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University of Hawaii, Ph.D., 1975
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PLANKTONIC PROSOBRANCH VELIGERS OF KANEOHE BAY

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN ZOOLOGY

MAY 1975

By

Jane Bartlett Taylor

Dissertation Committee:

E. Alison Kay, Chairman

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Philip Helfrich
Howard W. Klemmer

PREFACE

Time and tide wait for no one.

Anonymous

During the several years of research and writing which were involved in this dissertation many people and institutions provided support in many forms. Most of the financial support was provided by an NDEA Title IV Fellowship. Additional materials were supplied by Dr. Philip Helfrich of the Hawaii Institute of Marine Biology, Dr. Fred Kamemoto of the Department of Zoology and Dr. Robert Kane of the Kewalo Marine Laboratory.

Identification of the prosobranch veligers to the level of species would not have been possible without many shell collectors allowing me to see specimens from their private collections; among these many collectors are several whom I would like to thank here: Betsy, Ibby and Arch Harrison, Dr. Vernon Smith, Dr. C. M. Burgess, Eric Guinther, Dr. Carl Berg, Dr. Fred Bernstein, Dr. Ralph Bowers, Ed Konopka and Dr. E. Alison Kay. All were generous in permitting me to spend hours drawing the protoconchs on specimens in their collections.

The typing of this tome presented problems and I am an inexpert typist. Ms. Freda Hellinger extended invaluable advice, help, good humor and the temporary use of a typewriter. Ms. Carol Ammerman also extended the use of her typewriter at a critical time.

The unsung heroes of any dissertation effort are the members of

the author's family. Throughout the past four summers my family has accommodated my need to work on my dissertation and has simply accepted that I had little or no time to spend with them, so special thanks go to David, Maria, and my mother, Mrs. Vera Bartlett.

The research on this dissertation provided me with the rare opportunity to meet and work with Dr. Vera Fretter of the University of Reading (England). She shared with me through several discussions some of her ideas and insight with respect to experimental design and expression. I appreciate very much her help and inspiration. My only regret is that Dr. Marie Lebour, whose publications were so helpful in the initial identifications, died before I had the chance to tell her how much her work meant to me.

Advice rē experimental design and statistical analysis was gratefully received from Dr. Alan Kohn, Dr. Steve Smith, Dr. Jeannette Struhsaker and Gerry Key. The incredibly tireless Russian microbiologist, Dr. Yuri Sorokin, took the time to teach me how some isotopic tracer techniques are applied to marine microbiological studies.

A final and very special expression of gratitude goes to Mrs. Ibby Harrison who provided a supportive environment in Hawaii during that last drive to get it all finished, and who helped immeasurably in the assembly of the final draft-plus-seven-copies. Every author of a dissertation needs someone to prod her when her attention is diverted to other less tedious tasks and to inspire her from time to time with the necessary energy and drive to finish that last stretch. Mrs. Harrison filled that role abundantly well.

PLANKTONIC PROSOBRANCH VELIGERS OF KANEOHE BAY

By Jane Bartlett Taylor

A dissertation submitted to the Graduate Division of the University of Hawaii in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Abstract

As a result of weekly samplings of the surface waters of the Kaneohe Bay (Oahu, Hawaii) plankton during a two and one-half year period, more than two hundred species of planktonic prosobranch veligers have been described, their temporal and spatial distribution in the plankton established, the growth patterns of their juveniles examined and the capacity of veligers of Crucibulum spinosum to withstand heat and detergent stress quantified. It was found that diversity of species increases from the inner bay to the outer reef areas; abundance decreases from the southeastern to the northwestern region. Ecological factors which may restrict species of veligers to defined areas are discussed.

Crucibulum spinosum, a calyptraeid, is the species of prosobranch veliger most abundant in Kaneohe Bay throughout the year; the ability of these veligers to withstand heat and detergent stress was quantified in separate experiments. In veligers of C. spinosum, temperatures

ranging from 30° C. to 36.5° C. produce highly significant increases in death rates in the experimental groups as compared with the control groups at 27° C. (ambient temperature during collection). At 30° C., these differences in per cent mortality become significant ($p = 0.01$) after 67 hours, at 33° C. after 53 hours ($p = 0.001$), at 35° C. after 35 hours and at temperatures above 36.5° C. within eight hours ($p = 0.001$).

Transferral of C. spinosum larvae to temperatures only a few degrees higher than that of ambient sea water appears to be one factor which stimulates metamorphosis in the veliger. These post-metamorphic juveniles are more likely to survive at continuously high temperatures than are the veliger stages.

Linear alkyl sulfonates (LAS), the compounds common to most synthetic detergents manufactured in the United States, are degraded after 48 - 50 hours in sea water containing normal amounts of bacteria. In many instances, veligers that survive a 48-hour exposure to LAS recover from most ill effects. While some veligers introduced to concentrations of 3 ppm LAS-in-sea-water survive, the initial toxicity associated with concentrations of 3.3 ppm is too great for any veligers to outlive the duration of toxicity. Veligers that are able to metamorphose quickly upon exposure to LAS are more likely to survive than those remaining as veligers.

Successful rearing techniques and problems encountered in rearing juvenile gastropods of differing life styles are described and discussed. Variations in diet, temperature and other factors alter rates of growth, but generally the following species require the following

periods from metamorphosis to reproductive maturity with a temperature range of 25 - 28° C.: Styliferina goniochila, 16 days; Epitonium ulu, 21 days; Litiopa melanostoma, 23 days; Cerithium atromarginatum, 5 weeks; Smaragdia bryanae, 10 weeks; Natica gualtieriana, 12 weeks; Crucibulum spinosum, 3 - 4 weeks for development of the male gonad, 12-15 weeks for the female apparatus to become functional.

Discontinuous growth occurs in some carnivorous juveniles; it may be sharply discontinuous (as in Bursa cruentata and Cymatium muricinum) or it may be more gradual. The more gradual type is exemplified by Natica gualtieriana wherein periods of 3 - 12 days may elapse with growth in greatest diameter not exceeding 34 μm.

The range of variation in growth rate in all molluscivorous thaidids and miters studied varies approximately as much as the range of variation in growth rate within the population of one species, N. gualtieriana. Most of the growth curves of molluscivorous juveniles are clustered within a narrow range; this observation suggests that animals which feed on similar food supplies under similar environmental conditions tend to process and assimilate food at similar rates.

Pre-settlement planktonic veligers are described for the first time for the following families: Neritidae, Phenacolepadidae, Janthinidae, Thaididae, Mitridae, Conidae and Terebridae.

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Introduction

While patterns of occurrence, seasonal abundance and biological processes are well known for many inhabitants of polar and temperate seas, little information is presently available on which to base broad generalizations concerning reproductive and developmental patterns of tropical organisms. Even less is known of tropical inshore plankton and its wealth of larval stages from shallow water communities. The purpose of this study is to examine the biology of the planktonic larvae and benthic juveniles of prosobranch gastropods (Mollusca) in the sub-tropical inshore waters of the Hawaiian Islands. The major focus of the study is that of pre-metamorphic larvae: their descriptions, spatial and temporal distribution, and tolerance to heat and detergent stresses; a secondary focus is the nutrition and growth of the juveniles into which these larvae metamorphose. Although the study deals with only one of many phyla comprising the planktonic community and is limited to a single inshore area, it is hoped that it will provide insights into an understanding of trophic relationships, turnover rates in populations, growth rates, larval ability to tolerate environmental stresses, and the temporal and spatial distribution of planktonic communities in tropical waters in general.

Justification for conducting such a study is not difficult to find. Coral reef ecosystems are credited with the highest recorded rates of primary productivity in the marine world (Woodwell, 1970). Planktonic

organisms are vital links in contributing to that productivity. Despite the obvious importance of these communities, present information on plankton in tropical and subtropical waters is so incomplete as to make it difficult even to identify components of a plankton sample to the level of family, and identification of all specimens in a sample to genus and species is a rare event.

As the incidence of environmental stresses grows, it is becoming increasingly urgent that the ability of larval stages to cope with agents of stress be investigated in detail. Major constituents of tropical zooplankton communities,--eggs, larval stages, and juveniles--represent adults which inhabit the benthos of both intertidal and shallow subtidal areas of island coastlines. Generally, the early stages in life histories have narrower ranges of tolerance to environmental stresses than do conspecific adults (Moore, 1958). It follows that if extremes of tolerance ranges are surpassed, entire generations of species may be eliminated from areas subject to modern environmental stresses, --areas which prior to these stresses served in recruitment for both benthic and pelagic communities far from the source of stress. Finally, a knowledge of the spatial and temporal distribution of prosobranch larvae may suggest possible research tools to students of developmental biology, behavior and physiology. Thus, a study of planktonic larval stages is useful in a variety of ways.

If one is to undertake a study of planktonic larvae, the central remaining difficulty is that of defining the problem such that any results can be woven into a cohesive pattern rather than be left standing as an array of isolated bits of information. Though one could select types of organisms which represent trophic levels, feeding groups,

size groups, age groups etc., one approach is the selection of a group of larval stages which will satisfy several criteria: it includes a sufficient variety of species to represent a variety of habitats and physiological requirements, it is consistently available, and it includes a variety of species which can be reared under laboratory conditions.

These criteria preclude, at least in Hawaiian waters, such otherwise obvious choices as coral planulae and crustacean larvae. Coral planulae are not particularly abundant in Hawaiian plankton tows (comprising less than two per cent of the numbers of individuals of most tows) and are somewhat sporadic in their occurrence (J. Harrigan-Lum, pers. comm.). Crustacean larvae, although easy to rear from the megalops stage, are also sporadic in their occurrence and are found in greater numbers in night tows than in day tows (Harrigan-Lum, ibid.). Among mollusks, the larvae of both bivalves and opisthobranchs also present several problems. There are relatively few species of bivalves (Kay, 1967) and appearance of their larvae in the plankton is strikingly seasonal. Opisthobranch veligers, also represented by relatively few species (Kay, ibid.) are not abundant, the juveniles are extremely specific in food habits making laboratory rearing difficult, and there are only subtle differences in protoconch (i.e., larval shell) morphology, which impedes identification.

Prosobranch veligers, on the other hand, satisfy most of the criteria. They consistently account for 10 to 25% (wet weight) of the surface-water (top one meter) plankton of Kaneohe Bay, and are represented by a minimum of 20 or 30 species, and often, especially during

spring and summer, by more than 100 species. Prosobranch gastropods not only include a variety of feeding types, but inhabit a variety of habitats, from sessile commensals to pelagic forms. There is also the advantage that there is considerable literature on prosobranchs to guide one through the intricacies of both their taxonomy and physiology.

Several classic works on mollusks were particularly useful in this study. As an introduction to the anatomy and functional morphology of prosobranch larvae, Fretter and Graham (1962) provide a solid base from which to explore other literature sources which deal with more esoteric topics and which demand a good understanding of the scope one encounters in the study of prosobranch veligers. Unfortunately, there is no adequate review of the physiology of prosobranch larvae; however, there are good summaries of the physiology of bivalve larvae (Loosanoff, 1954; Walne, 1964) and reviews of the later development of freshwater and terrestrial snail larvae (Raven, 1964). Although there are numerous articles dealing with the subject of prosobranch veligers, most describe larvae newly hatched from egg capsules. Relatively few papers describe the later veliger stages encountered in the plankton; the next paragraph discusses the most useful of these.

Of Thorson's several contributions to the study of prosobranch veligers, his 1936 and 1940a papers are most useful in providing descriptions of pre-metamorphic veligers. Thorson's 1946 tome is also useful because of the fine quality of the drawings, the collection data, and the generalizations which summarize what was then known about the larval development of Danish marine bottom invertebrates. Most of the detective work involved in the identification of prosobranch veli-

gers in temperate Atlantic plankton samples was done by Lebour (1936, 1937), who also provides a helpful guide to the planktonic prosobranch veligers of Bermuda (1945). A key to 37 species of prosobranch veligers from the temperate Atlantic plankton which aids in their identification is provided by Fretter and Pilkington (1970); new descriptions are provided and the text includes comments on the original veliger descriptions. Review articles by Anderson (1960) and Radwin and Chamberlin (1973) survey, family by family, the developmental patterns of prosobranchs and provide helpful summaries of the literature; Natarajan (1957) presents informative text and fine drawings of the veligers of Palk Bay and the Gulf of Mannar, India.

Although the works of Risbec (1932, 1935) and Lewis (1960) are cited occasionally as valuable contributions to the literature, the poor quality of figures detracts from their usefulness.

The only works which deal with planktonic prosobranch veligers in Hawaiian waters are those by Ostergaard (1950), Struhsaker (1966, 1968b), Struhsaker and Costlow (1968a) and Fretter (1969).

Cited authors, dates and areas of interest are summarized (Table 1) for the reader's convenience.

Table 1

Cited authors, dates and areas of study

Reference	Area of study					
	1	2	3	4	5	6
Amio 1955-1963						x
Anderson 1959-1966					x	
Broekhuysen 1940			x			
Cernohorsky 1965-1973					x	
Coe 1938, 1948						x
Coe and Fox 1942						x
D'Asaro 1965, 1966, 1969, 1970b	x					
D'Asaro 1970a						x
Dawydoff 1940						x
Eisawy and Sorial 1968				x		
Fischer 1887		x				
Fretter and Pilkington 1970		x				
Fretter 1970						x
Gohar and Eisawy 1962, 1967				x		
Hadfield et al. 1971						x
Kay 1966						x
Knudsen 1950			x			
Kohn 1960, 1961a						x
Kohn 1961b				x		
Lamy 1928		x				

Kohn 1960, 1961a						x
Kohn 1961b				x		
Lamy 1928		x				
Lebour, all years except 1945		x				
Lebour 1945	x					
Lewis 1960	x					
Lo Bianco 1888		x				
Marcus and Marcus 1962	x					
Miller 1970						x
Natarajan 1957				x		
Ostergaard 1950						x
Petit and Risbec 1929					x	
Radwin and Chamberlin 1973	x					
Risbec 1931, 1932, 1935					x	
Robertson 1967	x					
Robertson 1964		x				
Robertson 1970a						x
Scheltema 1956-1971		x				
Simroth 1964		x				
Strubsaker 1966						x
Thiriot-Quievreux 1966, 1967		x				
Thorson 1940a				x		
Thorson 1935, 1936, 1940b, 1946		x				
Tregouboff and Rose 1957			x			
Vestergaard 1935		x				

Explanation of area of study numbers:

1 = Tropical western Atlantic

2 = Temperate and Arctic Atlantic

3 = Mediterranean Sea and West Africa

4 = the Red Sea, Iranian Gulf and Indian Ocean

5 = Australia, New Zealand, New Caledonia, Fiji and the southern Indo-Pacific

6 = Japan, Philippines, Hawaii, the northern Pacific and the eastern Pacific

Materials and Methods

Collection of veligers was made with a nylon plankton net one meter wide at the mouth and with a mesh size of 330 μm. Daytime plankton tows were conducted at low speed in three principal areas of Kaneohe Bay (see Appendix A) at least once each week for two and a half consecutive years. After towing for 10 - 15 minutes, the contents of the collection were poured through a fish net (mesh size, 2 mm) into a bucket containing a few centimeters of fresh sea water to separate unwanted large components such as algae, jellyfish, chaetognaths etc. from the desired smaller components. During the tow, buckets of fresh sea water were obtained for subsequent filtration with a 50 μm mesh nylon cloth. This was followed by storage in a 20-liter glass container for a week. Most diotocardians except for the neritaceans (see next chapter, pp. 17 and 23, for definitions) were not obtained by this method. Possible reasons for their omission are suggested in the next chapter (see p. 20).

Upon return to the laboratory, the plankton sample was transferred to two-liter beakers and the organisms were allowed to settle for a few minutes. The supernatant organisms were returned to the Bay or used as food for juvenile fish and bivalves. Upon swirling the remainder, more veligers were caught in the vortex and deposited at the bottom than were other organisms. The process was repeated until quick scanning of the deposit indicated veligers were no longer present.

The veliger portion of the sample was transferred to petri dishes and scanned for organisms not seen before. Veligers previously described were noted. 'New' species of veligers were described, photo-

graphed in color and isolated in small (diam., 5.5 cm) plastic petri dishes which contained fresh, filtered sea water. If 50 or more small (> 800 μm) veligers are crowded into one small dish, the probability of their imminent metamorphosis increases. At these population densities metamorphosis is more likely to occur than at lower densities. Veligers which can metamorphose within a week or two are more likely to grow to sizes large enough to permit tagging and recognition after subsequent release in sea water tables than are individuals which continue as veligers more than two weeks after being collected.

Each small petri dish was provided with small amounts of Phaeodactylum tricornutum, a golden-brown diatom; individuals of this algal species measure approximately 12 μm and are thus in a size range which can be ingested by most veligers. The number of drops of culture varied with the density of algal culture and the number of veligers in the petri dish. If an excess of food is provided, the diatom particles adhere to the mucus of the veliger and decrease viability.

Clean smooth rock chips with a thin covering of algae were provided to induce settlement. Some clean, fine sand was included to insure an ion system favorable for shell deposition (Wilbur, 1964, p. 249). Many veligers, for example Crucibulum spinosum, will metamorphose without these inducements; however, sand swellers such as Natica gualtieriana metamorphose more readily on a sandy substratum than on bare plastic.

The sea water in each petri dish was renewed with the stored filtered sea water every 48 hours to prevent the accumulation of detrimental protozoan and bacterial populations, to renew the oxygen supply

and to eliminate waste products.

Identification to the level of species was accomplished by one or more of the following means. Some species of pre-metamorphic veligers have been described (Lebour 1937, 1945; Thorson 1940, 1946; Natarajan 1957; Gohar and Eisawy 1967; Eisawy and Sorial 1968; Robertson 1970b, Robertson et al 1970; Scheltema 1971). There are also descriptions of newly-hatched veligers (Risbec 1932, 1935; Ostergaard 1950; Kohn 1961a) which occasionally provide clues to the appearance of the pre-metamorphic larvae. Some veligers metamorphose readily and grow on diets which are easy for the investigator to provide; those individuals were transferred to sea water tables and reared until their identities were certain. Protoconchs of those veligers that were difficult to rear much beyond metamorphosis were drawn on Vidalon heavy tracing paper -- all to the same scale --with a Wild microscope equipped with 10x ocular lenses, a 50x objective lens, a camera lucida attachment and a trans-illumination base. Later, protoconchs on adult shells from various collections (see Preface) were drawn to the same scale and the drawings of planktonic protoconchs were superimposed on the drawings of protoconchs of adult shells. In some cases, variability in size of protoconch within a species of planktonic veliger abetted the confusion of identities, but usually this method permitted different species to be distinguished.

Counting the number of whorls can be a confusing task,--particularly in shells with few whorls. To avoid confusion, on apical and lateral views (see Fig. 1) of the protoconch a line was drawn from the sutural point at the aperture such that it crossed perpendicularly

sutures posterior from the aperture. In counting whorls, beginning with the sutural point at the aperture and counting it as one complete whorl, I continued apically along the sutural line and each time the perpendicular line was crossed, another whorl was added to the count. The final fraction was judged as the fraction of a circle or oval which was completed. I chose to count whorls in this manner because most larval shells are not usually planar and this method yields the most reproducible results.

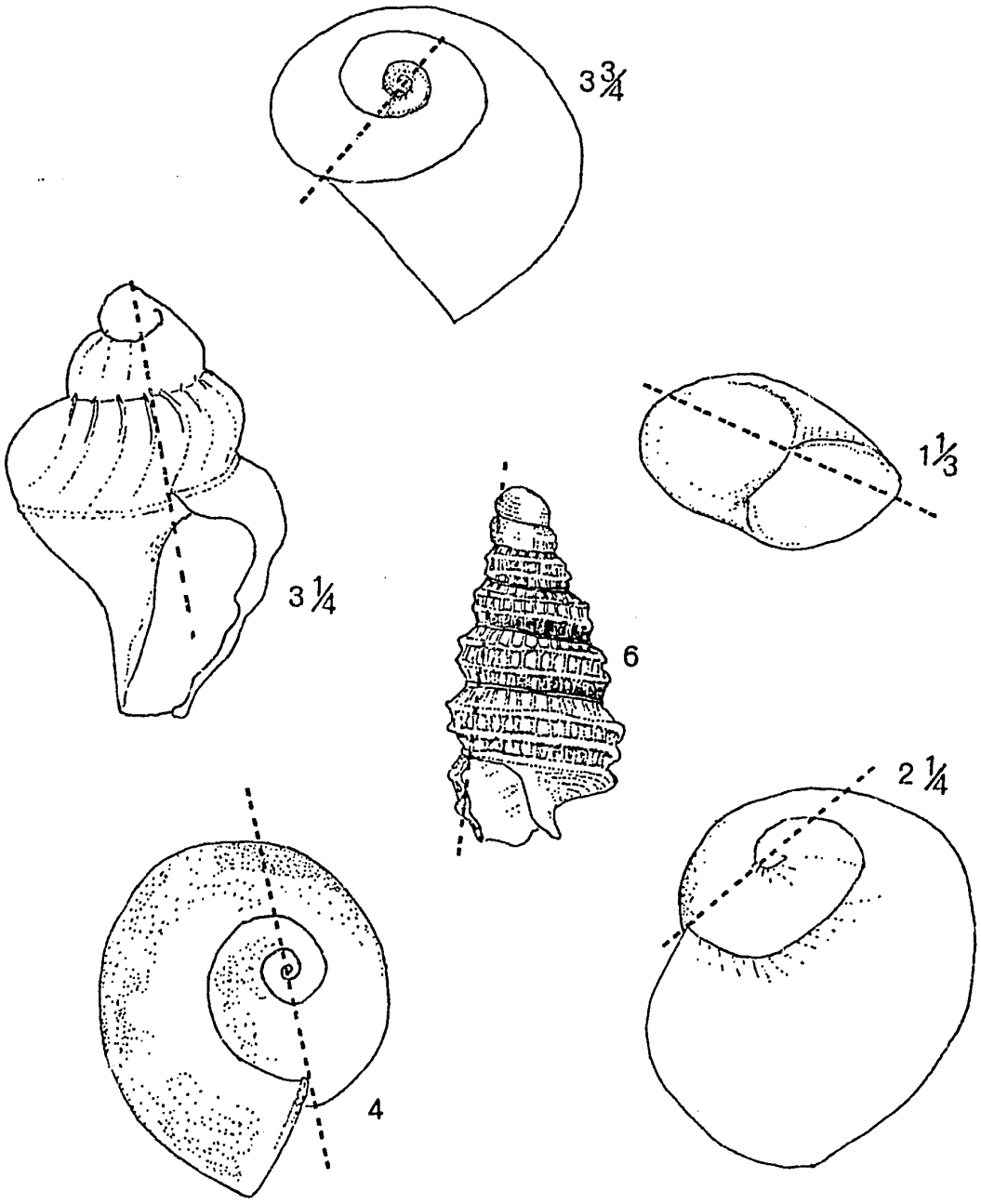


Figure 1. How protoconchal whorls are counted. The numbers indicate the number of whorls estimated using the method described on page 10.

Species of prosobranchs which have planktonic larvae can generally be distinguished from those which do not by examination of the shell apex. Apices (protoconchs) of planktonic larvae usually exhibit two distinct parts. The posterior-most whorl is formed during *in capsulo* development and generally is devoid of sculpture except for slight pustules or punctae which are apparently loci of shell deposition; hereafter, this part of the shell is referred to as the capsular protoconch. The protoconchal whorls which are anterior to the capsular protoconch often are delicately (Turridae) or robustly (Thaisidae) sculptured in patterns which suggest that certain rhythms are operative in shell deposition which occurs during the planktonic phase. In some species, especially in many tonnaceans, elongate spines, presumably of conchiolin, adorn the protoconch in precise spiral rows. In other species (*Phalium*, *Natica*), the planktonic protoconch may be smooth.

Species with no planktonic larvae lack the planktonic protoconch stage in their shell development. Thorson (1950) suggests that "as a general rule, a clumsy, large apex points to a non-pelagic development while a narrowly-twisted apex, often with delicate sculptures, points to a pelagic development." He follows this statement with some qualifications and cautions that "a general rule valid for all apices cannot be given." Thorson's statements deserve even further amplification for it is important to realize that many of the archaeogastropod larvae are tiny (< 300 μm) at the time of metamorphosis and many never adopt a planktonic existence. It is inaccurate to describe their apices as "clumsy" or "large"; conversely, some of the tropical planktonic larvae

(Philippia, Turris, tonnaceans) attain columellar lengths of two to four millimeters or more before settlement. This size is greater than that of many non-planktonic larvae at metamorphosis.

If the species has a planktonic phase, when the shell under examination is complete and well-preserved, one can find two distinct breaks in shell growth. The posterior break marks the end of in capsulo existence and the anterior discontinuity marks the end of planktonic existence. Generally, the former occurs between the completion of one-half to two whorls and the latter occurs when 1 1/2 - 6 whorls are completed. In many otherwise well-preserved shells, often the capsular protoconch is missing; often this is an indication that the larval shell is fragile and easily eroded.

Descriptions of Larval Forms

In the following sections, brief lists of superfamily characteristics of prosobranch relationships have been included. Unless otherwise indicated, these have been condensed further from Fretter and Graham's (1962, p. 612-35) scholarly synthesis of many contributions to molluscan taxonomy, especially those of Thiele (1929-35) and Wenz (1938). Figure 2 attempts to summarize, using an hypothetical phylogenetic tree, some of the current thinking re prosobranch relationships.

The general taxonomic scheme is that proposed by Taylor and Sohl (1962) unless indicated otherwise. Pyramidellids are omitted in keeping with the tendency of various taxonomists to include the group in the subclass Opisthobranchia. Species listed and families starred (*) conform with the list of Hawaiian forms compiled by Kay (unpublished). Deep-water species of prosobranchs, i.e., those living at depths of more than 50 meters, are also omitted; so little is known of their biology and taxonomic relationships that their inclusion in this work would be premature.

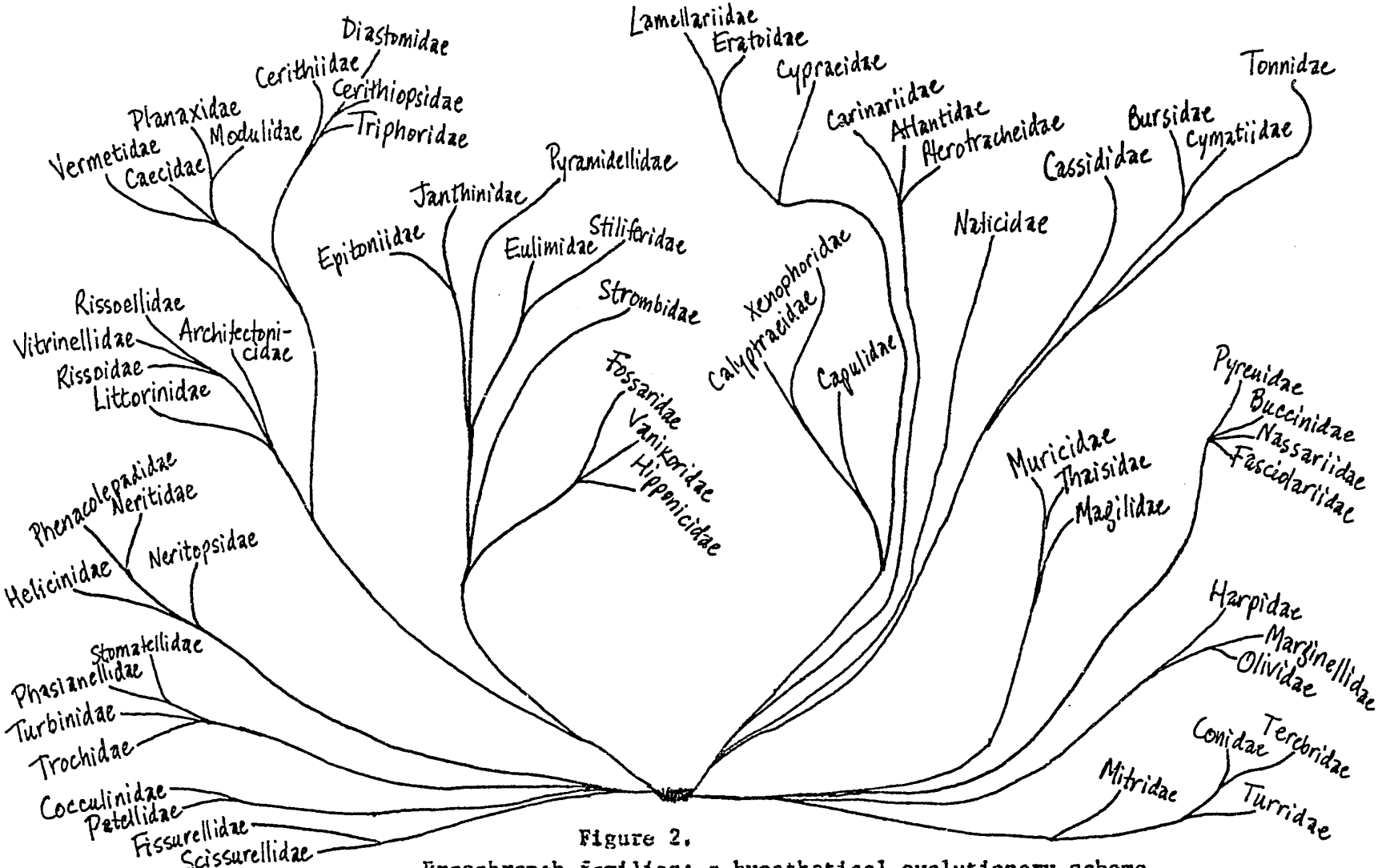


Figure 2.
Prosobranch families: a hypothetical evolutionary scheme.

Prosobranchia: Archaeogastropoda

Diotocardian life histories typically show the following characteristics (Anderson 1960; Fretter and Graham 1962):

1) fertilization external; copulation rare (neritaceans).
2) gametes either shed into the water with little protection or deposited in clumps supported and protected by a simple jelly matrix (some trochids, neritaceans).
3) eggs small (60-100 µm in diameter), microlecithal, which quickly (i.e., within an interval of days rather than weeks) develop into free-swimming trochophore larvae.
4) shell formation and torsion quickly proceed while ciliated areas of the trochophore elaborate to form the velum, the locomotory and food-collecting organ of the veliger stage. The velum is usually circular, oval or bilobed; four-lobed vela occur in neritaceans.
5) time spent in the plankton by the veliger stage generally is short, seldom longer than two to three days. Metamorphosis follows, during which the velum either is cast off or resorbed and the benthic mode of existence is assumed by the juvenile stage. Metamorphosis typically occurs in veligers smaller than 250 µm (except in the neritaceans).

Superfamily 1. Pleurotomariacea

The Pleurotomariacea (Wenz 1938, =Zeugobranchia; Thiele 1929-35) includes the families Pleurotomariidae, Scissurellidae* and Haliotidae. As the asterisk indicates, of this superfamily only scissurellids are known to occur in Hawaii. Generally speaking, pleurotomariacean

shells are perforated by slits or series of holes representing slits. The animals usually cling to rocks and are found in tropical or temperate waters. A scissurellid typically has a small, tight spiral shell, an operculum, two shell muscles of equal size, ctenidia with finger-shaped leaflets and all muscles except the columellar muscles composed of striped fibers. The early life history of scissurellids apparently is unknown.

In Hawaii, there are two species of Scissurella. During this study, no scissurellid juveniles were collected and none of the veligers which metamorphosed was identified as a scissurellid.

Superfamily 2. Fissurellacea (Keyhole limpets)

Taylor and Sohl (1962) created a separate superfamily, the Fissurellacea, for the lone family Fissurellidae. Keyhole limpets differ from zeugobranchs by 1) the presence of a diverticulum within the buccal mass, and by 2) the intestinal groove being separated from the main part of the intestine, forming a siphon (Fretter and Graham, 1962, p. 614).

Various developmental patterns are described for the fissurellids. Diodora apertura of the northeastern Atlantic spawns eggs in a jelly mass from which the young crawl forth (Boutan 1885). Fissurella barbadensis Gmelin in the West Indies sheds eggs singly, the egg and larva each measure approximately 200 μm in diameter and pelagic life lasts at most two or three days (Lewis 1960). Hemitoma octoradiata Gmelin also in the West Indies, sheds eggs singly and hatches at 240 μm in length; because they failed to settle after a few days, they may have a longer pelagic phase than larvae of F. barbadensis (Lewis, ibid.).

The fissurellids are represented in Hawaii by three genera and six species. No veligers which metamorphosed and grew to resemble keyhole limpets were obtained during this study; presumably their supposed small size, less than 330 μm, precluded netting them.

Superfamily 3. Patellacea

The Patellacea include the Acmaeidae, Patellidae* and Lepetidae.

Superfamily characteristics: shells conical, without holes or slits; ctenidia replaced by pallial gills set marginally about the mantle; shell muscle horseshoe-shaped; intestine lengthened, radula docoglossate; 181 recent species; first appeared in the Triassic, presumably derived from a zeugobranch ancestor.

Acmaeids have only one ctenidium persisting, sometimes with, sometimes without accompanying pallial gills. Gills are lacking in the lepetids and only pallial gills occur in patellids. Acmaeids show a diversity of life history patterns which are figured and described (Boutan 1899; Wilcox 1898, 1905; Thorson 1935, 1946; Lebour 1937; Lewis 1960; Anderson 1965). Lepetid larvae, i.e. those of Lepeta coeca, are presumed to be non-planktonic (Thorson 1946).

Patellidae

Anderson (1960) reports that all patellids studied thus far freely shed large numbers of gametes into the water and fertilization occurs externally. The eggs are generally small (100-200 μm), contain small amounts of yolk relative to those of meso- and neogastropods and develop quickly into planktotrophic trochophores and veligers: Patella cerulea (Patten 1886; Lo Bianco 1899); Patella vulgata (Smith 1935;

Lebour 1937; Crofts 1955; Dodd 1957). Some patellids, e.g., Patina pellucida (Smith 1935; Lebour 1937; Thorson 1946; Crofts 1955), produce larger eggs with more yolk, the embryo becomes free-swimming as a lecithotrophic trochophore and organs typifying the trochophore stage are suppressed. Smith (1935) details methods of inducing artificial spawning in patellids.

Patellid veligers are usually small and their planktonic life is short. The mature, pre-settlement veliger of Patina (=Helcion) pellucida is 240 µm, greatest diameter, by 170 µm across (Lebour 1937; Thorson 1946). Other measurements of patellid veligers are also less than 250 µm. The early life history of Cellana tramoserica is summarized as follows: egg, 160 µm; 22 hours later, a trochophore (210 µm x 160 µm) forms; hatches as a lecithotrophic trochophore; two days later it becomes a bilobed veliger; gradual metamorphosis four to six days after hatching, velar lobes regress; larval shell and operculum shed a few days after settling; mature veliger 240 µm in length at settlement (Anderson 1962). Thorson (1946) mentions that the pelagic life of P. pellucida seems to be short.

Four species in the genus Cellana occur in Hawaiian waters. If pre-metamorphic larvae of Hawaiian Cellana exist in the plankton and if they approximate the dimensions reported above, it is unlikely that they would be obtained by a 330 µm mesh plankton net. Thus it is not surprising that none resembling the published figures of patellid larvae have been collected.

Superfamily 4. Cocculinacea

Cocculinaceans include Cocculinidae* and Lepetellidae. Although

cocculinids are represented in Hawaiian waters by the genus Cocculina, they are deep sea forms and nothing is known of their larval stages.

Superfamily 5. Trochacea

The trochaceans include the Trochidae*, Stomatellidae*, Turbinidae*, Skeneidae, Phasianellidae* and Orbitestellidae.

Superfamily characteristics: typically marine; shell tightly spiral, often umbilicate; foot with epipodial tentacles and sense organs; eyes on stalks separate from cephalic tentacles; eggs fertilized externally, laid singly or in gelatinous masses; 929 recent species; presumably derived from zeugobranch ancestry in the Triassic.

Trochidae

The only trochids known to hatch as planktonic veligers are three northern hemisphere species of Gibbula: G. magus, G. cineraria, and G. umbilicalis (Robert 1902; Lebour 1937), and Monodonta lineata, whose eggs Lebour (1937) reports to be similar to those of Gibbula. All others are reported to crawl at hatching: Gibbula tumida (Gersch 1936; Lebour 1937), Margarites helicinus (Thorson 1935; Lebour 1937), M. groenlandicus (Lebour 1937), Euchelus gemmatus (Duch 1969), Calliostoma zizyphinum (Lebour 1936, 1937a; Crofts 1955), C. papillosum (Lebour 1937; Crofts 1955), C. miliare (Thorson 1946), Cantharidus (=Trochus) exasperatus (Robert 1902; Lebour 1937), C. striatus (Robert 1902; Lebour 1937), Trochus niloticus (Moorehouse 1932), T. erythraeus (Gohar and Eisawy 1962). Trochid eggs are generally small (140-170 µm) and reported larval stages at hatching vary from 250 µm to 320 µm (Duch 1969).

Hawaiian trochids include eight species in five genera (Kay, unpublished). No larval forms attributed to the trochids have been obtained in local nettings, but juveniles of two species, Fossarina marmorea (Pease 1861) and Thalotia rubra (Pease 1861) occur regularly, even on days when there is little surge or wave action. Members of this superfamily, like many cerithiaceans, construct mucous nets which contribute to their buoyancy and which they use as ladders; this activity may contribute to their horizontal and vertical dispersal from the area of hatching.

Stomatellidae

Synaptocochlea concinna (Gould 1845) is the sole Hawaiian representative of this family. Examination of the protoconchs of juveniles shows that these gastropods metamorphose when they are approximately 300 μm in length, a size too small to be netted. There is apparently no literature on the larval stages of this family.

Turbinidae

Ai (1965) describes how spawning is induced in Turbo cornutus and the ensuing developmental events. Turbinids are represented in Hawaii by four species in two genera (Kay, unpubl.). Examination of juvenile protoconchs suggests that turbinid veligers, if planktonic, would be too small to obtain from the plankton with the nets used.

Phasianellidae

Lebour (1937) reported that Tricolia pullus deposits eggs 140 μm in diameter singly into the water like the trochid Gibbula.

Tricolia (=Hiloa) variabilis (Pease 1861b) is the sole Hawaiian

representative of the pheasant shells. Wertzberger (1967) records this species as hatching in the crawling stage. Although I have encountered no phasianellid veligers in the plankton, juveniles of fricolia occur in almost every plankton tow both in turbulent or calm surface waters. These gastropods, like some of the trochids, make mucous nets and apparently use them to climb and traverse water columns.

Superfamily 6. Neritacea

Neritaceans include the following families: Neritopsidae*, Neritidae*, Helicinidae*, Phenacolepadidae*, Hydrocenidae, and Titiscanidae.

Superfamily characteristics: shell spiral, flatly globular to conical, lacking in nacre; epipodial tentacles lacking; nutrition of microorganisms and detritus; a variety of habitats: marine, brackish water, freshwater, epiphytic-terrestrial; distribution worldwide, more abundant in tropical and subtropical areas; 582 extant species.

The spawn and larval stages of neritids are described in several publications, but there is apparently no literature on the larval stages of neritopsids, helicinids or phenacolepadids.

The rarity of Neritopsis radula Linn. 1798 in Hawaiian waters (two collected at 200 m and several as fossils) makes it unlikely that this species would be found in the Kaneohe Bay plankton.

Neritidae

Nerite egg capsules have been described and figured by several authors (Lamy 1928; Risbec 1932, 1935; Andrews 1935; Lebour 1945; Knudsen 1950). Seven nerites are reported to have planktonic veligers:

Nerita albicilla (Risbec 1932; Natarajan 1957), N. versicolor, N. peloronta and N. tessellata (Lebour 1945; Lewis 1960), N. orgzarum (Desai 1962), Neritina pupa (Lewis 1960) and Smaragdia viridis (Scheltema 1971). Two species are reported to hatch in the crawling stage: Nerita reticulata (Risbec 1932), Neritina fluviatilis (Bondensen 1940; Thorson 1946). Heretofore, only newly-hatched veligers have been figured (Lebour 1945; Lewis 1960) except S. viridis, for which empty protoconchs are figured (Scheltema 1971).

The common Hawaiian nerites include four marine species (Nerita picea (Recluz 1841), N. polita Linn. 1758, Smaragdia bryanae Pilsbry 1917, and Theodoxus neglectus (Pease 1861b) as well as three brackish- and freshwater species (Kay, unpublished).

Mature veligers of Nerita picea, Smaragdia bryanae and Theodoxus neglectus have in common the following characteristics: protoconch globose, transparent; foot semi-lunate, velum quadri-lobed, sides of lobes parallel; cephalic tentacles long, tapering distally; eyes prominent, black, lateral to base of cephalic tentacles; all are active swimmers; less than 750 μm at greatest diameter. The three species of veligers are differentiated principally on the bases of 1) differing pigmentation associated with the digestive gland, foot and 'face' and 2) size of greatest diameter. Veligers of Phenacolepas are almost identical with those of nerites in size, anatomy and behavior, but differ in pigmentation. Naticid veligers are probably the only others which could be confused with nerites, but naticids less than 900 μm are rarely encountered in surface plankton tows. The three nerites appear in the plankton all months of the year, which suggests that some

adults of a given population produce egg capsules during all months.

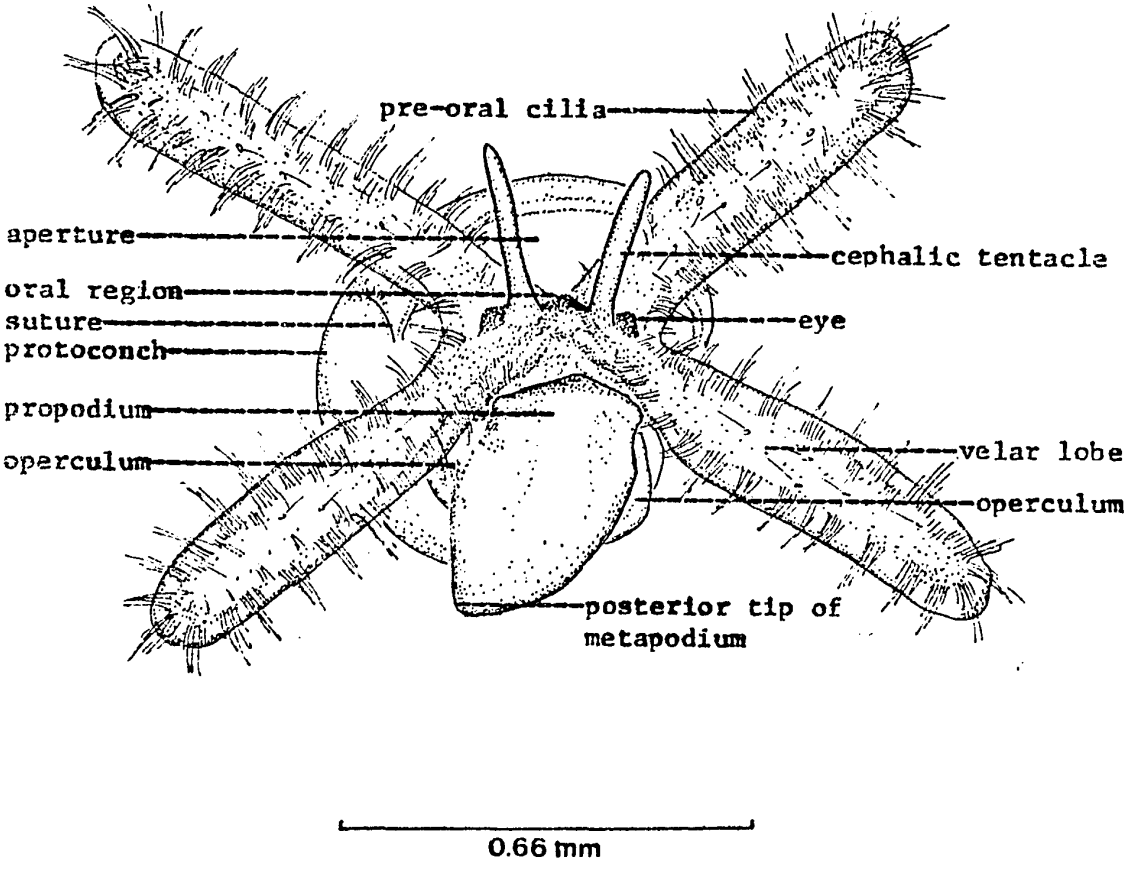


Figure 3. A generalized neritid veliger.

Smaragdia bryanae Pilsbry 1917. Plate I, figs. a-e.

Veliger:

Protoconch: globose, transparent, colorless, unsculptured; beak, siphonal canal absent; teleoconch with red-brown streaks, black-brown patches on cream background with occasional spots of white.

Velum: early planktonic veliger with bilobed, unpigmented velum, dorsal lobes recurved over protoconch; premetamorphic veligers with four-lobed unpigmented velum; velar lobes rectangular in premetamorphic veligers.

Cephalic area: tentacles medium-long, tapered, with tiny magenta spots along full length; eyes lateral at bases of tentacles; oral region occasionally with charcoal tinge.

Foot: broad; generally unpigmented except for anterior edge which bears tiny magenta spots; propodium blunt; mesopodium undistinguished; metapodium broadly rounded; opercular periphery with tiny magenta spots.

Viscera: digestive gland bright emerald green when in plankton, later becoming tan to colorless; style sac, intestine clear.

Months found in plankton: all months; peak settlement during summer.

Areas found: Sampan Channel, Dredged Island; occasionally in the southern end of the Bay.

Remarks:

Magenta spots pepper the mantle edge, the periphery of the foot and are occasionally dispersed along the cephalic tentacles. The young larvae are very easily confused with those of Nerita picea. These are the smallest of the neritid veligers; average protoconch size is 485 μm, greatest dimension; 420 μm, dimension perpendicular to greatest dimension.

Nerita picea (Recluz 1841). Plate I, figs. f-h; Plate III, above.

Veliger:

Protoconch: globose, transparent, colorless, unsculptured; beak, siphonal canal absent; teleoconch with charcoal gray spiral ribs on opaque dirty cream background.

Velum: early planktonic veliger with bilobed, unpigmented velum, of which the dorsal edges of the lobes curve back over protoconch; premetamorphic veligers with four-lobed velum suffused with brown; velar lobes rectangular in premetamorphic veligers.

Cephalic area: tentacles medium-long, tapered; proximal half of tentacles black, remainder colorless; eyes lateral to tentacular bases; oral region black.

Foot: broad, anterior 3/4 black, posterior 1/4 colorless; propodium blunt; mesopodium undistinguished; metapodium broadly rounded; medial semi-lunate portion of operculum brown, periphery colorless.

Viscera: digestive gland usually black while planktonic; frequently becomes green-black to black during further growth in laboratory.

Months found in plankton: all months; peak settlement during winter months, --especially during February.

Areas found: Sampan Channel, Dredged Island; occasionally in inner regions of Kaneohe Bay.

Remarks:

Average size of the protoconch approximates 580 μm, greatest diameter, 450 μm perpendicular to greatest diameter. This species rarely metamorphoses under laboratory conditions; when it does metamorphose, its growth rate is much slower than that of Theodoxus neglectus.

Theodoxus neglectus (Pease 1861b). Plate I, figs. i-l; Plate III, below.

Veliger:

Protoconch: globose, transparent, colorless, unsculptured; siphonal canal absent; shallow beak present; teleoconch slate gray with lighter tent-shaped patches scattered uniformly over outer surface.

Velum: four-lobed; velar lobes rectangular, either unpigmented or with proximal areas of dorsal lobes charcoal gray; width: 1.2 mm, height: 0.8 mm.

Cephalic area: intertentacular area humped, bears charcoal pattern; cephalic tentacles long, tapered, often charcoal gray proximally; eyes lateral to tentacles, larger than in other nerites.

Foot: broad; propodium extended laterally forming two blunt projections; mesopodium undistinguished; metapodium broadly rounded; ventral and/or dorsal areas often brushed with charcoal; operculum with two red-orange areas in intermediate and premetamorphic veligers; premetamorphic veligers also have two semilunate yellow-green areas on distal operculum.

Viscera: digestive gland, style sac and oral region charcoal gray in premetamorphic veligers; early veligers (greatest diameter of protoconch <500 μm) with emerald green digestive gland.

Months found in plankton: all months; peak abundance during summer.

Areas found: Sampan Channel, Dredged Island; least abundant in inner regions of Kaneohe Bay.

Remarks:

T. neglectus veligers are the largest (710-750 μm x 550 μm) of the neritid veligers. They metamorphose and settle more readily than other neritids under laboratory conditions. The teleoconch is produced at a faster rate than the rates occurring in N. picea and Smaragdia bryanae and the juveniles are less susceptible to predation by ciliates. The density of charcoal gray on the tissues of

the veligers is apparently age-dependent; the early veligers lack extensive markings. Metamorphosis occurs when 1 1/2 whorls are completed.

PLATE I

Figs. a-e. Smaragdia bryanae

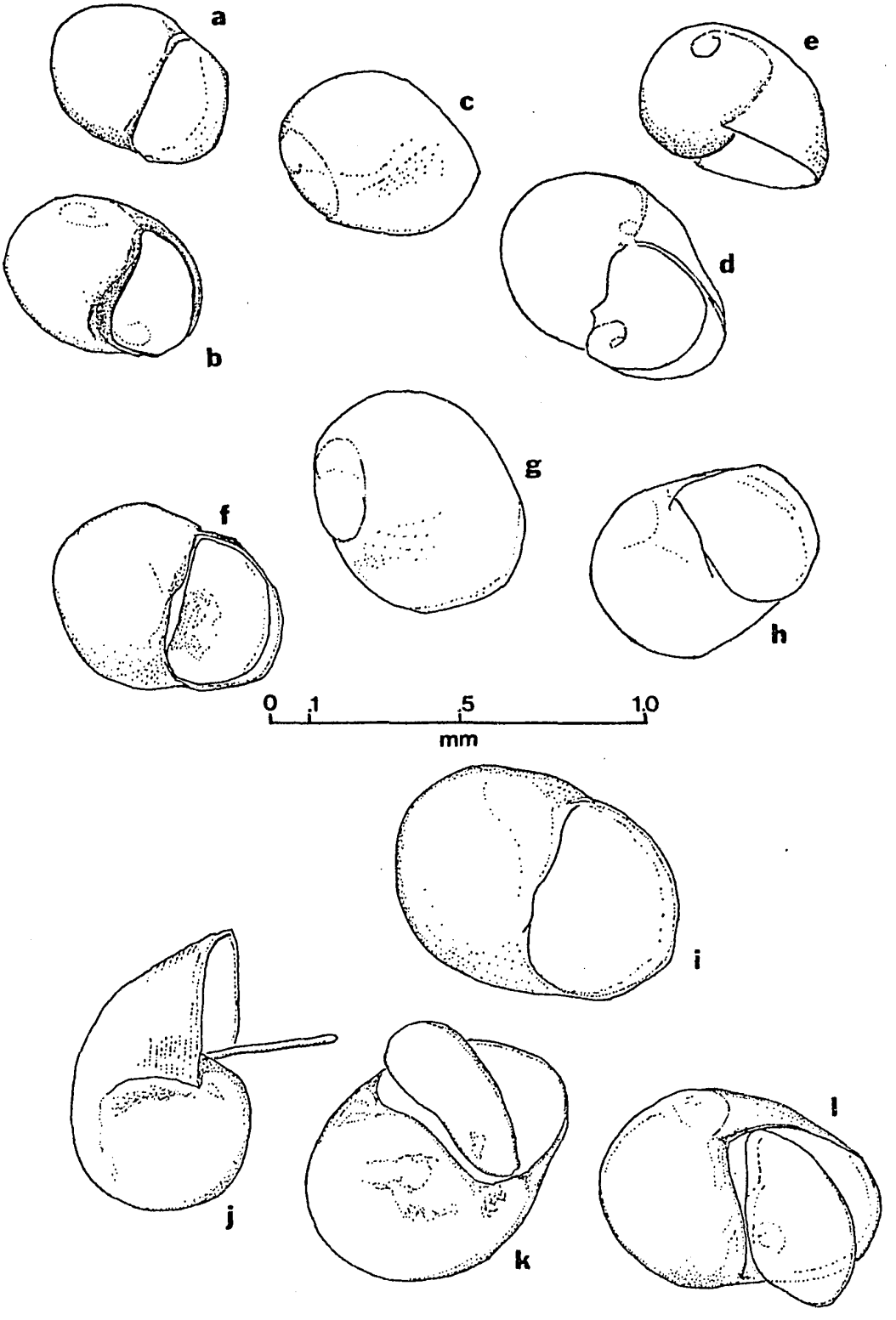
a. premetamorphic protoconch, apertural view
b. premetamorphic protoconch and operculum, apertural view
c. premetamorphic protoconch, dorsal view
d. juvenile shell with protoconch and operculum
e. premetamorphic protoconch

Figs. f-h. Nerita picea

f. premetamorphic protoconch and operculum, apertural view
g. premetamorphic protoconch, dorsal view
h. premetamorphic protoconch, ventral view

Figs. i-l. Theodoxus neglectus

i. premetamorphic protoconch, apertural view
j. premetamorphic protoconch and operculum, apical view
k. premetamorphic protoconch and operculum, ventral view
l. premetamorphic protoconch and operculum, apertural view



Neritidae

Helicinidae

In Hawaii, the sole marine helicinid is known only from fossils; the remaining helicinids are terrestrial.

Phenacolepadidae

Phenacolepadids are small limpet-like gastropods (8-10 mm) with oval cap-like shells. The apex is entire and is strongly recurved.

Two local species are found:

Phenacolepas granocostata (Pease 1868); uncommon in Kaneohe Bay, and

Phenacolepas scobinata Gould 1859; common underneath rocks in the Bay.

Veligers of P. scobinata are obtained throughout the year in windward areas of the bay. Pre-settlement phenacolepadid veligers are virtually identical with neritid veligers and differ primarily in pigmentation of the digestive gland and inter-tentacular areas. Close agreement in morphology of the larval forms of the Neritidae and Phenacolepadidae supports the taxonomic placement based on adult anatomy.

P. scobinata veligers metamorphose most readily if presented with coral chips covered with a thin algal film. Upon metamorphosis, the globose protoconch is partly hidden in the conical teleoconch. The apical area assumes a red-orange tinge; its position with respect to the posterior margin of the shell varies with age. Although the juveniles have only fine radiating ribs and concentric striae and lack sharp nodules which are characteristic of adult shells, this could be the result of developing in an unusually calm environment, i.e., a petri dish.

Phenacolepas scobinata Gould 1859. Plate II, figs. a-g.

Veliger:

Protoconch: globose, transparent, colorless; beak and siphonal canal absent; teleoconch conical with fine, radiating ribs and concentric striae, white or white tinged with brown, apex red-orange.

Velum: four-lobed, unpigmented; velar lobes rectangular in pre-settlement veligers.

Cephalic area: tentacles medium-long, tapered.

Foot: colorless, broad, rectangular; metapodium broadly rounded; opercular periphery orange.

Viscera: colorless except for intestine which is light orange.

Months found in plankton: all months, more or less equally abundant.

Areas found: Sampan Channel, Dredged Island; occasionally in south end of Bay.

Remarks:

Veligers of this species resemble the larva of Theodoxus neglectus in anatomy and behavior, but differ in pigmentation. The average maximum dimension is 680 μm.

PLATE II

Phenacolepadidae

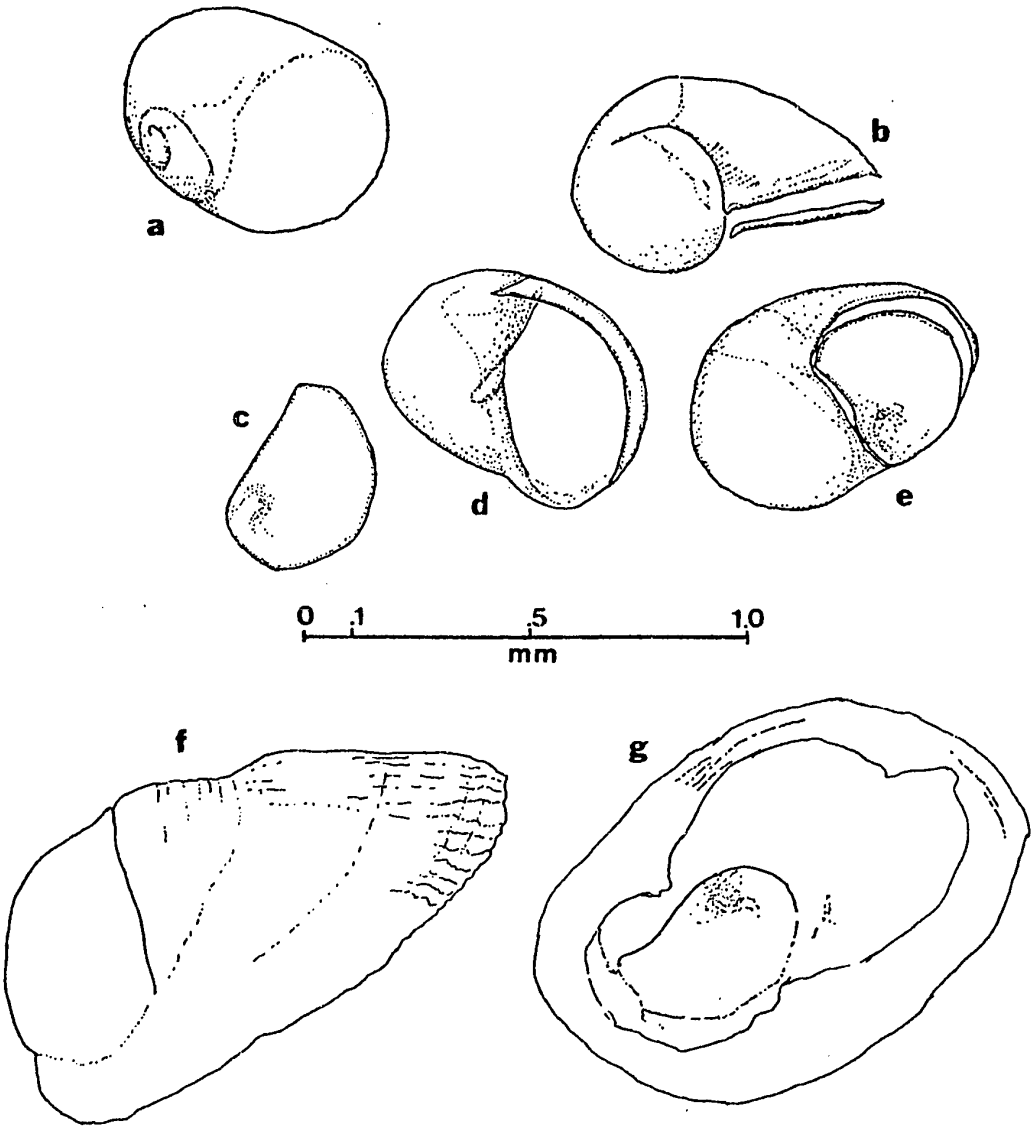
Figs. a-e. Phenacolepas scobinata: larval shell anatomy

a. premetamorphic protoconch, abapertural view
b. premetamorphic protoconch and operculum, apical view
c. premetamorphic operculum
d. premetamorphic protoconch, apertural view
e. premetamorphic protoconch, ventral view

Figs. f,g. Phenacolepas scobinata: juvenile shell anatomy

f. abapertural view, with protoconch and initial teleoconch
g. apertural view, showing larval operculum retained

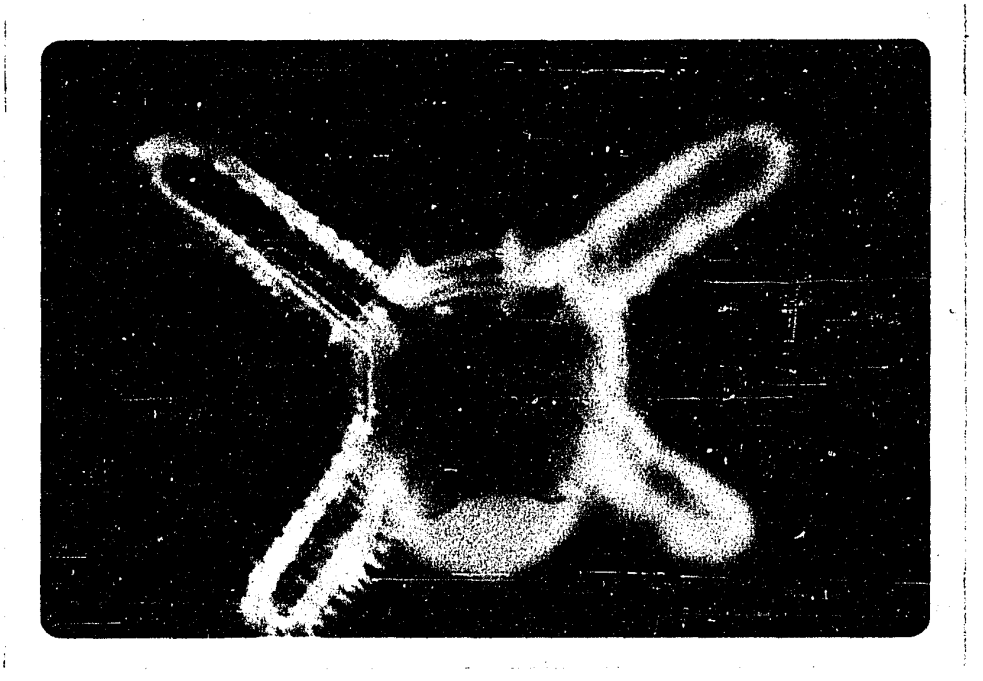
PLATE II



Phenacolepadidae

PLATE III
Neritidae

Figure 1 (above): Nerita picea.
2 (below): Theodoxus neglectus.



1.3mm

Monotocardian life histories typically show the following characteristics (Anderson 1960; Fretter and Graham 1962):

1) fertilization internal via copulation or spermatozeugmata; mesogastropods oviparous or ovoviviparous, neogastropods oviparous; morphology of mesogastropod egg capsules highly diverse, morphology of neogastropod capsules generally vasiform or resembling clusters of grapes
2) eggs small (>60 μm) to large (> 500 μm), often macrolecithal, and may require one to several weeks *in capsulo* until hatching
3) no monotocardian hatches before veliger stage; veligers, veliconchas or juveniles may exit from monotocardian egg capsules
4) rate of shell formation and torsion variable: in gastropods with extensive planktonic lives, shell formation and torsion generally occur quickly (a few hours to a few days); for those with short planktonic lives, shell formation and torsion appear to occur more slowly by differential growth
5) number of velar lobes in pre-settlement veligers varies from two (*Crucibulum*) to at least six (*Strombus*) in veligers from Kaneohe Bay
6) time spent in plankton by veliger stage variable: in some, (Tonnacea), longer than four weeks; typically, one and one-half to four weeks (Conidae, Thaisidae); occasionally,(some conids and terebrids), only a few hours to a few days.

Metamorphosis occurs as in the diotocardians, but the greatest linear measurement of most monotocardian pre-settlement veligers typically exceeds 500 µm.

Superfamily 7. Littorinacea

The Littorinacea includes the Littorinidae*, Lacunidae, Pomatiasidae and Chondropomidae (=Aciculidae).

Superfamily characteristics: shell spiral, globose-conical trochiform, operculum horny; aperture without an anterior notch or siphonal canal; predominantly marine with the tendency of species to adopt a terrestrial mode of life; 605 living species, presumably derived from the Architaenioglossa in the Carboniferous.

Littorinidae

All but 20 per cent of the littorinids for which the early life history is known have planktonic veligers (Table 2). Those littorines which emerge from their egg capsules as veliconchas or juveniles develop from eggs 200-250 µm in diameter and hatch from their capsules in the 450-515 µm range. Planktonic littorine veligers generally develop from eggs 80-130 µm in diameter, hatch in the 100-230 µm range and metamorphose in the 450-515 µm range. N. picta metamorphoses at an atypically small size of 210 µm (Struhsaker 1966).

There are four common species in three genera: Littorina, Nodilittorina and Peasiella in Hawaii (Kay, unpubl.).

Table 2

Summary of Littorinacean Life History Data

Larval type	References
A. With planktonic veligers	
Bembicium auratum	Anderson 1962
B. nanum	Anderson 1961
Echinella trochiformis	Lebour 1945
Lacuna vincta (=divaricata)	Hertling & Ankel 1927; Hertling 1928, 1931 Lebour 1937a; Thorson 1946
**Littorina angulifera*	Lebour 1945; Lenderking 1954
L. littorea	Pelseneer 1911; Delsman 1914; Tattersall 1920; Hayes 1929; Linke 1935; Lebour 1934a; Thorson 1946
L. meleagris	Lewis 1960
L. neritoides	Lebour 1935b
L. picta	Struhsaker 1966
L. pintado	Ostergaard 1950; Struhsaker 1966
**L. scabra*	Struhsaker 1966
L. ziczac	Lebour 1945; Lewis 1960
Melaraphe unifasciata	Anderson 1965
Nodilittorina pyramidalis	Anderson 1965
Tectarius muricatus	Lebour 1945; Lewis 1960
T. tuberculatus	Lewis 1960
B. Velum lost by the time of hatching from egg capsules or emergence from the female	
**Bembicium melanostoma*	Anderson 1965
Lacuna pallidula	Pelseneer 1911; Hertling & Ankel 1927; Lebour 1937a; Thorson 1946
Littorina littoralis (=L. obtusata)	Hertling & Ankel 1927; Linke 1933b; Lebour 1937a; Thorson 1946
L. saxatilis	Pelseneer 1911; Ankel 1936a; Lebour 1937a Thorson 1946

* = ovoviviparous, as well as planktonic

Littorina pintado Wood 1828. Plate IV, figs. v,w,x.

Veliger:

Protoconch: red-brown; inflated teardrop shape; sculpture of uneven spiral ribs; shallow beak present; no siphonal canal, but columella produced; umbilicus comma-shaped; just prior to metamorphosis, body whorl (3rd whorl) bears ten arched ribs, 2nd whorl with 2-3 ribs, one rib on first whorl; first two whorls light red-brown; teleoconch smooth, predominantly red-brown.

Velum: bilobed, right lobe slightly larger than left; velar lobes dense purple-black at base of post-oral cilia, shading to lighter purple-black medially; cilia long; velar lobes rectangular-oval.

Cephalic area: tentacles tapered, stout, knobbed at tips; eyes inside swollen tentacluaar bases; esophagus purple-black.

Foot: background colorless, brushed with purple-black uniformly on ventral side; propodium rectangular, long; mesopodium flares laterally; metapodium broadly rounded; operculum oval, transparent; metapodium 'bristled' posteriorly.

Viscera: protoconch too thick to discern digestive gland or other viscera.

Months found in plankton: all months of the year, equally abundant.

Areas found: Sampan Channel, Dredged Island, vicinity of Coconut Island.

Remarks:

Veligers of this species metamorphose during the formation of the fourth whorl. After metamorphosis, juveniles are wuite hardy; when coral chips with algal films are placed in small containers of sea water, fast growth rates in the juveniles are obtained. Juveniles are often observed above the water line adhered with dry mucus to the side of the container.

Veligers attributable to Nodilittorina picta and Littorina scabra were not obtained from the Kaneohe Bay plankton. Veligers of N. picta may have slipped through the mesh of the net.

Superfamily 8. Rissoacea

Rissoaceans include the Hydrobiidae, Truncatellidae, Hydrococcidae, Stenothyridae, Bithyniidae, Iravadiidae, Micromelaniidae, Rissoidae*, Assimineidae, Vitrinellidae*, Skeneopsidae, Omalogyridae*, Rissoellidae*, Cingulopsidae, ?Choristidae amd ?Trochaclisidae.

Superfamily characteristics: shell turriform, aperture entire, not nacreous within, transparent and glassy, white or brown, but lacking an overall pattern, no columellar folds; foot long, richly provided with pedal glands, can spin mucous webs; predominantly marine; nearly all detrital feeders; appeared in Carboniferous; 1,331 living species.

In general, rissoaceans display a variety of life styles (Tables 3 and 4), but most life histories are variations upon two basic themes. Those rissoaceans which hatch with no planktonic larval stage tend to produce relatively large (140-320 µm) eggs, tend to spend more than ten days in capsulo and hatch as juveniles when the greatest dimension approximates 380 µm or greater. Those which hatch with a planktonic larval stage tend to have relatively small (60-130 µm) eggs, tend to spend about ten days in capsulo, hatch when approximately 150-200 µm, greatest dimension, spend two to three weeks in the plankton and settle when approximately 450 µm in length.

Heretofore, no life histories have been described for rissoaceans from the Indo-Pacific, or, indeed, from any tropical areas.

Table 3

Life History Data: Ri

Species	Egg size (µm)	in capsule time	Size at hatching (µm)	Planktonic duration
Barleeia unifasciata	320		420-480, 1 1/2 whorls	hatch with the ability to crawl
Onoba striata	240		420 x 490	"
Cingula semicostata	240		320	"
Onoba aculeus	?			"
Cingula cingillus	160		480, 2 1/2 whorls	"
Cingula fulgida	140-160		160	"
Rissoa membranacea	130	10-12 days	320	3 weeks
Alvania abyssicola	?		215-325	long
Alvania crassa	?		160, 1 1/2 whorls	moderately long
Cingula (=Onoba) vitrea	?		?	?
Cingula semistriata	80		100, 1 whorl	?
Rissoa guerini	90	10 days	160, 1 1/2 whorls	?
Rissoa parva	90	10 days	130, 1 1/2 whorls	?
Rissoa sarsii	80		80-160, 1 1/2 whorls	long
Rissoa inconspicua	80	10 days	100	long
Alvania punctura	60		450, 1 1/2 whorls	long

Table 3

e History Data: Rissoidae

	Planktonic duration	Size at metamorphosis	Remarks	References
!	hatch with the ability to crawl	480 µm	protoconch dark brown, spawn during March to April	Lebour 1934a Lebour 1937a
	"	420 µm		Thorson 1946
	"	320 µm	spawn during March to May	Lebour 1934a
	"	320 µm	panarctic	Thorson 1946
orls	"	480 µm	spawn in March	Lebour 1936, 1937a
	"	160 µm	spawn in April, resemble Barleeia	Lebour 1936 Lebour 1937a
	3 weeks	370 µm 2 whorls	brown at post-oral cilia; spawn May-July and Dec.-Mar.; adults by September	Lebour 1934a Lebour 1937a Smidt 1938
	long	325 µm	planktonic summer and fall	Lebour 1934a Thorson 1946
orls	moderately long	480 µm 2 1/2 whorls	metamorphosed in captivity	Lebour 1934a Lebour 1937a
	?	400 µm		Thorson 1946
	?		planktonic from spring to fall; late veliger with 3 processes at back of foot and 2 conspicuous lines on body whorl	Lebour 1934a Lebour 1937a
orls	?	3-3 1/2 whorls	velum spotted with dark brown bordered with irregular brown spots; planktonic spring to autumn	Lebour 1934a
orls	?	480 µm 3-4 whorls	planktonic all year, chiefly spring and summer	Lebour 1934a
	long	480 µm 2 1/2-3 1/2 whorls	velum bordered with a fine dark band; planktonic all year; 4 mos. to attain 6 whorls, adult has 7 whorls, late larva with pallial and metapodial tentacles	Lebour 1934a, Lebour 1936, 1937a
	long	400-500 µm	velum bordered with brown, newly metamorphosed with purple apex	Lebour 1934a Lebour 1937a
orls	long	640 µm	planktonic summer, autumn	Lebour 1934, 1937a Thorson 1946

Table 4

Life History Data: Rissoacea exclusive of Rissoidae

Name	Remarks	References
1. Hydrobiidae		
Hydrobia jenkinsi	hatch crawling with velum reduced; metamorphose when greatest width 400-410 µm	Lebour 1937a; Thorson 1946
Hydrobia ulvae	larvae planktonic	Henking 1894; Lebour 1937a; Rothschild 1940; Thorson 1946
Hydrobia ventrosa	hatch lacking a functional velum; metamorphose when greatest width approximates 175 µm	Van Benthem Jütting 1922
2. Vitrinellidae (=Tornidae)		
Cyclostremiscus minutissimus	veliger planktonic	this work
Tornus subcarinatus	hatches when greatest dimension 160 µm; veliger planktonic; metamorphoses when greatest dimension 480 µm and 3 whorls present	Lebour 1937a
3. Skeneopsidae		
Skeneopsis planorbis	breed all year; hatch when length approximates 320 µm; velum not functional	Lebour 1937a
4. Omalogyridae		
Omalogyra atomus	planktonic phase lacking; metamorphose when greatest width approximates 160 µm	Lebour 1937a
5. Rissoellidae		
Rissoella diaphana	not planktonic; hatch when width approximates 240 µm with ability to crawl	Lebour 1937a
Rissoella opalina	not known; describes spawn	Lebour 1937a

There are 22 species in twelve genera of the Hawaiian Rissoidae (Kay, unpubl.). I have found twelve rissoid species in five genera to have planktonic veligers: Rissoina (6), Schwartziella (2), Zebina (2), Merelina (1) and Parashiela (1); with the exception of the latter, all are in the subfamily Rissoininae. Barleeia pellucida is a rissoid species (Rissoinae) which apparently does not have a planktonic veliger stage.

The planktonic rissoid veligers all have bilobed, unequal vela which are generally unpigmented. The foot is simple, --without protruding tentacles. Usually the protoconch is paucispiral (1 1/2 - 3 whorls), smooth and inflated (P. beetsi, Zebina tridentata, Z. semiplicata, Schwartziella triticea, Rissoina ambigua, R. turricula). In a few instances (R. miltozona, R. pulchella, Merelina granulosa) there is spiral sculpturing. Four veliger species (R. ephamilla, R. striatula, R. imbricata, Schwartziella gracilis) have protoconchs reminiscent of the epitoniid protoconch.

Parashiela beetsi Ladd 1966. Plate IV, fig. b.

Veliger:

Protoconch: small, light tan, smooth, inflated, sutures impressed; beak prominent; metamorphosis occurs when two whorls complete, length: 270 µm, width: 280 µm.

Velum: bilobed, unpigmented, unequal; right lobe larger than left.

Cephalic area: light tan.

Foot: cream, simple.

Viscera: digestive gland golden-brown; remainder of gut unpigmented.

Months found in plankton: February, July, August.

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of this species resemble that in fig. a, Plate IV, which has magenta sutures and a protoconch with more pronounced punctae.

Zebina tridentata (Michaud 1830). Plate IV, figs. c,d.

Veliger:

Protoconch: smooth, glistening, translucent tan, with columella, beak, sutures pink-tan; bulbous; apical whorl mamillate; beak flaring, well-developed; columella slightly produced anteriorly; metamorphosis occurs when two and one-fourth whorls complete, length: 390-400 μm, width: 350 μm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented; tentacles medium-long; eyes inside tentacular bases.

Foot: cream, with tan pigment spots posteriorly; propodium medium-long.

Viscera: digestive gland tan-brown; style sac gray.

Months found in plankton: March, April

Areas found: Dredged Island

Remarks:

Veligers of Zebina semiplicata (Pease 1862) resemble those described above too closely to warrant a separate description. The apical whorl is broader, beak smaller, and there is a sutural whorl of punctae (see Pl. IV, fig. e). At metamorphosis, its protoconchal length is 400 μm; its width is 300 μm. Veligers of Z. semiplicata were collected from the Dredged Island area in July and August.

Schwartziella triticea Pease 1861. Plate IV, figs. f,g.

Veliger:

Protoconch: smooth, inflated, bulbous, glistening, clear, light tan; sutures moderately impressed; metamorphosis occurs when two and one-half whorls complete, length: 360 µm, width: 340 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: cream, simple.

Viscera: digestive gland light gold.

Months found in plankton: March through August

Areas found: Dredged Island

Haplocochlias minutissimus (Pilsbry 1921). Plate IV, figs. h,i.

Veliger:

Protoconch: apical whorl smooth, colorless; abapical and third whorls light red-brown with regularly-spaced oblique-axial ridges above shoulder; remainder of whorl with spiralled grooves; aperture entire, expanded obliquely; metamorphosis occurs when three whorls complete, length: 340 µm, width: 360 µm.

Velum: bilobed, unpigmented, slightly unequal.

Cephalic area: white; tentacles moderately close together; eyes inside tentacular bases.

Foot: white; operculum oval, tan.

Viscera: cannot be discerned through protoconch.

Months found in plankton: July, August

Areas found: Dredged Island

Remarks:

Veligers of this species resemble rissoaceans with respect to the inflated shell, but resemble some cerithiids in terms of sculpturing and the rounded aperture.

The systematics of this family and its genera are unresolved yet; inclusion of this species in the Rissoacea may be erroneous.

Merelina granulosa (Pease 1862). Plate IV, figs. j,k.

Veliger:

Protoconch: apical whorl smooth, colorless; abapical whorl with low spiral keels, tan; sutures, columella light red-brown; sutures moderately impressed; beak prominent; anterior columella produced; metamorphosis occurs when 2 3/4 whorls complete, length: 270 μm, width: 250 μm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: tan, simple.

Months found in plankton: July

Area found: Dredged Island

Remarks:

Veligers of this species are seldom collected in Kaneohe Bay plankton tows.

Rissoina ambigua (Gould 1849). Plate IV, figs. 1,m,n,y, and z.

Veliger:

Protoconch: transparent, with light pink-orange tinge on sutures, beak; glistening, smooth, inflated; sutures impressed, with sutural spiral of punctae; beak pronounced; anterior half of columella pink-orange; metamorphosis occurs when 3 1/2 whorls complete, length: 420 μm, width: 340 μm.

Velum: bilobed, unequal, unpigmented; velar lobes oval.

Cephalic area: tentacles medium-long, lumpy, not tapered; eyes far apart.

Foot: propodium long, anterior pedal gland evident; mesopodial ventrum with black pigment spots; operculum oval, translucent; dorsal surface covered with reticulated pattern of purple-black pigment; ventral surface with gold pigment spots overlying light charcoal ground color.

Viscera: digestive gland golden to yellow-green; style sac with yellow-brown pigment spots; intestine transparent.

Months found in plankton: September through November

Areas found: Dredged Island, Sampan Channel

Remarks:

These veligers tend to feed with the velum held downward.

Rissoina turricula Pease 1861. Plate IV, fig. o.

Veliger:

Protoconch: transparent, colorless, smooth, inflated; sutures barely impressed; columella light red-brown; beak pronounced; metamorphosis occurs when two whorls complete, length: 325 µm, width: 320 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: tentacles medium; eyes inside tentacular bases.

Foot: cream, simple.

Viscera: style sac charcoal; digestive gland golden.

Months found in plankton: July

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of this species resemble those of Schwartziella triticea except for the broader apical whorl of R. turricula.

Schwartziella gracilis Pease 1861. Plate IV, figs. p,q.

Veliger:

Protoconch: white to clear, glossy, smooth, elongate; whorls convex; sutures light red-brown; beak not prominent; metamorphosis occurs when 3 1/2 whorls complete, length: 460 µm, width: 250 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: cream, simple.

Viscera: digestive gland golden.

Months found in plankton: January, March, April

Areas found: Dredged Island

Remarks:

Juveniles of this species develop sinuous axial ribs on a red-brown teleoconch.

Rissoina ephamilla Watson 1886. Plate IV, fig. r.

Veliger:

Protoconch: white, translucent, smooth, glossy, conical; whorls straight-sided; sutures barely impressed; anterior-most suture light red-brown; beak not prominent; metamorphosis occurs when 3 1/2 whorls complete, length: 500 µm, width: 275 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: cream, simple.

Viscera: digestive gland golden.

Months found in plankton: March, April

Areas found: Sampan Channel, Dredged Island

Rissoina miltozona Tomlin 1915. Plate IV, figs. s,t.

Veliger:

Protoconch: tan, somewhat transparent, bulbous; sutures barely impressed; apical whorl smooth; second, third whorls with raised serrate spirals; sutures dark tan; columella light red-brown; beak pronounced; metamorphosis occurs when 2 1/2 - 3 whorls complete, length: 460 µm, width: 350 µm.

Velum: bilobed, unequal; velar lobes oval, transparent, except middle of right velar lobe with purple-black; purple-black lacking on left velar lobe.

Cephalic area: tentacles medium-long, tips knobbed; eyes inside tentacular bases; oral area black; esophagus charcoal.

Foot: light gold; propodium medium-long.

Viscera: digestive gland gold-brown; style sac charcoal; rectum black.

Months found in plankton: March, May

Areas found: Dredged Island, Sampan Channel, occasionally Coconut Island

Remarks:

Veligers of this species are among the most common rissoid larvae in the Kaneohe Bay plankton. They resemble veligers of Rissoina pulchella (Brazier 1877) too closely to warrant a separate description. R. pulchella veligers have a rose-orange columella, beak and sutures, metamorphose at a larger size (length: 500 µm, width: 380 µm; Pl. IV, fig. u), but retain the same shape and sculpturing.

Veligers of R. pulchella are most abundant during July.

Litiopa ?melanostoma Rang 1829. Plate XI, fig. 2.

Veliger:

Protoconch: inflated-lanceolate; tan with red-brown tints; sutures red-brown; first two whorls lacking axial ribs, remainder with smooth axial ribs; metamorphosis occurs when 5 1/2 whorls complete, length: 700 µm, width: 430 µm.

Velum: bilobed, unequal, unpigmented; velar lobes subcircular.

Cephalic area: tentacles medium; eyes tiny, inside tentacular bases.

Foot: cream to light yellow; posterior margin slightly cleft; propodium rectangular, blunt.

Viscera: not visible through protoconch.

Months found in plankton: January, March - August

Areas found: Coconut Island, Dredged Island, Sampan Channel

Remarks:

Veligers of this species resemble the Litiopa veliger and juvenile described by Lebour (1945) from Bermuda. These veligers settle readily in sea water tables and, like Styliferina goniochila lay their first viable egg masses approximately three weeks after metamorphosis.

After metamorphosis, the meso- and metapodial regions of the foot develop seven to nine tentacles.

In Hawaii, there is a small black-bodied rissoacean which has a transparent inflated shell. The larvae of this species are not planktonic; one egg is deposited in a spherical capsule, which is fastened to another conspecific shell (Fig. 4). The juveniles hatch lacking a functional velum and actively crawl about rasping at algal films. Year-round breeding populations of this species are easily maintained under culture as food for organisms predatory upon small gastropods.

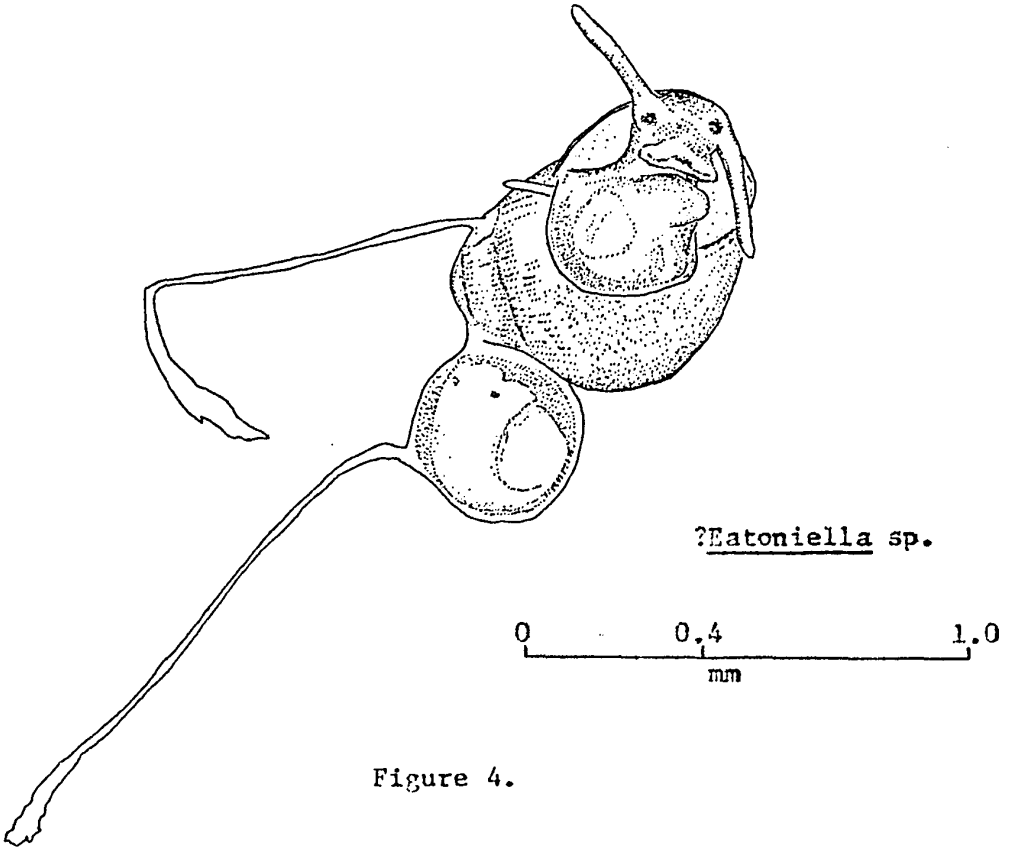


Figure 4.

