermeij, 1972). There are very few investigations encompassing the complete life history of prosobranch mollusks done in such a way that life cycles of the species can be illustrated from one spawning season to the next and so related to seasonal changes in population density and size distribution (however, see Frank, 1965). Results reported here, coupled with those obtained in a previous study on reproductive behavior (Gallagher and Reid, 1974) depict events in the life history of this snail, but we do not attempt to analyze the factors, whether physiological or environmental which may be causal in these events.

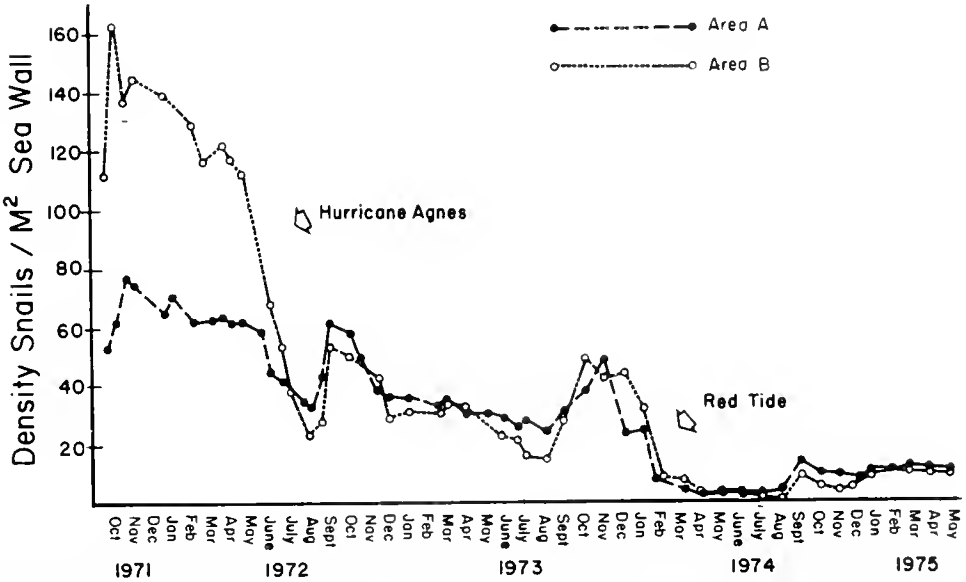


FIG. 1. *Fluctuations in population density of* Littorina angulifera *from October 1971 through May 1975 in two areas of seawall. Except for the large differences in recruitment in the fall of 1971 the populations densities in the two areas were similar.*

TAXONOMIC NOTE

There is some question regarding the taxonomic status of this snail. Rosewater (1963) stated that it was a subspecies of the Indo-Pacific snail *Littorina scabra* and so should be called *L. scabra angulifera*. It was so called in our first report (Gallagher and Reid, 1974). However, Bandel (1974), in his study of Atlantic Littorinidae, more recently stated that radular differences between the two are such that they should be considered separate species. Because of this and because Abbott (1974) also considers these two as separate species, this animal is so considered in this report. Until this taxonomic problem is cleared up we believe it less confusing to refer to the organism as *L. angulifera* since it is so designated in most of the literature.

HABITAT

Most of the animals in this study occupied a vertical concrete seawall bordering a canal in Boca Ciega Bay immediately south of John's Pass in Treasure Island, Florida (27°47′N, 82°47′W). The seawall habitat was chosen because of the ease of observing and counting animals on it in contrast to attempts to study these animals in a *Spartina*-mangrove community. Although previous work (Gallagher and Reid, 1974) indicated that the seawall is a less favorable habitat than the *Spartina*-mangrove area, observations indicated that the same pattern of recruitment and zonation occurred in both places. Therefore, we felt results of this study would apply generally to the species in this area.

The seawall is composed of upright concrete slabs 130-140 cm high and 120 cm wide; the canal bottom is composed of soft mud and oyster bar. During the study the lowermost 30-40 cm of seawall were encrusted with oysters (*Crassostrea virginica*) and barnacles (*Balanus amphitrite*, *Chthamalus* spp.). The isopod, *Ligia* sp. was one of the most conspicuous animals in the habitat. An intertidal zone approximately 9 m wide extended horizontally from the base of the seawall since this much of the canal bottom was exposed at low spring tides. In 1971, at the beginning of the study, both *L. angulifera* and *L. irrorata* were present on the seawall, but during that year the numbers of the latter species gradually declined so that by 1972 none remained. This

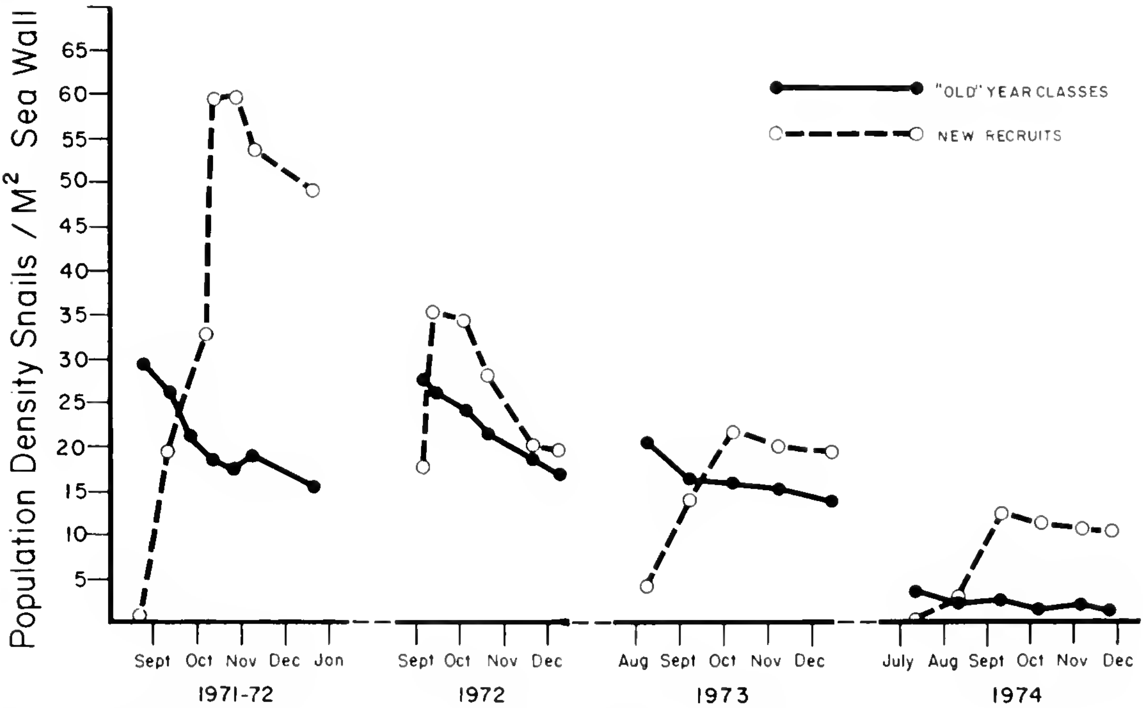


FIG. 2. *Comparison of population density of new recruits and older year classes of* L. angulifera *in the months in which the two groups are easily distinguished.*

species continued to be abundant in local *Spartina* marshes but did not return to the seawall. Casual observation of other seawalls in the area showed that while *L. angulifera* was frequently present, *L. irrorata* was rarely present, suggesting that it was less able to adapt to that environment. Although these were the only two supratidal mollusks on seawalls several intertidal mollusks inhabited the canal bottom.

Several species of algae grew upon the encrusted basal zone of the seawall. The following species of Cyanophyta (blue green) were found: *Anacystis aeruginosa*, *A. montana*, *Porphyrosiphon notarisii*, *Schizothrix arenaria*, *S. calcicola*, *Microcoleus lyngbyaceus*, *Entophysalis deusta*, and *Mastigocoleus testarum*. The last two and *Schizothrix calcicola* were found boring into oyster and barnacle shells in the upper parts of the encrusted zone. In addition to the blue green algae, several species of red and green algae were consistantly found on the lower 20 cm of seawall, usually where it was protected by an overhang of oyster growth and not subject to excessive desiccation. The following species of Rhodophyta (red algae) were found: *Polysiphonia subtilissima*, *Centroceras clavulatum*, and *Ceramium fastigiatum*. Chlorophyta (green algae) included: *Ulva* sp., *Enteromorpha compressa*, *E. lingulata*, *Chaetomorpha aerea*, *Cladophora delicatula*, and *Cladophora* sp. In addition numerous diatom species were present. Both littorines fed in this zone but actual species eaten were not determined.

Thus, while creation of seawalled canals has apparently contributed to the decrease of species diversity in Boca Ciega Bay (Taylor and Saloman, 1968; Sykes and Hall, 1970) some species are able to adapt to the conditions, especially if an intertidal zone is present. Since much of the shallow water area of this bay formerly consiting of grass flats, mangrove shores and *Spartina* marshes has been converted to seawalled canals (Simon, 1974), we felt that studying snails in this type of environment might add to knowledge of some long-term effects of "dredge and fill" as well as provide information of the life cycle of *L. angulifera*.

METHODS

Population fluctuations

Population changes were studied by means of censuses of all *L. angulifera* in two areas of seawall. Area A was a portion of seawall 13.2 m long (eleven 120 cm slabs). Area B, 10.8 m long (nine 120 cm slabs) was located approximately 25 m from Area A. All snails in these areas were counted every 2-3 weeks from October 1971 through June 1972, and approximately each month thereafter through May 1975, with additional censuses in May and July 1976. In some instances slightly longer intervals elapsed between counts. The seawall was 140 cm high in Area A and the substrate at the base was soft mud; the base of the wall was encrusted with oysters and barnacles. In Area B the seawall was 130 cm high and the substrate at the base was oyster bar; the base was also encrusted with oysters and barnacles, although the zone of encrustation was not as wide as in Area A due to the contour of the canal bottom. Total counts of *L. angulifera* were converted to population densities expressed as numbers of snails m^2 of seawall (Figure 1). From September through December of each year new recruits were recorded separately from previous year classes since size differences between the two groups were evident during censusing (Figure 2).

Total shell height (from base of aperature to tip of spire) of random samples (including all snails on an area of exposed seawall at all levels) of usually at least 100 snails was measured to 0.1 mm with vernier calipers to study the pattern of size distribution and growth. Sizes of samples taken after the 1974 red tide were small because of the decrease in snail population then, but such samples represent a large percentage of the remaining population. The samples were taken near to but not in census areas and usually were returned to the seawall after measurement to avoid depleting the population and disturbing the census areas. Size distribution curves (Figure 3) are based on size classes of 1 mm intervals. Figure 4 depicts the seasonal variation in mean shell height for the population as a whole. Growth of new recruits during 1972-73 was compared with that of older snails (Figure 5) by calculating mean shell height of new recruits and older snails separately. During months when

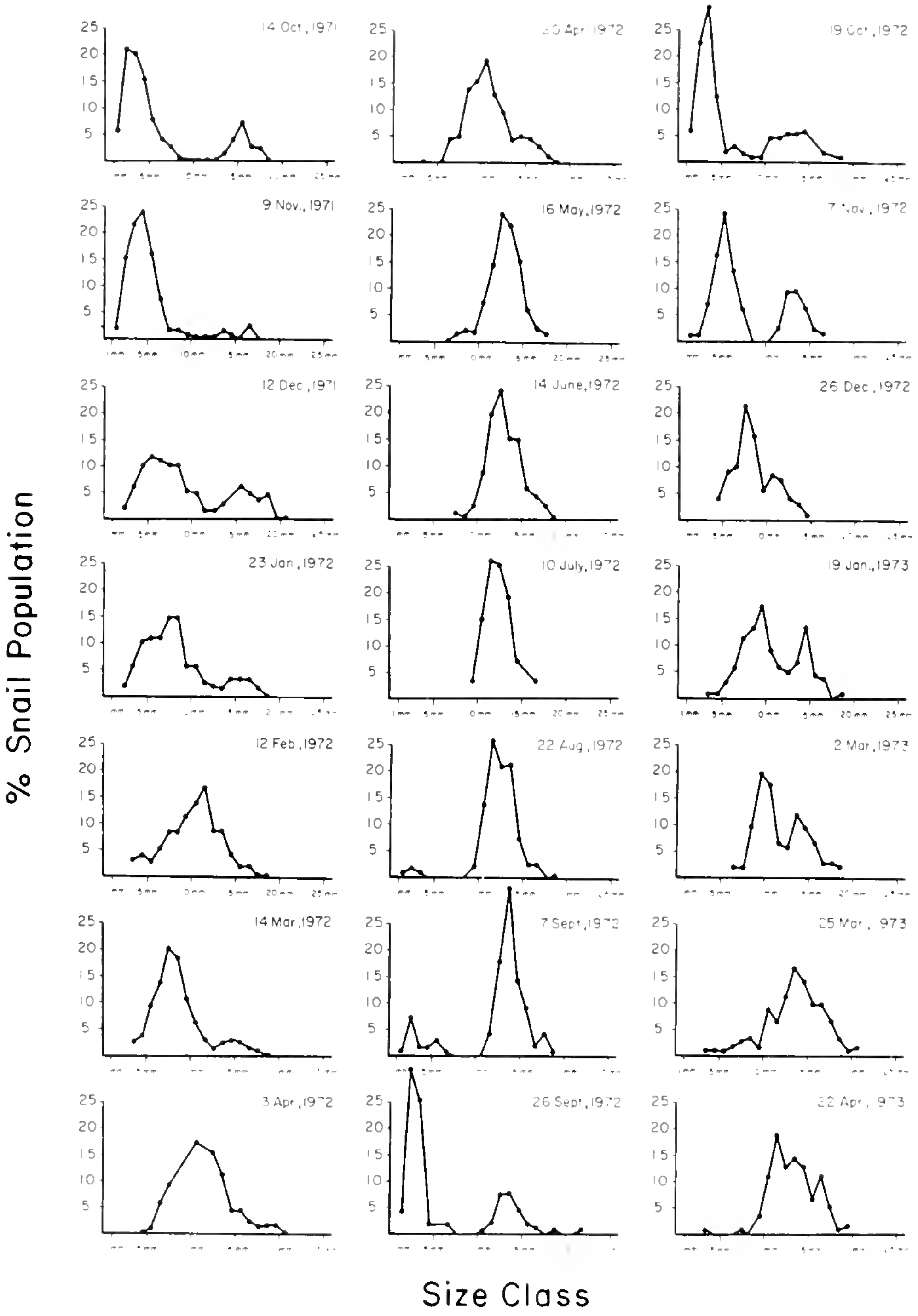


FIG 3. *Seasonal variations in size class distribution of* L. angulifera *from October 1971 through May 1973*