PLATE IV
Littorinidae, Rissoidae

Figure a. unknown

b. *Parashiela beetsi*

c. *Zebina tridentata*

d. " "

e. *Zebina semiplicata*

f. *Schwartziella triticea*

g. " "

h. *Haplocochlias minutissimus*

i. " "

j. *Merelina granulosa*

k. " "

l. *Rissoina ambigua*

m. " "

n. " "

o. *Rissoina turricula*

p. *Schwartziella gracilis*

q. " "

r. *Rissoina ephamilla*

s. *Rissoina miltozona*

t. " "

v. *Littorina pintado*

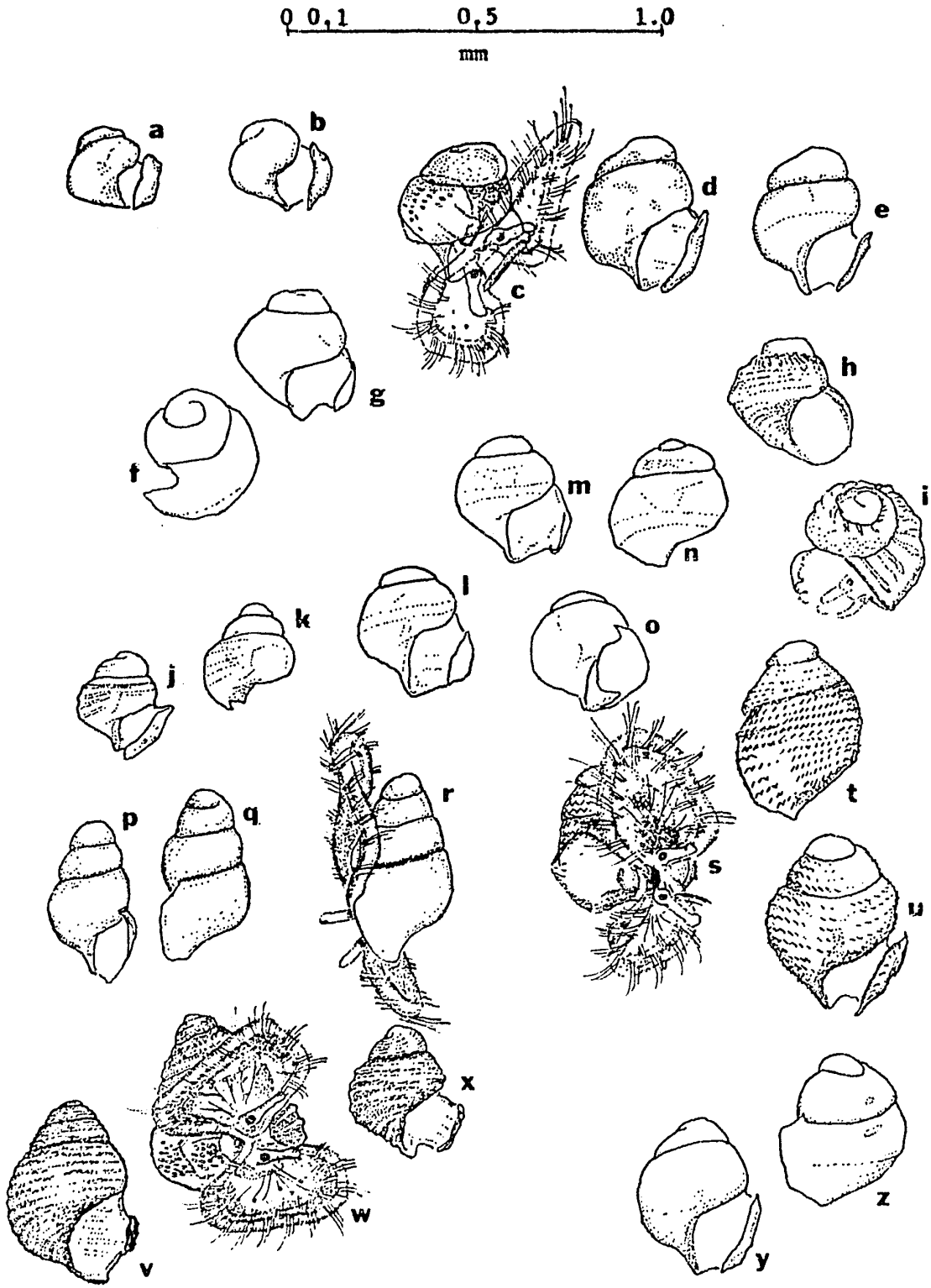
w. " "

x. " "

y. *Rissoina ambigua*

z. " "

PLATE IV
Littorinidae, Rissoidae



Superfamily 9. Architectonicacea

Architectonicacea includes the Architectonicidae* and the ?Omalaxidae.

Architectonicid characteristics: shell flattened or conical; aperture usually angular, closed by an operculum; umbilicus conspicuous; feed on coelenterates in tropical and subtropical waters; sexes separate, eggs encapsulated, pyramidellid-like, small (< 100 μm in diameter).

The affinities of the architectonicids are in dispute. Thiele (1928) emphasizes that they share with the Mathildidae (which he placed with the Cerithiacea) similar radular characterisitcs, a similar operculum and the presence of a heterostrophic protoconch. Risbec (1955) and Robertson et al. (1970) observe that the architectonicids have much in common with the euthyneuran pyramidellids and the prosobranch epitoniids, in particular, radular structure and egg-capsule shape. Though Thiele (loc. cit.) recognized affinities between epitoniids and architectonicids, he attributed the affinities to convergence due to similarities in diet, rather than phylogenetic relationship.

There are no descriptions of architectonicid *in capsulo* development, although the veligers of *Philippia krebsii* (Mörch) are reported to be remarkably abundant in near-surface waters of the tropical and subtropical Atlantic Ocean. Robertson et al. (1970) provide a figure of the pre-settlement veliger of *P. krebsii* accompanied by a brief description. Nothing is known of the hatching process or planktonic

growth rate. No architectonicid is reported to hatch with the ability to crawl, to exhibit brood protection of larval stages or to be viviparous. Egg size and capsule size are reported for P. radiata (Röding) only (Robertson 1970). Size at settlement has been estimated by measuring the diameters of protoconchs found on adult shells of all Atlantic architectonicids other than P. krebsii. Proximity to coelenterates is not a prerequisite to settlement; metamorphosis can be induced by contact with any solid surface (Robertson et al. 1970) and is followed by active searching for coelenterates as food. Architectonicid life histories are summarized in Table 5.

Because the eggs and capsules of one species, P. radiata, are reported to be small (63 μm and 85 μm respectively), it is tempting to assume that architectonicids hatch a few days after deposition of the capsules, as do most other gastropods with such small eggs. P. radiata individuals are between 1200 μm and 1450 μm, greatest diameter, at settlement; in the interval from hatching to settlement, the veliger must grow considerably and presumably must require a fairly lengthy time in the plankton. Scheltema (1971) estimates that P. krebsii is planktonic for 74 days; Robertson (1964) believes the veligers to be planktonic for at least three months.

Table 5

Life History Data: Architectonicidae

Name	Size at metamorphosis	Remarks	References
Architectonica nobilis	1000	commonly washed ashore on Texas beaches with pennatulids	Robertson 1964
Gyriscus sp.	1000	may live on gorgonians and/or sponges	Robertson 1964
Philippia hybrida	800	a Mediterranean species	Robertson 1964
P. krebsii	1400	on *Astrangia danae*; 15-16 days *in capsulo*, 74-90 days in plankton	Tesch 1946; Robertson 1964; Scheltema 1971
P. layardi	1600-1700		Robertson 1964
P. lepida	900		Robertson 1964
P. n. sp.	800		Robertson 1964
P. oxytropis	1550-1750	(=*P. layardi*?)	Robertson 1970
P. radiata	1200-1450	on *Porites lobata*; eggs 63 µm	Robertson 1970
P. uruguaya	1100		Robertson 1964
"*Solarium boreale*"	900		Robertson 1964

Philippia oxytropis A. Adams 1855. Plate V, figs. a, b.
Plate VII, below.

Veliger:

Protoconch: heterostrophic, planorbiform, large; transparent cream predominates with areas of rich red-brown; beak lacking, but exterior of apertural outer lip red-brown; sutures stained red-brown; capsular protoconch light red-brown; metamorphose when 4 - 4 1/2 whorls complete, 1690 µm, greatest dimension, x 700 - 750 µm, thickness.

Velum: four-lobed; edged with brilliant red-orange suffusion; velar lobes elongate; ingested during metamorphosis, appears red-orange in digestive gland later.

Cephalic area: white; cephalic tentacles long, tapered, white.

Foot: white; propodium deeply cleft; mesopodial region expanded laterally; metapodial margin broadly rounded.

Viscera: digestive gland white, granular with vitreous beads; posterior to large black area, an opaque white contractile area.

Months found in plankton: March through September, greatest abundance; occur sporadically through remaining months.

Areas found: Sampan Channel, Dredged Island, Ala Moana Reef (Honolulu)

Remarks:

After metamorphosis, the large black patch remains and a lighter gray-brown patch develops just anterior to it. In captivity, P. oxytropis juveniles feed on Aiptasia, an anemone that is easily reared in sea water tables.

Heliacus variegatus (Gmelin 1791). Plate V, figs. c-e; Plate VII, fig. 1.

Veliger:

Protoconch: planorbiform, heterostrophic, smooth, shining; sutures, aperture suffused with medium red-brown pigment; metamorphosis occurs when three whorls complete, greatest diameter: 850 µm, its perpendicular: 670 µm.

Velum: four-lobed, unpigmented.

Cephalic area: tinged with light red-brown; eyes flush with face; interocular area with black pigment.

Foot: unpigmented; propodium cleft medially; propodial furcae flared laterally; operculum round, transparent, colorless.

Viscera: digestive gland dirty tan; anterodorsal mantle with large rectangular black area.

Months found in plankton: all months, peak abundance: March-May

Areas found: Dredged Island, Sampan Channel

Plate V

Architectonicidae

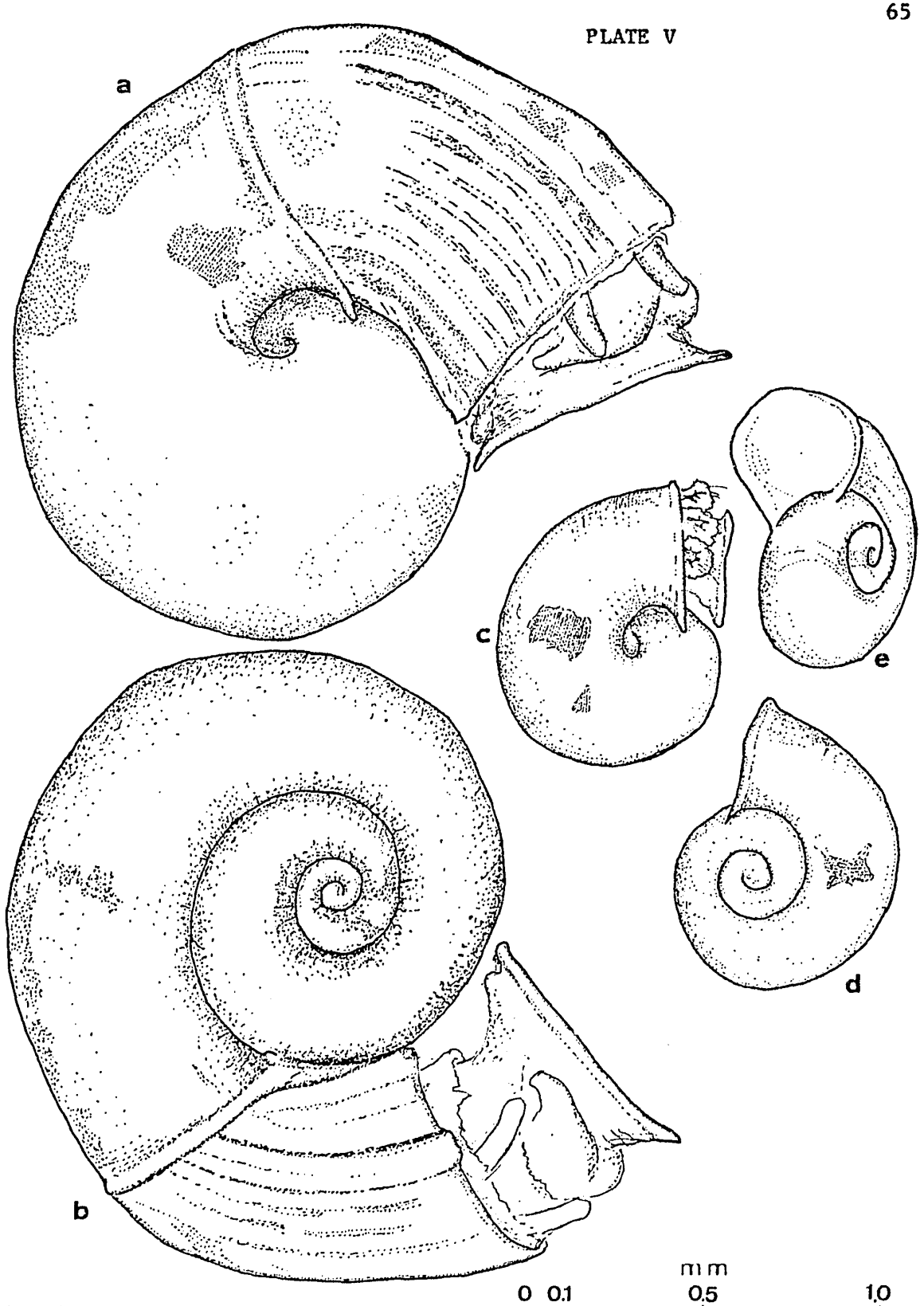
Figs. a,b. Philippia oxytropis

a. newly-metamorphosed juvenile, abapical view
b. newly-metamorphosed juvenile, apical view

Figs. c-e. Heliacus variegatus, premetamorphic protoconchs

c. abapical view
d. apical view
e. apertural/apical view

PLATE V



Architectonicidae

PLATE VI
Architectonicidae

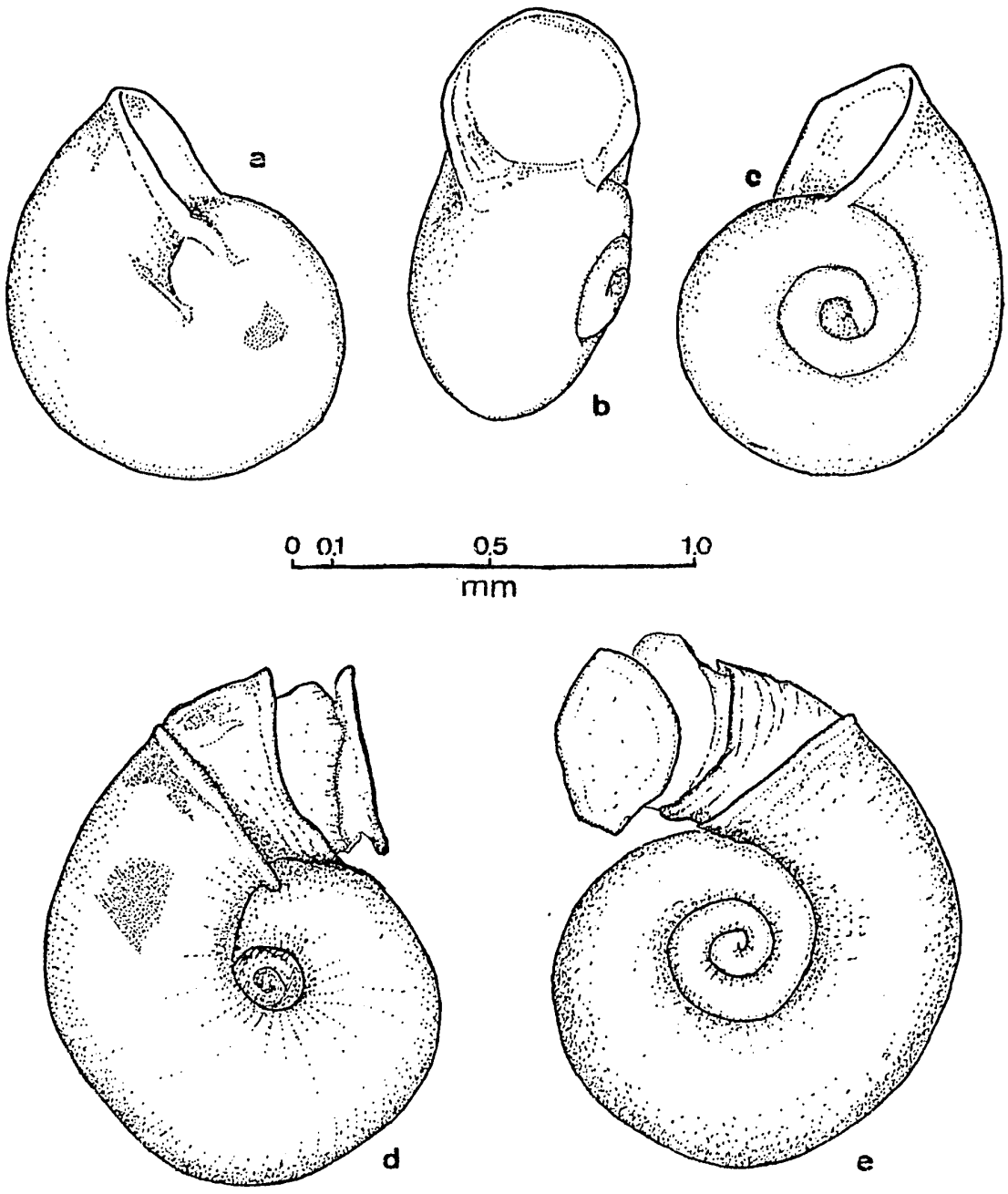
Figs. a-c. Philippia radiata, premetamorphic protoconchs

a. abapical view
b. apertural view
c. apical view

Figs. d, e. Heliacus implexus, premetamorphic protoconchs

d. abapical view
e. apical view

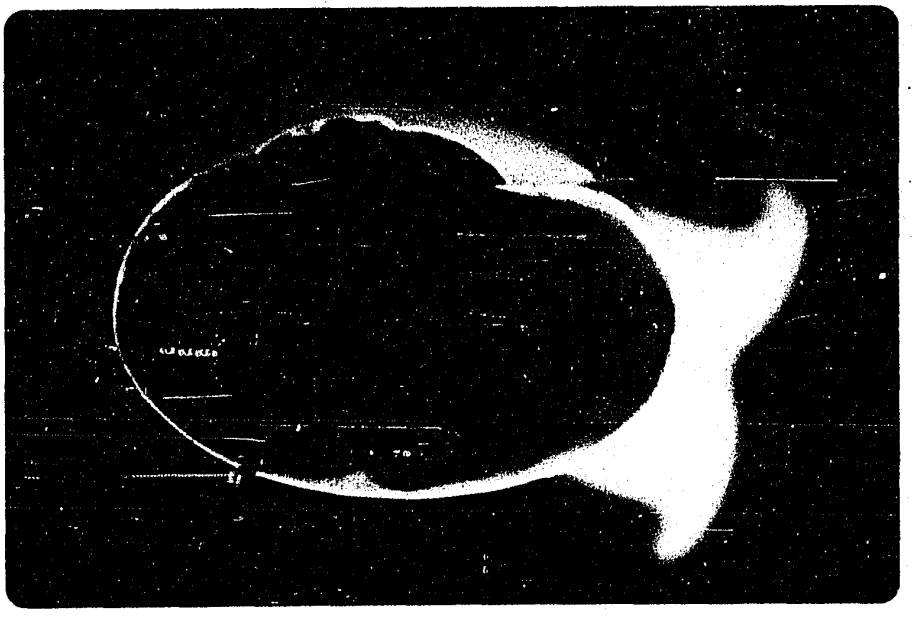
PLATE VI



Architectonicidae

PLATE VII
Architectonicidae

Figure 1 (above): Heliacus variegatus, swimming veliger.
2 (below): Philippia oxytropis, newly-metamorphosed juvenile.



1.3mm

Superfamily 10. Cerithiacea

Cerithiacea includes the Turritellidae, Vermetidae*, Siliquaridae, Caecidae*, Planaxidae*, Modulidae*, Cerithiidae*, Cerithiopsidae*, Triphoridae*, Mathildidae, Syrnolopsidae, Melaniidae*, Melanopsidae, Pleuroceridae, Abyssochrysidae, Potamididae, Diastomidae*, and Sequenziidae.

Superfamily characteristics: shell usually turriform, multi-whorled; umbilicus generally lacking; copulation usually lacking (except Caecum); egg capsules small with few eggs; some freshwater cerithiaceans viviparous; presumably derived from the Pleurotomariacea, first appeared in the Permian; 1,297 living species.

Information relating to cerithiacean life histories is available for turritellids, vermetids, triphorids, cerithiids, cerithiopsids, modulids, caecids and potamidids (Tables 6,7,8, and 9).

Table 6

Types of Development in the Cerithiacea

Genus	P	M	D	?	References
1. Turritellidae					
Turritella	1	-	-	-	Lebour 1933, 1937a; Thorson 1946
2. Vermetidae					
Dendropoma	-	2	4	-	Morton 1951, 1965; Hadfield et al. 1972
Petaloconchus	2	1	1	-	Lewis 1960; Morton 1965; Hadfield 1966; Hadfield et al. 1972
Serpulorbis	2	-	3	-	Holmes 1900; Morton 1951, 1965; Hadfield et al. 1972
Spiroglyphus	1	-	-	-	Lewis 1960
Vermetus	1	-	1	1	Lacaze-Duthiers 1860; Hadfield et al. 1972
Vermetus (?)	1	-	-	-	Lebour 1945
3. Caecidae					
Caecum	2	-	-	-	Lebour 1936, 1937a; Thorson 1946
4. Planaxidae					
Planaxis	2	1	-	-	Risbec 1935; Thorson 1940
5. Modulidae					
Modulus	1	-	-	-	Lebour 1945
6. Cerithiidae					
Cerithium	4	-	-	2	Lebour 1945; Natarajan 1957; D'Asaro 1970
Clava	1	-	-	-	Ostergaard 1950
Litiopa	1	-	-	-	Lebour 1945
7. Cerithiopsidae					
Cerithiopsis	5	-	-	-	Lebour 1933, 1936, 1945
8. Triphoridae					
Triphora	2	-	-	-	Pelseneer 1926a; Lebour 1933d, 1937a, 1945

Table 6. (Continued) Types of Development in the Cerithiacea

9. Potamididae					
Bittium	1	-	-	-	Lebour 1936
Cerithidea	1	-	-	-	Panikkar and Aiyar 1939; Natarajan 1957
Velacumantus	1	-	-	-	MacIntyre 1961

P (=pelagic), with a planktonic larval stage

M (=mixed), within the population some have a planktonic larval stage; some do not

D (=direct), without a planktonic larval stage

? = unknown or doubtful

Vermetidae

Larval characteristics and extent of brood protection exhibited by Hawaiian vermetids are described in detail by Hadfield et al. (1972) and summarized in Table 7. For additional descriptions of pelagic vermetid veligers, see Lebour (1945) and Lewis (1960). Holmes (1900) and Lacaze-Duthiers (1860) describe and discuss the early embryology of vermetid larvae.

Table 7

Types of Development in the Vermetidae

Genus	Species	P	M	D	?	References
Dendropoma	gregaria			x		Hadfield et al. 1972
"	lamellosa			x		Morton 1951, 1965
"	meroclista		x			Hadfield et al. 1972
"	platypus		x			Hadfield et al. 1972
"	psarocephala			x		Hadfield et al. 1972
"	rhyssoconcha			x		Hadfield et al. 1972
Petaloconchus	keenae		x			Hadfield et al. 1972
"	montereyensis			x		Hadfield 1966
"	nigricans	x				Morton 1965
" c.f.	varians	x				Lewis 1960
Serpulorbis	aotearoicus			x		Morton 1951, 1965
"	imbricatus			x		Morton 1951, 1965; Habe 1953
"	squamigerus	x				Holmes 1900
"	variabilis	x				Hadfield et al. 1972
"	zealandicus			x		Morton 1951, 1965
Spiroglyphus	irregularis	x				Lewis 1960
Vermetus	alii	x				Hadfield et al. 1972
"	semisurrectus				x	Lacaze-Duthiers 1860
"	triqueter			x		Lacaze-Duthiers 1860
Vermetus (?)	sp.	x				Lebour 1945

P (=pelagic), with a planktonic larval stage

M (=mixed), within the population some have a planktonic larval stage; some do not

D (=direct), without a planktonic larval stage

? = unknown or doubtful

Table 8

Summary of Hawaiian Vermetid Data (Hadfield et al. 1972; this study)

Species	Egg size (μm)	Protoconch at hatching		Protoconch at metamorphosis		Larval developmental style
		# of whorls	Size (μm)	# of whorls	Size (μm)	
Dendropoma gregaria	310	$1\frac{1}{2}$ - 2	470 x 410	$1\frac{1}{2}$	470 x 410	direct
D. meroclista	270	$1\frac{1}{2}$	450 x 350	$1\frac{1}{2}$	470 x 360	mixed
D. platypus	350	$1\frac{1+}{2}$	600 x 480	$1\frac{1}{2}$ - $1\frac{2}{3}$	594 x 578	mixed
D. psarocephala	300	$1\frac{1+}{4}$	500 x 330	$1\frac{1}{4}$ - $1\frac{1}{3}$	500 x 330	direct
D. rhyssoconcha	315	$1\frac{1}{2}$	580 x 440	$1\frac{1}{2}$	580 x 440	direct
Petaloconchus keenae	217	$2\frac{1}{2}$ - 3	660 x 450	$2\frac{1}{4}$ - $2\frac{3}{4}$	660-700 x 400-460	mixed
Serpulorbis variabilis	190	$1\frac{1}{2}$	290 x 390	$2\frac{3}{4}$ - $3\frac{1}{2}$	610 x 462	indirect
Vermetus alii	225	$1\frac{3}{4}$ - 2	420 x 350	$1\frac{3}{4}$ - 2		indirect

1. a. protoconch barrel-shaped or bulbous-trochoidal.....2

   b. protoconch globose.....6

2. (1a) a. whorls inflated, sutures impressed.....*Vermetus alii*

   (1a) b. whorls not so inflated, sutures not impressed.....3

3. (2b) a. protoconch transparent, with tinges of red-brown.....
   .....*Serpulorbis variabilis*

   (2b) b. protoconch milky-white, more or less opaque.....4

4. (3b) a. sutures red-brown.....*Petaloconchus* nov. sp.

   (3b) b. sutures colorless.....5

5. (4b) a. protoconch large, length approximately 900 µm; metamorphoses when two whorls complete.....vermetid nov. sp.

   (4b) b. ventral lobe of digestive gland with red-orange spots; width of protoconch exceeds 430 µm.....*Petaloconchus keenae*

6. (1b) a. protoconch with well-defined axial ridges.....7

   (1b) b. well-defined axial ridges lacking.....8

7. (6a) a. protoconch large (680 x 530 µm), stout, beak rounded.....
   .....*Dendropoma platypus*

   (6a) b. protoconch smaller (580 x 440 µm), beak sharply V-shaped....
   .....*Dendropoma rhyssoconcha*

8. (6b) a. last half of body whorl smooth.....9

   (6b) b. last half of body whorl cross-hatched....*Dendropoma gregaria*

9. (8a) a. protoconch with 1 3/4 whorls at hatching; resembles *V. alii*, but more globose.....*Dendropoma meroclista*

   (8a) b. protoconch of 1 1/4 - 1 1/3 whorls at hatching; sub-planorboid.....*Dendropoma psarocephala*

Dendropoma meroclista Hadfield and Kay 1972. Plate VIII, figs. i,j.

Veliger:

Protoconch: creamy, opaque; after metamorphosis, protoconch dull pink-brown to magenta; 1 1/2 to 1 2/3 whorls complete at metamorphosis; suture prominent, impressed; unsculptured.

Velum: bilobed; velar lobes oval, subequal, unpigmented.

Cephalic area: tentacles medium-long, far apart, sparsely ciliated entire length, slightly expanded near bases; intertentacular distance broad, lightly tinged with charcoal.

Foot: propodium glandular with long cilia on anterior end; metapodium basically triangular but rounded; mesopodium undistinguished; operculum larger than metapodium, triangular, with bristles, retained after metamorphosis; statocysts prominent in pre-settlement veligers.

Viscera: digestive gland yellow-green in metamorphosed specimens and veligers; style sac golden-brown; rectum red-brown.

Months found in plankton: August through December

Areas found: Dredged Island, Coconut Island

Remarks: Newly-metamorphosed individuals have a foot functional in crawling until the teleoconch is suffuciently elaborated to impede function. The teleoconch has uneven growth striae and low bumps on initial shell. Black pigment spots appear on the proboscis area of post-larvae. Veligers of D. meroclista are probably not planktonic for more than a few hours, or at most, a few days.

Early development: eggs 150-200 μm; much yolk included in the capsules, ingested by developing embryos; "at hatching, the embryos vary in size and the velar lobes are in varying states of regression. None of the juveniles hatched in the laboratory can swim, and a few have no evident velum (Hadfield et al. 1972)." "At hatching 0.68 mm by 0.53 mm, of 1 1/2 to 1 2/3 whorls, the second whorl sculptured with well-defined axial ribs; unpigmented and opaque or with two brown spirals, one along the suture, the other along the mid-dorsal line. The larval operculum has an orange center and is marked by an orange ring; it is shed after settling. The larval foot is marked with yellow pigment (Hadfield et al. 1972)."

Remarks: Veligers obtained in plankton tows were smaller (595 μm x 575 μm) than those reared in the laboratory and had 1 2/3 to two complete whorls. The bilobed velum was functional in food-acquisition and locomotion, but metamorphosis occurred within a few hours after the plankton tow; usually, the lobes acquired a ragged appearance and were dropped but not ingested.

Veliger:

Protoconch: white to cream, opaque; globose; stout; first 3/4 whorl finely punctate, smooth; remainder obliquely axially ridged; siphonal canal lacking; beak keeled; axial ridges wavy, overlapping, low; after metamorphosis, entire protoconch suffused with red-brown; sutural cord present on last part of body whorl of protoconch.

Velum: bilobed, equal, not large; unpigmented.

Cephalic area: tentacles long, ciliated distally, bases slightly expanded; eyes inside bases of tentacles; oral region unpigmented.

Foot: propodium rectangular, tinged with pink; metapodial dorsal surface tinged with green; mesopodium slightly expanded laterally; metapodium rounded; operculum with red-brown or orange center, translucent edge.

Viscera: digestive gland yellow-green.

Months found in plankton: all months except February, May, June, November, December

Areas found: Sampan Channel, Dredged Island, Coconut Island, Checker Reef (northwest of Coconut Island)

Dendropoma psarocephala Hadfield and Kay 1972. Plate VIII, figs.e,f.

Descriptions of this species (ibid.) served to identify one lone specimen which was collected during August. The protoconch is white and not ridged and is approximately 2/3 as large as that of D. platypus. The operculum is retained after metamorphosis and the species metamorphoses easily in captivity; the teleoconch is magenta.

Dendropoma gregaria Hadfield and Kay 1972. Plate VIII, figs. k,l.

A few specimens of D. gregaria have been obtained from time to time. The protoconch is smooth, dark red-brown, with 1 1/2 to 2 whorls complete and a length of approximately 680 μm and width of 805 μm.

The foot bears two extremely long, thick, tapered epipodial tentacles and the operculum is retained after metamorphosis. The velum regresses rather than being cast off and ingested. Initial teleoconch is white and ridged.

Planktonic veligers of this species have been obtained only from the Sampan Channel area of Kaneohe Bay during August.

Vermetus alii Hadfield and Kay 1972. Plate VIII, figs. g,h.

Early development: egg size, 225 µm; hatch when 1 1/4 whorls complete (410-465 µm long, 340-350 µm wide); obligate meroplankters for a few days to a few weeks.

Veliger:

Protoconch: small, barrel-shaped, sutures impressed; lightly punctate; brown-tan or transparent; sutures and lower half of columella light red-brown; beak shallow and rounded; siphonal canal lacking; metamorphosis occurs when 1 3/4 - 2 1/4 whorls complete (515 µm long x 340-350 µm wide); beak and columella cinnamon.

Velum: bilobed, unpigmented; oval-rectangular lobes equal in size.

Cephalic area: tentacles with fine 'setae' entire length, not expanded at base, medium-long; eyes inside bases of tentacles; oral region unpigmented.

Foot: posterior edge of metapodium with 'setae'; mesopodium with yellow-green oval spots; operculum rounded-triangular; anterior pedal gland golden, prominent; background colorless; propodium rectangular.

Viscera: digestive gland golden with dark spots; intestine black or brown.

Months found in plankton: February, March, April, July, August, September, October, November, December

Areas found: Sampan Channel, Dredged Island, Coconut Island, Checker Reef (northwest of Coconut Island)

Remarks: The operculum is triangular, but rounded, and is retained after metamorphosis. While Vermetus alii is considered to be primarily a ciliary feeder (Hadfield et al. 1972), soon after metamorphosis, two ciliated podial tentacles are extended from the aperture and engaged in attracting food.

A female collected August 6, 1968 spawned twice in captivity, -- on September 29, 1968 and November 17, 1968. On November 17, there were 18 young veligers in the petri dish. The female had been fed only Phaeodactylum and what was on her 'rock'. The veligers hatched when 413 μm was their greatest dimension.

PLATE VIII

Figs. a-d: Dendropoma platypus, premetamorphic protoconchs

a. apertural view
b. abapertural view
c. apical view
d. apertural view

Figs. e, f: Dendropoma psarocephala

e. juvenile with protoconch and initial teleoconch
f. premetamorphic veliger, ventral view

Figs. g, h: Vermetus alii, premetamorphic protoconchs

g. abapertural view
h. apertural view

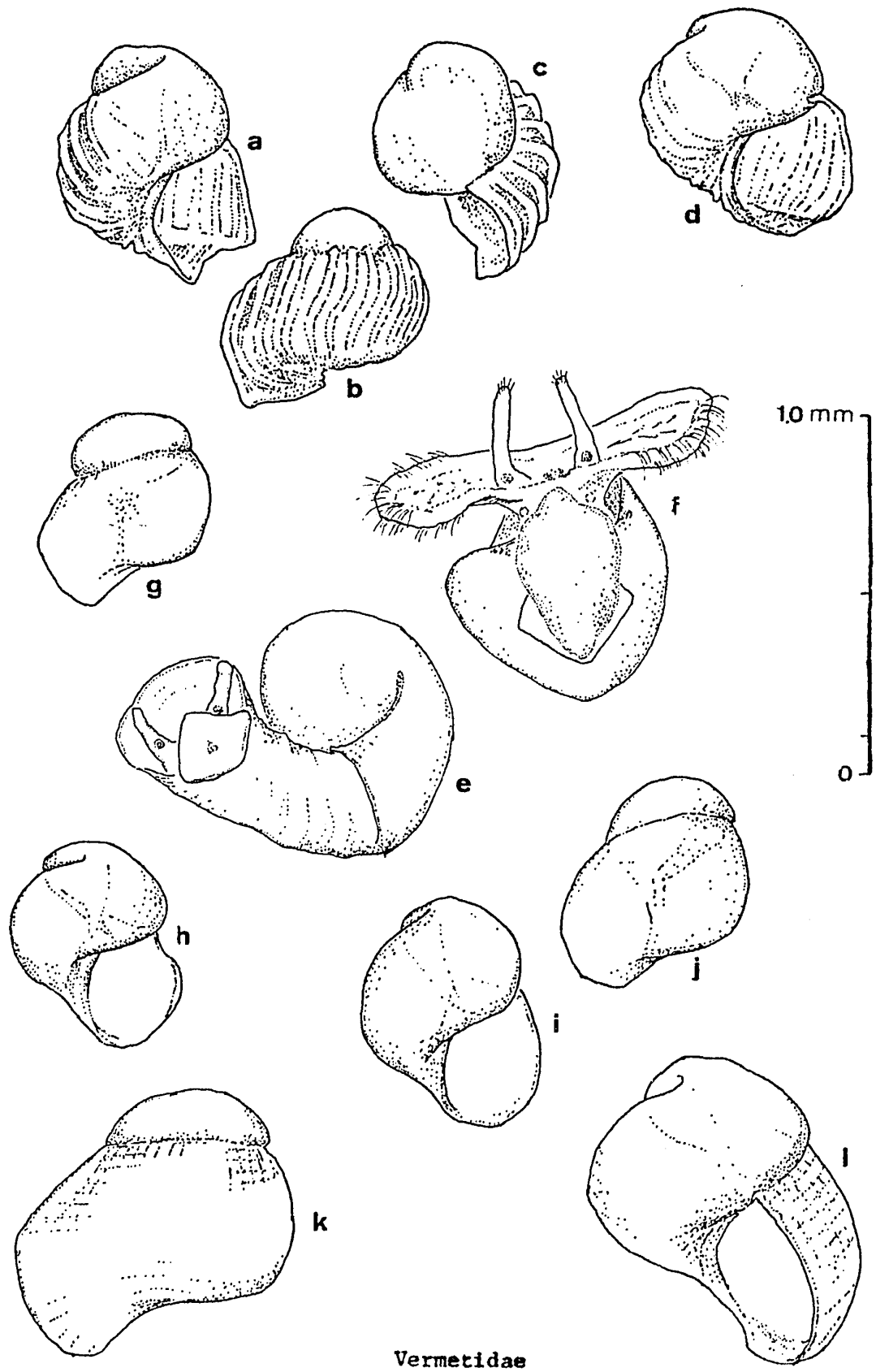
Figs. i, j: Dendropoma meroclista, premetamorphic protoconchs

i. apertural view
j. abapertural view

Figs. k, l: Dendropoma gregaria, premetamorphic protoconchs

k. abapertural view
l. apertural view

PLATE VIII



Vermetidae

Petaloconchus keenae Hadfield and Kay 1972. Plate IX, figs. h-j.

Early development: eggs 217 µm in diameter; nurse yolk present in large amounts; hatch with protoconch of 2 1/2 to 3 whorls, size, 660 µm long x 450 µm wide; early veligers with purple-black esophagus; later larvae with red-orange ventral lobe of digestive gland; most post-hatching larvae never become planktonic, --crawl for a short time, then become cemented to substratum (Hadfield et al. 1972); some P. keenae post-hatching larvae become planktonic with functional velar lobes.

Planktonic veligers:

Protoconch: transparent before metamorphosis, then red-brown; columella colorless before metamorphosis; narrower than Serpulorbis; unsculptured save for ridged beak; siphonal canal lacking; beak angular, centrally ridged; teleoconch red-brown; metamorphosis occurs when 2 1/2 to 2 3/4 whorls complete; slight umbilicus present.

Velum: bilobed; velar lobes oval, unpigmented.

Cephalic area: tentacles medium-long, not tapered, knobbed terminally, far apart; eyes inside bases of tentacles; anterior and medial to each eye is one black spot.

Foot: unpigmented, operculum retained after metamorphosis; meta- and mesopodial ventrum diamond-shaped, frequently with tiny red spots; propodium rectangular; after metamorphosis, anterior pedal gland becomes darkened, triangular; skin of foot and cephalic area white.

Viscera: digestive gland tan to colorless; ventral lobe of digestive gland red-orange; style sac colorless.

Months found in plankton: all months except January, June

Areas found: Sampan Channel, Dredged Island, Coconut Island

Remarks: This species is hardy and a few occur almost weekly in plankton tows in all parts of Kaneohe Bay. Planktonic duration is probably limited to periods from a few minutes to several days; dissection of adult females reveals that the most well-developed veligers in the mantle cavity are approximately the same size as those occurring in the plankton. The veligers will metamorphose on plastic and feed on filamentous algae.

?*Petaloconchus* sp.$_1$ Plate IX, figs. e-g.

This species resembles none of the descriptions of Hawaiian vermetids. Protoconchs are barrel-shaped like those of *Petaloconchus keenae*, but are 40 µm narrower and are approximately as long as those of *P. keenae*. The smooth protoconch is translucent white; the sutures, columella and aperture are red-brown. The beak is not recurved and the siphonal canal is lacking. The tentacles are short and far apart. The operculum is retained after metamorphosis. The rectum bears white asterisk-shaped fecal pellets.

During February and March, veligers were netted in Sampan Channel; later these metamorphosed in plastic petri dishes. Veligers of this species metamorphose when 2 1/2 to 3 1/4 whorls are complete, with shell length approximately 670 µm and width approximately 365 µm.

Months found in plankton: February through July.

Serpulorbis variabilis Hadfield and Kay 1972. Plate IX, figs. a-d.

Early development: eggs approximately 190 μm in diameter, some eggs serve as nurse yolk; juveniles hatch as small (270 x 120 μm) bulbous, trochoidal planktonic veligers with 1 1/2 whorls; velum at hatching is a simple bilobed appendage (Hadfield et al. 1972).

Planktonic veliger:

Protoconch: planktonic from 1 1/2 whorls until 2 3/4 - 3 1/2 whorls complete, metamorphosis occurs when length approximates 600-660 μm, width, 400-480 μm; transparent, except for red-brown columella, beak, tip and suture of third whorl; all whorls with rows of parallel punctae; beak present, well-developed, recurved and tipped with red-brown; siphonal canal absent; protoconchal shape dependent on age of veliger, --at metamorphosis, barrel-shaped; umbilicus present.

Velum: initially bilobed, later expansively four-lobed, unpigmented; pre-metamorphic veliger holds velum recurved gracefully over protoconch, swims slowly; cilia long.

Cephalic area: tentacles medium, slightly knobbed distally; eyes 1/4 of the distance distal from bases; oral region purple-black.

Foot: wedge-shaped; mesopodium laterally expanded, in juveniles, ventro-medial area tinged with purple-black; early operculum sickle-shaped, thin, colorless; anterior pedal gland prominent, colorless in veliger; operculum retained immediately after metamorphosis, may be lost when teleoconch deposited.

Viscera: digestive gland golden- or red-brown; style sac purple-black or colorless; rectum purple-black.

Months found in plankton: all months, with peaks of abundance in January, March, August.

Areas found: seaward portions of Kaneohe Bay, --especially Sampan Channel, east of Dredged Island; found shoreward during periods of strong trade winds.

Remarks: S. variabilis is an excellent indicator of non-turbid, well-mixed water.

There seem to be two main color varieties: one which has stellate chrome-yellow spots dispersed in the mantle and foot, and another variety which lacks these. These two varieties coexist in space and time.

Initially-deposited teleoconch is magenta or unpigmented. Juvenile bodies are light charcoal gray.

Vermetid sp. Plate IX, figs. k-m.

Veliger:

Protoconch: bulbous, inflated, barrel-shaped; clear, slightly opaque white; smooth with irregular punctae; body whorl with sutural keel.

Velum: bilobed, unpigmented.

Cephalic area: tentacles medium-long with light yellow pigment spots; eyes inside bases; oral region unpigmented.

Foot: two epipodial tentacles, short, not thick; periphery of foot with yellow spots; anterior pedal gland a gray triangle; operculum transparent, occasionally retained after metamorphosis.

Viscera: rectum colorless; digestive gland colorless to tan.

Months found in plankton: March, August

Areas found: Sampan Channel

Remarks: Metamorphosis occurs when 1 3/4 whorls are complete. Originally gray-pink, the teleoconch gradually becomes clear and slightly ridged. The body is white and the mantle has dark gray spots.

At metamorphosis, the length is approximately 890-1056 μm; the width approximates 725 μm. The body of the metamorphosed animal is cream with yellow-green spots on the pedal dorsum and tentacles.

PLATE IX

Figs. a-d. *Serpulorbis variabilis*

a. post-hatching (early) protoconch, ventral view
b. post-hatching (early) protoconch, apical view
c. intermediate protoconch, apertural view
d. premetamorphic protoconch, apertural view

Figs. e-g. *Petaloconchus* sp.$_1$

e. post-metamorphic juvenile with protoconch and initial teleoconch
f. premetamorphic protoconch, apertural view
g. premetamorphic protoconch, lateral view

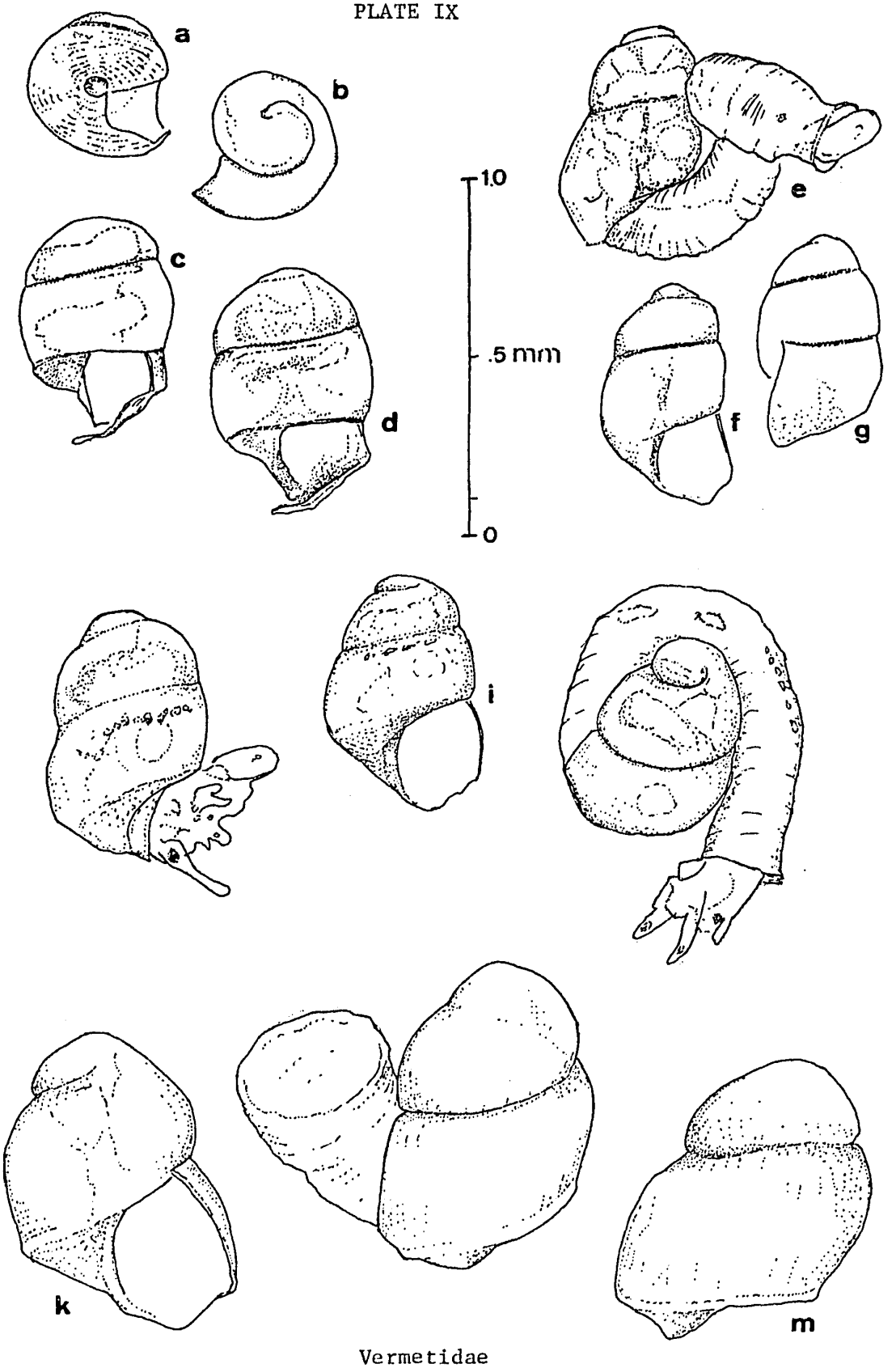
Figs. h-j. *Petaloconchus keenae*

h. newly-metamorphosed juvenile
i. premetamorphic protoconch, apertural view
j. post-metamorphic protoconch and initial teleoconch

Figs. k-m. Vermetid sp.

k. premetamorphic protoconch, apertural view
l. post-metamorphic juvenile
m. premetamorphic protoconch, abapertural view

PLATE IX



Vermetidae

PLATE X

Vermetidae

Vermetid sp.: juvenile, showing protoconch and early teleoconch.

1.3mm

No veligers of Caecum, Planaxis or Modulus were collected from the Bay during the years of this study. In 1973, veligers of Caecum sp. and Modulus tectum were obtained from the leeward side of Oahu near Kewalo Basin using a plankton net with a smaller pore size. Presumably these tiny larvae slipped through the net used in the Kaneohe Bay study.

Cerithiidae and Diastomidae

Adult cerithiids are associated with algal mats and living or dead coral. They deposit long, coiled, gelatinous egg strings from which hatch planktotrophic veligers (Anderson 1960).

Cerithiid veligers are small at metamorphosis (Lebour 1937a); most of those reported heretofore were smaller than 330 µm. A cerithiid veliger generally is characterized as having an unpigmented, bilobed velum, a protoconch shaped like a teardrop and a foot which is undistinguished by tentacles or extensive pigmentation. Planktonic duration is unknown, but cerithiid veligers settle readily in petri dishes.

In Hawaii there are 19 species in five genera of cerithiids; I collected at least seven species of Cerithium veligers from the plankton. The Hawaiian cerithiid veligers are generally larger than those heretofore reported, but their characteristics fit the above pattern.

Little is known of diastomid life histories (Table 9). Hawaiian forms are represented by nine species in five genera; I have collected at least three of these as swimming veligers; others occur regularly in the plankton as juveniles (Obtortio). Cerithidium and Styliferina are the two diastomid genera with planktonic larval stages.

Table 9

Life History Data: Cerithiidae, Cerithiopsidae, and Potamididae

Name	Remarks	References
Cerithiidae		
Bittium reticulatum	egg diameter 60-65 µm; hatch as planktonic veligers when length approximates 170 µm; metamorphose when 320 µm	Lebour 1933c, 1936 1937a; Thorson 1946
Cerithium auricoma	veliger planktonic	D'Asaro 1970
C. ferrugineum	hatch when length approximates 90 µm; veliger planktonic	Lebour 1945
C. gemmulatum	veliger planktonic	Risbec 1935
C. literatum	veliger planktonic	D'Asaro 1970
C. morus	hatch three days after spawning when length approximates 150-170 µm; one day later, length = 200 µm; veliger planktonic; long pelagic phase presumed	Natarajan 1957
C. spp. A, B and D	veliger planktonic [these larvae are more likely in the family Cerithiopsidae]	Lebour 1945
Clava obeliscus	eggs deposited in March (Hawaii); *in capsulo* 6 days; hatch as planktonic veligers when length approximates 160 µm	Ostergaard 1950
Cerithiopsidae		
Cerithiopsis barleei	hatch as planktonic veligers when length approximates 140 µm, 1 1/2 whorls complete; metamorphose when length approximates 640 µm, 4 1/2 whorls complete	Lebour 1933c, 1937a
C. jeffreysi	veliger planktonic	Lebour 1933c
C. tubercularis	egg diameter 60 µm; veliger planktonic; metamorphose when length approximates 640 µm; 4 1/2 whorls complete	Lebour 1933c, 1936 1937a

Potamididae

Cerithidea fluviatilis	spawn Jan.-Sept. in Palk Bay, India; egg diameter 130-130 µm; in capsulo 4 days; hatch as planktonic veligers when length approximates 200 µm	Natarajan 1957

Cerithium columna Sowerby 1834. Plate XI, figs. c,d,e.

Veliger:

Protoconch: apical whorl colorless, smooth; remaining 2 1/4 whorls red-brown with subsutural spiral of axial riblets plus spiral keels cross axial striae; metamorphosis occurs when 3 1/4 whorls complete, length: 320 μm, width: 240 μm.

Velum: unpigmented, bilobed, unequal.

Cephalic area: unpigmented.

Foot: simple, white.

Viscera: cannot be discerned through protoconch.

Months found in plankton: April through August

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of Cerithium interstriatum Sowerby 1855 (Pl. XI, figs. f, g and h) resemble those described above too closely to warrant a separate description. C. interstriatum protoconchs differ in being more slender and in having a second beaded keel on the third whorl, but they are equally abundant in the plankton during the same months as those of C. columna.

Cerithiid sp.$_1$ Plate XI, fig. b.

Veligers of this species metamorphose and grow into a slender cerithiid whose teleoconch is cream-colored with angled ribs. The veligers were collected in the February plankton from Sampan Channel.

Cerithiid sp.$_3$ Plate XI, figs. k, l.

Veliger:

Protoconch: apical whorl pink, faintly pitted; abapical whorl magenta, punctate; third whorl magenta with three spirals of granules; sutures, beak, columella pink-purple; beak prominent; metamorphosis occurs when three whorls complete, length: 360 μm, width: 270 μm.

Velum: diaphanous white, bilobed, unequal.

Cephalic area: white.

Foot: white, simple.

Viscera: cannot be discerned through protoconch.

Months found in plankton: March through July

Areas found: Sampan Channel, Dredged Island

Remarks:

Veligers of this species frequent the plankton during the spring and summer.

Cerithium atromarginatum Dautzenberg and Bouge 1933. Plate XI, figs. m,n.

Veliger:

Protoconch: apical whorl tan, smooth; remaining whorls medium red-brown with sutures beaded; abapical whorl unicarinate; next whorl bicarinate; anterior columella slightly produced; metamorphosis occurs when 3 1/2 whorls complete, length: 325 µm, width: 240 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: simple, unpigmented.

Viscera: cannot be discerned through protoconch.

Months found in plankton: May through August

Areas found: Sampan Channel

Remarks:

Veligers of C. atromarginatum settle readily in the sea-water tables and grow rapidly.

Cerithium mutatum Sowerby 1834. Plate XI, figs. o, p.

Veliger:

Protoconch: transparent, light tan; apical whorl smooth; abapical whorl with two spiral keels; metamorphosis occurs when two whorls complete, length: 300 μm, width: 240 μm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: light tan.

Foot: simple, light tan.

Viscera: digestive gland light brown.

Months found in plankton: July, August

Areas found: Dredged Island

Remarks:

Veligers of this species have shapes similar to Vermetus alii, with which they co-occur in the plankton; veligers of V. alii lack the spiral ridges characteristic of C. mutatum veligers and metamorphose at a larger size.

Cerithidium perparvulum (Watson 1886). Plate XI, figs. s, t.

Veliger:

Protoconch: tan; apical whorl smooth; remaining whorls with spiral shallow grooves; body whorl with small red-brown subsutural flammulations; beak shallow; anterior columella produced, dark tan; metamorphosis occurs when 4 3/4 whorls complete, length: 500 μm, width: 330 μm.

Velum: bilobed, sub-equal, unpigmented; apical lobe approximately 20 per cent larger than circular abapical lobe.

Cephalic area: unpigmented; tentacles medium-short; eyes inside bases; esophageal area unpigmented.

Foot: simple, unpigmented.

Viscera: digestive gland light brown; remaining organs not discernible.

Months found in plankton: January, March through September

Areas found: Sampan Channel, Dredged Island

Remarks:

These veligers are among the most common cerithiids in the Hawaiian plankton. The veligers settle readily on the plastic substratum of petri dishes, metamorphose within a few minutes and grow rapidly when supplied with clean coral chips covered with thin algal films.

Individuals of this species deposit their first egg masses when the shell has 9-10 whorls (including the protoconch). The eggs are lenticular ovals, 1320 μ x 1650 μm, and contain 100-140 eggs per mass. When food is plentiful, individuals require less than one month to pass from newly-settled juvenile to reproductive adult.

Veligers of Cerithidium diplax (Watson 1886; Pl. XI, figs. q, r) resemble those of C. perparvulum too closely to merit a separate description. They differ by lacking subsutural flammulations, the anterior columella is not so produced, the apical whorl is less acuminate and they metamorphose at a slightly smaller size. They are less abundant and were collected during January.

Styliferina goniochila (A. Adams 1860). Plate XI, figs. u, v, w and 1.

Veliger:

Protoconch: styliform, fragile, light tan, smooth; anterior sutures, columella red-brown; beak, siphonal canal lacking; metamorphosis occurs when 5-6 whorls complete, length: 750 μm, width: 410 μm.

Velum: bilobed, unequal; food groove, medial region of velar lobes with large khaki to yellow-green pigment spots; right lobe larger than left.

Cephalic area: tentacles long, knobbed distally; right tentacle longer than left; eyes inside tentacular bases; oral region unpigmented.

Foot: tan with light brown mottlings; shaped like slim arrowhead; propodium blunt, rectangular; mesopodium expands laterally, then narrows; metapodium tapering, gently rounded; operculum transparent, lunate.

Viscera: digestive gland tan with khaki pigment bodies on gut in 3rd, 4th and 5th whorls; style sac, rectum brown.

Months found in plankton: January, February, March, May, June, August, October, December.

Areas found: Sampan Channel, Dredged Island

Remarks:

After metamorphosis, the initial teleoconch develops regularly-placed square sutural areas of pattern; red-brown alternates with white. The eighth and ninth whorls from the apex develop spiral threads. The cephalic tentacles develop orange-brown and purple-black pigment granules interiorly the entire length. The propodium develops one pair of epipodial tentacles; the rest of the foot has four to six tentacles.

S. goniochila is remarkable for its fast growth rate and short life span. From premetamorphic veliger to reproductive adult requires but three weeks. The juveniles are voracious herbivores and can utilize both detritus and algal films. Three egg masses were deposited in five minutes by a female whose shell length was 3.1 mm.

Cerithium bavayi Vignal 1902. Plate XI, figs. x, y.

Veliger:

Protoconch: inflated- trochoidal; apical whorl light tan to colorless; remaining whorls red-brown; apical whorl punctate, body whorl with spiral cords on subsutural area; suprasutural areas of red-brown whorls with sinuous axial riblets crossing spiral cords; protoconch ovate, sutures impressed; metamorphosis occurs when 3 - 3 1/4 whorls complete, length: 500 µm, width: 420 µm.

Velum: bilobed, equal, unpigmented; cilia long.

Cephalic area: esophageal area charcoal gray; tentacles medium, unpigmented, tapered; eyes large; remaining areas unpigmented.

Foot: white, posterior margin with 26 - 30 circular irridescent spots.

Viscera: cannot be discerned through protoconch.

Months found in plankton: January, March through August

Areas found: Sampan Channel. Dredged Island, Ala Moana Reef

Remarks:

Veligers of this species are commonly netted during the summer months in the above areas.

Cerithiid $sp._4$ Plate XI, fig. 2.

Veliger:

Protoconch: colorless, transparent; apical whorl smooth; abapical whorl with two spiral keels; third, fourth whorls with three spiral keels above suture; sutures light red-brown, impressed; umbilical area comma-shaped; siphonal area produced, orange to red-brown; beak prominent in some individuals; metamorphosis occurs when 3 1/4 - 4 whorls complete, length: 530 μm, width: 330 μm.

Velum: unpigmented, bilobed; velar lobes circular, with long cilia, unequal, right lobe larger (diameter = 400 μm), diameter of left lobe: 230 μm.

Cephalic area: tentacles medium-short, moderately far apart; eyes inside tentacular bases; interocular area with five light brown spots; oral area unpigmented.

Foot: colorless to white, with 8-10 brown-black spots randomly sparsely distributed along length: propodial ventrum with two brown spots laterally; metapodial area with one pair of tentacles.

Viscera: digestive gland, style sac light gold; esophagus gray; heart large.

Months found in plankton: January

Areas found: Dredged Island

Remarks:

Veligers of this species are seldom netted in the Kaneohe Bay plankton.

Cerithiid sp.$_5$ Plate XI, fig. 3.

Veliger:

Protoconch: transparent, light tan; apical whorl smooth; remaining whorls with spiral grooves; beak conspicuous in some individuals; metamorphosis occurs when five whorls complete, length: 610 µm, width: 400 µm.

Velum: bilobed, subequal, unpigmented.

Cephalic area: tentacles short, tapered, thick at base; eyes inside tentacular bases.

Foot: light tan, simple.

Viscera: digestive gland light gold; remainder of gut colorless.

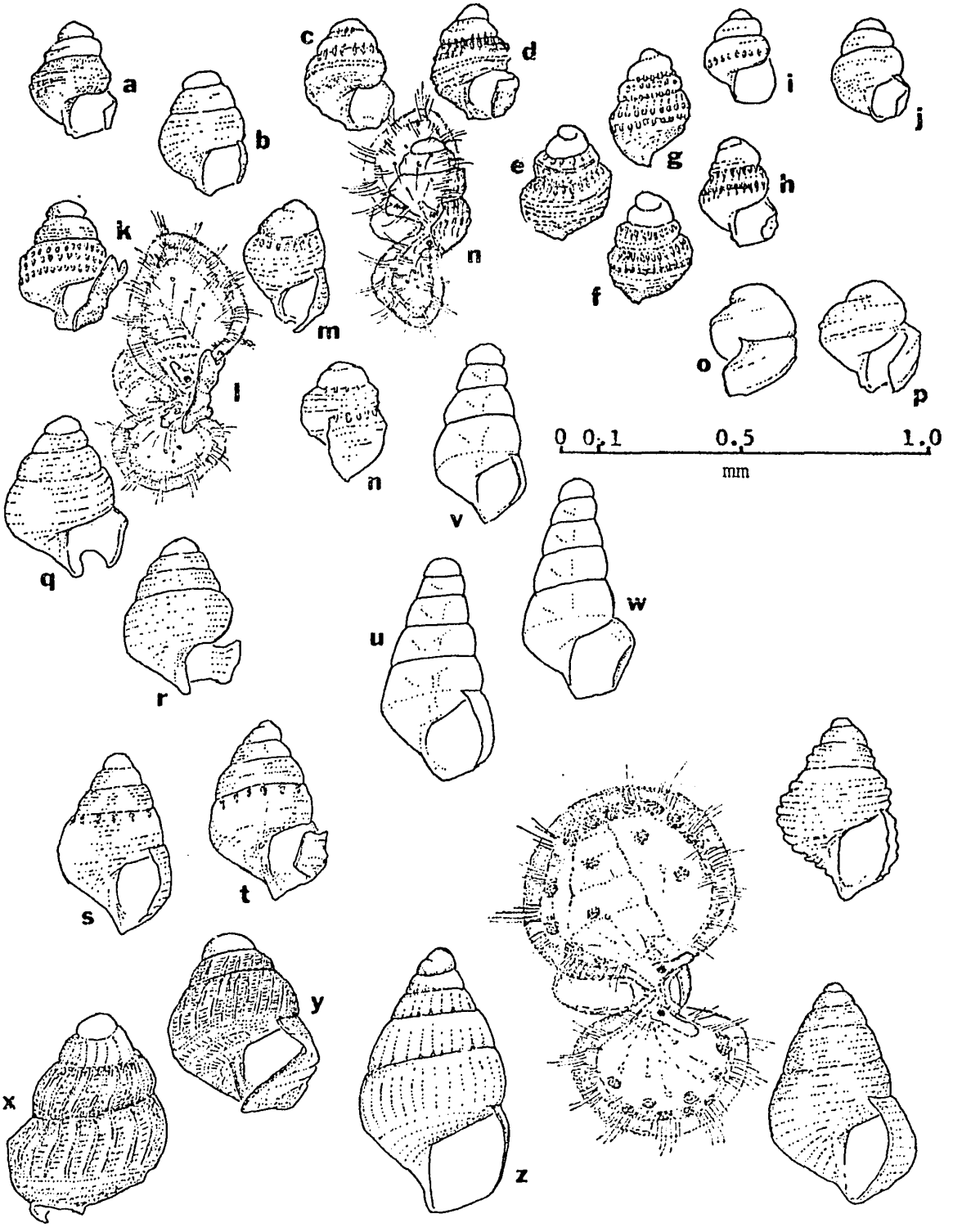
Months found in plankton: January

Areas found: Dredged Island

PLATE XI
Cerithiidae, Diastomidae:
premetamorphic protoconchs.

Figure a. *Cerithium* sp. 1
b. Cerithiid sp.1
c, d. *Cerithium columna*
e. *C. columna*, swimming veliger
f, g, h. *Cerithium interstriatum*
i. *Cerithium* sp.2
j. Cerithiid sp.2
k, l. Cerithiid sp.3
m, n. *Cerithium atromarginatum*
o, p. *C. mutatum*
q, r. *Cerithidium diplax*
s, t. *Cerithidium perparvulum*
u, v, w. *Styliferina goniochila*
x, y. *Cerithium bavayi*
z. *Litiopa ?melanostoma*
1. *Styliferina goniochila*, swimming veliger
2. Cerithiid sp.4
3. Cerithiid sp.5

PLATE XI



Cerithiidae, Diastomidae

Cerithiopsidae

Adult cerithiopsids live among sponges (Lebour 1933c); two species are reported as laying their eggs in sponges. Cerithiopsids typically produce small (<80 μm) eggs. The larvae hatch as small planktonic veligers which attain several whorls while still in the plankton, then metamorphose when the protoconchal length approximates 650 μm (Lebour 1937a).

Little is known of the Hawaiian populations of cerithiopsids, but the results of plankton tows suggest that there are at least four species and perhaps as many as nine which inhabit Kaneohe Bay.

Cerithiopsid life history data are summarized in Table 9.

Cerithiopsis tricarinata (Pease 1861). Plate XII, figs. a-c.

Veliger:

Protoconch: lanceolate, sutures not very impressed; sutures, columella dark red-brown; sutures with tiny red-brown axial riblets regularly spaced; siphonal canal truncate; beak broadly angular; body whorl with area anterior to suture red-brown, area posterior to suture unpigmented; metamorphoses when 4 3/4 to 5 whorls complete, length: 600-645 µm, width: 330-340 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: tentacles medium-long, close together; 'face' area charcoal gray.

Foot: simple, brushed with charcoal gray.

Viscera: digestive gland light yellow.

Months found in plankton: July, August, September.

Areas found: Sampan Channel, Dredged Island, Coconut Island; also, Ala Moana Reef (Honolulu).

Remarks:

Veligers of this species are abundant during the few months they are found in the plankton. The red-brown sculpture is distinctive and facilitates their identification.

Cerithiopsis leucocephalum Watson 1886. Plate XII, figs. d-g.

Veliger:

Protoconch: elongate-conical, apex rounded; beak sometimes prominent; apical 1 3/4 whorls punctate; remaining whorls with curved axial ribs or threads; background clear tan; columella, sutures, subsutural area of body whorl with various amounts of red-brown; siphonal canal truncate; metamorphosis occurs when 4 - 4 1/4 whorls complete, length: 570-610 µm, width: 280-290 µm.

Velum: bilobed, unequal, unpigmented; velar lobes subcircular.

Cephalic area: unpigmented; tentacles medium-long.

Foot: unpigmented; typical cerithiopsid shape.

Viscera: digestive gland tan to light brown; stomach gray.

Months found in plankton: June, July, August

Areas found: Sampan Channel, Coconut Island, Dredged Island, Ala Moana Reef (Honolulu).

Remarks:

These veligers are one of the three most commonly netted cerithiopsid species in Hawaiian coastal waters.

Clathropsis turreta Laseron 1955. Plate XII, fig. h.

Veliger:

Protoconch: entirely rich red-brown, narrower than those of Cerithiopsis leucocephalum; metamorphosis occurs when four whorls complete, length: 450 µm, width: 240 µm.

Velum: as in C. leucocephalum.

Cephalic area: light tan.

Foot: golden.

Viscera: cannot be discerned through protoconch.

Months found in plankton: June, July

Areas found: Dredged Island

Remarks:

Veligers metamorphose and develop white teleoconchs.

Cerithiopsis sp.$_1$ Plate XII, fig. i.

The protoconch of this veliger is brown and broader than that of C. turreta.

Cerithiopsis sp.$_2$ Plate XII, fig. j.

This veliger is smaller than those of the other cerithiopsids, has a white, semi-transparent protoconch and is occasionally netted in the Bay.

Cerithiopsis balteata Watson 1886. Plate XII, fig. n.

This veliger most closely resembles veligers of C. sp.$_3$ with respect to all features except size. When veligers of both species have completed five whorls, individuals of C. balteata are approximately 560 µm while those pf C. sp.$_3$ are 710 µm.

Cerithiopsis sp.$_3$ Plate XII, figs. k-m.

Veliger:

Protoconch: elongate-conical, light tan, smooth; body whorl with spiral sutural thread; sutures tan to light brown; beak wide; siphonal canal truncate; metamorphosis occurs when 5 - 5 1/4 whorls complete, length: 700-710 µm, width: 300-310 µm.

Velum: bilobed, unequal, unpigmented; apical lobe 40 per cent larger than abapical.

Cephalic area: unpigmented; tentacles medium; eyes small, inside bases.

Foot: white, simple.

Viscera: digestive gland golden.

Months found in plankton: May, June

Areas found: Sampan Channel, Dredged Island, Coconut Island, Ala Moana Reef (Honolulu)

Remarks:

Veligers of this species are one of the three species of cerithiopsids netted in Kaneohe Bay.

Cerithiopsis sp.$_4$ Plate XII, fig. o.

Veliger:

Protoconch: elongate-conical, apex rounded; beak prominent, projecting; body whorl with axial riblets; remainder unsculptured save for scalloped sutures on anterior-most whorls, scalloping red-brown to maroon; background opaque light tan; siphonal canal truncate; metamorphosis occurs when 4-5 whorls complete, length: 570-630 µm, width: 280 µm.

Velum: bilobed, unequal, unpigmented; apical lobe elongate, abapical lobe rectangular; appears distorted.

Cephalic area: tentacles short, blunt; eyes far apart, inside tentacular bases; esophagus black.

Foot: shape typically cerithiopsid; meso- and metapodial areas heavily pigmented with purple-black, ciliated.

Viscera: digestive gland golden to red-brown; intestine lavendar-brown; stomach charcoal.

Months found in plankton: September, October

Areas found: Coconut Island

Remarks:

Veligers of this species are not commonly netted in Kaneohe Bay.

Cerithiopsis sp.$_5$ Plate XII, figs. p, q.

Veliger:

Protoconch: elongate, apex rounded; background light tan; smooth; columella, anterior half of body whorl red-brown; beak wide; siphonal canal truncate; metamorphosis occurs when 3 3/4 whorls complete, length: 480-500 μm, width: 250 μm.

Velum: bilobed, unpigmented; appears distorted; apical lobe elongate; abapical lobe auriculate.

Cephalic area: tentacles short; eyes small, inside bases; esophagus charcoal.

Foot: anterior margin tinted with red-brown; foot simple.

Viscera: digestive gland red-brown; intestine charcoal, long.

Months found in plankton: July, November, December

Areas found: Dredged Island

Remarks:

These veligers are not commonly collected in Kaneohe Bay.

Cerithiopsis filofusca Laseron 1951. Plate XII, figs. r-t.

Veliger:

Protoconch: elongate-conical, apex rounded; beak prominent, projecting; posterior four whorls faintly punctate; body whorl of protoconch with faint axial threads; transparent, light tan; sutures, columella, subsutural area of body whorl red-brown; siphonal canal truncate; metamorphoses when 600-700 µm long, 4 - 4 3/4 whorls complete, width: 240-280 µm.

Velum: bilobed, unequal; size of apical lobe almost twice that of abapical lobe; unpigmented; velar lobes subcircular; abapical lobe projects through siphonal canal.

Cephalic area: tentacles medium, slightly knobbed terminally; unpigmented.

Foot: cream to light tan; propodium rectangular; posterior margin a rounded vee; meso- and metapodial areas with circular patches of black pigment.

Viscera: digestive gland golden.

Months found in plankton: June through September

Areas found: Sampan Channel, Dredged Island, Coconut Island, Ala Moana Reef (Honolulu)

Remarks:

Veligers of this species are found in almost every two taken in the coastal waters of Hawaii. They metamorphose readily and graze on algal films on shells or rock chips.

Cerithiopsis turrigera Watson 1886. Plate XII, figs. u, v.

Veliger:

Protoconch: light tan, slender, lanceolate, smooth; sutures slightly impressed; metamorphosis occurs when 4 1/2 - 5 whorls complete, length: 500-590 µm, width: 210-230 µm.

Velum: bilobed, unpigmented, unequal.

Cephalic area: unpigmented.

Foot: simple, cream.

Viscera: digestive gland golden.

Months found in plankton: all months; peak abundance during summer months.

Areas found: Coconut Island, Dredged Island, Sampan Channel

Remarks:

Veligers of this species are among the most commonly collected cerithiopsids in the Kaneohe Bay plankton.

Cerithiopsis sp.$_6$ Plate XII, figs. w, z.

Veligers of this species resemble those of C. turrigera, but are wider and the protoconch is light tan with red-brown columellar and subsutural areas. Metamorphosis occurs when four whorls are complete; length: 570-620 µm, width: 240-270 µm.

PLATE XII

Cerithiopsidae: premetamorphic protoconchs.

Figs. a-c. *Cerithiopsis tricarinata*

d-g. *C. leucocephalum*

h. *Clathropsis turreta*

i. *Cerithiopsis* sp.$_1$

j. *C.* sp.$_2$

k-m. *C.* sp.$_3$

n. *C. balteata*

o. *C.* sp.$_4$

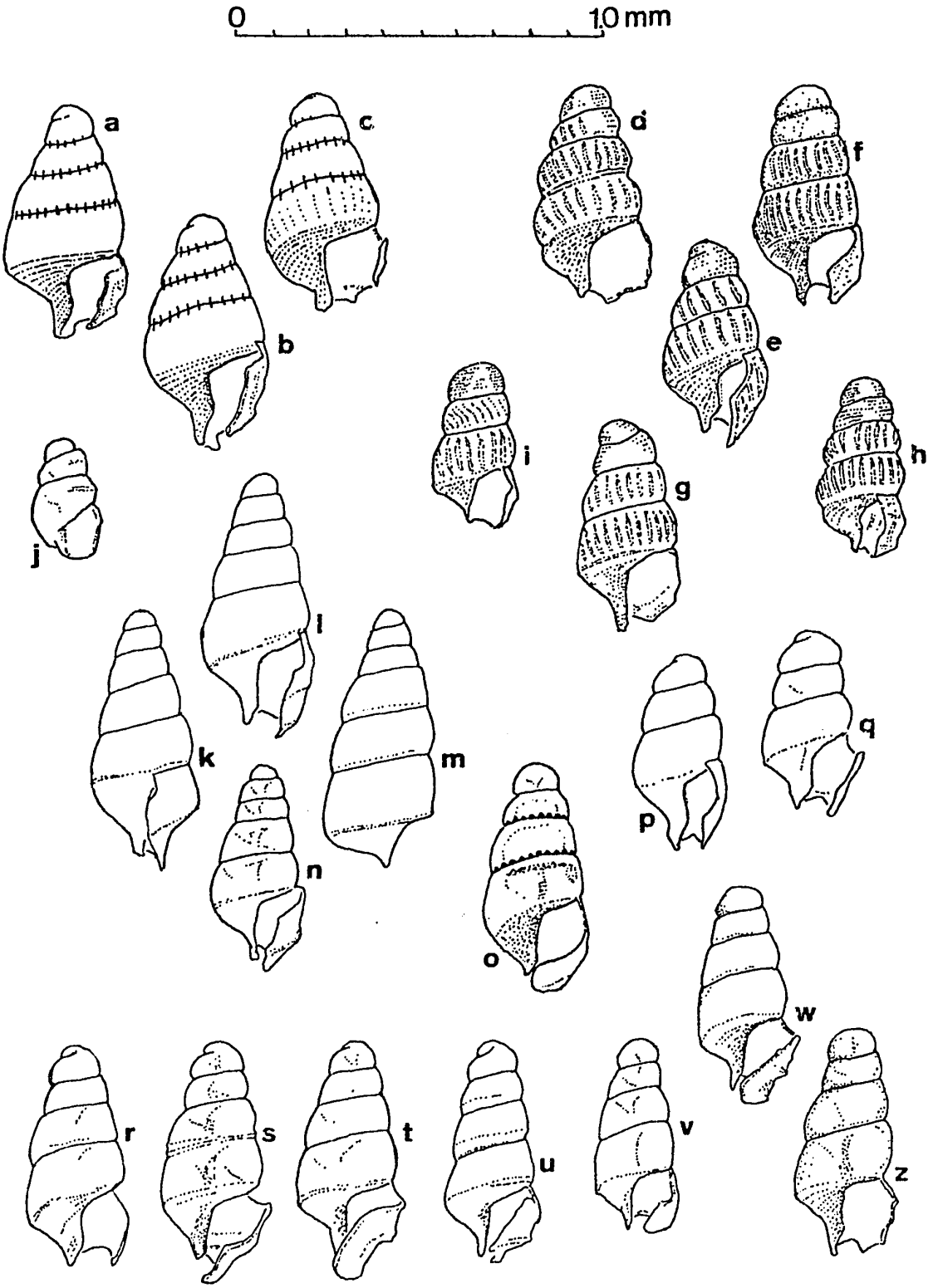
p, q. *C.* sp.$_5$

r-t. *C. filofusca*

u, v. *C. turrigera*

w, z. *C.* sp.$_6$

PLATE XII



Cerithiopsidae

Triphoridae

Triphorids are the only marine prosobranchs in Hawaii which have sinistral shells both as larvae and as adults. Molluscan larvae with sinistral protoconchs must be architectonicids, triphorids or opisthobranchs (which include pyramidellids). Adult triphorids are associated with sponges.

There are approximately 27 species of Triphora reported from Hawaii (Kay, unpubl.); with the possible exception of T. islandica, all appear to have a planktonic veliger stage.

I found three types of veligers: 1) the typical triphorid pattern with protoconchal sculpture of spiral keels connected or crossed by axial threadlets (see Pl. XIII, fig. b), 2) the type exemplified by T. maculata (Pl. XIII, fig. n) and 3) the type exemplified by T. tubularis (Pl. XIII, fig. p).

All of the planktonic triphorid veligers have bilobed, unequal velar lobes (left larger than right) which lack discrete patches of pigment but are occasionally suffused with a particular tinge of color (T. pallida). The triphorid foot is simple, with a rectangular propodium and a small tapered posterior edge.

Upon metamorphosis, the velum is usually ingested.

As with other families, maximal larval diversity and abundance occurs during the spring and summer months in Sampan Channel, but some triphorid veligers (e.g., T. incisa) are found in almost every tow.

Triphora cingulifera Hinds 1843. Plate XIII, fig. a.

Veliger:

Protoconch: acuminate; whorls straight-sided; sutures barely impressed; apical whorl colorless, faintly punctate; abapical whorl unicarinate; remaining whorls red-brown, bicarinate; metamorphosis occurs when 4 1/2 - 5 whorls complete, length: 560 µm, width: 330 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: light tan.

Foot: background cream with light pink-orange tinges.

Viscera: cannot be discerned through protoconch.

Months found in plankton: March through May

Areas found: Sampan Channel, Dredged Island, Coconut Island

Remarks:

These are some of the most commonly collected cerithiopsid veligers in the Kaneohe Bay plankton.

Triphora perfecta Pease 1870. Plate XIII, figs. b, c.

Veliger:

Protoconch: caramel-colored; apical whorl a little lighter than remaining whorls; apical 1 1/2 whorls punctate; remaining whorls unicarinate; metamorphosis occurs during formation of fifth whorl, length: 580 µm, width: 310 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: tentacles cream.

Foot: white.

Viscera: cannot be discerned through protoconch.

Months found in plankton: early March through June

Areas found: Sampan Channel, Dredged Island

Remarks:

Only a few of these veligers appear in any particular tow.

Triphora pallida (Pease 1870). Plate XIII, figs. d, e.

Veliger:

Protoconch: white; apical 1 1/2 whorls punctate; remaining whorls unicarinate with axial threadlets; metamorphosis occurs when 4 1/2 - 5 whorls complete, length: 570 µm, width: 350 µm.

Velum: bilobed, unequal; velar lobes circular; base of post-oral cilia tinged with pink-orange; diameter of larger lobe: 560 µm, smaller lobe: 365 µm.

Cephalic area: tentacles medium-short; eyes tiny, at base of cephalic tentacles.

Foot: white; ventrum with fine gray spots; propodium blunt, rectangular; posterior edge broadly tapered.

Viscera: digestive gland golden-brown; style sac light yellow.

Months found in plankton: January, August

Areas found: Sampan Channel, Dredged Island, Coconut Island

Triphora cancellata Hinds 1843. Plate XIII, fig. f.

Veliger:

Protoconch: long, slender; apical whorl punctate; remaining whorls bicarinate with axial threads; apical four whorls tan; remaining 2 1/2 whorls red-brown; metamorphosis occurs when 6 1/2 whorls complete, length: 880 μm, width: 445 μm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: light tan.

Foot: light tan.

Viscera: cannot be discerned through protoconch.

Months found in plankton: April through August

Areas found: Sampan Channel, Dredged Island

Remarks:

The initial teleoconch is white for the first half-whorl, then it becomes uniform red-brown. The remaining teleoconch has two crossed keels per whorl.

Triphora peasi Jousseaume 1884. Plate XIII, figs. g, h.

Veliger:

Protoconch: attenuate, caramel-colored; apical 1 1/2 - 2 whorls spirally punctate; whorls 3 - 7 bear two spiral keels and axial cross-ribs; siphonal canal short; metamorphosis occurs when 6 1/2 whorls complete, length: 870 µm, width: 445 µm.

Velum: bilobed, unpigmented, unequal; cruises in circles.

Cephalic area: tentacles medium-long; eyes inside bases of tentacles.

Foot: white; propodium blunt; metapodium tapering; simple.

Viscera: cannot be discerned through protoconch.

Months found in plankton: early March through August

Areas found: Sampan Channel, Dredged Island, Makapuu Point (Oahu)

Remarks:

Upon metamorphosis, the initial teleoconch is purple-pink with sparsely-spaced axial ribs; the two keels are retained.

Triphora flammulata (Pease 1861). Plate XIII, fig. i.

Veliger:

Protoconch: apical two whorls punctate, next whorl unicarinate; remaining two whorls bicarinate; red-brown; metamorphosis occurs when 4 1/2 - 5 whorls complete, length: 600 µm, width: 375 µm.

Velum: bilobed, unpigmented, unequal; left lobe larger than right.

Cephalic area: light tan.

Foot: light tan.

Viscera: cannot be discerned through protoconch.

Months found in plankton: August

Areas found: Sampan Channel

Remarks:

Veligers of this species are seldom collected from the Kaneohe Bay plankton.

Triphora incisa (Pease 1861). Plate XIII, figs 1, m.

Veliger:

Protoconch: apical whorl light red-brown, punctate; whorls 2-4 unicarinate with axial ribs; siphonal canal short; beak present; metamorphosis occurs during fifth whorl, length: 725 µm, width: 395 µm.

Velum: bilobed, unpigmented, unequal; left velar lobe larger than right.

Cephalic area: tentacles white, long, slender, with occasional brown granular areas interiorly; right tentacle longer than left; median to each eye, a brown spot; eyes inside tentacular bases.

Foot: white; operculum cream-colored, opaque, circular.

Viscera: cannot be discerned through protoconch.

Months found in plankton: all months; peak abundance during spring and summer months.

Areas found: Sampan Channel, Dredged Island, Coconut Island.

Remarks:

Veligers of T. incisa are the most common triphorids in the Kaneohe Bay plankton. Newly-metamorphosed juveniles of this species eat light brown filamentous algae. By the seventh whorl from the apex the adult spiral sculpture is established and the animal is sienna and white.

Triphora trilirata Deshayes 1863. Plate XIII, fig. k.

Veligers of this species resemble those of T. incisa too closely to warrant a separate description; those of T. trilirata tend to have braoder apical whorls and less prominently-projecting sculpture.

Triphora maculata Pease 1846. Plate XIII, figs. n,o.

Veliger:

Protoconch: pink-tan, stoutly-constructed; apical whorl lighter than remainder; sculpture of two spiral rows of round tubercles; metamorphosis occurs when 3 1/2 - 4 whorls complete, length: 930 µm, width: 580 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: white.

Foot: white.

Viscera: cannot be discerned through protoconch.

Months found in plankton: August

Area found: Sampan Channel

Remarks:

Veligers of this species are not commonly collected from the Kaneohe Bay plankton.

Triphora tubularis (Laseron 1958). Plate XIII, figs. p, q.

Veliger:

Protoconch: light golden, opaque, stout; apical whorl mamillate; remaining whorls with thick spiral cords and obsolete axial threadlets; metamorphosis occurs when 3 1/2 whorls complete, length: 640 µm, width: 440 µm.

Velum: bilobed, unpigmented, unequal.

Cephalic area: light tan.

Foot: light tan, simple.

Viscera: cannot be discerned through protoconch.

Months found in plankton: April

Area found: Sampan Channel

Triphora sulcosa (Pease 1870). Plate XIII, fig. r.

Veliger:

Protoconch: golden; resembles that of T. tubularis except spiral cords less prominent; metamorphosis occurs when 3 1/2 whorls complete, length: 590 µm, width: 390 µm.

Animal: light tan.

Months found in plankton: September

Areas found: Dredged Island

PLATE XIII
Triphoridae

Figure a. Triphora cingulifera

b. Triphora perfecta

c. " "

d. Triphora pallida

e. " "

f. Triphora cancellata

g. Triphora peasi

h. " "

i. Triphora flammulata

j. Triphora sp.

k. Triphora trilirata

l. Triphora incisa

m. " "

n. Triphora maculata

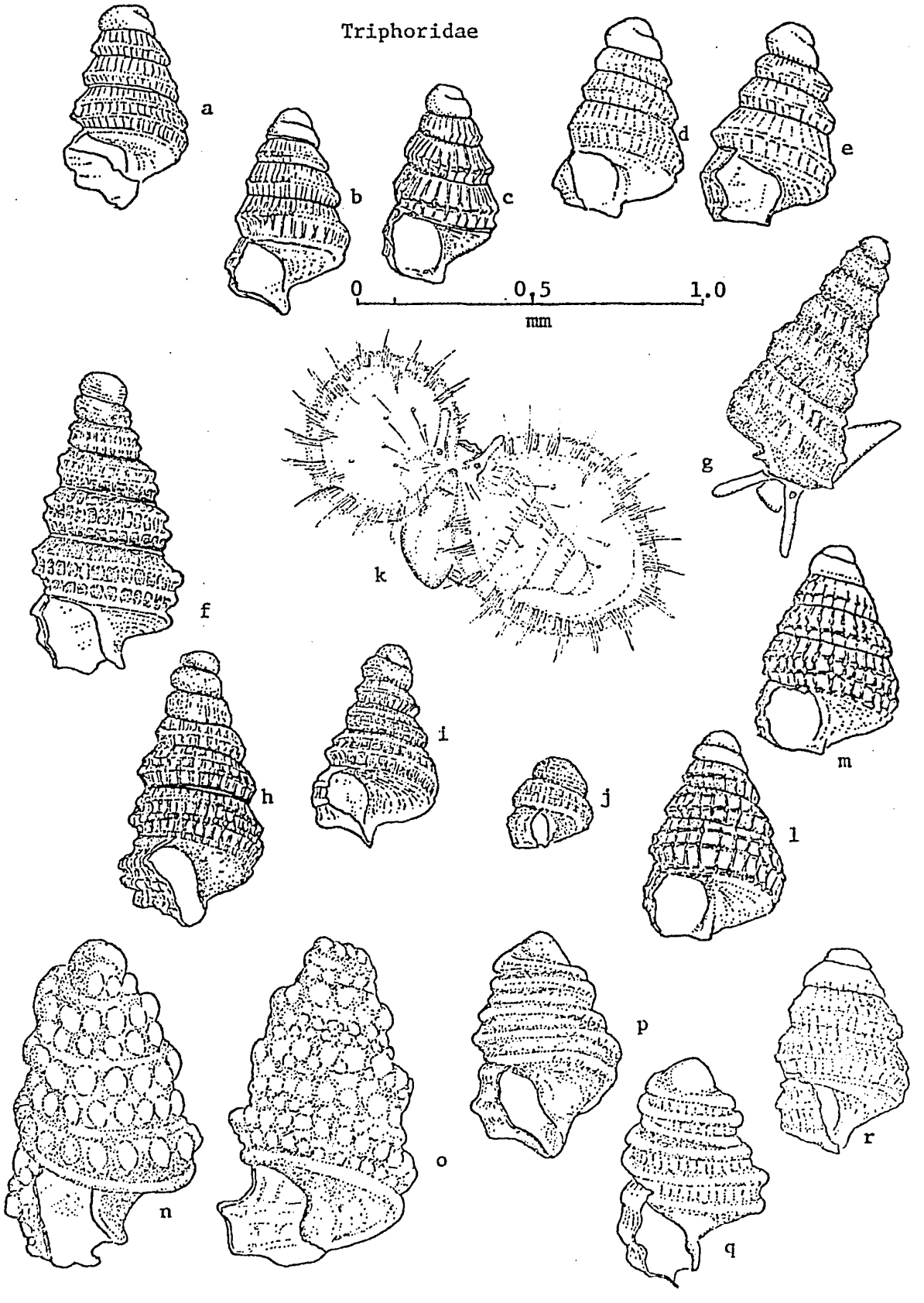
o. " "

p. Triphora tubularis

q. " "

r. Triphora sulcosa

Triphoridae



Superfamily 11. Epitoniacea

Epitoniaceans include the Epitoniidae* and Janthinidae*.

Superfamily characteristics: shell tall, turriform, axially ribbed, spiral lines occasionally present; radula ptenoglossate (teeth similar, recurved); feed on coelenterates; violet secretions produced by hypobranchial gland; protandrous hermaphrodites, penis lacking, spermatozeugmata formed in testis bear eupyrene sperm to mates; originated in the Jurassic.

Epitoniidae (=Scalidae)

Epitoniid life histories are summarized in Table 10. Epitoniids produce small eggs in small capsules and undergo short intracapsular phases. They hatch as planktonic veligers and metamorphose when three to six whorls are complete. Breeding of temperate species apparently is restricted to the summer months (Vestergaard 1935; Ankel 1936; Lebour 1937a), but Epitonium larvae are in the Kaneohe Bay plankton during all months.

When retained in sea water tables in which Aiptasia sp. is available, juveniles of two species of Epitonium required three weeks beyond metamorphosis to produce their first viable egg capsules. Intracapsular time is approximately five days.

In Hawaii, there are at least 15 species in three epitoniid genera. With the possible exception of Nodiscala attenuata, all appear to have a planktonic veliger stage.

Epitoniid veligers appear remarkably uniform. Each has a bilobed unequal velum (which may or may not be pigmented), a shining protoconch of teardrop shape, and a simple inconspicuous foot. The most conspicuous feature of the epitoniid veliger is the purple-black rectangular structure, presumably the larval hypobranchial gland, which releases brilliant purple secretions; it is located subsuturally in the body whorl adjacent to the intestine.

E. kanemoe, E. fucatum and E. ulu are the most commonly-collected epitoniid veligers in the Coconut Island region; as with other families, the greatest diversity and abundance of epitoniid veligers is encountered in Sampan Channel. I found veligers of twelve of the named species and larvae of two others which are as yet unnamed.

Table 10. Life History Data: Epitoniidae.

Species	Data	Source
Scala clathrus (Linne)	egg size: "480 μ" [48 μm?]; hatch at 1 1/2 whorls; velum bilobed; breed June-August; eggs in small capsules	Vestergaard 1935; Ankel 1936, 1938; Lebour 1937a
Scala turtonis Lamarck (=Epitonium communis)	hatch when 150-180 μm long; velum bilobed, colorless; umbilicus red-brown; breed during July; eggs in small capsules	Vestergaard 1935

Epitonium ulu Pilsbry 1921. Plate XIV, figs. a, b, c.

Veliger:

Protoconch: transparent, white; apex rounded; capsular protoconch with faint axial growth lines; sculpture otherwise smooth on all whorls; third whorl with five spirals of punctae; sutures light red-brown; beak, siphonal canal lacking; columella, outer apertural edge red-brown; metamorphosis occurs when four whorls complete, length: 630-650 µm, width: 370-390 µm.

Velum: small, bilobed, subequal, unpigmented; velum in newly-hatched veligers with long cilia; velar lobes rounded ventrally, more pointed dorsally.

Cephalic area: esophagus large, light gray-mauve; tentacles thick.

Foot: purple-black.

Viscera: digestive gland dark golden-brown; hypobranchial gland purple, occasionally releases purple fluid which suffuses protoconch with lavendar.

Months found in plankton: April, October

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of this species metamorphose readily in captivity and deposit viable egg capsules approximately 20 days after settling. In capsulo duration is five days (Guinther 1970); planktonic duration is unknown, but I would estimate that the maximal duration is two weeks.

Teleoconch: first 1 1/2 whorls develop low, sinuous, delicate varices which are curved and widely spaced, but not hooked;

varices tend to be abraded completely in older specimens; when feeding on Aiptasia, shell regularly mottled with tan blotches; interspaces between varices smooth.

Epitonium ?oahuense Pilsbry 1921. Plate XIV, figs. d, e.

Veliger:

Protoconch: pink-tan, smooth, sutures pink, barely impressed; whorls straight-sided; apex rounded; metamorphosis occurs when four whorls complete, length: 610 μm, width: 320 μm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: cream.

Foot: cream-tan.

Viscera: digestive gland light brown; hypobranchial gland rectangular, black.

Months found in plankton: July through September

Areas found: Sampan Channel

Remarks:

These veligers are uncommonly collected in the Kaneohe Bay plankton. The initial teleoconch is white and develops sinuous, widely-placed, low, rounded axial ribs and a basal keel. They resemble the veligers of E. ulu but the protoconchs of ?oahuense are narrower.

Epitonium fucatum (Pease 1861). Plate XIV, fig. f.

Veliger:

Protoconch: transparent, colorless except for columella; columella dark gold; sutures impressed; whorls inflated; when fourth whorl is body whorl light axial ribbing begins; beak, siphonal canal lacking; metamorphosis occurs when four whorls complete; length, 660 μm; width, 410-470 μm.

Velum: bilobed, unpigmented; right lobe slightly larger than left, auriculate.

Cephalic area: tentacles long.

Foot: propodium long; anterior edge rectangular; posterior margin with green-white glandular area; ventrum smudged with purple-black; operculum oval.

Viscera: digestive gland black; hypobranchial gland large, square, black.

Months found in plankton: all months

Areas found: Coconut Island, Dredged Island

Remarks:

These veligers are the second most commonly collected epitoniid in the Coconut Island area. After metamorphosis the digestive gland remains black; the purple-black hypobranchial gland area becomes stretched out and rounded. The teleoconch develops strongly-hooked, widely-placed axial flanges after about two whorls are constructed. Among other anthozoans, juveniles of E. fucatum prey upon Radianthus papillosa (as Macranthea cooki, Guinther 1970).

Epitonium umbilicatum (Pease 1869). Plate XIV, figs. g, h, i.
Plate XVI, color plate.

Veliger:

Protoconch: smooth, transparent; colorless except for outer apertural edge, sutures, columella (red-brown); beak, siphonal canal lacking; metamorphosis occurs when 4 1/2 - 5 whorls complete, length: 625 μm, width: 340-350 μm.

Velum: bilobed, unequal; right velar lobe larger, with light blue-gray pigment in central area, yellow-green pigment spots in food groove between pre- and post-oral cilia.

Cephalic area: tentacles with red-orange spots at bases; eyes far apart, inside tentacular bases.

Foot: with yellow-green pigment spots.

Viscera: digestive gland light brown; intestine brown; hypobranchial gland rectangular, black.

Months found in plankton: September

Areas found: Dredged Island, Sampan Channel, occasionally Coconut Island.

Remarks:

The initial teleoconch of these juveniles develops many closely placed, well-defined axial ribs and parallel spiral engravings. Veligers of E. kanemoe resemble E. umbilicatum except that E. kanemoe are more slender, the velum is pigmented and the initial teleoconch develops fewer axial ribs.

Epitonium millecostatum (Pease 1861). Plate XIV, fig. k.

Veligers of this species have a tan digestive gland and the usual bilobed, unequal, unpigmented velum characteristic of epitoniids. The protoconch is colorless with sutures barely impressed and whorls slightly inflated. Metamorphosis occurs when 3 3/4 to four whorls are complete; the length is 650 μm, and the width is 360 μm.

The larvae occur in the summer plankton of the Sampan Channel and Dredged Island areas.

Epitonium paumotensis (Pease 1868). Plate XIV, figs 1, m.

Veliger:

Protoconch: light tan, faintly punctate; sutures barely impressed; whorls slightly inflated; metamorphosis occurs when 4 1/2 whorls complete, length: 730 μm, width: 410 μm.

Velum: bilobed, unpigmented, unequal.

Cephalic area: unpigmented.

Foot: simple, white.

Viscera: digestive gland light tan; hypobranchial gland purple-black, rectangular.

Months found in plankton: April through September

Areas found: Sampan Channel, Dredged Island

Remarks:

Veligers of this species metamorphosed in captivity and are uncommon in the Kaneohe Bay plankton. The initial teleoconch develops stout, sparsely-placed hooked axial ribs; the interstices are smooth and white.

Epitonium sp.$_1$ Plate XIV, figs. n, o.

Veliger:

Protoconch: stout; apex rounded; punctate; sutures, columella red-brown; metamorphosis occurs when five whorls complete, length: 750 µm, width: 410 µm.

Velum: unpigmented, bilobed, subequal.

Cephalic area: unpigmented.

Foot: background light tan; ventrum smudged with purple-black.

Viscera: digestive gland golden; hypobranchial gland purple-black; intestine inconspicuous.

Months found in plankton: June through September

Area found: Sampan Channel

Epitonium alatum (Sowerby 1844). Plate XIV, figs. p, q, r.

Veliger:

Protoconch: light tan; punctate with spirals intersecting axial series creating a lattice effect; sutures, columella, umbilical area red-brown; metamorphosis occurs when five whorls complete, length: 800-890 µm, width: 400-420 µm.

Velum: unpigmented, bilobed, subequal.

Cephalic area: unpigmented.

Foot: simple, tinged with black; operculum oval, nucleus central, medium red-brown.

Viscera: digestive gland variable in color; hypobranchial gland large, easily releases purple secretions prior to and during metamorphosis.

Months found in plankton: April, May, August

Area found: Sampan Channel

Remarks:

Veligers of this species are abundant in the spring plankton of the outer Bay.

PLATE XIV

Figure a, b, c. *Epitonium ulu*

d, e. *E.* ?*oahuense*

f. *E. fucatum*

g, h, i. *E. umbilicatum*

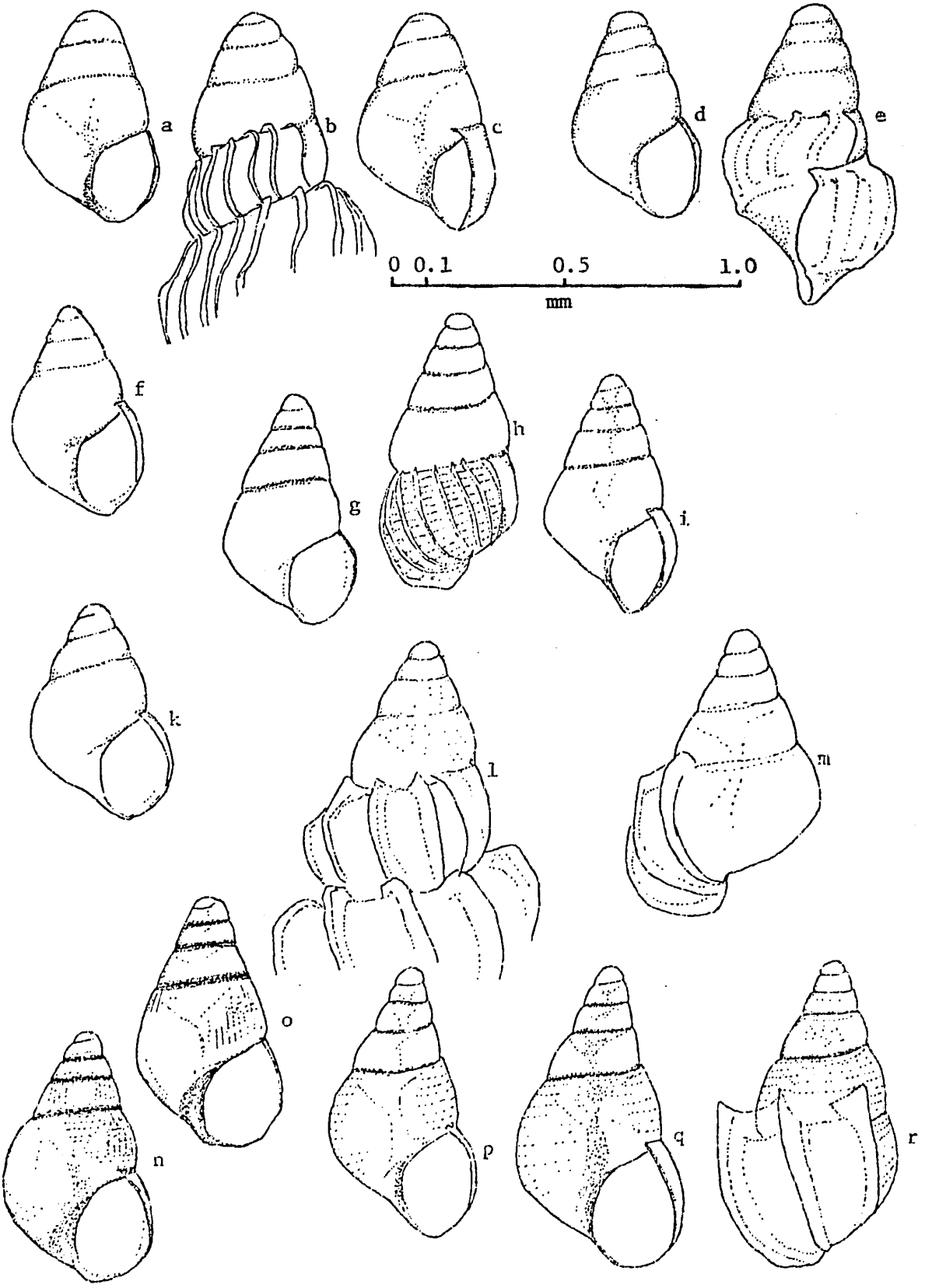
k. *E. millecostatum*

l, m. *E. paumotensis*

n, o. *E.* sp.$_1$

p, q, r. *E. alatum*

PLATE XIV



Epitoniidae

Epitonium kanemoe Pilsbry 1921. Plate XV, figs. a-c, i.

Veliger:

Protoconch: teardrop-shaped, white; sutures impressed; columella light red-brown, conspicuous; beak shallow, broadly angular; umbilicus shallow; body whorl of protoconch with low axial threads; metamorphosis occurs when five whorls complete, axial red-brown lineations acquired.

Velum: bilobed, unequal; right velar lobe larger, with yellow pigment; left smaller, with blue-gray cast; resting extended velum with pre-oral cilia projected anteriorly in a fringe; pre-oral cilia long.

Cephalic area: tentacles medium, blunt, terminated with short 'bristles'; eyes large, black, round.

Foot: long, slender, ciliated; propodium triangular; operculum oval.

Viscera: digestive gland yellow to light brown; hypobranchial gland black with five white spots.

Months found in plankton: March-October.

Areas found: Dredged Island, Sampan Channel, Coconut Island

Remarks:

Veligers of this species are the most commonly-collected epitoniid veligers of both the inner (southern end) and outer (east-north-eastern) side of Kaneohe Bay.

Epitonium sp.$_2$ (?*revolutum*) (Hedley 1899). Plate XV, figs. d-f.

Veliger:

Protoconch: light tan, smooth; sutures barely impressed; whorls straight-sided; metamorphosis occurs when 4 3/4 whorls complete, length: 590 µm, width: 270 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: light tan, simple.

Viscera: hypobranchial gland narrow, inconspicuous.

Months found in plankton: August-September

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of this species are uncommonly collected from the Kaneohe Bay plankton. The initial teleoconch develops low, broad axial ribs soon after metamorphosis.

Epitonium sp.$_3$ (?hyalinum mokuolensis Pilsbry 1921). Plate XV, figs. g-h.

Veliger:

Protoconch: transparent white; apex broad, round; whorls straight-sided; sutures, columella red-brown; metamorphosis occurs when three whorls complete, length: 480-500 µm, width: 290-300 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: simple, white.

Viscera: hypobranchial gland narrow, inconspicuous; digestive gland tan.

Months found in plankton: April through September

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers of this species closely resemble those of E. ulu except they metamorphose earlier and develop a different teleoconch. The initial teleoconch develops sparsely-distributed angular axial ribs with smooth interstices.

Epitonium perplexum (Deshayes 1863). Plate XV, figs. j, k.

Veliger:

Protoconch: slender, tan, smooth; sutures barely impressed; whorls almost straight-sided, slightly inflated; metamorphosis occurs when 4 3/4 - 5 whorls complete, length: 620 µm, width: 280-300 µm.

Velum: bilobed, subequal; apical lobe with spots of yellow at base of post-oral cilia; abapical lobe with blue-gray spots.

Cephalic area: unpigmented.

Foot: simple; light tan, spotted with yellow-green.

Viscera: digestive gland light brown; hypobranchial gland inconspicuous relative to other epitoniid larvae.

Months found in plankton: July, September-November

Areas found: Sampan Channel, Dredged Island

Remarks:

The initial white teleoconch develops well-defined sparsely-distributed axial ribs at the shoulder.

Figure 1 of the same plate resembles the above description except that its protoconch has rose-orange sutures. They may be variations of E. perplexum.

Epitonium sp.$_4$ Plate XV, fig. n.

Veliger:

Protoconch: white, slender, acuminate, smooth; sutures barely impressed; third whorl with axial parallel indentations; beak and siphonal canal lacking; metamorphosis occurs when 5 1/2 - 6 whorls complete, length: 625 µm, width: 300 µm.

Velum: bilobed, with yellow-gold pigment at base of post-oral cilia.

Cephalic area: tentacles medium-long, tapered; eyes peripheral to base of tentacles.

Foot: posterior margin black.

Viscera: digestive gland golden; intestinal area with large black rectangular hypobranchial gland.

Months found in plankton: September-October

Areas found: Coconut Island, Dredged Island

Remarks:

Veligers of this species are not commonly netted in Kaneohe Bay.

Epitonium aculeatum (Sowerby 1844). Plate XV, figs. o, p.

Veliger:

Protoconch: light tan; all whorls with parallel spirals of punctae; sutures, columella medium red-brown; metamorphosis occurs when five whorls complete, length: 630 µm, width: 320 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: simple, light tan.

Viscera: hypobranchial gland inconspicuous.

Months found in plankton: May

Areas found: Sampan Channel, Dredged Island

Remarks:

The initial teleoconch develops somewhat hooked oblique axial ribs; the interspaces are smooth.

PLATE XV

Figure a, b, c. *Epitonium kanemoe*

d, e, f. *E.* sp.$_2$ (?*revolutum*)

g, h. *E.* sp.$_3$ (?*hyalinum mokuolensis*)

i. *E. kanemoe*

j, k. *E. perplexum*

l. *E.* ?*perplexum*

m. *Janthina globosa*

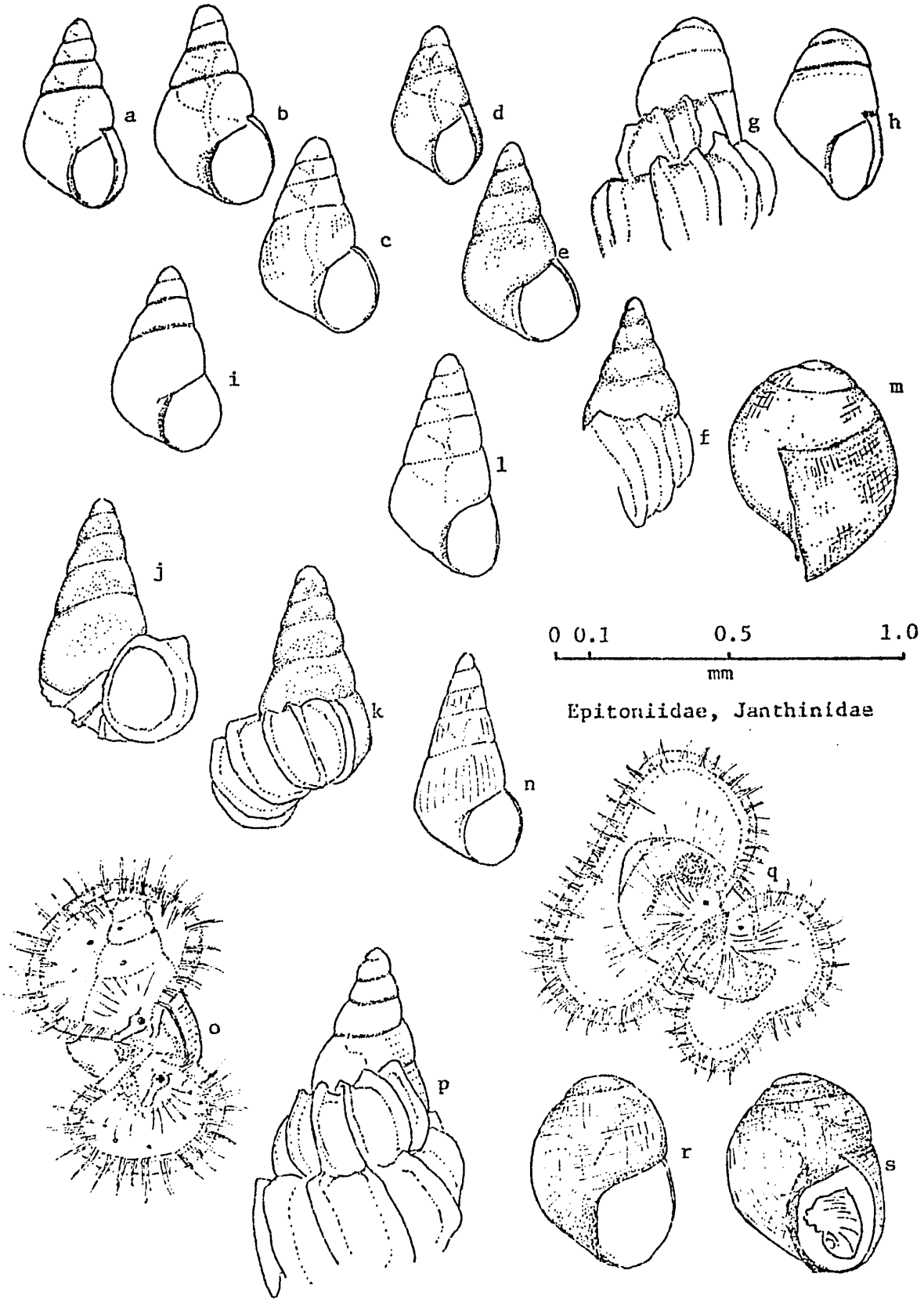
n. *E.* sp.$_4$

o, p. *E. aculeatum*

q, r. *Janthina janthina*

s. *Janthina globosa*

PLATE XV



Epitoniidae, Janthinidae

PLATE XVI

Epitonium umbilicatum: left, newly-metamorphosed juvenile; right, swimming veliger.

1.3mm

Janthinidae

Although many authors have described the floats and egg capsules produced by janthinids, little is known of janthinid planktonic larvae except for that provided by Natarajan (1957) for veligers in Indian waters (Table 11). Heretofore, no premetamorphic veligers have been figured.

In Hawaiian waters, there are four species of Janthina (Kay, unpubl.). Of these, two species of veligers (J. globosa, J. janthina) have been collected in Sampan Channel during plankton tows following strong offshore winds. Veligers of the two species are quite similar (see Plates XV, XVII). Affinities between the janthinids and epitoniids are suggested by the conspicuous presence in both families of a larval hypobranchial gland which produces violet secretions.

Table 11
Life History Data: Janthinidae

Species	Data	Reference
Janthina globosa Swainson =J. prolongata Blainville	egg size: 66 µm; in capsulo period 'at least 2 days'; hatching size 83-100 µm across; velum 'like a sheet without lobes', unpigmented, bordered by small cilia; spawn July-August (India); newly-hatched larva is ~100 µm, greatest dimension.	Natarajan 1957; Simroth 1964
Janthina janthina =J. fragilis Lamarck	viviparous	Lebour 1937a; Natarajan 1957; Simroth 1964.

Janthina globosa Swainson 1822. Plate XV, figs. m, s;
Plate XVII, below.

Veliger:

Protoconch: clear with tints of suffused magenta-pink-purple; apical whorl barely evident; sculpture of fine, closely-crowded cancellations; columella red-brown; suture purple; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 600 µm, width: 450-70 µm.

Velum: bilobed, unequal, unpigmented; apical lobe larger by 50% than abapical; abapical lobe indented, oval, with many conspicuous muscle endings; cilia medium-long.

Cephalic area: 'face' area with one streak of charcoal gray lateral to each eye; tentacles inconspicuous before metamorphosis.

Foot: magenta; propodium spatulate; operculum magenta.

Viscera: style sac, intestine black; digestive gland tan.

Months found in plankton: August, October, March

Areas found: Sampan Channel

Juvenile:

In the newly-metamorphosed juvenile, for a short while the rectangular hypobranchial gland remains inconspicuous; it resembles that of epitoniid veligers.

Plate XVII (below) shows a juvenile with the proboscis extended upward and part of the ptenoglossate radula exposed. Directly below the bulbous proboscis are the stubby bifid cephalic tentacles with the round purple-black eye at the base. Extending to the left of the photograph is the spatulate propodium.

Unless one is committed to procure the siphonophores upon which these juveniles feed, efforts to determine growth rates of these juveniles will fail.

Janthina janthina (Linnaeus 1758). Plate XV, figs. q, r; Plate XVII, fig. 1 (above)

Veliger:

Protoconch: globose, suffused with lavendar; metamorphosis occurs when 2 - 2 1/4 whorls complete, length: 570 µm, width: 350 - 380 µm.

Velum, cephalic area, foot and viscera like those of J. globosa.

Remarks:

Veligers of this species are occasionally taken in the March through May plankton in Sampan Channel. J. janthina 'appears to be viviparous' (Natarajan 1957).

PLATE XVII
Janthinidae

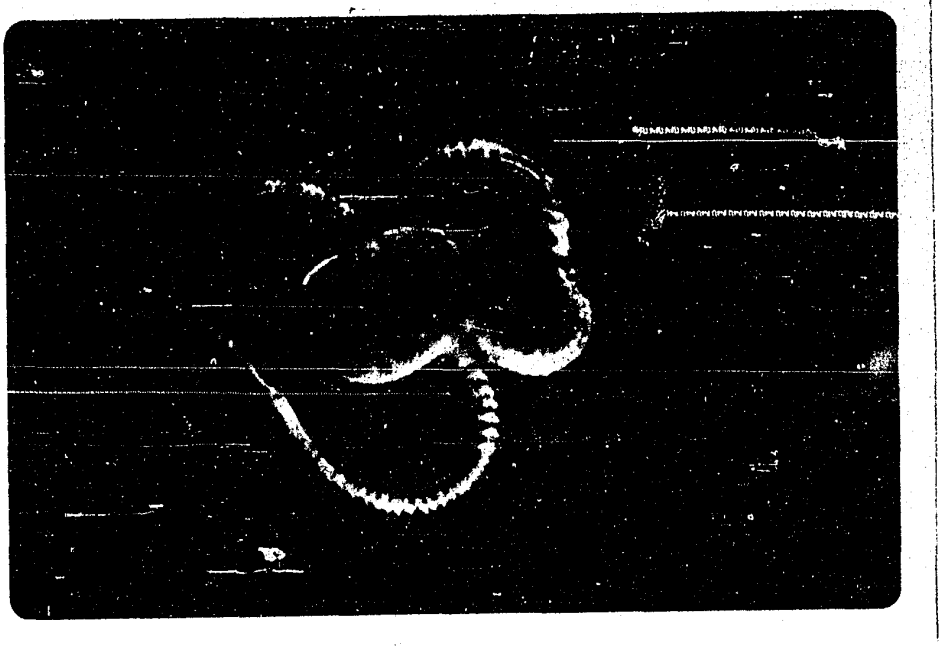
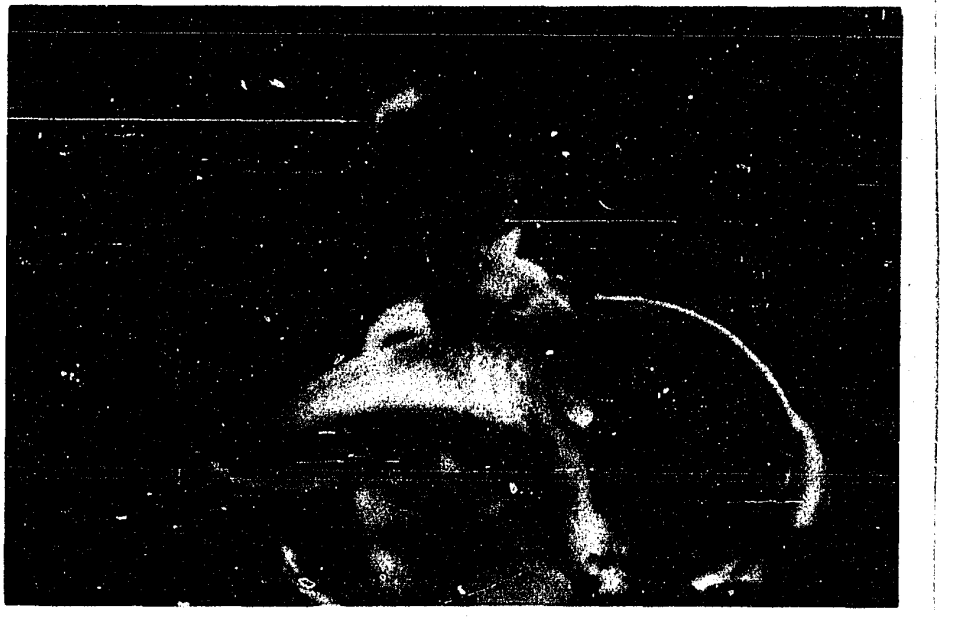


Figure 1 (above): Janthina janthina, premetamorphic veliger.
Figure 2 (below): Janthina globosa, newly-metamorphosed juvenile.



1.3mm

Superfamily Eulimacea.

Eulimacea includes the families Aclididae, Eulimidae* (=Melanellidae), Paedophoropodidae and Stiliferidae*.

Superfamily characteristics: shell tall, smooth, highly-polished; ectoparasitic on echinoderms; radula frequently absent; proboscis generally long; buccal region transformed into a pump; stomach small; operculum lacking; sexes generally separate, some hermaphroditism.

There are no descriptions of paedophoropodid development in the literature.

Eulimid and stiliferid veligers have protoconchs shaped like teardrops; they are distinguished from epitoniid protoconchs by the shape of the aperture (compare Plate XVIII with Plates XIV and XV) and by their glassy smoothness. Although the velum in both cases is bilobed and unequal, I know of no eulimacean with velar spots or suffusions of pigment. I cannot yet distinguish eulimid veligers from stiliferid veligers.

Table 12
Life History Data: Eulimidae

Species	Data	Reference
Balcis alba (da Costa)	eggs: 100-160µm; hatch 3 weeks later; remain for a long time as veligers (until August, September) newly-hatched larva: 160-180µm, 1 1/2 whorls; apex very broad; oral and esophageal areas black; velum bilobed, colorless, unequal; foot gray to black; metamorphosis occurs when 660-720µm long; adult with white body flecked with orange and yellow; breed March, April	Lebour 1935
Balcis devians	apex broad; whorls straight-sided; sutures barely impressed; velum colorless, lobes round; digestive gland pale yellowish brown; metamorphosis occurs when 4-5 whorls complete; larvae common in July through September	Lebour 1935; Thorson 1946
Melanella acicula	like Balcis, length: 480µm	

Eulimidae

In Hawaii, there are approximately fifteen eulimid species in one genus.

In Hawaiian waters, most eulimids parasitize holothurians, but some are free-living. In adult eulimids, the operculum is thin and flexible; the apex is not mucronate (Kay, unpubl.).

Table 13. Life History Data: Aclididae, Stiliferidae

Species	Data	References
Aclididae		
Aclis minor	protoconch faint purplish-blue with purplish-red columella and umbilicus; youngest larva is 200µm; the veliconcha is greater than 550µm; velum bilobed, unequal, unpigmented; breed August through September; hypobranchial gland purple-black; digestive gland red-brown to yellow-brown; foot bordered with red-brown dots; sculpture of axial growth lines; oral area purple-black	Thorson 1946
Stiliferidae		
Stilifer stylifer	early veliger: egg size, 100µm; capsular protoconch pale brownish-horn color, transparent; hatching size: 130µm across; velum of two rounded, colorless lobes; foot short, round; eyes very far apart; metamorphose when 2 1/2 - 3 whorls complete	Lebour 1932, 1937a; Ankel 1938; Thorson 1946

Stiliferidae

In Hawaii, there are approximately eight stiliferid species in four genera. Stiliferids are reported as parasitizing echinoids ectoparasitically and asteroids endoparasitically. In adult stiliferids the apex is mucronate and the operculum lacking (Kay, unpubl.).

Eulimacean sp.$_1$ (?Mucronalia nitidula Pease 1861). Plate XVIII, figs. a, b, and d.

Veliger:

Protoconch: colorless, transparent, smooth, glassy; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 610 µm, width: 320 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented; tentacles thick, short, blunt with red-orange pigment bodies adjacent to eyes.

Foot: cream, simple.

Viscera: digestive gland light brown.

Months found in plankton: all months

Areas found: Dredged Island, Coconut Island

Eulimacean sp.$_2$ (?Balcis subpellucida Pease 1865). Plate XVIII, fig. c.

Veligers of this species resemble those described above too closely to warrant a separate description. They differ primarily in 1)protoconchal shape and 2)abundance (M. nitidula are commonly collected, B. subpellucida, not). B. subpellucida veligers have cephalic tentacles with yellow pigment interiorly and red-orange basally.

Eulimacean sp.3 [?*Balcis kanaka* (Pilsbry 1917)]. Plate XVIII, figs. e-g.

Veliger:

Protoconch: clear, transparent, smooth, glassy; sutures, columella red-brown; beak develops when 3 1/2 whorls complete: metamorphosis occurs when four whorls complete, length: 510-545 µm, width: 230-240 µ.

Velum: bilobed, unequal, unpigmented; velar lobes oval, right lobe 50% larger than left.

Cephalic area: right tentacle longer than left; tentacles short, thick, with opaque white spots; eyes far apart, with magenta purple shine, inside tentacular bases; esophagus, mouth purple-black.

Foot: small, white; anterior edge rectangular, smudged with gray.

Viscera: digestive gland emerald green, like clusters of green grapelets; larval heart conspicuous; hypobranchial gland pink-purple.

Months found in plankton: September through November

Areas found: Dredged Island, Coconut Island

Remarks:

Veligers of this species are among the most commonly collected planktonic eulimids of the inner bay during the autumnal months.

Eulimacean sp.$_4$ [?*Balcis cumingii* (A. Adams 1851)]. Plate XVIII, fig. h.

Veliger:

Protoconch: translucent cream, smooth; sutures impressed, whorls slightly inflated; columella red-brown; metamorphosis occurs when three whorls complete, length: 620 µm, width: 320 µm.

Velum: unpigmented, unequal, bilobed.

Cephalic area: tentacles short, thick, with yellow spots.

Foot: cream, bordered with chrome yellow spots.

Viscera: digestive gland golden.

Months found in plankton: March through August

Areas found: Dredged Island, Sampan Channel

Eulimacean sp.$_5$ (?Stilifer thaanumi Pilsbry 1917). Plate XVIII, fig. i.

Veliger:

Protoconch: transparent, colorless, glassy; body whorl angled slightly; metamorphosis occurs when three whorls complete, length: 580 µm, width: 280 µm.

Remarks:

The remainder of the data was misplaced. These veligers are neither abundant nor rare in the plankton near Dredged Island.

Eulimacean sp.$_6$ Plate XVIII, fig. j.

Metamorphosis occurs when four whorls are complete, length: 550 µm, width: 270 µm.

Eulimacean sp.$_7$ (?Balcis thaanumi Pilsbry 1917). Plate XVIII, fig. k.

Metamorphosis occurs when three whorls are complete, length: 480 µm, width: 280 µm.

Eulimacean sp.$_8$ [?Balcis aciculata (Pease 1861)]. Plate XVIII, figs. 1, m, q.

Veliger:

Protoconch: translucent cream, smooth; sutures barely impressed; metamorphosis occurs when four whorls complete, length: 620 µm, width: 300 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: tentacles, short, thick, with red-orange pigment bodies interiorly; eyes close together.

Foot: cream, simple.

Viscera: digestive gland tan.

Months found in plankton: July, August, February.

Areas found: Dredged Island

Remarks:

The juveniles develop a teleoconch of pure shining white. The mantle is white tinged with charcoal and with discrete circular red-orange spots. There are also red-orange spots in the tentacles.

Eulimacean sp.$_9$ [?Balcis bryani (Pilsbry 1917)]. Plate XVIII, figs. n,r.

Veligers of this species metamorphose when three whorls are complete; the length is 460 to 480 µm and the width is 260 to 270 µm. The sutures are tinged with red-brown. In the cephalic area, the tentacles are long with purple pigment bodies interiorly. These veligers may be found during October east of Dredged Island.

?Eulimacean sp.$_{10}$ Plate XVIII, figs. o, p.

Veliger:

Protoconch: transparent, colorless, glassy; sutures colorless, not impressed; columella, umbilical area red-brown; metamorphosis occurs when 3 - 3 1/2 whorls complete, length: 680 µm, width: 400 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: tentacles close together, knobbed terminally.

Foot: charcoal.

Viscera: digestive gland emerald green.

Months found in plankton: May through August; peak abundance in May

Areas found: Dredged Island, Coconut Island.

Remarks:

The brilliant green of the digestive gland suggests that veligers of this species are feeding primarily on chlorophytes and that they are ingesting their food into the digestive gland with little digestive alteration.

I do not know for certain in what superfamily to include these veligers. Though they have metamorphosed, the juveniles have never deposited sufficient teleoconch to permit identification. I have included them in the eulimacean plate because of 1) their glassy appearance, 2) the shape of the aperture, 3) the similarity of the 'face' and foot to those of eulimid veligers and 4) the presence of the emerald green digestive gland. I could not superimpose its protoconch with that of any eulimacean. The shape of the protoconch is reminiscent of the tiny marginellid abundant in the area east of Dredged Island, Granula sandwichensis (Pease 1861).

Eulimacean sp.$_{11}$ (?Subularia metcalfei A. Adams 1853). Plate XVIII, fig. s.

Veliger:

Protoconch: smooth, transparent white, glassy; sutures barely impressed; metamorphosis occurs when three whorls complete, length: 580 µm, width: 300 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: unpigmented.

Foot: simple, cream.

Viscera: digestive gland golden.

Months found in plankton: March through October

Areas found: Dredged Island, Sampan Channel, Coconut Island

Eulimacean sp.$_{12}$ (?Stilifer mittrei Petit 1851). Plate XVIII, fig. t.

Veliger:

Protoconch: colorless, apex narrow; sutures unpigmented, not impressed; metamorphosis occurs when four whorls complete, length: 620 - 630 µm, width: 310 µm.

Velum: bilobed, unpigmented, unequal.

Cephalic area: unpigmented.

Foot: tinged with charcoal.

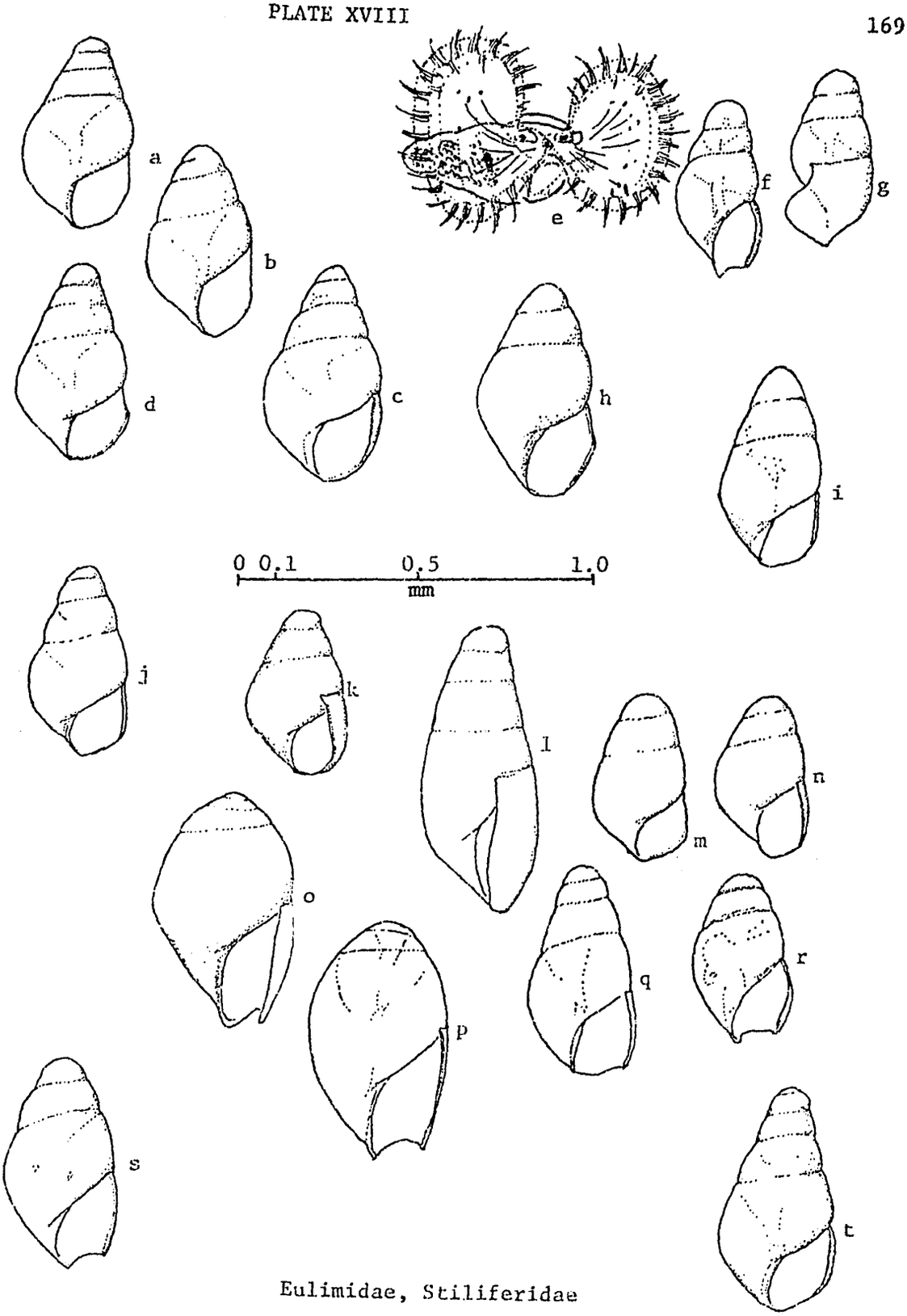
Viscera: digestive gland generally gold, but variable; intestine a thin, black thread.

Months found in plankton: March through August, December, January

Areas found: Sampan Channel, Dredged Island, Coconut Island

PLATE XVIII
Eulimidae, Stiliferidae

Figure(s)	a, b, d.	Eulimacean sp.$_1$ (=?Mucronalia nitidula)
	c.	" sp.$_2$ (=?Balcis subpellucida)
	e-g.	" sp.$_3$ (=?Balcis kanaka)
	h.	" sp.$_4$ (=?Balcis cumingii)
	i.	" sp.$_5$ (=?Stilifer thaanumi)
	j.	" sp.$_6$
	k.	" sp.$_7$ (=?Balcis thaanumi)
	l, m, q.	" sp.$_8$ (=?Balcis aciculata)
	n, r.	" sp.$_9$ (=?Balcis bryani)
	o, p.	?Eulimacean sp.$_{10}$
	s.	Eulimacean sp.$_{11}$ (=?Subularia metcalfei)
	t.	" sp.$_{12}$ (=?Stilifer mittrei)



Eulimidae, Stiliferidae

Superfamily 13. Strombacea

Strombacea includes the families Strombidae*, Aporrhaidae, and Struthiolariidae. The Xenophoridae* are sometimes included in this superfamily (Thiele 1931-35), but Morton (1958a) argues that they more properly belong in the Calyptraeacea.

There are no descriptions of struthiolarid development in the literature and there is only one species of aporrhaid for which the larval stages have been described: Aporrhais pes-pelecani (Linne), (Lebour 1933d, 1937a). Details of the life history of this species are presented with those of strombid life histories in Table 14.

Strombidae

In addition to those species listed in Table 14, S. gallus Linne (D'Asaro 1970), S. costatus Gmelin, S. raninus Gmelin (Robertson 1959) are also reported to have planktonic veligers. No strombacean is reported to be viviparous or to hatch with the ability to crawl. The egg masses of Strombus rugosus Sowerby, S. canarium Linne, S. pugilis alatus Gmelin and Pterocera lambis Linne have been described in varying detail (Risbec 1927, 1932; Lamy 1928; Bower 1945; Perry and Schwengel 1955)

There are descriptions of pre-metamorphic veligers of S. gigas (D'Asaro 1965), S. tricornis (Eisawy and Sorial 1968), A. pes-pelecani (Lebour 1933d) and Pterocera bryonia (Gohar and Eisawy 1967). To these, I now add that of S. maculatus.

Six species of Strombus occur in the Hawaiian Islands (Kay, unpubl.). The only common shallow-water species is S. maculatus, which is found on solution benches such as those at Kapapa Island.

Veligers of S. maculatus are probably planktonic for at least five weeks. Measurements of greatest diameter (from 1-3.3 mm) were plotted versus time on semi-logarithmic graph paper. A straight line obtains, which shows that growth during this interval is logarithmic. While retaining the same slope (i.e., assuming a steady rate of growth) the curve was extended backward to the larval size at hatching. The assumption that there is no change in growth rate from hatching to a size of 3.3 mm may or may not be correct. If it is correct, one can assume that the statement beginning this paragraph is correct. Egg size also corresponds closely with that of S. gigas, which has a planktonic period of four to five weeks (D'Asaro 1965).

A pattern emerges when one compares egg diameter, hatching size and length of time in the plankton of strombids: the larger the egg diameter, the larger the hatching size; the larger the hatching size, the shorter the time spent in the plankton (see Table 14).

Observations of freshly-netted S. maculatus larvae indicate that these veligers are planktotrophic rather than lecithotrophic. The larval digestive gland and style sac are most often green, but are occasionally tan to yellow-brown; the variable color suggests that S. maculatus veligers feed on a variety of appropriately-sized phytoplankters. Veligers do not grow satisfactorially on a diet in which the sole constituent is Phaeodactylum tricornutum.

The pre-settlement veliger of S. maculatus most closely resembles that of S. gigas in terms of 1) number of velar lobes at metamorphosis, 2) size of protoconch at metamorphosis, 3) pigmentation of body, 4)

sculpture of protoconch, 5) egg size and 6) probable length of time in the plankton. Although D'Asaro (1965) was not able to rear S. gigas through metamorphosis, he includes a photograph of a veliger taken fifteen days after hatching. Except for the broader apex, the veliger resembles the pre-settlement veligers of S. maculatus. Only S. tricornis has been reared from spawning through metamorphosis prior to this work. In this strombid, the eggs are large (410-440 μm) and planktonic life is short (four days).

Table 1

Life History Data: St

	Strombus tricornis Lamarck	Pterocera bryonia Gmelin	Str Lir
egg size	410-440 µm	213-256 µm	*1!
days from spawning to hatching	10-11 days @ 28°C.	5-7 days @ 26°C.	3 1 5 (
estimated* or known length of time in the plankton	4 days	*probably about 10 days; after 5th day yolk used up	apj 4-!
velum: # of lobes in pre-settlement veliger	four	four, but the 5th and 6th lobes starting to be formed	
velum: pigmentation	irregularly-scattered orange pigment spots	none	apj
months veligers collected from plankton	May-August	April-July	Ma;
size at metamorphosis	2-2 1/2 whorls; 1200 µm long x 970 µm wide	1 1/2-1 3/4 whorls; 480 µm long x 450 µm wide	*n pr an
length of time after spawning	14-16 days	probably 8-10 days	ab
accomplished a complete metamorphosis in captivity?	yes	doubtful	
references	Eisawy and Sorial 1968	Gohar and Eisawy 1967	Ro D'

Table 14

e History Data: Strombacea

bryonia	Strombus gigas Linne	Aporrhais pes-pelecani	Strombus maculatus
m	*155-185 µm	120 µm; 240 µm if membranes are included	100 µm
@ 26°C.	3 1/2 days @ 28-30°C.; 5 days @ 26°C.	probably 14 days	5-7 days
about 10 er 5th day up	approximately 33 days 4-5 weeks	*at least 2-3 weeks	*4-8 weeks
the 5th and starting to	six	four in the mid-veliger, but definitely six in the pre-settlement veliger	six
	apparently none	originally brown; later, conspicuous red spots	purple-black at base of post-oral cilia
y	May-September	Late March-early summer (Lebour); all year except February (Thorson)	February-October; main months: March, April, May
/4 whorls; ng x 450 µm	*never metamorphosed; probably 3 1/2 whorls and 1000 µm long	2 1/2-3 whorls; length, 1500 µm x width, 1080 µm; apex broad; sometimes 1120 µm x 1000 µm	4 1/2 whorls long 950-1200 µm long x 840-935 µm wide
8-10 days	about 38 days	not known; 3-4 weeks(?)	*5-9 weeks(?)
ıl	no	yes	yes
l Eisawy	Robertson 1959 D'Asaro 1965	Lebour 1933d, growth; Thorson 1946	Berg 1971 this study

Strombus maculatus Sowerby 1842. Plate XIX, figs. a-d.
Plate XX.

Veliger:

Protoconch: spindle-shaped, body whorl inflated; unsculptured except for faint spiral striae and punctae; colorless; beak lacking in mature veligers, but pronounced in immature veligers, beak line on body whorl; siphonal canal lacking, although columella extended, tinted red-brown; suture of body whorl magenta near aperture; 4 - 4 1/2 whorls at metamorphosis*.

Velum: six-lobed; mature veliger with purple-black at base of postoral cilia; velar lobes with parallel sides, not inflated distally; width, 2900 µm; height, 1620 µm.

Cephalic area: tentacles widely separated, medium-long; unpigmented except for green pigment granules proximal to eyes, expanded at base accommodating eyes; esophagus colorless, brown or charcoal gray.

Foot: colorless except for charcoal gray ventral propodium and medial areas of meso- and metapodium; metapodial tentacle present posteriorly, with long cilia; operculum with a definite spur anteriorly, proximal surface covered with foot tissue.

Viscera: digestive gland golden or chlorophyll green; style sac light gray; intestine clear.

Months found in plankton: all months except November, December and January; peak months, March and May.

Areas found: Sampan Channel, Artificial Island; none collected in shoreward regions.

*Although Abbott (1960) reports S. maculatus to have a protoconch of 2 1/2 whorls, all of the pre-metamorphic veligers that I obtained from plankton tows contained no less than 4 - 4 1/2 whorls. Abbott may have examined adult specimens which lacked capsular protoconchs.

Remarks: The six-lobed velum in combination with a spurred operculum serve to distinguish Strombus from other veligers. The veliconcha displays the characteristic righting behavior commonly found in adult strombids. A pallial tentacle is present near the suture of the aperture.

S. maculatus: metamorphosis.

Successful metamorphosis occurs within a few hours to a few days after capture; if individuals are captured at a stage of development insufficient to allow metamorphosis, and if in vitro nutrition is inadequate, the resorption of one or more velar lobes begins. If maintained on the same nutritional supply, metamorphosis is usually incomplete and the larvae become progressively debilitated.

Successful metamorphosis involves the velar lobes being detached and ingested into the esophagus, where they are clearly visible through the protoconch. In healthy, developmentally-advanced individuals, this act may occur within less than one minute. Occasionally part or all of the velum is detached and not ingested; velar ciliary activity proceeds until all the energy supply presumably is exhausted, and the detached velum moves through the water in much the same manner as when it was attached.

S. maculatus: juveniles.

S. maculatus juveniles have been reared through metamorphosis by myself and C. J. Berg (1971). If metamorphosis is completed, the juvenile begins to feed and grow on a diet of very fine filamentous brown or red algae within a few days. The juveniles grow well in small plastic petri dishes until the shell is approximately three millimeters long. After the juveniles attained this length, they were transferred to sea water tables and supplied with appropriate algal food.

Six weeks after metamorphosis, the juveniles exhibit the escape response peculiar to strombids if an appropriate stimulus (e.g., diluted secretions from Conus pennaceus) is introduced (C. J. Berg 1971). At this stage of development, the eyes bulge laterally on the cephalic ten-

tacles and a ring of ornage pigment becomes increasingly conspicuous on the periphery of each eye. The teleoconch develops faint spiral grooves and assumes a blotched appearance which is augmented by bits of algae adhering to the shell. The body gradually acquires a pattern of white blotches and green spots on a light green background. The proboscis is white. Green spots develop in the mantle and the ctenidium becomes erectable. I would estimate that a period of four to six months is required to attain adult size (8-10 mm, smallest recorded adult size, R. T. Abbott 1960) in situ. This estimate is based on the growth rate which obtained in the sea water tables.

The age at which S. maculatus can first spawn is not known. D'Asaro (1965) states that S. gigas first reproduces during the third year after metamorphosis; the adults of S. gigas are much larger than those of S. maculatus (15-30 cm long vs 27 mm long, Abbott 1954 and Kay unpubl.) and can therefore be expected to undergo a longer period in the juvenile stage before attaining adult size. S. maculatus in Hawaiian waters can probably reproduce within one year after settlement. This guess is based on data which are indirect bits of evidence at best:

1) that Natica gualtieriana, a carnivorous snail of about the same size, lays its first functional egg ribbon three months after settlement (E. Guinther, pers. comm.),
2) that Epitonium ulu is known to deposit its first egg capsules within three weeks after settlement (Guinther 19); Aiptasia suffices as the food of this species during juvenilehood, and
3) that Styliferina goniochila lays its first egg mass two to three weeks after metamorphosis while subsisting on the same diet utilized by S. maculatus.

Strombus sp. (?*dentatus*) Linnaeus 1758. Plate XIX, fig. e.

Veliger:

Protoconch: spindle-shaped; apex resembles that of *S. maculatus*, but more slender; unsculptured save for punctae; beak line present on body whorl of protoconch; columella extended, shell light yellow-green.

Velum: six-lobed; unpigmented; velar lobes rounded and not so long as in *S. maculatus*; width, 1700 µm; height, 1300 µm.

Cephalic area: tentacles medium-long; eyes tiny, inside bases of tentacles; oral region unpigmented.

Foot: colorless; propodium blunt; mesopodium undistinguished; metapodium with metapodial tentacle; operculum shaped like aperture, barely visible, spurred, but not covered with foot tissue.

Viscera: digestive gland clear light yellow-green; style sac golden.

Months found in plankton: February, March

Areas found: Sampan Channel

PLATE XIX

Strombidae

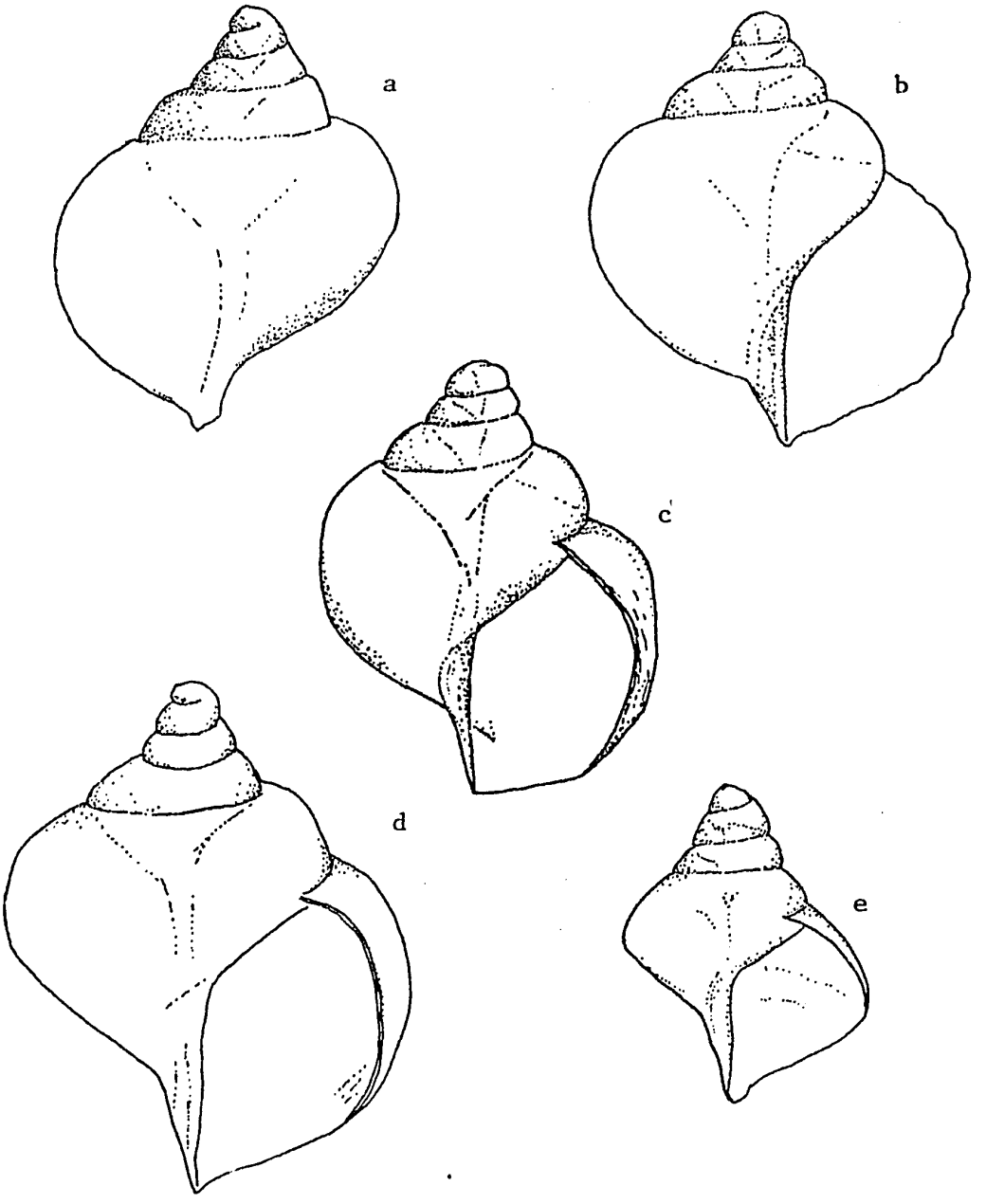
Figure a. abapertural view, Strombus maculatus

b, c, and d. Strombus maculatus, apertural views

e. Strombus ?dentatus, apertural view

PLATE XIX

Strombidae



0 0.1 0.5 1.0

mm

PLATE XX

Strombus maculatus: premetamorphic veliger.

1.3mm

Superfamily 14. Hipponicacea

Hipponicaceans include the Fossaridae*, Vanikoridae* (=Naricidae), and Hipponicidae* (=Amaltheidae).

Superfamily characteristics: shells either flattened, caplike or depressed, conical; radula taenioglossate; nutrition of herbivorous scavenging.

Fossaridae

There are no descriptions of fossarid life histories, nor illustrations of the larval stages.

There are three species of Fossarus in Hawaii (Kay, unpubl.). During this study, larvae of all three were collected; those of F. cumingii were the most abundant of the fossarid veligers and occurred in most of the spring and summer tows.

Fossarus garrettii Pease 1868. Plate XXI, fig. a.

Veliger:

Protoconch: red-brown; apical whorl with faint punctae; metamorphosis occurs when 2 1/2 whorls complete, length: 300 μm, width: 210 μm.

Velum: bilobed, unpigmented; velar lobes unequal in size, oval.

Cephalic area: unpigmented.

Foot: simple, broad, unpigmented.

Viscera: cannot be discerned through protoconch.

Months found in plankton: June

Areas found: Sampan Channel, Dredged Island

Fossarus cumingii (A. Adams 1863). Plate XXI, figs. b, c, d.

Veliger:

Protoconch: diaphanous white, turriform; apical whorl with faint punctae; 2nd, 3rd and 4th whorls with sinuous axial riblets; 'body whorl' of protoconch with three spiral threadlets crossing axial sculpture; metamorphosis occurs when four whorls complete, length: 390 μm, width: 270 μm.

Velum: bilobed, unpigmented; velar lobes unequal in size, oval.

Cephalic area: unpigmented.

Foot: simple, broad, unpigmented.

Viscera: digestive gland, style sac golden; rectum charcoal.

Months found in plankton: April through August

Areas found: Sampan Channel, Dredged Island

Remarks:

Upon metamorphosis, the axial whorls become light red-brown and the remaining whorls assume a rich red-brown shade.

Fossarus multicostatus Pease 1861. Plate XXI, figs e, f.

Veliger:

Protoconch: light tan, turriform; slightly inflated; sutures barely impressed; apical whorl faintly punctate; remaining whorls with sinuous axial ribs; metamorphosis occurs when 3 - 3 1/2 whorls complete, length: 360 µm, width: 240 µm.

Velum: bilobed, unpigmented; velar lobes unequal in size, oval.

Cephalic area: unpigmented.

Foot: simple, broad, unpigmented.

Viscera: digestive gland brown.

Months found in plankton: March, July

Areas found: Sampan Channel, Dredged Island

Vanikoridae

The family is represented in Hawaii by at least three species of Vanikoro. Kay (unpubl.) describes the shell of the vanikoros as "umbilicate, the last whorl is large and globose and the protoconch disproportionately small." There are no descriptions of vanikorid life histories, nor illustrations of their larvae.

During this study, larvae of three species were collected; those of V. acuta and V. recluziana occurred frequently in spring and summer tows.

Vanikoro recluziana Adams and Angas 1863). Plate XXI, figs. m, n, o.

Veliger:

Protoconch: apical whorl colorless, with spiral rows of punctae; remaining whorls medium red-brown, with spirals of fine granules; metamorphosis occurs when 2 3/4 - 3 1/4 whorls complete, length: 410 µm, width: 300 µm.

Velum: bilobed, unpigmented; velar lobes circular.

Cephalic area: unpigmented.

Foot: simple, white.

Viscera: cannot be discerned through protoconch.

Months found in plankton: March, July

Areas found: Sampan Channel, Dredged Island

Vanikoro acuta (Recluz 1844). Plate XXI, figs. i, j, k.

Veliger:

Protoconch: apical whorl broad, colorless, faintly punctate; remaining whorls red-brown with spirals of raised punctae; columella red-brown, slightly produced; metamorphosis occurs when two whorls complete, length: 350 μm, width: 270 μm.

Velum: bilobed, unpigmented; velar lobes circular.

Cephalic area: unpigmented.

Foot: simple, white.

Viscera: cannot be discerned through protoconch.

Months found in plankton: March, September.

Areas found: Sampan Channel, Dredged Island.

Vanikoro cancellata (Quoy and Gaimard 1832). Plate XXI, figs. g, h.

Veliger:

Protoconch: apical whorl colorless, faintly punctate; remaining whorls rose-gray with cancellate system of raised punctae; columella rounded, not produced; beak poorly developed; metamorphosis occurs when 2 1/2 - 2 3/4 whorls complete, length: 370 μm, width: 275 μm.

Velum: bilobed, unpigmented; velar lobes circular.

Cephalic area: oral area gray; tentacles medium-long; eyes inside tentacular bases.

Foot: white, simple.

Viscera: digestive gland dark gold; rectum charcoal.

Months found in plankton: March

Areas found: Sampan Channel

PLATE XXI
Fossaridae, Vanikoridae

Figure a. *Fossarus garrettii*

b, c, d. *Fossarus cumingii*

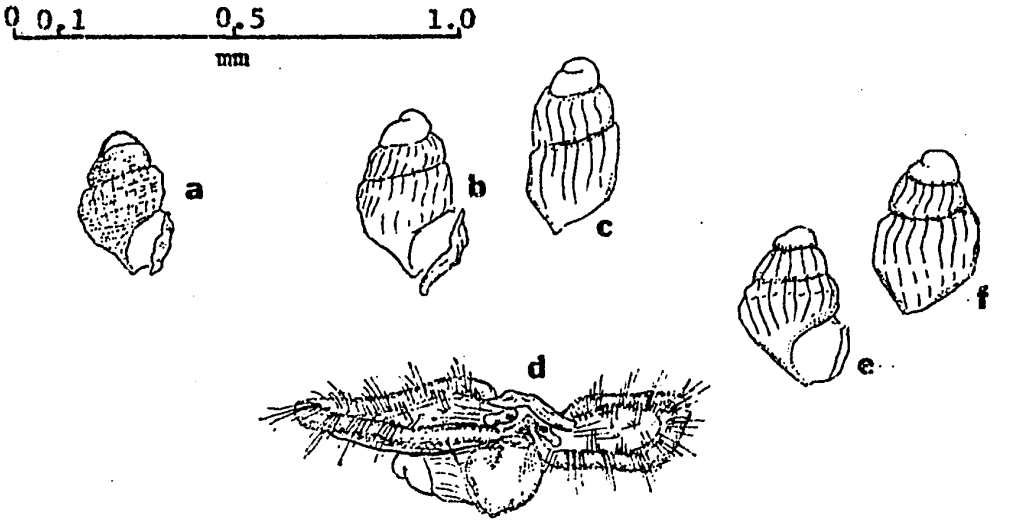
e, f. *Fossarus multicostatus*

g, h. *Vanikoro cancellata*

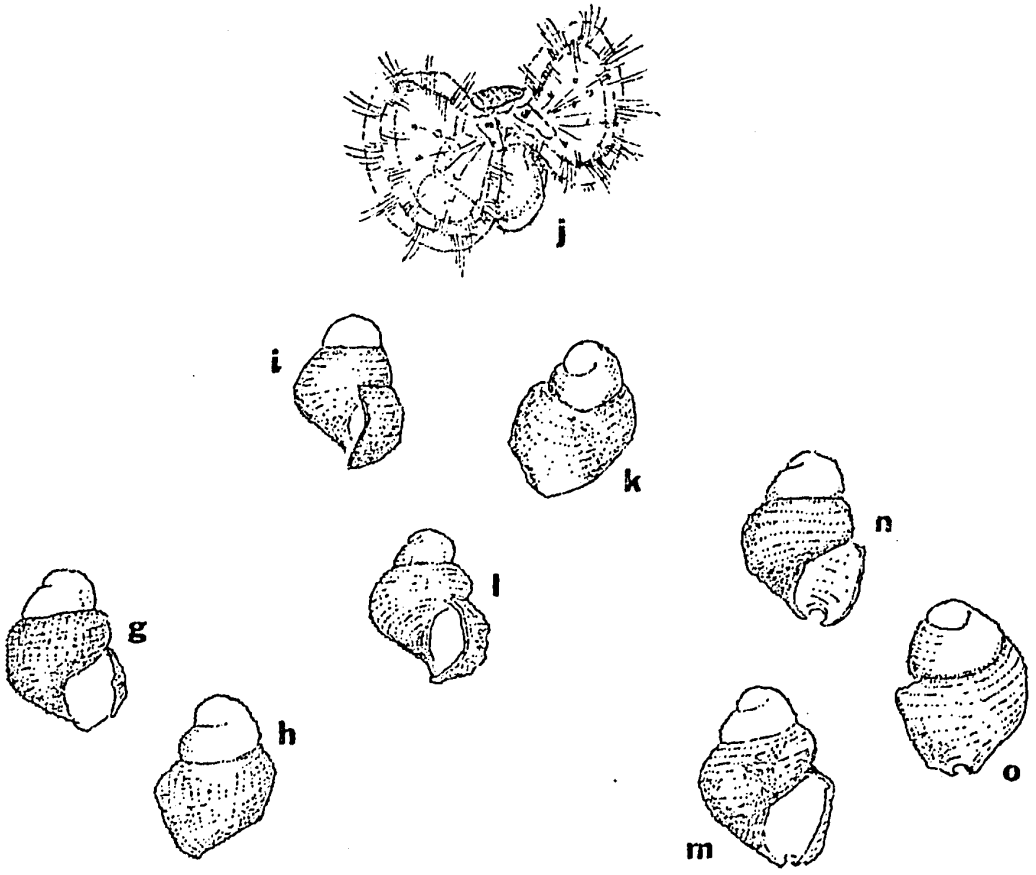
i, j, k. *Vanikoro acuta*

m, n, o. *Vanikoro recluziana*

PLATE XXI



Above: Fossaridae



Below: Vanikoridae

Hipponicidae

Little is known of hipponicid life histories. Individuals of the genus Hipponix are reported to be protandrous hermaphrodites. As in calyptraeids, brood protection seems to be the rule for hipponicids. Six to 36 or more egg capsules crowd the mantle cavity of a brooding Hipponix female (Risbec 1935; Yonge 1953; Cernohorsky 1968). No nurse eggs are reported in this family.

Hipponicid young are liberated either as juveniles (Amalthea australis Quoy and Gaimard in New Caledonian waters) or as veligers (Amalthea lissa E.A.Smith in the Iranian Gulf and Hipponix conicus Schumacher in the southern Pacific ocean)(Risbec 1935; Thorson 1940; Yonge 1953). Thorson (1940) estimates that A. lissa veligers are planktonic for as long as is necessary to add 400 μm in length, -- a "long time", he thinks. He adds that the veliger is bilobed at hatching and is not an echinospira. H. conicus is alleged to be an echinospira (Cernohorsky 1968).

Horseshoe limpets are cemented to the substratum, either rocks or the shells of other mollusks, by a calcareous base secreted by the foot. Once the juveniles have settled, they have limited potential to decalcify the base and settle elsewhere; thus, they are dependent upon being able to ingest whatever vegetable and detrital material can be reached by the long, flexible proboscis.

Four species of hipponicids occur in Hawaii and larvae of each have been netted from the plankton. Of these, Hipponix trigona probably is planktonic for at least a week; the others probably spend no

more than several hours to two or three days in the plankton. These short-term plankters may be poecilogonous.

Although Cernohorsky (1968) states that both hipponicids and capulids hatch as echinospira veligers (see p.213), I find no evidence that any of the Hipponix veligers are echinospiras. Cernohorsky (loc. cit.) does not cite sources for this statement and provides no adequate description of the veligers of Hipponix conicus. As Lebour (1932a) once observed, when cypraeid protoconchs are preserved, the periostracal layer lifts off and the preserved larva resembles an echinospira. Perhaps Cernohorsky's observations of 'echinospira' veligers in H. conicus were based upon preserved protoconchs.

Taxonomic Key to the Veligers and Juveniles of the Hipponicidae.

1. Protoconch not cancellate; colorless to tan before metamorphosis....2

   Protoconch finely cancellate, red-brown, apical whorl cream.....
   .....*Sabia conica*

2. (1) Protoconch large (greatest diameter, 600-1100 μm), inflated, globose with impressed sutures.....*Hipponix trigona*

   (1) Protoconch flattened, depressed; sutures not very impressed; apical angle large.....3

3. (2) Living veliger and newly-metamorphosed juveniles with red-orange fecal pellets in intestine; juvenile protoconch light tan.....
   .....*Hipponix foliacea*

   (2) Red-orange fecal pellets lacking; protoconch of living veliger light tan; newly-metamorphosed juvenile tinged with red-brown...
   .....*Hipponix imbricatus*

Hipponix (Cochlear) imbricatus Gould 1846. Plate XXII, figs. a-e.

Synonym: Hipponix grayanus (Menke 1835).

Veliger:

Protoconch: flattened-neritoid; colorless to light tan; smooth, occasionally with faint spiral striae; umbilicus comma-shaped; beak and siphonal canal lacking; metamorphosis when 1 1/2 whorls complete, greatest diameter, 650-850 µm.

Velum: bilobed, colorless; velum not retained more than a few days after capture; probably planktonic for less than one week*.

Cephalic area: tentacles long, knobbed slightly at tips; eyes inside bases of tentacles.

Foot: propodium with anterior gland; metapodial tentacle lacking; operculum colorless, semilunate.

Viscera: digestive gland light yellow; intestine charcoal.

Months found in plankton: January, February, March

Areas found: Sampan Channel, Dredged Island

*An adult H. imbricatus is reported as brooding a transparent egg capsule (Lum, pers. comm.). The young hatched as veligers and settled after six days of swimming. Two metamorphosed successfully.

Juvenile:

The juveniles acquire a light red-brown tinge after completing metamorphosis. They utilize algal detritus by sucking pebbles in flowing sea water. Because some of the individuals develop flexible spines which project anteriorly from the initial teleoconch, juveniles of this species may be confused with small juveniles of H. trigona.

Hipponix (Pilosabia) pilosus (Deshayes 1832) Plate, XXII, figs. f-h.

Veliger:

Protoconch: light gold to dirty tan; spirally wound, depressed-globose; apical whorls rounded, not peaked; aperture entire; sculpture lacking except for faint subsutural oblique axial striae; beak and siphonal canal lacking, umbilicus comma-shaped; metamorphosis usually at 2 1/2 whorls.

Velum: four-lobed; lobes rectangular, pigment lacking.

Cephalic area: light tan; tentacles widely separated, tips knobbed slightly at distal ends, long, moderately thick; eyes small, lateral to bases of tentacles.

Foot: light tan; propodium with conspicuous anterior gland, elongate; metapodium rounded, tentacles lacking; operculum oval-semilunate, conspicuous, extends beyond pedal margins, sturdy.

Viscera: digestive gland light yellow; intestine charcoal.

Months found in plankton: January.

Area found: Sampan Channel.

Remarks: Veligers of H. pilosus are the most commonly encountered hipponicids in the Kaneohe Bay plankton. The velum is the most widely developed hipponicid velum and is retained for a longer period after capture than the velum of other species. These observations suggest that H. pilosus veligers are planktonic for at least a week.

Juvenile:

Metamorphosis occurs pronptly and the protoconch acquires a red-brown tinge if smooth coral chips or stones are included in the petri dish. The initial teleoconch develops flexible horny periostracal spines which radiate conspicuously from the margin (see fig.

h). The axial striae are not heavy, but are noticeable at the shell margin. The teleoconch shows axial ridges due to uneven growth, but the predominant sculpturing is of interrupted spiral ribs. The ground color is cream, with red-brown patches superimposed.

Within a week after settlement, juveniles of this species are cemented to the substratum. Fast growth rates are then obtained if the juveniles are transferred to sea water tables which have much algal detritus and fine, filamentous algae within reaching distance of the proboscis.

PLATE XXII

Hipponicidae

Figs. a-e: Hipponix (Cochlear) imbricatus.

a. protoconch perched on adult shell

b. protoconch, apertural view

c. protoconch, apertural view

d. protoconch, apical view

e. protoconch and initial teleoconch

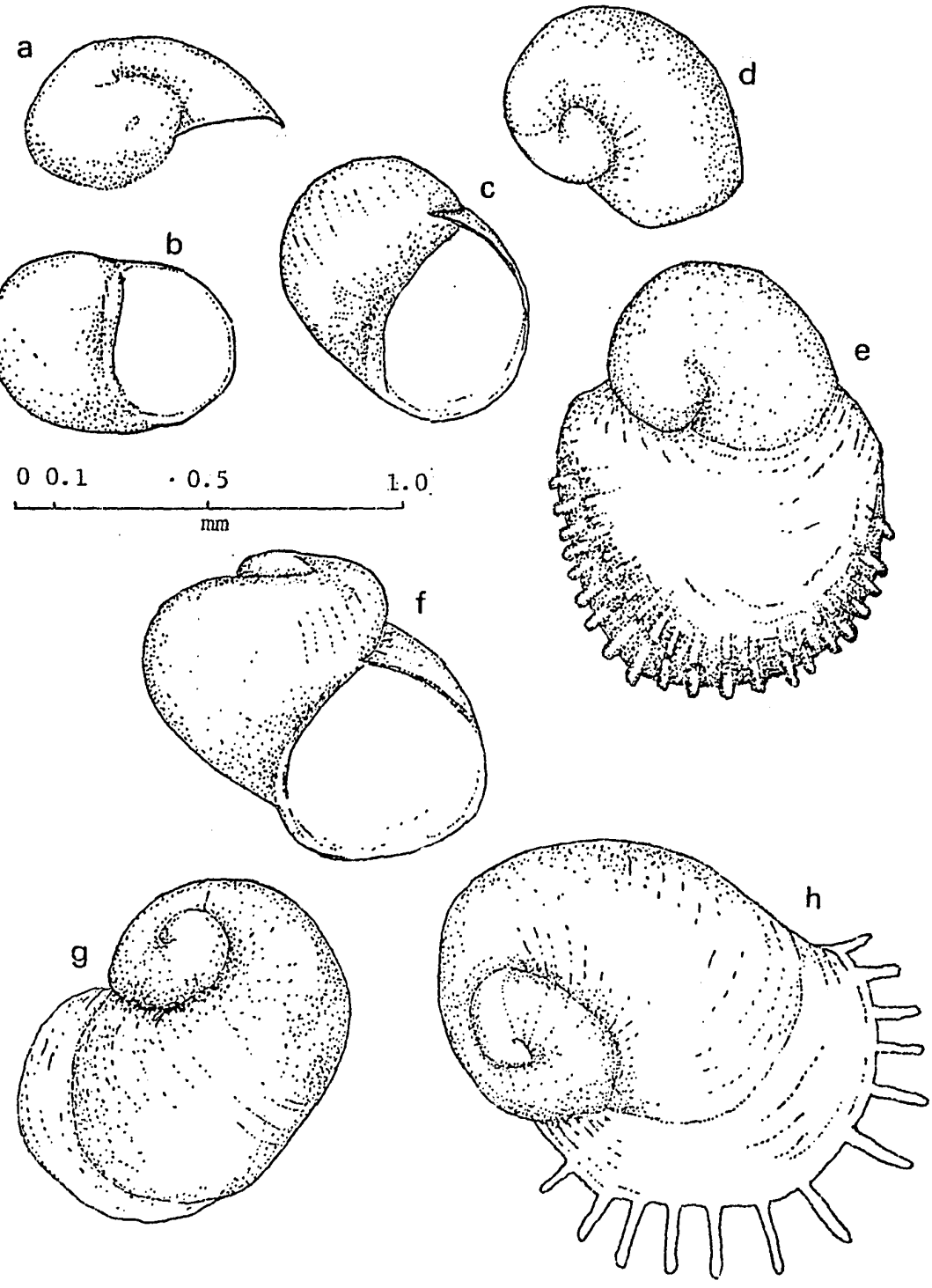
Figs. f-h: Hipponix (Pilosabia) pilosus.

f. protoconch, apertural view

g. protoconch, apical view

h. protoconch and initial teleoconch

PLATE XXII



HIPPONICIDAE

Hipponix (Antisabia) foliacea Quoy and Gaimard 1835. Plate XXIII, figs. a-e.

Veliger:

Protoconch: flattened-neretoid; colorless to light tan; apical whorl smooth, latter part of body whorl with spiral grooves; sutures barely impressed; metamorphosis when 1 1/4 whorls complete.

Velum: bilobed, colorless; velum rarely retained for more than two days after capture; planktonic less than one week.

Cephalic area: colorless; tentacles medium-long, slender; esophageal pigment lacking.

Foot: colorless, small meso- and metapodial area; propodium with anterior gland, elongate, slender.

Viscera: conspicuous red-orange fecal pellets near suture of body whorl; mantle and other visceral organs cream.

Months found in plankton: August

Areas found: Sampan Channel, Dredged Island

Remarks:

The velar lobes are ingested during metamorphosis; subsequently, the initial teleoconch acquires a medium red-brown tinge. This is the smallest of the Hawaiian hipponicid larvae. The later teleoconch is white with axial foliations.

Sabia conica Schumacher 1817. Plate XXIII, figs. f-j.

Veliger:

Protoconch: apical whorl cream, remainder light to medium red-brown with oblique axial striae overlying spiral threads; spirally wound, globose; sutures not very impressed; metamorphosis when 2 1/4 whorls complete.

Velum: four-lobed; lobes rectangular, colorless to white.

Cephalic area: tentacles white, slender, long; eyes inside bases of tentacles; esophagus without pigment.

Foot: propodium with anterior gland; metapodium rounded, metapodial tentacle lacking; operculum tinged with red-brown, oval-semilunate.

Viscera: not discernible through protoconch; body tissues white.

Months found in plankton: August

Areas found: Sampan Channel, Dredged Island

Remarks:

The well-developed velum and the high frequency of capture suggest that veligers of this species are planktonic for at least a week. Veligers of S. conica settle preferentially on the shells of other gastropods (Kay, unpubl.).

Juvenile:

The initial teleoconch is cream with red-brown streaks; the later teleoconch is white. Immediately after metamorphosis, the columellar area of the protoconch develops a thin callus; the axis lies at right angles to the main axis of the teleoconch.

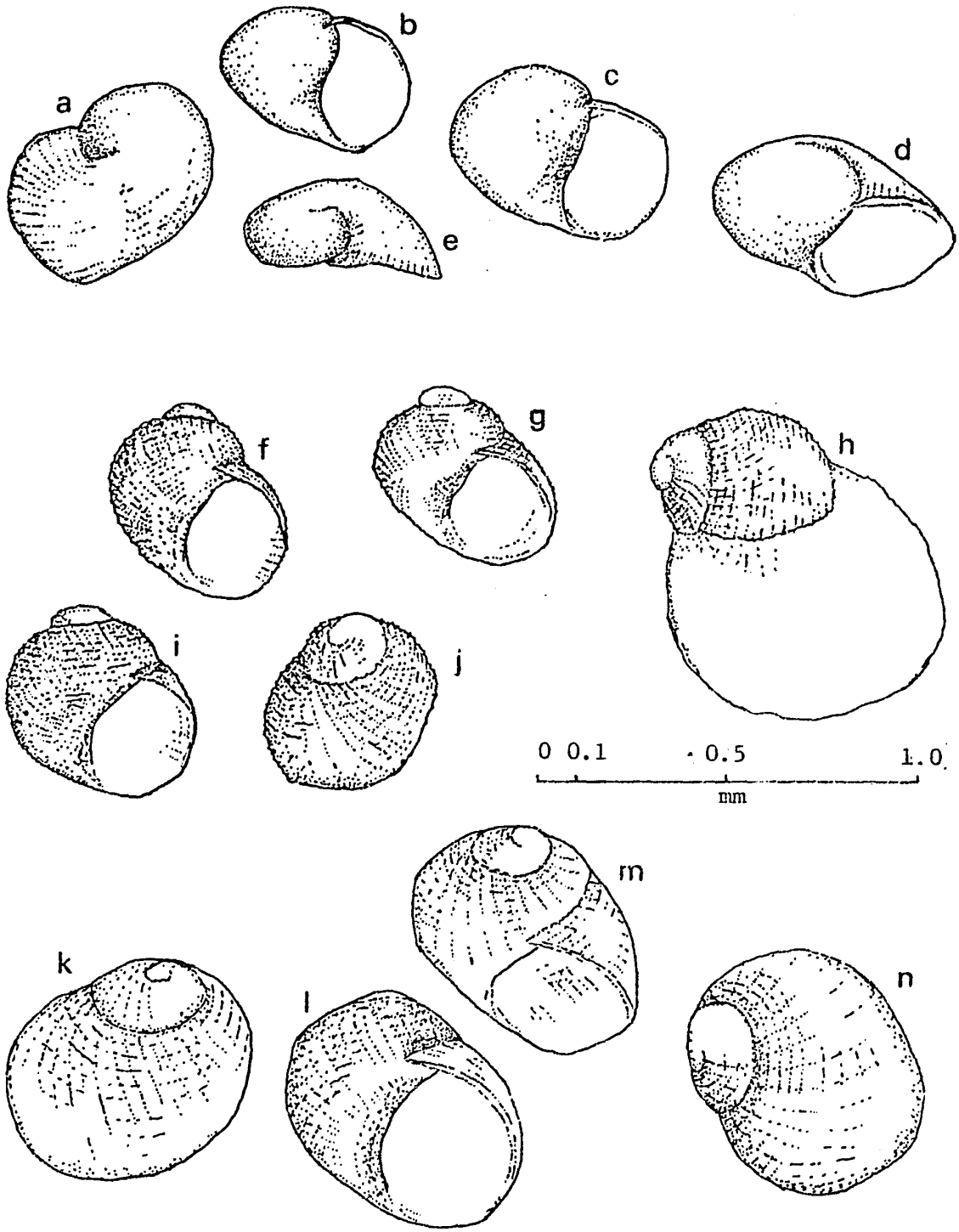
PLATE XXIII
Hipponicidae

Figures a-e. *Hipponix (Antisabia) foliacea*

f-j. *Sabia conica*

k-n. Unidentified.

PLATE XXIII



HIPPONICIDAE

Superfamily 15. Calyptraeacea

Calyptraeaceans include the Trichotropididae, Capulidae*, Calyptraeidae* and Xenophoridae* (see Morton 1958a).

Superfamily characteristics: shell spirally conical (Trichotropididae, Xenophoridae) or caplike without an operculum in the adults (Capulidae, Calyptraeidae); generally ciliary and detrital feeders; protandric hermaphrodites.

There are no accounts of xenophorid life histories; data relating to the remaining three families are summarized and presented in Tables 15 and 16.

Capulidae

Adults are sessile on bivalves and starfish. Capulus has an echinospira larva; Thyca does not (Fretter and Graham 1962).

Although there are three species and three genera of capulids in Hawaiian waters, no larvae collected resembled either figure of Capulus or the protoconch of Thyca. Capulus protoconchs may be mistakenly identified as Trivia, while Thyca protoconchs most closely resemble protoconchs of Epitonium.

Table 15

Life History Data: Capulidae and Trichotropididae

	Capulus hungaricus	Trichotropis borealis
egg size	diameter, 200 µm	
time: spawning to hatching	37 days	
size at hatching	hatch as echinospiras; inner shell, 240 µm; outer shell, 400 µm	
estimated* or known duration in plankton	long	hatch with the ability to crawl
velum: pre-settlement veliger	elongate, bilobed as in Trivia; indented centrally	
velum: pigmentation	colorless	
months breeding	March-May; June	
remarks	brood-protecting, temperate E. Atlantic	nurse eggs lacking, East Greenland
references	Odhner 1914a; Lebour 1937a; Knudsen 1950	Thorson 1935

Calyptraeidae

Adult calyptraeids are sessile ciliary feeders which brood rather undistinguished larvae. Calyptraea trochiformis (Chemn.), C. calyptraeiformis Lam., Crepidula convexa, C. unguiformis and C. adunca are all reported to protect their larvae by brooding them (Lamy 1928; Korschelt and Heider 1900; Moritz 1939). A summary of their life history data is provided in Table 16.

There are three species of calyptraeids in Hawaii. Veligers of Crepidula aculeata are seldom netted in Kaneohe Bay, but Crucibulum spinosum larvae account for approximately 90-95% of the veliger component of the plankton east of Coconut Island (see Appendix A for location) at all times of the year. A few veligers of Cheilea dillwyni are netted in almost every tow conducted east of Dredged Island, but they are never very abundant.

Calyptraeids collect their food by means of ciliary action from the veliger to the adult stage. They are hardy and survive well under laboratory conditions.

Hawaii's calyptraeid life histories are consistent with those summarized in Table 16.