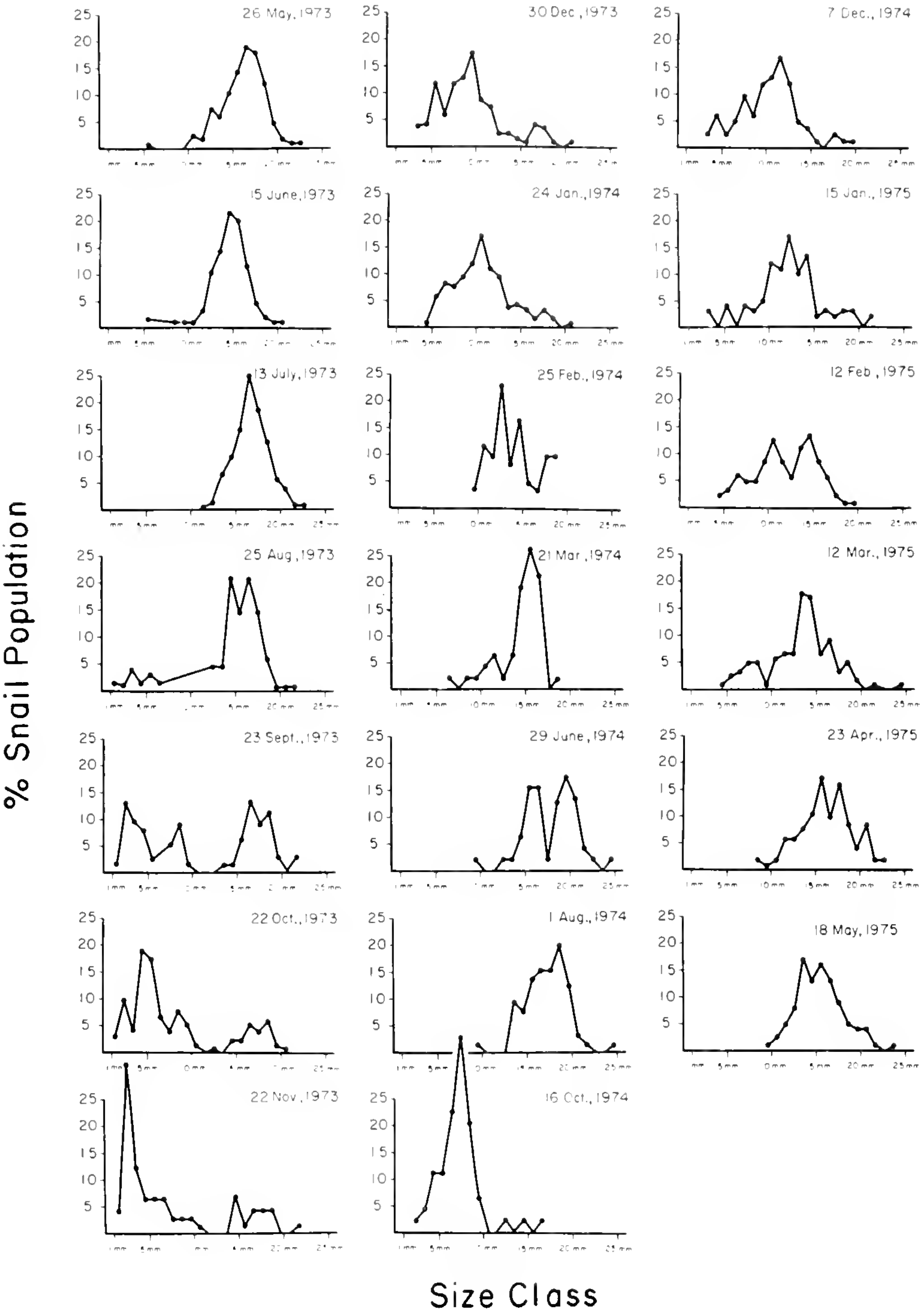


FIG. 3. (continued)

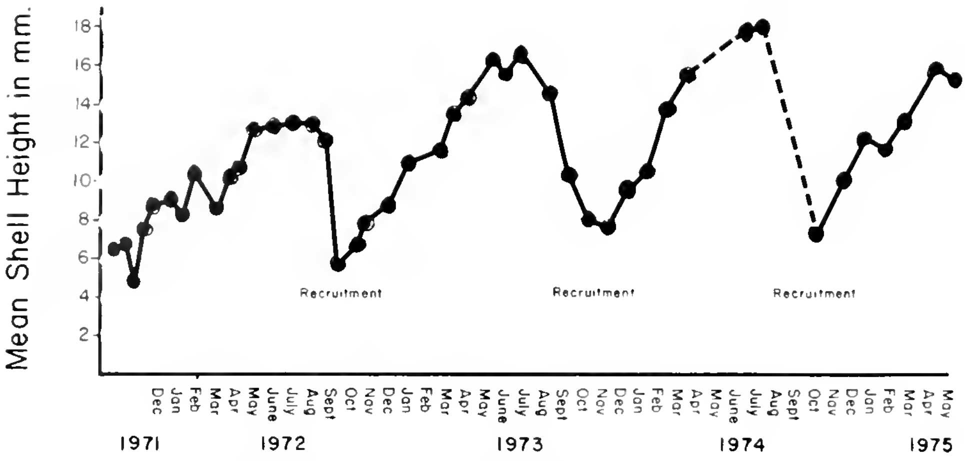


FIG. 4 *Seasonal variations in mean shell height of* L. angulifera.

sizes of the two groups overlapped a "cut-off" point based on relative numbers of individuals in different size classes was used. The same methods of censusing and shell height measurement were continued during and after the high tide and red tide episodes. Particular attention was paid to resultant changes.

In addition to the 1974 red tide there was a less extensive outbreak in the summer of 1971. Accurate census data were not obtained at this time because snails in the census areas were disturbed during other studies, but data available indicate that there was a decline in population density as a result of exposure to two "patches" of red tide.

Zonation Patterns

Both the vertical migration and zonation level of adult snails were investigated during the spawning season from May to October. Additionally the developing zonation pattern of new recruits was studied from November 1971 through May 1972. The position of snails on the seawall was designated by dividing the seawall into six zones from base to cap. The lowermost zone (zone 1) consisted of that part of the seawall encrusted with oysters and barnacles and varied from 30-40 cm deep depending upon the contour of the canal bottom. The next higher zone (zone 2) included the area from the top of the encrustation to a dark stain on the seawall and was uniformly 20 cm deep. The uppermost limit of this zone was that of Mean High Water Spring and the base of the seawall was at or just above Mean Low Water. The remaining portion of the seawall was arbitrarily divided into four additional zones (zones 3-6) each 20 cm deep. All zonation study was done in Area A and snails therein were not moved or disturbed.

To determine the zonation pattern of adult snails, numbers of individuals in each of the six zones in from 2-3 sections of seawall (about 75-100 animals) were counted and that number converted to percent of all snails counted. Water level, time of day, and general weather conditions were recorded at each observation. If the tide was sufficiently low to uncover the entire seawall the water level was recorded as "0". Since snails were not ordinarily found below the base of the seawall, specific data on tides lower than this were not obtained. Observations included the hours from approximately 0900 to 2300 on 17 different days during both neap and spring tides from 26 May to 2 October 1971, although not all days included the very late observations. Observations were usually made four to five times per day, but as few as three and as many as eight were made on some days.

Since newly recruited snails were not seen readily in the encrusted zone, the zonation pattern of these small snails was studied only when zone 1 was under water and small snails visible on bare seawall. In this case the relationship between the size of the snail and the distance above the waterline was determined and zones only 10 cm wide were used. Figure 6 shows percentages of snails at different levels above the water and placement of snails as a function of size. The two sets of data on zonation show different aspects of the life cycle. One illustrates the adult pattern of zonation and the other the development of that pattern.

OBSERVATIONS AND RESULTS

Population Changes

a) *General*

Data in Figures 1 through 5 show that there are seasonal changes in population density and mean shell height reflecting the seasonal nature of the *L. angulifera* reproductive cycle in this area. The first new recruits settled on the seawall sometime between late July and mid-August of each year studied. Increases in population density were evident by the end of August or early September; there then followed a period of from as few as 39 days to as many as 113 days when the population density increased. Greatest population density was reached during peak recruitment in the fall of each year studied. Actual dates varied from late September in 1974 to mid-November in 1973, but after these dates the population declined steadily and reached a yearly low in July or August just before recruitment began again.

The smallest snails settling on the seawall were 1.5 mm total shell height but most newly settled individuals were in the 2.0-2.9 mm size class and had five or six whorls. Attempts to find presettlement snails in the environment failed, so that the course of development from swimming veliger with a maximum shell length of only 0.13 mm (Gallagher and Reid, 1974) to those capable of settlement at 1.5 mm as found here is unknown. Length of time spent in the pelagic stage can be estimated, however. In 1971, peak spawning occurred during late August and early September (Gallagher and Reid, 1974) and peak recruitment occurred in early November (Figures 1 and 2). Thus about eight to ten weeks elapsed between maximum spawning and maximum recruitment; this likely represents the length of pelagic life for this snail.

Comparison of Figures 1 and 4 shows that mean shell height of the population varies inversely with density. This is due in part, of course, to the presence of large numbers of new recruits during certain months, but in years of greatest overall density snails tended to remain smaller than in years of overall low density. A weak positive correlation (r = 0.74) between density and mean shell height of adult snails compared and tested by the X^2 method was found.

Size distribution curves (Figure 3) show seasonal changes in recruitment and growth. There is a distinct bimodal pattern in late summer and fall, although numbers of adults

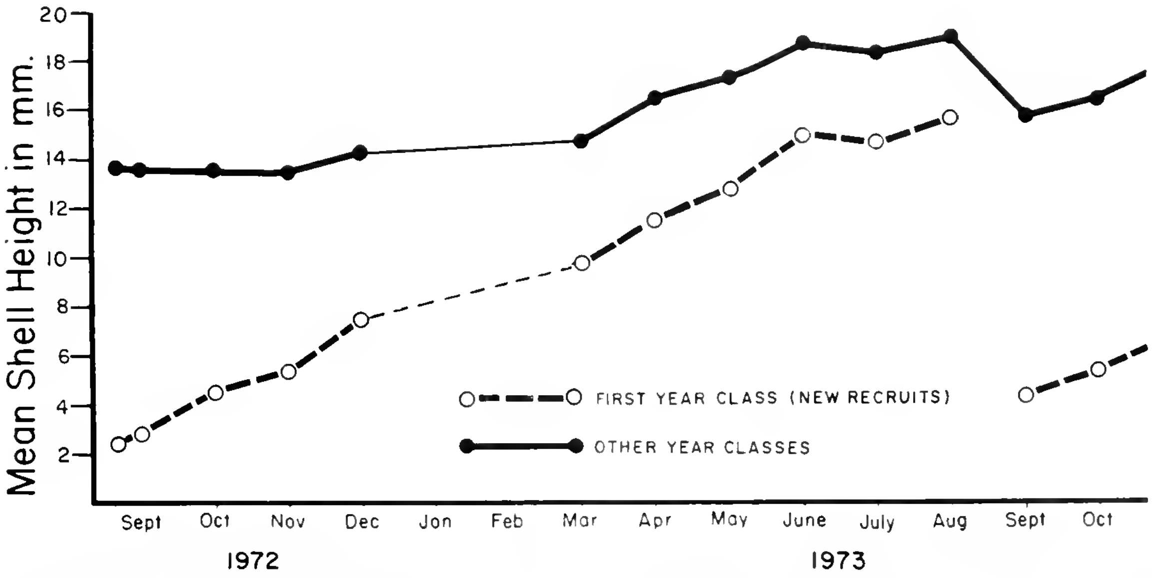


FIG. 5. *Comparison of the mean shell heights of new recruits and older year classes of* L. angulifera *in 1972-73 to show differences in growth rate between the two groups*

representing previous year classes were much smaller than those of new recruits. By the end of December the two distinct sizes could not be detected by gross observation but were still evident in size distribution curves. By March, however, size distribution curves were no longer distinctly bimodal, indicating that growth of new recruits was greater than that of older year classes and that they were "catching up" to them in size. The total size range at this time was large, ranging from 3.0 to 20.0 mm shell height (except in 1974 following the red tide outbreak). In summer, during spawning and just before recruitment began, the size range was much smaller, being from 9.0 to 18.0 mm in 1972 and 11.0 to 20.0 mm in 1973. Since snails can begin spawning at approximately 10.0 mm shell height (Gallagher and Reid, 1974), these data indicate that most surviving recruits reached spawning size toward the end of their first year or at about 9-10 months post metamorphosis. Thus the size of the total population in May, which is the start of the spawning season in the Tampa Bay area, can be regarded as the size of the breeding population at the start of any given breeding season. Figure 5, which compares mean shell heights of new recruits and older year classes from September 1972 through June 1973, shows the difference in growth rates of the two groups of snails. New recruits grew rapidly through the fall and winter while older year classes grew little or not at all during that period but increased in size from March to May. Apparently growth is minimal during spawning and winter months for adult snails but is rapid for new recruits until they reach adult size.

b) *Mortality*

Although the data do not show seasonal changes in mortality rate which may occur in this snail, total yearly percent mortality can be determined by converting the decrease in population density (from highest yearly density after fall recruitment to lowest yearly density just before recruitment) to percent of snails lost (Table 1). This gives approximate ten month "mortality rates" of 58 and 57 percent in 1971-72 and 1972-73 respectively, increasing to 94.5 percent in 1973-74, the year of the extensive bloom of *Gymnodinium breve*. If 57-58 percent is considered a normal ten month mortality (average 5.75 percent per month) expected yearly mortality can be extrapolated to be about 70 percent in an average year. Older year classes continue to decrease in density from September through December (Figure 2) while new recruits show a sharp increase in density for a period of six to twelve weeks during recruitment. Therefore there is a sharp decline followed by a more moderate rate of decrease (Figure 2). Apparently many new recruits do not survive even a few weeks in the intertidal environment, and older year classes decline in numbers throughout the year.

The percent increase in snails also varied in different years (Table 2). Increase during recruitment in Area A was 235 percent following losses from the July 1971 red tide. Due to lack of summer census data for Area B, the percent increase is not known. Figure 1 shows an exceptionally heavy recruitment for both areas, especially Area B. There is no explanation for this difference but population densities in the two areas were similar in all other years studied (Figure 1). During the next two years there was a 90 percent increase in density (though actual numbers of snails were different) possibly representing a normal or average increase. Percent increase was exceptionally large (462 percent) following severe population depletion after the 1974 red tide; actual population size, however, was greatly reduced. The 1971 summer red tide, which consisted of only two "patches" in the study area, did not reduce the population to exceptionally low densities (Table 2).

c) *Effects of extremely high tides and a red tide bloom*

During the extremely high tides which accompanied Hurricane Agnes in June 1972, water completely covered seawalls in the area, causing

TABLE 1. *Percent decrease in snail population (Area A) from highest yearly density at peak recruitment in fall of one year to lowest yearly density before recruitment starts in the following year*

	1971-72	1972-73	1973-74
High Density*	77.0	58.7	47.5
Low Density	32.3	25.0	2.6
Total Decrease	44.7	33.7	44.9
Percent Decrease	58.1	57.4	94.5

*Denisity = number of individuals m^2 seawall.

TABLE 2. *Percent increase in snail population during recruitment - Area A*

	1971	1972	1973	1974
Low Density*	23	32.3	25.0	2.6
High Density	77	61.6	17.5	117
Total Increase	54	29.3	22.5	12.1
Percent Increase	235%	90%	90%	462%

*Density = number of snails/m² seawall.

L. angulifera to crawl onto the cap of the seawall. This left many individuals stranded on a horizontal surface. Fifty stranded snails were marked with waterproof paint to determine if they would return to the vertical portion of the seawall. After five days five of them had returned, but subsequent observations showed no more did so. There was a sharp drop in population density from 59/m² to 46/m² in Area A (Figure 1) immediately after the storm. The decline was even greater in Area B which had exceptionally large numbers of snails from the heavy fall 1971 recruitment. Resultant loss from these high tides was 27 percent in Area A and 42 percent in Area B. As a consequence of greater loss in Area B, population densities for the two areas became similar and remained so during the remainder of the study. These population losses occurred suddenly over the course of a few days, and there was no subsequent increase indicating that stranded snails had returned to the seawall. Thus, such stranding constitutes a lethal hazard for this species in a seawall environment. It is possible that in a mangrove habitat snails would be able to move up and down greater distances on mangrove trees and probably not be stranded. In a *Spartina* marsh, snails would probably remain submerged near the tops of *Spartina* stalks and if wave action or currents were strong be washed off and lost. Most snails remained submerged just under the cap of the seawall for several hours during the hurricane. Lowest density for that year was 32 snails/m² (Figure 1) so effects of Hurricane Agnes did not reduce sharply the actual numbers of spawning snails. No doubt the extremely large numbers of snails as a result of the heavy 1971 recruitment somewhat ameliorated the damaging effects of Hurricane Agnes on the population.

An outbreak of red tide caused by the dinoflagellate *Gymnodinium breve*, occurred in the study area from February through March, 1974. In the canal it appeared as patches of infested water and was not present continuously. It was most prevalent at high tides and tended to concentrate in the upper 30 cm of water. Often the accumulation was heaviest adjacent to the seawall as if the wind was pushing the dinoflagellates against the seawall which then acted as a barrier to its dispersal, hence some very high concentrations occurred here. The patch almost always dispersed on the outgoing tide or if the wind shifted. A new patch sometimes, but not always, occurred with the next incoming tide. Most patches extended between 5 and 10 m out from the wall and lasted approximately six hours. In the study area, most occurred from mid-February through March, but the outbreak in the Tampa Bay region lasted from January through April. Following the appearance of red tide in the canal, many *L. angulifera* were found dead and dying in the mud at the base of the seawall. Moribund animals seemed paralyzed and unable to withdraw into shells or attach to substrate. Many recovered when placed in non-infested seawater in laboratory aquaria but no controlled studies to determine effects of exposure time and concentration were done.

There was a drastic reduction in the snail population as a result of the red tide. The population density on 24 January 1974 before any red tide appeared in the canal was 27 and 31 snails/m² in Areas A and B respectively. This is comparable to densities in those areas on 19 January 1973 (36 and 32 snails/m², Areas A and B). On 25 February 1974 a few days after the first appearance of red tide in the canal population densities were only 8 and 9 in the two areas (A and B). In 1973 density reduction after a comparable time was only by three snails in Area A and none in Area B. There were further reductions in the population until low densities of 2.6 and 2.3 individuals/m² were reached in the summer of 1974 (Figure 1), representing a 94.5 percent reduction from peak density in November to yearly low in August (Table 1). Density of the breeding population in May of that year was only 3 snails/m² in the two areas studied. Presumably similar changes occurred in other habitats in the area so that the breeding population of *L. angulifera* would be much reduced in the Tampa Bay region for the 1974 spawning season.

Recruitment in 1974 began at the end of July and reached a peak in late September, slightly earlier than in previous years. The peak density reached in the fall of 1974 following the red tide of the previous winter-spring was 15 and 8 snails/m² in Areas A and B, far below peak densities reached in other years (Figure 1) even though the percent of increase was much greater than in previous years (Figure 2). In May 1975 population densities were 12 and 9 indicating that the *L. angulifera* population was not back to pre-red tide levels and still had a very reduced breeding population. One year later in May 1976 population densities were 15 and 13 snails/m² in Areas A and B, still below comparable dates for other years. The last census taken (July 1976) showed population densities of 12 and 5 snails/m² in the two areas counted. Apparently the effects of red tide are long lasting for this snail for after two years the population had not recovered in terms of density.

A marked increase in mean shell height from 10.6 mm on 24 January to 13.8 mm (a total of 3.2 mm) on 25 February 1974 accompanied the initial sharp decline in population density. On comparable dates in previous years shell heights increased by 1.2 mm in 1973 and 0.4 mm in 1972. In addition, on 24 January (before red tide) sizes ranged from 4.0 mm to 20.0 mm (Figure 3). On 25 February (after red tide) sizes ranged from 9.0 to 18.0 mm. Since it is unlikely that snails in the 4.0 to 4.9 mm size class could grow to 9.0 mm in that time, the data apparently indicate that mortality was greater among the small snails; indeed, none of the very small snails remained. Nearly all individuals still alive were of adult size. It is probable, therefore, that the breeding population in May 1974 was made up largely of animals two or more years old. Thus, although few snails survive through two spawning seasons, those that do would be important in species survival should an event which kills new recruits differentially occur.

Zonation Patterns

a) *Adult zonation and vertical movements*

Adult *L. angulifera* were never found submerged but always occurred above the water line. During low tide periods, snails might migrate down into the encrusted zone to feed, but as they became wet with the rising tide, they moved up and remained out of the water. In the laboratory, animals placed in aquaria with small amounts of water responded by crawling out of it within 5-10 minutes. Lenderking (1954) noted similar behavior, and Hayes (1929), Evans (1965), and Bingham (1972) demonstrated similar responses in other species of *Littorina*. When kept in aquaria for periods of two or more weeks, however, *L. angulifera* migrated down to the water level on occasion and fed from algae covered rocks or shells. Records indicate no periodicity to these migrations but tidal tanks were not used. In this species, only spawning appeared to have true tidal and lunar periodicities (Lenderking, 1954; Gallagher and Reid, 1974).

Data obtained from observations on vertical migrations of adult snails on the seawall show that most *L. angulifera* were found in zones 3 and 4 or between 60 and 100 cm above the base of the seawall in Area A. Measurements of the water level at different tidal phases showed that extreme high spring tides generally reach no higher than 80 cm on the seawall, mean high spring tide was at the top of the dark stain on the seawall (zone 2), and mean low water just below the base of the seawall in the study area. Actual measurements on the seawall varied with the contour of the canal bottom, resulting in narrowing of the encrusted zone (zone 1), but the pattern of zonation in terms of tidal level is the same, only the measurements are different. These observations show that *L. augulifera* is a supratidal snail occupying a zone corresponding to the level of high spring tides and almost always remaining out of the water. Since it is a species of quiet water areas and wave splash is not a factor, it is thus seldom subject to wetting from spray as are some supratidal animals.

Movements into lower zones, presumably to feed, took place only when those zones were exposed but did not occur at every exposure. Data presented in Table 3 show that at any given low tide, whether neap or spring, usually less than 50 percent of the adult snail population migrated into the encrusted zone, indicating such migrations for adults are relatively infrequent. Dates of heaviest migration occurred during more humid periods when rain had occurred or when low tides occurred in evening or early morning hours.

Apparently snails were more likely to move when relative humidity was high. *L. angulifera* did not crawl in the mud at the base of the seawall even during very low tides but always remained on the upright seawall; thus, they never moved lower than mean low water, and usually remained well above this level. The same pattern of zonation was also seen in *Spartina*-mangrove areas, where snails were found only on stems and prop stems of mangroves or *Spartina* stalks, not crawling on sand or mud at bases of these plants.

b) *Zonation in new recruits*

Newly recruited *L. angulifera* remained close to the waterline in a zone wetted by the minimal wave wash in the canal. This zone was very narrow, usually not exceeding 10 cm. Snails nearly always moved up and down so as to remain in this wet zone, but they remained in the encrusted zone during very low tides and did not move out over the mud at the base of the canal.

Smaller snails are closest to the waterline and there is a progressive increase in size as distance from the water increases until the snails reach adult size when they assume the adult position and are likely to be found distributed throughout the supratidal zone (Figure 6). There is nearly always a small percentage of adult snails near the waterline since snails go to the water (though they do not submerge), probably to prevent excessive desiccation. During November, when mean size is small due to large numbers of new recruits, between 62.4 and 65 percent of all snails were within 10 cm of the waterline, and between 17 and 25 percent were from 10-20 cm of it. By December and January, the percent of snails within 10 cm of the waterline had decreased to between 22 and 30.5 percent. Sizes of such snails remained small but there were fewer of them. Data presented in Figure 6 show changes in zonation pattern of new recruits as they grow to spawning size. With the exception of the unusually low zonation pattern seen for 14 March, there is a general rise in zone level of this species as the size of snails increases; adult size is reached when animals are zoned at the level of high spring tides. This occurs in May at the start of the spawning season when most new recruits have reached adult size. These observations also showed that during the fall and winter months, mature snails from previous year classes remained at the supratidal level; there was no seasonal shift in zonation pattern of adults as has been reported for other intertidal snails (Frank, 1965; Palant and Fishelson, 1968). Only the new recruits shifted from a waterline position where they remained wet to a dry position as they grew to adult size. Thus, the change in zonation pattern seen as postlarval snails reach spawning size can be considered a developmental phenomenon.

DISCUSSION AND CONCLUSIONS

The results presented here can best be summarized in Figure 7 which illustrates yearly changes in a population of *L. angulifera* in the Tampa Bay, Florida, area. In this area all the life history stages are seasonal, therefore, it is easy to delimit them. Spawning occurs during the warmer months of the year (May to October). The pelagic larvae also develop and begin to settle during this time but peak recruitment is reached in the fall 8 to 10 weeks after peak spawning. Juveniles grow rapidly during cooler months of fall, winter and early spring; at the same time they attain the adult zonation pattern. Thus, during growth to adult size there is a change from a water-line position to a supratidal position. By late May most of the young snails are ready to spawn. Population changes and size distribution

TABLE 3. *Migration into encrusted zone 26 May to 2 October 1972.*

Percent Snails moving into Encrusted zone	Number of Days Seen in Encrusted zone	Percent of Total days
Less than 10%	19 days	40.4%
10 - 25%	5 days	10.6%
25 - 50%	19 days	40.4%
50 - 75%	2 days	4.3%
More than 75%	2 days	4.3%

Total number of days observed — 47

The percent of snails seen in the encrusted zone during low tides on 47 different days of the 1972 spawning season. The days include both neap and spring tides

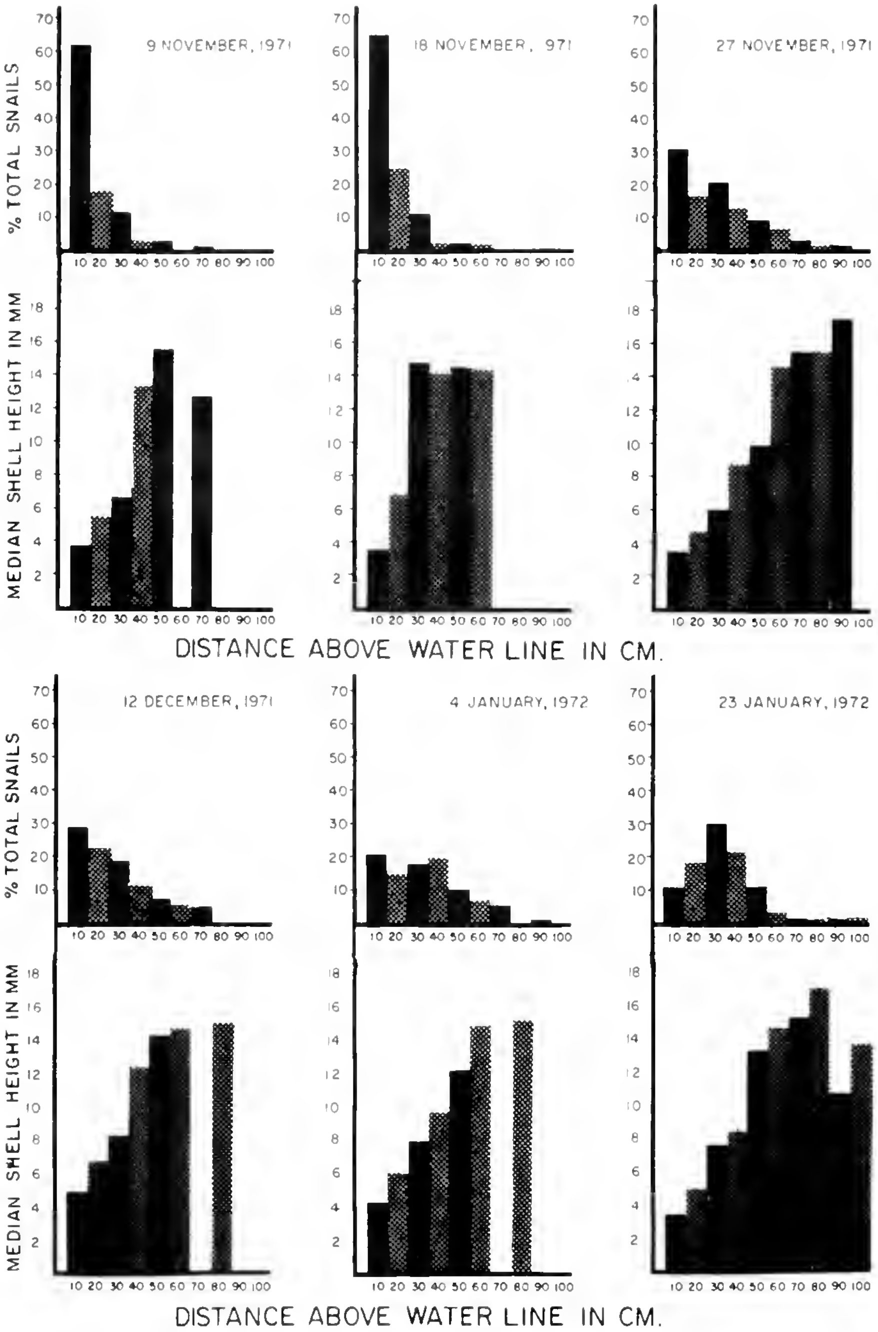
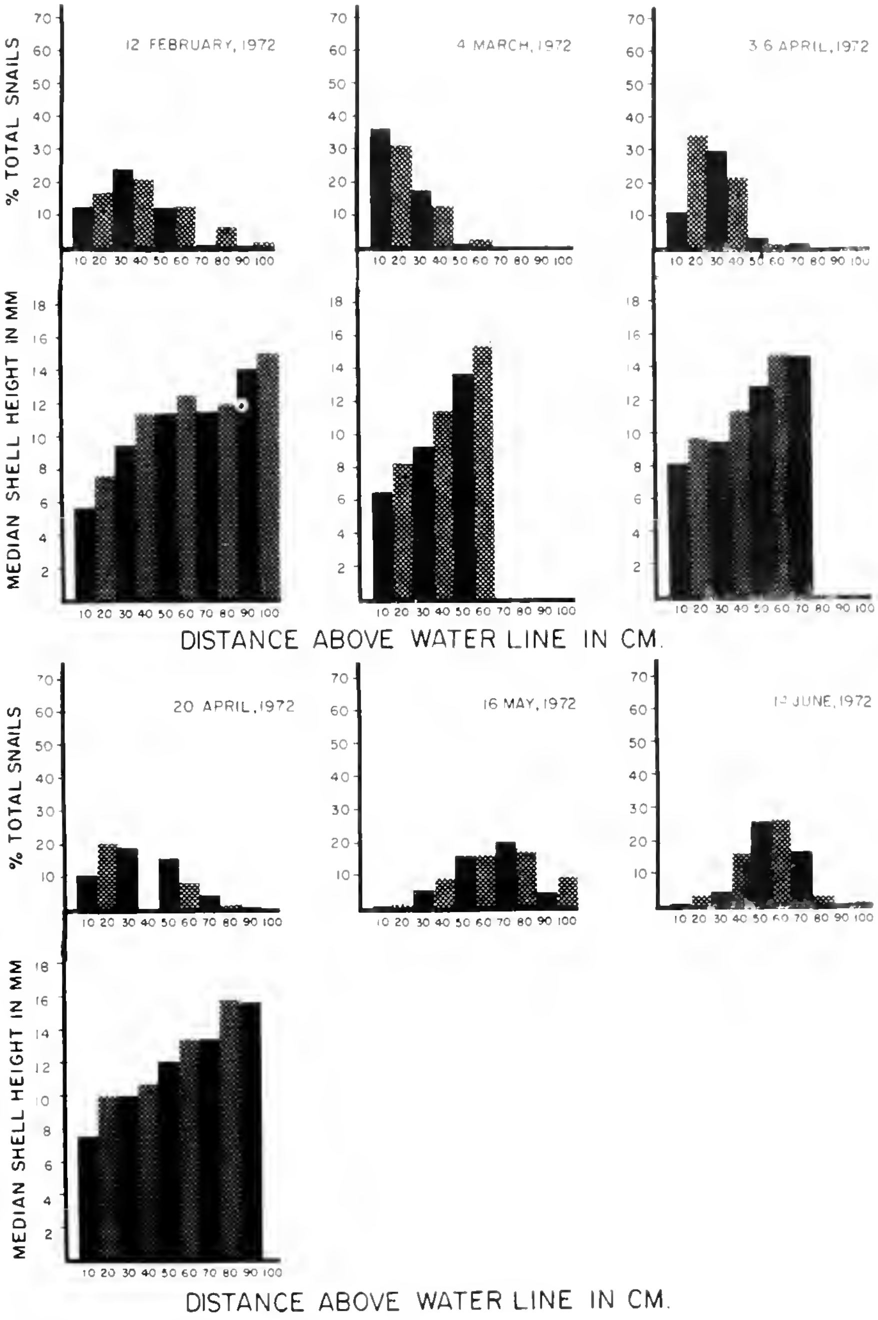