Table 16

Life History Data: Calyp

	Crepidula fornicata	C. walshi	C. porcellana
egg size			400 µm
time: spawning to hatching		3 weeks	?
size at hatching	300-330 µm, 3/4 whorl	350 µm	1000 µm
estimated* or known duration in plankton	moderately long	long, at least 2 wks in Japan	hatch with the ability to crawl
velum: pre-settlement veliger	bilobed, large; Thorson says "slightly 4-lobed"	bilobed, cilia long	------
velum: pigmentation	2 rows of red-purple border	colorless	------
months breeding		May-Sept. in Japan	------
remarks	hermaphroditism; larvae with regular spots of pigment (green, red, brown or black); form long chains	protandric hermaphrodites; sexual dimorphism; foot with purple-black pigment; adults do not form chains	------
references	Orton 1909, 1922; Ankel 1935, 1936b; Lebour 1937a; Werner 1955	Thorson 1940	Knudsen 1950

Table 16

/ Data: Calyptraeidae

porcellana	Crucibulum spinosum	C. scutellatum	Calyptraea chinensis	C. pellucida
400 µm	egg sac with 55- 150 eggs, 170 x 190 µm	?	480 µm	120 µm
?	3-4 weeks	?	?	?
.000 µm	?	700 µm	640-700 µm	220-270 µm
iatch with :he ability :o crawl	variable, 2 wks to 2 mos	?	hatch with the ability to crawl	long
------	bilobed	large, 4-lobed	large, bilobed	----
------	colorless	bordered with wine-red pigment	?	wine-red at base of velar fringe
------	all months; max. intensity, March-April	------	-------	----
------	protandric hermaphrodites; foot with yellow pigment; protect larvae by brooding	protandric hermaphrodites; foot with yellow pigment; sides of foot with red-purple pigment	-------	protect larvae by brooding; olive green pigment spot on foot
nudsen 1950	Coe 1936, 1938		Lebour 1936; Thorson 1940; Knudsen 1950	Thorson 1940

Taxonomic Key to the Veligers and Juveniles of the Calyptraeidae.

1. Apex of protoconch bluntly peaked; protoconch light tan to pink-orange.....*Cheilea dillwyni*

   Apex of protoconch depressed, rounded.....2

2. (1) Mantle with two or more black streaks dorsally; very common in the inner bay plankton; after metamorphosis, a cup develops ventral to the apex.....*Crucibulum spinosum*

   (1) More depressed than *C. spinosum*; rarely in the plankton; after metamorphosis, a shelf develops ventral to the apex.....*Crepidula aculeata*

Crepidula aculeata (Gmelin 1791). Plate XXIV, Figs. a-c.

Veliger:

Protoconch: colorless; spirally wound, a little more depressed than that of C. spinosum; unsculptured except for punctae which are loci of shell deposition; beak and siphonal canal lacking; metamorphosis occurs at sizes larger than C. spinosum, but same number of whorls.

Velum: resembles that of C. spinosum.

Cephalic area: tentacles slender, closer together than those of C. spinosum.

Foot: colorless; otherwise, like that of C. spinosum.

Viscera: generally colorless.

Months found in plankton: March, April, July, September

Areas found: east of Coconut Island and Dredged Island; seldom netted; few in Sampan Channel.

Remarks: C. aculeata resembles C. spinosum at the veliger stage, but Crepidula veligers are generally larger and their protoconchs more depressed than those of C. spinosum. After metamorphosis, a shelf develops ventral to the apex in Crepidula juveniles and spiral rows of beads become evident.

Crucibulum spinosum (Sowerby 1824). Plate XXIV, Figs. d-f; Plate XXV,

Veliger:

Protoconch: colorless; spirally wound, ovate, generational angle large; unsculptured except for punctae which are loci of shell deposition; beak and siphonal canal lacking.

Velum: bilobed; lobes oval, unpigmented; cilia long.

Cephalic area: tentacles medium-long, medium-wide, eyes inside swollen bases.

Foot: wide, tapering; anterior pedal gland on propodium secretes abundant mucus; variable shading of fine black spots on ventral medial area; metapodium tapers into short metapodial tentacle, bristled posteriorly; operculum semilunate, transparent.

Viscera: digestive gland usually golden, varies from light yellow to dark khaki; intestine, a thin black line on right side posterior to head; developing ctenidium and osphradium conspicuous at left of intestine when viewed dorsally; larval and definitive hearts readily visible in intermediate and pre-settlement veligers.

Months found in plankton: all months of the year.

Areas found: east of Coconut Island, abundant entire year; east of Dredged Island, moderately abundant; Sampan Channel, few.

Remarks: The veligers hatch after 2-3 weeks of incubation in egg capsules retained beneath the shell of the female. While in the plankton veliger size varies widely. C. spinosum larvae are approximately 250-300 µm, greatest dimension, at hatching. Most C. spinosum veligers remain in the plankton for a minimum of three weeks and a probable maximum of eight weeks. If adverse conditions exist, planktonic life is shortened. Veligers of this species can metamorphose after a length of 400 µm is attained; metamorphosis usually occurs when the veliger's length approximates 650-700 µm.

C. spinosum veligers apparently are euryhaline and seem to be most abundant in those parts of Kaneohe Bay which contain much suspended matter. For larval ability to tolerate heat and detergent stress, see pp.

Metamorphosis: This complex process has been described in detail for C. spinosum (Fretter 1969). Veligers which complete metamorphosis satisfactorily usually ingest the velum, although one can occasionally find stray velar lobes moving about the petri dishes; at this time, velar powers of locomotion are independent of nervous control. Presumably, cilia beat until local energy supplies are exhausted. The operculum is lost at metamorphosis; retention would be a hindrance to the juveniles as they adopt the limpet habit.

At metamorphosis, the colorless protoconch becomes tan to red-brown and a peripheral flange develops. The cephalic tentacles elongate and the juveniles begin their search for settling areas.

Juveniles: Individuals of Crucibulum exhibit protandric development (Coe 1938c). Approximately 3-4 weeks after metamorphosis, the male gonad is visible in the metapodial region as a cream-colored clustered structure. At this time, the shell exceeds 1 mm and resembles the adult. The adults are ciliary feeders and C. spinosum can be reared to maturity in Cuno-filtered sea water (see p. 513) on a diet of Phaeodactylum tricornutum. Growth is maximal when a ciliate-free coral chip is included in the dish during metamorphosis, although juveniles can mature on a plastic substratum. A faster rate of growth is obtained by liberating newly-metamorphosed juveniles into sea water tables with water flowing in from the Bay.

Crucibulum spinosum was introduced in Hawaii during World War II.

Cheilea dillwyni Gray 1825. Plate XXIV, Figs. g-i.

Veliger:

Protoconch: transparent, suffused with light tan to pink-orange; spire produced with a rounded peak; sculpture variable, smooth to obliquely cancellate; subsutural groove evident in some, absent in others; beak and siphonal canal lacking; 3 1/4 - 3 1/2 whorls, columellar length approximates 710 μm at metamorphosis.

Velum: four lobes; lobes rectangular; pigment lacking.

Cephalic area: tentacles moderately long, widely separated; eyes small, on distal bases of tentacles.

Foot: colorless or smudged with purple-black; propodium tripartite; propodial adhesive gland conspicuous; metapodium blunt, tentacle lacking; operculum sturdy, triangular-oval, nucleus central.

Viscera: digestive gland golden-brown; style sac, esophagus and intestine colorless; prominent knobbed pallial tentacle.

Months found in plankton: January, July, August

Areas found: Sampan Channel, Dredged Island

Juvenile:

Teleoconch: white, fragile; sculpture of sinuous axial striae, closely-spaced spiral striae.

Settlement: on rock chips.

PLATE XXIV

Calyptraeidae

Figs. a-c. Crepidula aculeata

a. premetamorphic protoconch, apical view
b. premetamorphic protoconch, apertural view
c. metamorphosed protoconch, apical view

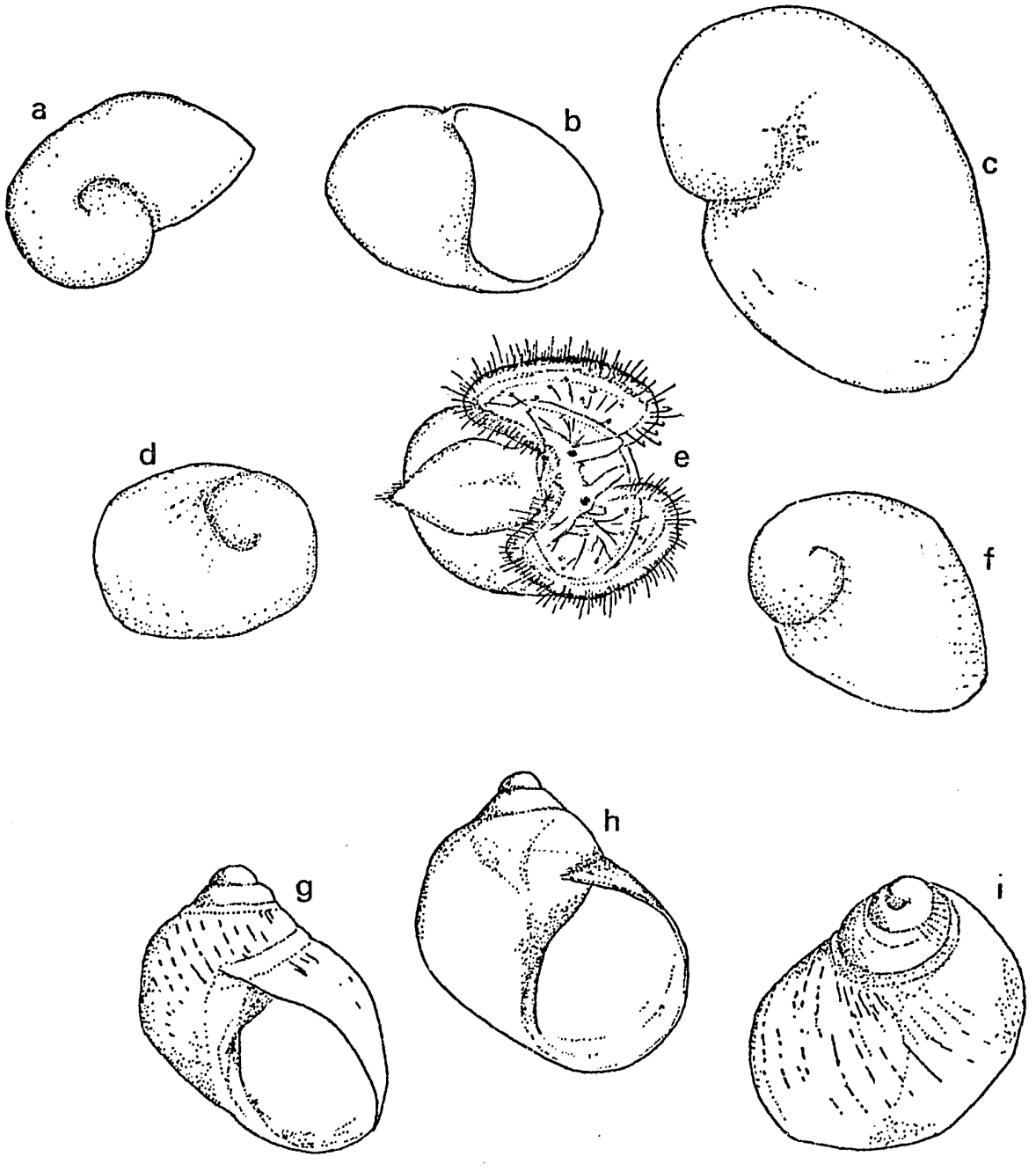
Figs. d-f. Crucibulum spinosum

d. premetamorphic protoconch, apical view
e. veliger, apertural view
f. metamorphosed protoconch, apical view

Figs. g-i. Cheilea dillwyni

g. premetamorphic protoconch, apertural view
h. premetamorphic protoconch, apertural view
i. premetamorphic protoconch, apical/dorsal view

PLATE XXIV



Calyptraeidae

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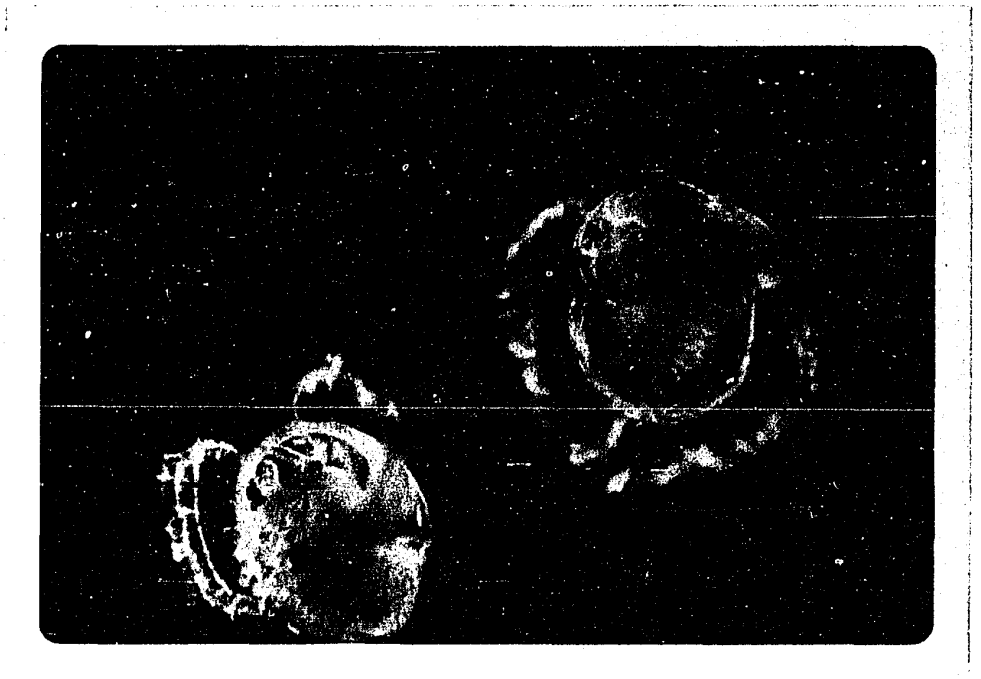
PLATE XXV



1.3mm

Crucibulum spinosum veligers: left, anterodorsal aspect; right, posterodorsal aspect.

Superfamily 16. Lamellariacea

Lamellariaceans include the Lamellariidae*, Eratoidae* (Fretter and Graham 1962, pp. 626-29), Pseudosacculidae, Asterophilidae and Ctenosculidae.

Superfamily characteristics: shell auriculate or boat-shaped, partly (Velutina, Erato, Trivia) or wholly (Lamellaria) concealed by mantle; operculum absent in adults, present in veligers; two shell muscles; gut with well-developed esophageal glands; osphradium bipectinate; approximately twelve genera predatory on tunicates, flesh rasped with radula; echinospira larva present.

An echinospira larva is a planktotrophic veliger which bears an apparently additional outer shell (=scaphoconch). Presumably, the scaphoconch augments the natural buoyancy of the larvae (Ankel 1936; Lebour 1935a, 1937). More recently (Fretter and Graham 1962), the scaphoconch was recognized to be the periostracal layer, constructed largely of conchiolin and separated by extra-pallial fluid from the true shell, which is made of conchiolin impregnated with calcareous material.

Lamellariacean life history data are summarized in Tables 17 and 18.

Lamellariidae

Lamellariid adults have transparent caplike shells "permanently enclosed in the mantle from the late larval stage" (Fretter and Graham 1962) and are predatory upon sessile tunicates.

Coiling is planar and nautiloid in lamellariid echinospirae. Veligers of Lamellaria have several whorls and a carinated (=keeled)

periphery while those of Velutina have gelatinous echinospirae with only one whorl and the periphery is not carinated.

Very little is known of the systematics of the Hawaiian species of this group. "A single living animal [Lamellaria] has been collected on a yellow tridemnid tunicate at a depth of 10 m; one or two shells have been found in beach drift" (Kay, unpubl.). To date, no specific names are granted the Hawaiian species of Lamellaria.

While no Velutina veligers have been obtained in tows, three species of Lamellaria appear with various degrees of regularity in the Hawaiian plankton.

Veligers of two species have metamorphosed in captivity during this study. When Lamellaria metamorphose, the scaphoconch slips off the calcareous shell, the mantle edges recurve dorsally over the true shell and fuse medially and dorsally. The six-lobed velum is ingested and the juvenile usually will feed on individuals of Perophora viridis.

Table 17

Life History Data: Lamellariidae

Name	Remarks	References
Lamellaria latens	has fewer and coarser scaphoconchal ridges than L. perspicua; metamorphoses when greatest dimension approximates 3000 µm; less spotted than L. perspicua; tend to deep water	Lebour 1935b, 19377a
L. perspicua	eggs 300 µm; newly-hatched veligers 350 µm; spend long time in plankton; velum 6-lobed; velum and mantle with brown and orange spots; breed spring and summer; metamorphose when greatest dimension approximates 2000 µm; periphery of scaphoconch with numerous fine serrations	Ankel 1935b; Lebour 1935b
L. form A	long in plankton; velum 6-lobed, with dark spots; breed all months; metamorphose in captivity when less than 2000 µm; probable identity: the Echinospira diaphana of Krohn 1855; outer scaphoconch with large serrations	Lebour 1945
L. form B	long in plankton; 6-lobed; breed in August; didn't metamorphose in captivity; scaphoconchal periphery smooth	Lebour 1945
L. form C	like form A, but flatter and with finer teeth around outer whorl, none on inner whorl; possibility: a younger stage of form A	Lebour 1945
Velutina laevigata	provides a figure	Simroth 1964
V. plicatilis (=V. flexilis)	velum with four long lobes, unpigmented; metamorphose when 2 1/2 whorls complete	Lebour 1935b
V. undata	hatch with the ability to crawl	Thorson 1935
V. velutina	hatch when scaphoconch diameter less than 960 µm; long in plankton; velum 4-lobed, usually unpigmented, sometimes with dark red-brown border; breed late spring and summer; metamorphoses in captivity when 2 1/2 whorls complete, scaphoconchal greatest dimen-	Lebour 1935b, 1937a

Lamellaria latens	has fewer and coarser scaphoconchal ridges than *L. perspicua*; metamorphoses when greatest dimension approximates 3000 µm; less spotted than *L. perspicua*; tend to deep water	Lebour 1935b, 1937a
L. perspicua	eggs 300 µm; newly-hatched veligers 350 µm; spend long time in plankton; velum 6-lobed; velum and mantle with brown and orange spots; breed spring and summer; metamorphose when greatest dimension approximates 2000 µm; periphery of scaphoconch with numerous fine serrations	Ankel 1935b; Lebour 1935b
L. form A	long in plankton; velum 6-lobed, with dark spots; breed all months; metamorphose in captivity when less than 2000 µm; probable identity: the *Echinospira diaphana* of Krohn 1855; outer scaphoconch with large serrations	Lebour 1945
L. form B	long in plankton; 6-lobed; breed in August; didn't metamorphose in captivity; scaphoconchal periphery smooth	Lebour 1945
L. form C	like form A, but flatter and with finer teeth around outer whorl, none on inner whorl; possibility: a younger stage of form A	Lebour 1945
Velutina laevigata	provides a figure	Simroth 1964
V. plicatilis (=*V. flexilis*)	velum with four long lobes, unpigmented; metamorphose when 2 1/2 whorls complete	Lebour 1935b
V. undata	hatch with the ability to crawl	Thorson 1935
V. velutina	hatch when scaphoconch diameter less than 960 µm; long in plankton; velum 4-lobed, usually unpigmented, sometimes with dark red-brown border; breed late spring and summer; metamorphoses in captivity when 3 1/2 whorls complete, scaphoconchal greatest dimension less than 2000 µm; inner shell, greatest dimension 1280 µm; shell with longitudinal ridges	Lebour 1935b, 1937a

Lamellaria sp.$_1$ Plate XXVI, fig. a, b, c.

Veliger:

Protoconch: an echinospira; planar; colorless; scaphoconch with two central rows of large triangular serrations and one similar row on each side; umbilicate; at metamorphosis, greatest diameter = 2805 μm, least diameter = 2310 μm.

Velum: six-lobed, not very deeply indented; velar lobes with yellow-green pigment at each extremity.

Cephalic area: tentacles long, far apart.

Foot: elongate; background cream with yellow-green spots.

Viscera: digestive gland light yellow; other organs colorless.

Months found in plankton: June

Areas found: Sampan Channel

Remarks: Veligers of this species metamorphosed in response to harassment by juvenile crabs; the velum is swallowed at metamorphosis. These veligers resemble the figure of *Echinospira diaphana* (Simroth 1964), which in turn resembles *Lamellaria* form A (Lebour 1945).

Lamellaria sp.$_2$ Plate XXVI

Veliger:

Protoconch: an echinospira; planar, but slightly helicoid; protoconch proper without sculpture, colorless, equiangular spiral; scaphoconch with four finely-serrated flanges, well-defined beak.

Velum: six-lobed with fewer, but larger, khaki-green spots in food groove.

Cephalic area: white, lightly brushed with charcoal, spots lacking.

Foot: white with tiny spots; operculum not visible.

Viscera: digestive gland charcoal and tan.

Months found in plankton: August, September

Areas found: Sampan Channel

Remarks: This species of Lamellaria is smaller than the preceding and has more numerous uniform khaki spots. There are no small spots in the white mantle, but four large khaki smudges are seen through the shell. Veligers of this species resemble figures of L. perspicua (Lebour 1937a) and L. form C (Lebour 1945).

After metamorphosis, multitudes of tiny densely-distributed khaki spots are uniformly dispersed throughout the mantle.

Lamellaria sp.$_3$ Plate XXVIII, fig. 1.

Veliger:

Protoconch: an echinospira; colorless; unsculptured; double shell separated by pallial fluid; protoconch laterally compressed, resembles a nautiloid shell; scaphoconch not serrated; beak, siphonal canal lacking.

Velum: six-lobed; velar lobes with light yellow-green or khaki spots in food groove.

Cephalic area: tentacles medium-long, white, uniformly thick; eyes inside bases of tentacles.

Foot: elongate; propodium long, blunt; mesopodium undistinguished; metapodium tapered; background colorless with 10-12 light yellow-green or khaki patches dorsally and ventrally.

Viscera: digestive gland golden to medium red-brown.

Months found in plankton: April

Areas found: Sampan Channel

Remarks: In the veliger, the mantle is white with sparsely-distributed khaki spots concentrated anteriorly; posteriorly there are 24 larger khaki spots. These veligers resemble Lamellaria form B (Lebour 1945). They will metamorphose in the laboratory and grow if offered Perophora, a tiny colorless stolonate tunicate.

After metamorphosis, the number of whorls is difficult to determine for the mantle completely covers the shell. In the juvenile, the eyes are almost covered with yellow pigment except for a small medial area.

PLATE XXVI
Lamellariacea

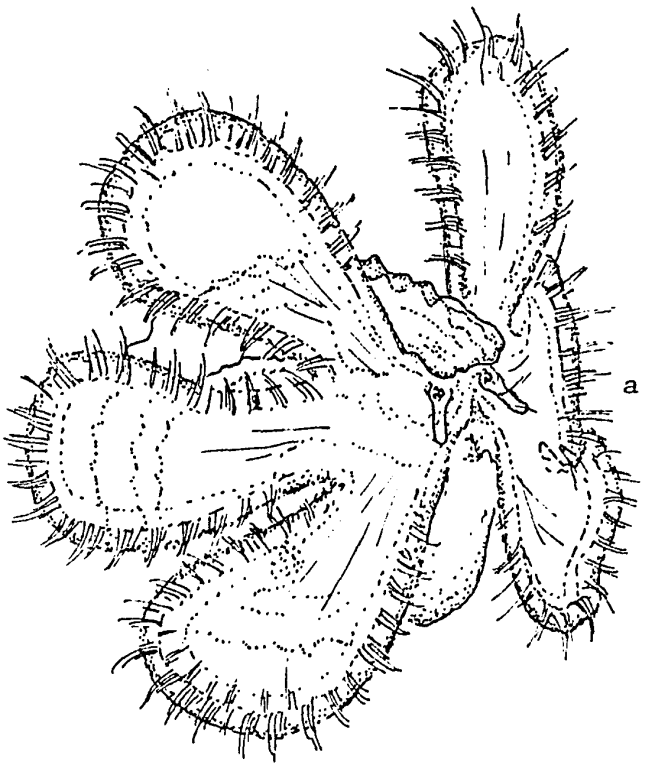
Lamellaria sp.$_1$

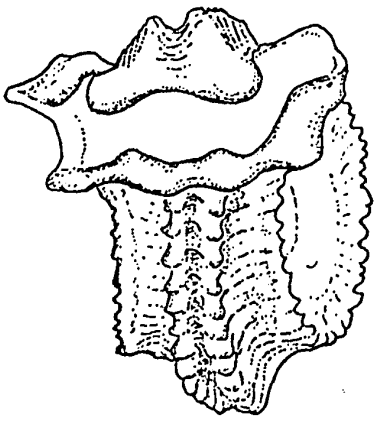
Figure a. swimming veliger

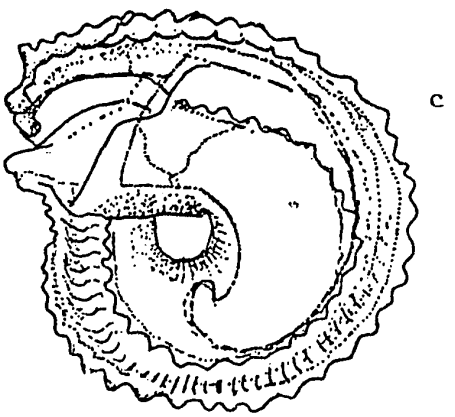
b. scaphoconch, anteroventral aspect

c. scaphoconch and protoconch with veliger, left lateral aspect

PLATE XXVI
Lamellariacea







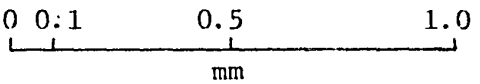


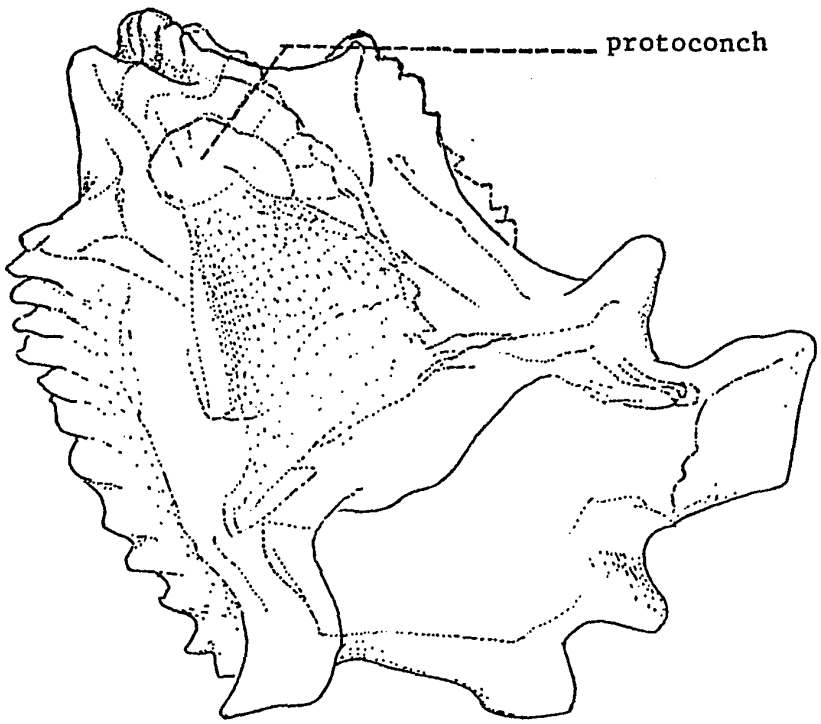
PLATE XXVII

Lamellariacea

Opposite: *Lamellaria* sp.$_2$: scaphoconch with protoconch interior (left of central)

PLATE XXVII

Lamellariacea



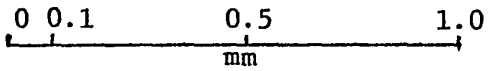


PLATE XXVIII. Lamellariacean premetamorphic veligers.

1.3mm

Above: Lamellaria sp.$_1$, anterodorsal aspect.

Below: Erato sandwichensis, left lateral aspect.

Eratoidae (=Triviidae)

Eratoid adult shells are cypraeiform, either with pustulate, pyriform shells or with grooved, ovate shells. The adults feed on sponges and sessile tunicates.

Coiling is helicoid in eratoid echinospirae. The whorls of the true shell coincide with those of the scaphoconch and the mantle envelops the scaphoconch at metamorphosis in Trivia. In veligers of Erato, the whorls of the true shell do not coincide with those of the scaphoconch and metamorphosis occurs before becoming free of the scaphoconch (Lebour 1935b).

Table 18

Life History Data: Eratoidae

Name	Remarks	References
Erato voluta	newly-hatched echinospira less than 640 µm, greatest dimension; bilobed, tends to become slightly 4-lobed; velum with a narrow brown border; metamorphoses in captivity when greatest dimension approximates 2 mm; mantle covers shell proper when scaphoconch still present; scaphoconch eventually shed	Lebour 1933b, 1937a
Trivia arctica (= *T. europea*)	newly-hatched veliger less than 400 µm across scaphoconch; spends long time in plankton; velum with four long lobes which have a fine dark border; breed chiefly in winter; at metamorphosis, greatest dimension approximates 1600 µm; mantle surrounds scaphoconch which either is absorbed or disappears	Lebour 1933a, 1937a
T. monacha	eggs less than 350 µm; hatch when greatest dimension approximates 350 µm, 1 1/2 whorls complete; long time in plankton; velum large, bilobed, with indentation in center; velar lobes elongate with dark purple border; breed spring and summer; metamorphose in captivity when greatest dimension approximates 1250 µm; mantle yellow with purple spots; adults feed on *Diplosoma* or *Botryllus*	Lebour 1931b, 1937a
Echinospira D	metamorphose in captivity when greatest dimension approximates 460 µm	Lebour 1945

Erato sandwicensis Pease 1860. Plate XXVIII, fig. 2.

Veliger:

Protoconch: an echinospira; colorless; unsculptured; scaphoconch with three rounded ridges on body whorl; beak transparent, rounded; metamorphosis occurs when 2 1/2 whorls complete.

Velum: four-lobed, with tiny khaki streaks.

Cephalic area: unpigmented.

Foot: broad; cream with medial tan streak; operculigerous lobes opaque, appear like wings extending from mesopodium; operculum not visible; propodium with about 16 medium khaki spots.

Viscera: digestive gland dark cream; ctenidium cream, well-developed.

Months found in plankton: April

Areas found: Sampan Channel

Remarks: The protoconch of this veliger is much larger than that of the Trivia veliger which is common in Kaneohe Bay.

Trivia sp.$_1$ Plate XXX, figs. a-d.

Veliger:

Protoconch: an echinospira; colorless; unsculptured; beak barely ly noticeable; greatest dimension of scaphoconch, 1000 µm; greatest dimension of shell proper, 692 µm; metamorphosis occurs when 2 1/4 whorls complete.

Velum: four-lobed; colorless except for 14 tiny chrome yellow spots in food groove of entire velum.

Cephalic area: tentacles medium-long; eyes inside tentacular bases; esophagus brushed with charcoal.

Foot: light yellow; propodium long, bears one circular light yellow terminal spot.

Viscera: digestive gland yellow-orange; mantle colorless with tiny purple-black spots sprinkled throughout.

Months found in plankton: August

Areas found: Sampan Channel, Dredged Island, Ala Moana Reef (Honolulu)

Remarks: The animal is suffused with light yellow and is uncommon relative to the other species of *Trivia*.

Trivia hordacea Kiener 1845. Plate XXIX, figs. a-e; Plate XXXI.

Veliger:

Protoconch: an echinospira; unpigmented; unsculptured; beak present on scaphoconch, gently rounded; both parts of protoconch flexible, uncalcified; thick scaphoconch separated from shell proper by opaque region; siphonal canal, a truncate indentation; scaphoconch resembles an albuminous bubble; metamorphosis occurs when 2 1/2 whorls complete; scaphoconch: greatest dimension, 1800 µm; shell proper: greatest dimension, 1200 µm.

Velum: four-lobed; velar lobes thin, long, curved; unpigmented; velar height 2000 µm, width, 1500 µm.

Cephalic area: medium-long, not tapered; tiny spots along entire length; eyes at base of tentacles, consist of bits of yellow and black pigment.

Foot: propodium narrow, blunt, with small lateral extensions; mesopodium narrow; metapodium narrow, tapered; entire foot with yellow-green to khaki patches, occasionally brushed with charcoal, mostly concentrated in propodium; operculigerous lobes conspicuous; operculum large, transparent, gibbous-shaped, covers aperture.

Viscera: digestive gland pink-tan to salmon-colored; ctenidium tinted with pink-brown.

Months found in plankton: January, May, June, August, September

Areas found: Sampan Channel

Remarks: The anterior half of the mantle is invested with many tiny khaki spots.

Trivia sp.$_2$ Plate XXX, figs. e,f.

Veliger:

Protoconch: an echinospira; colorless; unsculptured; beak pronounced; scaphoconch: greatest dimension, 1075 µm x its perpendicular, 845 µm; protoconch proper: greatest dimension, 540 µm x its perpendicular, 415 µm.

Velum: four-lobed; velar lobes with 14 large 'tufted' chrome yellow patches in food groove; bases of post-oral cilia stained with purple-black.

Cephalic area: tentacles knobbed; esophagus brushed with charcoal; eyes inside bases of tentacles.

Foot: foot and foot-stalk light yellow, brushed uniformly with charcoal; propodium medium-long; operculigerous lobes noticeable in this species.

Viscera: digestive gland tan-brown.

Months found in plankton: August

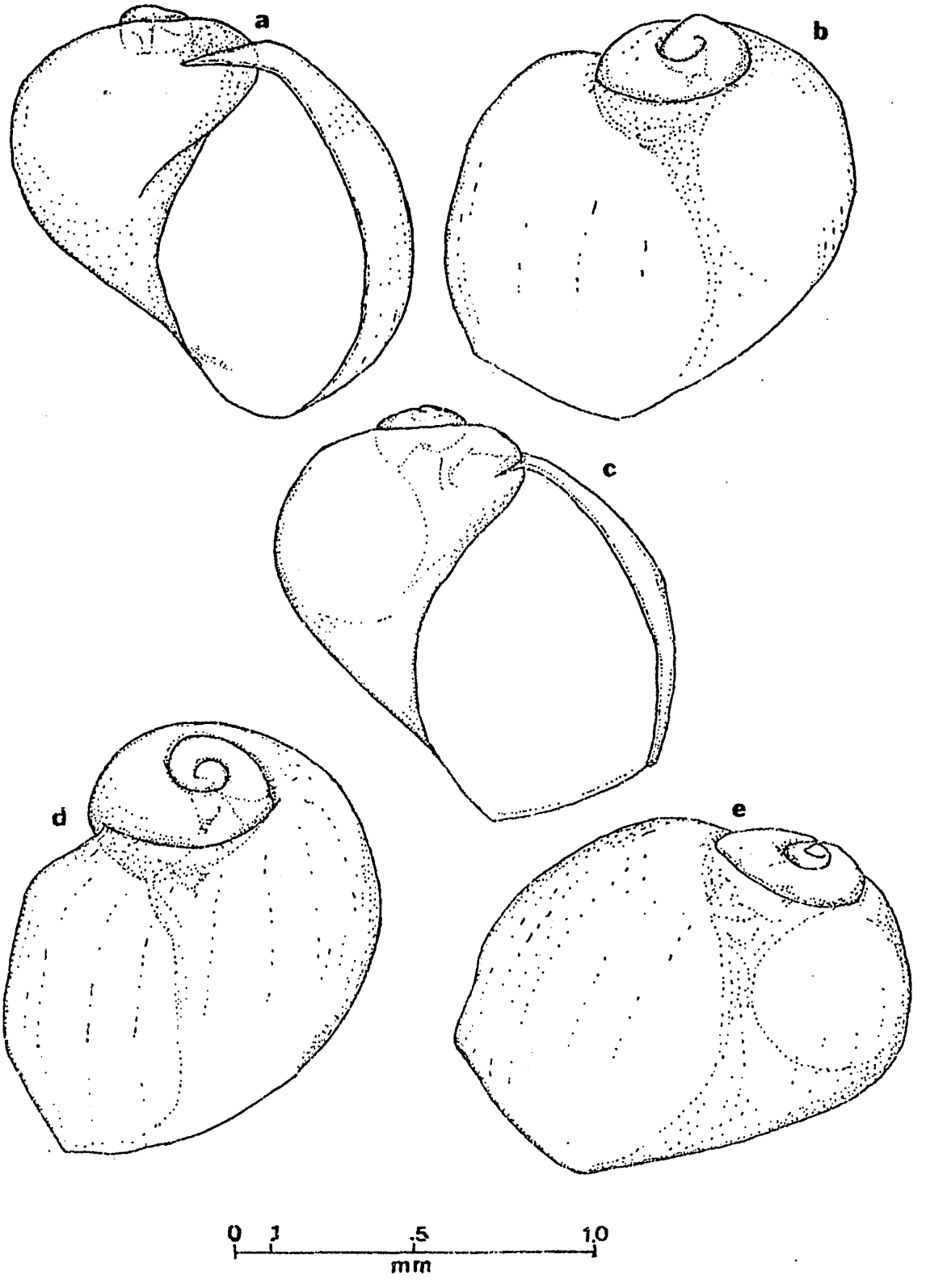
Areas found: Sampan Channel, Dredged Island, Ala Moana Reef (Honolulu)

Remarks: The mantle is colorless with large yellow spots scattered throughout; the interior of the mantle is brushed with purple-black. The post-velar skin is brushed with charcoal.

PLATE XXIX
Triviidae

Figures a-e. Trivia hordacea

PLATE XXIX



Triviidae

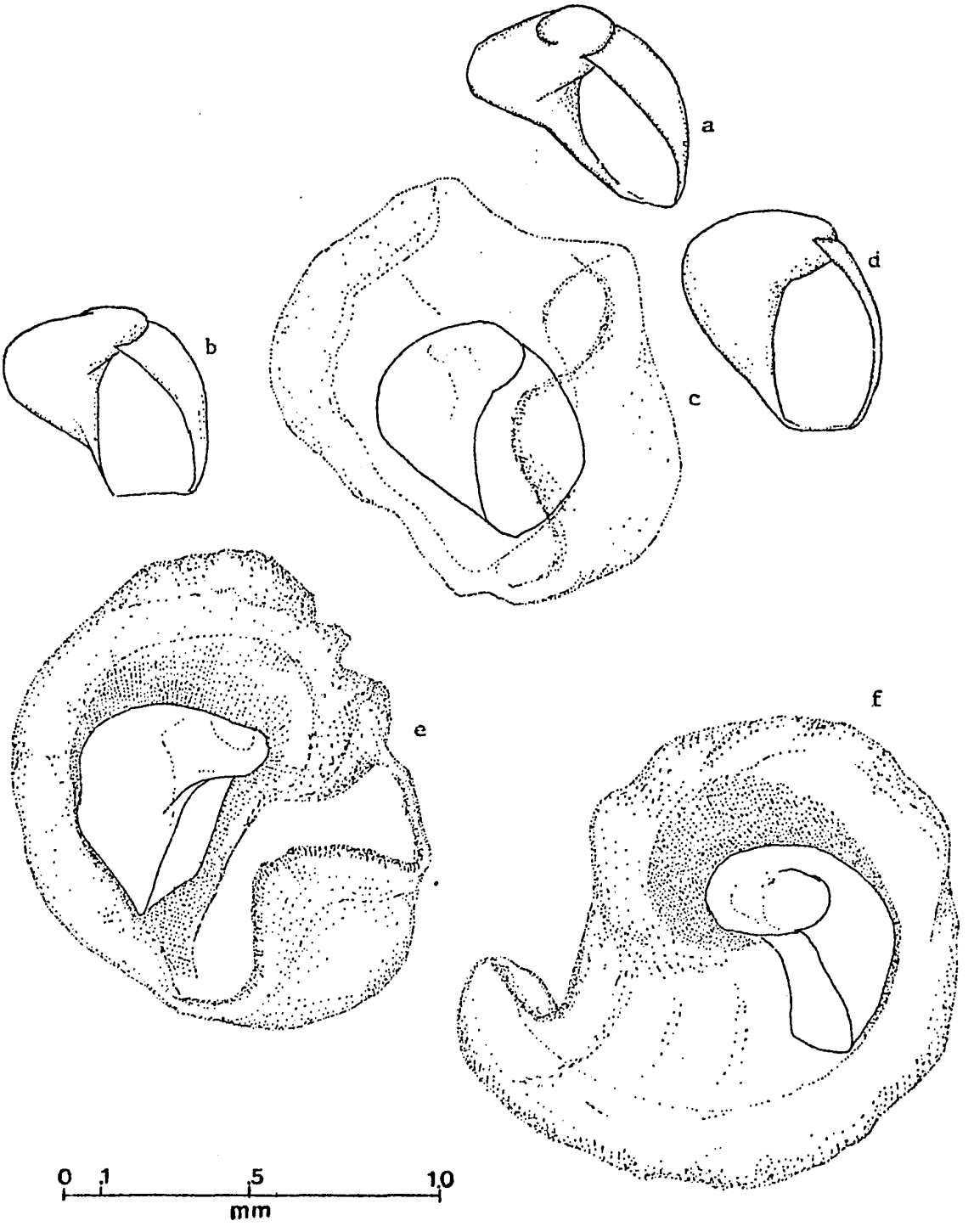
PLATE XXX

Triviidae

Figures a-d. *Trivia* sp.$_1$

e-f. *Trivia* sp.$_2$

PLATE XXX



Triviidae

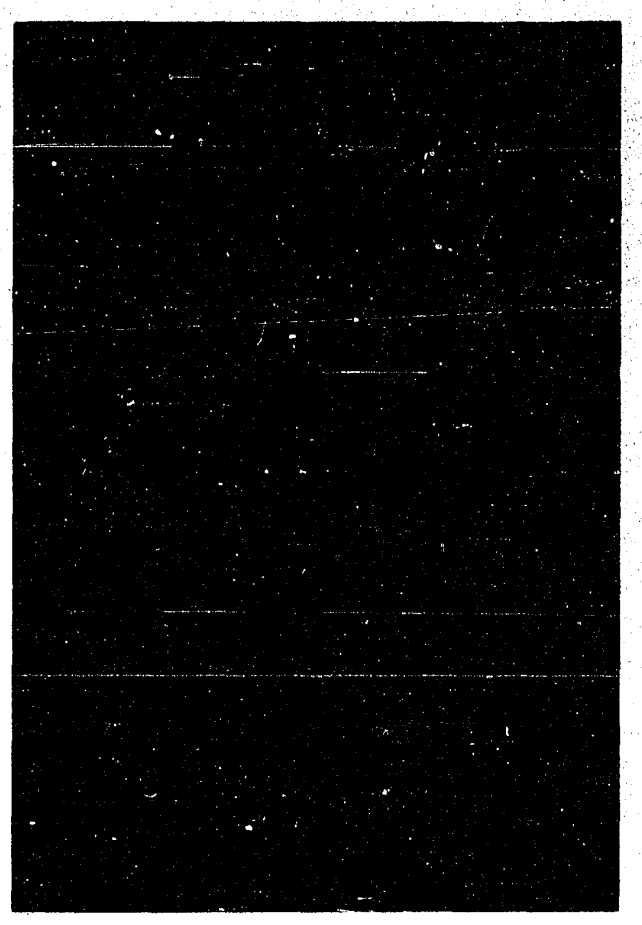
PLATE XXXI
Triviidae

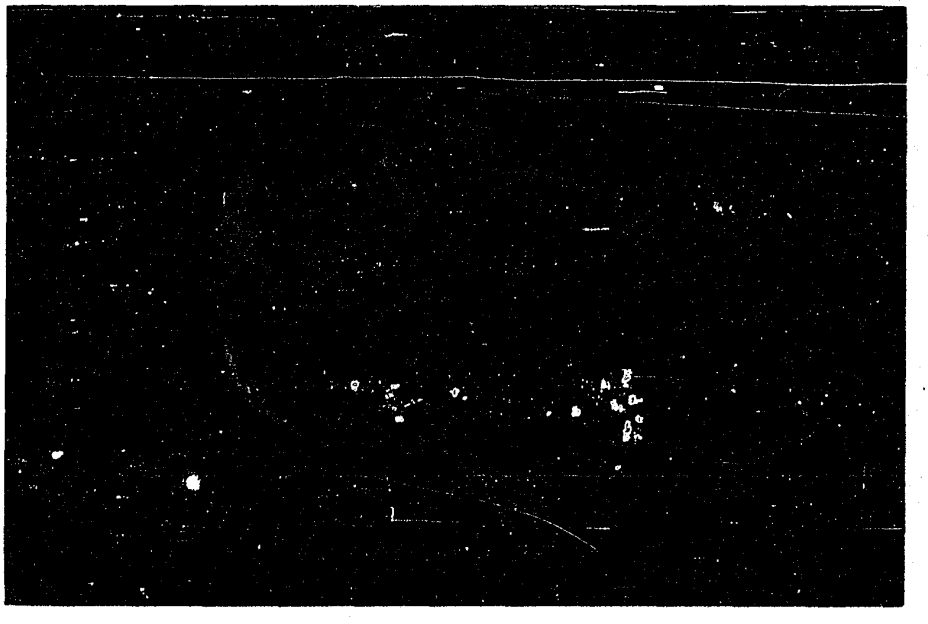
Trivia hordacea: pre-metamorphic veligers.

Above: swimming pre-metamorphic veliger.

1.3mm

Below: retracted veliger, showing 'scaphoconch'.





Superfamily 17. Cypraeacea

Cypraeaceans include the Cypraeidae* and Ovulidae.

Superfamily characteristics: shell ovoid with a narrow, ventral aperture; periostracum lacking; osphradium triradiate; feed on corals and algae; generally tropical to subtropical; sinusigera larva present.

Studies in cypraeacean reproductive biology have concentrated mainly on the eggs, early veligers and adults. Little is known of the pre-settlement veligers and early juveniles. Cypraeacean egg capsules have been described by several authors (LoBianco 1899; Vayssiere 1923, 1927; Lebour 1932; Ostergaard 1950; Natarajan 1957; D'Asaro 1969,1970). Many cypraeacean females brood their egg capsules: Simnia patula (Lebour 1932), Cypraea carneola, C. isabella, C. helvola, C. caputserpentis, C. poraria (Ostergaard 1950), C. errones (Natarajan 1957) and C. spurca acicularis (D'Asaro 1970). Non-brooding cypraeaceans include Jenneria pustulata and many ovulids (D'Asaro 1970).

The larval stages of several cypraeaceans have been described in varying detail. Early veligers of nine cypraeid species are figured (Lebour 1932; Ostergaard 1950; Natarajan 1957, and Fretter and Pilkington 1970) as well as the pre-settlement veligers of four ovulids: Simnia patula (Lebour 1932), an (?)ovulid (Lebour 1945), Simnia spelta (Thiriot-Quievreux 1967) and Pedicularia sicula (Scheltema 1971). No figures of pre-settlement cypraeid veligers have been published to date, although x-rays and drawings of their protoconchs are available (Ranson 1967, J. Taylor 1971).

Cypraeidae

As far as is known, cypraeids surround their eggs with a firm gelatinous substance and deposit ovoid or triangular egg capsules with parchment-like walls. Intra-capsular development lasts from one to two and one-half weeks and a veliger which will become planktotrophic emerges.

As the veliger assumes a planktonic existence, the protoconch begins to acquire sculpture of spiral and sinuous axial threads, which at the sutures are mutually perpendicular. The fragile pre-settlement protoconch bears 2 1/2 to 5 1/2 cancellate whorls. The color of the protoconch varies from colorless to dark red-brown. The mature velum is invariably four-lobed and although discrete pigment spots are absent, the velum is often suffused with tinges of pigment at the velar extremities.

Some species, e.g., Cypraea fimbriata, do not require the presence of coelenterates to undergo metamorphosis successfully. Cypraeid veligers require clear, well-aerated water and although there are some cypraeid larvae, e.g., C. isabella, in the plankton of Sampan Channel during all months, the greatest diversity and abundance occur during the spring and summer.

I have never reared any cypraeids beyond a maximum length of 2.5 mm for I have had difficulty duplicating the condition of their normal habitats. The presence of living or dead Pocillopora meandrina or Porites lobata heads provides something which is necessary to their existence; whether it be food or shelter is not known.

Table 19

Life History Data: Cypraeidae

Name	Size of egg (µm)	Days in capsulo	Size at hatching (µm)	Protoconchal description	Month(s) breeding	References cited
Cypraea caputserpentis	90	18	100-120	pitted, faint red-brown; pedal ventrum red-brown	October	Ostergaard 1950 Kay 1960 Anderson 1965
C. carneola	140	14	?	pitted, tinged with purple; pedal ventrum purple	June-July	Ostergaard 1950
C. errones	263-267	?	373	alimentary tract dark purple; velum unpigmented	Sept.-March	Natarajan 1957
C. helvola	90	5-9	140	pedal ventrum with large purple area	July	Ostergaard 1950
C. isabella	110	11	150	pitted, purple-brown; outer lip of aperture purple-brown	July	Ostergaard 1950
C. mauritiana	150	17	235	carmine	June	Ostergaard 1950
C. poraria	?	?	140	delicately pitted; pale golden yellow	May	Ostergaard 1950
C. spurca acicularis	100	?	?	brood protection	May-June	D'Asaro 1970

Cypraea fimbriata Gmelin 1791. Plate XXXII.

Veliger:

Protoconch: globose sinusigera; sculpture of fine parallel spiral threads crossed by sinuous parallel axial threads; structural areas medium red-brown; background light tan; metamorphosis occurs when 3 1/4 - 3 1/2 whorls complete, length: 1080 µm, width: 1090 µm.

Velum: four-lobed; bases of post-oral cilia tinged with red-orange.

Cephalic area: unpigmented; tentacles medium-long, tapered.

Foot: diaphanous white with tiny red-brown flecks.

Viscera: mantle diaphanous cream with medium red-brown small patches which enlarge upon metamorphosis.

Months found in plankton: March through October

Areas found: Sampan Channel, Dredged Island

Remarks:

Veligers of C. fimbriata are among the most commonly collected cypraeid veligers of the Sampan Channel plankton.

PLATE XXXII

Cypraea fimbriata, protoconch development.

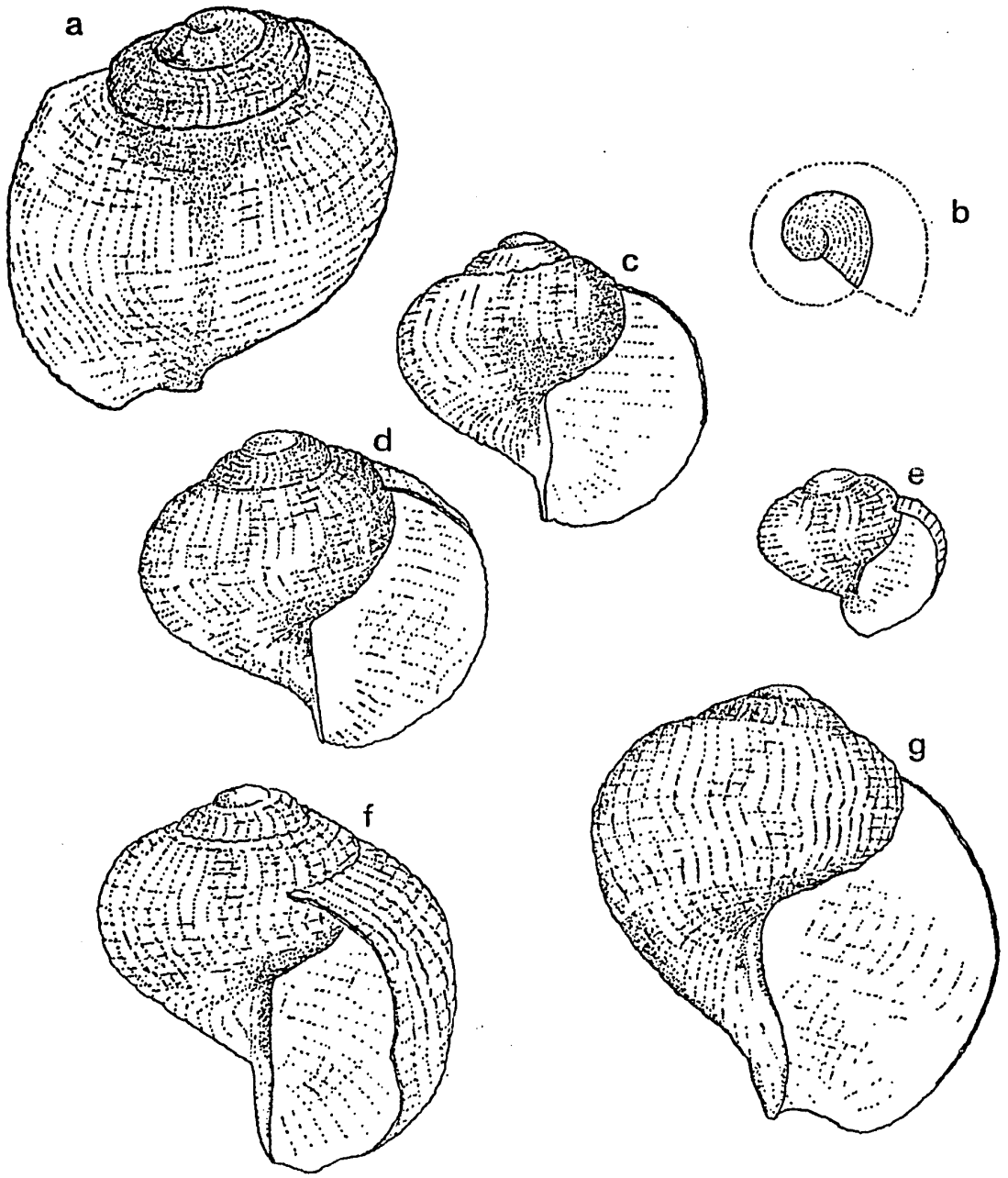
a. pre-metamorphic protoconch, abapertural view.

b. capsular protoconch, apical view.

c, d, e, and f. protoconchs from intermediate veligers.

g. pre-metamorphic protoconch, apertural view.

PLATE XXXII



CYPRAEIDAE

Cypraea ? chinensis Gmelin 1791. Plate XXXIII, figs. a-c.

Veliger:

Protoconch: broadly-globose sinusigera; 1st whorl elongate; 1st two whorls dark red-brown, 3rd and 4th orange-brown; siphonal canal shallow; beak lacking; 4th whorl with 13 spiral threads; metamorphoses when 4-4 1/2 whorls complete, length: 1050 µm, width: 1050 µm.

Velum: four-lobed; extremely elongate; each velar lobe with well-defined medial ridge, tinted with light orange throughout.

Cephalic area: tentacles long, tinted with orange; eyes far apart.

Foot: background orange-brown; ventral medial foot with brown tinge; propodium blunt; mesopodium undistinguished; metapodium tapering, but rounded; dorso-lateral areas bear papillae with fine setae.

Viscera: digestive gland red-brown.

Months found in plankton: February

Areas found: Sampan Channel

Remarks: Veligers of this species produce copious amounts of mucus. The mantle contains stellate white and red-brown spots and extends backward over the shell. Some of the mantle papillae are setose. Juveniles of C. chinensis resemble juvenile C. rashleighana (Plate XXXIII), but the protoconch of C. chinensis has a lower spire and a broader body whorl.

Cypraea helvola Linnaeus 1758. Plate XXXIII, fig. f.

Veliger:

Protoconch: globose sinusigera; capsular protoconch light red-brown; planktonic protoconch pink; metamorphoses when 5 1/2 whorls complete.

Velum: four-lobed; velar lobes long, thin, suffused with light pink, edged with purple-black; width, 4.95 mm; height, 1.65 mm.

Cephalic area: tentacles long, tapered; oral region smudged with charcoal.

Foot: as if dusted with fine black particles; may or may not bear one or more black lines.

Viscera: stomach two-parted; anterior part black, posterior part gray; intestine and style sac charcoal; digestive gland light orange-brown.

Months found in plankton: June, July

Areas found: Sampan Channel, Kewalo Basin (Honolulu)

Mantle: suffused with pink, extends over protoconch.

Remarks: Veligers of C. helvola are rather abundant in Sampan Channel plankton tows during the summer months.

C. poraria veligers resemble these veligers closely in terms of shape, coloration and number of whorls, but are smaller at metamorphosis.

PLATE XXXIII

Figure a. *Cypraea ?chinensis*, early intermediate protoconch.

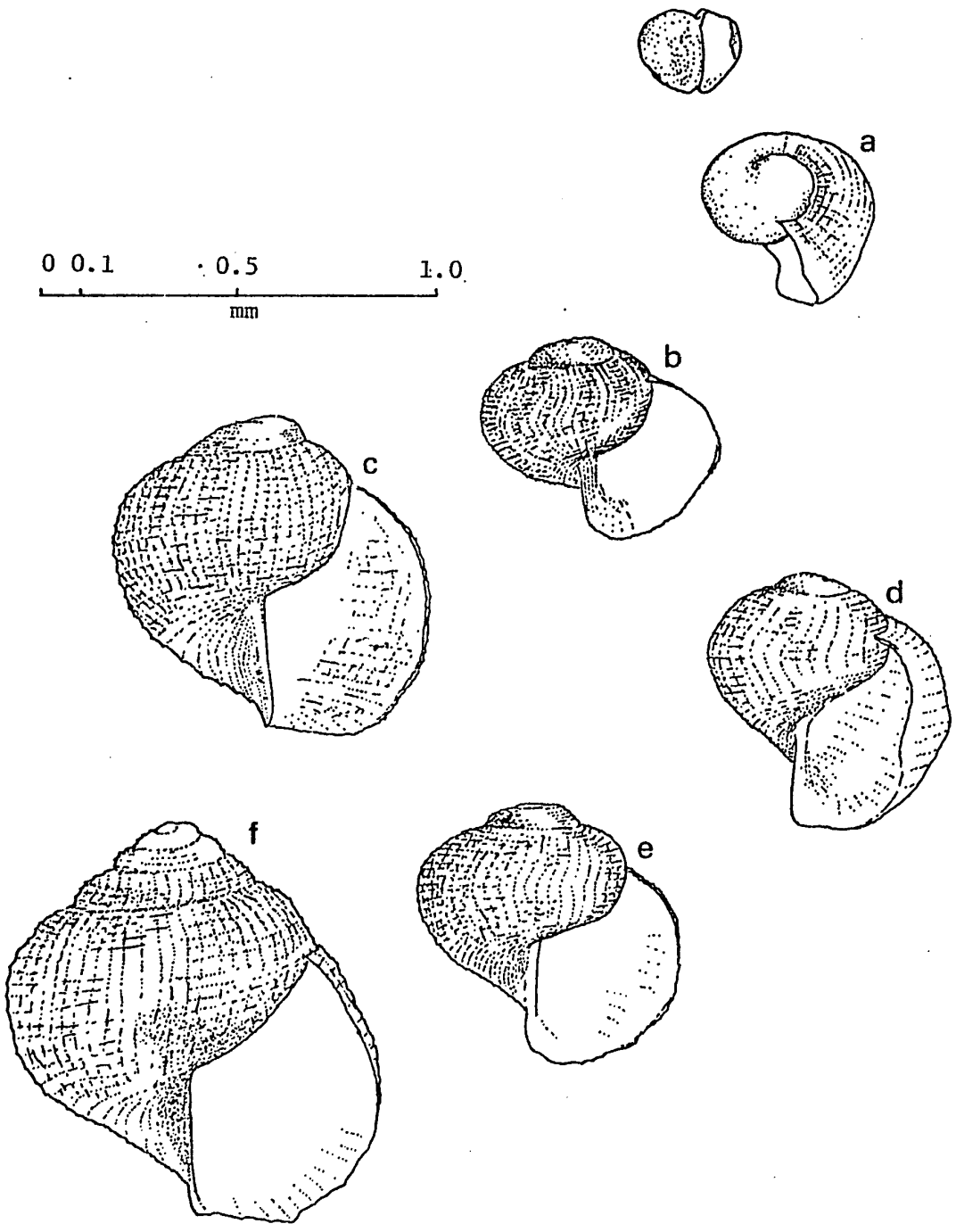
b. *C. ?chinensis*, intermediate protoconch.

c. *C. ?chinensis*, late intermediate protoconch.

d, e. *C. ?gaskoini*, intermediate protoconchs.

f. *C. helvola*, pre-metamorphic protoconch.

PLATE XXXIII



CYPRAEIDAE

Cypraea isabella Linnaeus 1758. Plate XXXIV, figs. d, e.
Plate XXXVI, fig. b.

Veliger:

Protoconch: sinusigera: elongate, teardrop-shaped, dark red-brown, apex rounded; sculpture sinuously cancellate on third to sixth whorls; first whorl punctate; second whorl with delicate spiral threads; sutures barely impressed; beak well developed, projects forward like tongue indented at tip just before new section of protoconch deposited; siphonal notch wide, short; metamorphoses when 5 1/2 - 6 whorls complete, length: 1100-1180 µm, width: 700-750 µm.

Velum: four-lobed, large, extremities held partly furled; velar lobes elongate, unpigmented; width: 4.8 mm, height: 1.9 mm.

Cephalic area: tentacles medium-long, slim, unpigmented; eyes inside tentacular bases; oral region purple-black to charcoal.

Foot: propodium square, blunt; posterior margin, a rounded vee; pedal background colorless, occasionally lightly brushed with charcoal; mesopodium bears an inverted charcoal Y; metapodium with peripheral opaque white spots.

Mantle: colorless, with numerous tiny irridescent spots; covers protoconch.

Viscera: not discernible through protoconch.

Months found in plankton:

Areas found: Sampan Channel, Dredged Island, Ala Moana Reef (Honolulu)

Remarks: In Hawaii, veligers of C. isabella resemble those of only one other species: C. tessellata. At metamorphosis, both species have about the same number of whorls and have the shape of an elongate teardrop; they differ in that C. tessellata protoconchs are longer and the whorls are less ovate.

During 1969, in the reefs seaward of the mouth of Sampan Channel, C. isabella adults were collected at least twenty times more frequently than adults of C. tessellata (Ralph Bowers, pers. comm.).

After metamorphosis, the mantle, which covers the entire protoconch, is white with dark red-brown irregular spots at the anterior end.

Cypraea ?talpa Linnaeus 1758. Plate XXIV, fig. h.

Veliger:

Protoconch: globose, red-brown sinusigera; siphonal notch truncate; beak vee-shaped; metamorphose when 2 3/4 to 3 whorls complete, length: 825 μm, width: 660 μm.

Velum: four-lobed, unpigmented; velar lobes slim, elongate; width, 4.6 mm; height, 2.2 mm; angle between upper and lower velar lobes characteristically about 45°.

Cephalic area: tentacles of medium length; eyes inside bases of tentacles; oral region purple-black.

Foot: white; meso- and metapodial areas combined resemble lily pad; propodium extends forward like blunt tongue; metapodium broadly tapered.

Mantle: colorless.

Viscera: digestive gland light area beneath shell; style sac gray.

Months found in plankton: November

Areas found: Sampan Channel

Remarks: Upon metamorphosis, the previously uniform red-brown protoconch acquires a magenta tinge. This veliger is probably Cypraea talpa. Two other secondary possibilities are C. tigris and C. vitellus. There are only five species of fairly common corwies in Hawaii which have three or less complete whorls at metamorphosis. The shapes of two of these --C. fimbriata and C. gaskoini are too broad and their protoconchs are more tan than red-brown. The protoconchs of C. tigris and C. vitellus are thought to be light in color.

PLATE XXXIV

Figure a. Cypraea ?lynx, pre-metamorphic protoconch.

b. C. fimbriata, protoconch of intermediate veliger.

c. C. ?chinensis, protoconch of intermediate veliger.

d. C. isabella, protoconch of intermediate veliger.

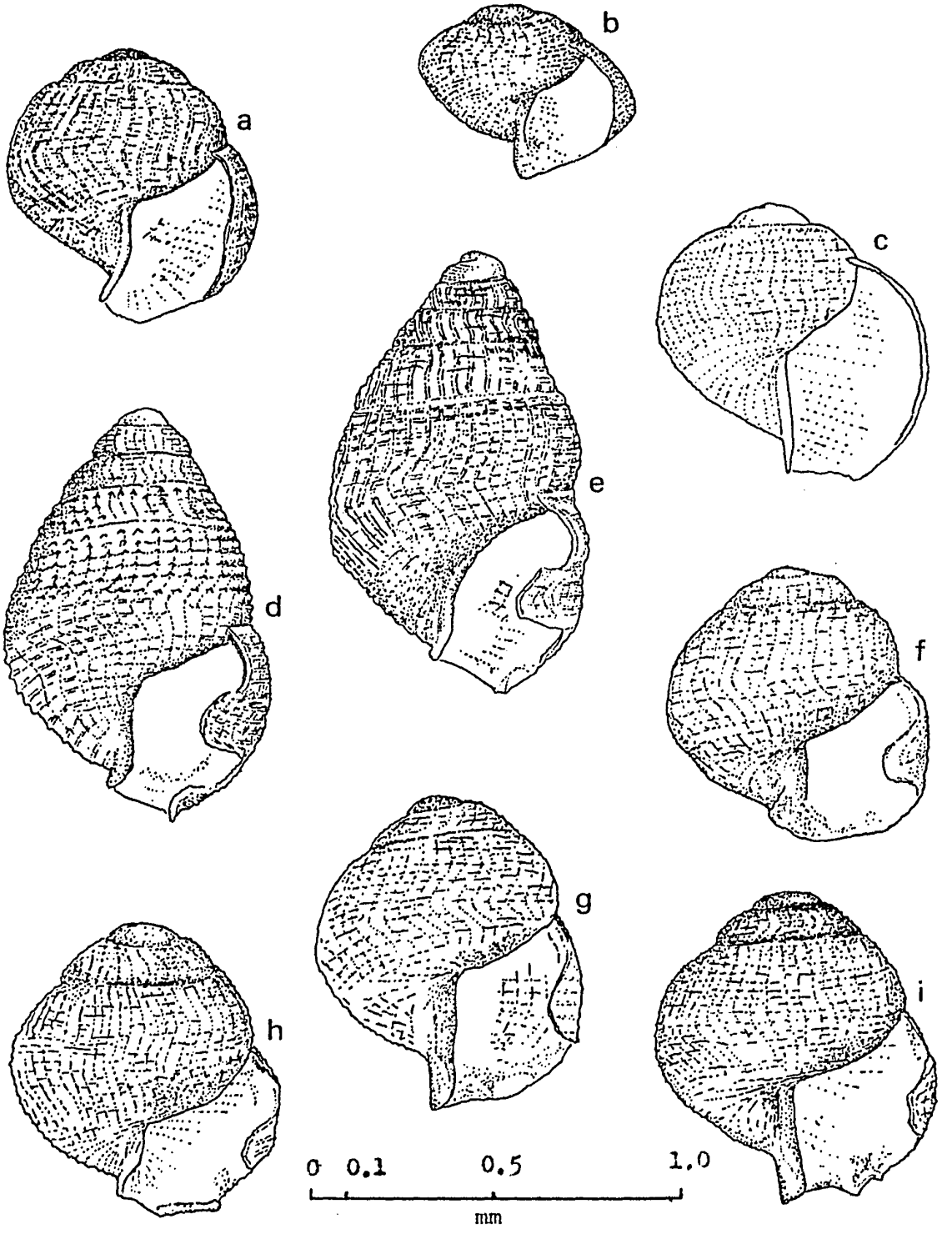
e. C. isabella, protoconch of pre-metamorphic veliger.

f. C. ?lynx, pre-metamorphic protoconch.

g. C. ?lynx, pre-metamorphic protoconch.

h, i. C. ?talpa, pre-metamorphic protoconchs.

PLATE XXXIV



CYPRAEIDAE

Cypraea teres Gmelin 1791. Plate XXXV, fig. d.

Veliger:

Protoconch: broadly globose sinusigera; clear light orange; siphonal canal truncate rather than rounded; metamorphoses when 5 - 5 1/2 whorls complete, length: 1155 µm, width: 1385 µm.

Velum: four-lobed, large, unpigmented; velar lobes elongate; tips of velar lobes recurve anteriorly when velum expanded and larva at rest.

Cephalic area: oral region unpigmented; tentacles white, slightly tapering; eyes lateral inside tentacular bases.

Foot: white; metapodium bluntly tapered; operculum transparent.

Mantle: clear, tinted light orange.

Viscera: digestive gland red-orange; stomach clear; intestine white.

Months found in plankton: May

Areas found: Sampan Channel

Remarks: Veligers of this species metamorphosed under laboratory conditions; soon thereafter, the mantle papillae acquired white patches.

Cypraea ?sulcidentata Gray 1824. Plate XXXV, fig. f; Plate XXXVI, fig. a.

Veliger:

Protoconch: globose colorless sinusigera; size intermediate; siphonal canal almost non-existent; beak vee-shaped, edged with red-brown, abbreviated; 3rd and 4th whorls with regularly and closely-spaced fine axial grooves; metamorphose when 3 1/2 to 4 whorls complete, length: 905-970 µm, width: 825-840 µm.

Velum: four-lobed, unpigmented; velar lobes elongate, sometimes edged with charcoal.

Cephalic area: entire area charcoal; eyes and tentacles far apart.

Foot: broad; black anteriorly, shading to charcoal gray on mesopodium, metapodium dirty white; operculum transparent, difficult to see.

Mantle: white, contains irridescent spots, usually covers protoconch even while swimming.

Viscera: digestive gland purple-black; gut black.

Months found in plankton: all months except September - November

Areas found: Sampan Channel, Dredged Island

Remarks:

Veligers of this species are some of the more commonly-occurring cypraeid larvae in the plankton. The adults probably have an extended breeding period, rather than one short time during the year.

These veligers have metamorphosed under laboratory conditions; after metamorphosis, the mantle is clear with white papillae. The initial teleoconch is light red-brown or light tan.

PLATE XXXV

Cypraeidae

Figure a. Cypraea poraria, pre-metamorphic protoconch.

b. C. granulata, pre-metamorphic protoconch.

c. C. schilderorum, pre-metamorphic protoconch.

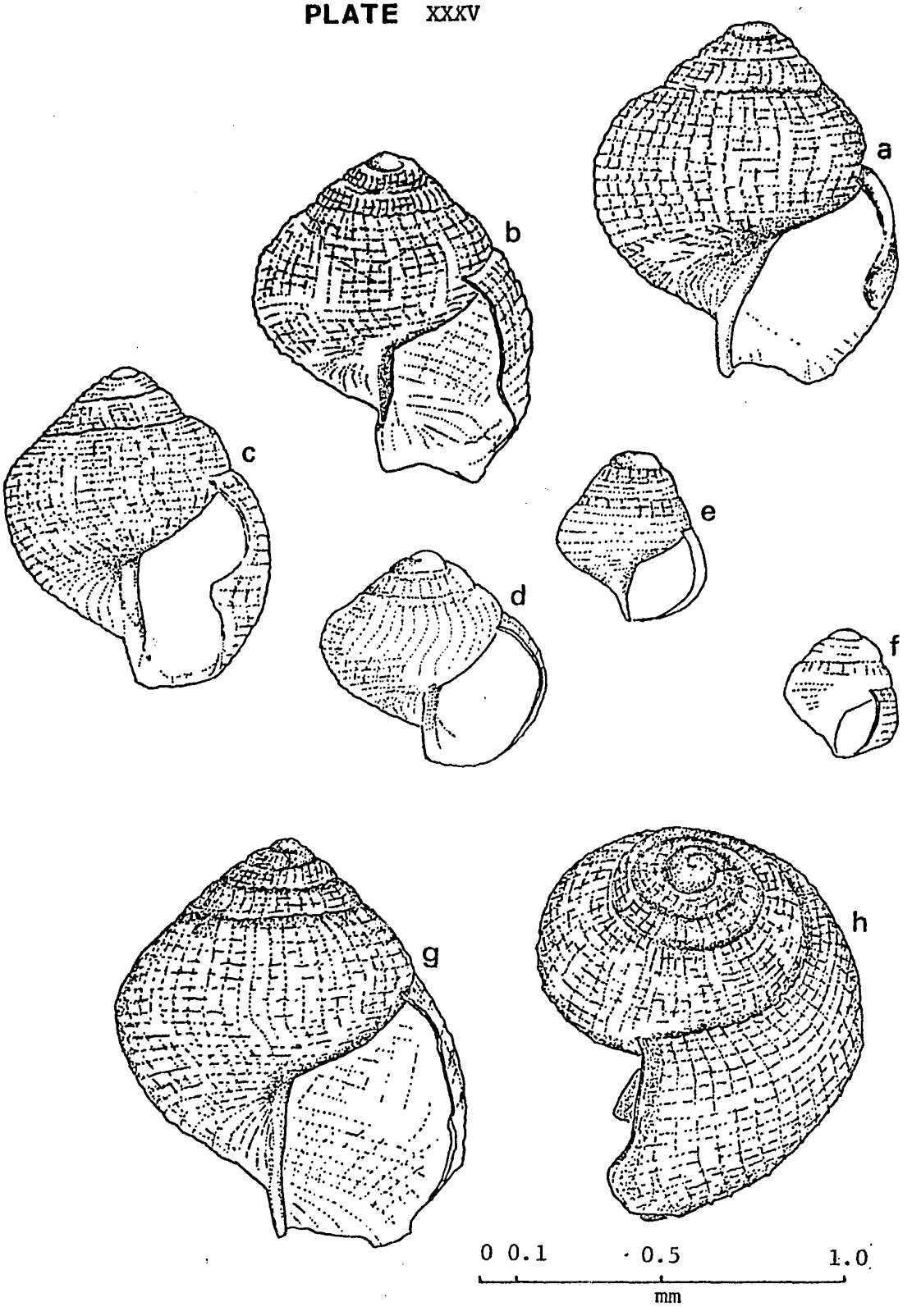
d. C. teres, pre-metamorphic protoconch.

e. C. caput-serpentis, protoconch of intermediate veliger.

f. C. sulcidentata, protoconch of early veliger.

g, h. C. rashleighana, pre-metamorphic protoconchs.

PLATE XXXV



CYPRAEIDAE

PLATE XXXVI
Cypraeidae

1.3mm

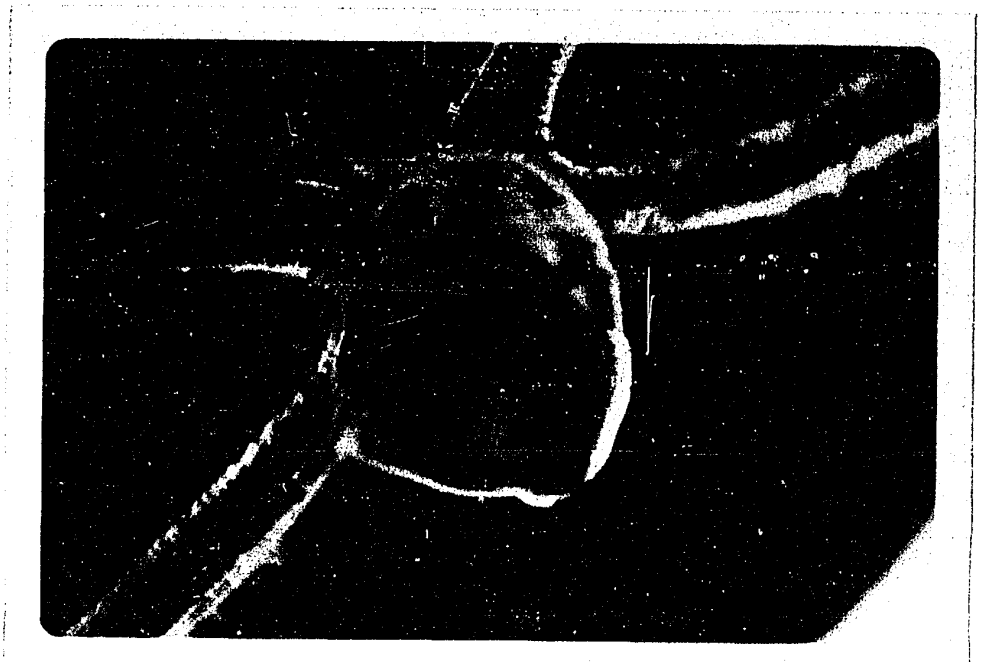


Figure a. Cypraea sulcidentata, premetamorphic veliger.

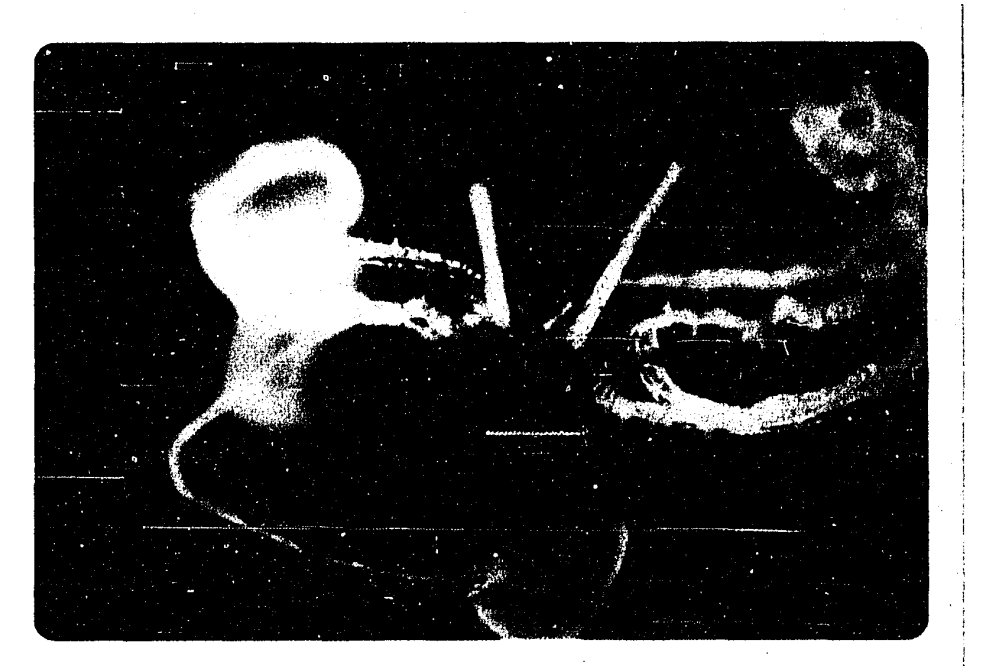


Figure b. Cypraea isabella, premetamorphic veliger.

Cypraea rashleighana Melvill 1888. Plate XXXVII.

Veliger:

Protoconch: globose sinusigera; apical 1 1/4 whorls punctate; planktonic protoconch clear, tinged with red-orange; metamorphoses when 4 whorls complete, length: 1010 μm, width: 1180 μm; apical breadth: 110 μm; sutures not very impressed, whorls not inflated.

Velum: four-lobed, tinged with red-orange.

Cephalic area: tentacles medium-long, unpigmented; eyes inside lateral bases; esophagus unpigmented.

Foot: propodium square; metapodium tapered; white.

Viscera: digestive gland dark tan.

Months found in plankton: June

Areas found: Sampan Channel

Remarks: Although Burgess (1970) and others regard this species as rare in Hawaii, Ralph Bowers (pers. comm.) has collected seven adults during 1969-70 from the benthos beneath the Sampan Channel plankton tow area.

Veligers of this species are distinguished from those of C. fimbriata and C. gaskoini by the presence of the extra whorl prior to metamorphosis and by the compact, symmetrical shape of this species of protoconch as compared with the ovate asymmetrical protoconchs of the other two species.

After metamorphosis, each mantle papilla develops a dark spot at the tip. The foot becomes light lemon-yellow. The mantle and mantle papillae acquire a reddish-cinnamon color and the siphon is also tinged with cinnamon.

PLATE XXXVII

Cypraea rashleighana, newly-metamorphosed juvenile.

1.3mm

Table 20

Life History Data: Ovulidae

Name	Remarks	References
Jenneria pustulata	provides descriptions of egg capsules	D'Asaro 1969
Ovula ovum		Thiriot-Quivreux 1967
Pedicularia sicula	metamorphoses when length approximates 1000 µm and width approximates 750 µm; two months from spawning to metamorphosis; adults feed on stylasterine corals; veliger planktonic	Dautzenberg 1889; Scheltema 1971
Simnia patula	egg diameter 130 µm; hatch when greatest dimension approximates 140 µm; velum initially bilobed, later 4-lobed; capsular protoconch irregularly granular, planktonic protoconch cancellate; planktonic for several weeks; brood protection; adults feed on *Alcyonium* and *Eunicella*	Lebour 1932
S. spelta	breed June-September	Thiriot-Quievreux 1967
(?) *Radius* or (?)*Cyphoma*	veliger planktonic; velum 4-lobed, colorless; protoconch dark brown, cancellate; animal also brown; metamorphoses when length approximates 800 µm	Lebour 1945

Superfamily 18. Atlantacea

Atlantaceans include the Atlantidae*, Carinariidae* and Pterotracheidae*.

Superfamily characteristics: visceral mass reduced; animals transparent with planar-nautiloid or tubular-conical protoconchs; sense organs well developed; predatory on small fish and worms, pelagic; sexes separate; may be related to lamellariaceans.

Little is known of atlantacean life histories. No descriptions of their egg masses or of their early larval stages are reported in the literature. Thus far, only planktonic veligers are reported for this group and several species of late veligers are depicted (see Table 18.1).

Without exception, late veligers of the Atlantidae have six-lobed velums. Protoconchal length at metamorphosis ranges from 450 to 700 μm. The distinctive appearance of the larval eyes resembles that of the adults; veligers of Atlanta are not easily confused with those of other genera. Veligers metamorphose readily in plastic petri dishes with clean sea water, but are difficult to rear from a nutritional point of view because their postlarvae feed on small zooplankters and require well-aerated sea water.

Table 21

Life History Data: Atlantacea

Name	Remarks	References
1. Atlantidae		
Atlanta fusca	velar lobes equal, unpigmented; metamorphose when length approximates 450 µm, 4 1/2 whorls complete; protoconch yellow-brown; head, foot and operculum with light brown markings	Thiriot-Quievreux 1967
A. helicinoides	velar lobes equal, unpigmented; metamorphose when length approximates 600 µm, 4 1/2 whorls complete; protoconch with spiral keels; head and foot light brown	Franc 1948; Thiriot-Quievreux 1967
A. lesueuri	velar lobes unequal with light brown border; metamorphose when length approximates 500 µm, 3 whorls complete; protoconch transparent	Thiriot-Quievreux 1967
A. peresi	velar lobes equal, very long, flexuous, bordered with light red-violet; metamorphose when length approximates 700 µm, 3 1/2 whorls complete; spire of protoconch rose-violet, remainder colorless	Thiriot-Quievreux 1967
A. peroni	provides a figure	Krohn 1860
A. quoyana	velar lobes equal, unpigmented; metamorphose when length approximates 550 µm, 4 1/2 whorls complete	Franc 1948; Thiriot-Quievreux 1967
A. rosea	protoconch cancellate	Franc 1949
A. sp.	provides a figure	Simroth 1911
Oxygyrus keraudreni	provides a figure	Thiriot-Quievreux 1967

	[illegible] length approximates 500 µm, 3 whorls complete; protoconch transparent	
A. peresi	velar lobes equal, very long, flexuous, bordered with light red-violet; metamorphose when length approximates 700 µm, 3 1/2 whorls complete; spire of protoconch rose-violet, remainder colorless	Thiriot-Quievreux 1967
A. peroni	provides a figure	Krohn 1860
A. quoyana	velar lobes equal, unpigmented; metamorphose when length approximates 550 µm, 4 1/2 whorls complete	Franc 1948; Thiriot-Quievreux 1967
A. rosea	protoconch cancellate	Franc 1949
A. sp.	provides a figure	Simroth 1911
Oxygyrus keraudreni	provides a figure	Thiriot-Quievreux 1967
2. Carinariidae		
Carinaria lamarcki	(=C. mediterranea); provides a figure	Simroth 1964
3. Pterotracheidae		
Firoloida desmaresti	provides a figure	Thiriot-Quievreux 1967
Pterotrachea coronata	provides a figure	Simroth 1964
Pterotrachea sp.	provides a figure	Simroth 1964

Atlanta sp.$_1$ Plate XXXVIII, figs. a-d.

Veliger:

Protoconch: globose; spire slightly produced, turreted; suffused with light gold; beak broadly rounded; siphonal canal shallow; sculpture initially of closely-spaced fine spiral grooves, last half-whorl of protoconch smooth; capsular protoconch faintly tinged with pink; metamorphoses when 4 - 5 whorls complete, length: 420 µm, width: 500 µm.

Velum: six-lobed; unpigmented.

Foot: unpigmented; operculum transparent, triangular, retained in juvenile.

Cephalic area: tentacles medium-short, thick; esophagus purple-black; eyes dorsal and posterior to tentacular bases; statocysts dorsal and posterior to eyes.

Viscera: heart tinged with charcoal; body whorl with large brown body underneath and posterior to foot; mantle edge under beak tinged with purple-black.

Months found in plankton: July, August

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Atlanta sp.$_2$ Plate XXXVIII, figs. e-h.

Veliger:

Protoconch: spire turreted, body whorl ovate; rust-colored; spirally grooved; capsular protoconch two whorls, medium red-brown; beak replaced by sutural slit; metamorphosis occurs when four whorls complete; siphonal canal lacking.

Velum: six-lobed; unpigmented.

Cephalic area: tentacles long, stout; intermediate veliger with eyes as tiny spots inside tentacular bases; in premetamorphic veliger, eyes large, cup-shaped bodies containing spherical lens-bubble, partly inside tentacular bases, partly extending posterodorsally; cephalic area unpigmented; proboscis tubular, differentiated partly before velum is lost.

Foot: intermediate veliger with meso- and metapodial areas combined forming subcircular shape, tiny yellow spots on white background, propodial area not yet developed; premetamorphic veliger with propodial region differentiated into flat, alate structures, propodium capable of spasmodic movement characteristic of adult atlantids.

Viscera: heart tinged with black; intestine black; gut well-defined, proboscis fairly well-developed before metamorphosis.

Mantle: edge serves as a pseudo-beak, appears hood-like above eyes and upper velar ridges.

Months found in plankton: July, August

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Plate XXXVIII, figs. i-l.

Atlanta sp.$_3$

Veliger:

Protoconch: rich red-purple; spire fragile, produced for 3 1/2 whorls, then whorls suddenly expand in planorbiform fashion; initial four whorls spirally grooved, then smooth; beak and siphonal canal lacking; metamorphosis occurs when 4 - 4 1/2 whorls complete, length: 420 - 480 µm, width: 400 µm.