FIG 6. *Development of the zonation pattern in* L. angulifera. *The distance above the waterline as percent total snail population is related to median shell height (Median shell height is used here rather than mean shell height in order to eliminate bias introduced by averaging the size of an adult snail which may be near the waterline—as mentioned such snails do occasionally migrate to the waterline but would belong to the adult group rather than the new recruits whose zonation pattern this figure depicts.)*


% TOTAL SNAILS
MEDIAN SHELL HEIGHT IN MM
12 FEBRUARY, 1972
4 MARCH, 1972
3 6 APRIL, 1972
20 APRIL, 1972
16 MAY, 1972
12 JUNE, 1972
10 20 30 40 50 60 70
2 4 6 8 10 12 14 16 18
10 20 30 40 50 60 70 80 90 100
DISTANCE ABOVE WATER LINE IN CM.
DISTANCE ABOVE WATER LINE IN CM.

patterns reflect these changes. The yearly cycle in this area is much more sharply delineated than in the Miami area where, as shown by Lenderking (1954), spawning occurs throughout the year. It follows, as she showed, that other life stages are more or less continuous in that area also. No doubt the greater seasonal variation in temperature in the Tampa Bay area is, in part, responsible for differences seen between the two localities.

Data and observations indicate that *L. angulifera* is a fast-maturing, probably short-lived species much like *Littorina lineata*, *L. lineolata*, and *L. ziczac* as reported by Borkowski (1974). Most snails begin spawning about 9 to 10 months after metamorphosis. About 70 percent of them do not reach a second spawning season, much the same percent Borkowski (1974) found for species of the *Littorina ziczac* complex.

Population changes in this snail are affected by a variety of factors. These include unusual environmental events that do not occur regularly every year. During the course of this study two such events, extremely high tides and a red tide bloom, occurred. Because population changes in groups of animals are susceptible to events of this nature which vary from year to year, it is difficult to ascertain just what "average" or "normal" changes are. This could only be done by observations over such a long period that effects of unusual events would cancel out. Obviously a three year study period is too short. In spite of this, however, changes occurring in the unusual years were compared with changes when no unusual events occurred. In this way some indication of the magnitude of these environmental stresses was obtained. The results show that while these events caused drastic changes in actual population numbers, the general changes accompanying the yearly life history remained the same. Of the two, the red tide bloom was more damaging than the extreme high tides. Not only were the immediate effects of the red tide bloom more severe but there were long term changes in population density as well. Further, since the red tide differentially killed small snails, the composition of the spawning population the following year consisted primarily of older snails. Thus, the older group, small in numbers compared to the most recently spawned group, had to make up the deficit caused by the high mortality among new recruits. As the data show, this caused a lasting effect on population density.

Upon settling, very small snails remain close to the waterline and move upward as they grow and mature so that by the beginning of the spawning season in May the adult zonation pattern has developed. Other investigators have also reported an upshore size gradient of this type for intertidal mollusks. Smith and Newell (1954) demonstrated that this occurred with *L. littorea* until the adult zonation pattern was reached at about one year of age, after which individual snails tended to remain at the level they had reached at that time. They did not report any vertical migrations of adults as noted here for *L. angulifera*, and by Bingham (1972) for *L. irrorata*. Palant and Fishelson (1968) found the same phenomenon for *L. punctata* in that small individuals remained clustered in a wet zone near the waterline, while large individuals were found higher on the seawall. Chow (1975) reported an upshore size gradient in *L. scutulata*, with smaller snails being found closer to the water. Frank (1965), in a study of population changes in the limpet *Acmaea digitalis*, found a similar size gradient, with largest and oldest animals being found higher in the intertidal zone. Vermeij (1972), in an excellent review, reported such a gradient for high intertidal to supratidal mollusks during post larval stages but the opposite gradient for those whose range was low to mid-intertidal. Chow (1975) found that while small snails were less resistant to desiccation than large ones, all sizes were resistant to desiccation encountered in the environment. Results of preliminary, as yet unpublished, experiments show that the same is true for *L. angulifera*. The zonation pattern of juvenile snails results in favorable placement in respect to food and probably helps to ensure frequent feeding excursions. This is likely necessary for snails to grow to maturity by the spawning season in May. It may be more important in determining the zonation pattern of juveniles than resistance to desiccation. It is also possible, however, that placement lower intertidally was an important factor in the greater mortality of small snails during the red tide outbreak. Larger snails remained higher on the seawall and hence had a better chance to

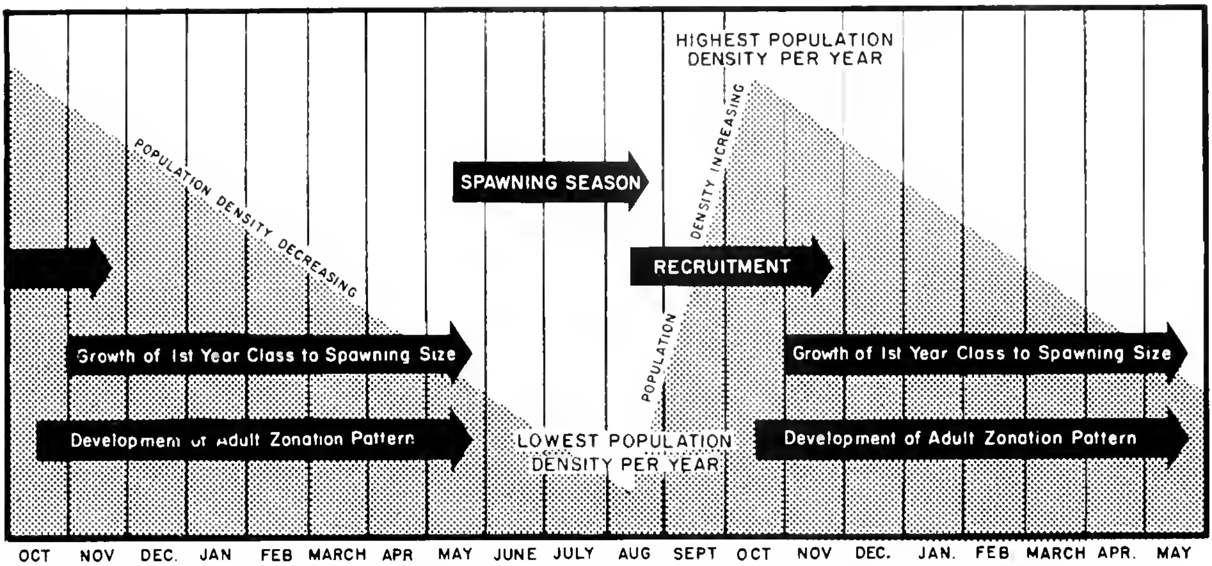


FIG. 7. *Diagrammatic representation of the yearly life history of* L. angulifera *in the Tampa Bay, Florida, area.*

escape it. Smaller snails also may be more susceptible to red tide toxins, but tests were not made.

There is some evidence that snail growth may be density dependent since during years when the lowest density of the year is high, the greatest mean shell height for that year is lower than in years when the lowest density for the year is low (Figures 1, 4). Vermeij (1972) reported this for the bivalve *Tellina tenuis* and Frank (1965) found that growth of *Acmaea digitalis* was reduced during crowding. Frank (1965) suggested that food availability may be a factor, and such may also be true here, although Bingham (1972) found that it was not important in the distribution of *L. irrorata* in a north Florida marsh since in that environment an excess of food was available in all areas. The situation might be different on a flat seawall which would present less surface area for the growth of food organisms than would a marsh or mangrove habitat. Gallagher and Reid (1974) showed that *L. angulifera* in a *Spartina*-mangrove area had a larger mean size than those on a seawall, suggesting that food availability may be a factor in a seawall environment.

Although this study illustrates and describes the yearly life history of *L. angulifera* in the Tampa Bay, Florida, area much remains to be investigated regarding factors regulating these events. Studies encompassing temperature tolerance, desiccation resistance, and identification of food organisms are planned.

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SPHAERIIDAE AS INDICATORS OF TROPHIC LAKE STAGES

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ABSTRACT

Analysis of field data associated with 35 species of boreal and arctic North American Sphaeriidae indicates interesting correlations between species occurrences and types of lentic habitats. A few species combine the attributes of stenotopy, broad geographical distribution, relative abundance and relative ease of taxonomic identification and appear to be of use as trophic lake stage indicators. These are: Pisidium conventus *Clessin and* Sphaerium nitidum *Clessin for oligotrophic lakes,* P. idahoense *Roper and* S. striatinum *(Lamarck) for mesotrophic lakes, and* P. rotundatum *Prime and* S. simile *(Say) for eutrophic lakes.*

The characterization of inland aquatic environments based on mollusks frequently constitutes an integral part of Quaternary paleoecological studies (Camp, 1974; Gibson, 1967; Miller, 1966; Taylor, 1957; and Warner, 1968). In such studies the whole biological assemblage present (often consisting of pollen, ostracod shells, mollusk shells, and fish bones) or the mollusk assemblage alone (consisting of gastropod and sphaeriid shells and possibly also of freshwater mussel shells) may be analyzed and evaluated. The use of only a few critical species of Sphaeriidae for interpretation of paleoenvironments, or for characterization of existing trophic lake stages, has not been attempted, at least in North America.

The Sphaeriidae (also known as Pisidiidae) (Superfamily Corbiculacea) are a large worldwide family of small freshwater, bivalved mollusks. Unlike the other native families of freshwater clams (Superfamily Unionacea) the shells are small (15 mm or less in most species), porcelaneous, and have lateral teeth both anterior and posterior to the cardinal teeth. The life histories of the North American species have been described by Heard (1965, 1977).

A preliminary summary of information concerning the relative abundance, regional geographical distribution, and kinds of aquatic habitats occupied by the sphaeriids of northern North America is presented in Table 1. The species list is believed to be complete for Canada. With the exception of two warm-temperate species in the southeastern United States (*Eupera cubensis* (Prime) and *Pisidium punctiferum* (Guppy)) and one, rare, relict species in northern California and southern Oregon (*P. ultramontanum* Prime), the list is also believed to be complete for the continental United States. Relative abundance estimates, distribution approximations, and habitat identifications refer only to populations in Canada and northern United States. The abbreviations under Distribution refer to phytogeographic regions (see brief summary in Clarke, 1973).

Inspection of the table reveals that most species are eurytopic, or wide-ranging in habitat preferences. Among those which are common and widely distributed, only a few are principally associated with lakes in any one particular stage of trophic development. These are, for oligotrophic lakes: *Pisidium conventus* and *Sphaerium nitidum:* for mesotrophic lakes: *P. idahoense* and *S. striatinum;* and for eutrophic lakes: *P. rotundatum* and *S. simile. S. occidentale* (uncommon in Canada but locally common in the United States) is characteristic of the most advanced aquatic stage in lake development, i.e. swamps and temporary (vernal) ponds and pools.

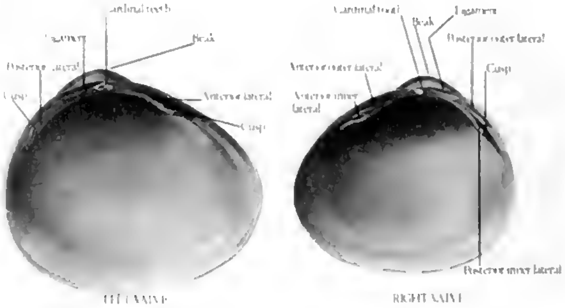

FIG. 1. *Parts of a sphaeriid shell* (Pisidium idahoense *Roper left and right valves from different specimens), semidiagrammatic.*

The following short descriptions and the illustrations are designed to assist limnologists who are unfamiliar with the Sphaeriidae but who wish to be able to identify the indicator species here selected. The structural terms used are defined in Figure 1 and the species are illustrated in Fig. 2 and 3. The beaks (umbones) are located dorsally and near the posterior end in most species of *Pisidium*. In species of sphaeriids which have the beaks more centrally located, the anterior and posterior of empty shells can be found by examination of the hinge teeth. The right valve bears a single, very small cardinal tooth located under the beak and 4 (2 pairs) of narrow, elongate lateral teeth, one pair located on either side of the cardinals. The left valve bears 2 cardinals and 2 single laterals which articulate with the corresponding teeth in the right valve. In life the animal moves forward with the beaks held upward, the right valve on the right and the left valve on the left. The most elevated part of each lateral tooth is the cusp. The position is proximal if it is close to the cardinal teeth (or tooth) and distal if it is far from them.

The user is cautioned that positive identification of sphaeriid species is often difficult.

TABLE 1

Relative Abundance, Approximate Distributions, and Usual Habitats of the Sphaeriidae of northern North America(1)

(1) Abbreviations. Abundance: C, abundant or common; R, uncommon or rare; I, recently introduced (relative abundance unstable). Distribution: A, arctic; T, arctic-boreal transition zone; B, boreal forest; M, western montane region; P, prairie and parkland region; G, Great Lakes-St. Lawrence forest region. Habitat: X, frequent occurrence; x, infrequent occurrence.

SPECIES	ABUND.	DISTRIBUTION		HABITAT			
		W of 95°	E of 95°	OLIGOTR.	MESOTR.	EUTROPH.	VERNAL
Pisidium waldeni Kuiper	R	A T		X X X X			
P. conventus Clessin	C	A T B M	A T B G	X X X X	x x x x		
Sphaerium nitidum Clessin	C	A T B M	A T B G	X X X X	x x x x	x x x x	
P. compressum Prime	C	T B M P	T B G	X X X X	X X X X	X X X X	
P. lilljeborgi Clessin	C	A T B M P	A T B G	X X X X	X X X X	X X X X	
P. nitidum Jenyns	C	A T B M P	T B G	X X X X	X X X X	X X X X	
P. subtruncatum Malm	R	A T B M P	B G	X X X X	X X X X	X X X X	
P. casertanum (Poli)	C	T B M P	T B G	X X X X	X X X X	X X X X	X X X X
P. idahoense Roper	C	A T B M	B G	x x x x	X X X X	x x x x	
P. fallax Sterki	R	B P	B G	x x x x	X X X X	X X X X	
S. striatinum (Lamarck)	C	T B M P	T B G		X X X X	x x x x	
S. corneum (L)	I		G		X X X X	X X X X	
P. amnicum (Müller)	I		G		X X X X	X X X X	
P. ferrugineum Prime	C	A T B M P	A T B G		X X X X	X X X X	
P. henslowanum (Sheppard)	I		G		X X X X	X X X X	
P. supinum Schmidt	R		G		X X X X	X X X X	
P. variabile Prime	C	T B M	T B G		X X X X	X X X X	
P. ventricosum Prime	C	T B M	T B G		X X X X	X X X X	
P. walkeri Sterki	R	A T B M	T B G		X X X X	X X X X	
S. transversum (Sav)	R	B M P	B G		x X X X	X x x x	
P. adamsi Prime	R	B P	B G		x x x x	X X X X	
P. milium Held	R	T B M	T B G		x x x x	X X X X	
S. lacustre (Müller)	C	T B M P	T B G		x x x x	X X X X	
P. cruciatum Sterki	R		G			X X X X	
P. dubium (Sav)	R		G			X X X X	
P. equilaterale Prime	R		B G			X X X X	
P. punctatum Sterki	R	B M	B G			X X X X	
P. rotundatum Prime	C	T B M	T B G			X X X X	
S. patella (Gould)	R	M				X X X X	
S. rhomboideum (Sav)	R	B M	T B G			X X X X	
S. simile (Sav)	C		B G			X X X X	
S. partumeium (Sav)	C	B P	B G			X X X X	x x x x
S. securis Prime	C	B M P	B G			X X X X	X X X X
S. occidentale Prime	R	M	T B G			X X X X	X X X X
P. insigne Gabb	R	M	G	- - - (lotic only) - - - - - - - -			
S. fabale Prime	R		G	- - - (lotic only) - - - - - - - -			

especially in *Pisidium*. Even though the eight indicator species are among the easiest to identify, for verification one should refer to Herrington (1963), Burch (1972), Clarke (1973, 1979), or better still, to all of these. *S. simile* and *S. striatinum* are the most abundant species of *Sphaerium* and are the most frequently encountered, but in *Pisidium* the most abundant is the variable species *P. casertanum* (Poli) followed by *P. compressum* Prime and several other species.

Sphaerium nitidum (Clessin) (Figs. 2, J-M) is up to 6 mm long, rounded anteriorly, posteriorly, and ventrally, and with centrally-located beaks. Fine concentric striae (more than 12 per mm) cover the shell and maintain their height and spacing up over the beaks. There is no radial ridge on the inside of the shell. The periostracum is shiny and pale yellowish-brown.

Sphaerium occidentale Prime (Figs. 2, N-Q) is up to 7 mm long, also rounded anteriorly, posteriorly, and ventrally and with centrally-located beaks. The fine concentric striae (more than 12 per mm) which cover the shell are even finer near and over the beaks. A low, flat, radial ridge on the inside of the shell runs from the beak cavity to the central ventral margin. The periostracum is pale yellowish-brown to brown and dull or somewhat glossy.

Sphaerium simile Say (Figs. 3, G-J), the largest *Sphaerium* in North America, ordinarily exceeds 16 mm in length and may reach 25 mm. The shell is long oval, rather thin to fairly thick, and

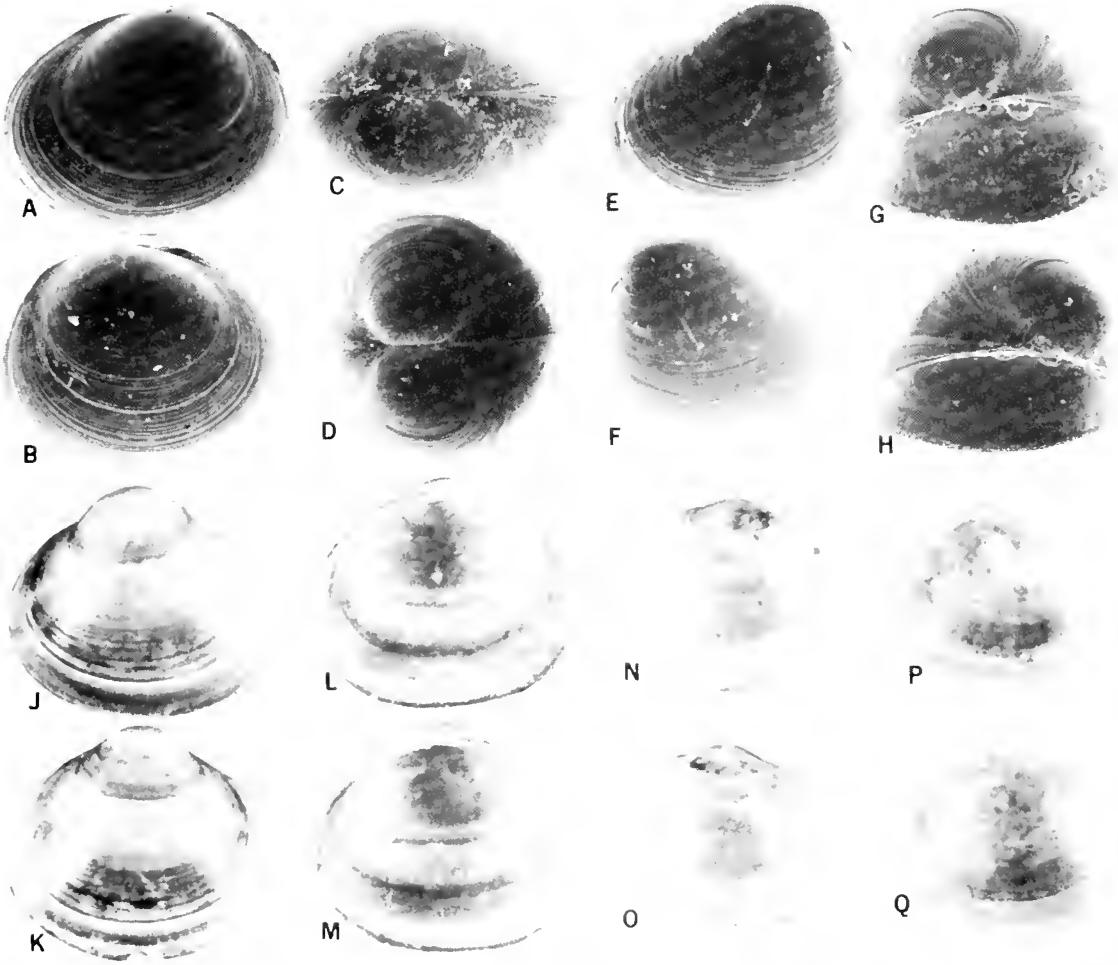

FIG. 2. *Trophic lake-stage indicator species of Sphaeridae.* **A-C,** Pisidium rotundatum *(USNM 595777, length 1.95 mm);* **D-H,** Pisidium ventricosum *(USNM 161425, 1.85 mm);* **J-M,** Sphaerium nitidum *(USNM 216222, 8.45 mm);* **N-Q,** Sphaerium occidentale *(USNM 474832, 7.55 mm)*

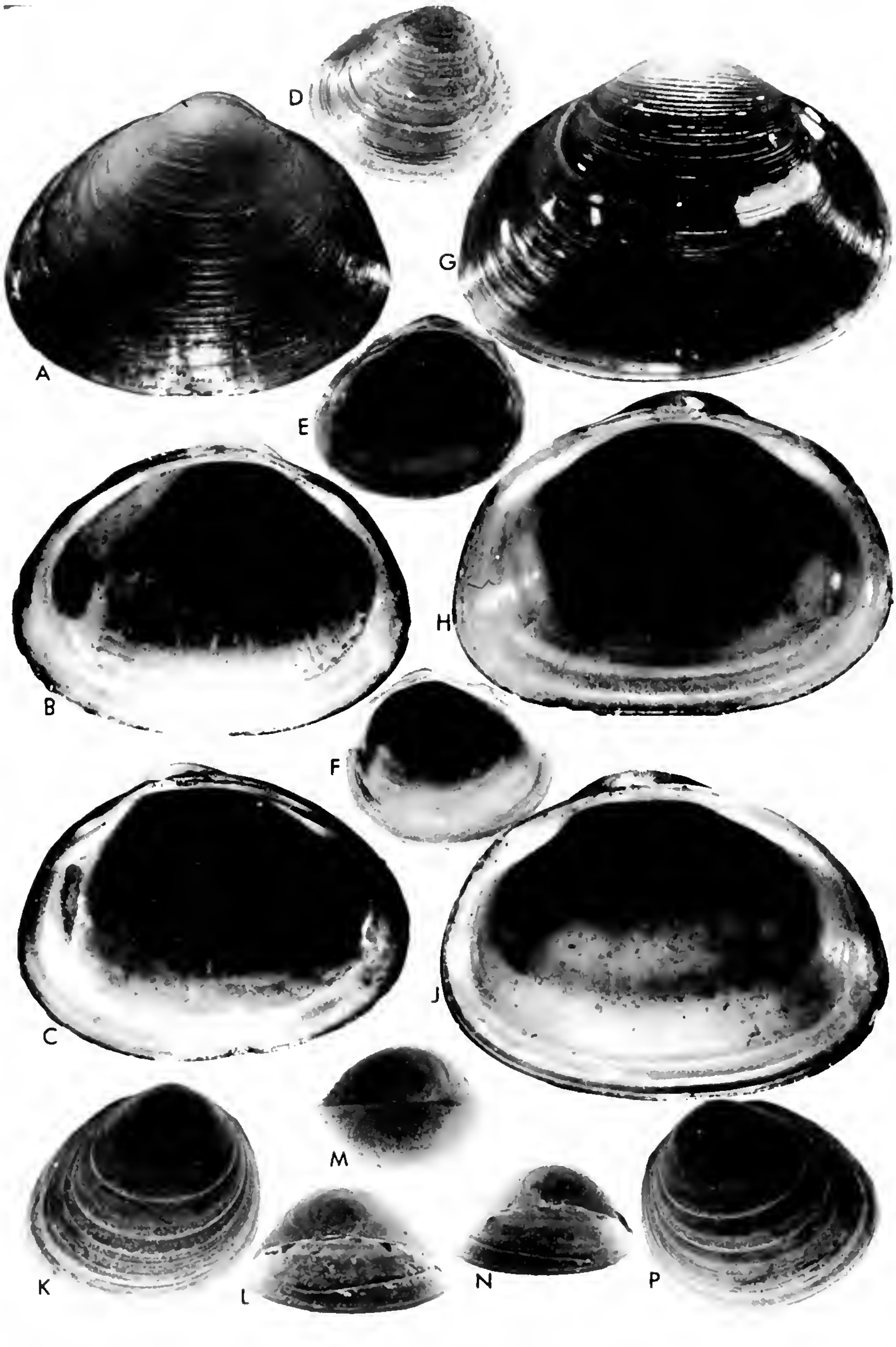

FIG. 3 *Trophic lake-stage indicator species of Sphaeriidae* **A-C,** Sphaerium striatinum *(NMC 50230, length 13.0 mm).* **D-F,** Pisidium idahoense *(NMC 32748, 7.1 mm).* **G-J,** Sphaerium simile *(NMC 45082, 14.8 mm);* **K-P,** Pisidium conventus *(USNM 363001, 3.0 mm)*

covered with coarse concentric striae (8 or fewer per mm near the center) which are more widely spaced over the beaks. The periostracum is brownish or yellowish, with concentric lighter and darker bands, and the interior of the shell is bluish.

Sphaerium striatinum (Lamarck) (Figs. 3, A-C) is up to 14 mm in length, oval, and relatively thick and strong. It is covered by concentric striae (8 or less per mm) which are unevenly spaced and irregularly strong or weak in the same specimen, but are not weaker on the beaks. It is also brownish or yellowish, with concentric darker and lighter bands, and with a bluish interior. In juveniles, the dorsal margin is curved in *S. striatinum* but straight in *S. simile*.

Pisidium conventus Clessin (Figs. 3, K-P) is small (less than 3 mm long), variable in shape (ordinarily some specimens are trapezoidal), thin, fragile, suboval, not inflated, and with a dull glossy periostracum. The hinge plate is long (more than 3/4 the shell length), with cardinal teeth overhanging the edge of the hinge plate, and with lateral teeth thin and narrow and with the cusps (the highest parts) located near the outer ends. For further details see Heard, 1963.

Pisidium idahoense Roper (Figs. 3, D-F) is large (for *Pisidium*), up to 12 mm long, but most specimens are closer to 8 mm. The shell is ovate, with a short dorsal margin, and with the surface covered by fine, concentric striae (15 or more per mm). These characters will distinguish *P. idahoense* from the other large species of *Pisidium (P. adamsi, P. amnicum,* and *P. dubium).* Although *P. idahoense* is characteristic of mesotrophic lakes throughout its range on the North American mainland, it occurs in eutrophic lakes on Prince Edward Island, Canada.

Pisidium rotundatum Prime (Figs. 2, A-C) (and *P. ventricosum* Prime, Figs. 2, D-H) are both small (about 3 mm long) and more spherical in shape than most other *Pisidium* species. In *P. rotundatum* the height divided by the length (H/L) is .80 to .92 and the width divided by the length (W/L) is .70 to .76. In *P. ventricosum* (H/L) is .82 to 1.00 and (W/L) is .80 to .95. In *P. rotundatum* the beaks are located almost centrally or are posterior of center but in *P. ventricosum* they are far posterior. In the left valve of *P. rotundatum* the hinge plate between the cardinal teeth and the anterior lateral tooth is narrow and much longer than wide, whereas in *P. ventricosum* it is thick and short, i.e. about equally long and wide. *P. rotundatum* is characteristic of eutrophic water bodies and *P. ventricosum* occurs in both mesotrophic and eutrophic lakes.

It is useful to remember that some small marine bivalve mollusks resemble sphaeriids and may be mistaken for them, and *vice versa*. This is especially important in the interpretation of fossil deposits. The various species of marine bivalves all possess unique hinge teeth and other differential characteristics, however, which can be observed by careful examination. See Abbott (1974) and included references for further information on marine mollusks.

It should be remembered that occasional specimens of most sphaeriid species may be found in all kinds of habitats. The presence of an indicator species is therefore only significant as a trophic lake-stage indicator if that species occurs in relative abundance.

As one gains familiarity with Sphaeriidae, interpretation of trophic lake stages based on them becomes more practical. The shells of most species are variable, however, and the significant characteristics of the hinge teeth of *Pisidium* are minute and difficult to observe. It is therefore recommended that limnologists utilize for lake classification a larger suite of indicator species than that provided by the Sphaeriidae alone.