Velum: six-lobed; unpigmented.

Foot: intermediate (i.e., 3 1/2 whorls) veliger with oval meso- and metapodial areas combined, white; premetamorphic veliger (i.e., > 4 whorls) with foot resembling adult atlantid foot, mesopodial regions with tinges of purple.

Cephalic area: intermediate veliger with eyes as tiny dots located posterior to upper velar ridges; premetamorphic veliger with prominent eyes characteristic of adult atlantids; tentacles medium-long, thick, tapered; esophagus edged with red-purple.

Viscera: heart tinged with red-purple.

Months found in plankton: July, August

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Remarks:

Differentiation of the eyes and foot coincides with the addition of smooth protoconch. Veligers of this species are commonly encountered in the Sampan Channel plankton, especially when there are offshore winds.

The juvenile of this species has a thin, black, rectangular area posterior and dorsal to the beak region; the black area proceeds posteriorly in the mantle. The anterior gut is well-defined because it is tinged with purple-black from the mouth to the stomach.

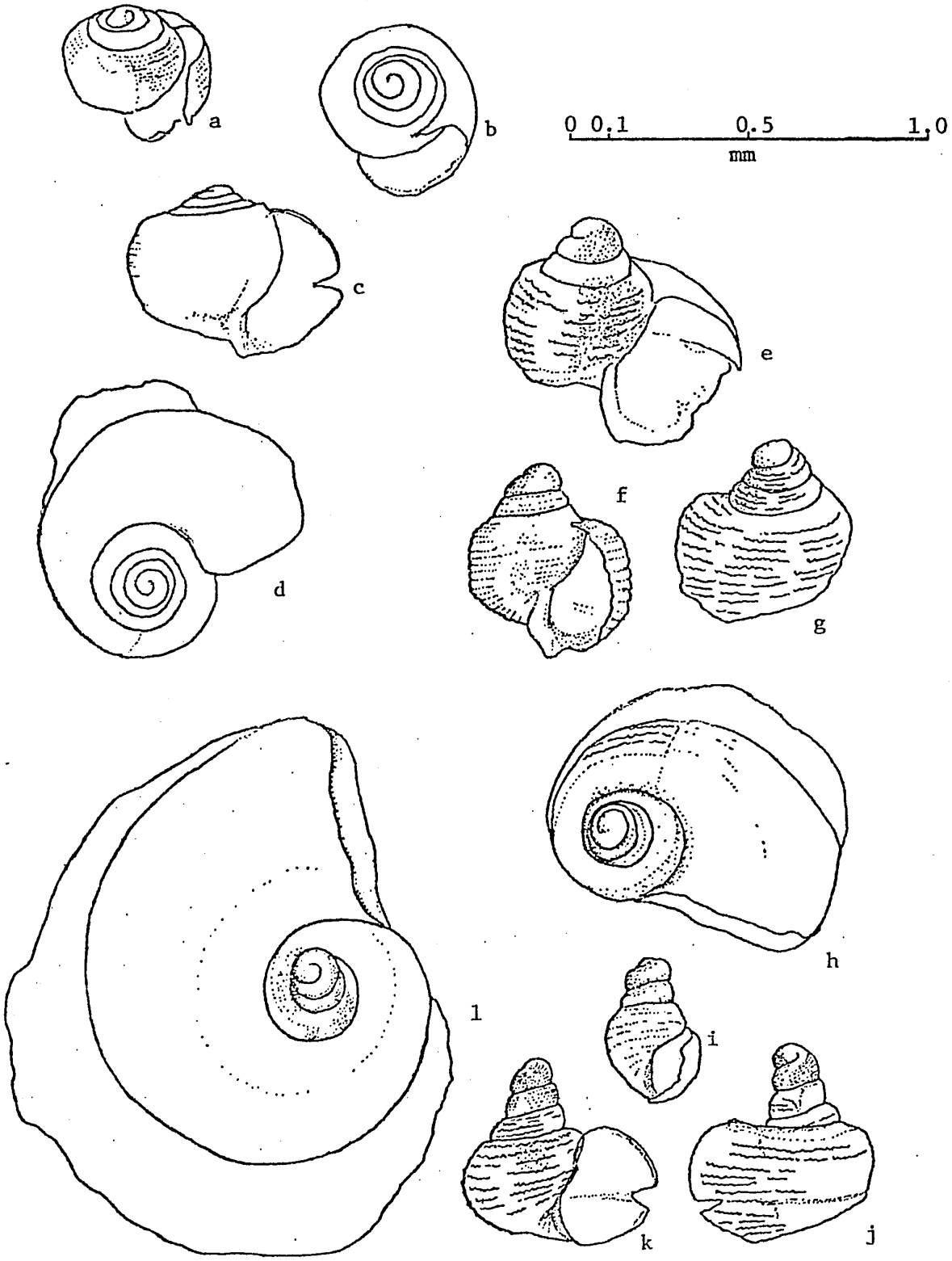
PLATE XXXVIII
Atlantidae

Figures a-d. *Atlanta* sp.$_1$

e-h. *Atlanta* sp.$_2$

i-l. *Atlanta* sp.$_3$

PLATE XXXVIII
Atlantidae



Atlanta sp.4 Plate XXXIX, figs. a-h.

Veliger:

Protoconch: as on previous page, but metamorphosis occurs when three whorls complete, approximately same size; most of protoconch rich magenta, thins to colorless on body whorl.

Velum: six-lobed; unpigmented.

Foot: white; posterior half broadly-cordate; operculum transparent; metapodium bristled at posterior tip.

Cephalic area: interocular area purple; eyes well-developed before velum is lost.

Viscera: cannot be discerned through protoconch.

Months found in plankton: July, August

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Remarks:

Veligers of this species and veligers of the preceding description occur in approximately equal numbers in the Kaneohe Bay plankton.

Of all the descriptions in the literature, veligers of this species most resemble Atlanta peresi Frontier (Thiriot-Quievreux 1967).

PLATE XXXIX

Figures a-h. All depicted opposite are growth stages of the same pink-purple atlantid, Atlanta sp.$_4$.

PLATE XXXIX

Atlantidae

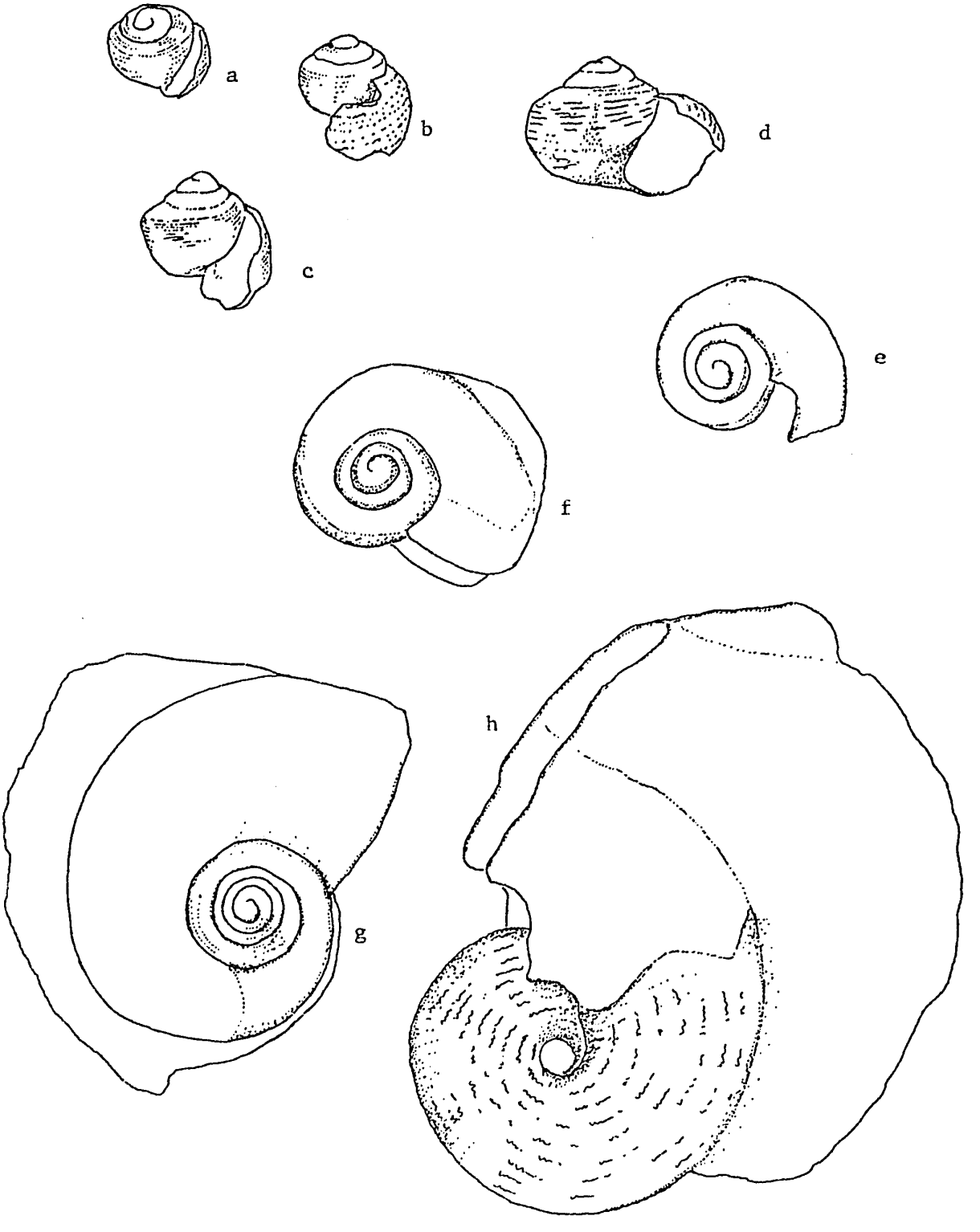


PLATE XL
Atlantidae, Carinariidae

Figures a-e. Cardiapoda sp.$_1$ (family: Carinariidae). A large pulsating structure can be seen through the ventrum of the foot; the protoconch is light yellow-green.

f-g. Cardiapoda sp.$_2$ (Carinariidae). Figure g is the operculum of Cardiapoda sp.$_2$.

h-i. Atlanta sp.$_5$ (Atlantidae). The protoconch is purple, smooth and transparent.

j-l. ?Carinaria sp.$_1$ (Carinariidae). The protoconch is glassy, smooth and suffused with pink, except for a lighter spiral stripe in the body whorl; the anterior columella has a magenta area, and the umbilicus is red-brown.

m. Atlantacean sp.$_1$. The protoconchal structure is tinged with pink, the body colorless, and the velum is six-lobed.

n. Atlantacean sp.$_2$. The protoconch and body are transparent, pure white; the velum is six-lobed.

o. Oxygyrus sp.$_1$ (Atlantidae). The protoconch is medium red-brown, the foot diaphanous white, and the velum is six-lobed, either colorless or with pink tinges.

p. Oxygyrus sp.$_2$ (Atlantidae). The protoconch is purple.

PLATE XL

Atlantidae

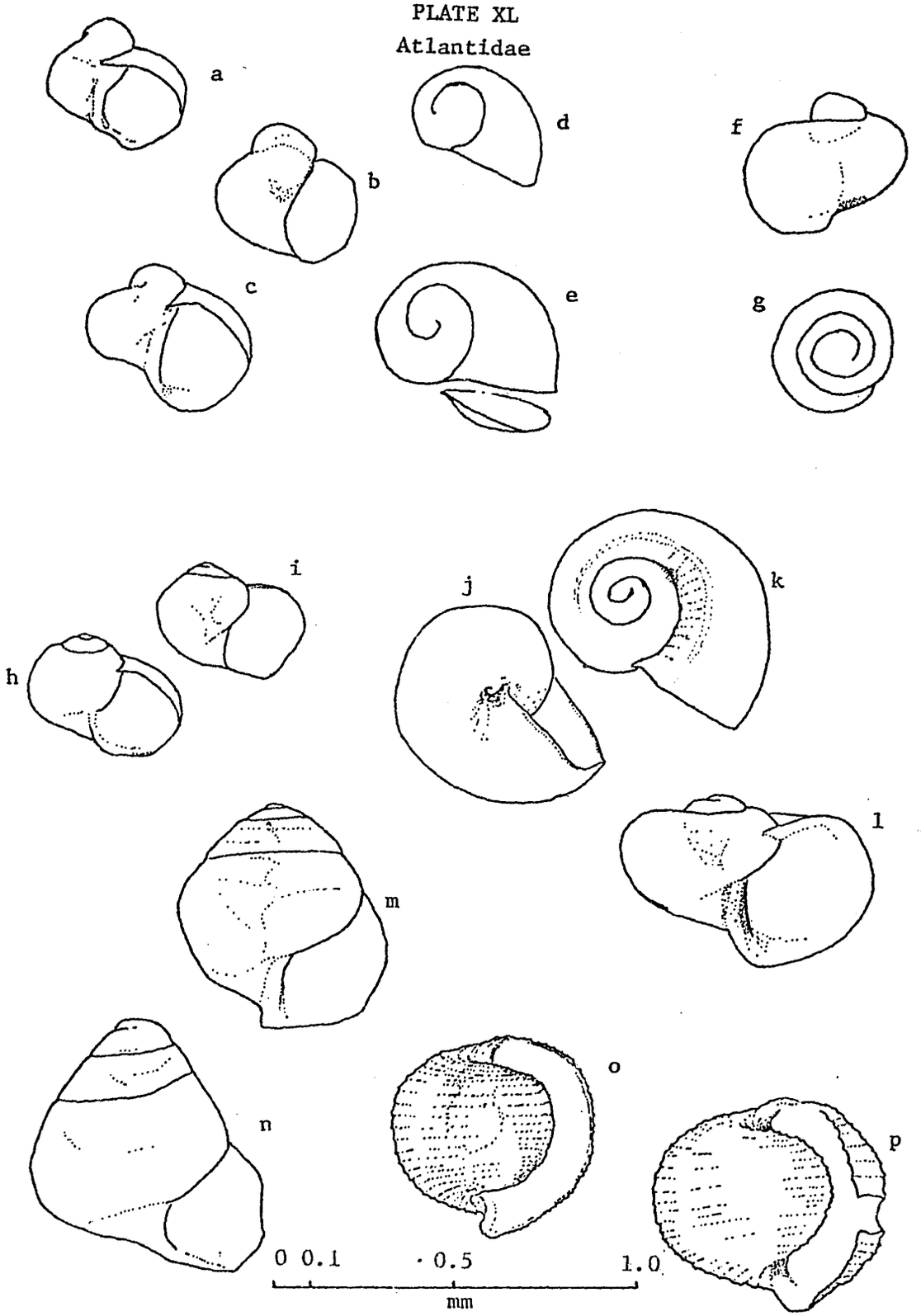


PLATE XLI

Pterotrachea sp.$_1$, premetamorphic veliger.

1.3mm

Superfamily 19. Naticacea

Naticidae* is the sole family in the Naticacea.

Family characteristics: shell smooth, inflated, umbilicate; propodium greatly expanded; eyes reduced; feed on bivalves (Fretter and Graham 1962) and other gastropods (this paper); can bore through shells with radula and accessory boring organ; jaws powerful, stomach capacity large; on sandy beaches and sandy sublittoral; sexes separate, females produce multicapsulate egg collars impregnated with sand; originated in Triassic (Fretter and Graham 1962).

Naticidae

Naticid egg collars have been described and figured by many authors. Veligers of 17 species are reported in the literature (see Table 22), but some may be conspecifics.

Nine species are reported to lack a planktonic larval stage. Most of these naticids are resident in colder waters and develop from eggs which contain relatively large amounts of yolk. In addition to intra-ovular yolk, nurse yolk is included in the egg collars of several naticids, e.g., N. catena (Hertling 1932); the amount of nurse yolk helps to determine the duration of in capsulo development.

Eleven species have larval stages which are planktonic for periods longer than two weeks. Three species have larvae planktonic for shorter periods; the remainder of the life histories is unknown. No naticid species is reported as viviparous.

Premetamorphic naticid veligers metamorphose readily when placed in small petri dishes with sea water and fine clean sand. If provided with regular supplies of acceptable food, and the water is changed every two days, naticid juveniles thrive and grow under these conditions. If more than two conspecific individuals are placed in the same petri dish, cannibalism often ensues.

Table 22

Life History Data: Naticidae

I. Without a planktonic larval stage:

Name	Egg size (μm)	Size at hatching (μm)	Remarks	References
Amauropsis islandica	1500	750	does it hatch crawling?	Thorson 1935a
Glossaulax aulacoglossa	?	?	hatches with the ability to crawl	Murray 1962b
Natica ampla	?	600-700	velum reduced; hatch with ability to crawl; breed January-April	Thorson 1940
N. catena	160	?	metamorphose when greatest diameter approximates 500 μm, 2 1/2 whorls complete; in more southerly latitudes, may hatch with ability to crawl; breed spring, summer	Ankel 1930; Lebour 1937; Thorson 1946; Knudsen 1950
N. clausa	?	?	breed April-November	Thorson 1935a
N. groenlandica (=N. pallida)	2250	1700	breed April-November	Thorson 1935a
N. maculata or millepunctata	?	?	hatch as veliconchas	Odhner 1914
N. rubromaculata	?	750, 1 1/2 whorls	velar lobes reduced; hatched with ability to crawl	Knudsen 1950
N. rufa	1000	?	hatch with ability to crawl, but some still had large velar lobes	Thorson 1940

Table 22 (cont.)

II. With a planktonic larval stage:

Name	Remarks	References cited
Conuber conicum	planktonic life long; described spawn of this species and also of C. melastoma and C. strangei	Murray 1962b
Natica canrena	breed June-July; hatch when greatest dimension approximates 520 µm; planktonic life long; velum 4-lobed; metapodial tentacle contractile; metamorphoses when greatest dimension approximates 640 µm	Lebour 1945
N. collaria and N. fulminea	described spawn and post-hatching veligers	Knudsen 1950
N. gualtieriana (=marochiensis)	egg diameter 66-83 µm; hatch when greatest dimension approximates 100 µm; capsular protoconch red-brown; planktonic protoconch milky	Knudsen 1950; Natarajan 1957
N. mamilla	zygote length 94 µm, width 79 µm	Gohar & Eisawy 1967
N. melanostoma		Gohar & Eisawy 1967
N. montagui	egg diameter 150 µm; hatch when greatest dimension approximates 320 µm; planktonic life long	Thorson 1946
N. nitida	(=pulchella,=intermedia,=alderi,=poliana); egg diameter, 160 µm	Hertling 1932b; Lebour 1937a
N. tigrina and N. trailli	provide mention of early veliger	Natarajan 1957
N. sp. A	hatch when greatest dimension approximates 370 µm; protoconch with coarse wavy spiral ribs; planktonic at least 9 days	Thorson 1940
N. sp. B	hatch when greatest dimension approximates 350 µm; each velar lobe	Thorson 1940

N. fulminea		
N. gualtieriana (=marochiensis)	egg diameter 66-83 µm; hatch when greatest dimension approximates 100 µm; capsular protoconch red-brown; planktonic protoconch milky	Knudsen 1950; Natarajan 1957
N. mamilla	zygote length 94 µm, width 79 µm	Gohar & Eisawy 1967
N. melanostoma		Gohar & Eisawy 1967
N. montagui	egg diameter 150 µm; hatch when greatest dimension approximates 320 µm; planktonic life long	Thorson 1946
N. nitida	(=pulchella,=intermedia,=alderi,=poliana); egg diameter, 160 µm	Hertling 1932b; Lebour 1937a
N. tigrina and N. trailli	provide mention of early veliger	Natarajan 1957
N. sp. A	hatch when greatest dimension approximates 370 µm; protoconch with coarse wavy spiral ribs; planktonic at least 9 days	Thorson 1940
N. sp. B	hatch when greatest dimension approximates 350 µm; each velar lobe with one wine-red pigment spot; protoconch colorless; planktonic at least nine days	Thorson 1940
N. sp. C	hatch when greatest dimension approximates 350 µm; velum 4-lobed, also with wine-red pigment spots	Thorson 1940
N. sp. A	egg diameter 116 µm; hatch when greatest dimension approximates 200 µm; planktonic at least seven days	Natarajan 1957
N. sp. B	hatch when greatest dimension approximates 634-651 µm; velum 4-lobed	Natarajan 1957
N. sp.	figured the larva	Pelseneer 1906
N. sp.	egg diameter 100 µm	Knudsen 1950

Natica gualtieriana Recluz 1844. Plate XLII, figs. a,b.

Veliger:

Protoconch: white, transparent, sturdy, globose; capsular protoconch red-brown, smooth; beak and siphonal canal lacking; metamorphosis occurs when greatest diameter approximates 900 - 1100 μm, 3 1/4 - 3 1/2 whorls complete.

Velum: four-lobed; velar lobes long, blunt, unpigmented except for purple-black at base of post-oral cilia; velum ingested at metamorphosis; captive premetamorphic veligers rarely extend velum.

Cephalic area: tentacles long, tapered; eyes small, inside bases of tentacles.

Foot: broad, white, blunt; propodium rectangular; operculum semilunate, glossy, flat.

Viscera: digestive gland colorless.

Months found in plankton: all months.

Areas found: Dredged Island, Sampan Channel; not generally in inner bay.

Post-larval juvenile:

Neat red-brown spots appear on the dorsal side of the foot and the teleoconch acquires fairly evenly-distributed red-brown pigment, but individuals vary in darkness of pigment. If the little black-bodied rissoacean is provided as food, N. gualtieriana juveniles are able to bore holes through shells within the first 24 hours after metamorphosis; the contents of the prey shell are ingested as soon as the hole is drilled.

When the greatest diameter approximates 2.0 mm, juveniles of this species tend to choose Bittium juveniles as food if presented with a choice between Bittium parcum and the small rissoacean. As Natica's foot enlarges, it can manage to hold larger and larger Bittium indi-

viduals while drilling and ingesting. As this species nears 3.0 mm, an individual will drill and ingest one or more adult Bittium parcum per day.

During this post-larval span (1.0 - 3.3 mm), if individuals are fed a surplus of prey, they display a linear logarithmic growth rate. As the animal grows, the shell becomes steadily more opaque. An individual reared on the small rissoacean and Bittium parcum, will eat B. parcum. If provided with a choice of B. parcum or Ctena bella, a bivalve which is its principal in situ prey species, it will choose B. parcum if it has been reared on that gastropod species. Thus, N. gualtieriana is probably an opportunist predatory upon various molluscan species and displays some tendency to continue feeding upon those foods to which it has initially become accustomed.

Natica gualtieriana veligers emerge from the egg collar when the greatest diameter approximates 120 μm. If first one plots the juvenile growth measurements on semilogarithmic paper, then extrapolates backward in time (assuming the planktonic growth rate has the same slope), one arrives at an estimate of 9 - 12 weeks that veligers of N. gualtieriana are planktonic. Only twelve weeks after metamorphosis are required for the first functional egg collars to be deposited.

Natica sagittifera Recluz 1852.

Premetamorphic veligers of this species differ from those of N. gualtieriana in four principal ways: (1) they are larger (1130 μm) than those of gualtieriana at metamorphosis, (2) the cephalic tentacles are longer, (3) the spots which appear on the dorsal part of the foot are sparse and light rather than the small, densely-located red-brown spots in N. gualtieriana, and (4) when both species are 3.3 mm, juveniles of N. gualtieriana are predominantly red-brown with some creamy splotches along the middle of the body whorl; juveniles of N. sagittifera bear tiny red-brown arrow-like markings along the mid-body whorl band, and these markings are on a background that is predominantly cream-colored.

Naticid veligers with undetermined identities.

Natica sp.$_1$

Protoconch: globose; capsular protoconch red-brown; planktonic protoconch milk-white; opercular nucleus, umbilicus red-brown; metamorphosis occurs when two whorls complete.

Velum: four-lobed; velar lobes elongate, edged with purple-black; swim with velum slightly unfurled.

Cephalic area: tentacles thin, twisted, close together; eyes tiny, outside tentacular bases.

Foot: subcircular; cream-colored, brushed with burnt sienna and purple-black; metapodium scalloped, with metapodial tentacle, anterior to which are structures which resemble colorless glass beads.

Viscera: digestive gland deep gold; style sac black.

Months found in plankton: June, July

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Natica sp$_2$

Protoconch: globose; milk-white; aperture not as long as that of sp.$_1$; operculum, umbilicus unpigmented.

Velum: four-lobed; velar lobes elongate, edged with purple-black.

Cephalic area: eyes large, far apart.

Foot: lightly-brushed with purple-black; operculum unpigmented; metapodium broadly scalloped, metapodial tentacle present.

Viscera: style sac golden; mantle edge purple-black.

Months found in plankton: June, July

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Naticid veligers with undetermined identities (cont.).

Natica sp.$_3$

Protoconch: globose; capsular protoconch opaque pink-brown; hatch when 1 1/2 whorls complete; operculum, umbilicus red-brown.

Velum: four-lobed; velar lobes elongate, edged with purple-black.

Cephalic area: unpigmented.

Foot: broad, with midventral longitudinal groove; propodium lightly brushed with charcoal; propodial shield well-developed; metapodium not scalloped.

Viscera: digestive gland light tan.

Months found in plankton: June, July

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Natica sp. $_4$

Protoconch: as in N. sp.$_1$ except capsular protoconch not red-brown.

Velum: as in N. sp.$_1$ with one green-black smudge centrally on each velar lobe.

Cephalic area: as in N. sp.$_1$

Foot: white, except for purple-black triangle on anterior propodium; otherwise, same as N. sp.$_1$.

Remarks: Veligers of this species resemble Natica sp.$_1$ except in pigmentation.

PLATE XLII

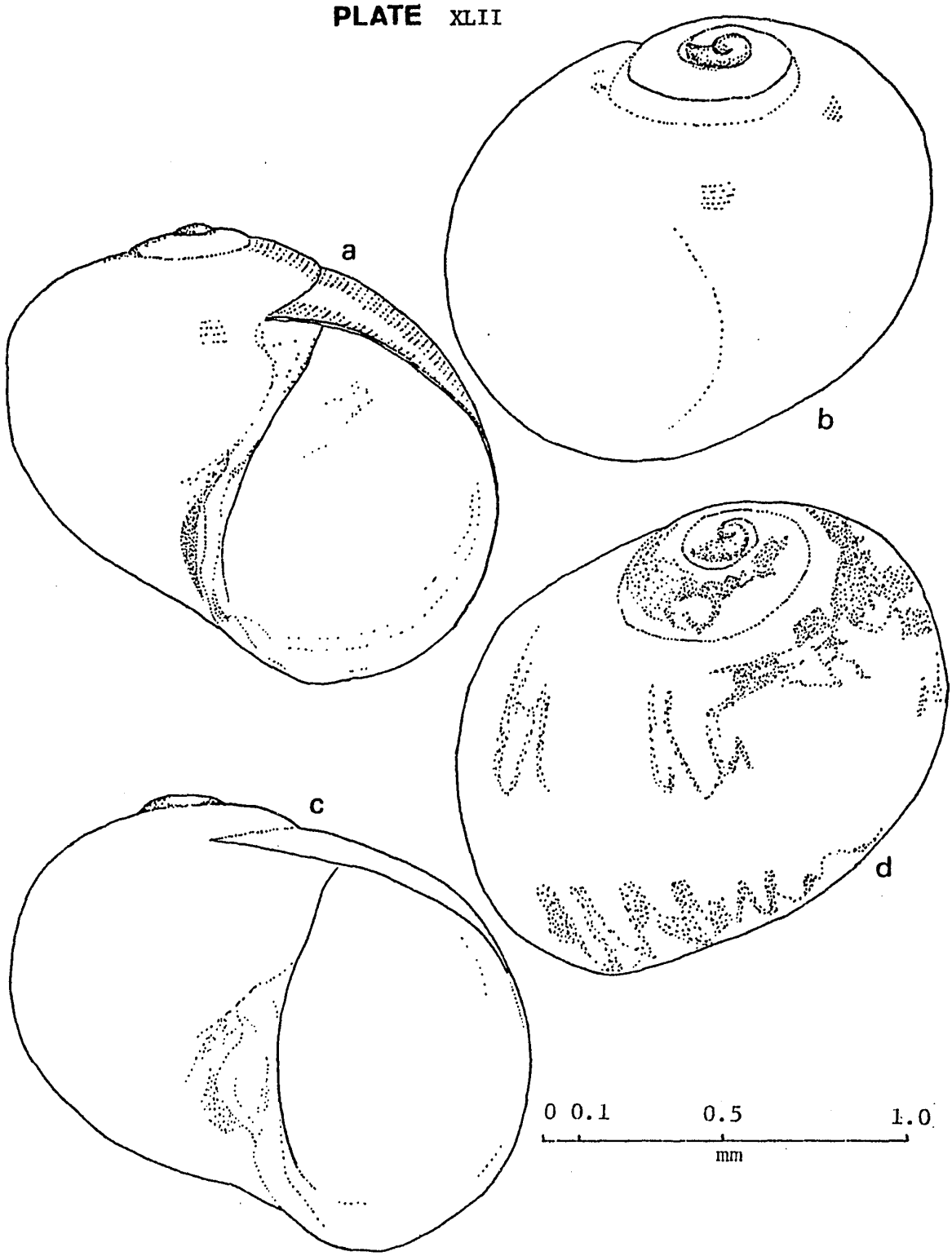
Figure a. Natica gualtieriana, premetamorphic protoconch.

b. " " " " .

c. Natica sp.$_3$, premetamorphic protoconch.

d. " " " .

PLATE XLII



NATICIDAE

Polinices mamilla (Linnaeus 1758). Plate XLIII, figs. a-c.

Veliger:

Protoconch: globose-planorbiform, smooth, shining, transparent white; fragile; aperture rimmed with red-brown; capsular protoconch 2 1/4 whorls, tinged with red-brown; metamorphosis occurs when 3 1/2 whorls complete, width: 1810 µm, height, 1228 µm; umbilicus and siphonal canal lacking.

Velum: four-lobed; velar lobes elongated, tipped with purple-black; bases of post-oral cilia purple-black.

Cephalic area: unpigmented; tentacles long.

Foot: large, white, rectangular; ventrum lightly brushed with charcoal; operculum oval, nucleus central.

Viscera: digestive gland rich golden-red-brown; ctenidium tinged with light maroon; body cream-colored; gut represented by two distinct charcoal streaks posteriorly.

Months found in plankton: March, July.

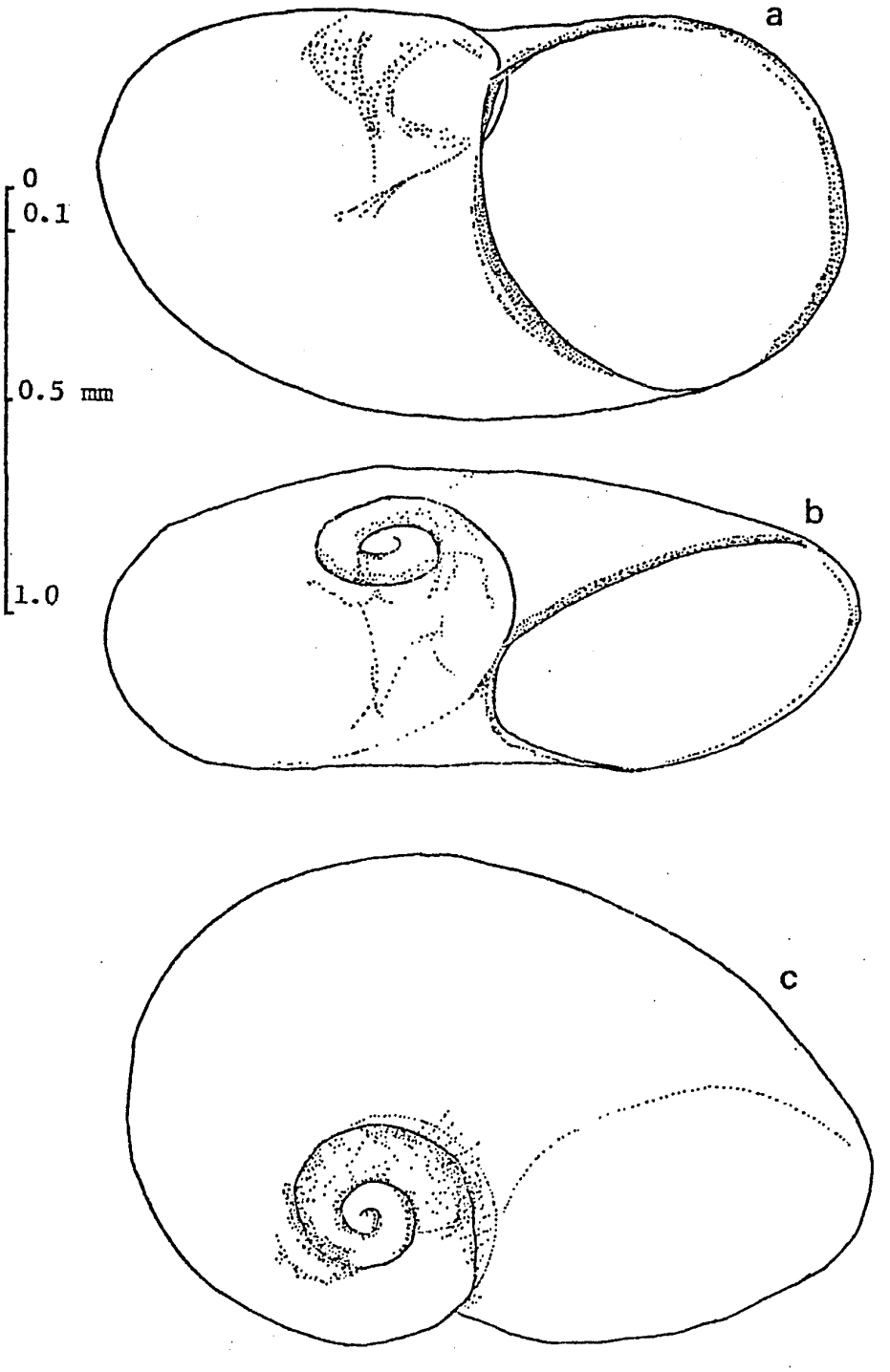
Areas found: Sampan Channel.

Remarks: This species metamorphosed in captivity, but died soon afterward.

PLATE XLIII

Figures a-c. Polinices mamilla, premetamorphic protoconchs.

PLATE XLIII



NATICIDAE

Superfamily 20. Tonnacea (=Doliacea)

Tonnaceans include the Cassididae*, Cymatiidae*, Bursidae*, Tonnidae* and Ficidae.

Superfamily characteristics: shells usually large, heavy, fusiform to conical-globose; siphonal canal short; salivary glands large, produce sulfuric acid; generally predatory on living echinoderms, sipunculids, mollusks and polychaetes, occasionally scavenge necrotic material; larvae planktonic for long periods; in tropical and temperate waters.

Periods of larval planktonic existence of tonnacean families are thought to be among the longest of all molluscan groups (Thorson 1940; Scheltema 1971). Adaptations which support these long planktonic periods are long, well-developed velar lobes and large globose protoconchs with arrays of flexible conchiolin spines. The spines are easily abraded, thus the protoconchs of many museum specimens provide clues to size, but cannot be depended upon to portray accurately the appearance of specific larvae.

Tonnacean protoconchs are diverse in form. Cassid protoconchs superficially resemble those of naticids, but the cassid operculum bears two braces while the naticid operculum bears none. In general, tonnid protoconchs are inflated, the sutures are not very impressed and the generational angle is large; the effect is rather like a naticid protoconch with or without flexible spines. Bursid and cymatid protoconchs are difficult to distinguish from one another. Bursid protoconchs are generally elongate-globose with the initial planktonic whorls cancellate; flexible spines adorn most of the protoconch. Cymatid protoconchs encompass a wide range of variation. Some (Gyrineum)

Table 23

Life History Data: Cassididae, Cymatiidae

Name	Remarks	References
Cassididae		
Phalium coronadoi	larva smaller than *P. granulatum*, wider apical angle	Scheltema 1971
P. granulatum	planktonic period exceeds three months	Abbott 1968; Scheltema 1971
P. saburon	larva smaller than *P. granulatum*, apical angle wider	Scheltema 1971
Xenogalea labiata	egg diameter 160 μm, pale orange; development in egg mass simultaneous; long-term plankter	Anderson 1965
Cymatiidae		
Charonia variegata	length exceeds 5 mm at metamorphosis	Scheltema 1971
Cymatium nicobaricum	larval body pink; velar lobes four, long, unpigmented; metamorphoses when length approximates 4.6 mm, when five whorls complete; animal spotted with orange; long-term plankter; western Atlantic and Indo-Pacific; described by Lebour as being ?*C. chlorostomum*	Simroth 1895; Lebour 1945; Scheltema 1971
C. parthenopeum	(=*Monoplex australasiae*); metamorphoses when greatest length approximates 3.5 mm	Simroth 1895; Scheltema 1966a, 1971
C. pileare	larval body yellow-brown; velar lobes four, colorless, 16 mm wide; metamorphoses when protoconchal length approximates 4 mm; grew in captivity to 9 mm; long-term plankter	Lebour 1945
Cymatilesta spengleri	brood protection; no planktonic stage	Anderson 1959

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Phalium coronadoi	larva smaller than *P. granulatum*, wider apical angle	Scheltema 1971
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C. pileare	larval body yellow-brown; velar lobes four, colorless, 16 mm wide; metamorphoses when protoconchal length approximates 4 mm; grew in captivity to 9 mm; long-term plankter	Lebour 1945
Cymatilesta spengleri	brood protection; no planktonic stage	Anderson 1959
Undetermined larva	radula of *Cymatium* type; velum 4-lobed, colorless; protoconch with long transparent spines arranged in spirals; metamorphoses when length approximates 1500 μm	Lebour 1945

resemble strongly the bursid type, while others (Charonia, Colubraria) resemble buccinacean and muricacean protoconchs. Most cymatid protoconchs are large and shaped like teardrops. The greatest dimension of most pre-metamorphic tonnacean protoconchs usually exceeds 1200 μm.

The tonnacean foot is massive and muscular, but narrower than that of the naticids; the tonnacean propodium is usually elongate (see Plate 48).

Cassididae

Helmet shells are distributed worldwide in temperate and tropical waters. They live on sandy bottoms and feed on sea urchins (Diadema), sand dollars and sea biscuits (Lyman 1937; Foster 1947; Moore 1956; Schroeder 1962 and Cornman 1963).

Little is known of cassid life histories. Although the protoconchs of many Indo-Pacific cassids have been figured and photographed (Abbott 1968), there are few data regarding post-hatching events and juvenilehood. Xenogalea labiata in New South Wales deposits pale orange eggs, 160 μm in diameter, which develop simultaneously. Egg masses of X. labiata are described and Anderson (1965) estimates that the veligers spend a long time in the plankton. Scheltema (1971) provides figures of both early and pre-settlement veligers of Phalium granulatum, mentions that P. coronadoi and P. saburon have larvae smaller than P. granulatum with wider apical angles, but gives no description of the soft parts of the planktonic veligers.

Although there are five species in four genera of Hawaiian cassids (Kay, unpubl.), only one pre-settlement veliger of Casmaria eri-

naceus was taken in July, 1970. The globose protoconch appears much like a very large Natica gualtieriana, except that the operculum has two bracing supports, while Natica has none. The velar, cephalic and pedal areas resemble similar areas of Tonna rather than Natica veligers.

Casmaria erinaceus (Linne 1758). Plate XLIV, figs. a, b.

Veliger:

Protoconch: capsular protoconch 1 1/2 whorls, red-brown; planktonic protoconch 2 - 2 1/4 additional glassy, smooth, transparent cream whorls; outer apertural lip light red-brown; beak, siphonal canal lacking; umbilicus shallow; metamorphosis occurs when 3 - 3 1/4 whorls complete, length: 1750 µm, width: 1850 µm.

Velum: four-lobed; unpigmented; velar lobes long.

Cephalic area: cephalic tentacles reduced; eyes large, round; charcoal 'eyebrows' and charcoal 'frowning eyebrows' dorsal and medial to eyes; esophageal region gray.

Foot: large, tinged with gray; background color dirty cream; propodium blunt; operculum with two curved braces, transparent with tinges of light red-brown on braces.

Viscera: digestive gland charcoal; style sac gray; two charcoal gray streaks in mantle dorsal to head region; mantle diaphanous cream.

Month found in plankton: July

Area found: Sampan Channel

Remarks:

The veliger of this species metamorphosed in captivity, but died before its specific food preference could be determined; presumably newly-settled sea urchins might have been acceptable.

PLATE LXIV

Cassididae

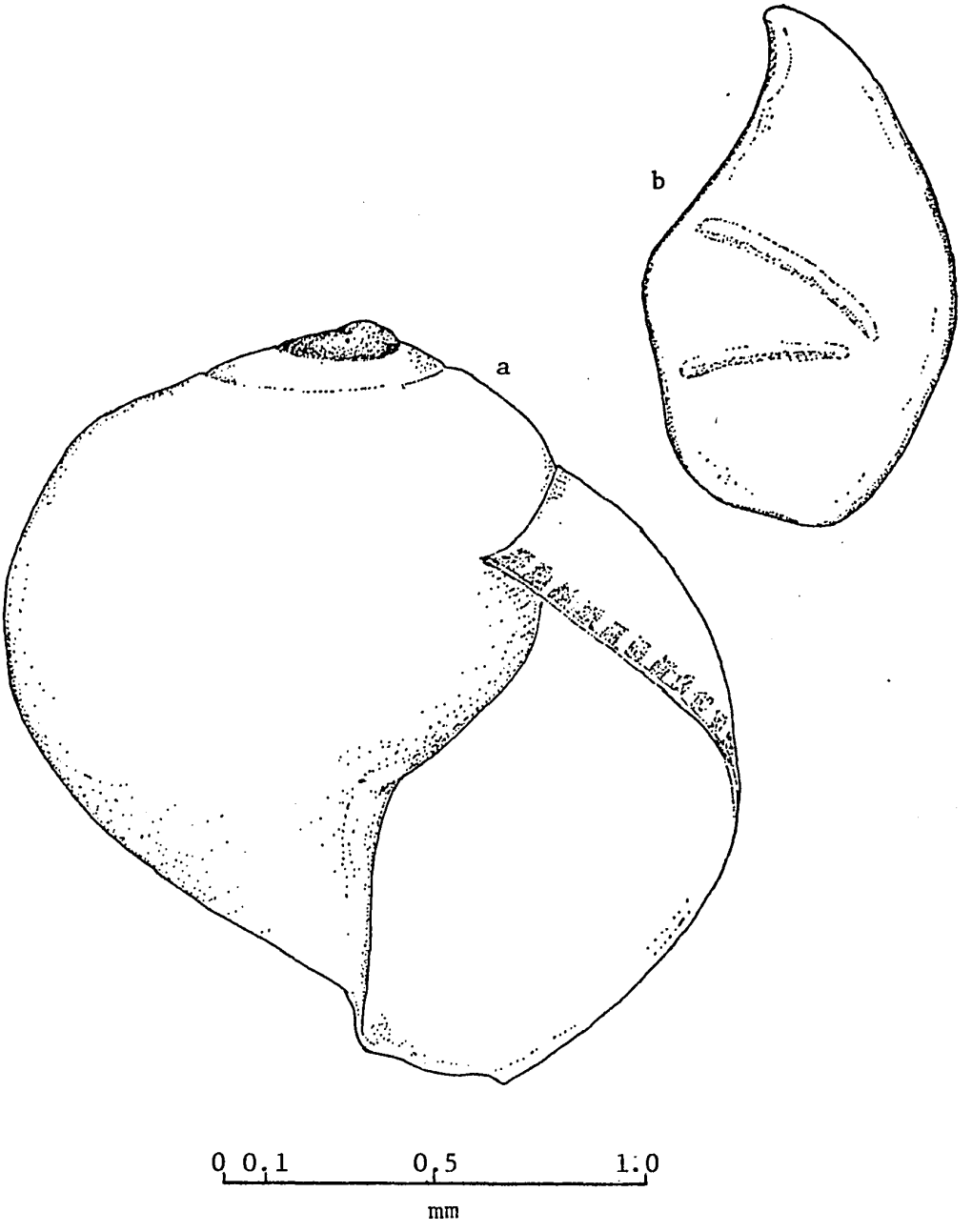


Figure a. Casmaria erinaceus, premetamorphic protoconch.

b. " " , larval operculum.

Cymatiidae

Triton species are generally widely distributed, favoring tropical and subtropical regions. While most cymatids are scavengers or are predatory upon other gastropods (Demond 1957; Kohn 1959; Houbrick and Fretter 1969), individuals of Charonia tritonis feed on starfish such as Acanthaster and Culcita.

Cymatid egg capsules vary in form. A few tough, large, oval attached bags are deposited by Charonia tritonis (Berg, pers. comm.); great cup-shaped masses of smaller oval capsules are usually produced by other cymatids (Anderson 1959).

Although most species of tritons are thought to produce long-term planktonic veligers (Thorson 1940; Scheltema 1971), Cymatilesta spengleri in Australia exhibit brood protection, the larvae hatch with the ability to crawl and apparently are not planktonic even for short periods (Anderson 1959). Several pre-metamorphic veligers have been figured (Table 23) and the length of planktonic existence has been estimated as follows: Charonia variegata, 276 days; Cymatium nicobaricum, 320 days; C. parthenopeum, 293 days (Scheltema 1971). Besides this paper, Lebour (1945) provides the sole figure of the soft parts of the cymatid veliger.

Charonia tritonis (Linnaeus 1767). Plate XLV, figs. a-c.

Early development: eggs deposited in captivity in December in Hawaii; larvae presumed newly-hatched obtained from plankton tows in mid-January; eggs salmon-colored.

No premetamorphic veligers of C. tritonis were obtained from plankton tows; however, the protoconch of a subadult specimen was drawn via camera lucida (Pl. XLV, Figs. b, c); it differs considerably from that of Charonia variegata (Scheltema 1971). Larvae presumed newly-hatched were frequently collected during the winter months; a description of this stage follows.

Early veliger:

Protoconch: transparent cream-yellow, globose-planorbiform; sculpture lacking; beak slight; siphonal canal lacking; umbilicate; interior surface of protoconch outlined; length: 725 μm, width: 430 μm; 1 1/2 whorls present.

Velum: four-lobed, unpigmented; width: 890 μm, height: 660 μm; velar pattern in shape of four-leaf clover.

Cephalic area: tentacles thick, medium-long, tapering; eyes small, inside base; esophageal area cream-yellow.

Foot: posterior section shaped like a lily pad, appears glandular; propodium elongate; foot colorless; metapodial tentacle present.

Viscera: digestive gland salmon-colored; gastric area cream-yellow; heart large, easily seen.

Months found in plankton: January

Areas found: Dredged Island, Sampan Channel

Remarks: Metamorphosis apparently occurs when the protoconch exceeds 1500 µm in length and is approximately 970 µm wide; 2 1/2 - 3 whorls are complete at metamorphosis.

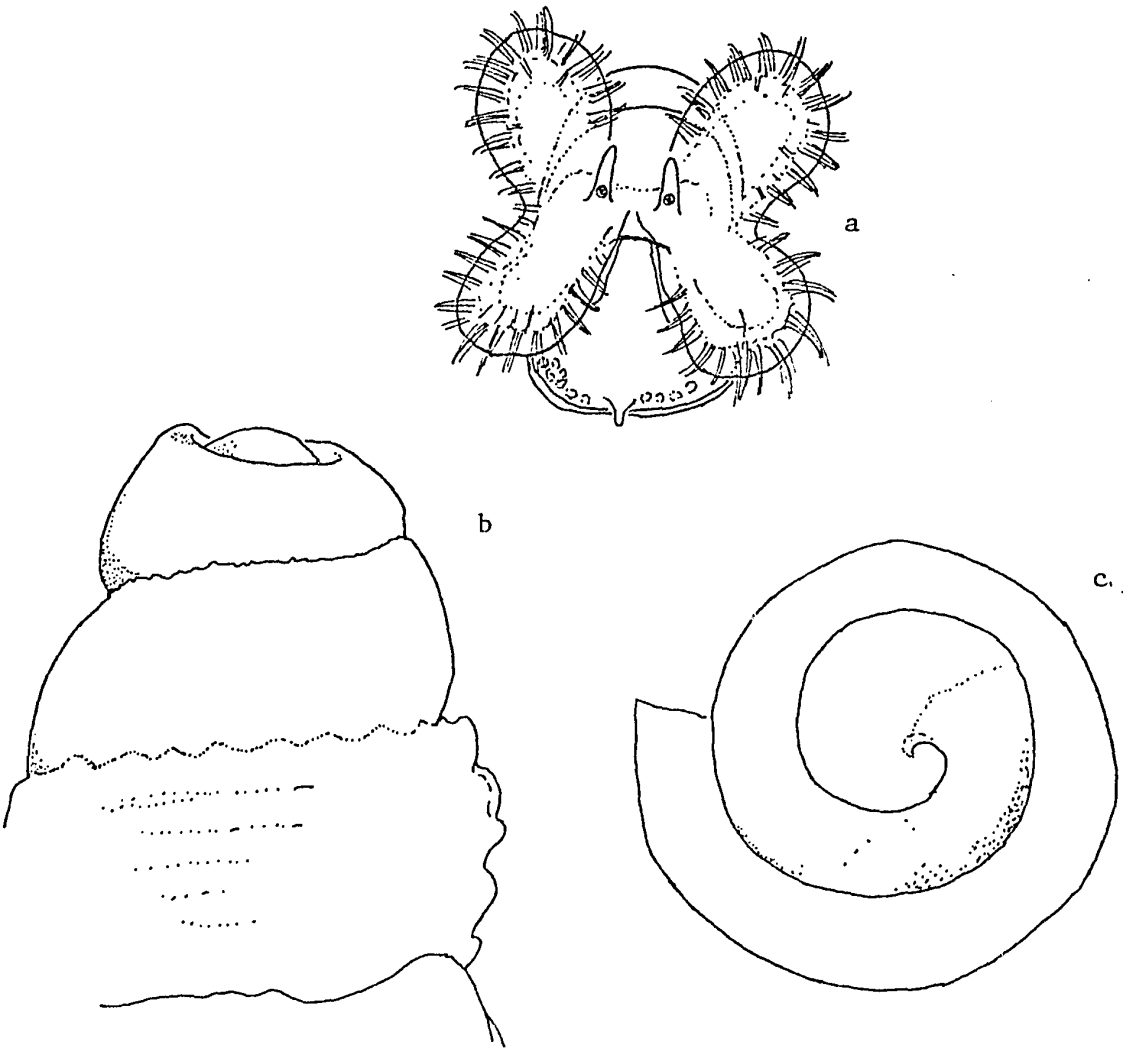
PLATE XLV

Figure a. Charonia tritonis, newly-hatched veliger.

b. " " , protoconch drawn from a juvenile shell, abapertural view.

c. " " , protoconch drawn from a juvenile shell, apical view.

PLATE XLV



Cymatiidae

Cymatium muricinum (Röding 1798).

Veliger:

Protoconch: creamy tan; elongate-globose; second whorl faintly cancellate; metamorphosis occurs when 5 1/2 whorls complete, length: 3.5 mm.

Velum: four-lobed; velar lobes elongate, suffused with light peach, spots lacking; width 15 mm..

Cephalic area: interocular area with royal purple stellate spots; tentacles medium-short, not tapered; eyes on stalks joined to bases of tentacles; oral region unpigmented.

Foot: propodium slit transversely, square; posterior margin of foot shaped like a wishbone; ventrum, sides with royal purple stellate spots; operculum shaped like that of adult.

Viscera: digestive gland light tan with vitreous beads; pallial edge with blunt tentacular extensions; mantle with royal purple stellate spots.

Month found in plankton: June

Area collected: seaward of Ala Moana Reef (Honolulu)

Remarks:

The siphon of the veliger is transparent and colorless with tiny opaque white spots. The veliger metamorphosed three days after capture; 42 days later, the juvenile was 12 mm in length. As in most cymatids, this species also has a discontinuous growth pattern.

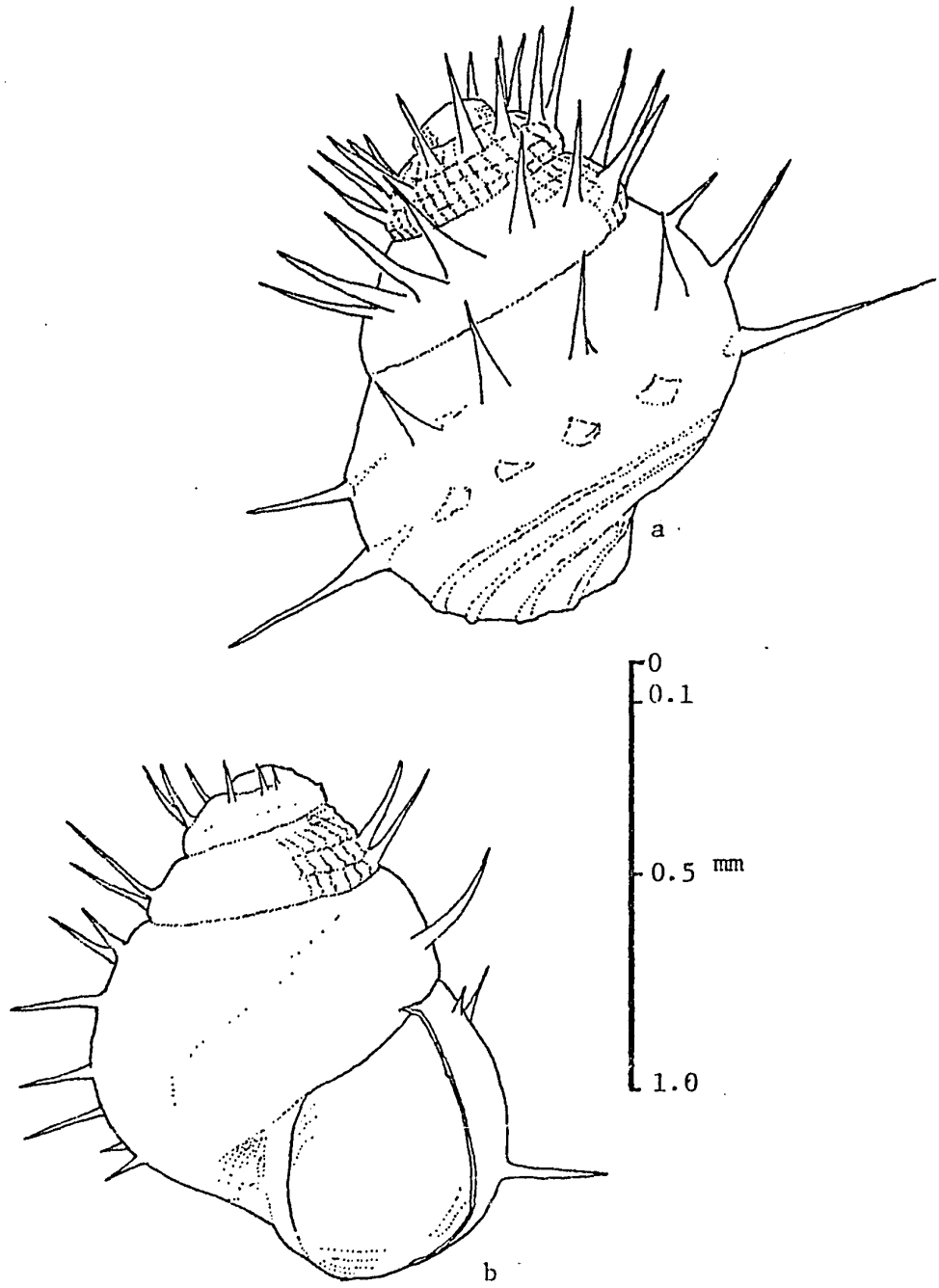
PLATE XLVI

Figure a. Cymatium muricinum, intermediate planktonic veliger: abapertural view.

b. Cymatium muricinum, intermediate planktonic veliger: apertural view.

PLATE XLVI

Cymatiidae



Cymatium nicobaricum Röding 1798. Plate XLVI , figs. a, b.

Veliger:

Protoconch: turbiniform, sutures impressed; milky-white with spiral tracts of long thin flexible spines; body whorl with three tracts of spines; beak non-existent in premetamorphic veliger; siphonal canal short; umbilicus shallow; sutural line becomes red-brown just prior to metamorphosis; aperture semicircular; metamorphosis occurs when 2 3/4 - 3 whorls complete.

Velum: four-lobed, edged with brown at bases of post-oral cilia; remaining area unpigmented; velar lobes long.

Cephalic area: tentacles medium-long, colorless; eyes inside lateral bases of tentacles; remaining cephalic area tan-brown; 'neck' region with pink-orange tints.

Foot: propodium square; posterior edge of foot a rounded vee; ventrum of mesopodium tan with tints of light pink-brown, medial charcoal streak; sides of foot stalk light charcoal.

Viscera: digestive gland dark tan.

Month found in plankton: May

Area found: Sampan Channel

Remarks:

Veligers of this species are larger than those of Bursa granularis and the spines are longer and more acute; both of these species lack the acute apex of Bursa cruentata.

Bursidae

Most bursids dwell on coral reefs in the tropics and are distinguished from the cymatids by the presence of an anal sulcus (a posterior groove or canal in the aperture). The distribution of some bursid species is circumtropical; one might suppose that these species also have long-term planktonic larval stages as in the circumtropical cymatid species Cymatium pileare. Bursids are reported to feed on diverse polychaete species as well as sipunculids (Houbrick and Fretter 1969).

Bursids deposit multitudes of vasiform egg capsules in a lenticular mass (Risbec 1931; Petit and Risbec 1929; Thorson 1940). B. granifera females exhibit brood protection; all bursid life histories reported thus far include a planktonic larval stage. Only one premetamorphic veliger has been figured (Lebour 1945) for Bursidae and its identity is uncertain because it did not metamorphose in captivity. This paper contains the first photographs of premetamorphic bursid veligers.

Table 24

Life History Data: Bursidae and Tonnidae

Name	Remarks	References
Bursidae		
Bursa granifera	brood protection	Risbec 1931
B. gyrina	deposits 10-15 eggs per capsule	Petit and Risbec 1929
B. spinosa	egg diameter 120-140 µm, no nurse eggs; hatch as veligers when length approximates 200 µm	Thorson 1940
B. ventricosa	larva illustrated, p. 451	d'Orbigny 1847
Veliger A (=*Bursa*(?) sp. or *Cymatium*(?) sp.	veliger long-term plankter; velum 4-lobed, colorless; protoconch brown, apex finely-sculptured, planktonic protoconch with spines; pre-settlement veliger with pallial tentacle; metamorphoses when length approximates 2.5 mm; breed spring, early summer in Caribbean	Lebour 1945
Tonnidae		
Dolium costatum	egg diameter 300 µm; probably not planktonic long due to large egg size	Knudsen 1950
D. olearium	egg diameter 240-250 µm; require 23-25 days at 25°C. to hatch; hatch when length approximates 400-450 µm, width, 300-320 µm; larva with metapodial tentacle; planktonic at least six days, probably longer; velum 4-lobed; breed August, September in Red Sea	Gohar and Eisawy 1967
Tonna dolium	(=*Dolium maculatum*, =*Tonna maculosa*); egg diameter 217-234 µm; in capsule 15-17 days; hatch when length approximates 380-420	Thorson 1940; Lebour 1945; Nataraian 1957

sp.	metamorphoses when length approximates 2.5 mm; breed spring, early summer in Caribbean	
Tonnidae		
Dolium costatum	egg diameter 300 µm; probably not planktonic long due to large egg size	Knudsen 1950
D. olearium	egg diameter 240-250 µm; require 23-25 days at 25°C. to hatch; hatch when length approximates 400-450 µm, width, 300-320 µm; larva with metapodial tentacle; planktonic at least six days, probably longer; velum 4-lobed; breed August, September in Red Sea	Gohar and Eisawy 1967
Tonna dolium	(=Dolium maculatum, =Tonna maculosa); egg diameter 217-234 µm; in capsulo 15-17 days; hatch when length approximates 380-420 µm; veliger planktonic; velum colorless; propodium long, metapodium with terminal tentacle	Thorson 1940; Lebour 1945; Natarajan 1957
T. galea	egg diameter 300 µm; hatch as veligers when length approximates 400 µm; long-term plankter; metamorphose when length approximates 3.5 mm	Lo Bianco 1888; Simroth 1895; Lamy 1928; Lebour 1945; Scheltema 1971
T. perdix	egg diameter 300 µm, yolk pale orange; breeds in June in Hawaii; hatch as veligers when length approximates 550 µm; velum 4-lobed, six times shell length, unpigmented; operculum with conspicuous central ridge; protoconch dark brown, with many long spines; in Kaneohe Bay; metamorphoses when length approximates 2.5 mm; originally described as Macgillivraya	Lebour 1945; Ostergaard 1950
Tonna sp.	egg diameter 233 µm; in capsulo 17 days; hatch when length approximates 317-334 µm; sculpture of capsular protoconch reticulate; velum bilobed, colorless; breed January, May, July and November in India	Natarajan 1957

Bursa rosa (Perry 1811). Plate XLVII, figs. 1, 2.

Veliger:

Protoconch: milky white; globose; sutures impressed, whorls inflated; siphonal canal short; aperture semicircular; umbilicus small; metamorphosis occurs when three whorls complete.

Velum: four-lobed; velar lobes long, edged with yellow-brown at base of post-oral cilia.

Cephalic area: tentacles colorless, medium-long; remainder of head tan-brown; neck region with tinges of pink-orange.

Foot: cream, with tints of light pink-brown, median streak of charcoal; sides of foot stalk charcoal.

Viscera: siphon white; digestive gland brown.

Months found in plankton: May, June

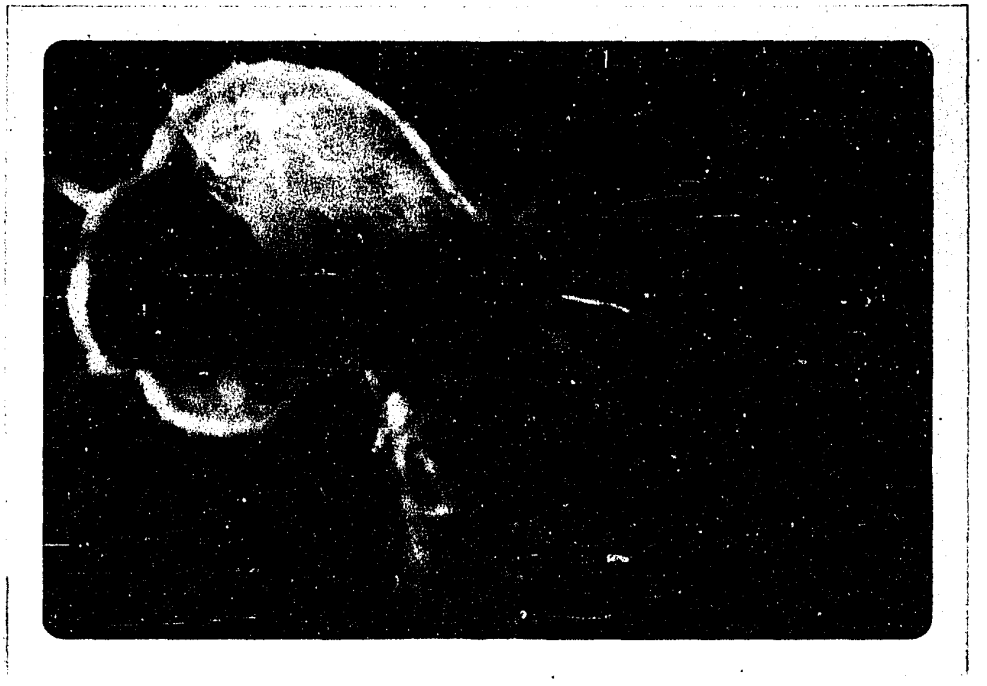
Areas found: Sampan Channel

Plate XLVII
Bursidae

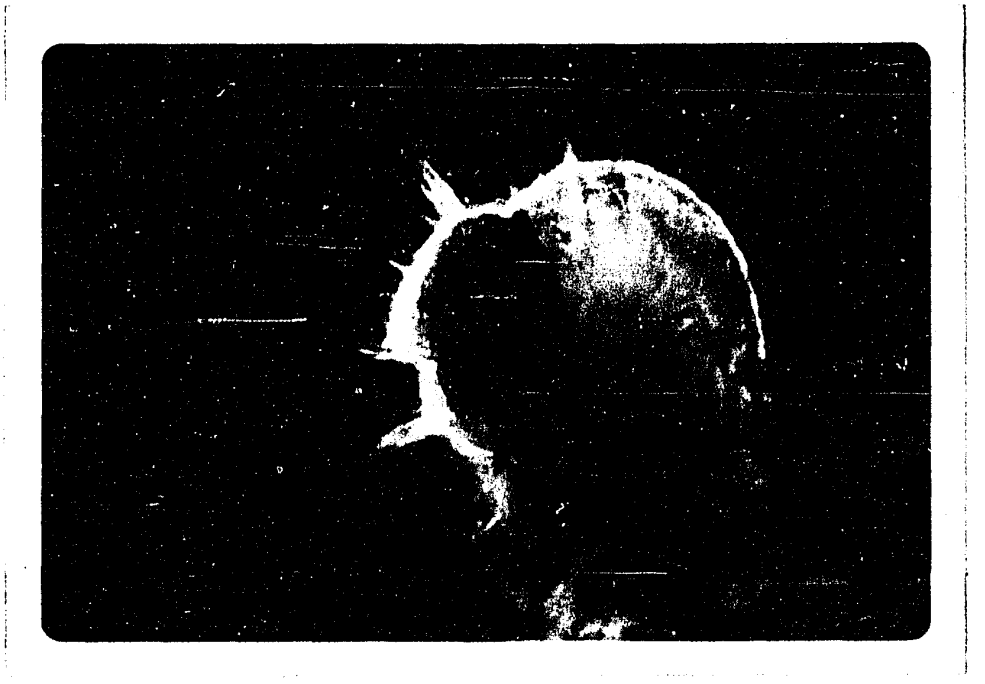
Figure 1. Bursa rosa, anterodorsal aspect. Note extended elongate propodium.

2. Bursa rosa, dorsal aspect. Note siphon projecting downward, and arrangement of spinal tracts.

PLATE XLVII
Bursidae



1.3mm



Bursa granularis (Röding 1798). Plate XLVIII, figs. a, b.

Veliger:

Protoconch: globose-turbiniform, with sutures impressed; transparent, colorless, with flexible broad triangular cockscomb-like spines; body whorl with three tracts of spines; sutural line of body whorl brown; columellar lip, capsular protoconch outer lip brown; beak lacking; siphonal canal short; operculum subcircular, colorless; metamorphosis occurs when 2 1/2 to 3 whorls complete.

Velum: four-lobed; bases of post-oral cilia tan; velar lobes elongate, unpigmented.

Cephalic area: tentacles colorless, medium-long; eyes inside lateral bases of tentacles; interocular area light red-brown.

Foot: cream; propodium light yellow-tan; anteromedian area of propodium connected to mouth via a light charcoal marking.

Viscera: digestive gland tan-brown; ctenidium faintly outlined with yellow-orange; siphon long.

Month found in plankton: May

Area found: Sampan Channel

Remarks:

Veligers of this species closely resemble a Bermudan veliger figured by Lebour (1945) labelled 'undetermined larva', but suspected, on the basis of radular shape, to be a cymatid larva. The Bermudan form had a pale brown protoconch; like the Hawaiian form, the animal is yellowish-brown and the velar lobes are long and colorless.

PLATE XLVIII

Bursidae

Figure 1. Bursa granularis, anteroventral aspect. Note triangular flexible spines, position of eyes in tentacular bases, and the contracted position of the foot.

2. Bursa granularis, left lateral aspect. Note half-extended velum, extended foot (long propodium) and round operculum.

PLATE XLVIII

Bursidae

1.3mm

Bursa cruentata (Sowerby 1841). Plate XLIX, L, LI.

Veliger:

Protoconch: globose, sutures slightly impressed; shining, white except for apical two whorls (red-brown) and outer lip of aperture (regularly spotted with red-brown); apical whorl with punctae; abapical whorl with thin oblique axial ribs plus fainter spiral threads; third whorl white with long conchiolin spines (up to 660 µm long); fourth whorl lacks oblique sculpturing, has regularly-placed flexible spines; small umbilicus present; beak lacking; siphonal canal shallow; metamorphosis occurs when four whorls complete, length: 2145 µm, width: 1485 µm.

Velum: four-lobed; velar lobes extremely long, thin; bases of post-oral cilia purple-black; at metamorphosis, width: 4 mm, height: 3 mm; velar lobes coiled.

Cephalic area: tentacles medium-long; eyes inside swollen bases of tentacles; oral region unpigmented.

Foot: propodium broad, square; posterior edge of foot a rounded vee; pedal background white; ventrum faintly brushed with purple-black; sides, dorsum with tiny circular opaque white spots; operculum oval, tan.

Viscera: digestive gland cannot be discerned; stomach gray.

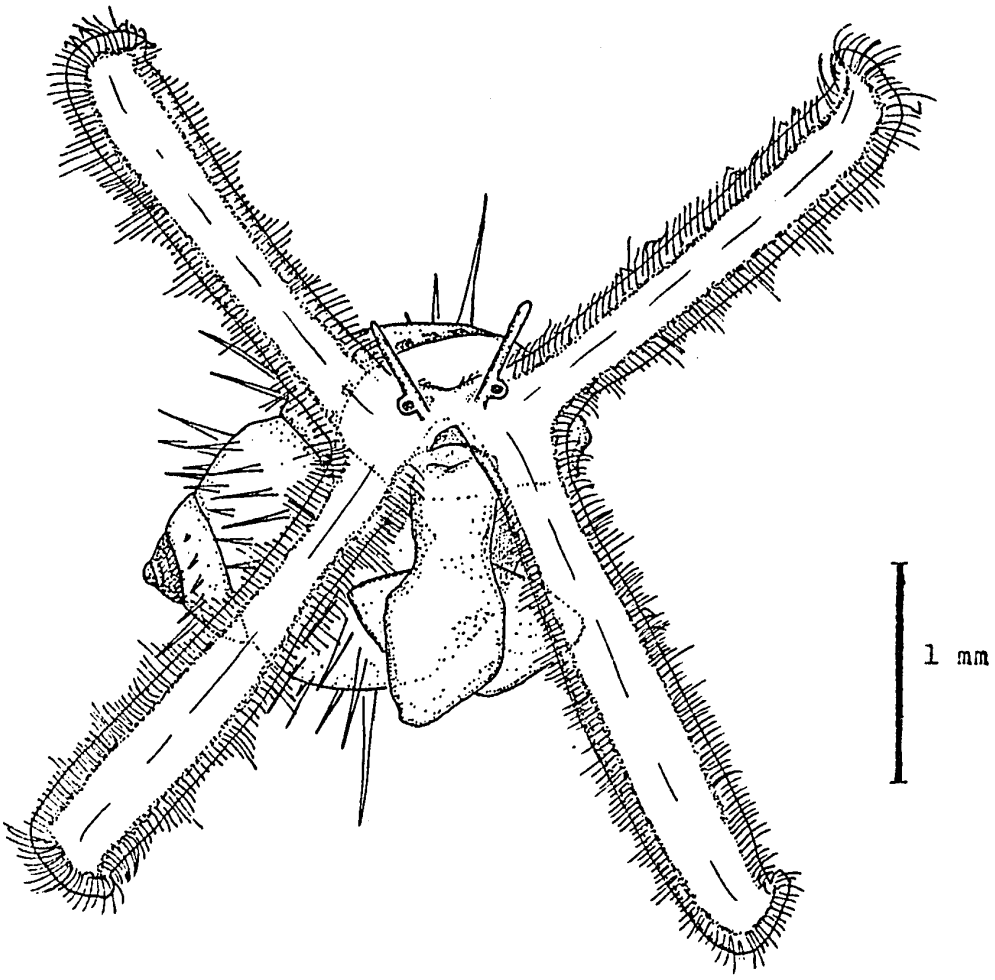
Month found in plankton: April

Area found: Sampan Channel

Remarks:

Soon after metamorphosis, the juvenile develops yellow-orange spots at siphonal edge (four days after metamorphosis). While the initial teleoconch is pure white, the sutures are undulatory. Under captive conditions, the juveniles feed upon newly-settled Crassostrea virginica juveniles and are attracted to fine, filamentous algae.

PLATE XLIX



Bursa cruentata, premetamorphic veliger: apertural view.

PLATE L

Bursa cruentata: premetamorphic protoconch drawn to same scale as other veliger drawings.

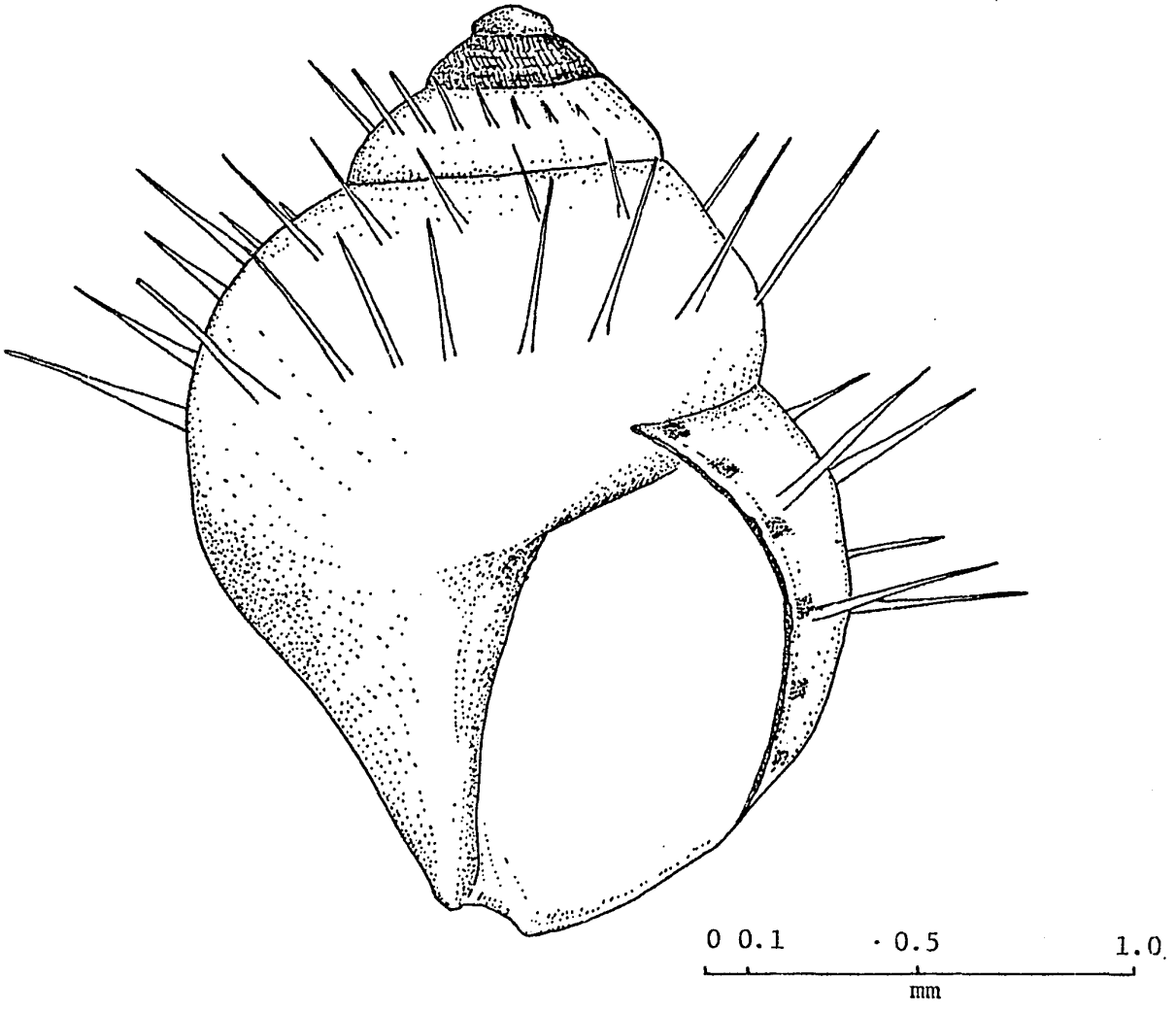
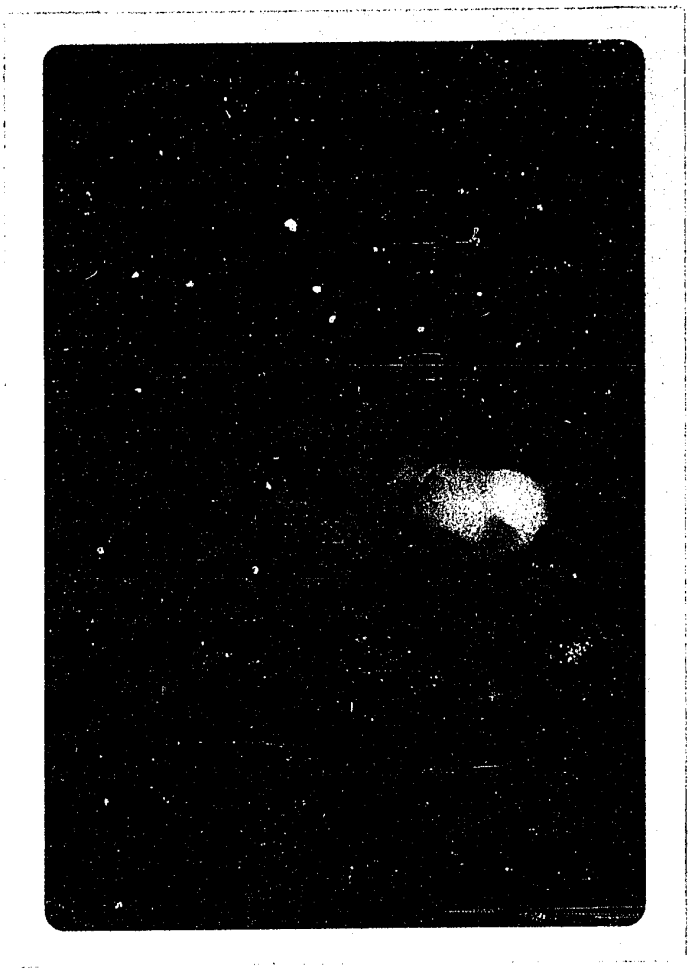


PLATE LI



Bursa cruentata: autotomy of the velar lobes.

1.3mm

Tonnidae

As with other tonnaceans, tun shells are generally found in tropical and subtropical waters. Tonna perdix has a circumtropical distribution, but the other Hawaiian species occur only in the Indo-Pacific. Adult tuns are usually large (7.5 cm or greater in length) and lack opercula; they are reported as feeding on sea cucumbers and bivalves. Although T. perdix inhabits shallow reef areas, the other Hawaiian tuns usually dwell in deep water.

Tonnid females deposit broad ribbons (e.g., Tonna dolium, 60 cm long by 10 cm wide) which contain transparent oval egg speces; each egg space contains 20-40 eggs (Thorson 1940; Knudsen 1950). The eggs are generally moderate (200-300 μm) in size, in capsulo intervals are generally two to three weeks, and the larvae usually metamorphose after the greatest dimension of the protoconch exceeds two millimeters.

Little is known of tonnid veligers as they exist immediately prior to settlement. Pre-metamorphic protoconchs of T. galea (Scheltema 1971) and the complete larva of T. perdix (Lebour 1945) have been figured. Planktonic periods have been estimated for T. galea (242 days) and T. maculosa (198 days)(Scheltema 1971).

The foot of the tonnid larva is characterized by a trilobate posterior region and an elongate propodium; the propodium is so long that both Thorson (1940) and Ostergaard (1950) erroneously labelled it as the proboscis.

Tonna perdix (Linnaeus 1758) Plate LII , Figs. a-c.

Early development: eggs 300 µm, pale orange; in capsulo duration unknown; hatch as pelagic veligers; early veliger with large velar lobes, a long propodium, and a rounded foot; operculum extends beyond pedal border; digestive gland light yellow; protoconch 550 µm at hatching, tinged with carmine along margin; sculpture of elevated polygonal areas crowded closely, creating reticulated appearance (Ostergaard 1950).

Early planktonic veliger:

Protoconch: planorbiform-globose; sculpture as above; first spine of 'cockscomb' appears at center of outer apertural lip; suture brown, well-defined.

Velum: velar lobes a little more elongate than above, unpigmented.

Cephalic area: tentacles short, blunt; eyes tiny; esophagus purple-black; upper lip underlined with purple.

Foot: posterior ventrum leaf-shaped, unpigmented; propodium elongate, with four brilliant elongate oval patches of golden-yellow; metapodial tentacle well-defined, with ciliation that lends a 'bristled' appearance.

Viscera: digestive gland golden yellow; style sac purple-black; heart large, evident.

Months found in plankton: October, November

Areas found: Dredged Island, Sampan Channel

Remarks:

These larvae are not fast swimmers. Three scallops of mantle edge project rather far out from the shell when the velum is extended. Most of the T. perdix obtained from Kaneohe Bay were recently hatched from egg masses; only two more mature veligers were taken from a November tow and these had not yet reached metamorphic size. Tonna perdix in Hawaii are also reported as breeding in June (Ostergaard 1950).

PLATE LII

Tonna perdix, newly-hatched veliger obtained from the plankton.

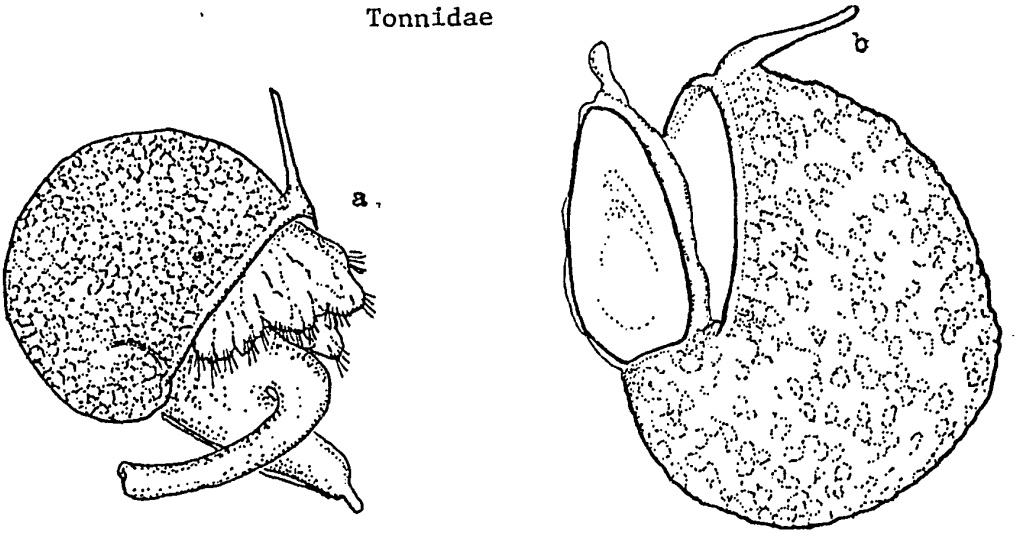
Figure a. retracted veliger.

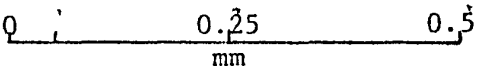
b. empty protoconch; operculum with part of foot remaining.

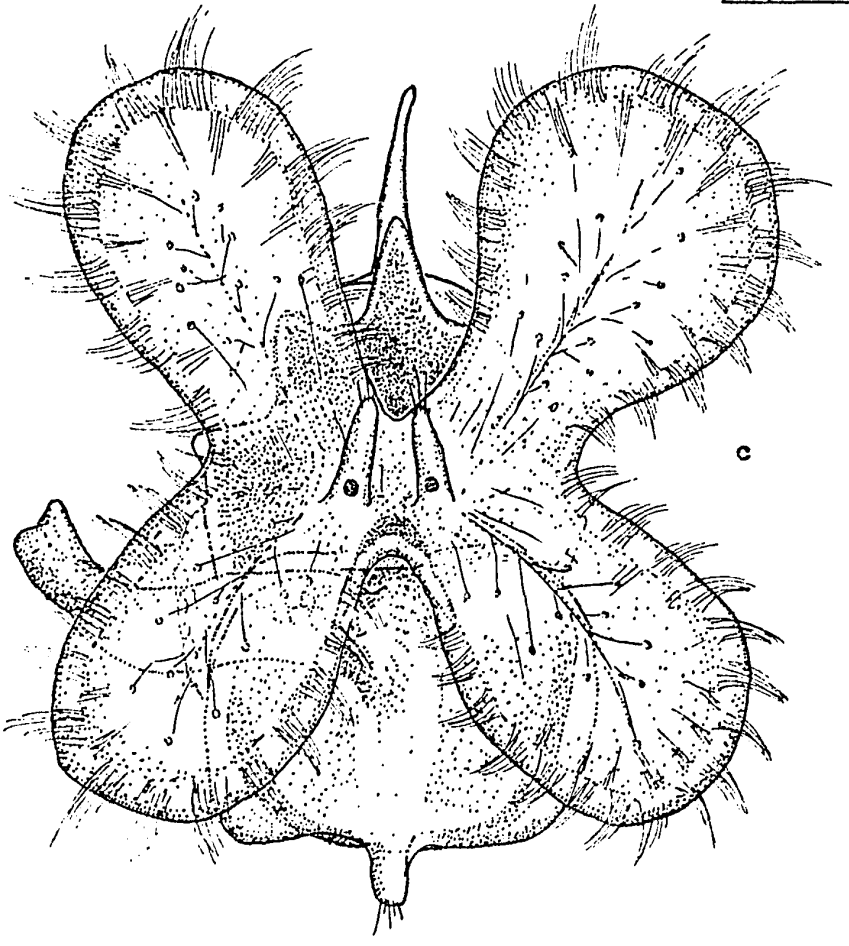
c. swimming veliger, apertural view.

PLATE LII

Tonnidae







Prosobranchia: Neogastropoda

Suborder Stenoglossa

Stenoglossans form an array of marine carnivorous species which prey predominantly on invertebrates. Within this group are three superfamilies, Muricacea, Buccinacea, Volutacea, which, on the basis of radular similarities, are referred to collectively as the Rachiglossa. The rachiglossan radula is relatively short and rarely has more than three teeth per row.

Rather constant features of the neogastropods are 1) a siphonal canal, or groove, at the anterior end of the shell's aperture and 2) a siphonal extension of the mantle which runs parallel to the canal. The sexes are separate; large eggs (400-600 μm) are deposited in capsules attached to hard substrata.

Superfamily 21. Muricacea

Muricaceans include the Muricidae*, Thaididae* and Magilidae* (=Coralliophilidae). Although thaidids are frequently included with muricids (Taylor and Sohl 1962; Fretter and Graham 1962; Hyman 1967), I have separated them (Drupa, Maculotriton, Morula, Nassa, Nucella, Pinaxia, Provexilla, Thais and Tribulus) from muricids (Aspella, Chicoreus, Favartia, Homolocantha, Pterynotus and Vitularia) in keeping with Keen (1971) and Kay (unpubl.) for ease in discussing life histories and larval types.

Superfamily characteristics: shell with conspicuous varices which form lamellae (Ocenebra) or rows of spines (many species of Murex); inner side of apertural outer lip frequently toothed in adult muricaceans; operculum present; radula rachiglossate; alimentary canal adapted for predation by boring through shells.

Muricidae

Rock shells have characteristic varices or spines. The operculum is horny and oval with the nucleus generally anterior, but sometimes displaced to the right. Muricid life histories are summarized in Table 25.

Table 25

Life History Data: Muricidae

Genus	P	?	N	References
Bedevina	1	-	-	Murray 1964
Boreotrophon	-	-	6	Melvill 1928; Thorson 1944; MacGinitie 1955; Fretter and Graham 1962
Calotrophon	-	-	1	Radwin and Chamberlin 1973
Ceratostoma	-	-	1	Amio 1963
Chicoreus	-	-	3	Risbec 1932; Murray and Goldsmith 1963; D'Asaro 1970b
Eupleura	-	-	1	Carriker 1955
Favartia	-	-	1	Raeihle 1966
Jopas	1	-	-	Gohar and Eisawy 1967
Murex	4	4	5	Risbec 1931, 1932; Thorson 1940a; Franc 1948; Chari 1950; Knudsen 1950; Natarajan 1957; Gohar and Eisawy 1967; D'Asaro 1970
Ocenebra	-	1	1	Lebour 1937a, 1945; Fretter and Graham 1962
Phyllonotus	3	-	1	Thorson 1940a; D'Asaro 1970b
Rapana	3	-	-	Hirase 1928; Thorson 1940a; Chukhchin 1957
Trophon (=Bedeva)	-	-	6	Lebour 1936; Thorson 1940a; Anderson 1965
Urosalpinx	1	-	3	Lebour 1937a; Carriker 1955; Hancock 1956; Radwin and Chamberlin 1973
Vitularia	1	-	-	D'Asaro 1970a

P = number of species with pelagic larvae
N = number of species with non-pelagic larvae
? = number of species with poecilogonous larvae

Thaididae

Thaidids are actively predatory on barnacles, mussels, gastropods and worms. The shells are more uniform in shape than the muricids and are solid, medium-sized, with knobby or spinose sculpture. The siphonal canal is short and the operculum has a ridge along the inside of the distal edge. Egg capsules are columnar or on short stalks. Data which summarize their life histories are presented in Table 26.

Table 26

Life History Data: Thaididae

Genus	P	?	N	References
Dicathais	1	-	-	Phillips 1969
Nucella	-	-	3	Pelseneer 1911; Portmann 1930b; Lebour 1937a; Fretter and Graham 1962; Houston 1971; Leboeuf 1971
Purpura	1	-	-	Lewis 1960
Thais	9	1	1	Lamy 1928; Thorson 1940a; Chari 1950; Knudsen 1950; Natarajan 1957; Lewis 1960; Amio 1963; D'Asaro 1966, 1970b; Scheltema 1971

P = number of species with pelagic larvae
? = number of species with peocilogonous larvae
N = number of species with non-pelagic larvae

Morula uva (Bolten 1798). Plate LIII, fig. a.

Veliger:

Protoconch: tan, smooth, conical; sutures corder, barely impressed; whorls slightly inflated; beak well-developed, rectangular, reinforced by sutural cord; siphonal canal truncate; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 1020 µm, width: 640 µm.

Velum: four-lobed, unpigmented.

Cephalic area: light tan.

Foot: light tan, smudged anteriorly with gray.

Viscera: digestive gland dark brown.

Months found in plankton: all months; peak abundance March-May

Areas found: Sampan Channel, Dredged Island

Remarks:

Upon metamorphosis, the protoconch turns red-brown with lighter banding; the apical whorls remain cream-tan. Veligers of M. uva are among the most common thaiidid larvae in the Sampan Channel plankton.

Morula granulata (Duclos 1832). Plate LIII, fig. b.

Veliger:

Protoconch: small, conic; transparent; beak and siphonal canal red-brown; beak rectangular; siphonal canal short; sculpture lacking; metamorphoses when 3 1/2 - 3 3/4 whorls complete, columellar length approximates 870 µm, width: 645 µm.

Velum: four-lobed; unpigmented except bases of post-oral cilia with tinge of black-red-brown; width, 1940 µm; height, 970 µm; sides of velar lobes parallel.

Foot: velvet black; propodium broad, blunt; metapodium tapered; operculum shaped like aperture, colorless.

Cephalic area: tentacles medium in length, widely separated, tapered, extreme base tinged with charcoal; eyes inside bases of tentacles; oral region charcoal.

Viscera: digestive gland, intestine black; style sac colorless; mantle entirely charcoal.

Months found in plankton: February, September

Areas found: Sampan Channel

Remarks: Veligers of this species are uncommonly netted in Kaneohe Bay. They metamorphose easily and are reared easily under the laboratory conditions used.

Drupa rubusidaeus Röding 1798. Plate LIII, fig. c.

Veliger:

Protoconch: cream, smooth, conical; sutures with cord of round beads; whorls slightly inflated; beak well-developed, involute, light red-brown, reinforced by sutural band of beads; columella striate; siphonal canal truncate, light red-brown; metamorphosis occurs when 3 3/4 whorls complete, length: 1370 µm, width: 850 µm.

Velum: four-lobed; distal areas of velar lobes with golden pigment spots.

Cephalic area: eyes tiny; oral area edged with charcoal.

Foot: cream.

Viscera: digestive gland golden; intestine inconspicuous.

Months found in plankton: August

Areas found: Sampan Channel

Maculotriton bracteatus (Hinds 1844). Plate LIII, fig. d.

Veliger:

Protoconch: light tan, smooth, conical; whorls slightly inflated; sutures filled with band of tiny light red-brown granules; columella striate; beak indented, reinforced with sutural cord; metamorphosis occurs when 4 - 4 1/4 whorls complete, length: 1150-1200 µm, width: 770 µm.

Velum: four-lobed; unpigmented.

Cephalic area: unpigmented.

Foot: cream smudged with gray.

Viscera: digestive gland golden.

Months found in plankton: March through June

Areas found: Sampan Channel, Dredged Island

Morula echinata (Reeve 1846). Plate LIII, fig. e.

Veliger:

Protoconch: conic-ovate; background transparent cream; sutures and columella lavendar; beak rich red-brown; sculpture lacking; siphonal canal medium in length; sutures slightly impressed; metamorphosis occurs when three whorls complete, columellar length approximates 1000 μm, width, 790 μm.

Velum: four-lobed; unpigmented except bases of post-oral cilia tinged lightly with yellow-orange.

Cephalic area: tentacles medium in length; eyes enclosed in bulges at bases of tentacles; esophageal region unpigmented.

Foot: cream; ventrum lightly tinged with charcoal; propodium rectangular; mesopodium slightly flared; metapodium tapered; operculum oval, transparent.

Viscera: digestive gland light gold; style sac light gray; intestine very broad, black.

Months found in plankton: April, May

Areas found: Sampan Channel

Remarks: During metamorphosis, the velum is ingested.

Plate LIII

Pre-metamorphic protoconchs: Thaisidae.

Figure a. Morula uva

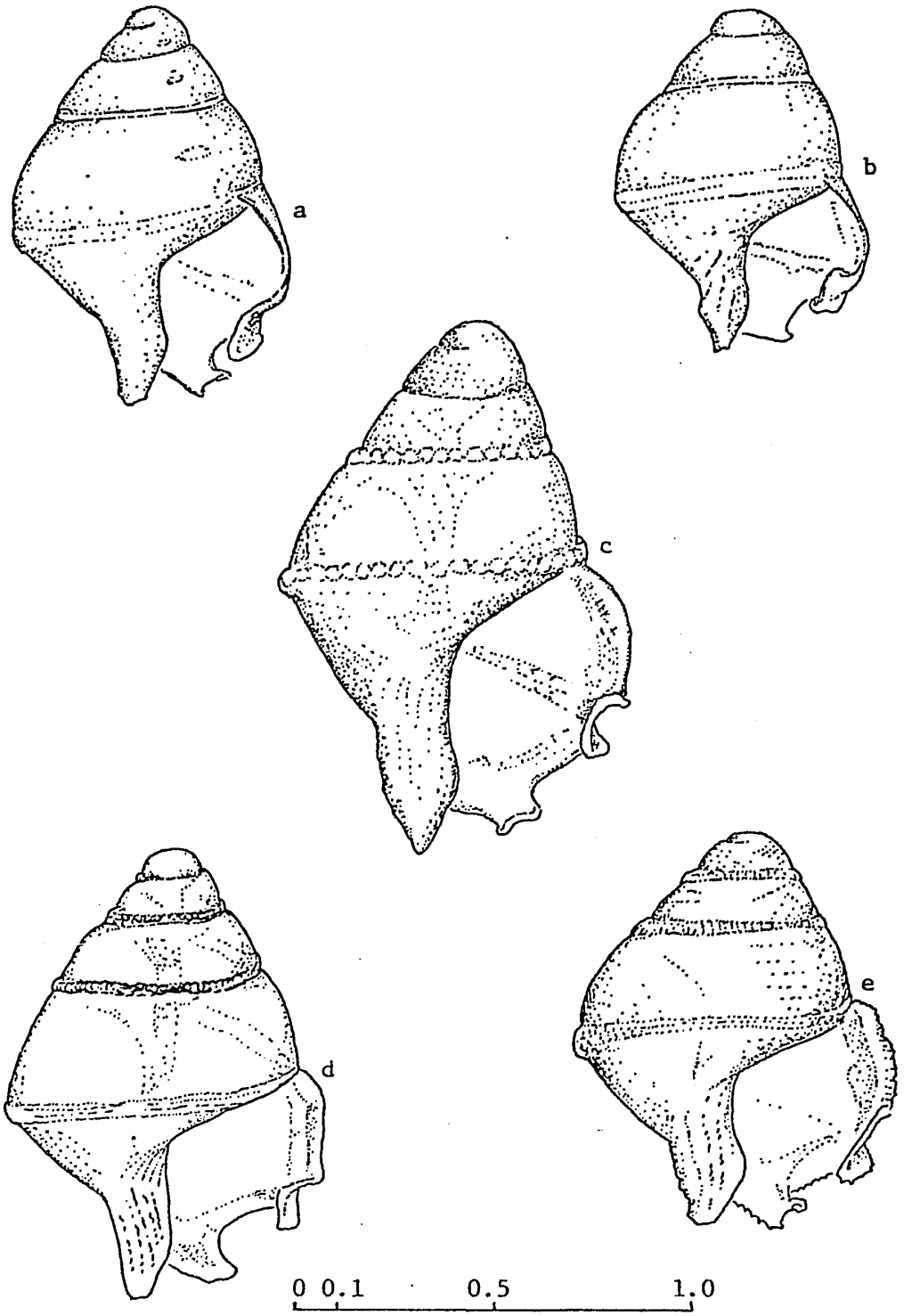
b. Morula granulata

c. Drupa rubusidaeus

d. Maculotriton bracteatus

e. Morula echinata

PLATE LIII



Thaididae

Morula parva (Reeve 1846). Plate LIV, fig. a.

Veliger:

Protoconch: white, smooth, conical; sutures of third and fourth whorls with corded band; whorls slightly inflated; columella striate; beak rectangular, reinforced by sutural band; metamorphosis occurs when four whorls complete, length: 1200-1250 µm, width: 820 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: cream, smudged anteriorly with charcoal.

Viscera: digestive gland brown; style sac, intestine charcoal.

Months found in plankton: April, May

Area found: Dredged Island

Drupella cornus (Röding 1798). Plate LIV, figs. b, c.

Veliger:

Protoconch: transparent cream; apex slightly broader than that of D. ochrostoma; smooth, conical; suture of body whorl with cord; beak reinforced with sutural cord; siphonal canal truncate; metamorphosis occurs when four whorls complete, length: 1250-1300 µm, width: 800-850 µm.

Velum: four-lobed; velar extremities with tan pigment in food groove.

Cephalic area: unpigmented.

Foot: cream with a light tinge of charcoal.

Viscera: digestive gland golden; intestine narrow, black, rectangular.

Months found in plankton: May, August

Areas found: Sampan Channel, Dredged Island.

Drupa ricina (Linnaeus 1758). Plate LIV, figs. d, e.

Veliger:

Protoconch: white, smooth, conical; sutures red-brown, with granulated band; whorls slightly inflated; columella unpigmented, striate; beak rectangular, with areas of red-brown; metamorphosis occurs when four whorls complete, length: 1300 µm, width: 850 µm.

Velum: four-lobed; unpigmented.

Cephalic area: oral area adged with charcoal.

Foot: white; propodium charcoal.

Viscera: intestine charcoal.

Months found in plankton: May

Areas found: Sampan Channel

Plate LIV

Pre-metamorphic protoconchs: Thaisidae.

Figure a. Morula parva

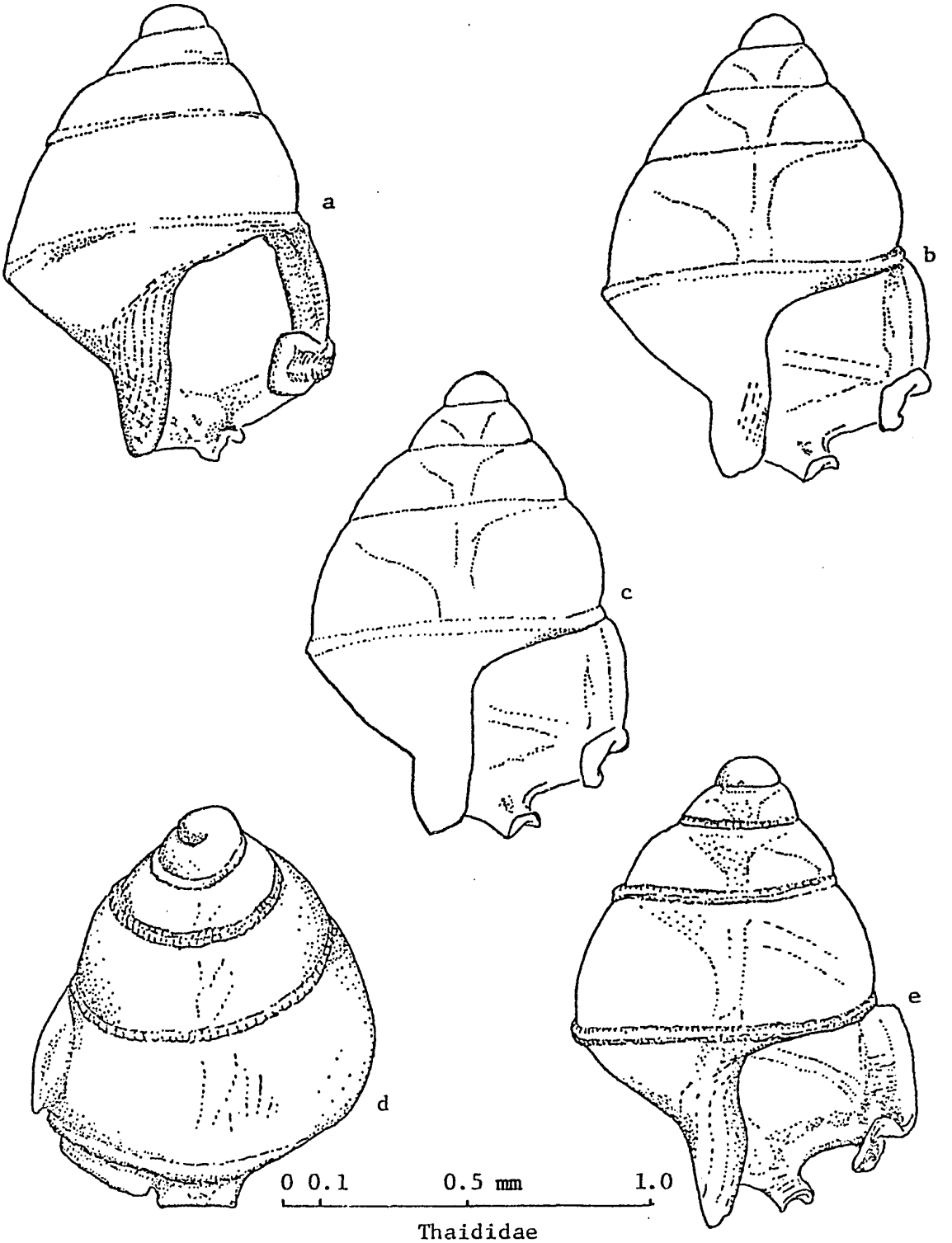
b. Drupella cornus

c. " "

d. Drupa ricina

e. " "

PLATE LIV



Thaididae

Pinaxia versicolor (Gray 1839). Plate LV, figs. a-c.

Veliger:

Protoconch: light tan, smooth, trochoidal; whorls inflated; sutures unpigmented, corded; beak unobtrusive; siphonal canal truncate; metamorphosis occurs when four whorls complete, length: 1100 µm, width: 780 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: tan, simple.

Viscera: digestive gland brown; intestine dark gray, rectangular.

Months found in plankton: March through August

Areas found: Sampan Channel, Dredged Island.

Remarks:

Upon metamorphosis, the protoconch becomes suffused with alternating indistinct spiral stripes of red-brown and tan-red-brown.

Vexilla fusconigra Pease 1861. Plate LV, figs. d,e.

Veliger:

Protoconch: transparent tan; punctate; conical, apical whorl narrowly rounded, pre-settlement whorl slightly inflated; sutures marked by densely-packed spiral threads and regularly-placed large axial diamond-shaped bosses; outer lip of pre-settlement aperture with varix perpendicular to growth plane of shell; beak produced, tinged with light red-brown; siphonal canal medium in length; metamorphosis occurs when 4 - 4 1/4 whorls complete; columellar length approximates 1550 µm; greatest width, 990 µm.

Velum: four-lobed; velar lobes elongate, broad; bases of post-oral cilia tinged with diffuse yellow-orange; cilia long.

Cephalic area: tentacles long, slender, not tapered; eyes inside bases; esophageal area narrow, dark tan.

Foot: transparent cream-tan; propodium broad, rectangular; metapodium tapered; operculum inconspicuous.

Viscera: digestive gland cream to light gold; style sac light charcoal, inconspicuous; intestine, a broad elongate black rectangle.

Months found in plankton: May, June

Areas found: Sampan Channel

Remarks: Soon after metamorphosis, the protoconch turns brown.

Plate LV

Pre-metamorphic protoconchs: Thaisidae.

Figure a. Pinaxia versicolor

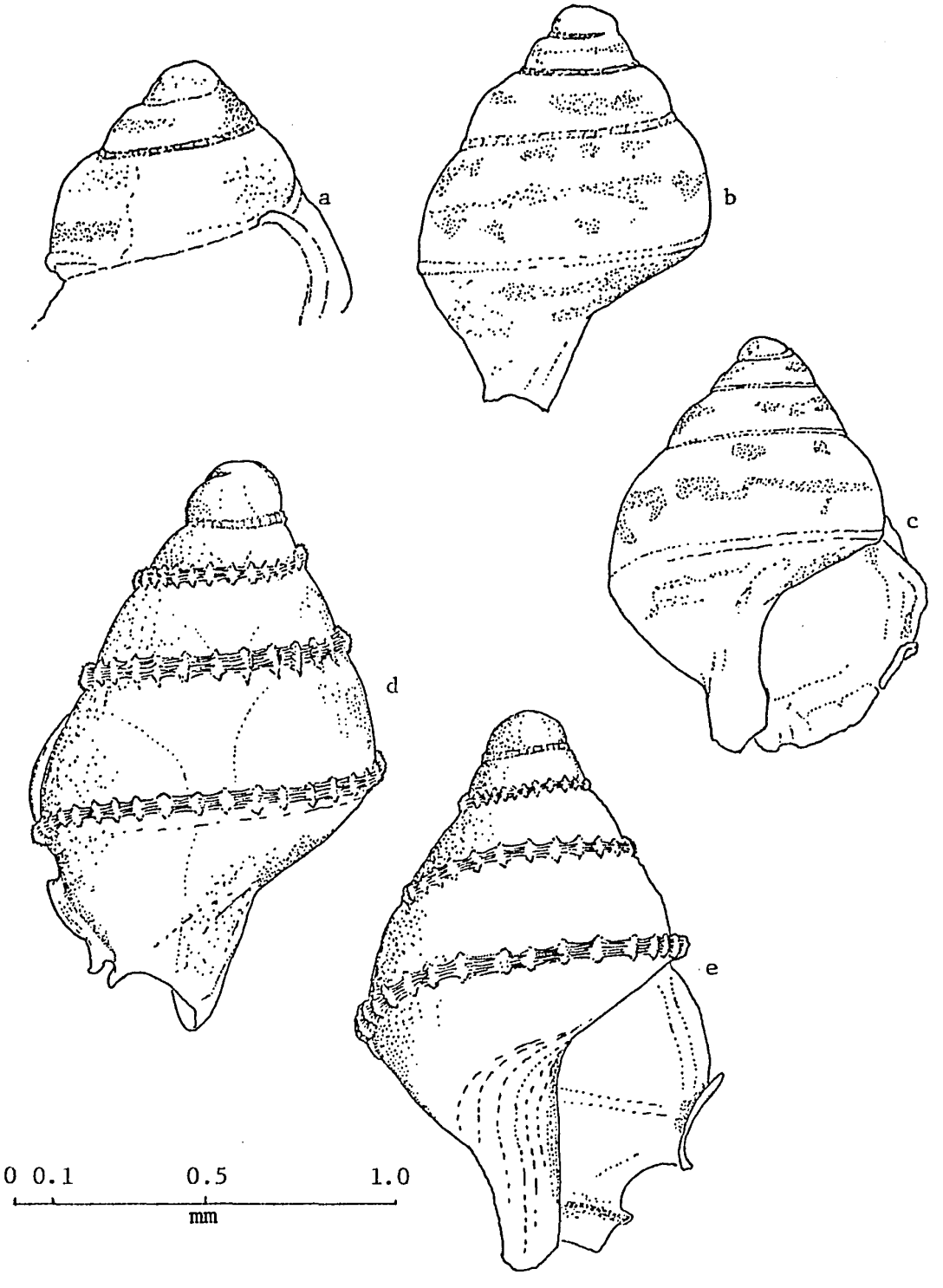
b. " "

c. " "

d. Vexilla fusconigra

e. Vexilla fusconigra

PLATE LV



Thaididae

Vexilla vexillum (Gmelin 1791). Plate LVI, figs. a, b.

Synonym: V. taeniata Rowys 1835.

Veliger:

Protoconch: bulbous-rhomboidal; transparent light gold; sutures with closely-spaced flat red-brown beads, slightly impressed; beak, columella red-brown; anterior columella striate; sculpture lacking; metamorphosis occurs when two whorls complete, columellar length approximates 1195 µm, width: 890 µm.

Velum: four-lobed, unpigmented.

Cephalic area: tentacles slender, widely separated, sides parallel; eyes inside bases; entire cephalic area clouded with charcoal.

Foot: ventrum and sides cream or velvet black; propodium rectangular, broad; metapodium broadly tapered.

Viscera: digestive gland gold with tinges of black; intestine broad, black, rectangular; mantle frequently suffused with varying amounts of black.

Months found in plankton: March, August, September

Areas found: Sampan Channel

Remarks;

Veligers of this species are confused with those of Morula granulata because both frequently have black feet; however, the species are distinguishable on the bases of size and shape of protoconchs.

Morula dumosa (Conrad 1837). Plate LVI, figs. c-f.

Veliger:

Protoconch: light golden; bulbous-conic, squat; sutures, columella and beak rich red-brown; sutures with closely-spaced red-brown granules; third whorl with ridge midway between sutures; siphonal canal very short; metamorphosis occurs when columellar length approximates 925 µm, width nearly 825 µm.

Velum: four-lobed; unpigmented; velar lobes medium-short.

Cephalic area: tentacles medium in length; eyes inside bases; esophageal area tinged with charcoal.

Foot: ventrum yellow; dorsum of anterior and posterior areas tinged with charcoal gray.

Viscera: digestive gland, esophagus light charcoal gray; intestine broad, black.

Months found in plankton: April

Areas found: Sampan Channel, Dredged Island

Morula foliacea (Conrad 1837). Plate LVI, figs. g, h.

Veliger:

Protoconch: transparent cream, rounded-conical; whorls slightly inflated; suture corded, pink-brown; beak arcuate; siphonal canal truncate; metamorphosis occurs when 3 1/2 whorls complete, length: 960 µm, width: 660-700 µm.

Velum: four-lobed, unpigmented.

Cephalic area: oral area edged with gray.

Foot: propodium smudged with gray.

Viscera: digestive gland brown; intestine inconspicuous.

Months found in plankton: March through July

Areas found: Sampan Channel, Dredged Island

PLATE LVI

Thaididae: premetamorphic protoconchs.

Figure a. Vexilla vexillum

b. Vexilla vexillum

c. Morula dumosa, juvenile with protoconch

d. Morula dumosa

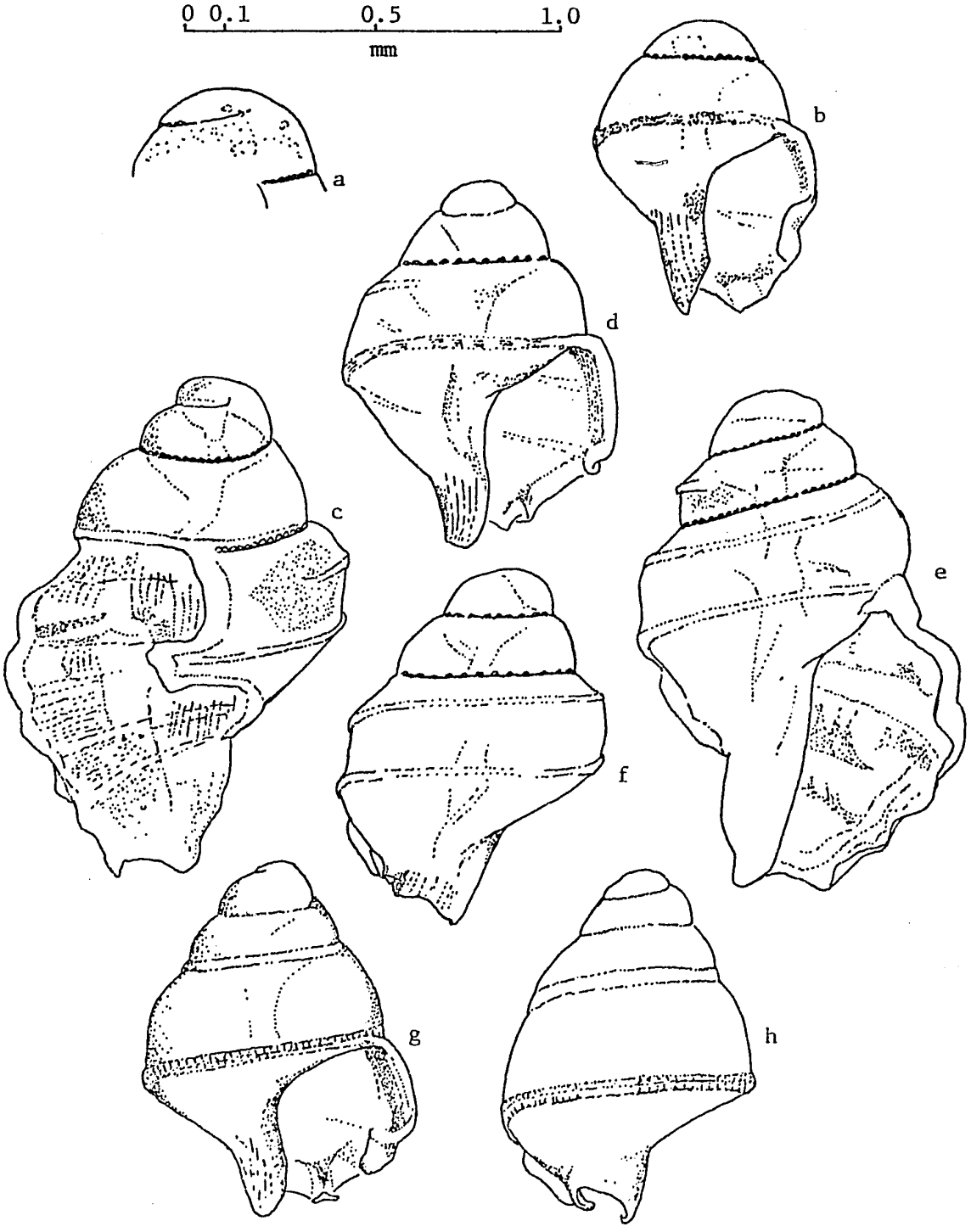
e. Morula dumosa, juvenile with protoconch, apertural view

f. Morula dumosa

g. Morula foliacea

h. Morula foliacea

PLATE LVI



Thaididae

Drupella ochrostoma (Blainville 1832). Plate LVII.

Veliger:

Protoconch: transparent; conic; third, fourth whorls slightly ovate; sutures, beak, siphonal canal red-brown; sculpture lacking except for tiny punctae; metamorphosis occurs when 4 - 4 1/2 whorls complete, columellar length approximates 1130 µm, width nearly 775 µm.

Velum: four-lobed; unpigmented; dorsal width, 2325 µm; ventral width, 1455 µm; height, 970 µm.

Cephalic area: tentacles widely separated, medium-long, slightly tapered; eyes inside bases of tentacles; oral region edged with charcoal.

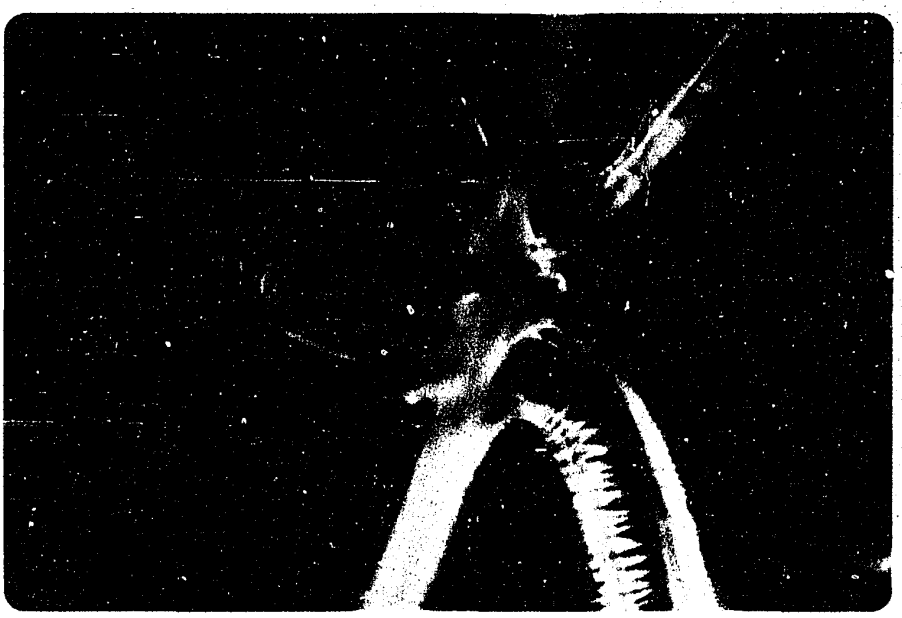
Foot: background dirty white; ventral portion brushed with charcoal; lateral areas with charcoal flecks; operculum transparent, fits aperture.

Viscera: digestive gland golden; style sac, intestine charcoal; intestine broad, rectangular.

Months found in plankton: February, August

Areas found: Sampan Channel, Dredged Island

PLATE LVII
Thaididae



1.3mm

Drupella ochrostoma, swimming veliger.

Magilidae (=Coralliophilidae)

Coralliophilids are predatory or parasitic on corals. Parasitic magilids generally lack radulae. Their shells are sculptured with spirals of overlapping scales and the opercula resemble those of thaidids.

Adult females of Coralliophila neritoidea and Magilopsis lamarckii brood the eggs in capsules under the shell until the pelagic larvae hatch; after a free-swimming period, the larvae settle upon coral (Demond 1957). No early early or pre-settlement coralliophilid veligers are described in the literature.

There are ten species and four genera of coralliophilids in Hawaiian waters. The adults prey upon corals and are usually found in or near living coral.

Coralliophilid protoconchs most closely resemble those of thaidids and turrids.

Coralliophila erosa (Röding 1798) Plate LVIII, figs. a, b; Plate LIX.

Veliger:

Protoconch: opaque white with tan tints, sturdy, shaped like an ovate, pustulose teardrop; embossed with spiral tracts of axially-oriented tubercles and sutural cords; beak well developed, tinged with red-brown; capsular protoconch punctate; apex broad; metamorphoses when 3 3/4 whorls complete, columellar length: 850 - 900 µm, width: 630 µm.

Velum: four-lobed; unpigmented; velar lobes medium-long, resemble those of thaisids.

Foot: white with black specks over meso- and metapodial regions of ventrum; propodium rectangular; posterior region of foot rounded-rhomboidal.

Cephalic area: unpigmented; eyes separated by beak, moderately far apart, inside bases of tentacles.

Viscera: undiscernible through protoconch.

Months found in plankton: March through September

Areas found: Sampan Channel, Dredged Island, Ala Moana Reef (Honolulu)

Remarks: The protoconch of this species is smaller and narrower than the protoconchs of the other two species of Coralliophila.

Coralliophila violacea (Kiener 1836). Plate LVIII, figs. c, d.

Synonym: C. neritoidea (Lamarck 1822)

Veliger:

Protoconch: all except apical whorl tinged with pink; beak, columella deep pink; apex white, broad, punctate; shaped like other two species of Coralliophila; embossed with spiral tracts of axially-oriented tubercles and sutural cords; metamorphosis occurs when 3 3/4 whorls complete, columellar length approximates 945 µm, width: 750 µm.

Velum: four-lobed; velar lobes medium-long, resemble those of thaidids.

Cephalic area: unpigmented.

Foot: background cream, smudged with tan.

Viscera: digestive gland golden.

Months found in plankton: July

Areas found: Sampan Channel, Ala Moana Reef (Honolulu)

Coralliophila d'Orbignyana (Petit 1851) Plate LVIII, figs. e, f.

Veliger:

Protoconch: white, sturdy, shaped like an ovate, pustulose teardrop; embossed with spiral tracts of axially-oriented tubercles and sutural cords; apex narrow; body whorl inflated; beak not stained; columella unpigmented; metamorphoses when five whorls complete, columellar length approximates 1040 µm; width, 850 µm.

Velum: four-lobed; velar lobes medium-long, resemble thaisid vela; edged with brownish-gray; remainder unpigmented; swims actively.

Cephalic area: tentacles each with two round yellow spots distal to each eye; oral area brown.

Foot: background smudged with brownish-green, decorated with discrete yellow spots.

Viscera: digestive gland yellow; style sac black-brown.

Months found in plankton: June, July

Areas found: Sampan Channel, Dredged Island, Kewalo Basin

Remarks: Between the propodium and the mouth is a round brown spot.

PLATE LVIII
Coralliophilidae

Figures a, b. *Coralliophila erosa*

c, d. *Coralliophila violacea*

e, f. *Coralliophila d'Orbignyana*

PLATE LVIII

Coralliophilidae

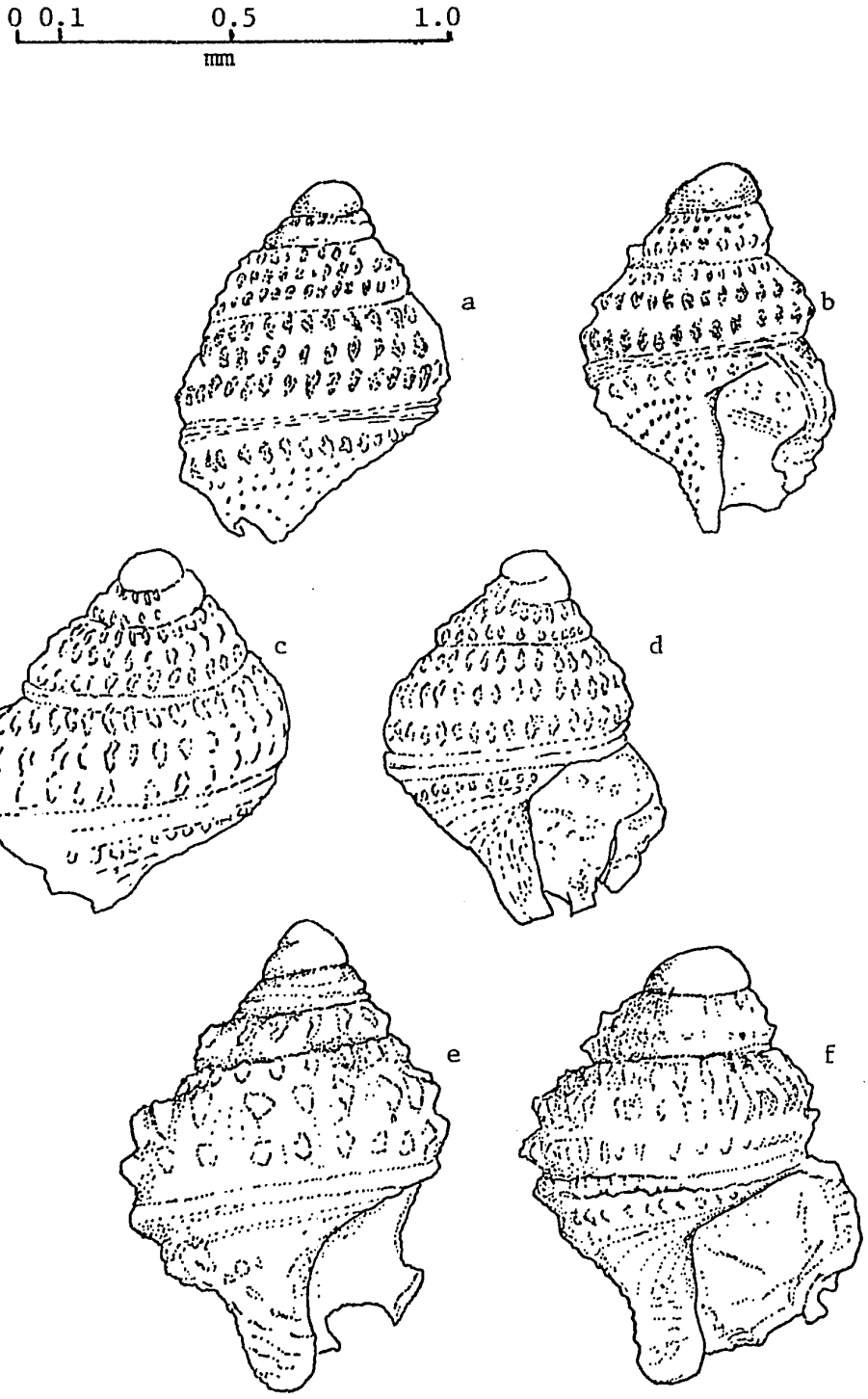


PLATE LIX
Coralliophilidae

1.3 mm

Coralliophila erosa: swimming veliger.

Superfamily 22. Buccinacea

Buccinaceans include the Pyrenidae* (=Columbellidae), Buccinidae*, Neptuneidae, Buccinulidae, Melongenidae (=Galeodidae), Nassariidae* (=Nassidae) and Fasciolariidae* (includes Fusinidae).

Superfamily characteristics: shells conical, of moderate to substantial height, sculpture mostly spiral, often tubercles and longitudinal ribs; advanced forms have tendency to lose operculum; shell less apt to acquire varices and alimentary tract not as adapted for predation as in Muricacea; carrion feeding as well as predation; generally in tropical waters.

Pyrenidae (=Columbellidae)

Dove shells are small conical forms with small, elongate apertures and very short siphonal canals. Data relating to their life histories are summarized in Table 27.

In Hawaii, there are approximately 15 species of columbellids in five genera.

Table 27

Life History Data: Pyrenidae (=Columbellidae)

Genus	Number of species with pelagic or direct development		References
Amphissa	1	---	Pelseneer 1906
Anachis	5	1	Marcus and Marcus 1962; Scheltema and Scheltema 1963; Amio 1963; D'Asaro 1970a
Astyris	---	1	Thorson 1935, 1944
Columbella	3	2	Petit and Risbec 1929; Risbec 1932; Thorson 1940; Lebour 1945; Knudsen 1950; Natarajan 1957
Mitrella	1	2	Thorson 1940; Natarajan 1957; Amio 1963
Pyrene	4	2	Petit and Risbec 1929; Thorson 1935; Natarajan 1957; Desai 1962
Zafrona	1	---	Amio 1956b, 1963
	15	8	

Euplica turturina (Lamarck 1822). Plate LX, figs. a-c.

Veliger:

Protoconch: rounded-conical, colorless, smooth; planktonic protoconch with closely-spaced thin axial riblets; sutural area of body whorl with band bordered by two spiral threads; metamorphosis occurs when 3 2/3 - 4 whorls complete, length: 950 µm, width: 570-630 µm.

Velum: velar lobes five; post-oral cilia suffused with charcoal.

Cephalic area: unpigmented.

Foot: white with medial charcoal streak.

Viscera: digestive gland golden.

Months found in plankton: January, May

Areas found: Sampan Channel, Dredged Island

Mitrella rorida (Reeve 1859). Plate LX, figs. d, e.

Veliger:

Protoconch: globose, large; sutures barely impressed, pink-brown; planktonic protoconchal whorls with axial riblets; columella pink-brown; metamorphosis occurs when 3 1/2 whorls complete, length: 1030-1060 µm, width: 730-770 µm.

Velum: asymmetrical; velar lobes five, unpigmented, expansive.

Cephalic area: eyes widely set; mouth tiny, edged with charcoal.

Foot: white; propodium blunt; metapodium with medial tentacle.

Viscera: digestive gland brown-tan.

Months found in plankton: April, July, August

Areas found: Dredged Island, Sampan Channel

Remarks:

Veligers caught in April have a white foot; those caught in July or August have developed a black foot. The intestine and style sac are charcoal, but the velum remains unpigmented.

Upon metamorphosis, the juveniles quickly set about eating the small black rissoacean, ?Eatoniella.

Euplica varians (Sowerby 1832). Plate LX, figs. f, g.

Veliger:

Protoconch: globose; sutures barely impressed; areas anterior to suture of body whorl suffused with rich red-brown; planktonic protoconch with thin axial riblets; metamorphosis occurs when 4 1/2 whorls complete, length: 1180 μm, width: 770-780 μm.

Velum: asymmetrical, four-lobed; unpigmented.

Cephalic area: unpigmented.

Foot: black.

Viscera: most of gut black.

Months found in plankton: April, May, August

Areas found: Dredged Island, Sampan Channel

Plate LX

Protoconchs: Columbellidae

Figure a. *Euplica turturina*

b. " "

c. " "

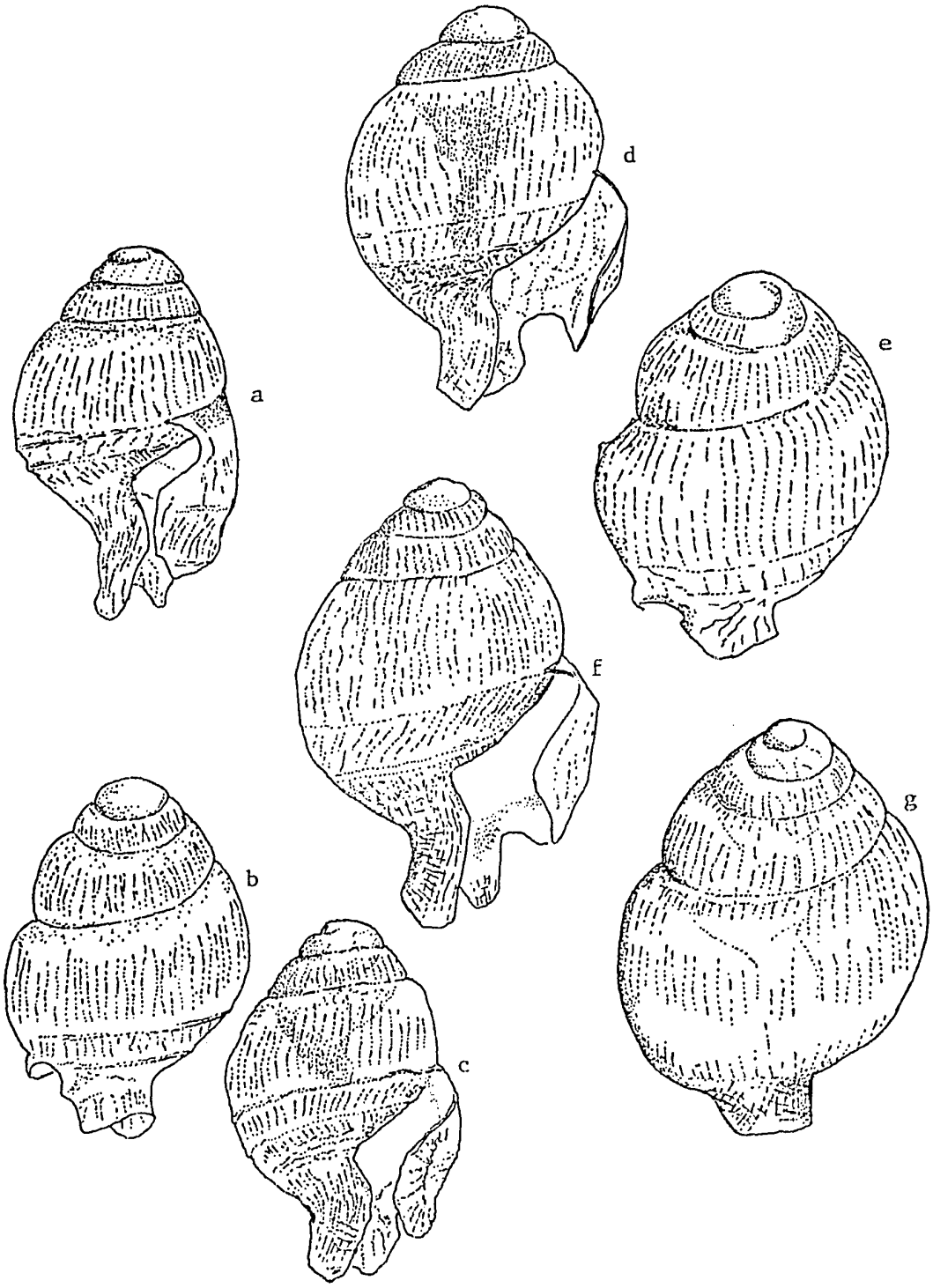
d. *Mitrella rorida*

e. " "

f. *Euplica varians*

g. " "

PLATE LX



Columbellidae

Mitrella bella (Reeve 1859). Plate LXI, fig. a.

Veliger:

Protoconch: smooth, slender, rounded-conical, tinged with faint pink; whorls straight-sided; body whorl with two spiral lines delineating beak, sutural area; columella red-brown, striate; beak present; metamorphosis occurs when 2 3/4 - 3 whorls complete, length: 850 µm, width: 470 µm.

Velum: quadri-lobed, unpigmented.

Cephalic area: tentacles medium-long; cream.

Foot: white, simple.

Viscera: digestive gland gold.

Months found in plankton: October

Area found: Dredged Island

Seminella virginea (Gould 1860). Plate LXI, figs. b, c.

Veliger:

Protoconch: white, smooth, shining; sutures impressed; beak gradually rounded; siphonal canal short; metamorphosis occurs when 3 - 3 1/4 whorls complete, length: 680-750 µm, width: 440 µm.

Velum: bilobed, unequal, unpigmented.

Cephalic area: cream.

Foot: cream.

Viscera: digestive gland yellow-green.

Months found in plankton: all months; peak abundance during summer.

Areas found: Dredged Island, Coconut Island, Sampan Channel

Mitrella margarita (Reeve 1859). Plate LXI, figs. d, f.

Veliger:

Protoconch: smooth, transparent with faint green tinge; sutures barely impressed; columella, beak light red-brown; siphonal canal medium-long; metamorphosis occurs when 3 - 3 1/4 whorls complete, length: 910 µm, width: 560 µm.

Velum: bilobed; each velar lobe auriculate.

Cephalic area: unpigmented.

Foot: white with tiny speckles of light charcoal; operculum white; propodium rectangular; posterior edge tapering.

Viscera: digestive gland tan; remainder colorless; siphon very long, white with brown spots.

Months found in plankton: January

Areas found: Sampan Channel

Remarks:

Juveniles eat ?Eatoniella and the body whorl develops a spiral of red-brown dashes.

Mitrella zebra (Gray 1828). Plate LXI, figs. g, h.

Veliger:

Protoconch: smooth, transparent; when 3rd whorl body whorl, protoconch acquires tinge of yellow; sculpture lacking except two spiral lines on body whorl which delineate beak; beak, siphonal canal present; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 1020-1070 µm, width: 630-670 µm.

Velum: bilobed, unequal; right velar lobe half again larger than left; base of pre-oral cilia purple-black.

Cephalic area: tentacles short, far apart; oral area tinged with light charcoal.

Foot: ventrum white with sparse black spots.

Viscera: digestive gland yellow-green; intestine charcoal gray; remainder colorless.

Months found in plankton: September, February, June

Areas found: Dredged Island, Sampan Channel

PLATE LXI

Columbellidae: protoconchs.

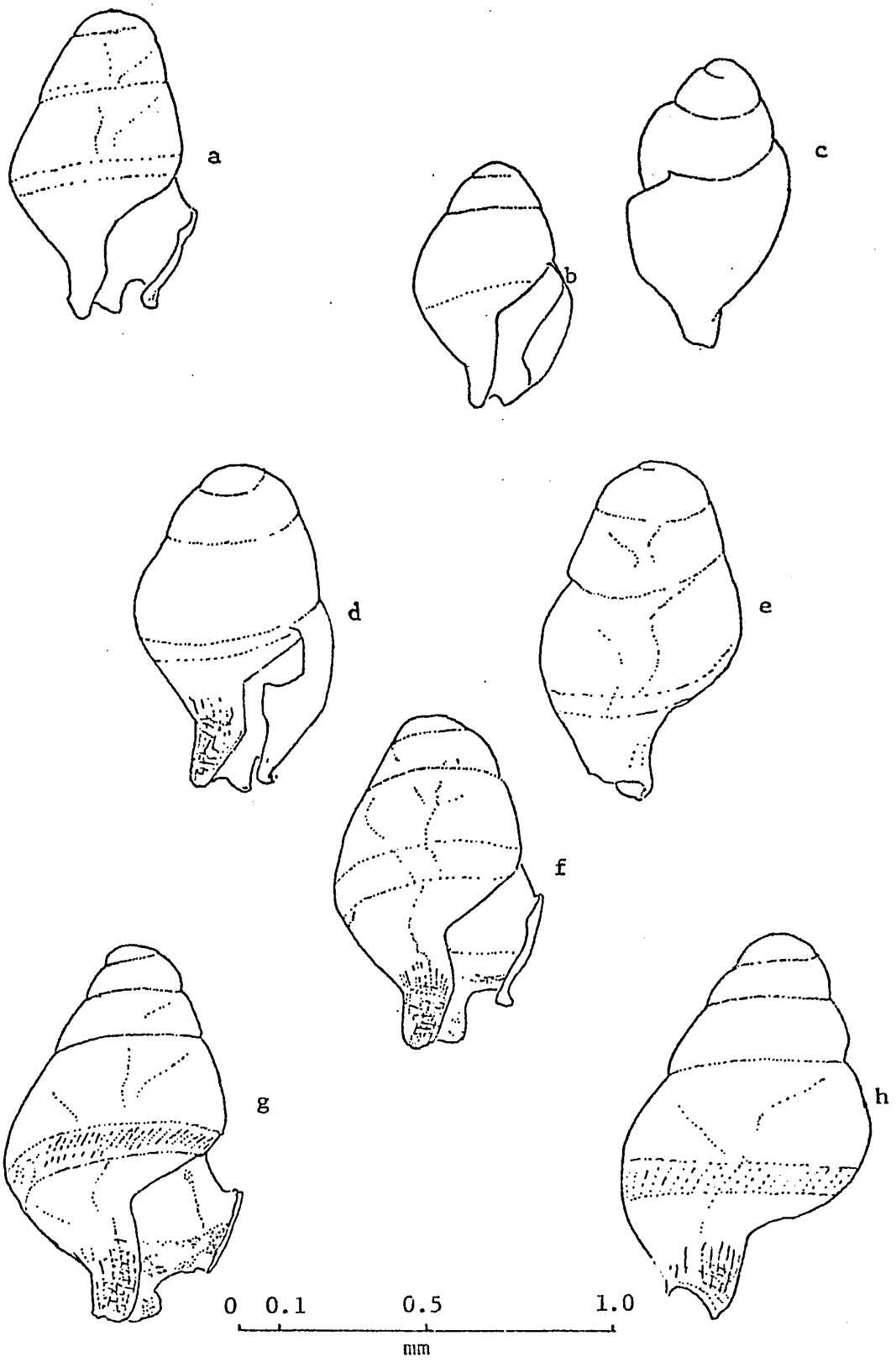
Figure a. *Mitrella bella*

b, c. *Seminella virginea*

d-f. *Mitrella margarita*

g-h. *Mitrella zebra*

PLATE LXI



Columbellidae

Buccinidae

Whelks are large gastropods which have sturdy shells with large apertures and short to moderately-long siphonal canals. Sutures are indented generally and the shells may be smooth or sculptured.

Data summarizing buccinid life histories are summarized in Table 28.

Table 28

Life History Data: Buccinidae[1]

Genus	No. of species	References cited
Beringius	4	Howse 1847; Thorson 1935; Lebour 1937a; MacGinitie 1955; Cowan 1964
Buccinum	8	Portmann 1925; Thorson 1935, 1940b; Lebour 1937a
"Cantharus"	22	Lebour 1945; D'Asaro 1970; Radwin and Chamberlin 1973
Chauvetia	1	Lebour 1937a
Colus	9	Thorson 1935, 1940b; Lebour 1937a; Radwin and Chamberlin 1973
Macron	1	Chace 1916
Neptunea	4	Johnson 1921; Fretter and Graham 1962; Amio 1963
Pisania	1	Franc 1943
Plicifusus	1	MacGinitie 1955
Pollia	1	Lebour 1945
Pyrulofusus	2	Gonor 1964; Cowan 1965
Siphonalia	1	Taki 1934
Volutoharpa	1	Fretter and Graham 1962
Volutopsius	1	Thorson 1935, 1944; Lebour 1937a
	37	

[1]No buccinids with planktonic larvae have been reported. The above genera, with number of species following each genus, have non-pelagic larvae.

Pisania gracilis (Reeve 1846). Plate LXII, fig. a.

Veliger:

Protoconch: transparent cream tinged with brown-pink; smooth, ovately conic, apex broadly rounded, whorls inflated; sutures impressed; beak pink-brown; siphonal canal abbreviated, tinged with brown-pink; metamorphosis occurs when 3 - 3 1/2 whorls complete, columellar length approximates 825 µm, greatest width nearly 615 µm.

Velum: four-lobed; unpigmented; height, 825 µm; width of dorsal velar lobes, 2000 µm; width of ventral lobes, 1000 µm.

Cephalic area: tentacles medium in length, not tapered; eyes inside bases of tentacles; oral region unpigmented.

Foot: shaped like an attenuated heart; metapodium tapered; operculum brown-pink, oval, periphery deep rose; body of foot unpigmented.

Viscera: digestive gland gold; other organs, oral region unpigmented.

Months found in plankton: April, May

Areas found: Sampan Channel

Engina iodosia (Duclos 1845). Plate LXII, figs. b, c.

Veliger:

Protoconch: rounded-conical; transparent white; suture of third whorl banded; metamorphosis occurs when 3 1/2 - 3 2/3 whorls complete, length: 980-1020 μm, width: 710 μm.

Velum: four-lobed, unpigmented.

Cephalic area: cream, eyes small.

Foot: simple, cream.

Viscera: digestive gland light golden; style sac, intestine gray.

Months found in plankton: April through July

Areas found: Sampan Channel, Dredged Island

Remarks:

Adults of E. iodosia are often found in beds of Palythoa and Zoanthus.

Monostiolum (Caducifer) decapitatus (Reeve 1844). Plate LXII, figs. d, e.

Veliger:

Protoconch: transparent cream; conical-rounded; smooth; apex rounded; sutures, columella pink-tan, barely impressed; beak, outer apertural lip medium red-brown; metamorphosis occurs when three whorls complete, length: 940 µm, width: 640 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: cream; operculum transparent, retained after metamorphosis.

Viscera: digestive gland tan; ctenidium with light pink-brown tinges.

Months found in plankton: May through August

Areas found: Sampan Channel, Dredged Island

Engina albocincta Pease 1860. Plate LXII, figs. f, g.

Veliger:

Protoconch: ovate-conical; background transparent lavendar; sutures, columella lavendar; suture of second whorl with single row of rhomboidal bosses; sutural area of body whorl with two spiral cords; columellar area striate; metamorphosis occurs when 3 1/2 whorls complete, length: 1040-1060 µm, width: 650-680 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: cream tinged with pink, simple.

Viscera: digestive gland brown; style sac charcoal.

Months found in plankton: July, August

Areas found: Sampan Channel

Remarks:

These veligers are uncommon in the Kaneohe Bay plankton. Upon metamorphosis, the protoconch becomes darker purple.

Plate LXII

Protoconchs: Thaisidae

Figure a. *Pisania gracilis*

b. *Engina iodosia*

c. " "

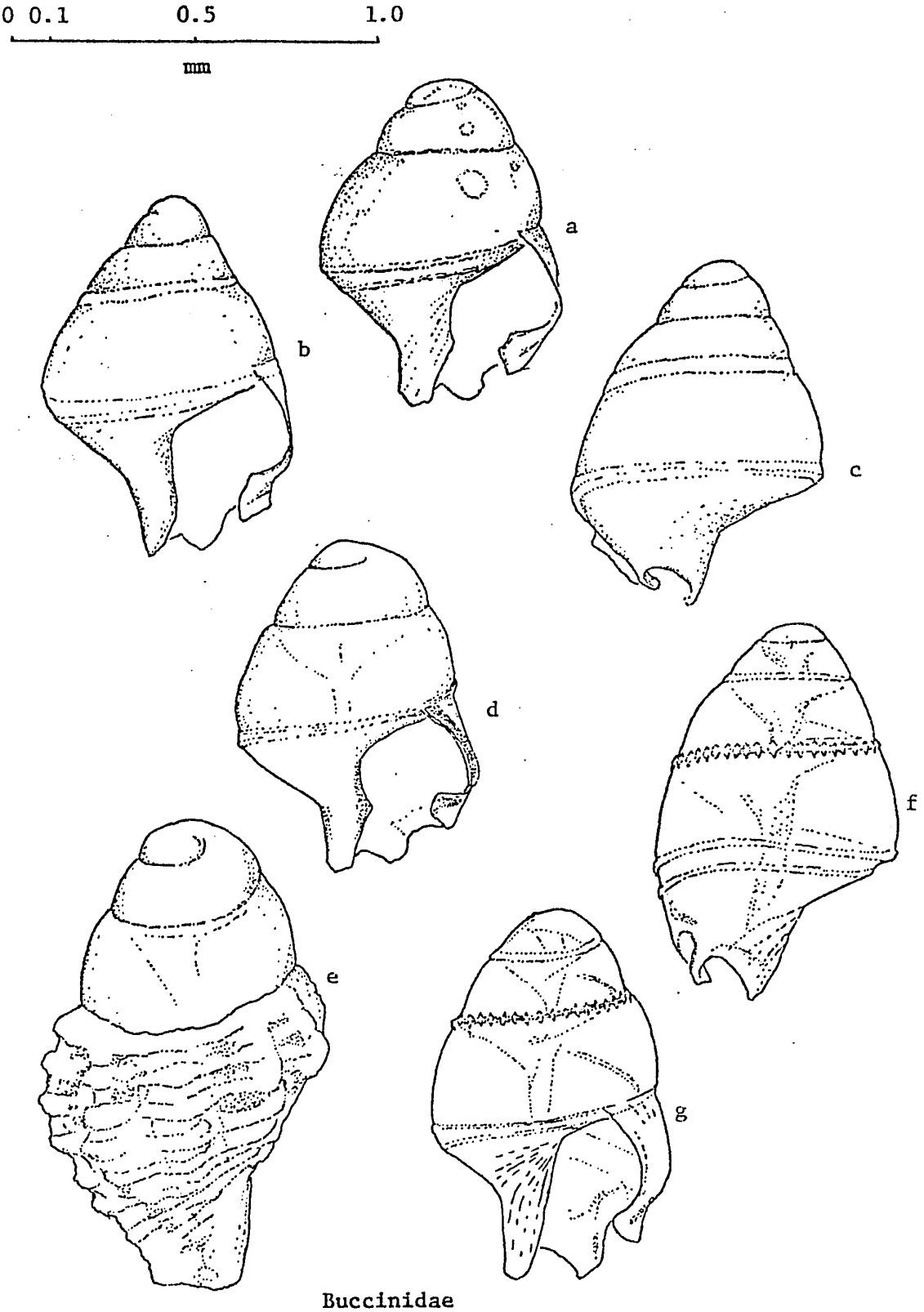
d. *Monostiolum (Caducifer) decapitatus*

e. " " "

f. *Engina albocincta*

g. " "

PLATE LXII



Buccinidae

Cantharus farinosus (Gould 1849). Plate LXIII, figs. a, b.

Veliger:

Protoconch: light tan, globose, randomly punctate; beak angular; siphonal canal truncate; metamorphosis occurs when 1 1/2 whorls complete, length: 730 µm, width: 700-730 µm.

Velum: four-lobed, unpigmented.

Cephalic area: light tan.

Foot: light tan.

Viscera: digestive gland golden; style sac gray.

Months found in plankton: March through September

Area found: Sampan Channel

Remarks:

At no time did these veligers metamorphose successfully under laboratory conditions.

Pisania (Ecmanis) ignea (Gmelin 1791). Plate LXIII, figs. c, d.

Veligers of this species (which is a synonym for P. tritonoides (Reeve 1846)) resemble those of Cantharus farinosus except that they are larger, with more finely punctate sculpture. They co-occur in time and space with veligers of C. farinosus and their animal tissues are a larger version of C. farinosus. Also, these veligers did not metamorphose in captivity.

Latirus nodatus (Gmelin 1791). Plate LXIII, figs. e-g.

Veliger:

Protoconch: rounded-conical; transparent pink-cream; sutures, columella pink-orange; metamorphosis occurs when 3 1/4 whorls complete, length: 1040 µm, width: 680 µm.

Velum: four-lobed, unpigmented.

Cephalic area: cream; oral area gray.

Foot: propodium smudged with black.

Viscera: digestive gland tan; intestine gray.

Months found in plankton: May, June.

Areas found: Sampan Channel, Dredged Island

Remarks:

The figures of L. nodatus were included in the buccinid plate in order to avoid making another plate for the sole fasciolariid which has a planktonic larval stage. Peristernia chlorostoma (Sowerby) does not have a planktonic larval stage (Taylor 1967); nothing is known of the life history of Fusinus novae-hollandiae.

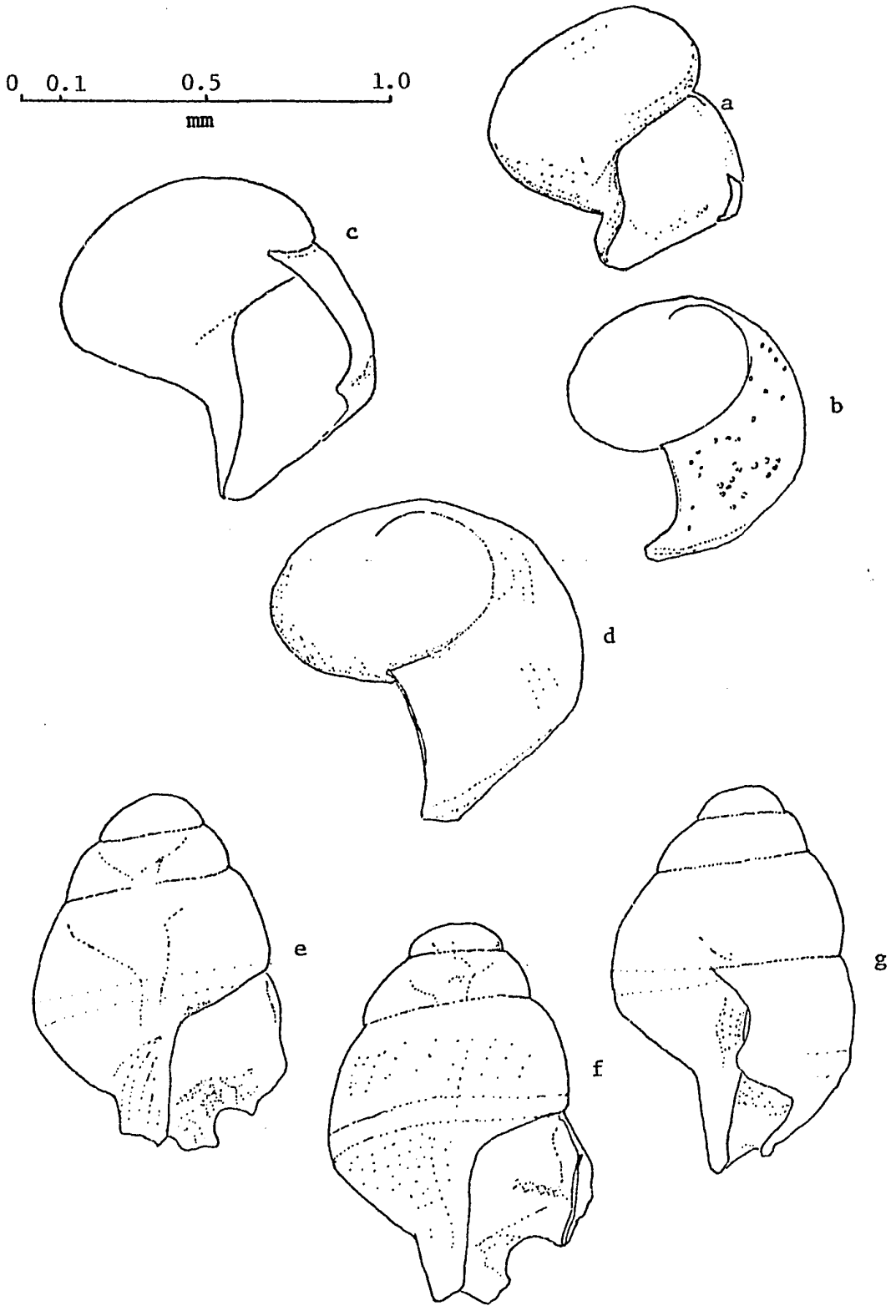
PLATE LXIII
Buccinidae, Fasciolariidae

Figures a, b. ?*Cantharus farinosus*

c, d. *Pisania ignea*

e-g. *Latirus nodatus*

PLATE LXIII



Buccinidae, Fasciolariidae

The figures of Latirus nodatus were included in the buccinid plate in order to avoid making another plate for the sole fasciolariid which has a planktonic larval stage. Peristernia chlorostoma does not have a planktonic larval stage (J. Taylor 1967); nothing is known of the life history of Fusinus novae-hollandiae.

That no fasciolariids are reported as having a planktonic larval stage should cast doubt on the certainty of the identification of this species. It should also be stressed that the larvae caught in the plankton net did not metamorphose and grow into recognizable juveniles of L. nodatus. Identification of this species arose solely on the basis of superimposition of drawings.

Because of the possibility of error, I repeated the drawings and verified that the protoconchs of the adult shells matched those obtained from the plankton. I compared the protoconchs with drawings of all of the other similar protoconchs and found that they only superimposed with those of L. nodatus (see pp. 374, 375). Reluctantly, therefore, I have identified the veliger as that of L. nodatus.

Nassariidae

Mud snails have ordinary conical shells, generally with spiral sculpture. The aperture is medium in size and exhibits a short siphonal canal. Nassarius is characterized as having a long proboscis and a foot distinguished by two 'horns' anteriorly and two 'tails' posteriorly; the operculum is tiny and perches on an expansible foot. Nassariid life history data are summarized in Table 29.

Nassariids generally have flattened, horny egg capsules which are shaped like flasks or distorted vases. No nurse eggs are reported to occur in this family and most species hatch as veligers.

In Hawaiian waters, nassariids are represented by five species of Nassarius. Veligers of only two of the five species were netted in Kaneohe Bay.

Table 2

Life History Data:

Name	Reference(s) cited
Hatch as juveniles with the ability to crawl; not planktonic	
Nassarius (*Alectrion*) *particeps*	Anderson 1965
Nassarius (*Nassa*) *suturalis* Lamarck	Risbec 1935
Veligers probably planktonic for less than one week	
Nassarius livescens	Amio 1957
Veligers planktonic for more than one week	
Ilyanassa trivittatus Say	Scheltema and Scheltema 1965
Nassarius (*Nassa*) *costata* Adams	Natarajan 1957
Nassarius incrassatus (Strøm)	Lebour 1931a, 1937; Thorson 194
Nassarius (*Nassa*) *jacksoniana* (Q and G)	Natarajan 1957
Nassarius (*Nassa*) *obsoletus* Say	Ankel 1929; Scheltema 1961
Nassarius pygmaeus Lamarck	Vestergaard 1935; Lebour 1937a; Thorson 1946; Christiansen 1964
Nassarius reticulatus (Linnaeus)	Pelseneer 1911; Ankel 1929; Lebour 1931a, 1937; Thorson 194
Nassarius (*Nassa*) *thersites* (Bruguiere)	Natarajan 1957
Nassarius vibex Say	Scheltema 1962
Tritia festivus	Amio 1957

Table 29

Life History Data: Nassariidae

ited	Month(s) spawning	Egg size (µm)	Size at hatching (µm)	Size at metamorphosis (µm)
	----	700	1000	----
	September	400	-----	-----
	----	320	----	----
Scheltema 1965	May-June, autumn	---	225	900-1100
	Jan.-March	200	300	----
1937; Thorson 1946	spring, summer	160	180-200	1500
	Dec.-May, August	150-167	233-250	----
heltema 1961	June-July	160	275	660
35; Lebour 1937a; Christiansen 1964	July	200	200	1000
; Ankel 1929; 1937; Thorson 1946	Jan.-May Mar.-August	160	280-300	720-800
	July-August	250	350	----
	June-July	160	250	745
	-----	---	---	----

Nassarius dermestina (Gould 1860). Plate LXIV, figs. a-c; Plate LXV, fig. 2.

Veliger:

Protoconch: globose, light tan, with sculpture of faint punctae, spiral zig-zag grooves; whorls inflated; metamorphosis occurs when two whorls complete, length: 780-830 µm, width: 590-610 µm.

Velum: four-lobed, unpigmented; distal sides of velar lobes expanded.

Cephalic area: esophageal area charcoal; eyes small, round.

Foot: light tan; propodium smudged with charcoal.

Viscera: digestive gland tan with charcoal areas; style sac charcoal.

Months found in plankton: all months; peak months: March-June

Areas found: Dredged Island, Sampan Channel

Nassarius ravidus (A. Adams 1851). Plate LXIV.

Synonym: Nassarius splendidulus

Veliger:

Protoconch: transparent light tan, sutural and columellar areas light red-brown; globose; sutures impressed; sculpture lacking except sutural ridge; beak well developed; siphonal canal short; metamorphosis occurs when 2 3/4 - 3 whorls complete, columellar length approximates 750 µm, width nearly 710 µm.

Velum: four-lobed; unpigmented; velar lobes elongate-oval.

Cephalic area: tentacles medium in length; eyes widely separated; esophageal area black; cephalic area dorsal to mouth cream.

Foot: light gray; propodium, mesopodial areas brushed ventrally with black; propodium cleft, mesopodium expanded laterally; metapodium tapers abruptly from mesopodium; operculum transparent.

Viscera: digestive gland cream to brown-tan; style sac tan; intestine charcoal, thin, elongate, rectangular.

Months found in plankton: August

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of this species metamorphose readily in captivity; they have been reared to lengths of 3.39 mm. Veligers of N. ravidus are much less abundant than those of N. dermestina and are apparently seasonal in their occurrence in Kaneohe Bay.

Juveniles of this species actively roam about the petri dishes. Fast growth rates are obtained when they are offered juvenile bivalves of Pinna and Crassostrea which are obtained as veligers from the plankton (see Fig. 19).

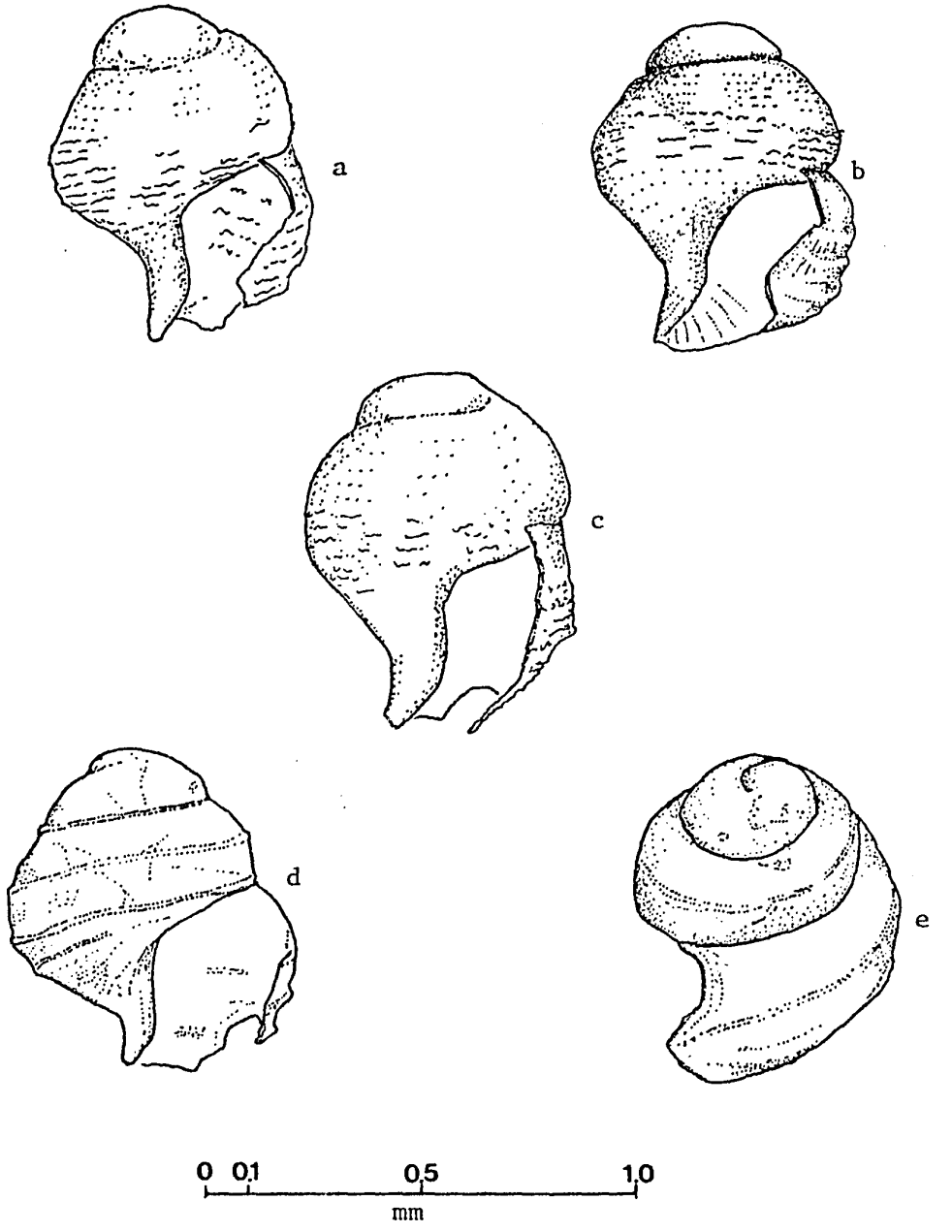
PLATE LXIV

Nassariidae: premetamorphic protoconchs.

Figures a-c. Nassarius dermestina

d-e. Nassarius ravidus

PLATE LXIV



Nassariidae

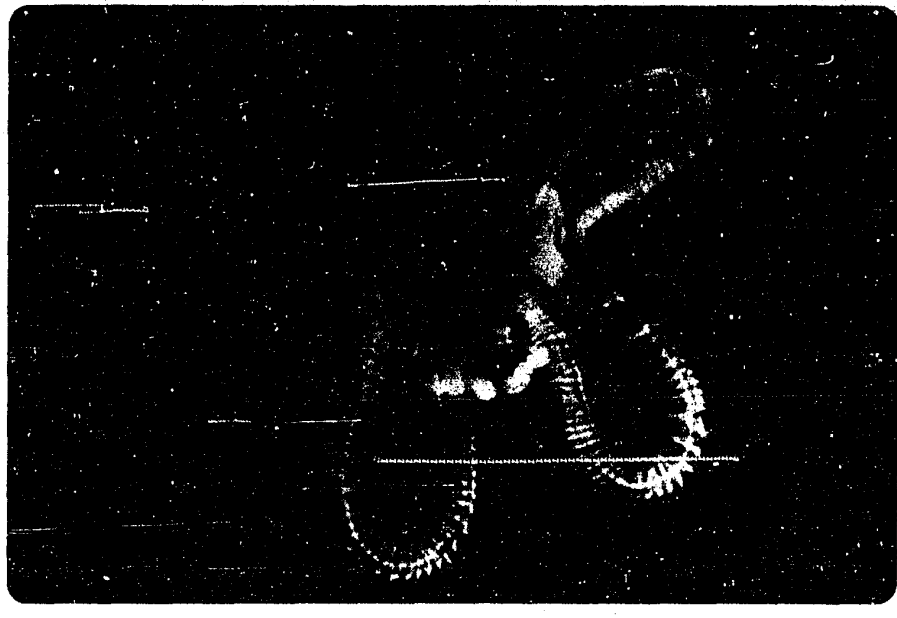
Plate LXV

Pre-settlement veligers: Nassariidae.

Figure 1 (above). Nassarius ravidus

2 (below). Nassarius dermestina

PLATE LXV
Nassariidae



1.3mm

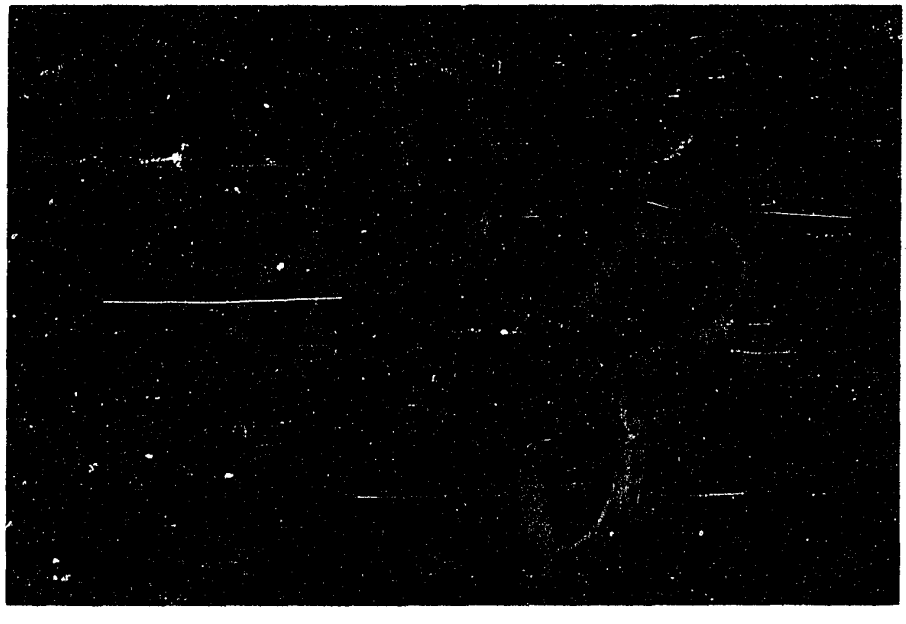


Table 30

Life History Data: Melongenidae

Genus	No. of species	References cited
Busycon	1	Lamy 1928; Perry and Schwengel 1955; Radwin and Chamberlin 1973
Hemifusus	1	Amio 1963
Melongena	1	Lamy 1928; Perry and Schwengel 1955; Hathaway and Woodburn 1961
Syrinx	1	Hedley 1900; Murray 1964

In this family, no species have been reported with planktonic larvae.

Fasciolariidae

Fasciolarids have elongate fusiform shells with moderate to long siphonal canals. The proboscis is long, the buccal glands large and the foot is short with an operculum medium in size. Data summarizing the life histories of fasciolarids and the remaining buccinacean families are presented in Table 31.

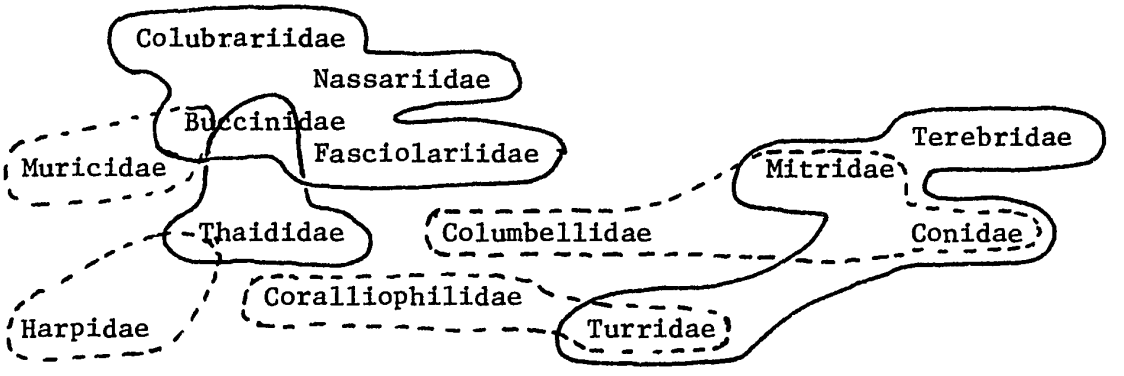
Table 31

Life History Data: Fasciolariidae

Genus	No. of species	References cited
Fasciolaria	3	Lamy 1928; D'Asaro 1970b; Radwin and Chamberlin 1973
Fusinus	2	Chace 1916; Knudsen 1950; Amio 1963
Leucozonia	2	Risbec 1931; Lewis 1960; D'Asaro 1970b
Peristernia	1	Kay 1966, pers. comm.
Pleuropoca	2	Lamy 1928; Risbec 1931
Troschelia	1	Fretter and Graham 1962

In this family, no species have been reported with planktonic larvae.

With respect to the affinities of neogastropods, no scheme has been presented which is based solely upon the appearance and behavior of veligers. I would like to present such a scheme now, --one which totally ignores the taxonomic relationships that have been carefully deduced and based upon considerations of adult anatomy, physiology, functional morphology, natural history and development.



It is interesting to compare this scheme with those of most taxonomists. It is somewhat surprising to find the harpids placed so close to the thaidids, and that coralliophilids have so much in common with thaidids. Additionally, it suggests that thaidids and muricids do not have so much in common and should not be lumped together into one family. The toxoglossan family most closely resembling rachiglossans contains the turrids; the rachiglossan family which most resembles the toxoglossan type is that of the columbellids. In general, the relationships depicted above are consistent with the Taylor and Sohl (1962) scheme.

Egg size dictates the acuteness of the apical whorl, the ultimate protoconchal shape, <u>in capsulo</u> duration and planktonic duration. Some families (Buccinidae, Columbellidae) display wide variation in the egg sizes deposited; others (Thaididae, Terebridae) exhibit little variation.

Superfamily 23. Volutacea

Volutaceans include the Olividae*, Vasidae (=Xancidae), Harpidae*, Volutidae, Cancellariidae and Marginellidae*.

Superfamily characteristics: shell with conical or low spire, less apt to develop varices than muricaceans; advanced forms tend to lack opercula; alimentary canal not as adapted for predation as in muricaceans, tend to feed on carrion in addition to living or recently-killed prey.

Cancellariids are often smooth, but sometimes with longitudinal or spiral ribbing; they are considered by Keen (1971) to be conaceans. Abbott (1954) includes the Vasidae with the Buccinacea.

No species of Cancellariidae, Volutidae or Vasidae has been reported to have planktonic larvae. Volutacean life history data are summarized in Table 32.

Olividae

Olive shells have smooth, glossy shells with low spires and elongate body whorls with long, narrow apertures notched anteriorly. They are sand dwellers and the propodium and lateral folds of the foot cover and protect the surface of the shell.

Protoconchs of museum specimens are presented in Plate LXVI; no larval forms with protoconchs resembling these have been obtained in Kaneohe Bay.