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URANIUM-SERIES AGES OF ECHINOIDS AND CORALS FROM THE UPPER PLEISTOCENE MAGDALENA TERRACE, BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

Nine ^{230}*Th/*^{234}*U and* ^{231}*Pa/*^{235}*U dates on six coexisting corals* (Porites californica) *and echinoids* (Encope grandis) *from the Magdalena Terrace, west coast of Baja California Sur, Mexico, average 116,500±6,000 years (± one standard deviation). Based on this average, the newly named Magdalena Terrace may be correlative with the Nestor Terrace in the San Diego, California area and possibly with several other late Pleistocene terraces along the California coast thought to have been formed during a highstand of the sea 120,000 - 125,000 years ago. Although fossil echinoids contain uranium of secondary origin, their ages are concordant with those of the coexisting corals and suggest that the uranium uptake occurred soon after the death of the organisms. This, as well as the low* ^{232}*Th content in both the living and fossil* Encope *analyzed, suggests that a further investigation of echinoids is warranted to examine their suitability for geochronological studies with U-series nuclides.*

We report the ^{230}Th/^{234}U and ^{231}Pa/^{235}U dating on two samples of the stony coral *Porites californica* and four samples of the irregular echinoid *Encope grandis* from marine terrace sediments at Magdalena Bay (Bahía Magdalena) on the west coast of Baja California Sur, Mexico. The mean and standard deviation of the six ^{230}Th/^{234}U dates are 117,000 ± 7,000 years. The mean and standard deviation of the three ^{231}Pa/^{235}U dates are 115,000 ± 5,000. The two methods are in concordance, giving an average age for the nine dates on the six samples as 116,500 ± 6,000 years. U-series dates exist for several terraces bordering southern California (summary in Ku and Kern, 1974) and from Guadalupe Island (Isla Guadalupe), some 400 km off Baja California Norte (Goldberg, 1965). Our dates are the first for Pleistocene terrace sediments from penisular Baja California. The radiometric dates now available for the richly fossiliferous deposits of Magdalena

Bay permit more precise regional comparisons of this fauna with those of chronologically related Pleistocene deposits dated previously.

The present results suggest that Pleistocene specimens of echinoids, and possibly those of other echinoderms, are potentially datable by the U-series methods. This is significant in view of the general scarcity of specimens of coral in terrace deposits. Echinoids, especially the disarticulated plates and spines of regular ones (sea urchins) and, to a lesser degree, the tests of irregular ones (sand dollars) are not uncommonly preserved in terrace sediments. If reliable radiometric dates can be obtained from echinoids, the numerous terrace deposits of late Pleistocene age along the West American borderland and elsewhere throughout the world can be dated more precisely.

SAMPLE LOCALITIES

The coexistent fossil specimens, comprising of two samples of *Porites californica* Verrill, 1870 and four samples of *Encope grandis* L. Agassiz, 1841, were collected from a Pleistocene terrace about 1.5 km north of the village of Puerto Magdalena (24°38′N, 112°09′W), on the east side of Santa Magdalena peninsula, Baja California Sur, Mexico, from The American Museum of Natural History [A.M.N.H.] locality F-6 [=California Academy of Sciences (C.A.S.) locality 754]; see Figure 1. The samples analyzed with U.S.C. lab. nos. designated as AO-3, -4, -5 (Table 1) are from A.M.N.H. locality F-6 collected on March 17, 1957 (Emerson, 1958). Those designated as AO-6, -7, -8 (Table 1) are from C.A.S. locality 754, collected July 25, 1925 by G D. Hanna and E. K. Jordan (Jordan, 1936).

The two Recent specimens (U.S.C. lab. no. AO-1, -2) of *Encope grandis* are from San Carlos Bay, near Guaymas, Sonora, Mexico (27°57′N, 111°04′W).

EXPERIMENTAL RESULTS AND DISCUSSION

Table 1 summarizes analytical results of samples AO-1 through AO-8. Known quantities of

Table 1. Radiometric and Age Data on Echinoids and Corals from Mexico

Lab No.	Material[1]	Mineralogy	U (ppm)	Th (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	$^{231}Pa/^{235}U$[5]	Age (10^3 yrs)	
									^{230}Th	^{231}Pa[5]
AO-1	E.g.[2]	High-Mg Calcite	0.204 ±,003	<0.02	1.14 ±.02	-	<0.01	<0.1	<1	<5
AO-2	E.g.[3]	High-Mg Calcite	0.293 ±.005	<0.02	1.14 ±.02	-	<0.01	<0.1	<1	<5
AO-3	P.c.[4]	Aragonite	3.50 ±.08	0.022 ±.007	1.08 ±.02	345 ±108	0.656 ±.025	0.892 ±.045	116±8	110^{+27}_{-18}
AO-4	E.g.[4]	High-Mg Calcite	0.465 ±.008	0.035 ±.003	1.01 ±.02	28.1 ±2.6	0.667 ±.016	0.906 ±.041	119±5	117^{+29}_{-18}
AO-5	E.g.[4]	Low-Mg Calcite	1.86 ±.04	<0.02	1.05 ±.02	>300	0.692 ±.025	n.m.	128±9	n.m.
AO-6	P.c.[4]	Aragonite	3.36 ±.12	0.062 ±.006	1.14 ±.03	128 ±39	0.663 ±.036	n.m.	118±12	n.m.
AO-7	E.g.[4]	Low-Mg Calcite	1.56 ±.04	0.070 ±.010	1.06 ±.02	46.2 ±6.5	0.632 ±.026	n.m.	108±8	n.m.
AO-8	E.g.[4]	Low-Mg Calcite	0.810 .010	<0.02	1.08 ±.01	>400	0.647 ±.020	0.910 ±.043	113±6	119^{+32}_{-19}

[1] E.G.: *Encope grandis*; P.c.: *Porites californica*.

[2] Recent, dead-collected, beach specimen.

[3] Recent, live-collected specimen.

[4] Pleistocene specimens.

[5] n.m.: not measured.

^{232}U, ^{228}Th and ^{233}Pa were used as yield tracers in the analyses of the radioisotopes listed. The quoted errors (one standard deviation) are based on the counting statistical fluctuations only. Mineralogical identifications were done with x-ray diffraction techniques. In computing the ages, we assumed that ^{230}Th and ^{231}Pa were initially absent or present in negligible amounts and that samples acted as a closed system after incorporation of the radioisotopes. The half-life values used for ^{230}Th and ^{231}Pa are 75,200 years and 34,300 years, respectively.

The assumption of negligible initial ^{230}Th and ^{231}Pa (Table 1) is supported by the observations that, firstly, ^{230}Th/^{232}Th values in the fossil specimens are very much higher than those values in natural waters or sediments, which are commonly 1 to 3, and secondly, modern specimens of *E. grandis* show very low ^{230}Th/^{234}U and ^{231}Pa/^{235}U values of <0.1, as is the case for corals (Ku, 1968). The closed-system assumption is supported by the concordancy checks between the ^{230}Th/^{234}U- and ^{231}Pa/^{235}U- derived ages on three samples in which such checks were made (Table 1). The validity of this assumption is also reflected in the agreement, within counting statistical error, of ages for the six coexisting fossil specimens.

As the present study reports the first measurements on echinoids, a discussion of the data obtained is in order. The ^{234}U/^{238} U ratios of 1.14 in AO-1 and AO-2 are the same as that for uranium in sea water (Ku, *et al.*, 1977). Living *E. grandis* apparently incorporate about 0.2-0.3 ppm of uranium directly from sea water. Unlike coral, there appears to be a discrimination factor of 10 to 1 in favor of Ca to U in the uptake of these two elements from sea water by the organism. With the exception of the echinoderm teeth, the hard tissue of echinoderms is known to be originally composed of calcite containing several per cent Mg (Chave, 1954; Schroeder *et al.*, 1969). This is the case for samples AO-1, -2, and -4. Because high-Mg calcite is metastable under surface conditions, its transformation to low-Mg calcite could provide conditions condusive to exchange of radionuclides with those in the surroundings—conditions similar to the conversion from aragonite to calcite for coral. Data on samples AO-5, -7, and -8 suggest that during the transformation to low-Mg calcite, significant amounts of uranium may have entered the echinoid skeletal tests with little or no accompanying thorium isotopes. For sample AO-4, the slightly higher-than-modern U value (ppm) further suggests that limited addition of uranium could have also occurred before the transformation. This secondary uranium added to the sample is largely of non-marine origin, judging from the ^{234}U/^{238}U value of 1.01 ± .02 (oceanic uranium would decay from 1.14 to *1.10* in about 120,000 years).

From the above discussion, one sees some parallel between *E. grandis* and mollusks in terms of open system for secondary uranium uptake in fossil specimens. However, the present results show two encouraging aspects of dating *E. grandis:* (1) The concordant ages obtained here suggest that the open-system episode must have been brief and limited to a period very close to the death of the organism. (2) There is evidence for negligible presence of initial and extraneous ^{230}Th and ^{231}Pa in the samples analyzed (Table 1). These favorable conditions have been found in mollusks, but they are not common (Kaufman, *et al.*, 1971). Thus for echinoids, one needs to determine how commonly these conditions occur and what criteria are required to distinguish them. These questions cannot be answered from the present limited number of analyses. Further studies of echinoid tests to evaluate their suitability for U-series dating are warranted.

MAGDALENA TERRACE—OCCURRENCE, FAUNAL ASSEMBLAGE AND CORRELATION

The terrace represented by A.M.N.H. locality F-6 (Fig. 1) extends along the shore at a maximum elevation of approximately 6 meters above sea level. The fossils are most numerous in sediments of poorly sorted sand and angular igneous rocks exposed along the shore at the high tide level to an elevation of 1.5 to 1.8 meters. The fossiliferous sand is locally overlain by 0 to 4.6 meters of non-fossiliferous alluvial cover. A conglomerate resting on the terrace platform, which cuts into the basal igneous bench-rock, is exposed at the level of the present beach on the apparently correlative terrace remnants that are preserved along the shore for about 1.5 km south of

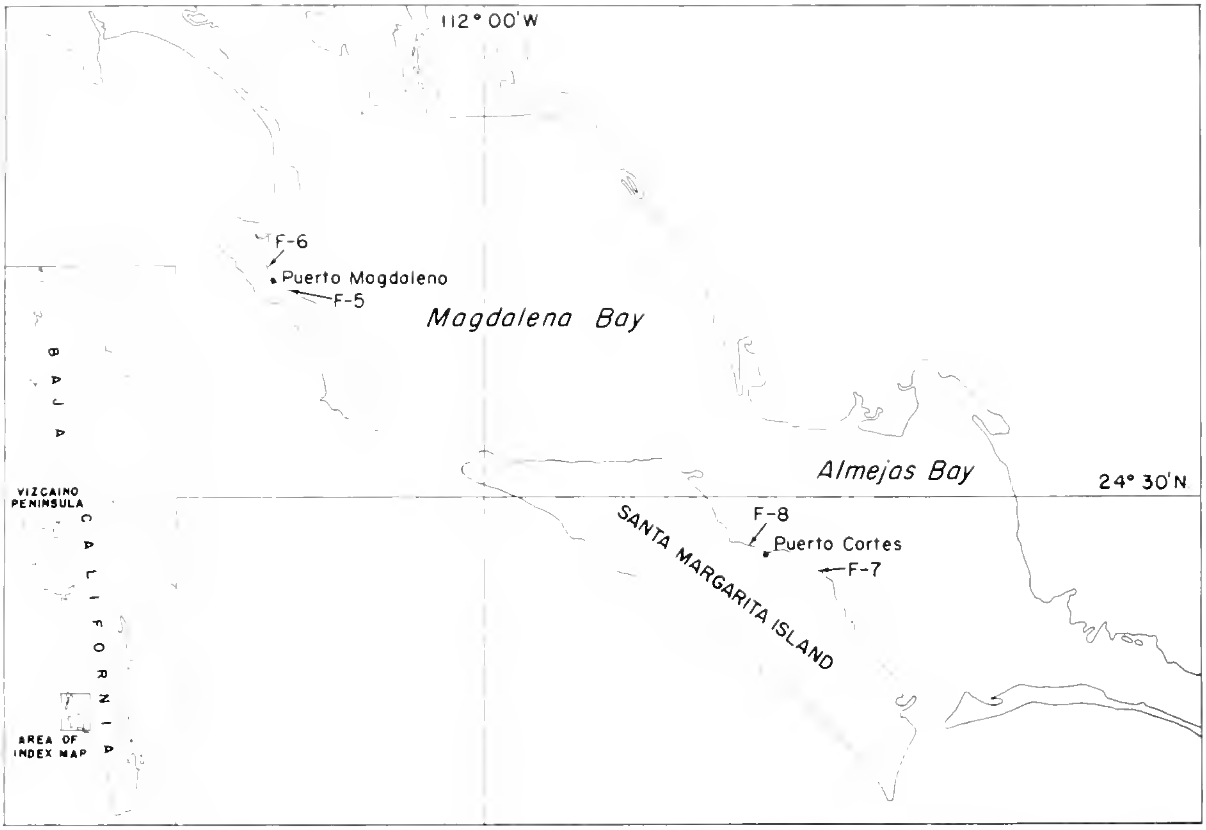

FIG. 1. *Index map of the Magdalena Bay - Almejas Bay area of Baja California Sur, Mexico, showing Pleistocene fossil localities (F-5, F-6 on Santa Magdalena peninsula, F-7, F-8 on Santa Margarita Island) described in the text.*

Puerto Magdalena village (Figure 1, A.M.N.H. locality F-5=C.A.S. locality 982). This conglomerate and the terrace platform are not exposed at locality F-6. According to Hanna (1925), these terrace remnants represent the beach-line existing at the time of uplift of the igneous and metamorphic rocks which form the higher terrain behind the village, and this tectonic event resulted in the closure of the northern entrance to Magdalena Bay. A terrace similar to that at Puerto Magdalena is exposed north and south of the village of Puerto Cortes on the eastern shore of adjacent Santa Margarita Island (Isla Santa Margarita), which faces Almejas Bay (Bahía Almejas), see Figure 1. This terrace extends about 6.5 km along the shore south of Puerto Cortes at a maximum elevation of about 4.6 m (at A.M.N.H. locality F-7) and continues north of the village at the same height for about 1.2 km (Figure 1, A.M.N.H. locality F-8=C.A.S. locality 932). The terraces exposed at the localities on Santa Margarita Island are cut into basal igneous rocks (0-1.5 m in thickness) and are overlain by conglomerates (.5 to 6 m), fossiliferous sand pebbles (.5 to 1.2 m), and pebbly soil cover (.5 and 1.2 m). The terrace appears to be tilted slightly to the northwest, as is the terrace on the Santa Magdalena peninsula. These topographic features are here designated the Magdalena Terrace, with the type locality restricted to the section exposed at A.M.N.H. locality F-6 on the Santa Magdalena peninsula.

The presence of well-preserved metazoan invertebrate fossils, mostly mollusks, in terrace sediments in the vicinity of Magdalena Bay has long been known. Hinds (1844) was the first to report mollusks "... embedded in the fossiliferous cliffs which surround a portion of the Bay of Magdalena." Dall (1918), Smith (1919), Jordan (1924), and Hanna (1925) considered the age of these terraces to be Pleistocene, based on faunal evidence. Jordan (1936) listed a total of 442 species-group taxa, including 4 echinoderms, 1 coral, and 337 mollusks, from three locations in

Magdalena Bay (C.A.S. localities 754, 932, and 982). He concluded that "...the beds should be correlated with the warm Upper San Pedro, or Upper Quaternary" (of Arnold (1903) in the Los Angeles Basin, now referable to the upper Pleistocene Palos Verdes Sand). The Magdalena Bay assemblage is the largest Pleistocene invertebrate fauna described from Pacific Baja California (Emerson, 1956; Gastil *et al.*, 1975) and, in western North America, it is second in size only to the assemblages reported from Newport Bay, California, where nearly 500 species of metazoan invertebrates are recorded from late Pleistocene deposits (Kanakoff and Emerson, 1959).