Table 32

Life History Data: Volutacea

Genus	Number of species with pelagic or direct development		References cited
Olividae			
Ancilla	---	1	Natarajan 1957
Oliva	2	---	Olsson and Crovo 1968; D'Asaro 1970
Olivella	---	4	Marcus and Marcus 1959; Paine 1962; Amio 1963
Vasidae (=Xancidae,=Turbinellidae)			
Vasum	---	1	D'Asaro 1970b
Xancus	---	2	Natarajan 1957; D'Asaro 1970b
Volutidae			
Alcithoe	---	1	Graham 1941
Cymba	---	1	Marche-Marchad 1968a
Cymbiola	---	2	Lamy 1928; Berry 1968
Melo	---	4	Hornell 1922; Cotton 1944; Allen and Middleton 1946; Tokioka 1962; Amio 1963
Voluta	---	2	Strebel 1905; Lamy 1928
Cancellariidae			
Cancellaria	---	1	Knudsen 1950
Admete	---	1	Thorson 1935
Marginellidae			

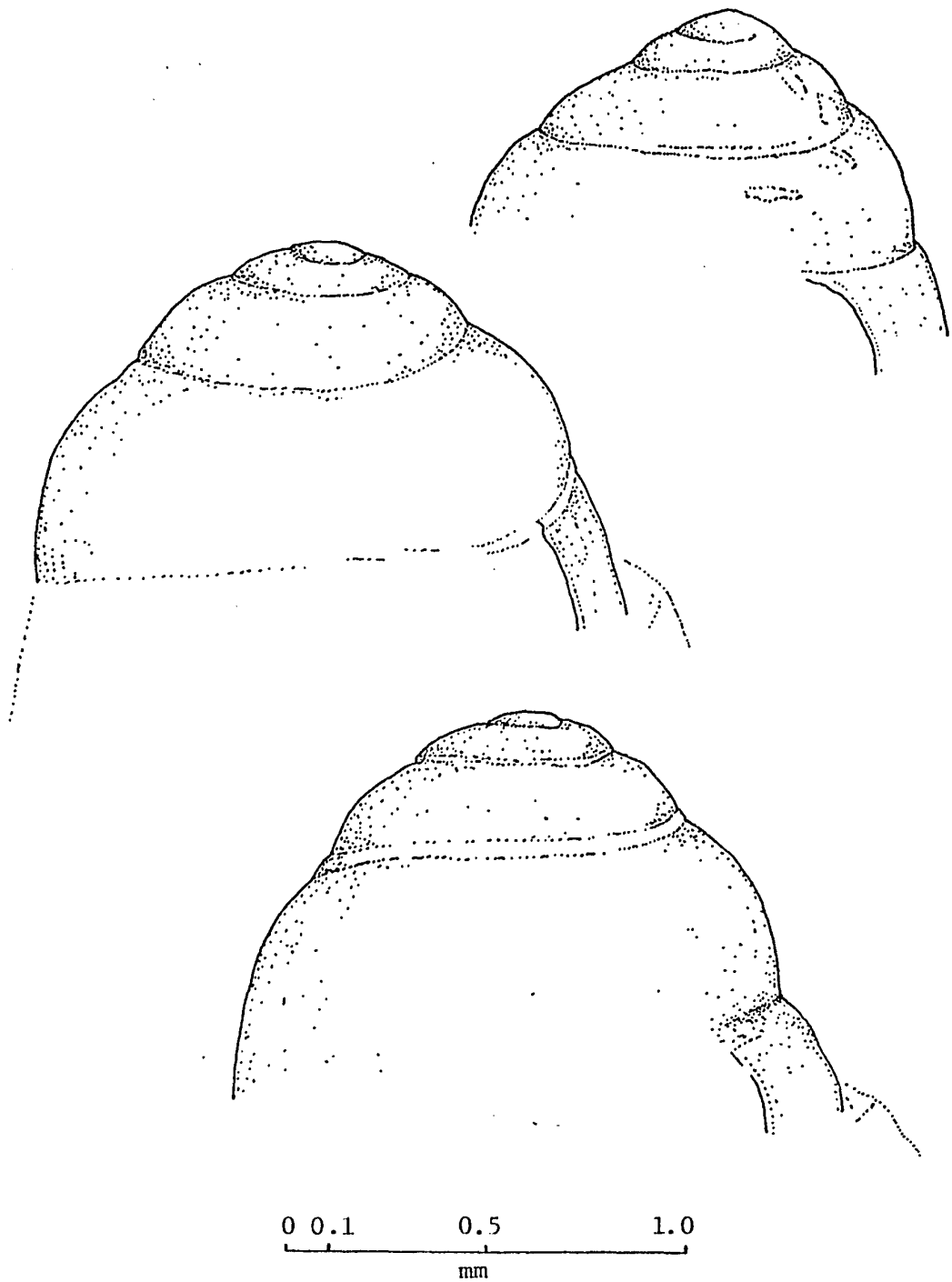
Genus	Number of species with pelagic or direct development		References cited
Olividae			
Ancilla	---	1	Natarajan 1957
Oliva	2	---	Olsson and Crovo 1968; D'Asaro 1970
Olivella	---	4	Marcus and Marcus 1959; Paine 1962; Amio 1963
Vasidae (=Xancidae,=Turbinellidae)			
Vasum	---	1	D'Asaro 1970b
Xancus	---	2	Natarajan 1957; D'Asaro 1970b
Volutidae			
Alcithoe	---	1	Graham 1941
Cymba	---	1	Marche-Marchad 1968a
Cymbiola	---	2	Lamy 1928; Berry 1968
Melo	---	4	Hornell 1922; Cotton 1944; Allen and Middleton 1946; Tokioka 1962; Amio 1963
Voluta	---	2	Strebel 1905; Lamy 1928
Cancellariidae			
Cancellaria	---	1	Knudsen 1950
Admete	---	1	Thorson 1935
Marginellidae			
Marginella	---	6	Knudsen 1950
Persicula	---	1	Knudsen 1950
Prunum	---	1	D'Asaro 1970b

Plate LXVI

Figures a, b, and c. Oliva sandwichensis: protoconchs drawn from adult shells.

PLATE LXVI

Olividae



Figures a, b, and c. Oliva sandwichensis: protoconchs drawn from adult shells.

Harpidae

Harp shells inhabit warmer waters. The adult shell has a low spire and the body whorl is almost globose with strong longitudinal ribbing. The large aperture lacks a siphonal canal. The anterior angles of the large foot are extended laterally as tentacle-like projections and the operculum is wanting. Although the adults are thought to feed on infaunal crustaceans and to inhabit bay areas (Abbott 1960), little is known of their habits.

Pre-settlement larvae of harp shells remain undescribed in the literature.

Harps are represented in Hawaiian waters by two species of the genus Harpa.

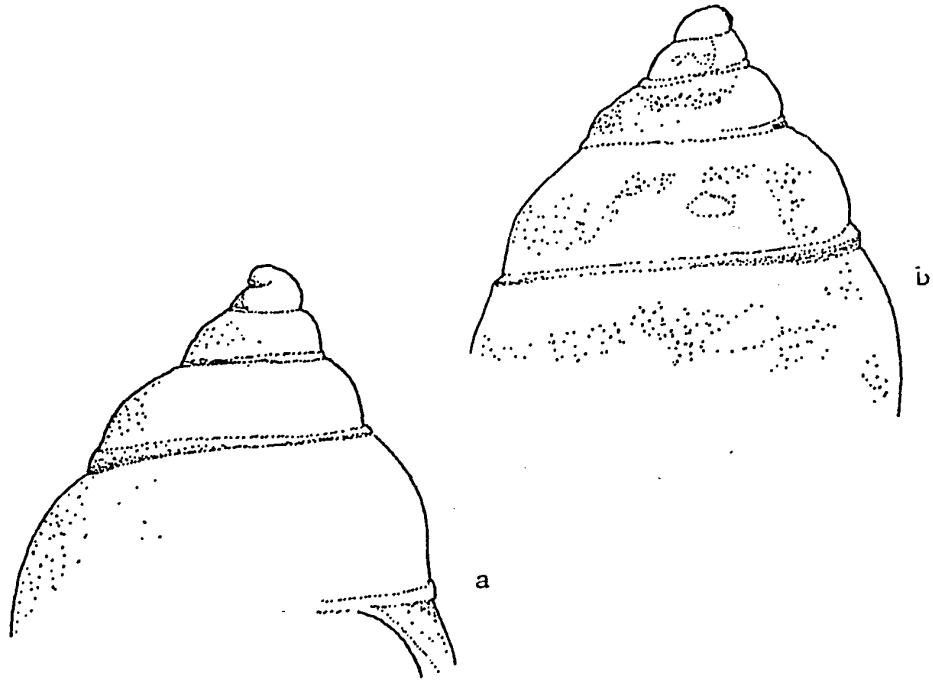
Examination of harp protoconchs (see Plate 48) allows the investigator to guess that harp larvae are pelagic, that their protoconchs are tinged with light to dark rose-pink and that a harp veliger has a foot similar to the foot of other sand-dwelling gastropods. The protoconchs are smooth and shining and their sutures are well defined. Harp shell larvae hatch when 1 1/4 - 1 1/2 light tan whorls are complete, appear to be planktonic for at least four to six weeks (assuming that their planktonic growth rates resemble those of thaidids) as they add 3 - 3 1/2 more whorls of pink-tinged protoconch. Because other neogastropod pre-metamorphic veligers have vela which are four, five or six-lobed, one may suppose that Harpa veligers have similar vela. Upon metamorphosis, the protoconch darkens.

None of these rare larvae has been collected from the plankton of Kaneohe Bay; indeed, few adult harps have been found in this area

in recent years. Kahana Bay is a more likely area in which to find these larvae; a pair of adults of Harpa major were collected during the autumn of 1968 by Dr. Joseph Branham (pers. comm.) from that area.

Plate LXVII

Figures a and b. Harpa amouretta: protoconchs drawn from adult shells.



Marginellidae

Marginellids are small, with smooth shells in which the spire is either low or sunken. The aperture is long and narrow and bears columellar folds. Marginellids are believed to be non-selective carnivores and scavengers which feed principally upon bivalves and crustaceans.

In Hawaiian waters there are five species of marginellids. Protoconchs of Volvarina have blunt, domed apices with no planktonic protoconchs, while those of Granula are conical and suggest a possible planktonic history.

In the Kaneohe Bay plankton, larvae with protoconchs which resemble in size, shape and color the protoconchs of Granula sandwichensis are common. For the purpose of this dissertation these larvae (see Plate XVIII, figs. o,p) could be tentatively identified as those of Granula; however, these larvae have never been reared to a size sufficient to permit identification. If, in fact, these larvae are those of Granula, they are the first marginellid larvae reported as being planktonic.

Superfamily 24. Mitracea

Mitraceans include the lone 'family' Mitridae* (see note 25, p. 16, Taylor and Sohl 1962). It seems well-advised to classify these animals by themselves until mitrid systematics are less in dispute and until their affinities with other groups are better defined.

Superfamily characteristics: shell conical to fusiform; aperture somewhat narrowed, widely open anteriorly, siphonal canal ill-defined, columella plicate; operculum lacking; radula rachiglossate, predatory on worms and mollusks; principally Indo-Pacific.

Mitridae

There are few accounts of mitrid life histories. Mitra nodulosa, a Florida species, breeds in July and has planktonic veligers (D'Asaro 1970). On the basis of size, Knudsen (1950) guesses that "egg capsule B", produced by a South African miter which breeds in December, has non-pelagic development. Spawning, developmental procedure and egg capsules of miters are described or figured by Knudsen (1950), Ostergaard (1950), Cernohorsky (1965), J. Cate (1968) and Wolfson (1969). There are no descriptions of pre-settlement larvae identified as miters, although Cernohorsky (1970) provides figures of protoconchs on adult shells. Data which summarize mitrid life histories are presented in Table 33.

Table 33

Life History Data: Mitridae

	Mitra astricta	*Mitra auriculoides*	*Strigatella nodulosa*	*Atrimitra* sp.
egg size	140 µm	?	120 µm	?
duration: spawning to hatching	14 days	at least 7, and probably 10-14 days	?	?
size at hatching	220 µm	250 µm	?	?
estimated planktonic duration	hatch as pre-settlement veligers; short?	hatch as pre-settlement veligers; probably short?	?	?
descriptive remarks:	velum bilobed at hatching, with double line of purple-pink around borders; breed in October in Hawaii; protoconch colorless, granulated, distal half with granular spiral ridges; did not metamorphose successfully in laboratory	velum with marginal greenish-brown bands; foot also with greenish brown; breed in December in Hawaii; did not metamorphose successfully in laboratory	has a planktonic veliger stage	has a planktonic veliger stage
references:	Ostergaard 1950	Ostergaard 1950	D'Asaro 1970b	Chess and Rosenthal 1971

Vexillum (Pusia) lautum Reeve 1845. Plate LXVIII, fig. a;
Plate LXX, fig. 1.

Veliger:

Protoconch: barrel-shaped, apex rounded; background light yellow; sutures red-brown, barely impressed; columella red-brown with 2-3 columellar plaits; aperture ovate; metamorphosis occurs when three whorls complete, length: 870 µm, width: 470 µm.

Velum: four-lobed, unpigmented.

Cephalic area: light gold.

Foot: simple, narrow, light gold.

Months found in plankton: September through November

Areas found: Sampan Channel, Dredged Island

Remarks:

Upon metamorphosis, the protoconch becomes opaque brown. Adults of V. lautum are among the most commonly-collected miters in Hawaii.

Strigatella (Swainsonia) newcombii Pease 1896. Plate LXVIII, fig. b.

Veliger:

Protoconch: colorless; sutures barely impressed; metamorphosis occurs when three whorls complete, length: 900 µm, width: 520 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: narrow, cream, with metapodial extension.

Viscera: digestive gland golden.

Months found in plankton: May through August

Areas found: Sampan Channel

Remarks:

Upon metamorphosis, the protoconch becomes cream to light tan.

Mitrid sp.$_1$ Not figured.

Veliger:

Protoconch: fusiform; smooth except for suprasutural band on 2nd to 5th whorls, columellar striation and approximately ten denticles on interior of outer lip; apex rounded-acuminate; sutures slightly impressed; beak broadly angular; siphonal canal short, medium-wide; metamorphoses when columellar length approximates 1420 µm, width nearly 720 µm.

Velum: four-lobed; base of pre-oral cilia brown-black.

Cephalic area: tentacles slender, swollen at bases; eyes inside bases.

Viscera: digestive gland golden; style sac golden; intestine charcoal gray, fecal pellets discrete in some, closely-packed in others; mantle with circular golden spots sparsely distributed.

Foot: propodium blunt, rectangular; metapodium tapers; ventrum of foot lightly brushed with charcoal.

Months found in plankton: March

Areas found: Sampan Channel

Remarks: Veligers of this species hatch when 1 1/2 whorls are complete, spend a relatively long time in the plankton and metamorphose when 4 1/2 - 5 whorls are complete. The columellar length approximates 1355 µm and the width is nearly 675 µm.

Vexillum (Pusia) tusum Reeve 1845. Plate LXVIII, figs. e, i.

Veliger:

Protoconch: background light gold; peg-like: sutures red-brown, barely impressed; columella with three plaits, red-brown; siphonal canal truncate; metamorphosis occurs when 3 3/4 to 4 whorls complete, length: 960 µm, width: 550 µm.

Velum: four-lobed; distal areas of velar lobes with khaki pigment.

Cephalic area: light tan; oral area triangular, charcoal.

Foot: light gold; smudged lightly with charcoal.

Viscera: digestive gland golden; intestine khaki-brown.

Months found in plankton: August (peak abundance); occur sporadically throughout year

Areas found: Sampan Channel, Dredged Island

Remarks:

Veligers of this species are the most commonly-collected mitrid larvae in Kaneohe Bay. Upon metamorphosis, the apical whorl becomes opaque cream; the remaining whorls are opaque gray-brown.

Vexillum (Costellaria) bellum Pease 1860. Plate LXVIII, fig. f.

Veliger:

Protoconch: transparent light tan; peg-like; sutures tan, barely impressed; columella with two plaits; metamorphosis occurs when 2 2/3 - 3 whorls present, length: 800 µm, width: 440 µm.

Velum: four-lobed, unpigmented.

Foot: light tan with pink tinges; shaped like a narrow, attenuate shield.

Viscera: digestive gland light gold.

Months found in plankton: August

Areas found: Sampan Channel

Mitra (Strigatella) ?auriculoides Reeve 1845. Plate LXVIII, fig. g.

Veliger:

Protoconch: reddish-tan, transparent; rounded-conical; sutures barely impressed; columella with two plaits; beak, columella tinged with red-brown; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 1040 µm, width: 550 µm.

Velum: four-lobed; base of post-oral cilia suffused with red-orange.

Cephalic area: light tan; oral area light gray.

Foot: tan, narrow.

Viscera: digestive gland dark tan.

Months found in plankton: August, October, March through May

Areas found: Sampan Channel

Remarks:

In the laboratory, the juveniles feed on small mollusks: Styliferina, Rissoella. The adults are common in shallow water. Upon metamorphosis, the protoconch becomes rich red-brown.

Vexillum (Costellaria) interruptum Anton 1839. Plate LXVIII, fig. h.

Synonym: V. cimelium

Veliger:

Protoconch: suffused with pink; sutures dark pink; metamorphosis occurs when 3 1/4 - 3 1/2 whorls complete, length: 900 µm, width: 490 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented; eyes small, inside tentacular bases.

Foot: cream tinted with light pink, narrow.

Viscera: digestive gland light gold.

Months found in plankton: March through July

Areas found: Sampan Channel, Dredged Island

Mitra (Strigatella) litterata (Lamarck 1811). Plate LXVIII, fig. j.

Veliger:

Protoconch: transparent yellow-tan; smooth; beak poorly developed; siphonal canal relatively short; metamorphoses when four whorls complete, columellar length approximates 990 µm, width nearly 530 µm.

Velum: four-lobed, unpigmented.

Cephalic area: tentacles short, slender; eyes medium, rather close together inside bases of tentacles.

Foot: propodium blunt, rectangular; metapodium tapers; background colorless; foot brushed dorsally and ventrally with black.

Viscera: intestine dark brown; other organs colorless.

Months found in plankton: January, October, November, December.

Areas found: Dredged Island

Remarks:

Vexillum (Costellaria) ?interstriatum Sowerby 1870. Plate LXVIII, fig. k.

Veliger:

Protoconch: background colorless; sutures orange-pink, barely impressed; columella with two plaits; metamorphosis occurs when 2 1/2 - 2 2/3 whorls complete length: 690 µm, width: 450 µm.

Velum: four-lobed, unpigmented.

Cephalic area: colorless.

Foot: cream.

Viscera: digestive gland tan.

Months found in plankton: August

Area found: Sampan Channel

Remarks:

Veligers of this species are uncommonly collected from the Kaneohe Bay plankton.

Mitrid sp.$_2$ Not figured.

Veliger:

Protoconch: colorless; smooth except for suprasutural band, columellar striations and denticles on interior of outer lip; length twice width; apex rounded-acuminate; sutures slightly impressed; beak broadly angular; siphonal canal attenuate; metamorphosis occurs when columellar length approximates 1420 µm, width nearly 710 µm.

Velum: four-lobed; food groove with long patches and circular spots of gold; veliger's right ventral lobe shorter than other lobes; velar lobes elongate, sides parallel; velar height, 2640 µm; velar width, 3300 - 4620 µm.

Cephalic area: tentacles medium in length; eyes round, inside tentacles approximately one-third tentacle's length from base; esophagus light charcoal.

Viscera: digestive gland golden; style sac, intestine charcoal gray; ctenidium conspicuous.

Foot: background light golden, ventrum and anterior end brushed with charcoal; operculum transparent.

Months found in plankton: March

Areas found: Sampan Channel

Remarks: Veligers of this species metamorphose when 3 1/4 - 3 1/2 whorls are complete.

PLATE LXVIII

Mitridae: presettlement protoconchs.

Figure a. Vexillum lautum

b. Strigatella newcombii

c. Mitrid sp.$_1$

d. " "

e. Vexillum tusum

f. Vexillum bellum

g. Mitra ?auriculoides

h. Vexillum interruptum

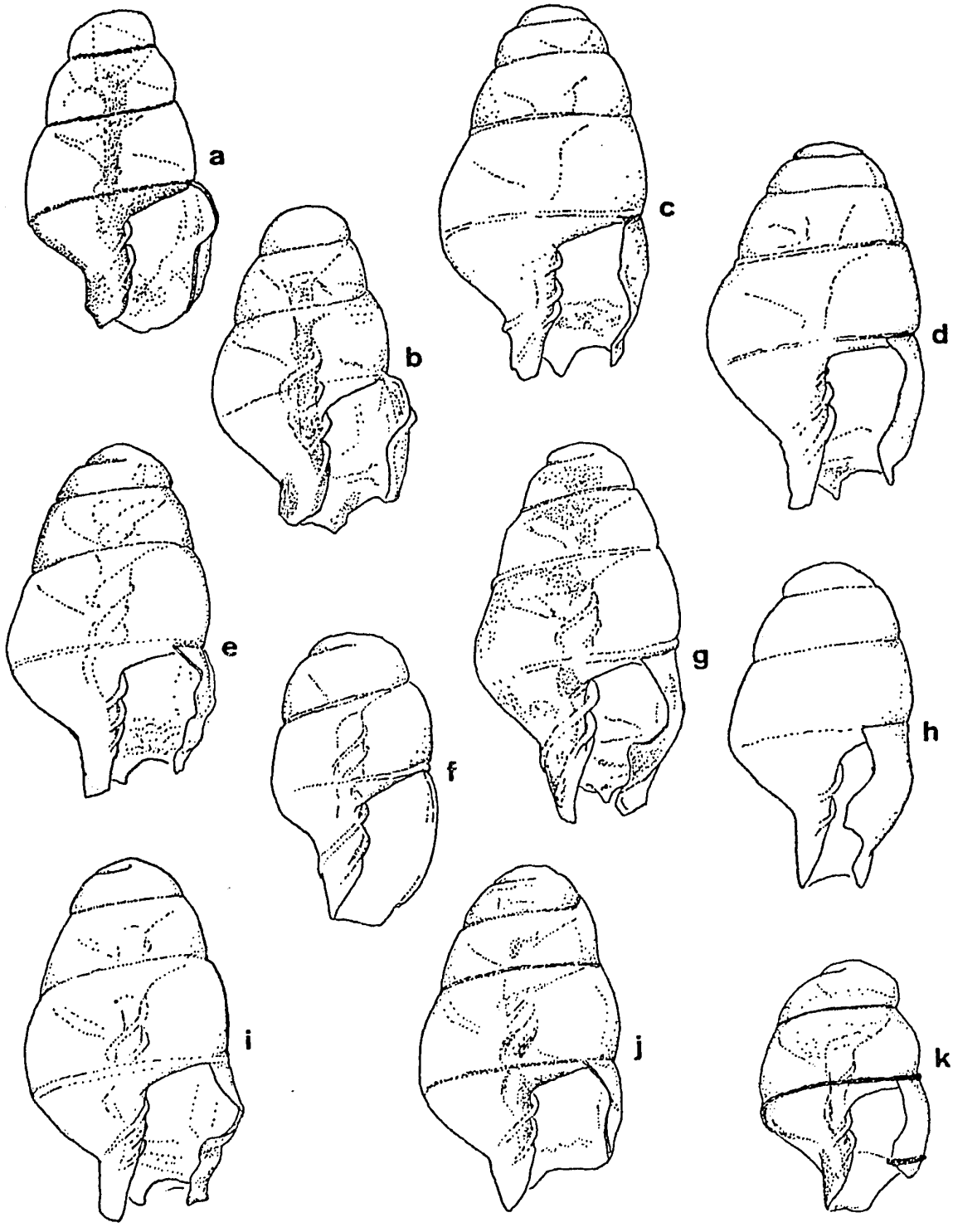
i. Vexillum tusum

j. Strigatella litterata

k. Vexillum interstriatum

PLATE LXVIII

Mitridae



Mitra (Nebularia) tabanula Lamarck 1811. Plate LXIX, fig. a.

Veliger:

Protoconch: colorless; rounded-conical; sutures barely impressed; columella with two plaits; beak angular; metamorphosis occurs when 3 1/4 whorls complete, length: 1000 µm, width: 510 µm.

Velum: four-lobed, unpigmented.

Cephalic area: cream.

Foot: light tan.

Viscera: digestive gland light gold.

Months found in plankton: March through September

Area found: Sampan Channel

Remarks:

Upon metamorphosis, the protoconch becomes darker tan. Veligers of this species are abundant in the Sampan Channel plankton during the spring and summer months.

Mitra ?mitra Linnaeus 1758. Plate LXIX, fig. b.

Veliger:

Protoconch: colorless; rounded-conical; sutures medium red-brown; columella with two plaits; metamorphosis occurs when 3 1/4 - 3 1/2 whorls complete, length: 1000 µm, width: 490 µm.

Velum: four-lobed; base of post-oral cilia suffused with red-brown.

Cephalic area: unpigmented.

Foot: cream.

Viscera: digestive gland tan.

Months found in plankton: March

Area found: Sampan Channel

Subcancilla interlirata Reeve 1844. Plate LXIX, fig. c.

Veliger:

Protoconch: fusiform; background colorless, subsutural bands ochre; sculpture of punctae; beak poorly developed; siphonal canal short, narrow; columella dark golden-yellow; metamorphosis occurs when four whorls complete, columellar length approximates 1060 μm, width 500 μm.

Velum: four-lobed; velar lobes elongate, blunt; base of post-oral cilia golden; cilia long; effective swimmer.

Cephalic area: tentacles thick at bases, medium-short, blunt with 'bristles' at distal tips; eyes large, inside bases of tentacles, close together.

Foot: propodium blunt, rectangular; metapodium tapers; operculum inconspicuous; ventrum tinged with brown.

Viscera: digestive gland golden; intestine with discrete round fecal pellets; edges of mantle, ctenidium conspicuous.

Months found in plankton: January

Areas found: Dredged Island

Remarks:

Veligers of this species are uncommonly collected from the Kaneohe Bay plankton.

Imbricaria olivaeformis Swainson 1821. Plate LXIX, fig. d.

Veliger:

Protoconch: fusiform; transparent, suffused with tinges of red-purple; sutures barely impressed; columella with two plaits; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 1040 µm, width: 510 µm.

Velum: four-lobed, unpigmented.

Cephalic area: light yellow.

Foot: lemon yellow.

Viscera: digestive gland tan.

Months found in plankton: May through August

Area found: Sampan Channel

Remarks:

Veligers of this species are not commonly encountered in the Kaneohe Bay plankton. Upon metamorphosis, the third and fourth protoconchal whorls become dark indigo-blue; the apical two whorls become slate gray.

Strigatella typha Reeve 1845. Plate LXIX, fig. e.

Veliger:

Protoconch: fusiform; transparent light gold; sculpture lacking; sutures caramel-orange; beak broadly angular; siphonal canal short, medium in width; metamorphoses when 4 1/2 - 5 whorls complete, columellar length approximates 1056 µm, width nearly 595 µm.

Velum: four-lobed, unpigmented.

Cephalic area: tentacles medium in length, slim, close together; eyes inside bases of tentacles; esophageal region charcoal.

Foot: light gold; propodium blunt, rectangular; metapodium tapers.

Viscera: digestive gland golden brown; style sac golden; intestine charcoal.

Months found in plankton: March

Areas found: Sampan Channel

Remarks: Veligers of this species ingest the velum during metamorphosis.

Vexillum (Pusia) ?piceum Pease 1860. Plate LXIX, fig. f.

Veliger:

Protoconch: fusiform, light tan; sutures red-brown, barely impressed; siphonal canal truncate; columella with one plait; metamorphosis occurs when five whorls complete, length: 1550-1600 µm, width: 750 µm.

Velum: four-lobed; base of post-oral cilia suffused with orange.

Cephalic area: tan.

Foot: tan.

Viscera: digestive gland brown.

Months found in plankton: September, October

Area found: Sampan Channel

Remarks:

Upon metamorphosis, the protoconch becomes dark red-brown.

Cancilla (Domiporta) granatina (Lamarck 1811). Plate LXIX, fig. g.

Veliger:

Protoconch: fusiform; clear cream; sculpture lacking; suprasutural line rather than band present; interior of outer lip denticulate; beak broadly angular; siphonal canal short; metamorphosis occurs when 4 1/2 - 5 whorls complete, columellar length approximates 1420 μm, width: nearly 625 μm.

Velum: four-lobed; velar lobes elongate, slim with parallel sides.

Cephalic area: tentacles short, slim; eyes close together; esophageal region unpigmented.

Foot: propodium blunt, rectangular; metapodium tapers, light yellow.

Viscera: digestive gland light yellow; style sac clear; intestine light yellow.

Months found in plankton: March

Areas found: Sampan Channel

Remarks: Veligers of this species were observed ingesting the velum during metamorphosis. Upon metamorphosis, the protoconch becomes pink.

Neocancilla waikikiensis Pilsbry 1921. Plate LXIX, fig. h.

Veliger:

Protoconch: suffused with rich red-brown; conical; columella with three plaits; siphonal canal truncate; metamorphosis occurs when 5 - 5 1/4 whorls complete, length: 1500-1550 µm, width: 720 µm.

Velum: four-lobed; base of post-oral cilia suffused with orange.

Cephalic area: light tan.

Foot: light tan.

Viscera: digestive gland brown.

Month found in plankton: February

Area found: Sampan Channel

Plate LXIX

Pre-settlement protoconchs: Mitridae

Figure a. *Mitra tabanula*

b. *Mitra ?mitra*

c. *Subcancilla interlirata*

d. *Imbricaria olivaeformis*

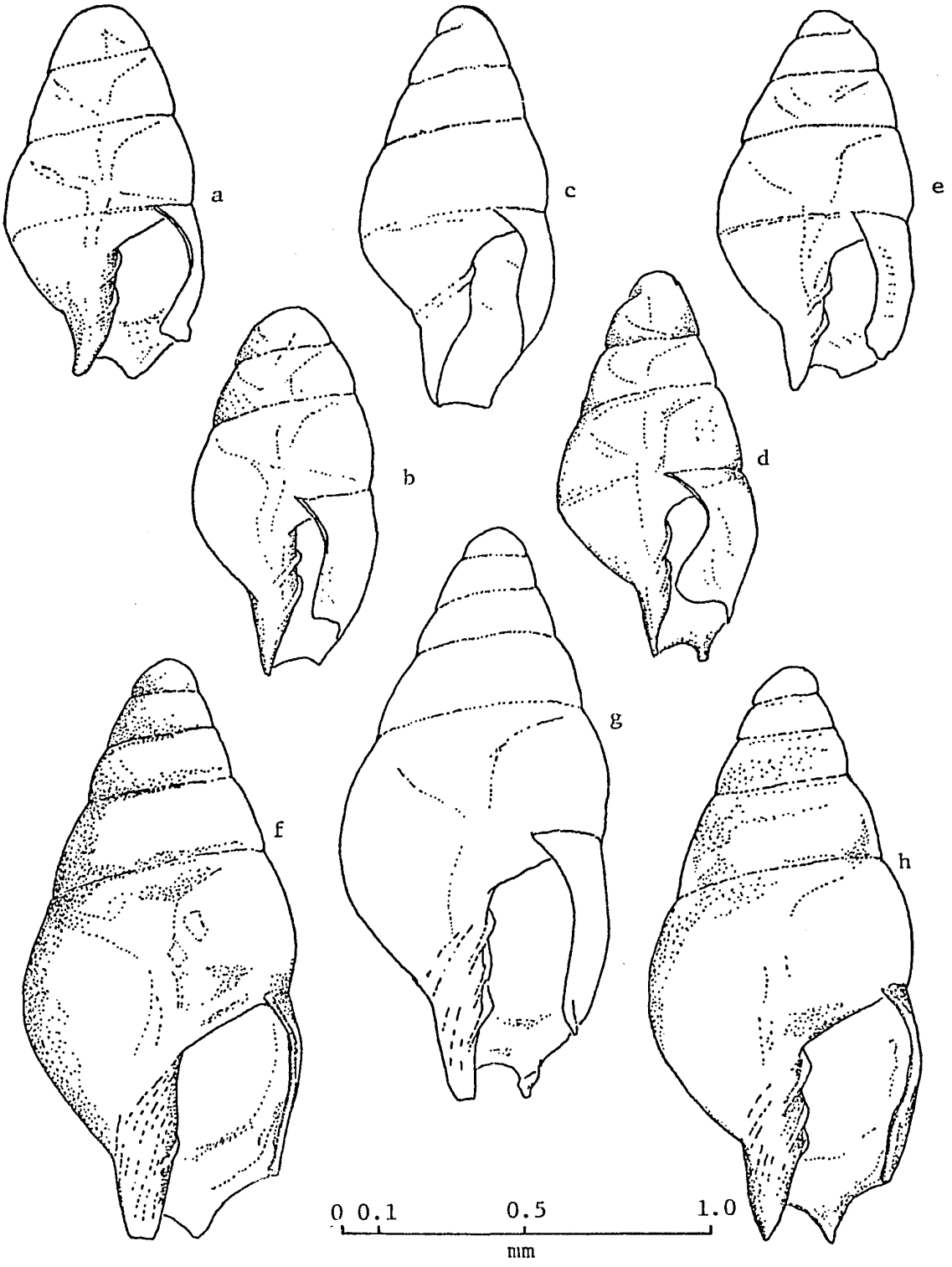
e. *Strigatella typha*

f. *Vexillum ?piceum*

g. *Cancilla granatina*

h. *Neocancilla waikikiensis*

PLATE LXIX



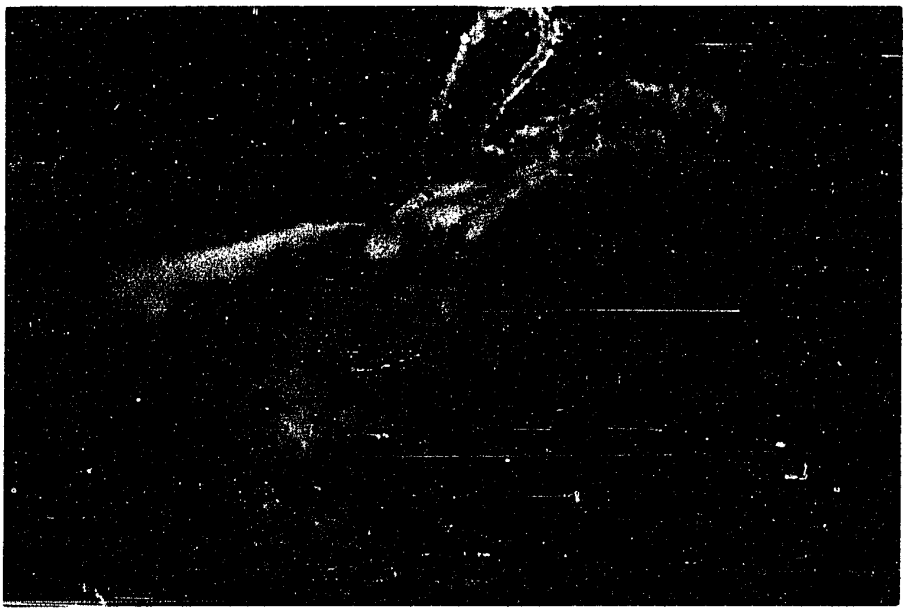
Mitridae

PLATE LXX

Mitridae

1.3mm

Figure 1 (above). Mitrid sp.$_1$.
2 (below). Unidentified.



Superfamily 25. Conacea

Conaceans include the Turridae*, Conidae* and Terebridae*.

Superfamily characteristics: shell conical, turriform or fusiform; aperture with (Turridae) or without (Conidae, Terebridae) a sutural notch; carnivorous; proboscis long; radula altered; generally in tropical or subtropical seas.

Turridae

Turrids comprise a large family (500 genera and subgenera) with many taxonomic problems. Turrid shells are turriform and conical; a posterior notch or indentation on the outer lip of the aperture is one of several features which distinguish members of this family from other gastropods. Most turrid species inhabit regions of warmer waters and with rachiglossan radulae feed primarily on polychaetes. Zygotes are deposited in lenticular egg capsules from which veligers (often elaborately sculptured) or juveniles escape.

Data regarding larval stages are presented in Table 34. All of Lebour's publications except the 1945 paper concern veligers found in English coastal waters near Plymouth; the exception deals with planktonic veligers of Bermuda. Thorson studied gastropod young in the waters of east Greenland (1935), in the Iranian Gulf (1940) and in Danish coastal areas (1946). Vestergaard's work (1935) also concerned veligers in Danish waters. Knudsen (1950) reported on the life histories of gastropods in South African coastal areas. Pacific turrid larvae remain to be described.

Of the 24 species of turrids described to date, half are known to have a planktonic phase (Lebour 1934, 1936, 1937 and 1945; Thorson 1940,

1946), seven are reported to be completely benthic (Thorson 1935) and the remainder of larval stages either have not been seen in the plankton or the presence or absence of planktonic larval stages has been conjecture based upon protoconch structure.

At least 46 species of turrids are reported from Hawaii (Kay, unpubl.); none of their life histories has been reported previously.

Table 34

Life History Data: Turridae

Name	Reference(s) Lebour	Thorson
Hatch as juveniles with the ability to crawl:		
Bela bicarinata (Couth.)		1935
Bela exarata (Møller)		1935
Bela nobilis Møller (=rugulata Troschel)		1935
Bela pyramidalis Strøm		1935
Bela simplex (Midd.)		1935
Clavatula diadema Kiener	Knudsen 1950	
Drillia sp.	Knudsen 1950	
With planktonic veligers:		
Bela trevelyana Turton		1946
Drillia (Pleurotoma) crenularis Lamarck		1940
Lora sp.	1936	
Lora (Bela) turricola (Montagu)	Vestergaard 1935	
Haedropleura septangularis (Montagu)?	1934b,'36	
Mangelia attenuata (Montagu)		1946
Mangelia brachystoma (Philippi)		1946
Mangelia coarctata (Forbes)?	1936,'37	
Mangelia nebula (Montagu)	1934b	
Mangelia sp.	1945	
Veliger F	1945	
Philbertia asperrima (Brown)	1934b	
Philbertia gracilis (Montagu)	1933c,'34b, 1937a	
Philbertia leufroyi (Smith)	1934b	
Philbertia linearis (Montagu)	1934b,'37a	
Philbertia purpurea (Montagu)	1934b	
Philbertia teres (Reeve)	1934b	

Gemmula monilifera (Pease 1860). Plate LXXI, fig. c.

Veliger:

Protoconch: fusiform except for ovate aperture; apical whorls smooth; fifth and sixth whorls with axial ribs extending entire length of whorl; protoconch deep golden-brown; beak, siphonal canal abbreviated; metamorphosis occurs when 5 - 6 whorls complete.

Velum: four-lobed; unpigmented; velar lobes elongate with parallel sides.

Cephalic area: unpigmented.

Foot: unpigmented; anterolateral edges produced.

Viscera: difficult to discern through protoconch.

Months found in plankton: March, May, August

Areas found: Sampan Channel

Remarks: This is one of the largest turrid veligers in Kaneohe Bay.

Xenoturris kingae Powell 1964. Plate LXXI, fig. b.

Veliger:

Protoconch: fusiform, apex blunt; apical whorls lightly punctate; third, fourth whorls with arcuate axial ribs; protoconch deep red-brown; siphonal canal medium-long; metamorphosis occurs when four whorls complete, length: 1650 µm, width: 830 µm.

Velum: four-lobed; unpigmented.

Cephalic area: unpigmented.

Foot: unpigmented; anterolateral edges produced.

Viscera: cannot be discerned through protoconch.

Months found in plankton: September, October

Areas found: Sampan Channel

Remarks:

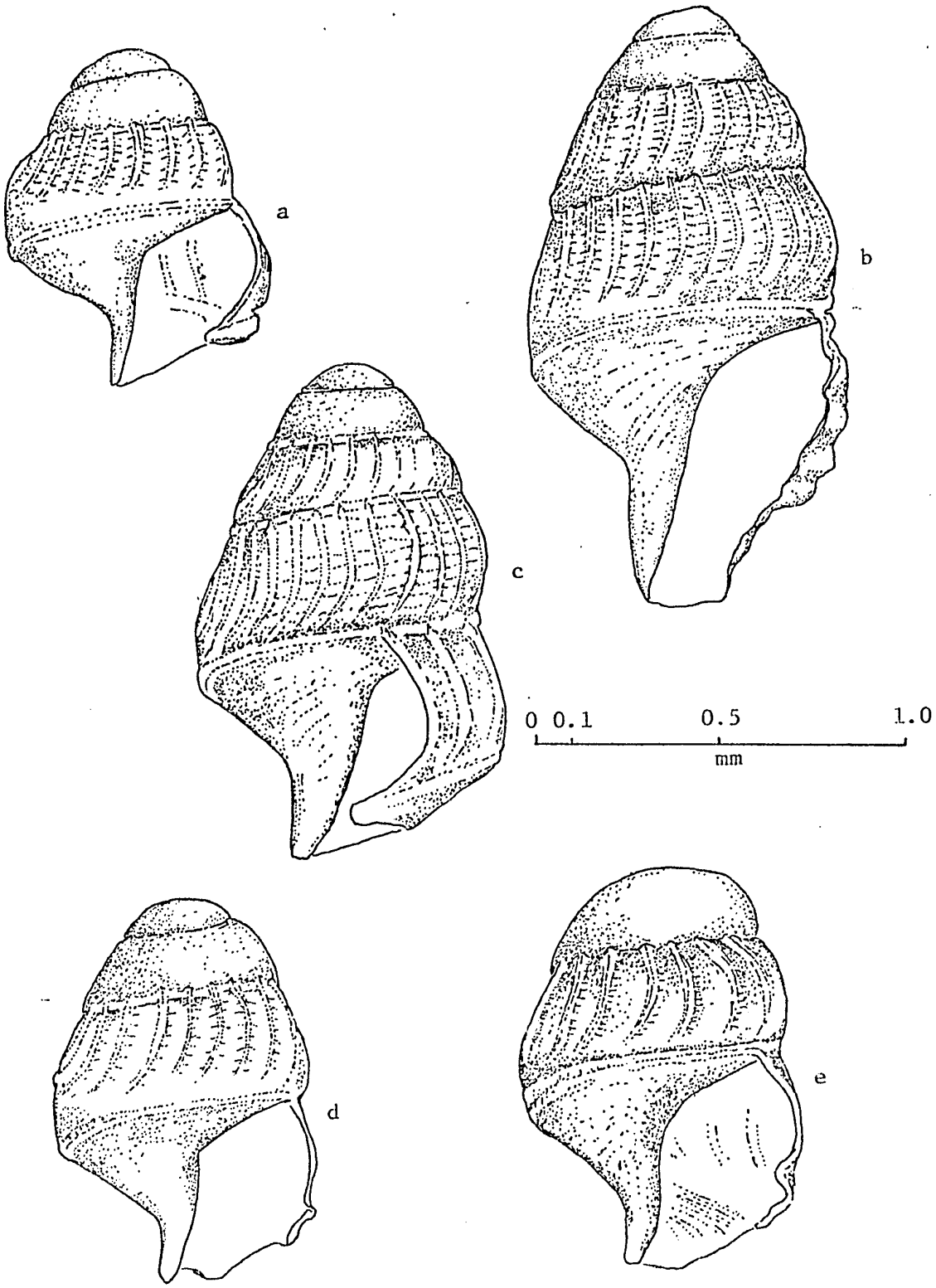
This is the most commonly-collected veliger of the Borsoniinae.

PLATE LXXI

Turridae: pre-settlement protoconchs.

Figure a. Turridrupa albofasciata, apertural view.
b. Xenoturris kingae, apertural view.
c. Gemmula monilifera, apertural view.
d. Turridrupa bijubata, apertural view.
e. Turridrupa weaveri, apertural view.

PLATE LXXI



Turridae.

Microdaphne sp. Plate LXXII, figs. a-c.

Veliger:

Protoconch: golden; conical, turreted; first 1 1/2 whorls with approximately ten rows of parallel punctae; peripheral areas of remaining whorls with conspicuous golden bosses; beak, siphonal canal present; metamorphosis occurs when 3 1/2 - 4 whorls complete.

Velum: four-lobed; unpigmented; velar lobes pyriform, diaphanous, not recurved far back over protoconch.

Cephalic area: tentacles medium-long, slender; eyes inside swollen tentacular bases; esophageal region unpigmented.

Foot: cream in veliger, white in juvenile; propodium moderately cleft; mesopodium undistinguished; metapodium tapered.

Viscera: digestive gland golden-brown.

Months found in plankton: February, May, August

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of this species metamorphose easily in captivity, but the author was unsuccessful in determining their food preference.

Carinapex minutissimus (Garrett 1873). Plate LXXII, figs. d-e.

Veliger:

Protoconch: stout, ovately conic; apical 1 1/4 whorls clear, sculpture lacking; 2nd, 3rd and 4th whorls red-brown, sculpture of beaded spiral keels, subsutural abbreviated axial ribs; axial ribs on 3rd and 4th whorls; two spiral keels plus one presumptive suture on 4th whorl; lower half of last whorl with pattern of axial threads perpendicularly crossing a strong sutural keel; beak, siphonal canal present, beak three-keeled if four whorls present on protoconch; siphonal canal broad, short; metamorphosis occurs when four whorls complete.

Velum: unpigmented; four-lobed; velar width, 2100 µm; height, 1400 µm; velar lobes slightly expand distally.

Cephalic area: tentacles medium-long, lumpy, blunt; eyes tiny, widely separated; oral region unpigmented.

Foot: unpigmented; propodium short, square; meso- and metapodium with cordate form; metapodium tapered.

Viscera: not visible through protoconch.

Months found in plankton: all months, especially March, April.

Areas found: Sampan Channel, Dredged Island.

Remarks: Veligers of this species are among the most abundant turrid veligers in the Kaneohe Bay plankton. Although they metamorphose easily under culture conditions, they will not grow much beyond their size at metamorphosis (length: 825 µm; width: 560 µm); this observation suggests that they may be food specialists.

Lienardia mighelsi Iredale and Tomlin 1917 Plate LXXII, figs. f-h.

Synonym: Pleurotoma rugosa Mighels

Veliger:

Protoconch: clear, light yellow; sculpture confined to crenulated beaded sutures, spiral keels; sculpture dark red-brown; beak, siphonal canal present; metamorphosis occurs when 3 - 3 1/2 whorls complete.

Velum: four-lobed; velar lobes with bright yellow-green circular spots in food groove and distal regions; base of post-oral cilia with thin line of purple-black.

Cephalic area: tentacles medium-long; eyes small, inside lateral bases of tentacles; oral region unpigmented.

Foot: colorless, opaque; propodium blunt; meso- and metapodium undistinguished; operculum transparent, unpigmented.

Viscera: digestive gland yellow-green.

Months found in plankton: March, April, May, August

Areas found: Sampan Channel, Dredged Island

Remarks: Metamorphosis occurs when the columellar length approximates 700 μm.

Plate LXXII

Turridae: pre-settlement protoconchs.

Figure a. Microdaphne

b. "

c. "

d. Carinapex minutissimus: apertural view.

e. " " dorsal view.

f. " " apertural view.

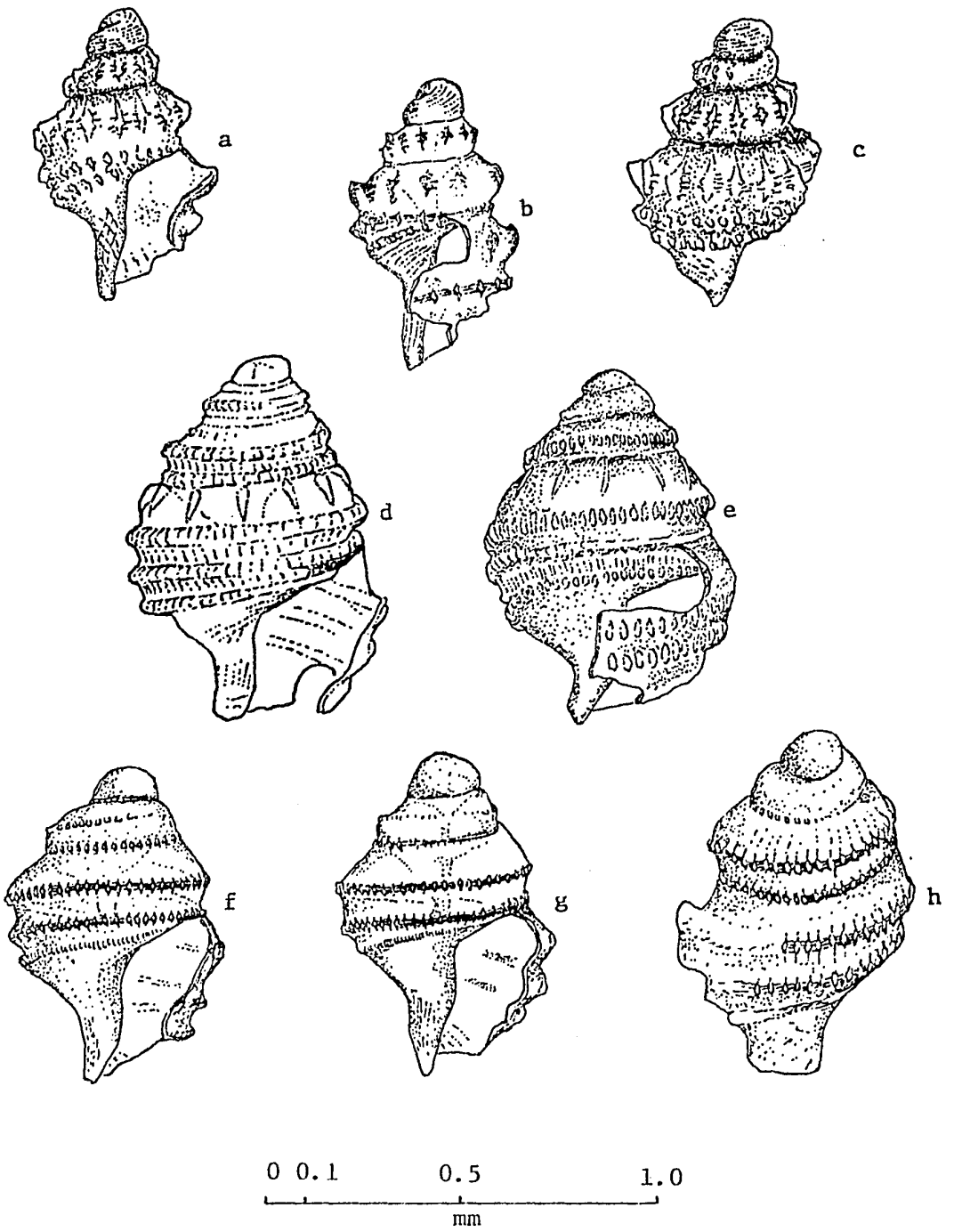
g. Lienardia mighelsi: apertural view.

h. " " dorsal view.

i. " " apertural view.

PLATE LXXII

Turridae



Kermia melanoxytum (Hervier 1895). Plate LXXIII, fig. a.

Veliger:

Protoconch: fawn to red-brown, whorls inflated; first 1 1/2 whorls with spiral rows of punctae; remaining whorls with slightly oblique cross-hatching; beak with two spiral sutural keels interrupting cross-hatching, well-developed; siphonal canal wide, short; metamorphosis occurs when 3 1/2 - 4 whorls complete, columellar length approximates 695 µm.

Velum: four-lobed; velar lobes suffused with light red-brown.

Cephalic area: tentacles slender, medium-long; eyes inside slightly swollen bases.

Foot: white, typical daphnellid shape; propodium deeply cleft; metapodium tapers gradually; metapodial tentacle lacking.

Viscera: cannot be discerned through protoconch; exposed body tissues white.

Months found in plankton: January, March, April

Areas found: Dredged Island

Lienardia (Hemilienardia) balteata (Pease 1860). Plate LXXIII, fig. b.

Veliger:

Protoconch: colorless; inflated daphnellid shape; first 1 1/2 whorls with spiral rows of punctae; remaining whorls with oblique cross-hatching; beak angular; siphonal canal attenuate; metamorphoses when three whorls complete.

Velum: four-lobed; unpigmented.

Cephalic area: tentacles long, slender; eyes inside bases.

Foot: propodium slightly cleft; mesopodium undistinguished; metapodium tapered; metapodial tentacle lacking; pedal, pallial and cephalic areas cream.

Viscera: digestive gland golden brown.

Months found in plankton: January

Areas found: Sampan Channel

Remarks: Metamorphosis occurs when the columellar length approximates 580 μm.

Kermia apicalis (Montrouzier 1861). Plate LXXIII, figs. c, d.

Veliger:

Protoconch: fusiform, golden; first 1 1/2 whorls spirally punctate with about seven parallel rows of punctae; remaining whorls with delicate oblique cross-hatching; junctions of cross-hatching raised, rendering protoconch profile slightly spinose; beak rounded, with central sutural keel; siphonal canal medium-long; metamorphosis occurs when four whorls complete, columellar length approximates 695 µm, width of body whorl, 400 µm.

Velum: four-lobed; unpigmented.

Cephalic area: light gold.

Months found in plankton: January

Areas found: Sampan Channel, Dredged Island

Daphnella interrupta Pease 1860. Plate LXXIII, fig. e.

Veliger:

Protoconch: first two whorls light golden-brown; third whorl tan and fourth whorl dark golden-brown; fusiform, with inflated whorls; beak angular; siphonal canal medium in length and width; first 1 1/2 whorls with spiral rows of parallel punctae; dense cross-hatching of fine threads at angle of 45° with respect to sutures; beak prominent; subsutural keel on 4th whorl.

Velum: four-lobed; unpigmented; span of dorsal velar lobes broader than ventral span.

Cephalic area: tentacles medium-long, 'bristled' at tips; eyes inside swollen bases; intertentacular distance fairly wide.

Foot: colorless; propodium blunt, rectangular.

Viscera: intestine dark gray; other organs golden.

Months found in plankton: March, July, August, December

Areas found: Coconut Island vicinity

Remarks: Veligers of this species readily metamorphose in captivity. After metamorphosis, the anterior cleft of the foot deepens and the metapodium tapers sharply, ending in a tiny metapodial tentacle. The author suspects that the food preference of the juveniles consists of small, sparsely bristled polychaetes.

Kermia brunnea (Pease 1860). Plate LXXIII, figs. f, g.

Veliger:

Protoconch: apical whorl colorless, with 12 spiral rows of punctae; remaining whorls with red-brown background, colorless rhombi at shoulder areas of whorls, oblique cross-hatching; junctions of cross-hatching not beaded; body whorl with ten mid-whorl colorless rhombi; beak with five crenulations, rounded rather than angular; siphonal canal short; metamorphosis occurs when five whorls complete, columellar length approximates 1220 μm, width of body whorl 625 μm.

Velum: four-lobed; unpigmented; velar lobes expansive, carried like a veil.

Cephalic area: tentacles medium-long, tips knobbed with 'bristles'; eyes large, in center of bases.

Foot: propodium deeply cleft; propodial tips reflected; metapodium gradually tapers; white; metapodial tentacle lacking.

Viscera: invisible through red-brown protoconch; body tissues white.

Months found in plankton: February, May, June, August

Areas found: Sampan Channel

Remarks: Immediately after metamorphosis, the initial teleoconch is light red-brown with the apertural lip crinkled. The body becomes light lemon-yellow.

This species is the largest of all planktonic daphnellids obtained from Kaneohe Bay.

Tritonoturris elegans (Pease 1860). Plate LXXIII, fig. j.

Veliger:

Protoconch: background golden; ovate-fusiform; whorls inflated; thread-sculpture light red-brown; apical whorls with spirals of punctae; anterior half of remaining whorls with oblique cross-hatching; posterior half of whorls with arcuate axial threads; sutural band present; sutures medium red-brown, impressed; beak, siphonal canal present; metamorphosis occurs 3 - 3 1/4 whorls complete, length: 840-870 µm, width: 450 µm.

Velum: four-lobed, unpigmented.

Cephalic area: yellow-cream.

Foot: yellow-cream; propodium cleft medially; posterior edge of foot attenuate.

Viscera: digestive gland dark tan; intestine charcoal.

Months found in plankton: May through August

Areas found: Sampan Channel, Dredged Island

Daphnella sandwichensis Pease 1860. Plate LXXIII, fig. k.

Veliger:

Protoconch: dark red-brown, teardrop-shaped; sutures barely impressed; sculpture of oblique cross-hatching with fine threadlets; metamorphosis occurs when 3 1/4 - 3 1/2 whorls complete, length: 800-850 µm, width: 470 µm.

Velum: colorless, four-lobed; velar lobes expansive; not fast swimmers.

Cephalic area: diaphanous white.

Foot: white; propodium cleft medially, produced anterolaterally.

Viscera: cannot be discerned through protoconch.

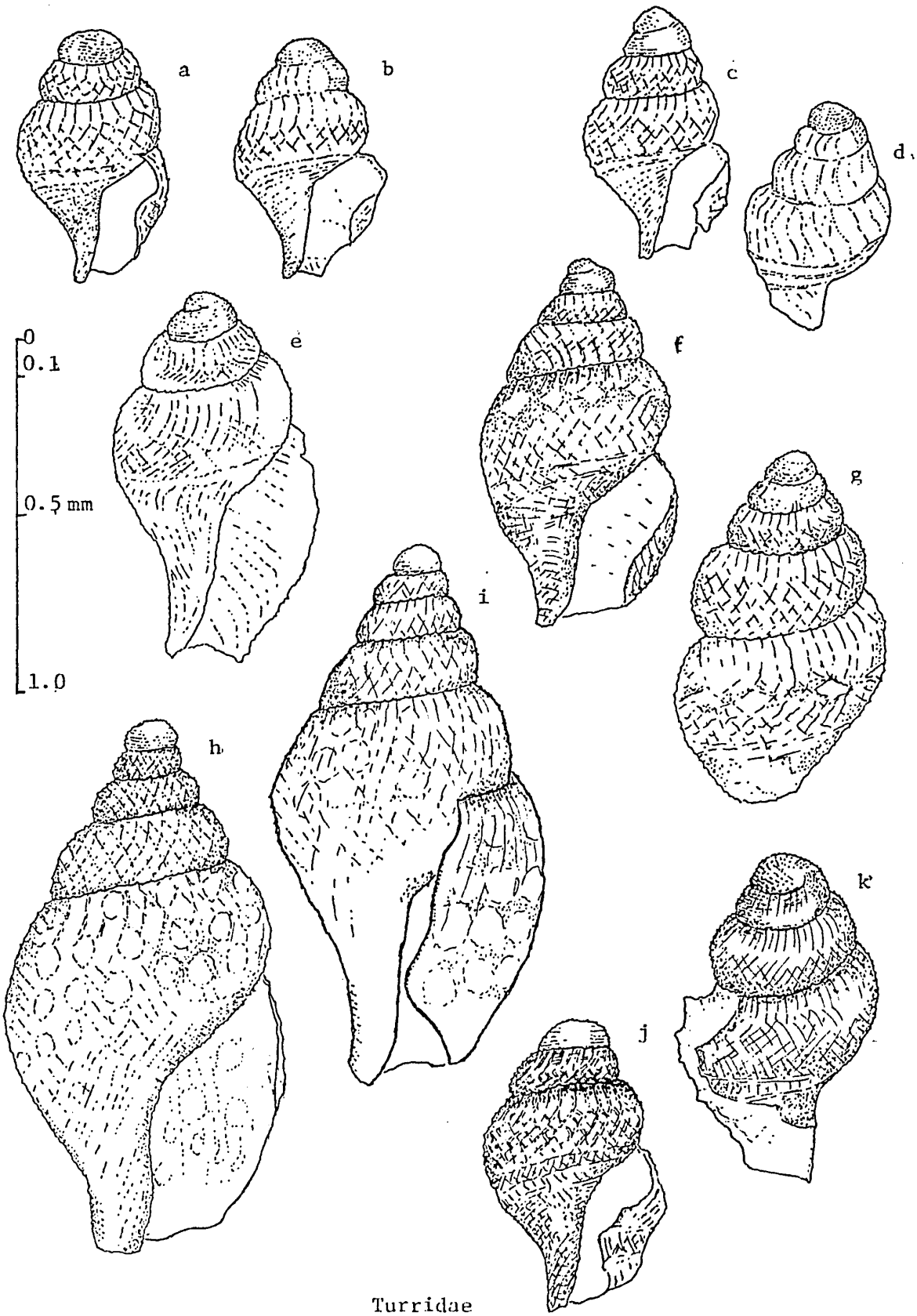
Months found in plankton: all months; peak abundance during spring

Areas found: Sampan Channel, Dredged Island

PLATE LXXIII
Turridae

Figure a. Kermia melanoxytum
b. Lienardia (Hemilienardia) balteata
c. Kermia apicalis
d. " "
e. Daphnella interrupta
f. Kermia brunnea
g. " "
h. Daphnella ornata
i. " "
j. Tritonoturris elegans
k. Daphnella sandwichensis

PLATE LXXIII



Turridae

Veprecula brunonia (Dall 1924). Plate LXXIV, figs. a, b.

Veliger:

Protoconch: first 1 1/2 whorls light red-brown, punctate; remaining whorls golden, with axial ribs; columella elongate, attenuate; beak with one pre-sutural rib; metamorphosis occurs when five whorls complete.

Velum: four-lobed; width, 990 μm; velar lobes oval, differing in lengths, carried over protoconch like a veil; central areas of lobes with circular golden spots; other areas either colorless or with opaque white spots.

Cephalic area: tentacles elongate; eyes small, inside bases of tentacles; cephalic region unpigmented.

Foot: white; anterolateral edges taper, produced laterally.

Viscera: difficult to discern through protoconch.

Months found in plankton: March

Areas found: Sampan Channel

Remarks: Metamorphosis occurs when the columellar length approximates 725 μm.

Kermia sp. Plate LXXIV, fig. c.

Veliger:

Protoconch: fusiform; cream-colored; first 1 1/2 whorls with nine parallel rows of raised punctae; remaining whorls with cross-hatching of oblique raised threads; siphonal canal medium short, narrow; beak with two spiral sutural ribs, rounded rather than angular; metamorphosis occurs when 3 1/2 whorls complete, columellar length approximates 640 µm.

Velum: four-lobed; base of post-oral cilia with purple-black pigment; food groove broad; height, 660 µm; width, 1155 µm.

Cephalic area: tentacles short, tapered, bases swollen enclosing eyes; oral region golden.

Foot: background white; medial line delineated by beads of charcoal which diverge, forming an inverted Y at the meso-metaposial junction; propodium deeply cleft; mesoposium expanded slightly; metapodium tapers narrowly, forming one rounded metapodial tentacle.

Viscera: digestive gland yellow; style sac cream; intestine charcoal.

Months found in plankton: January, February, March, April, July.

Areas found: Sampan Channel, Dredged Island.

Remarks: A triangular black spot is located between the propodium and the mouth.

Kermia bifasciata (Pease 1860). Plate LXXIV, fig. f.

Veliger:

Protoconch: golden to medium red-brown; fusiform, inflated; first 1 - 1 1/2 whorls with eight rows of parallel punctae; remaining whorls with moderately-raised oblique cross-hatching; beak, siphonal canal present; metamorphosis occurs when 3 1/4 whorls complete, columellar length approximates 625 μm.

Velum: four-lobed; unpigmented.

Cephalic area: tentacles medium-short, slender, slightly knobbed, with sparse 'bristles' distally; eyes large, inside bases.

Foot: light golden; propodium moderately cleft; metapodium tapered.

Viscera: digestive gland golden-brown; intestine dark brown.

Months found in plankton: February

Areas found: Sampan Channel

Kermia pumila (Mighels 1845). Plate LXXIV, fig. h.

Veliger:

Protoconch: red-brown; fusiform; sutures impressed, whorls moderately rounded; first whorl with definite, raised punctae; second and third whorls with oblique cross-hatching; beak angular with medial sutural keel; metamorphosis occurs when 2 1/2 to 2 3/4 whorls complete.

Velum: four-lobed; velar lobes tinged with gray-blue; pigment at base of post-oral cilia lacking; each velar lobe circular-oval.

Cephalic area: tentacles short and blunt; eyes inside bases.

Foot: tissues cream.

Viscera: digestive gland golden; style sac, intestine black.

Months found in plankton: October

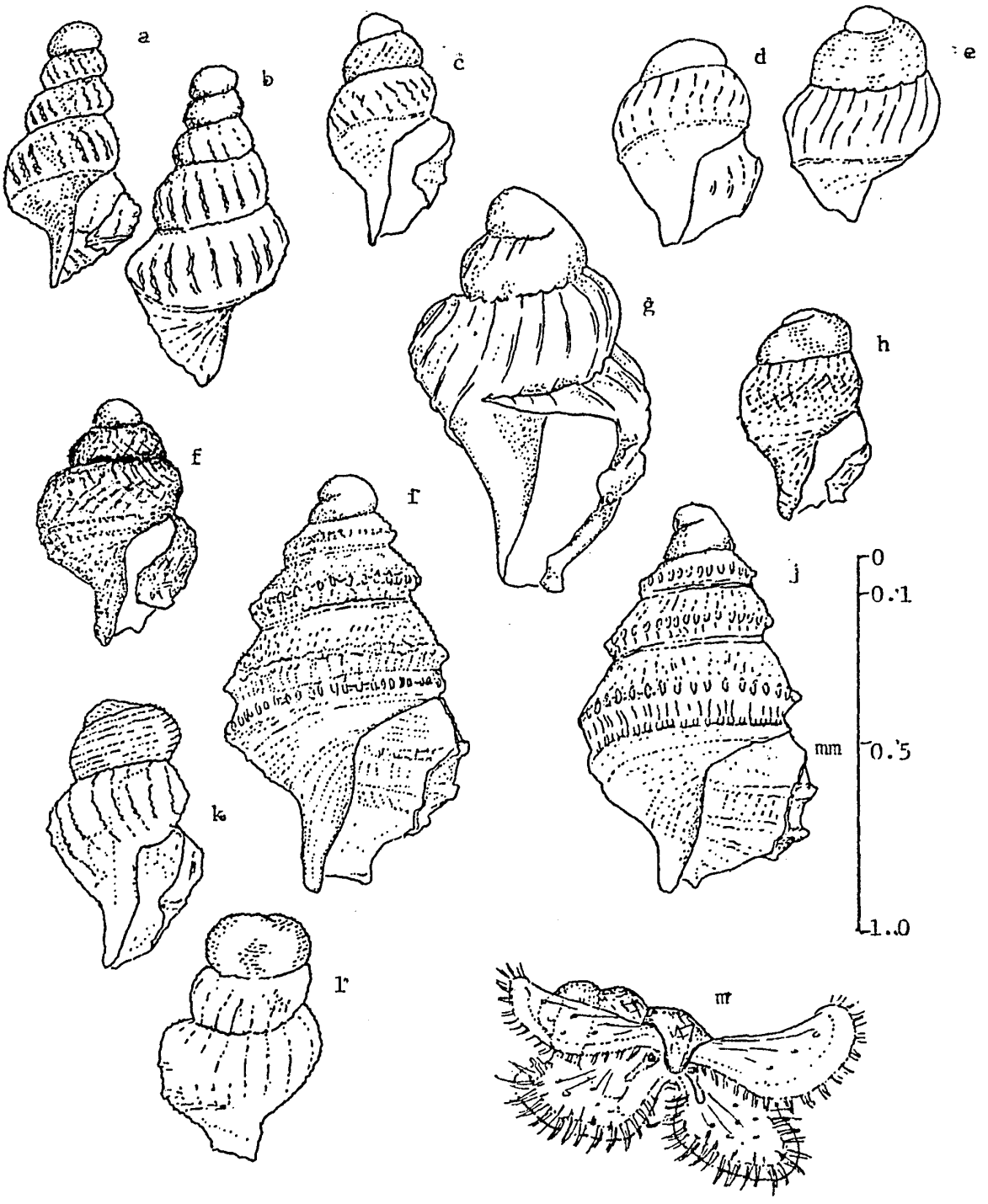
Areas found: Coconut Island vicinity

PLATE LXXIV

Turridae

Figure a. Veprecula brunonia
b. " "
c. Kermia sp.
d. Lienardia apiculata
e. " "
f. Kermia bifasciata
g. Eucithara angiostoma
h. Kermia pumila
i. Ceritoturris bittium
j. " "
k. Turrid sp.$_1$
l. " "
m. Turrid sp.$_2$

PLATE LXXIV
Turridae



Daphnella ornata (Hinds 1844). Plate LXXIII, figs. h, i;
Plate LXXV, fig. 1.

Veliger:

Protoconch: golden red-brown with four spiral rows of light tan circular spots on body whorl; fusiform with oblique cross-hatching of fine, densely-placed oblique threadlets; metamorphosis occurs when 5 - 5 1/4 whorls complete, length: 1550 μm, width: 750-780 μm.

Velum: four-lobed, unpigmented, diaphanous; velar lobes expansive.

Cephalic area: tentacles long, tapered, moderately far apart; eyes inside tentacular bases, distinct; oral area unpigmented.

Foot: diaphanous; propodium cleft; posterior edge attenuate.

Viscera: cannot be discerned through protoconch.

Months found in plankton: May

Areas found: Sampan Channel, Dredged Island

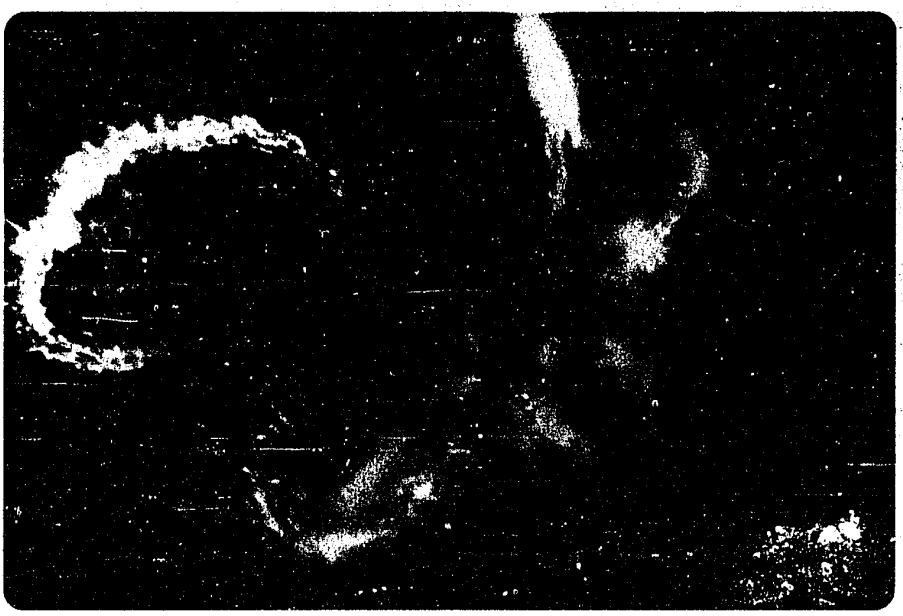
Plate LXXV

Turridae: premetamorphic veligers.

Figure a. Daphnella ornata, apertural view.

b. Paramontana bifasciata, abapertural view.

PLATE LXXV
Turridae



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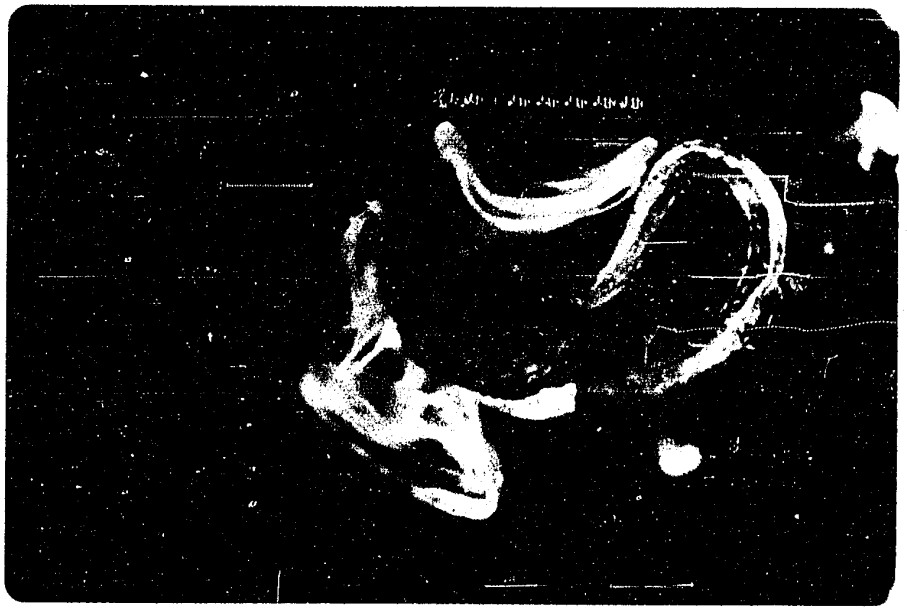


Eucithara angiostoma (Pease 1868). Plate LXXIV, fig. g; Plate LXXVI

Veliger:

Protoconch colorless, fragile, transparent; fusiform; sutures impressed, whorls inflated; sculpture of straight, fine, widely-spaced axial riblets; metamorphosis occurs when four whorls almost complete.

Velum: pre-settlement velum six-lobed; velar lobes diaphanous, expansive, pyriform, carried like a veil recurved over shell; pre-settlement velum with round, crimson spots scattered throughout lobes; swims by drifting through water; immature veligers may be four-lobed with tan-orange spots at distal tips of velar lobes.

Cephalic area: tentacles colorless, tapered, knobbed at tips, close together; eyes round, black, inside bases of tentacles; oral area charcoal.

Foot: background cream with many crimson spots; propodium rectangular, blunt; meso- and metapodium expanded, oval; metapodial tentacle cordate, 'bristled'; operculum present; immature foot narrow, pigment less.

Viscera: digestive gland golden; style sac green to tan; intestine with short, brick-red area; ctenidium colorless, conspicuous; mantle with crimson spots scattered through anterior half.

Months found in plankton: April, July, August, September, October

Areas found: Sampan Channel

Remarks: Veligers of E. angiostoma are among the most beautiful and distinctive in the plankton. The food of the juveniles is suspected to be sparsely-bristled juvenile polychaetes.

Plate LXXVI

Turridae: pre-settlement veligers.

Figure 1 (above): Eucithara angiostoma, anteroventral aspect.

2 (below): E. angiostoma, posterodorsal aspect.

PLATE LXXVI

Turridae

1.3mm

Conidae

Cone shells live primarily in tropical waters and effectively utilize long probosces and toxoglossan radulae to prey on mollusks, polychaetes and fish. The cone shell features a disproportionately large body whorl of elongate, conic shape, a long, narrow aperture and a spire which abruptly decreases in size. Angular, vasiform egg capsules contain few to many eggs, of which the majority hatch as pelagic veligers. Data on conid life histories are summarized in Table 35.

Table 35

Life History Data:

Name	Reference(s) cited
Hatch as juveniles with the ability to crawl; not planktonic	
Conus pennaceus (=*omaria*) Born	Ostergaard 1950; Kohn 1961
Egg capsule C	Knudsen 1950
Veligers probably planktonic for less than one week	
Conus araneosus Hwass	Natarajan 1957
Conus mercator L.	Knudsen 1950
Conus monachus	Desai 1962
Conus planiliratus Sowerby	Thorson 1940
Conus tessellatus Born	Thorson 1940
With veligers planktonic for more than one week	
Conus abbreviatus Nuttall	Ostergaard 1950; Kohn 1961
Conus capitaneus L.	Risbec 1931, 1932
Conus catus Hwass	Ostergaard 1950; Kohn 1961
Conus ebraeus L.	Risbec 1931, 1932; Ostergaa
Conus marmoreus L.	Risbec 1931, 1932
Conus mus Bruguiere	Lebour 1945; Lewis 1960
Conus regius Gmelin	D'Asaro 1970
Conus sp.	Knudsen 1950
Conus sp.	Natarajan 1957
Conus spurius atlanticus Clench	D'Asaro 1970
Conus sumatrensis Hwass	Ostergaard 1950
Conus tahitensis rattus Hwass	Ostergaard 1950; Kohn 1961
Planktonic status of veliger unknown	
Conus imperialis L.	Kohn 1961
Conus leopardus Röding	Kohn 1961
Conus lividus Hwass	Kohn 1961
Conus quercinus Solander	Kohn 1961
Conus vexillum Gmelin	Kohn 1961
Conus vitulinus Hwass	Kohn 1961

Table 35

e History Data: Conidae

cited	Month(s) spawning	Egg size (µm)	Size at hatching (µm)	Size at metamorphosis (µm)
950; Kohn 1961	May-August	460	1250	1300
)	---	---	> 600	---
57	Oct.-March	467-517	1100	1200
)	---	400	---	---
	---	---	---	"large"
)	---	500-650	1100	---
)	Apr.-March	250	700-800	---
.950; Kohn 1961	March	200	270	---
, 1932	---	---	---	---
950; Kohn 1961	June	200-220	375	---
, 1932; Ostergaard 1950; Kohn 1961	March (Hawaii)	120	280	---
, 1932	---	---	---	---
; Lewis 1960	June-November(?)	100-120	240	---
)	---	---	---	---
)	---	150-175	>200	---
957	August	---	200-233	---
)	April-August	---	---	---
1950	May	140	250	---
1950; Kohn 1961	Feb., August	125	240	---
	July	225	---	---
	April	---	360	---
	February	---	250	---
	February	215	285	---
	May	140	250	---
	July	225	360	---

Conus sp.$_1$ Plate LXXVII, fig. a.

Veliger:

Protoconch: transparent light tan, fusiform; apex flattened, rounded; sutures impressed; columellar area with growth striae; siphonal canal attenuate; metamorphosis occurs when 4 - 4 1/2 whorls complete, length: 1550-1650 µm, width: 620 µm.

Velum: four-lobed; unpigmented.

Cephalic area: unpigmented.

Foot: background cream with light gray lateral smudges.

Viscera: digestive gland gold.

Months found in plankton: May, July, August

Area found: Sampan Channel

Remarks:

Some possibilities for the identity of this species are: C. catus, C. chaldeus, C. ebraeus, C. distans or C. imperialis.

Conus sp.$_2$ Plate LXXVII, fig. b.

Veligers of this species are also found in Sampan Channel and may be the same as those of Conus sp.$_1$. The protoconch is transparent light ochre, fusiform and the apex is flattened. The sutures are impressed, with a narrow suprasutural area of axial growth striae. The columella also has growth striae. Metamorphosis occurs when 4 to 4 1/4 whorls are complete and the length is 1550-1650 µm and the width is 610 µm. The velum is four-lobed and unpigmented.

Conus sp. $_3$ Plate LXXXIII, figs. 1, 2.

Veliger:

Protoconch: background gold; sutures dark gold, impressed; whorls inflated, with faint reticulum of sculpture; beak angular, approximately 90°; columella dark gold; metamorphosis occurs when three whorls complete, length: 970-1050 µm; width: 550 µm.

Velum: four-lobed, with stellate golden spots throughout; velar lobes arched, distally-flared.

Cephalic area: esophageal area distinct, charcoal; eyes small, indistinct; tentacles small.

Foot: with dark gold round spots; background lighter gold; ventrum shield-shaped; metapodial tentacle blunt, well-defined.

Viscera: entire mantle invested with dark gold, round spots; digestive gland gold; style sac, intestine charcoal.

Months found in plankton: April through August

Areas found: Sampan Channel; occasionally Dredged Island

Conus striatus Linnaeus 1758. Plate LXXVII, fig. c.

Veliger:

Protoconch: moderately fusiform, apical whorls bulbous, sutures impressed; transparent, suffused with pale pink; sutures and columella purple-pink; beak angular; siphonal canal attenuate; metamorphosis occurs when 5-6 whorls complete, columellar length approximates 2500 µm.

Velum: four-lobed; lobes medium in length; discrete, small olive spots regularly placed in entire length of food groove.

Cephalic area: tentacles medium in length, thickened at bases; eyes tiny; esophageal region unpigmented.

Foot: transparent; narrow; propodium narrow, blunt; metapodium narrows abruptly, forming a broad metapodial tentacle.

Viscera: digestive gland light golden; style sac golden; intestine inconspicuous.

Months found in plankton: July, August

Areas found: Sampan Channel

Remarks: Veligers of this species generally complete 1 1/2 - 3 whorls when they are netted in the summer plankton. Although the shape of the protoconch resembles strongly that of Conus textile, it differs in color. Velar differences in the size and color of pigment spots and length of velar lobes exist when both species of veligers have completed three whorls. In terms of color, C. striatus and textile are the same. Protoconchs differ in size of apical whorls and whether or not spots are in the mantle. The juveniles feed on small benthic fish (Kohn 1955).

Conus sp.$_4$. Plate LXXVII, figs. d, e; Plate LXXXI, fig. 2a.

Veliger:

Protoconch: background transparent colorless; fusiform; apex blunt; sutures, columella light rose; metamorphosis occurs when 3 3/4 - 4 whorls complete, length: 1300-1350 μm, width: 630-670 μm.

Velum: four-lobed; food groove with discrete round green-khaki spots; velar lobes long, held in a curled position.

Cephalic area: colorless; eyes moderately far apart, inside tentacular bases; esophageal area light gray.

Foot: background colorless; mesopodium with faint pink tinges.

Viscera: digestive gland light gold; intestine khaki; mantle diaphanous white; ctenidium colorless, distinct.

Months found in plankton: May

Areas found: Sampan Channel

Plate LXXVII

Conidae

Figure a. Conus sp.$_1$

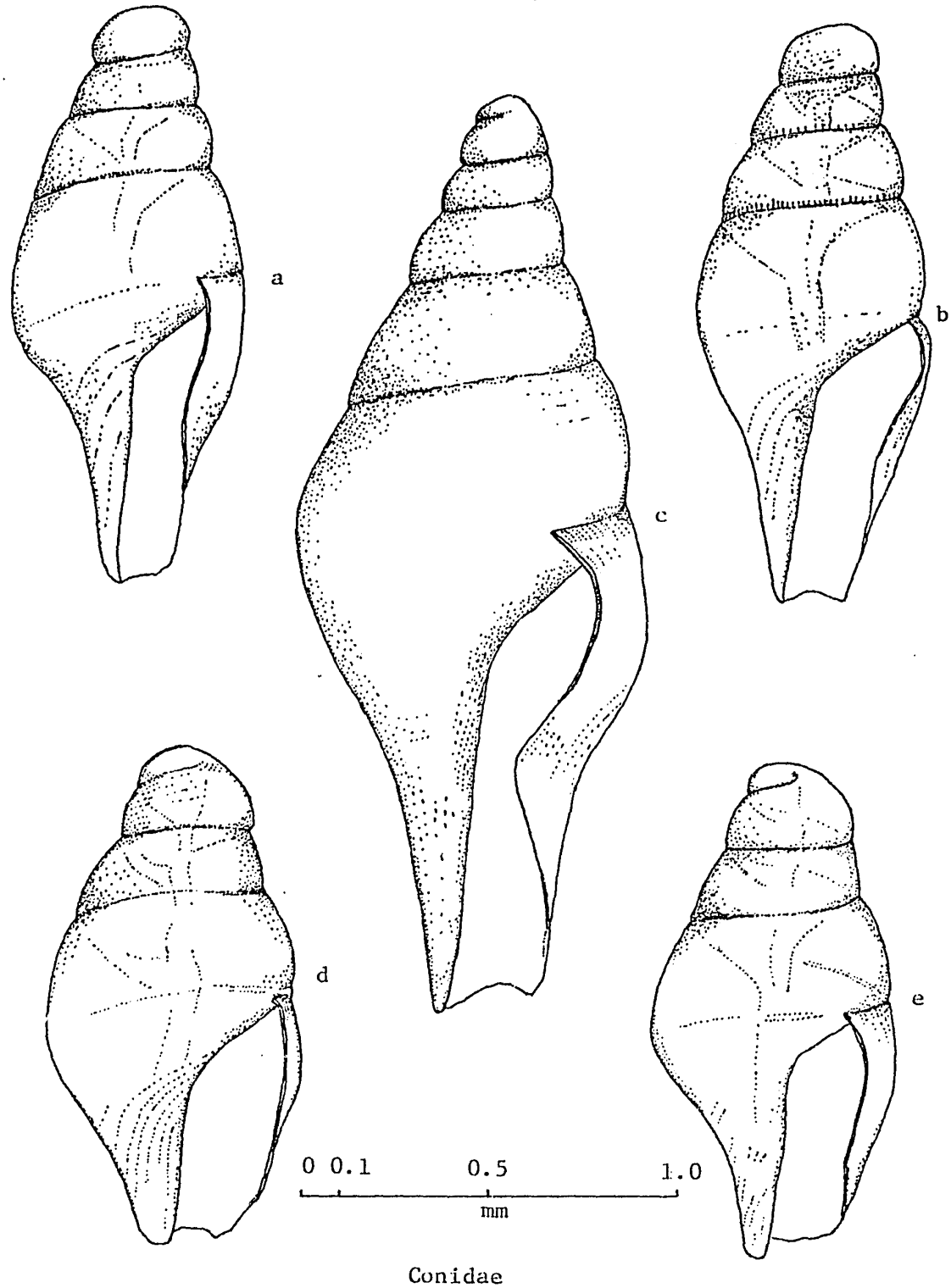
b. Conus sp.$_2$

c. Conus striatus

d. Conus sp.$_3$

e. Conus sp.$_4$

PLATE LXXVII



Conidae

Conus vitulinus Hwass in Bruguiere 1792. Plate LXXVIII, fig. a.

Veliger:

Protoconch: yellow-tan, conical; sutures barely impressed; body whorl inflated; beak lacking; siphonal canal truncate; columellar area striate; metamorphosis occurs when five whorls complete, length: 1600-1700 µm, width: 770 µm.

Velum: four-lobed, with yellow-green pigment spots throughout.

Cephalic area: light yellow; eyes small.

Foot: cream yellow.

Viscera: digestive gland tan; intestine, style sac brown.

Months found in plankton: July through September

Areas found: Sampan Channel

Remarks:

Juveniles of this species feed on eunicid polychaetes (Kohn 1955). Larvae are in capsulo 14-15 days and hatch when their greatest dimension is 360 µm (Kohn 1961a).

Conus sp. 5. Plate LXXVIII, fig. b.

Veliger:

Protoconch: transparent cream, fusiform; apex flattened, rounded; sutures impressed; columellar area striate; siphonal canal truncate; metamorphosis occurs when 4 - 4 1/4 whorls complete, length: 1450 µm, width: 600 µm.

Velum: four-lobed, unpigmented.

Cephalic area: cream.

Foot: narrow, cream.

Viscera: digestive gland tan; intestine brown.

Months found in plankton: May through July

Areas found: Sampan Channel

Remarks:

Veligers of this species may be the same species as those in Plate LXXVII, fig. a.

Conus sp.$_6$. Plate LXXVIII, fig. c.

Veliger:

Protoconch: fusiform; apex rounded; light gold; suprasutural area of whorls 2, 3, and 4 with axial beads; columellar area striate; metamorphosis occurs when 4 - 4 1/4 whorls complete, length: 1500-1550 µm, width: 730-750 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: cream-tan.

Viscera: digestive gland golden; style sac, intestine brown.

Months found in plankton: April through August

Areas found: Sampan Channel

Conus sp.$_7$. Plate LXXVIII, fig. e.

Veliger:

Protoconch: fusiform; background opaque light pink-orange; sutures barely impressed, without beads; columellar area striate; metamorphosis occurs when five whorls complete, length: 1500 µm, width: 670-700 µm.

Velum: four-lobed; unpigmented.

Cephalic area: light pink-cream.

Foot: cream.

Viscera: cannot be discerned through protoconch.

Months found in plankton: May

Areas found: Sampan Channel

Conus sponsalis Hwass in Bruguiere 1792. Plate LXXVIII, figs. d, f; Plate LXXXI, fig. 1, 2c; Plate LXXXII, fig. 1.

Veliger:

Protoconch: fusiform; sculpture lacking; colorless except for dark caramel sutures; suprasutural band subdivided by axial growth striae; beak poorly developed; siphonal canal short; metamorphoses when 5 - 5 1/3 whorls complete, height: 1450 µm, width: 695 µm.

Velum: four-lobed; food groove with yellow-orange pigment.

Cephalic area: esophageal region yellow.

Foot: propodium blunt; metapodium bluntly tapering; operculum oval.

Viscera: digestive gland, style sac yellow; intestine light yellow-green, black; ctenidium colorless, but distinct.

Months found in plankton: August

Areas found: Sampan Channel

Remarks: Veligers of this species swallow the velum during metamorphosis. The juveniles retain the larval operculum, and the protoconch becomes purplish-blue upon metamorphosis. Juveniles feed on polychaetes (Kohn 1955).

Plate LXXVIII

Conidae: premetamorphic protoconchs.