The faunal constituents of the Magdalena Terrace are essentially modern in composition, containing a nearly equal mixture of Panamic and Californian Provincial faunal elements, together with wide-ranging, eurytopic taxa. The metazoan invertebrates living at the present time in Magdalena Bay also represent a blending of these faunal components, with perhaps a diminution in the ratio of the warm water (Panamic element) to the temperate water components (Californian element). The Panamic element is present in similar terrace deposits occurring northward along the continental borderland. This southern, warm-water element diminishes in numbers rapidly in Pleistocene assemblages north of Vizcaino Peninsula (27°50'N., 115°5'W) and is a minor faunal component in the San Diego and Los Angeles embayments, where wide-ranging and cooler faunal elements dominate (Emerson, 1956). Changes in the composition of these assemblages have been largely ascribed to alternating hydroclimatic regimes that accompanied the late Pleistocene oscillations of the continental ice sheets (cf. Valentine, 1955, 1961; Kanakoff and Emerson, 1959; Addicott and Emerson, 1959; Kennedy *et al.*, 1979). Because species-level extinctions in faunas have been negligible during the late Pleistocene and tectonic changes in the coastal configuration have locally obscured the effects of eustatic changes in sea level during this period, traditional stratigraphic and paleontologic methods do not permit absolute temporal and regional correlations of these terraces (cf. Durham and Allison, 1960; Ku and Kern, 1974). The U-series ages obtained here suggest correlation of the Magdalena Terrace with the Nestor Terrace in San Diego and similar terraces in the region, formed during a highstrand of the sea approximately 120,000 yrs. ago (Ku and Kern, 1974) during the early Sangamon (isotopic stage 5e of Shackleton and Opdyke, 1973). More precise correlation must await absolute dating of additional regional deposits.

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THE NAIAD FAUNA OF LAKE SPRINGFIELD, ILLINOIS: AN ASSESSMENT AFTER TWO DECADES

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ABSTRACT

A survey of the naiad fauna of Lake Springfield during 1953 produced nine species of freshwater mussels. A second survey of the identical collection localities, conducted in 1977, produced the same nine species. Patterned quantative changes in the fauna were observed. Qualitative changes have resulted from the introduction of four previously unrecorded species. Variations in the naiad populations have been discussed in terms of observed changes in other artificially formed lentic habitats as well as unimpounded fluvial systems.

Nearly two decades after the construction of Lake Springfield during 1935, a survey of the lake's naiad fauna was conducted and reported by the junior author (Parmalee 1955). The lake, situated in Sangamon County in central Illinois, is fed by Lick and Sugar creeks, has a surface area of 17.6 km², and roughly 90 km of shoreline. At the time of the 1953 survey central Illinois had suffered several months of below average rainfall and by October, 1953, the level of Lake Springfield fell to an average (169.07 m MSL) 1.62 m below normal pool (170.69 m).

The exposed shoreline of the relatively shallow lake ($\overline{X}$ depth = 4.57 m) gave rise to the survey of stranded freshwater mussels along the waters edge. Nine hundred and eighty-seven specimens representing nine species were recovered from 20 different collecting stations (Fig. 1). The area

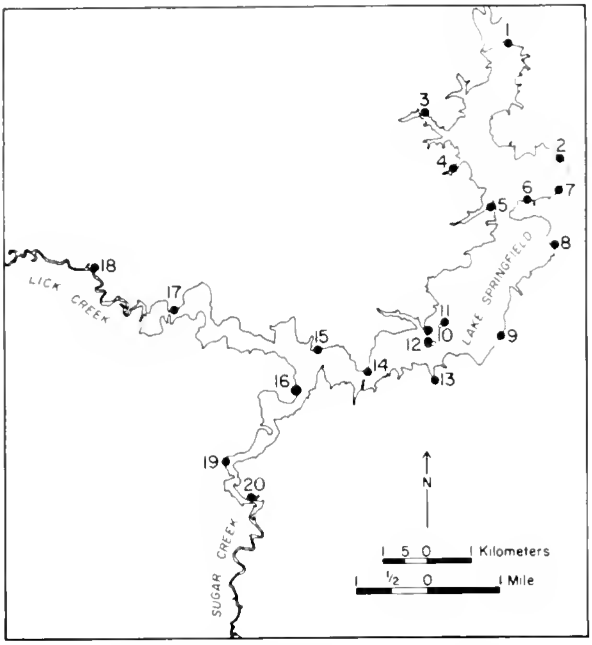

FIG. 1. *Lake Springfield, Illinois, showing stations where naiads were collected in 1953 and 1977.*

sampled (4x50 yr.) at each loci was about 167.4 m. (200 yr^2), bringing the total area collected to 3346 m^2 and providing a mean density of .295/m^2.

Quadrula quadrula (Rafinesque, 1820) occurred in greatest abundance (48%), followed by *Leptodea laevissima* (Lea, 1830)—22%, *Lasmigona complanata* (Barnes, 1823)—11%, *Ligumia nasuta* (Say, 1817)—11%, *Anodonta grandis* (Say, 1829) — 6%, *Amblema plicata* (Say, 1817)—1%, and *Anodonta imbecilis* (Say, 1829)—1%. *Fusconaia flava undata* (Barnes, 1823)—1% and *Arcidens confragosus* (Say, 1829)—1% were represented by only one specimen each (Parmalee 1955:32).

During 1976, slightly over two decades after the low water of 1953, central Illinois was once again subjected to below average rainfall which, by early winter, had left Lake Springfield 1.56 m (169.13 m MSL) below normal pool. The water level continued to drop until February, 1977, when it finally reached a low of 168.80 m MSL.

By March, 1977, the snow cover that had blanketed the otherwise exposed shoreline had melted, and during the next ten days a second survey of the 20 loci collected during 1953 was completed. During this period the lake level ranged from 169.13 m MSL to 168.95 m MSL (Fig. 2a) and was an average 169.19 m MSL; a mean level only 12 cm higher than the mean level for October, 1953, when the initial survey was conducted. By May, 1977, the lake had again attained a normal pool (Fig. 2b).

Distances of 50 m were marked off along the waters edge at 18 of the 20 stations and collections of all shells with one dimension larger than 1.5 cm were made for a distance of 4 m back from the waters edge. In two instances (Stations 9 and 23) the areas collected were extended to 100 m long by only 2 m wide because of heavy grass and brush cover that occurred within 3 to 4 m of the waters edge. Both of these stations are at the headwaters of the lake where the water line begins to take on characteristics more like the banks of Sugar and Lick creeks than the shoreline of Lake Springfield. Although the dimensions (100x2 m) differ from areas established at the other 18 stations (50x4 m), every attempt was made to collect the same amount of surface area at all stations, i.e. 200 m^2. It should be noted at this point that the areas collected during 1977 (200 m^2) are roughly 20 percent larger than the areas collected in 1953 (200 yr^2 = 167.3 m^2).

A total of 2177 paired valves were recovered from the 20 stations during 1977. The area sampled at each station was 200 m^2, bringing the total area collected to 4000 m^2 and providing a mean density of .544/m^2, or almost twice as many specimens per unit area as found at the same loci during 1953.

Quantative Changes in the Naiad Fauna

Qualitative changes have occurred in the lake's fauna as a result of the introduction of four new species (*Carunculina parva* (Barnes, 1823), *Truncilla truncata* Rafinesque 1820, *Obliquaria reflexa* Rafinesque 1820 and *Corbicula manilensis* Philippi). There has also been an overall increase in the lake's naiad fauna of roughly ten percent per unit area as well as statistically significant quantative changes among the nine original species. Unfortunately the myriad of unmonitored, interrelated factors responsible for the observed changes cannot be fully delineated *post de facto*, but there are some patterned variations that can be discussed.

The nine original species (1953) constitute 1296 of the total 2177 specimens recovered in 1977. When these primary species are considered separately (n = 1296), the naiad density per unit area is only slightly greater (.324/m²) than that found during the first survey (.295/m²). Increases in the mussel fauna are restricted to as few as seven stations (i.e. 2, 5, 6, 9, 10, 12, and 15) situated along the main body of the lake (Fig. 1) where increases per unit area by station range from 71 percent to 204 percent. Density was nearly the same per unit area at station 16 (i.e. < 2 percent change) while densities per unit area at the remaining 12 stations decreased rather markedly.

The upper reaches of the lake and the heads of many of the inlets have undergone considerable aggradation through siltation. This phenomenon was readily apparent when collections were made in 1977. The substrate at stations 4 and 13 (inlets), 17, 18, 19 and 20 (upper reaches of lake) consisted of poorly consolidated silty clay loams and were difficult to collect without sinking waist deep in "muck". Also, the color of these aggrading deposits was noticeably darker (Table

TABLE 1. *Freshwater mussels recovered from twenty stations along the exposed shoreline of Lake Springfield, Illinois, during 1953 and 1977.*

Station Number	Legal Description	Munsell Color	Year Collected	*Amblema plicata*	*Fusconaia flava*	*Quadrula quadrula*	*Anodonta grandis*	*Anodonta imbecillis*	*Arcidens confragosus*	*Lasmigona complanata*	*Leptodea laevissima*	*Ligumia nasuta*	*Total primary species*	*Carunculina parva*	*Truncilla truncata*	*Obliquaria reflexa*	*Corbicula manilensis*	*Total*
1	ne,ne,se,se of Sec. 12; T15N; R5W (SE)*		1953			17	1						18					18
		10YR 5/4	1977			8	3					4	15			4	57	76
2	nw,se,sw,ne of Sec. 19; T15N; R4W (NC)		1953								3	2	5					5
		10YR 4/4	1977			105	2			1	3	4	115		2	18	15	150
3	nw,nw,se,se of Sec. 14; T15N; R5W (NC)		1953	1		26	7			11	15	25	85					85
		10YR 4/4	1977			25	13	2		3	7	7	57	2		18	16	93
4	nw,ne,nw,sw of Sec. 24; T15N, R5W (NC)		1953	1		26	9	2		8	18	17	81					81
		10YR 3/2	1977			17	11	1			13	3	45	3		18	27	93
5	se,ne,nw,ne of Sec. 25; T15N; R5W (NC)		1953			28	1			5	12	6	52					52
		10YR 4/2	1977			26	24	1		1	24	33	109	3		59	26	197
6	se,se,sw,sw of Sec. 19; T15N; R4W (NC)		1953			4					3	9	16					16
		10YR 5/4	1977			18	1			2	5	11	37		6	11	223	277
7	se,sw,sw,se of Sec. 19; T15N; R4W (NC)		1953			78	8			3	6	1	96					96
		10YR 4/4	1977			22					6	4	32		2	3	70	107
8	sw,nw,nw,sw of Sec. 30; T15N; R4W (NC)		1953	2		25	5			10	10	2	54					54
		10YR 5/4	1977			23	1				3	3	30		3	23	48	104
9	sw,nw,se,se of Sec. 36; T15N; R5W (NC)		1953			20	1			3	8	4	36					36
		10YR 3/1	1977			65	1	1			5	2	74			17	5	96
10	ne,nw,sw,se of Sec. 35; T15N; R5W (NC)		1953		1	12	4	1		16	29	5	68					68
		10YR 3/3	1977		1	174	17	4			48	6	249	4		24	75	353
11	se,se,nw,sw of Sec. 36; T15N; R5W (NC)		1953			33	1				5	6	45					45
		10YR 3/3	1977	1		16	1				3		21			7	3	31
12	ne,sw,se,se of Sec. 35; T15N; R5W (NC)		1953	2		26			1	5	21	5	60					60
		10YR 3/3	1977			203	4	3	1		14	6	231	1		26	10	268
13	sw,se,se,ne of Sec. 2; T14N, R5W (NC)		1953			21	4	1		3	2	3	34					34
		10YR 3/1	1977			2	3				3	2	10			1	4	15
14	ne,ne,sw,nw of Sec. 2; T14N; R5W (C)		1953			16	3	1		12	13	4	49					49
		10YR 4/3	1977			33	2			1	5		41			11	1	53
15	sw,nw,ne,nw of Sec. 16; T14N; R5W (C)		1953	6				1		6	7	10	30					30
		10YR 3/3	1977			75	8	1		2	10		96	1		7	1	105
16	sw,nw,nw,sw of Sec. 3; T14N, R5W (C)		1953	2		25	2	1		9	13		52					52
		10YR 3/2	1977			44	6			3	8		61			6	12	79
17	nw,sw,se,nw of Sec. 32; T15N; R5W (C)		1953			14	1			3	13		31					31
		10YR 3/1	1977			10	11	1			9		31	1			5	37
18	n½,ne,sw,sw of Sec. 30, T15N; R5W (C)		1953			30	3				5	1	39					39
		10YR 3/1	1977					2			2		4					4
19	nw,nw,nw,sw of Sec. 9; T14N, R5W (C)		1953			54	12			13	21		100					100
		10YR 3/1	1977			7	12				6		25					25
20	sw,sw,se,sw of Sec. 34, T15N, R5W (C)		1953			17	1			4	9	5	36					36
		10YR 3/2	1977			1	4	4			3		12				2	14

*Determined from 7.5 minute USGS quadrangles: (SE) = Springfield East, (NC) - New City; (C) = Chatham.

1—10YR 3/1, 3/2) than substrates at most other stations where yellowish brown and brown soils (primarily Hickory, Clinton, and Elco series—as depicted on advance soil sheets for Sangamon County) are eroding from the former valley walls of Sugar Creek (Table 1). Aggrading deposits transported into the lake from the nearly black upland prairie soils are very dark gray (10YR 3/1—Munsell) to very dark grayish brown (10YR 3/2) and consistently produced fewer naiads per unit area ($\bar{X}$.11/m²) than were found during 1953 ($\bar{X}$.32/m²). The relatively undiluted herbicides and/or pesticides, and large quantities of smothering silt particles that settle out when they reach the sluggish waters of the lake have probably contributed to this decrease in primary naiad density at these stations.

Quantative changes among the primary species have also taken place over the past two decades. A chi square conducted on the 1953 and 1977 populations (Table 2) clearly shows that there have been significant quantative changes in the naiad fauna (X^2 = 202, df = 8, p .< .001). *Q. quadrula, A. grandis* and *A. imbecilis* occurred in greater frequencies than expected during 1977 while *L. complanata, L. laevissima, A. plicata,* and *L. nasuta* have decreased. Variation in occurrence of *L. complanata, Q. quadrula, L. laevissima, A. plicata* and *L. nasuta* contribute the greatest respective amounts to the high chi square value.

A comparison of the combined assemblages from the heads of inlets and upper reaches of the lake (i.e. stations 4, 13, 17, 18, 19 and 20) for the 1953 and 1977 populations has been made by constructing a contingency table similar to that in Table 2. At these loci *A. grandis, A. imbecilis* and *L. laevissima* occurred in greater frequencies than expected during 1977 while *Q. quadrula, L. complanata, L. nasuta* and *A. plicata* occurred in fewer numbers than expected. Even when the "no zero cell' requirement is fulfilled and *A. plicata* and *L. complanata* are excluded (including only *Q. quadrula, A. grandis, A. imbecilis, L. laevissima,* and *L. nasuta*), a chi square shows a statistically significant difference between 1953 and 1977 population (X^2 = 33, df = 4, p < .001).

TABLE 2. *Naiad fauna recorded for Lake Springfield during 1953 compared to the same species recovered in 1977*

	total naiad fauna (1953)		partial naiad fauna (1977)		
naiad species	*fo*	*fe*	*fo*	*fe*	total
Amblema plicata	14	6.5	1	8.5	15
Fusconaia flava undata	1	0.9	1	1.1	2
Quadrula quadrula	472	581.9	874	764.1	1346
Anodonta grandis	63	80.4	124	106.1	187
Anodonta imbecilis	7	11.7	20	15.3	27
Arcidens confragosus	1	0.9	1	1.1	2
Lasmigona complanata	111	53.6	13	70.4	124
Leptodea laevissima	213	168.6	177	221.4	390
Ligumia nasuta	105	82.2	85	107.9	190
Total	987		1296		2283
	202		df = 8		p < 0.001

All three of the species that occurred in greater frequencies than expected are known to be more tolerant of mud substrates and lentic waters than many of the species that occur in the lake (Parmalee 1967:47, 48, 74). This observation tends to substantiate our previous supposition that naiad populations at these loci are being influenced by siltation, as does the fact that *Q. quadrula* recovered from these areas are all mature individuals generally over five years of age.

By way of comparison we have combined the assemblages at the seven stations on the main body of the lake that showed an increase mussel density per unit area (i.e. Stations 2, 5, 6, 9, 10, 12, and 15) between 1953 and 1977. A contingency table shows that *Q. quadrula, A. grandis* and *A. imbecilis* occur in greater numbers than expected while the other six primary species occur in a lower frequency than expected. A chi square on eight of the nine species (excluding *A. plicata* since none was found during 1977) shows the two populations to be significantly different (X^2 = 235 df = 7: p < .001). These species are the same three that occurred in greater frequencies than expected when all 20 stations were combined and 1953/1977 samples were compared. A similar manipulation of mussel counts from remaining stations, i.e. those with decreased naiad density but not on the upper reaches of the lake or at heads of inlets, show changes in the same direction that other stations on the main body of the lake display.

Despite the lower naiad densities at these stations, *Q. quadrula, A. grandis* and *A. imbecilis*

FIG. 2. *Lake Springfield, Illinois at Station 13 showing exposed substrate near the head of an inlet during March, 1977. Water level is at 169 in MSL*

occur in greater frequencies than expected while the remaining species occur in fewer numbers than would be expected if the populations had undergone no change over the past two decades.

Qualitative Changes in the Naiad Fauna

Four species of freshwater mussels recovered during 1977 were not found in the lake during the 1953 survey. Of the four species established since 1953, *C. manilensis* was found in greatest frequency. It made up 28 percent of the total specimens recovered during the 1977 survey and was second in abundance only to *Q. quadrula*. Had all specimens of the Asiatic clam been collected, they would have been quantitatively the most significant naiad in Lake Springfield. Literally thousands of *C. manilensis* were not collected because they were less than 15 mm in diameter. In fact, the lower limit of 15 mm was established after the first station was visited as the task of collecting all *Corbicula* was found to be nearly impossible given the amount of time available for the second survey.

Corbicula manilensis was introduced into the fluvial systems of North America as late as 1938 and has since spread to most major drainages in the United States (Sinclair 1971). The environmental conditions this freshwater clam is able to tolerate in Illinois are varied but as late as the mid 1960s it was not found in the Mississippi drainage above Cario in Illinois (Parmalee 1967:95). However, over the past ten years the species has become established in the Illinois River (Thompson and Sparks 1977:34) and the major reservoirs of the Sangamon River drainage (e.g. Lake Springfield, Lake Decatur, Sangchris Lake) in central Illinois. In some drainages this species has been found to exceed 269,000/M² in density and in instances has become so numerous

FIG. 3. *Lake Springfield, Illinois, at Station 13 (inlet) during May, 1977 Water level is at normal pool (170.69 m MSL)*

as to pose problems at power generating and water filteration installations (Sinclair 1971).

Three species of naiads (i.e. *O. reflexa*, *C. parva*, and *T. truncata)* endemic to the Mississippi River drainage have also become established in Lake Springfield since the initial survey. All three species were known to exist in the Sangamon River drainage at the time of the 1953 survey. *O. reflexa* and *T. truncata* were reported common in the South Fork of the Sangamon not far from the lake, and an abundant population of *T. truncata* and *C. parva* was noted observed in Lake Decatur (Parmalee 1955:31) just upstream from Lake Springfield in the Sangamon River. It was speculated at the time of the 1953 survey that these species were either not present in Sugar Creek prior to its impoundment or that they were primarily lotic species that were not able to adapt to the man-made lentic habitat formed by Lake Springfield.

Results of our 1977 survey clearly demonstrate that these three, especially *O. reflexa*, are capable of maintaining viable populations in a man-made reservoir like Lake Springfield. The fact that over 3300 M^2 was systematically collected at 20 different loci and that considerably more shoreline was sporadically surveyed (but not collected) and none of these naiads were found during 1953 argues strongly for a more recent establishment of the species. Live specimens of *O. reflexa*, utilized in another study (Parmalee and Klippel 1974), were collected at Station 9 in August 1971; several individuals were between five and six years of age, which indicates this species had become established in the lake at least by 1965—and probably earlier. In contrast, *C. manilensis* was not present at this same station as late as spring 1973.

The means by which these mussels could have been introduced are numerous, but two of the most likely avenues known to us are: 1) their introduction as glochidia with fish (primarily, but not exclusively, white bass) obtained from other fluvial systems in Illinois and placed in Lake Springfield by the Illinois Department of Conservation during 1951 and 1974, or 2) through the emergency water supply system that was established by City Water, Light, and Power shortly after the low water of 1953. This system consists of a canal that was excavated from a dividing dam along the east shore of the lake to nearby Horse Creek. Water from Horse Creek flows in the canal to the dividing dam from where it is pumped into the lake. According to City Water, Light, and Power records, the pumping facility was operated for a short period after its completion in 1956 and again during 1976 and 1977 when as many as 900 million gallons per month were pumped from the canal into Lake Springfield. Either small fish infested with glochidia and/or glochidia suspended in the water may have been carried through this pumping facility.

Regardless of how these three species were introduced they all seem to have become well established and are fairly widely distributed. *O. reflexa* was the third most numerous species recovered during the 1977 survey. It was only outranked in frequency by *Q. quadrula* and *C. manilensis* and was nearly as ubiquitous as the first and second ranked species (Table 1). *O. reflexa* is noticeably absent and/or in low frequencies along the upper reaches of the lake and at the heads of inlets (e.g. Stations 13, 17, 18, 19, and 20). In general, *O. reflexa* occurred in greatest frequencies at those same stations where the primary species were found in increased density per unit area during 1977 (e.g. Stations 2, 5, 9, 10, and 12).

C. parva and *T. truncata* were the eighth and ninth respective most numerous of the 13 species recovered. *C. parva* was found at and near collection stations throughout the lake while *T. truncata* in sampling strata were exclusively restricted to the east shore of the main body of the lake (e.g. Stations 2, 6, 7, and 8). At least 20 additional *T. truncata* were observed outside the sampling loci at these stations but in only one instance was the species observed along any other portion of the lake. This location was approximately 90 meters outside the area collected at Station 5 which is also along the lower portion of the main body of Lake Springfield but on the west shore. Whether the present low population number is a result of what appears to be a fairly recent introduction (the largest individuals are ca. 4-5 years of age) or the inability of a typical river species to adapt to a lake environment is not clearly understood.

Comparisons and Discussion

Few thorough studies of quantitative and qualitative changes in naiad fauna resulting from artificial impoundment of fluvial systems and subsequent adaptation to lentic environment have been reported for North America. The pelecypod fauna from Lake Texoma in Texas and Oklahoma have been studied and reported (Riggs and Webb 1965; White and White 1977) and some work had been conducted in the Red River prior to its impoundment (Isely 1925). Conclusions set forth on the basis of the most recent studied suggests that "despite the many conditions seemingly working against the pelecypods of Lake Texoma, it can be said with some degree of confidence that they are flourishing when compared to their original diversity and abundance" (White and White 1977: 251).

Unfortunately quantitative data are not available to measure the strength of this observation. Variations in survey strategies preclude the possibility of making direct comparisons from one report to the next. White and White (1977:248) note, for example, that "The study by Riggs and Webb (1956) found that the mussel populations of the lake were much more established than had been indicated previously; however, since they surveyed only one of the possible lake habitats, a loamy-sand substrate, the data could not be used to draw conclusions about the abundance of species throughout the entire lake." In fact Riggs and Webb (1956:200) report information that indicate the average naiad density was .39/m² during 1953 while information provided for more varied habitats by White and White (1977:242) show that the mean density was .12/m² during 1975-1976. Only two of the stations collected by White and White (1977—stations 7 and 9) produced as high a density (> .24/m²) as the station producing the lowest density during 1953 (Station 8) when a portion of the lake was collected by Riggs and Webb (1956). The 1975-1976 collections did produce three species not collected by Riggs and Webb (1956), i.e. *L. complanata, O. reflexa* and *Lampsilis teres*. However, the significance of this observation is also rendered less impressive when one considers that White and White (1977) collected a surface area of over seven times as great as the area collected during 1953.

Unlike the claims made for Lake Texoma, most observations made on naiads in the impoundments of the larger, previously swift, streams and rivers of southeastern United States indicate that mussel populations have been drastically altered (e.g. Bates 1966; Stansbery 1964; Isom 1969). Bates (1966:235) notes, for example, that "Most of the large river forms which were characteristic of the pre-impoundment assemblage [in the Tennessee River] are now typically absent from these shallow water habitats" in the Kentucky Reservoir. "The one exception noted here is *Q. quadrula*, which has successfully invaded these areas. Many juveniles of this species were collected from both the beach areas and the mud shallows indicating a much higher biotic potential for this species than for the other Unioninae." In addition to *Q. quadrula* and *C. parva*, various species of *Leptodea* and *Anodonta* comprised the dominant naiads recovered by Bates (1966).

Pronounced changes in mussel population of unimpounded fluvial systems have also been well documented. In many of the streams of the Midwest the overriding observation is that populations have undergone various degrees of degradiation (e.g. Clark 1976; Matteson and Dexter 1966; Starrett 1971). One point of interest here is that all three of these reports on mussels in streams flowing through or bordering Illinois note the hardiness of *Quadrula quadrula* despite siltation and pollution (Clark 1976:8; Matteson and Dexter 1966:99; Starrett 1971:363). Also of interest is Clark's (1976:8) notation of recent increases in the occurrence of *O. reflexa* in the Wabash River.

A survey of pre-impoundment Lick and Sugar creeks in central Illinois was never undertaken. Consequently it is impossible to compare or contrast species of the original lotic environment with those in the subsequent artificially produced lentic environment resulting from the construction of Lake Springfield. However, mussel populations of the lake were surveyed (1953) nearly two decades after impoundment (1935). Slightly over two decades later (1977) a survey of the same loci collected during 1953 was again undertaken. Results of this second survey conclusively demonstrate that naiad density per unit area has generally increased and that species diversity has also taken place in Lake Springfield. In this respect the results of this second survey are similar to the claim for Lake Texoma, i.e. "increasing density and diversity within the lake" (White and White 1977:235).

Seven of the ten species reported for Lake Texoma occur in Lake Springfield and seven of the 12 species recovered from Lake Springfield are also found in Lake Texoma. Riggs and Webb (1956:201) report *L. laevissima* and *Q. quadrula* as the first and second respective most common species in Lake Texoma while White and White (1977:242) report *L. laevissima* and *A. grandis* as the two most numerous species. In the Lake Springfield populations for both 1953 and 1977, *Q. quadrula* was most numerous and *L. laevissima* the second most common of the Unionacea. Also, as in the case of Lake Springfield, *O. reflexa* is a recent addition to Lake Texoma as it was not recovered by Riggs and Webb (1956) in 1953.

While *Q. quadrula* has seemingly decreased in Lake Texoma, the species has actually increased in frequency in Lake Springfield. This seems to conform to some findings in both streams and rivers of the Midwest (Matteson and Dexter 1966) and lake environments in the South (Bates 1962). The manner in which Lake Springfield does not appear to compare favorably with many other reported populations in the Midwest and Southeast is that there does not seem to be an overall degradation of naiad populations. Degradation of the population seems to be occurring in the upper reaches of Lake Springfield, as well as at the heads of inlets, but populations in the main body of the lake generally have thrived over the past two decades. However, as Lake Springfield continues to silt in, it is expected that the naiad density per unit area will continue to decrease and that *A. grandis*, *A. imbecilis*, and *L. laevissima* will continue to increase in relation to other species in the agrading portions of the lake.

Hinge Anomalies

Anomalies occurring in the form of transposed lateral hinge teeth have been noted in freshwater bivalves for over a century (Agassiz 1859; Lea 1860). Van der Schalie (1936) revised Lea's 1860 list and included his own records of species exhibiting various combinations of transposed teeth which he accumulated during many years of intensive collecting. In addition to the eight species recorded by Lea, van der Schalie listed 18 others which represented (for all species) 72 anomalous individuals. None of the hinge variations described by these workers were found in species belonging to the genus *Quadrula*, so the occurrence of transposed teeth in 13 individuals from the 1977 sample of *Q. quadrula* collected in Lake Springfield is worthy of note.

The normal dentition in species belonging to the family Unionidae consists of double lateral and pseudocardinal teeth in the left valve and a single lateral and pseudocardinal tooth in the right. At least five distinct variations were observed among the 13 anomalous individuals: single lateral in each valve (N=3); double lateral in both valves (N=3); single lateral in left, double in right (N=4); double lateral in left valve, partly treble in right (N=2); treble laterals in both valves (N=1). One of the individuals possessing a single lateral in the left valve and double lateral in the right is additionally noteworthy because the pseudocardinal teeth are also transposed. Whether or not reversed or transposed hinge teeth in freshwater bivalves are a result of environmental or genetic factors is not clearly understood. However, the fact that such variations in hinge structure do occur, even if uncommonly to rarely, is significant in relation to their use as characters in identification and classification. Transposed hinge teeth were not noted in individuals of the other species from Lake Springfield. The anomalous specimens of *Q. quadrula* comprised approximately one percent of the sample of that species.

Summary

Systematic surveys of the naiad fauna in the artificially formed lentic environment of Lake Springfield of central Illinois were undertaken during 1953 and 1977. Comparable survey strategies employed during both surveys has made it possible to make direct comparisons of the naiad populations over a period of a quarter of a century.

Both quantitative and qualitative changes have occurred in the naiad fauna. Generally, the naiad density per unit area has increased along the shores of the main body of the lake while the density in the upper reaches of the lake and at the heads of the inlets has decreased. Commencerate with the decreased density that has occurred in these portions of the lake that have been agrading over the past 25 years are the changes in relative proportions of certain species of mussels; *L. lacrissima*, *A. grandis*, and *A. imbecilis* have increased with respect to other species in these habitats.

Qualitative changes in the mussel fauna have also taken place in Lake Springfield. All of the species recovered during 1953 were also recorded during 1977. In addition, four species (i.e. *C. parva*, *T. truncata*, *O. reflexa*, and *C. manilensis*) have become newly established in the lake. Deposition of silt in the areas of entry of the feeder creeks appears to greatly inhibit the establishment and growth of naiads. With continued heavy silting at several locales in the lake, accidental introduction or periodic stocking of fish, and with possible unforeseen changes in the present lake habitat, a future study of the mussels of Lake Springfield may well provide additional useful data relative to population dynamics under artificial conditions.

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