Figure a. *Conus vitulinus*

b. *Conus* sp.$_5$

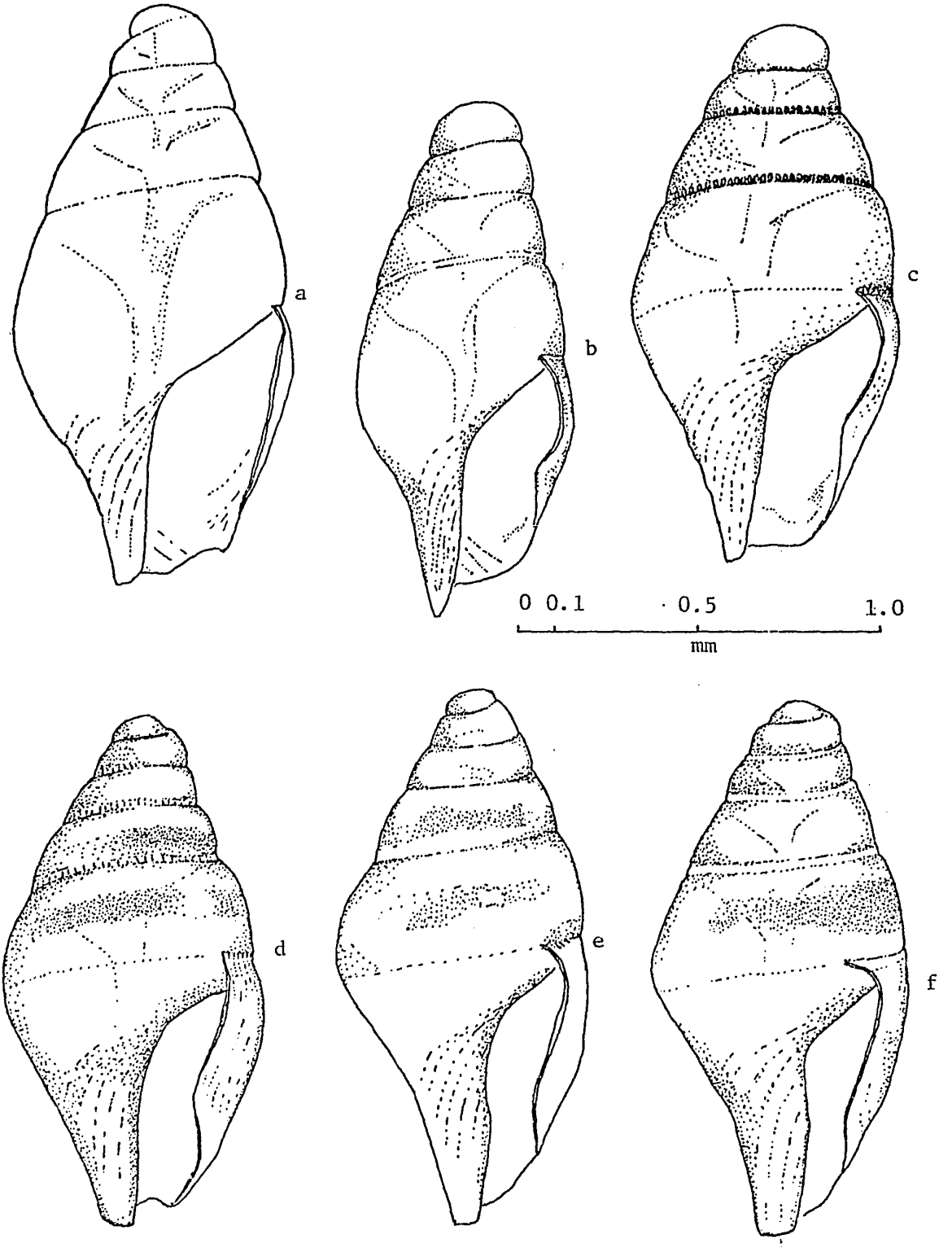
c. *Conus* sp.$_6$

d. *Conus sponsalis*

e. *Conus* sp.$_7$

f. *Conus sponsalis*

PLATE LXXVIII



Conidae

Conus sp.$_8$ Plate LXXIX, fig. a.
Plate LXXXI, fig. 2b

Veliger:

Protoconch: light gold; conical, shaped like tear-drop; sutures barely impressed, caramel; siphonal canal truncate; columellar striae faint; metamorphosis occurs when 4 3/4-5 whorls complete; length: 1180-1200 μm, width 620 μm.

Velum: four-lobed; base of post-oral cilia suffused with gold.

Cephalic area: esophageal area light charcoal.

Foot: light charcoal, metapodial region attenuate.

Viscera: digestive gland gold with gray area.

Months found in plankton: July.

Areas found: Sampan Channel.

Conus rattus Hwass in Bruguiere 1792. Plate LXXIX, fig. b.

Veliger:

Protoconch: fusiform; transparent, light yellow-green; sutures caramel-colored; protoconch smooth; beak and siphonal canal present; siphonal canal attenuate; metamorphosis occurs when four whorls complete, columellar length approximates 1357 µm, width nearly 690 µm.

Velum: four-lobed; base of post-oral cilia charcoal; area just medial to food groove with circular yellow-green spots; width, 1775 µm; height, 970 µm.

Cephalic area: tentacles medium in length; eyes inside lateral bulges near bases of tentacles; oral region charcoal.

Foot: propodium blunt, ventrum brushed with charcoal, rectangular; metapodium tapers gradually; operculum transparent.

Viscera: digestive gland golden; style sac clear; intestine charcoal.

Months found in plankton: October

Areas found: Sampan Channel

Remarks: After metamorphosis, the two apical whorls become red-brown. The teleoconch is clear white with closely-set spiral ribs. Veligers of this species are uncommonly collected from the Kaneohe Bay plankton.

Conus pulicarius Hwass in Bruguiere 1792. Plate LXXIX, fig. c.

Veliger:

Protoconch: conical, shaped like a teardrop; cream to light yellow; sutures barely impressed, banded; siphonal canal truncate; metamorphosis occurs when 4 3/4 - 5 whorls complete, length: 1220-1250 µm, width: 620 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented; eyes small.

Foot: cream with smudges of light charcoal.

Viscera: digestive gland light yellow.

Months found in plankton: June through September

Areas found: Sampan Channel

Remarks:

Juveniles feed on polychaetes and the echiuroid, Thalassema.

Conus obscurus Sowerby 1833. Plate LXXIX, fig. d.

Veliger:

Protoconch: pink-orange, fusiform-conical; siphonal canal truncate; columellar area striate; sutures barely impressed; whorls 4, 5, and 6 with sutural band; metamorphosis occurs when 5 1/2 - 5 3/4 whorls complete, length: 2100 µm, width: 950-960 µm.

Velum: four-lobed, unpigmented.

Cephalic area: unpigmented.

Foot: cream smudged with tan.

Viscera: style sac, intestine brown.

Months found in plankton: July

Areas found: Sampan Channel

Remarks:

Juveniles of C. obscurus feed on small benthic fish (Kohn 1959).

Conus pertusus Hwass in Bruguiere 1792. Plate LXXIX, fig. e.

Veliger:

Protoconch: cream-tan, smooth, conical; sutural band present; siphonal canal truncate; columellar area striate; metamorphosis occurs when six whorls complete, length: 2100-2200 µm, width: 1050 µm.

Velum: four-lobed, unpigmented.

Cephalic area: cream.

Foot: light gold flecked with tiny black spots.

Viscera: digestive gland golden.

Months found in plankton: June

Areas found: Sampan Channel

Plate LXXIX

Conidae: premetamorphic protoconchs.

Figure a. *Conus* sp.$_8$

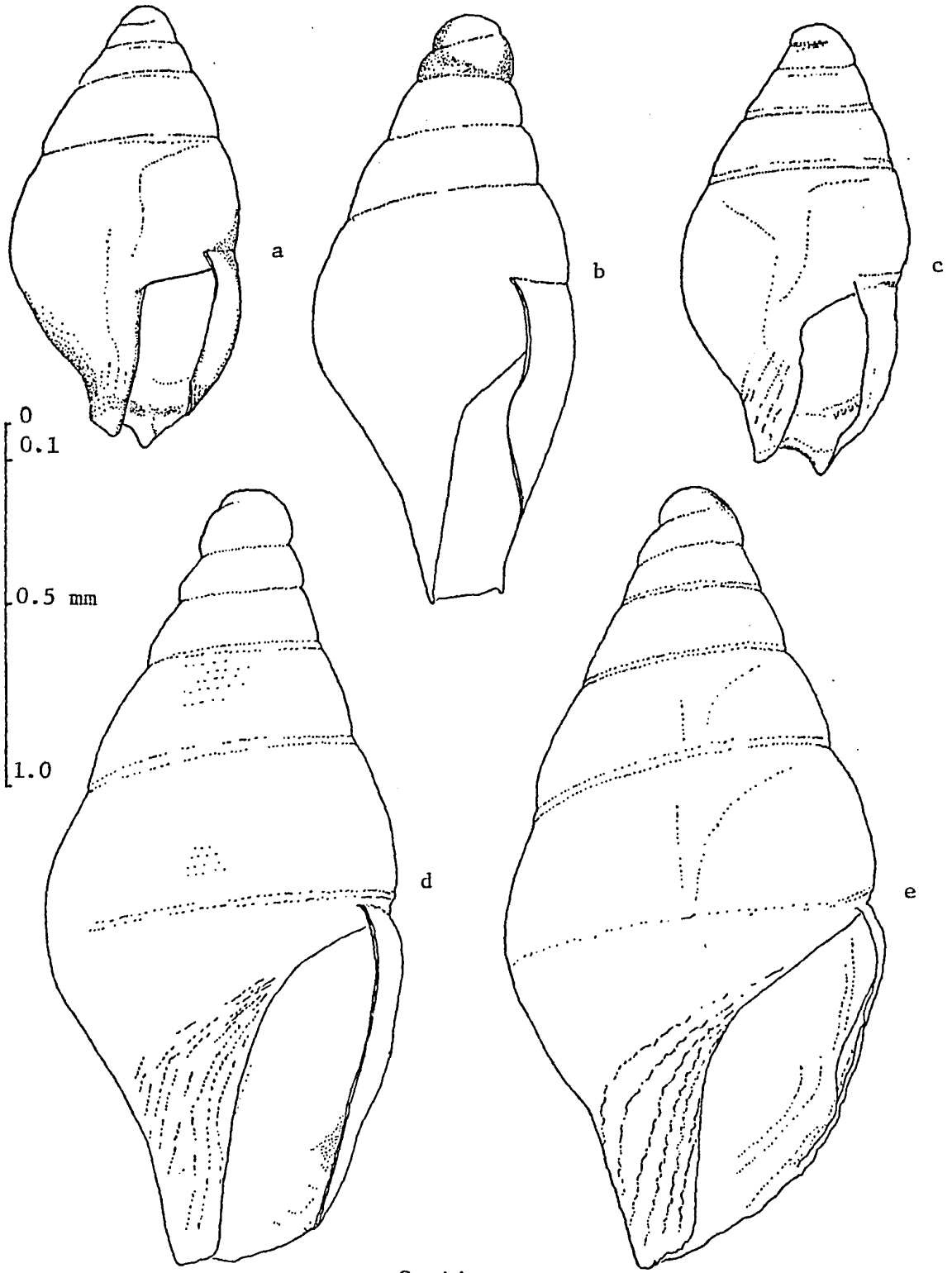
b. *Conus rattus*

c. *Conus pulicarius*

d. *Conus obscurus*

e. *Conus pertusus*

PLATE LXXIX



Conidae

Conus sp.$_9$ Plate LXXX, fig. a.

Veliger: fusiform; siphonal canal very short; sculpture lacking; colorless, sutures light yellow-green; beak poorly developed; metamorphoses when 4 1/2 - 5 whorls are complete, when columellar length approximates 1025 µm, width nearly 560 µm.

Velum: four-lobed; base of post-oral cilia charcoal-brown; velar lobes reflected back over protoconch, each lobe approximately 1500 µm, elongate, slim, with parallel sides.

Cephalic area: tentacles medium in length, far apart, slim; eyes round, inside bases; esophageal region charcoal.

Foot: light yellow-green; anterior end brushed with charcoal; propodium blunt, rectangular; metapodium tapers.

Viscera: digestive gland light yellow-green; intestine with black fecal pellets.

Months found in plankton: August

Areas found: Sampan Channel

Remarks: Juveniles of this species are uncommonly collected from the Sampan Channel plankton.

Conus pennaceus Born 1780 Plate LXXX, fig. b.

Synonym: Conus omaria

Veliger:

Protoconch: bulbous, sutures impressed; light pink-orange, transparent, anterior end brown; sculpture of fine punctae and axial growth striae; beak lacking; siphonal canal short; hatch when 2 1/4 whorls complete, columellar length approximates 1250 - 1300 μm.

Velum: four-lobed; generally unpigmented, but distal areas of food groove occasionally with olive spots; generally ineffective in swimming after hatching.

Cephalic area: tentacles thick, medium in length; bases of tentacles fleshy, glandular; eyes midway up tentacles in bulge; statocysts conspicuous.

Foot: light tan; propodium blunt, angular; mesopodium wide; metapodium tapered.

Viscera: digestive gland yellow to khaki.

Date veligers hatched: June 30, 1968

Date metamorphosed: July 9, 1968

Area egg capsules collected: Maili Point, Oahu

Remarks: If veligers of C. pennaceus are planktonic, they are not planktonic for long periods. Even though the velum is well developed at hatching, the mass of the veliger is too great to enable extended vertical swimming. Veligers of this species were not taken in plankton tows conducted in Kaneohe Bay. Kohn (1961) has noted that they remain as veligers for a few hours to, at most, a few days. The adults are reported as molluscivores (Kohn 1955). Metamorphosis occurs by resorption of velar lobes.

Conus vexillum Gmelin 1791 Plate LXXX, fig. c; Plate LXXXII, fig.2.

Veliger:

Protoconch: large; fusiform; siphonal canal medium in length; apex blunt-acuminate; smooth; transparent light yellow-orange; sutures tan, slightly impressed; columella dull yellow-orange; metamorphosis occurs when 5 1/2 - 6 whorls complete, columellar length approximates two mm, width nearly 820 µm.

Velum: four-lobed, velar lobes elongate, sides parallel; bases of pre- and post-oral cilia charcoal gray; medial areas of velar lobes suffused with light yellow-orange; areas medial to food groove suffused with vivid yellow orange.

Cephalic area: tentacles medium in length; eyes round, inside laterally-bulging bases of tentacles; esophageal area rimmed with charcoal.

Foot: large; background light orange-tan; ventrum smudged with gray, blunt, rectangular; propodium smudged with charcoal; metapodium bluntly tapered; operculum transparent, colorless.

Viscera: digestive gland yellow-green; style sac inconspicuous; intestine black, elongate, rectangular; ctenidium edged with black.

Months found in plankton: May, October

Areas found: Sampan Channel

Remarks: Veligers of C. vexillum are relatively uncommon in the Kaneohe Bay plankton. One veliger settled, metamorphosed and was released in the sea water table. It grew to a columellar length of 8.1 mm. The adults reportedly feed on polychaetes (Kohn 1959).

Conus abbreviatus Reeve 1843 Plate LXXX, fig. d.

Veliger:

Protoconch: fragile; buff to tan; moderately fusiform; apical whorls inflated; sutures impressed; sculpture lacking except for punctae; beak broadly angular; siphonal canal attenuate; metamorphosis occurs when 4 1/4 whorls complete, columellar length approximates 1120 µm.

Velum: four-lobed; early veliger with velar lobes short and wide; base of pre- and post-oral cilia black; pre-settlement veliger with elongate velar lobes, more pigment spots; central areas of velar lobes fluorescent yellow-green; height, 560 µm; width, 725 µm.

Cephalic area: tentacles medium in length, thick; eyes small, inside bases of tentacles; esophageal region charcoal.

Foot: background light yellow-green with small scattered tan spots; medial areas lightly brushed with charcoal.

Viscera: digestive gland golden; intestine and style sac charcoal.

Months found in plankton: January, February, July, August

Areas found: Sampan Channel

Remarks: Veligers of this species are commonly in the plankton during February when the columellar length is approximately 500 µm and when two whorls are complete. These veligers and younger veligers of this species also may have pigment spots scattered on the ventrum of the foot. Pigment spots in the velar lobes of younger veligers are peripherally located and the velum is bilobed. After metamorphosis, the protoconch is light red-brown.

Veligers of C. abbreviatus are in the plankton for the length of time required to change columellar length from 270 - 300 µm to more than 1100 µm. A minimum of five to seven weeks would be a likely estimate of the length of time that C. abbreviatus veligers are planktonic.

The following is a summary of information previously reported (Ostergaard 1950; Kohn 1961) concerning the reproductive biology of C. abbreviatus: adults common, dominant on marine benches, prefer eunicids as food; breed March-July; in capsulo 14 days during which the visceral mass is pink, green spots are inside the margins of the velar lobes; thought to spend at least ten days in the plankton.

Conus sp.$_{10}$ Plate LXXX, fig. e.

Veliger:

Protoconch: transparent light yellow-green; sutures light red-brown; umbilicus red-brown; fusiform; metamorphoses when 3 - 3 3/4 whorls complete.

Velum: four-lobed; suffused with gold.

Cephalic area: light gold; eyes tiny.

Foot: mesopodium with discrete tiny black spots on light gold background; propodium rectangular; meso- and metapodial areas combined triangular.

Viscera: digestive gland gold; intestine charcoal.

Months found in plankton: June, July

Areas found: Sampan Channel, seaward areas off Kewalo Basin (Honolulu)

Plate LXXX

Conidae: premetamorphic protoconchs.

Figure a. Conus sp.$_9$

b. Conus pennaceus

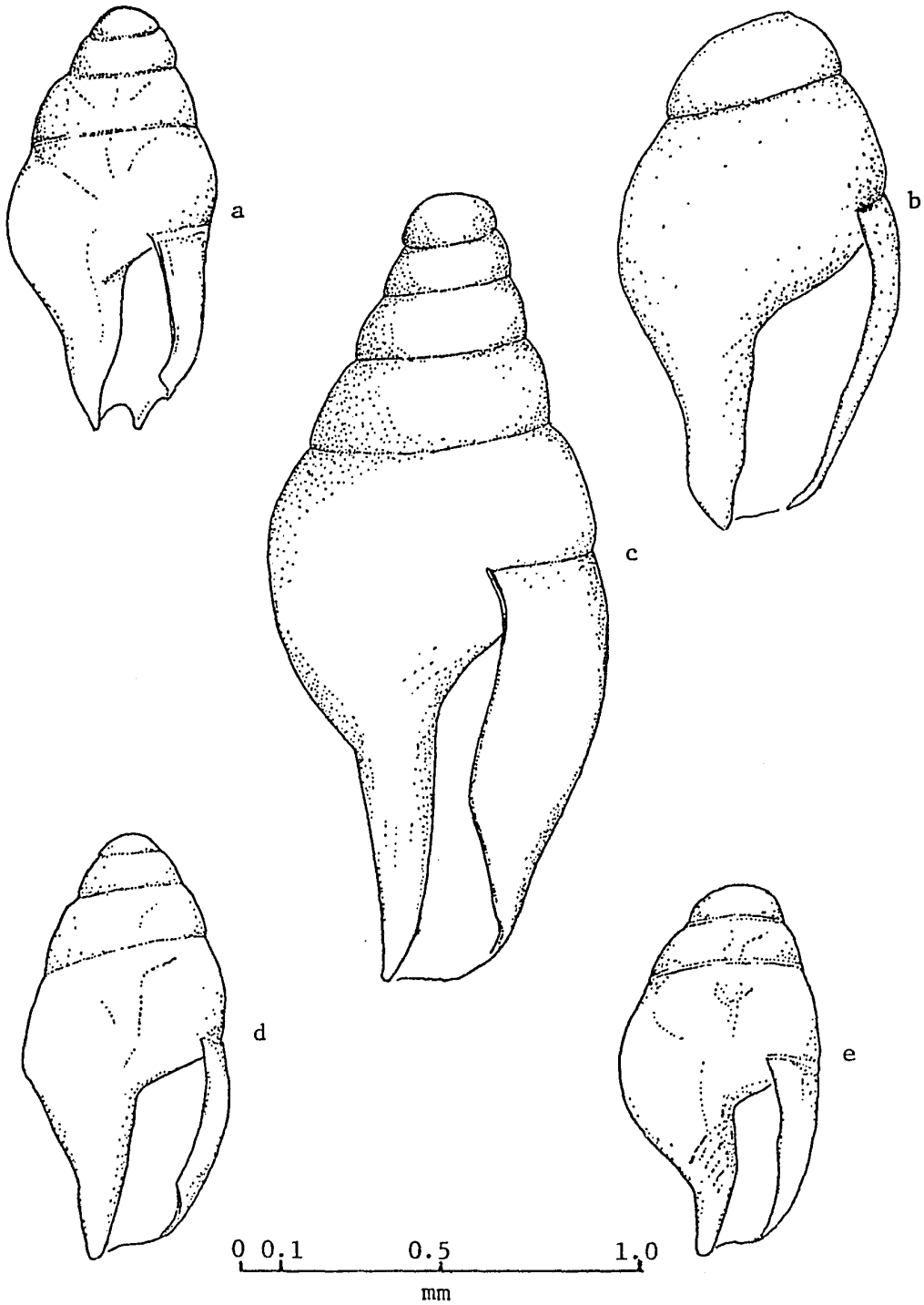
c. Conus vexillum

d. Conus abbreviatus

e. Conus sp.$_{10}$

PLATE LXXX

Conidae



Conidae

Plate LXXXI

Conidae: premetamorphic protoconchs.

Above: Conus sponsalis, ventral view.

Below: a. Conus sp.$_4$

b. Conus sp.$_8$

c. Conus sponsalis

PLATE LXXXI
Conidae

Figure 1 (above): Conus sponsalis
Figure 2 (below): a. Conus sp.4
b. Conus sp.8
c. Conus sponsalis

1.3mm

Plate LXXXII

Conidae: pre-settlement veligers.

Figure 1 (above): Conus sponsalis. ventral aspect.

Figure 2 (below): Conus vexillum, ventral aspect.

PLATE LXXXII
Conidae

1.3mm

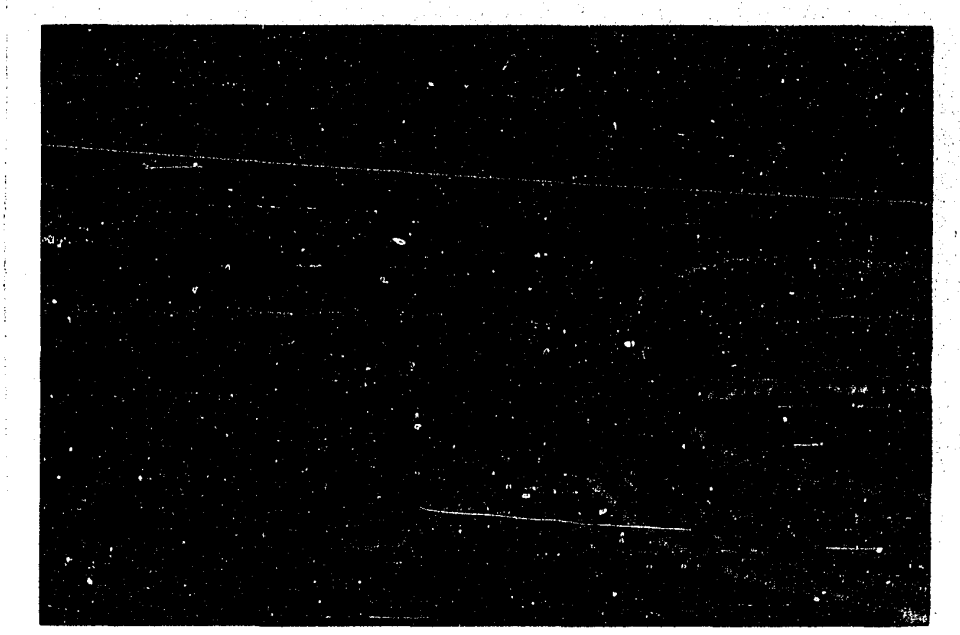
Plate LXXXIII

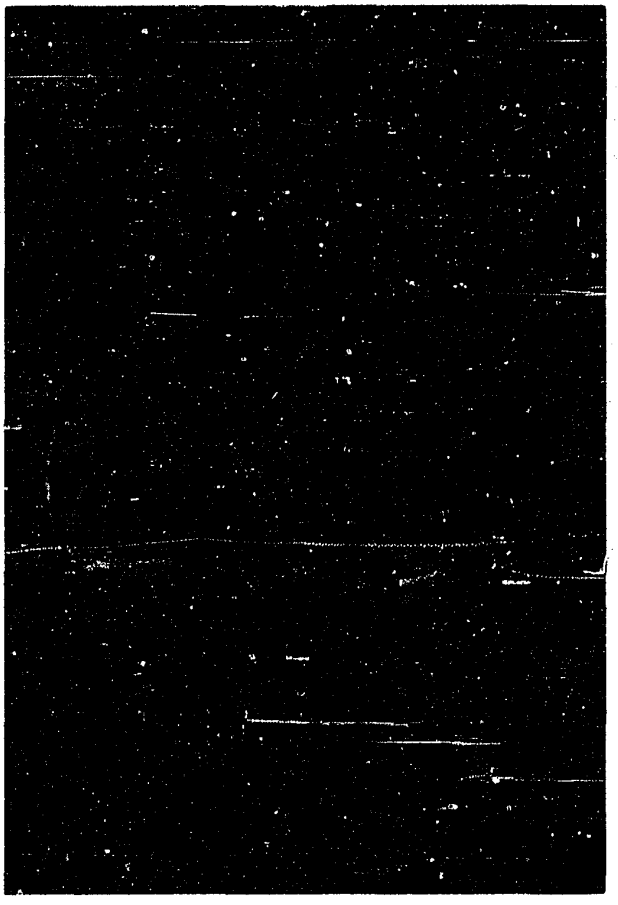
Conidae: pre-settlement veligers.

Figure 1 (above): Conus sp.$_3$

2 (below): Conus sp.$_3$

PLATE LXXXIII





1.3mm

Terebridae

Terebrids are generally sand-dwellers in warm seas. The long, slender, many-whorled shell of Terebra has a small aperture which opens anteriorly via a short siphonal notch. Well-preserved protoconchs frequently are seen on adult shells; from these one can construct educated guesses about the probable physical descriptions of specific terebrid larvae for later comparisons with netted veligers.

Hawaiian forms, some of which lack the radular apparatus, feed on a variety of prey species. T. gouldi lacks the radula, has a short buccal tube and feeds on a slowly-moving hemichordate, Ptychodera flava. The surf-dwelling Hastula inconstans feeds on Dispio magna, a deposit-feeding spionid polychaete, and has a radular apparatus similar to that of Conus with poison bulb and accessory feeding organs (Miller 1970).

Miller's (1970) dissertation provides the sole preliminary data (summarized in Table 36) which relate to terebrid life histories.

Terebrid veligers which are netted in the Kaneohe Bay plankton are remarkably alike. All of these pre-settlement veligers have vela with four lobes and have fat, short, stubby cephalic tentacles. All have some traces of a sutural band or cord; none have beaks and siphonal canals as well developed as those in the Muricidae and Turridae. Each has a foot with a well-developed, blunt, square propodium and a tapering metapodium. Terebrid veligers are operculate, although the operculum is inconspicuous. All are collected in the Sampan Channel and Dredged Island regions of the Bay.

Terebrid veligers differ from each other primarily in (1) the de-

gree to which the whorls are inflated and the columella twisted, (2) the amount and kinds of pigmentation in the shell and body tissues, (3) size and shape of the protoconch at settlement and (4) months found in the plankton. In the interests of brevity, the descriptions which follow will emphasize differences rather than reiterate similarities between veligers.

Veligers of Terebra can be distinguished from other veligers as follows: terebrid veligers

(1) lack the columellar plicae characteristic of most mitrid veligers,

(2) are generally smaller and lack the vivid pigmentation characteristic of many cone veligers, and

(3) lack the elaborate sculpturing characteristic of turrid larvae.

During metamorphosis, all planktonic terebrid veligers ingest the velum; without additional food, this act enables them to deposit three to seven axial ribs of the protoconch before they die. Investigators who wish to rear Terebra juveniles should determine the juvenile diet. My present guess is that these juveniles feed on some of the juveniles of the less bristly varieties of polychaetes, entoproct colonies or on juveniles of Ptychodera flava.

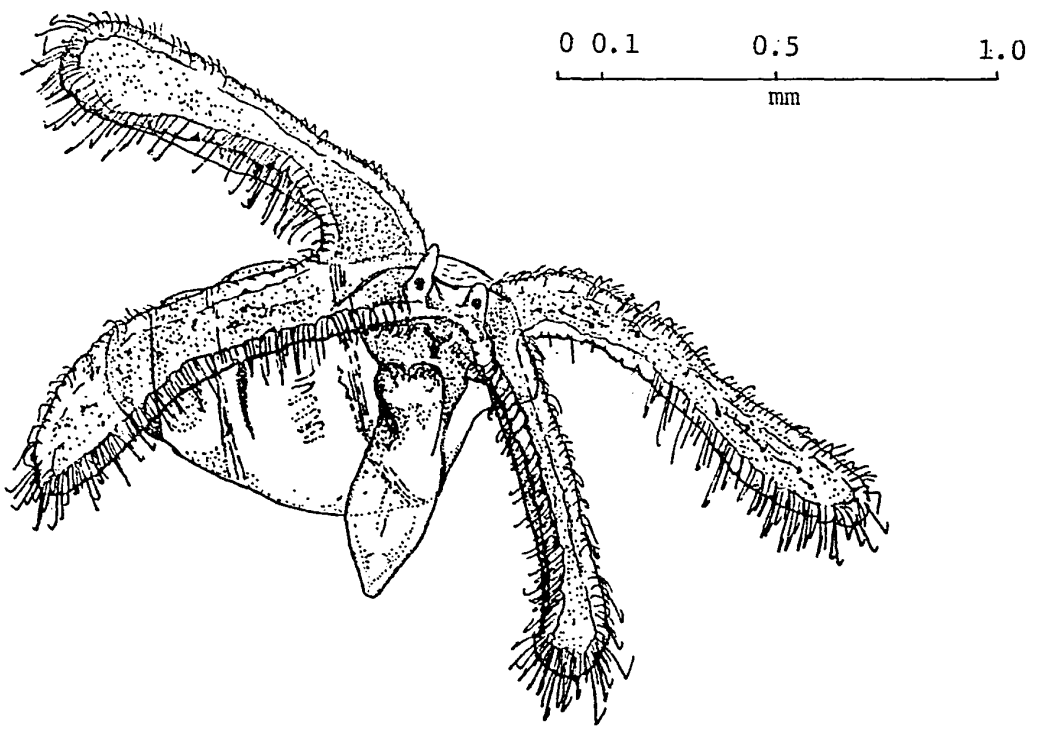


PLATE LXXXIV

Terebra (Hastula) strigilata

Table 36

Life History Data: Terebridae

	Terebra gouldi	*Terebra* (*Hastula*) *inconstans*
capsule descriptions	tiny, light tan, ovoid, small (1.5 x 1.2 mm) bodies; clustered like bunches of grapes	40 eggs per capsule; capsules attached to sand grains, pyriform
egg size	probably 300-350 µm	100 µm in diameter
in capsulo duration	at least 35 days @ 25°C.	---
size at hatching	650-750 µm long; 2 1/2 - 3 whorls	---
length of time in the plankton	hatch with the ability to crawl; not planktonic	---
months breeding	late spring, early summer	spring
size at metamorphosis	650-750 µm long	750-800 µm
remarks:	nurse eggs lacking; *in capsulo* veliger with 4-lobed velum; columella twisted	veliger settles at a size smaller than most terebrid veligers
source of information:	Miller 1970	Miller 1970

Terebra maculata (Linnaeus 1758). Plate LXXXV, fig. a.

Veliger:

Protoconch: barrel-shaped, apex broadly-rounded; cords at sutures not well-developed; columella straight; light gold.

Velum: unpigmented, four-lobed.

Viscera: digestive gland light gold; intestine charcoal gray.

Months found in plankton: July, September, October

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of T. maculata hatch when one whorl is complete, add two more whorls while planktonic and settle when the columella approximates 700-800 μm in length and when 3 - 3 1/2 whorls are complete. Upon metamorphosis, the protoconch darkens to warm tan; the teleoconch is predominantly cream.

Terebra (Hastula) penicillata Hinds 1844. Plate LXXXV, fig. b.

Veliger:

Protoconch: conic, inflated; columella straight; sutural cords not well developed; smooth; light tan.

Velum: unpigmented, four-lobed.

Viscera: digestive gland light tan; intestine charcoal gray.

Months found in plankton: July - October

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of this species hatch when 1 1/4 whorls are complete, add three more whorls and settle at lengths between 900 and 1000 μm when 4 - 4 1/2 whorls are complete. Upon metamorphosis, the protoconch develops orange-brown stains in its crevices. The teleoconch is cream with brown streaks.

Terebra (Hastula) inconstans (Hinds 1844). Plate LXXXV, fig. c.

Veliger:

Protoconch: attenuate, inflated-conical to narrow, peg-like; small; smooth; tan-cream.

Velum: unpigmented, four-lobed.

Viscera: digestive gland light gold; intestine brown.

Months found in plankton: May through July

Areas found: Sampan Channel

Remarks: These veligers hatch when one whorl is complete, add 2 - 2 1/2 more whorls and settle from the plankton when columellar lengths approximate 650 - 850 μm. 3 - 3 1/2 whorls are complete. Upon metamorphosis, the protoconch becomes opaque cream-tan in most, purple-brown in some individuals, and intermediate combinations in many. The variability seen in the adults is also manifest in the larvae.

Terebra (Hastula) strigilata (Linnaeus 1758). Plate LXXXV, fig. d.

Veliger:

Protoconch: peg-like, third whorl inflated; apical whorl broad; ex capsulo sutures corded; smooth, glassy; transparent, light tan.

Velum: unpigmented, four-lobed; length of each lobe approximates length of protoconch.

Cephalic area: esophagus charcoal; right tentacle longer than left at metamorphosis.

Foot: propodium lightly tinged with charcoal-gray on light tan background.

Viscera: anterior half of tissues in body whorl black; body tissues light tan; digestive gland golden brown; intestine black.

Months found in plankton: May, June

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of T. strigilata are commonly netted in Sampan Channel. They hatch when one whorl is complete, add two more whorls while planktonic, then settle when columellar lengths approximate 875 - 975 μm, when 3 1/4 - 3 1/2 whorls are complete. Upon metamorphosis, the posterior parts of the protoconchal whorls are cream-caramel or stained with dirty red. The anterior parts of the whorls are dark reddish brown. The teleoconch has a gray background.

Terebra (Hastula) plumbea Quoy and Gaimard 1832. Plate LXXXV, fig. e.

Veliger:

Protoconch: conical, sides straight; ex capsulo whorls with light sutural cording; smooth; transparent cream; sutures and columella tinged with caramel.

Velum: ciliary bases edged with charcoal; four-lobed.

Foot: mesopodium tinged with gray, remainder unpigmented; not as large as that of T. nitida.

Viscera: digestive gland brown; intestine charcoal gray.

Months found in plankton: August

Areas found: Sampan Channel

Remarks: Veligers of this species hatch when 1 1/2 whorls are complete, add 3 - 3 1/2 more whorls, then metamorphose when columellar lengths approximate 925 - 1025 μm and 4 1/2 - 5 whorls are complete. Upon metamorphosis, the protoconch becomes opaque red-brown with blotches of red-caramel. The background color of the teleoconch is dull gray.

Terebra crenulata (Linnaeus 1758) Plate LXXXV, fig. f.

Veliger:

Protoconch: fusiform-conical, attenuate, sides straight; smooth; light tan.

Velum: unpigmented, four-lobed.

Viscera: digestive gland golden; intestine charcoal gray.

Months found in plankton: April, May June, July, August, September

Remarks: This species is commonly netted in the plankton. The larvae settle when the length approximates 1 mm with 4 1/4 complete whorls. Upon metamorphosis, the protoconch becomes opaque cream.

Terebra areolata (Link 1807). Plate LXXXV, fig. g.

Veliger:

Protoconch: peg-like, apical whorl broad; smooth, light tan.

Velum: unpigmented, four-lobed.

Viscera: digestive gland golden; intestine charcoal gray.

Months found in plankton: July, August

Remarks: This species is uncommonly netted. Apparently, the veligers hatch when one whorl is complete, they add 2 1/2 whorls while planktonic and settle when between 725 and 875 μm in length with 3 1/2 whorls complete. Upon metamorphosis, the protoconch becomes opaque and varies in color from cream to yellow-tan.

Plate LXXXV

Terebridae

Figure a. *Terebra maculata*

b. *Terebra* (*Hastula*) *penicillata*

c. *Terebra* (*Hastula*) *inconstans*

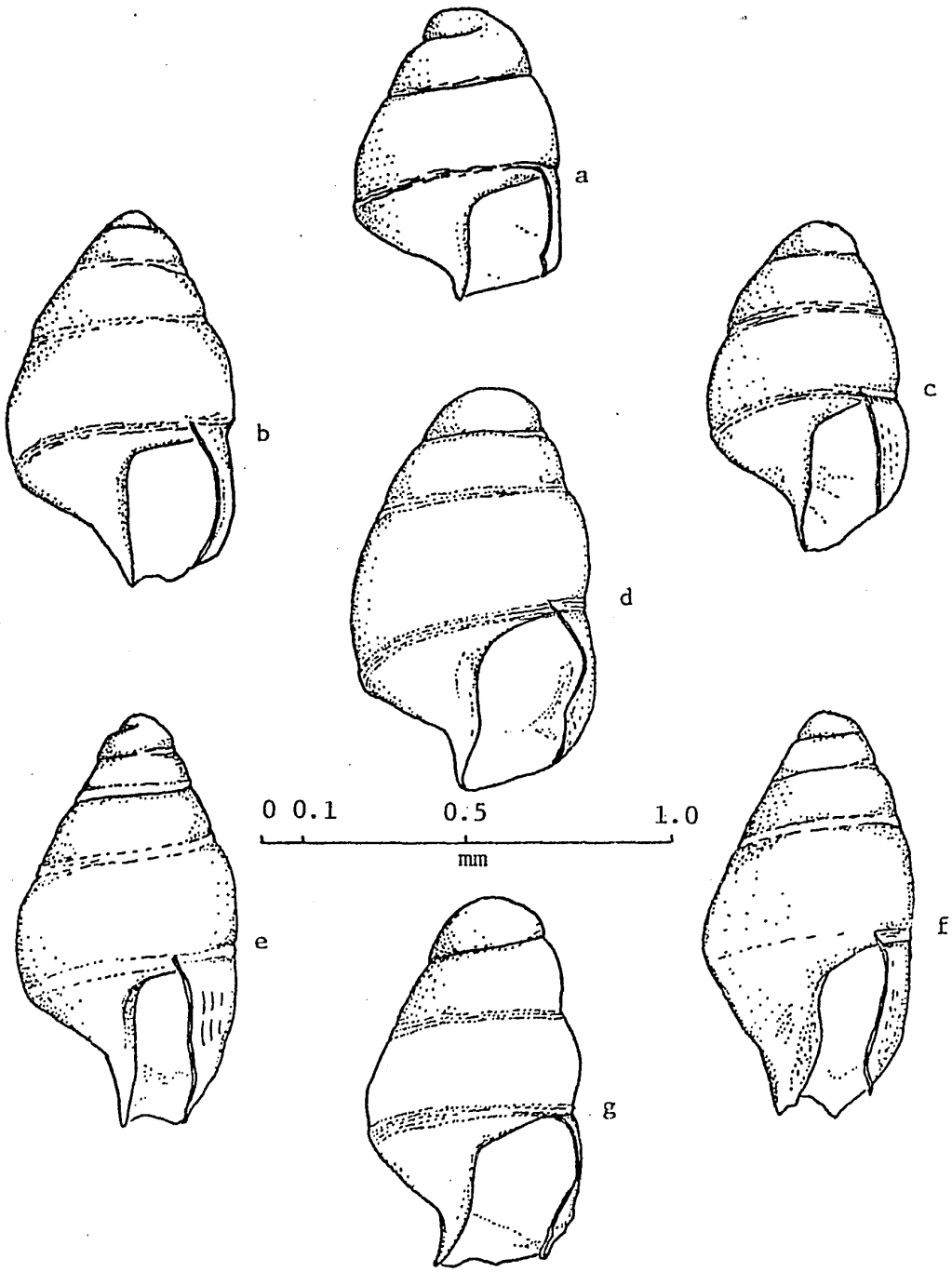
d. *Terebra* (*Hastula*) *strigilata*

e. *Terebra* (*Hastula*) *plumbea*

f. *Terebra* ?*crenulata*

g. *Terebra areolata*

PLATE LXXXV



Terebridae

Terebra (Hastula) lanceata (Linnaeus 1767). Plate LXXXVI, fig. a.

Veliger:

Protoconch: attenuate, fusiform; smooth; ex capsulo sutures corded; light tan.

Velum: unpigmented, four-lobed.

Viscera: digestive gland light gold; intestine light charcoal gray.

Months found in plankton: July through September.

Areas found: Sampan Channel, Dredged Island

Remarks: Veligers of T. lanceata are among the largest of the terebrid veligers. They hatch when 1 - 1 1/2 whorls are complete, generally add four more whorls and settle with columellar lengths between 1.2 and 1.6 mm when 4 1/4 to 5 1/2 whorls are complete. After metamorphosis the protoconch is a warm tan, but the teleoconch is cream with red-brown axial streaks.

Terebra affinis Gray 1834. Plate LXXXVI, fig. b.

Veliger:

Protoconch: fusiform, apex attenuate; smooth; orange-pink; sutures caramel; columella stained with red-brown.

Velum: unpigmented, four-lobed.

Viscera: digestive gland brown; intestine charcoal gray; remainder of body tissues colorless.

Months found in plankton: June, July, August

Areas found: Sampan Channel

Remarks: This species is commonly found in the plankton. It apparently hatches when 1 1/4 whorls are complete, adds three more whorls, then settles when the protoconchal length is 1.0 - 1.1 mm with 4 1/4 - 4 3/4 whorls complete. After metamorphosis, the protoconch becomes opaque rosy caramel and the teleoconch is initially flesh-colored, then yellow or cream blotched with brown.

Terebra nitida Hinds 1844. Plate LXXXVI, fig. c.

Veliger:

Protoconch: conical, slightly inflated; sutures corded on whorls formed ex capsulo; transparent, light peach; smooth; sutures and columella caramel.

Velum: ciliary bases edged with charcoal; periphery of velar lobes suffused with yellow-orange; four-lobed with elongate lobes.

Foot: propodium muscular, well-developed; tissues unpigmented except for mesopodium lightly tinged with gray.

Viscera: digestive gland tan-brown with charcoal tinges; intestine charcoal.

Months found in plankton: May

Areas found: Sampan Channel

Remarks: Veligers of T. nitida hatch when one whorl is complete, add three more while planktonic and settle when 1.0 - 1.1 mm in length with 4 - 4 1/4 complete whorls. After metamorphosis, the protoconch darkens variably to dark brown or dark purple. The remainder of the teleoconch is light gray to cream-tan.

Terebra (Hastula) albula Menke 1843. Plate LXXXVI, fig. d.

Veliger:

Protoconch: fusiform, attenuate with light axial threading marking periodic pauses in protoconch deposition; ex capsulo sutures corded; apex vivid rose-pink, lightly punctate; ex capsulo whorls light magenta pink, smooth, glassy.

Velum: unpigmented, four-lobed.

Viscera: digestive gland light brown; intestine charcoal gray.

Months found in plankton: August, September

Remarks: Veligers of T. albula vie with those of Terenolla pygmaea and T. lanceata for the title of largest terebrid veliger. Veligers of T. albula hatch when 1 1/2 - 2 whorls are complete, add 3 1/2 more whorls while in the plankton, then settle at variable lengths from 1.1 to 1.4 mm when five whorls are complete. After metamorphosis, the protoconch darkens to magenta pink or dark purple. The teleoconch becomes white streaked with orange.

Terebra flavofasciata Pilsbry 1921. Plate LXXXVI, fig. e.

Veliger:

Protoconch: fusiform-conical, attenuate; smooth; sutural cording not conspicuous; capsular protoconch light peach-lavendar, the remaining whorls caramel.

Velum: unpigmented, four-lobed.

Viscera: digestive gland golden; intestine charcoal gray.

Months found in plankton: July, August, September

Remarks: These veligers hatch when 1 1/2 whorls are complete, add 3 1/2 additional whorls while planktonic, settle out when they are 1.15 - 1.25 mm in length and have completed five whorls. After metamorphosis, the protoconch becomes opaque peach.

Plate LXXXVI

Terebridae

Figure a. Terebra (Hastula) lanceata

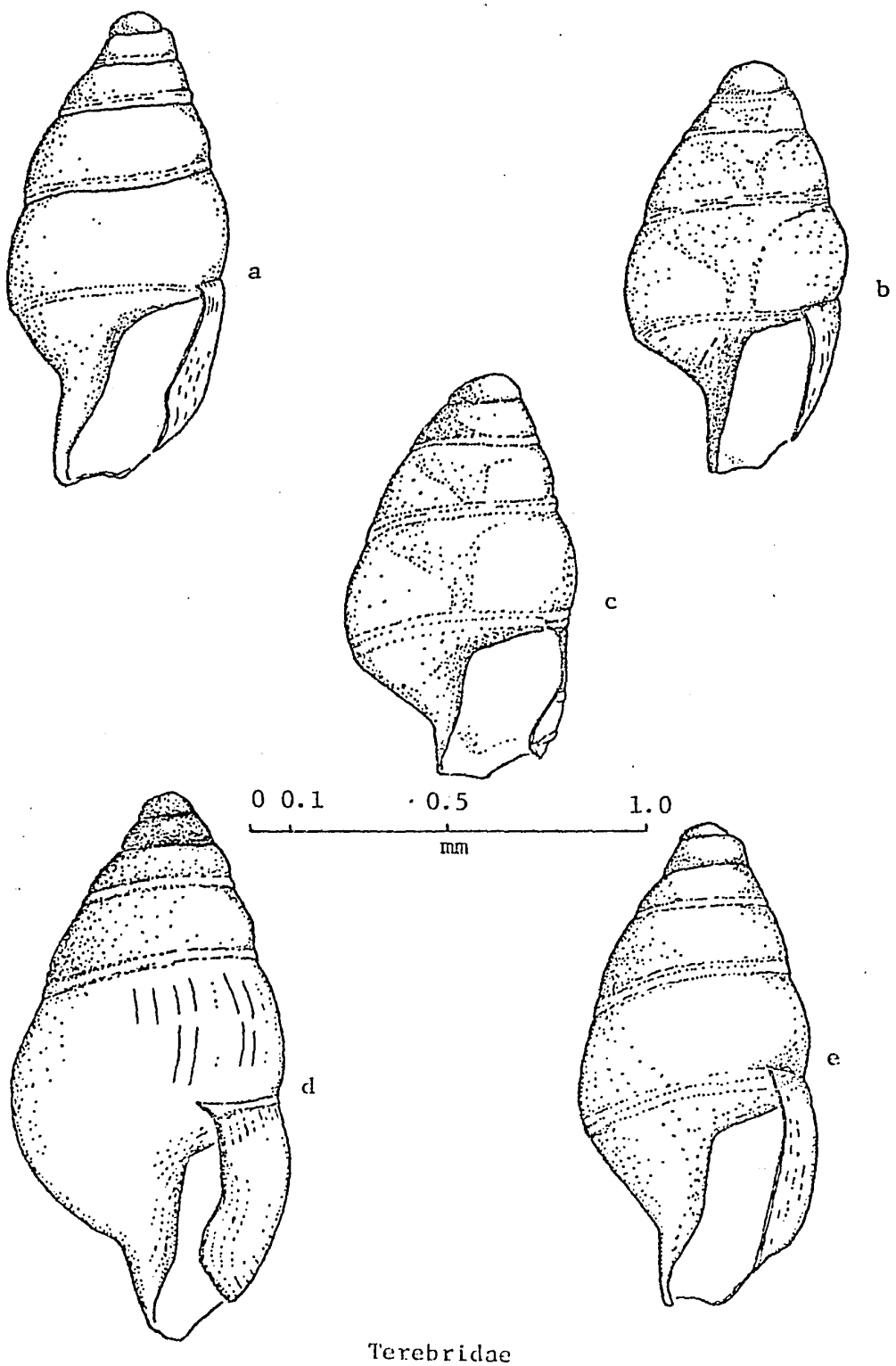
b. Terebra affinis

c. Terebra nitida

d. Terebra (Hastula) albula

e. Terebra flavofasciata

PLATE LXXXVI



Terebridae

Experimental section

Crucibulum spinosum (Sowerby): larval ability to tolerate heat stress.

Tolerable temperature ranges of marine larval forms are generally narrower than those of conspecific adults (Anon. 1963; DeSylva 1968) although data provided by Costlow (1968) contradict this generalization. A few investigators (Loosanoff 1959; Scheltema 1967) have studied temperature effects on marine molluscan larvae reared in the laboratory, but the upper thermal tolerance limits for marine larval forms collected from the plankton are virtually unknown.

Veligers of Crucibulum spinosum, a limpet of the family Calyptraeidae, were selected for larval thermal tolerance study because in Kaneohe Bay, Oahu, they are the only gastropod veligers amenable to experimentation which are dependably in the plankton.

C. spinosum has an Indo-Pacific distribution and the adults are abundant on sublittoral rocks and dead coral in Kaneohe Bay. The eggs are incubated (Coe 1938c) and, after an intra-capsular life of 2-3 weeks, the larvae hatch at the 1 1/2 whorl stage as early veligers. The veligers remain in the plankton for a minimum of two weeks, then settle and metamorphose. They are large (350-750 μm) and transparent enough for the investigator to discern readily the condition of major anatomical structures and thus their general physiological state.

Plankton samples were collected from Kaneohe Bay during July and August by towing a net, mesh 330 μm, at low speed for 15-20 minutes. The water temperature at the time of collection showed only slight (±0.5°C.) fluctuations around 27°C. Sample material was transferred to clean aquaria; C. spinosum veligers were separated from other plank-

tonic components and pipetted into a liter beaker of Cuno-filtered (Aqua-pure water filter with cartridge no. P110, Cuno Engineering Corp., Meriden, Conn.) sea water. In all experiments except those at 30°C., a new cartridge was installed immediately before drawing the filtered sea water, thus insuring against contamination of the sea water by toxic metabolites from decomposing brown algal particles trapped in the filter. The filter removes all particles larger than 5-10 μm.

Actively swimming veligers of a size 500-750 μm were divided into two groups of a hundred, each of which was transferred to 200 ml of filtered sea water in a 400 ml beaker. This depth of water allowed adequate vertical movement. One group, the control, was maintained at 27°C.±0.5°C.; the other at a higher experimental temperature. Experimental temperatures were begun at 30°C. and were raised successively until very short exposure times were necessary to produce death of all veligers in the experimental containers. Veligers were fed with Phaeodactylum tricornutum every 24 hours; the beakers were kept in incubators under constant illumination. To eliminate considerations of individual variation within the experimental populations, the results are expressed as TD-50's (see Fig. 5 , =LD-50),--measures of tolerance which indicate the time required for 50 per cent of the experimental population to die.

Diurnal sea water temperature of the areas from which the veligers were collected during the summer varies through 1°C. (Bathan 1968), approximately 1/8 of the annual temperature range for those areas.

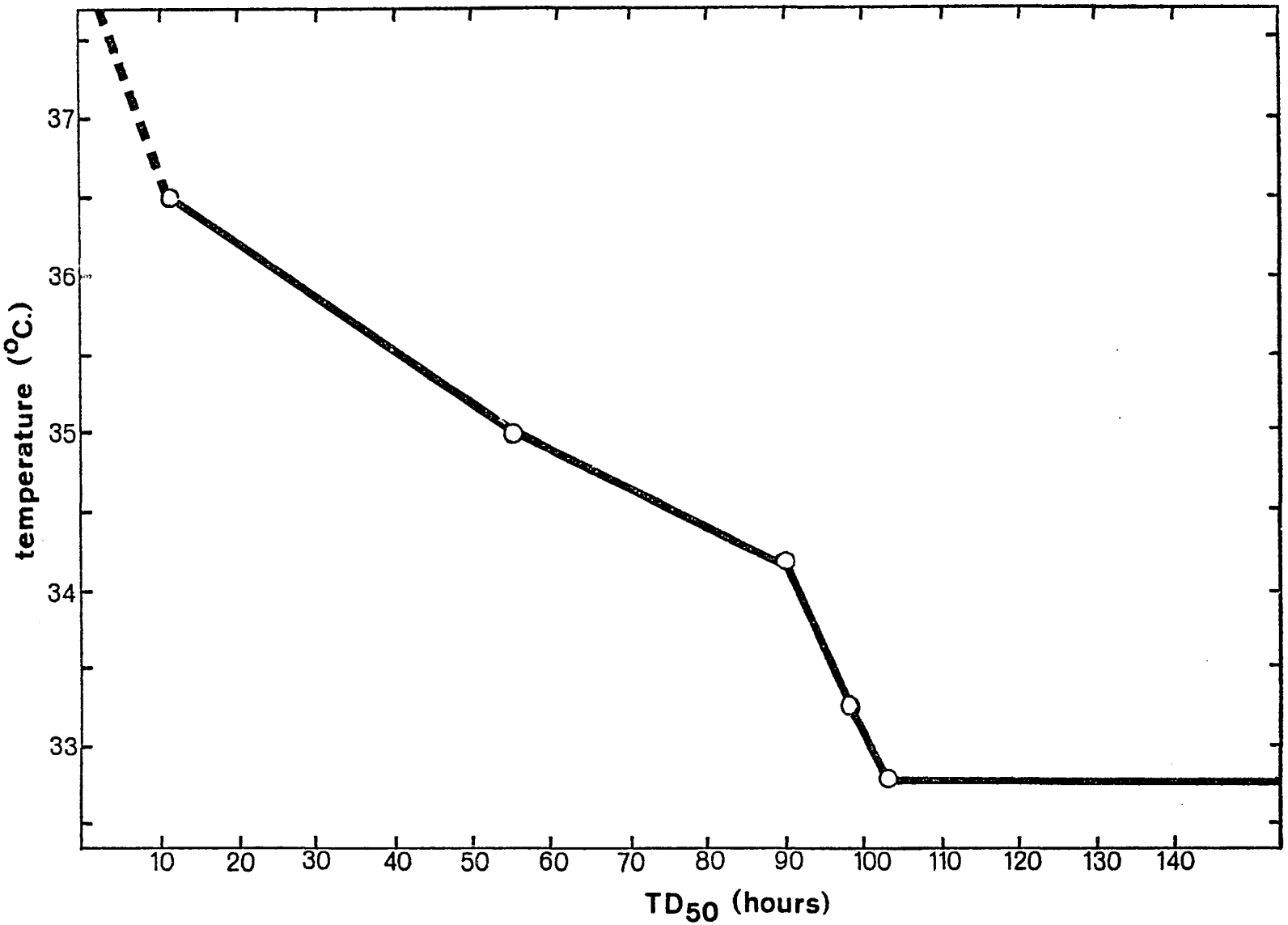


Figure 5. HEAT STRESS EFFECTS: CRUCIBULUM SPINOSUM

Direct transfer of larvae to temperatures considerably higher than ambient is disadvantageous (Allen and Nelson 1911); however, the relatively high specific heat of sea water allows a period of gradual acclimation to experimental temperature. After placing the beakers in incubators set at 36.5°C., approximately two hours are required for 200 ml of sea water in a 400 ml beaker to increase from 27°C. to the surrounding temperature. The sea water was renewed in the beakers every 24 hours. At this time, the larvae were transferred to a petri dish containing sea water at the experimental temperature and fed with Phaeodactylum for 20 minutes. Renewal of sea water and a minimal feeding period kept microorganisms deleterious to the larvae at a minimum.

The animals in the beakers were counted periodically at intervals varying with the temperature (Fig. 6). At each census, dead animals were removed from the beakers.

Active, healthy veligers exhibit strong ciliary activity. The regularly-pulsating larval heart is readily visible and the digestive gland has a golden color. Unhealthy animals display weakened ciliary activity and heart beat and heat coma effects (Heilbrunn et al. 1946) become manifest. Dead larvae are recognized by complete cessation of velar ciliary motion and heart beat, accompanied by deterioration of body tissues. Visceral organs are indistinct and contracted away from the shell.

If a freely-swimming individual with a velum could not yet use its foot in crawling, it was labelled a veliger. If it could both swim and crawl, the individual was designated a veliconcha and was grouped

Table 37. Data: Thermal Stress Experim

Temperature (°C.)	Elapsed Time (hrs.)	Number of Individuals Dead in Control	Number of Individuals Dead in Experiment	Corrected Percen
36.5	0	0	0	0
	6	0	0	0
	12	0	100	100
35	0	0	0	0
	6	0	0	0
	12	1	4	3
	24	2	20	18
	36	4	100	96
34.3	0	0	0	0
	16	0	0	0
	33	1	12	11
	64	3	75	72
33.8	0	0	0	0
	14	0	1	1
	41	1	8	7
	88	4	56	52
33	0	0	0	0
	42	0	1	1
	90	4	22	18
	118	7	41	34
30	0	0	0	0
	48	0	0	0
	96	1	31	30
	120	2	36	34
	164	4	44	40

Corrected Percent Mortality = the number of individuals dead in th
dead in the control container.

cont. = the number of individuals in the control container.

exp. = the number of individuals in the experimental container.

in Corrected Percent Mortality	Numbers of Individuals Alive as Veligers		Juveniles		Benthic with Velum	
	cont.	exp.	cont.	exp.	cont.	exp.
0	100	100	0	0	0	0
0	100	29	0	3	0	68
100	100	0	0	0	0	0
0	100	100	0	0	0	0
0	100	67	0	1	0	32
3	95	22	0	28	4	46
18	82	0	0	47	16	33
96	76	0	0	0	20	0
0	100	100	0	0	0	0
0	100	97	0	0	0	3
11	61	80	1	2	37	6
72	96	0	1	21	58	4
0	100	100	0	0	0	0
1	100	96	0	0	0	3
7	99	66	0	2	0	34
52	63	0	1	7	31	37
0	100	100	0	0	0	0
1	99	97	1	2	0	0
18	7	2	26	34	63	42
34	3	0	33	46	57	13
0	100	100	0	0	0	0
0	96	91	1	3	3	5
30	77	42	9	14	13	13
34	46	17	17	26	35	21
40	32	3	28	37	36	16

individuals dead in the experimental container minus the number of individuals
ntrol container.

trol container.

erimental container.

Figure 6. Mortality rate of Crucibulum spinosum pre-settlement veligers as a function of temperature. Corrected per cent mortality = per cent dead in experimental container minus per cent dead in control. After five days, larvae used in the experiments were returned to the control temperature (27°C.) to determine abeyant responses.

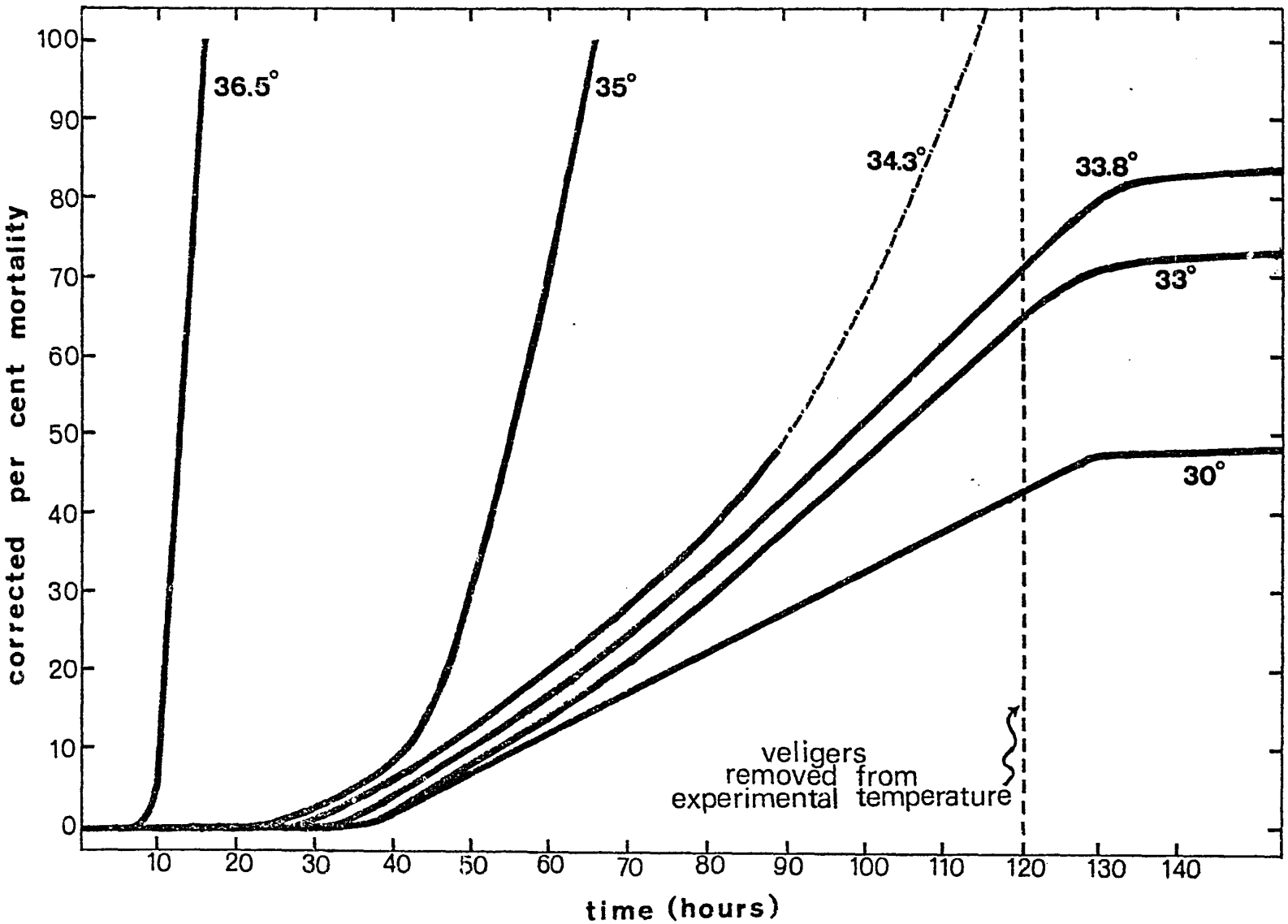


Figure 6. HEAT STRESS EFFECTS: CRUCIBULUM SPINOSUM

with the veligers in the graphs. Those with the velum either absent or not functional in swimming were termed totally benthic. Moribund animals are included with dead ones in the graph.

Two terms should be defined before discussing experiments dealing with exposure to different types of stress. If a stimulus is continually being applied, latent period is defined as the interval between initiation of the stimulus and the beginning of a response. Abeyant responses are defined as responses which appear after the stimulus either has been withdrawn or has lost its initial effectiveness. Within the range of experimental temperatures employed, length of latent period varies inversely with temperature. Abeyant responses were noted in those experimental lots subjected to temperatures less than 34°C.; these were expressed within 24 hours after withdrawal from the experimental temperature and transferral to the control temperature. Thereafter, there is little difference in the rates of mortality between the experimental and control groups.

Higher than ambient temperatures induce a physiological response in the veliger to cease swimming and become totally benthic. Veligers at higher experimental temperatures metamorphose successfully; others at these temperatures fail to complete metamorphosis. The control group (at 27°C.) and the experimental groups experienced different lengths of time required for individuals to become totally benthic. The corrected per cent of totally benthic individuals, i.e., the number of individuals totally benthic at a specific experimental temperature minus the number of totally benthic individuals in the control group, is graphed as a function of time elapsed in Figure 6 . These differ-

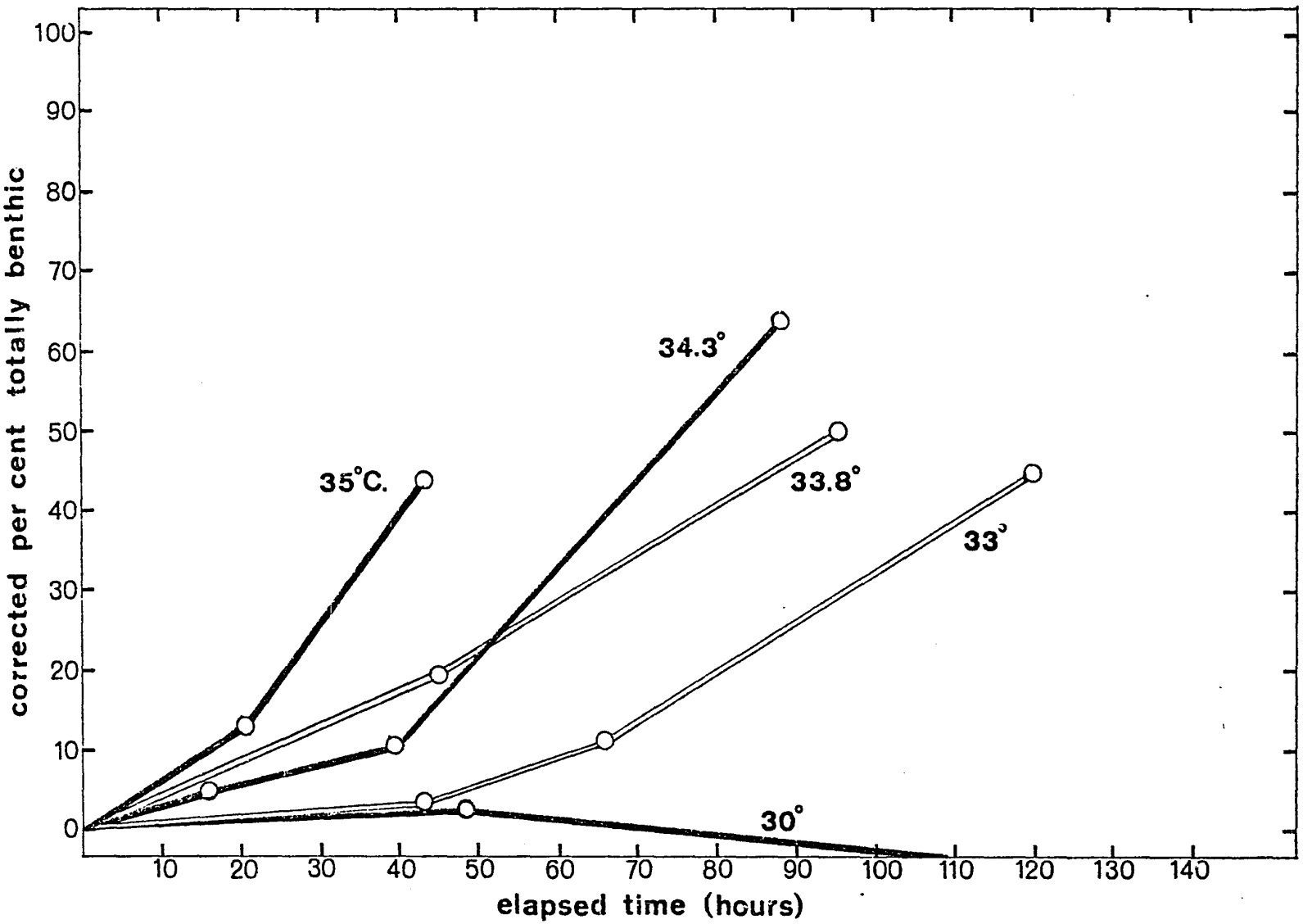


Figure 7. HEAT STRESS EFFECTS: CRUCIBULUM SPINOSUM

ences in lengths of time at which the larvae become totally benthic are highly significant (chi-square, p=0.001) at 35°C. after 22 hours, at 34.3°C. after 41 hours, at 33.8°C. after 96 hours and at 33°C. after 120 hours.

Temperatures ranging from 30°C. to 36.5°C. produce highly significant increases in death rates in experimental groups as compared with control groups. At 30°C., these differences in per cent mortality become significant (p=0.01) after 67 hours, at 33°C. after 53 hours (p=0.001), at 35°C. after 35 hours and at temperatures above 36.5°C. within 8-9 hours (p=0.001, see Fig. 7).

Transfer of Crucibulum spinosum larvae to temperatures only a few degrees higher than that of ambient sea water appears to be one factor which induces the veliger to become benthic and metamorphose. This agrees with Thorson's statement (1950) that length of time spent in the plankton is a function of temperature. Once the veligers have metamorphosed, they are more capable of living at continuously high temperatures than are the veliger stages. Virtually all which survived exposure to high temperatures had metamorphosed.

The Kaneohe Bay population of C. spinosum serves as one example of a subtropical gastropod whose larvae live only a few degrees below their maximal thermal tolerance. Since marine larvae generally demonstrate greater sensitivity to high temperatures than do adults (DeSylva 1968), the effect of thermal pollution would be felt initially on larval stages and would be evident first in waters that do not mix efficiently. In such waters, the potential exists for early settlement and/or massive elimination of planktonic organisms.

C. spinosum veligers demonstrate a mortality rate significantly higher than normal within 53 hours at 33°C. If such effects are found in other organisms, those who have the responsibility for determining the location and design of industrial plants which continually discharge effluent heated to 30°C. or greater may well be advised to establish their outfalls in deep, rapidly-mixing areas and not in poorly-flushing bays or estuaries where a clear danger exists that thermal increase may not remain a local phenomenon, but may affect large volumes of water.

Crucibulum spinosum(Sowerby): larval ability to tolerate linear alkyl sulfonate.

The discharge of detergent wastes into rivers and estuaries is another example of a modern environmental stress, the effects of which vary with concentration and extent of degradation by bacteria. Because the use of detergents is ubiquitous in the United States, it is important that we understand the extent to which detergent wastes affect the ecosystem into which they are liberated. Woodwell (1970) points out that the groups of organisms which are most affected, whether they be consumers, decomposers or producers, adults or larval stages, determine the subsequent character of the ecosystem. If larval populations are affected to a degree greater than are the adults, entire generations may be obliterated and their absence may remain undiscovered until the loss is irrevocable. The effects of the disaster need not remain a local phenomenon if the area of stress is a source area of recruits for other distant populations.

Several investigators (Hidu 1965; Calabrese and Davis 1967; Corner et al. 1968; Wilson 1968a) have studied detergent effects on marine larvae reared in the laboratory, but thus far no experiments have utilized prosobranch larvae, and the extent of effects due to detergents to the plankton community as a whole is largely unknown.

On June 30, 1965, detergent manufacturers in the United States converted from making detergents of the alkyl benzene sulfonate (ABS) type, which biodegrade slowly, to the linear alkyl sulfonate (LAS) type, which are quickly biodegradable (Brenner 1965). The breakdown of detergents in sewage (Brenner 1965; Renn 1965) and elsewhere (Swisher et al. 1964)

has been discussed several times, as have methods of analyzing water thought to contain detergents (APHA, Inc., N.Y., 1960; Gardner 1967). Characteristics which distinguish detergents, surfactants and soaps are defined in the Appendix B.

Two ampoules of reference LAS (linear alkyl sulfonic acid) were obtained from the Soap and Detergent Association, Technical and Materials Division, 485 Madison Avenue, New York, N.Y., 10022. Information which describes the contents of the ampoules accompanied the samples and is included in the Appendix (B).

The LAS stock solution was prepared as follows: 50 ml of the contents of the LAS ampoule were transferred to a one-liter volumetric flask, which was then filled to volume with distilled water at 20°C. The resulting stock solution (LAS = 1,980 mg/l, or ppm) was stored in the volumetric flask, which was wrapped with aluminum foil and refrigerated at 5°C. For the amount of error in using these pieces of chemical apparatus, as well as the calculation of total error, see Appendix C.

The 1,980 ppm LAS stock solution then was used to prepare a stock solution of LAS in sea water. A 20 ppm concentration of LAS in sea water was used to allow for possible comparisons of results with those reported by other investigators (Schmid and Mann 1961; Cairns et al. 1964; Hidu 1965; Calabrese and Davis 1967; Corner et al. 1968; Wilson 1968a).

Fresh sea water was obtained near Buoy One in Sampan Channel (see Appendix A) in Kaneohe Bay, filtered to remove all particles greater than 50 μm and cooled to 20°C. 10.1 ml of the LAS stock solution were

mixed with fresh filtered sea water to produce one liter of 20 ppm LAS in sea water stock solution. The 100-fold dilution of the 1,980 ppm stock solution results in a solution of LAS in sea water that is essentially identical in mineral content with that of sea water.

Experimental mixtures of LAS in sea water with concentrations of one to ten ppm must be freshly prepared because LAS is degraded easily and loses its detergent activity quickly when exposed to sea water, warmth and sunlight. Various quantities (Appendix D) of the 20 ppm stock solution were pipetted into clean, dry petri dishes. Appropriate volumes of fresh, filtered sea water were added to each petri dish to yield a total volume of 40 ml in each. Each petri dish was swirled ten times, mixing the LAS and sea water. Twenty pre-settlement veligers of Crucibulum spinosum which had been netted that same day were placed in each dish, incubated at 25°C., and the times of addition were noted. The frequency of subsequent observations varied with the concentration of detergent. During each period of observing the effects of LAS, if dead or moribund veligers were counted, they were removed from the experimental solution, placed in fresh sea water and observed from time to time to determine the larval capacity to recover from the effects of LAS.

The results of the first two trials influenced the experimental design of subsequent trials. In the first trial, all veligers in the 10 and 20 ppm dishes were dead within eight hours. These results prompted further investigation in the 1-10 ppm range so that the sequence of events culminating in death could be observed in greater

Table 38. The effects of linear alkyl sulfonate on the larvae and juveniles of Crucibulum spinosum.

	ppm 0		1		2		2.3		2.6		3		3.3		3.6		4		5		10	
hrs. read	df	%	df	%	df	%	df	%	df	%	df	%	df	%	df	%	df	%	df	%	df	%
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0											0	0	0	0	0	0			80/80	100
16	0	0	0	0	0	0													80/80	100		
20	0	0					0	0	0	0	5/100	5	7/40	17.5	20/40	50	90/100	90				
30	0	0									40/100	40	23/40	57.5	39/40	97.5						
40	0	0	0	0	8/60	13.3					78/100	78	40/40	100								
46	0	0	1/60	1.7	12/60	20																
48	0	0					9/20	45	14/20	70	92/100	92										
64	0	0	1/60	1.7	13/60	21.6																
72	0	0					12/20	60	16/20	80	95/100	95										
92	0	0	2/60	33	14/60	23.3																
116	0	0	2/60	33	14/60	23.3																

df, datum fraction = $\frac{\text{number of dead C. spinosum veligers and juveniles}}{\text{total number of experimental individuals at a specific concentration}}$

hrs. read indicates the amount of time elapsed since the beginning of the experiment.

ppm = parts per million, = mg/l

detail.

In the second trial it seemed evident after 48 hours that the critical region of LAS effect lay between 2 and 4 ppm for pre-settlement veligers of C. spinosum under these experimental conditions. Solutions of intermediate concentrations in this range were prepared, as well as repetitions of the 3, 4, 5, and 10 ppm solutions to check the reproducibility of symptoms observed at these concentrations and to check the strength of the 1,980 ppm stock solution. In each new trial, fresh sea water and veligers were obtained on the same day as experimentation began.

When a veliger is exposed to LAS, a specific sequence of physiological responses occurs; the intervals of time which separate these physiological responses decrease as concentration of LAS increases, but the sequence stays essentially the same. The first response by veligers exposed to concentrations greater than 3 ppm is the dissolution of purple-black pigment granules from the dorsal region of the mantle. As a result, a pink-purple substance diffuses through the pallial fluid. Veligers then retract into the protoconch for varying lengths of time. The frequency of heartbeat slows and becomes sporadic. After a while (length of time depends on concentration of LAS), the velum is extended hesitantly, and soon afterward, the pre-oral cilia become dislodged from their supportive cells. Several hours later, all cilia are dislodged and cells from the velum are also lost; the velum soon acquires a ragged appearance.

In concentrations of 3 ppm or less one observes first the swelling

and shortening of the cephalic tentacles followed by dissociation of the pre-oral cilia and dissolution of some pigment granules in the pallial fluid. Although there is little vertical movement and there are few examples of metamorphosis, the veligers swim actively along the bottom of the petri dish. The major effects of exposure to LAS are not manifest in the 2 ppm LAS petri dishes until 40-64 hours have elapsed.

The toxicity of LAS under these experimental conditions apparently begins to wane 43-65 hours after the LAS stock solution is mixed with sea water. Veligers introduced to the LAS-sea water mixtures two days after they were prepared were noticeably less damaged than those exhibited by veligers exposed to freshly-prepared mixtures. Rigorous experiments were not conducted on this aspect of the problem; only a few veligers were exposed to two-day-old 4, 5, and 10 ppm LAS solutions. The veligers were observed eight hours after the initial introduction to the two-day old mixtures and it was noted that a greater percentage was alive and well --swimming around the petri dish --than were observed in the freshly-prepared solutions of similar proportions of ingredients.

Numerical data from the LAS experiments are summarized in Table 38 and presented graphically in Fig. 8 . For raw data obtained, see Appendix E.

The data are straightforward and consistent. Total error is very small, --on the order of 0.57% for each of the experimental concentrations (i.e., the 10 ppm solution may be expressed as 10 ppm ±0.057 ppm)

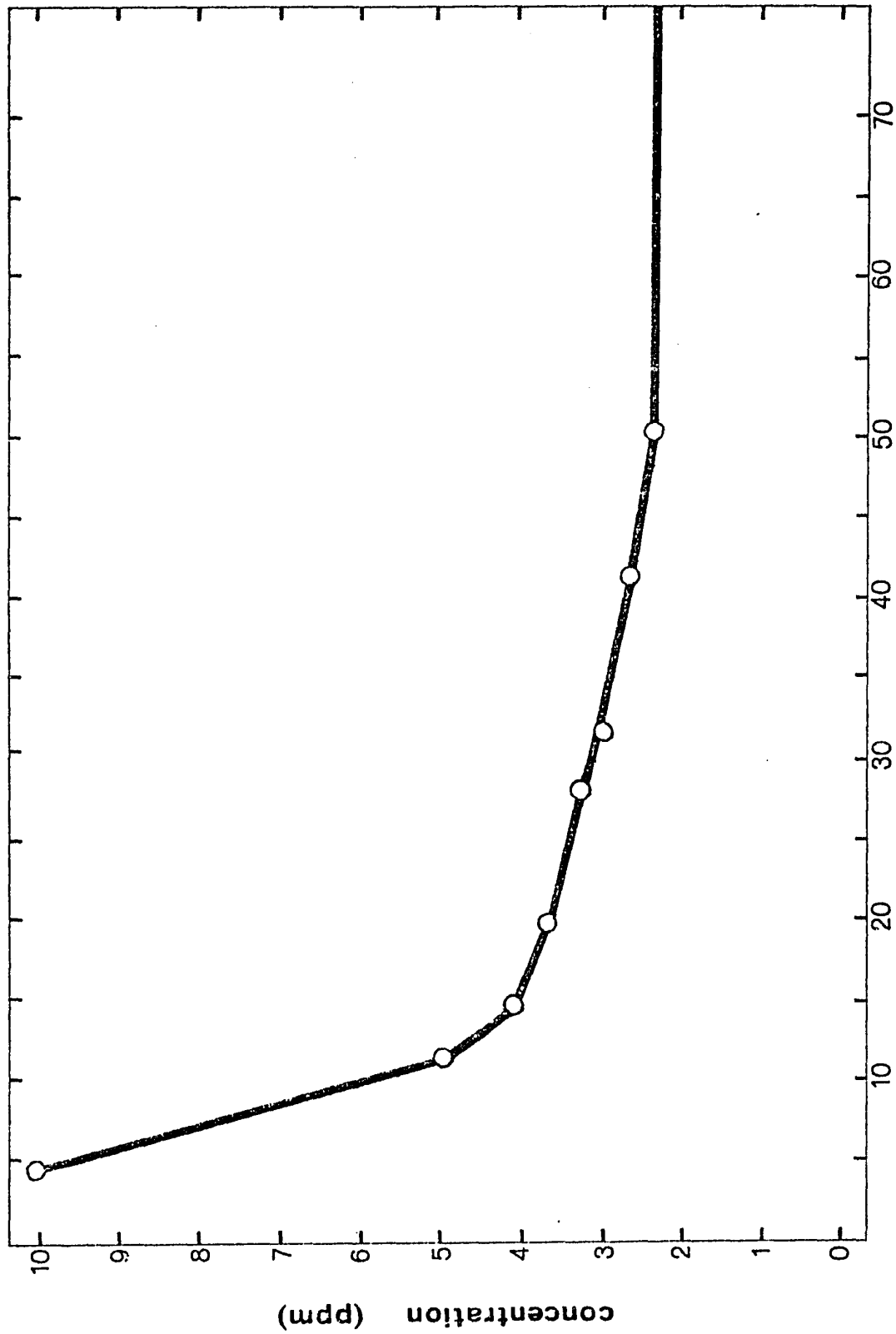


Figure 8. DETERGENT STRESS EFFECTS: CRUCIBULUM SPINOSUM

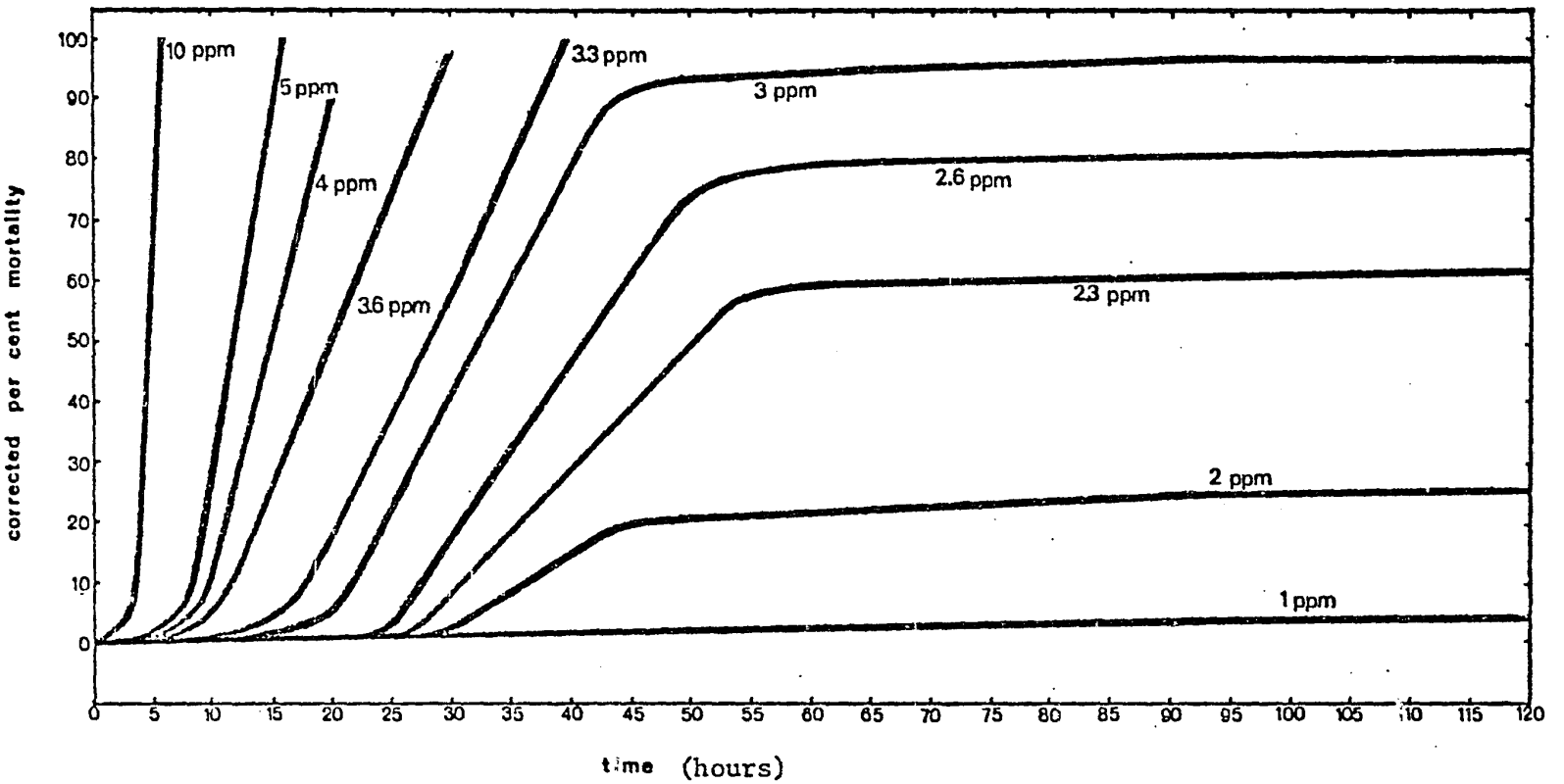


Figure 9. DETERGENT STRESS EFFECTS: CRUCIBULUM SPINOSUM

[see Appendix C].

The results depicted graphically in Fig. 8 agree favorably with those of other workers in the field. Qualitatively, veligers of C. spinosum exhibit some of the physiological responses previously noted by investigators working with other organisms: loosely-bound surface epithelial tissues were severely damaged (previously observed to occur in freshwater fish: Schmid and Mann 1961; Dooley 1968), ciliary activity was slowed or stopped, cilia were shed from cell bodies; also observed were autolysis and increased opacity of cytoplasm, indicative of denaturation (Rockstroh 1967). Quantitatively, veligers of C. spinosum react to concentrations similar to those evoking debility in Elminius modestus (a barnacle), Sabellaria spinulosa (a polychaete), Gambusia affinis (the mosquito minnow), and various crustaceans (marine forms) utilizing toxic agents both similar to LAS (BP 1002; ABS) and different from LAS ($HgCl_2$), (Corner and Sparrow 1956; Corner et al. 1968; Dooley 1968; Wilson 1968), i.e., the experimental range of solutions is most informative in the 1-5 ppm range. It is interesting that the continuous chitinous cuticle of Elminius modestus larvae does not protect those larvae noticeably better than the exposed epithelium of C. spinosum veligers. Possibly BP 1002 (which is a mixture of three components, a solvent, a surfactant, and a stabilizer and is used as an oil-spill remover) is more concentrated than my sample solutions of LAS.

Rockstroh (1967) states that the period of latency depends on four factors: (1)concentration of the experimental solution, (2)type of detergent (anionic, cationic and non-ionic), (3)temperature and

(4)resistance of cells and tissues concerned. In these experiments, the only applicable (i.e., measured) variable of the above four was that of concentration. The period of latency varied from six to forty hours with experimental concentrations ranging from 1 to 10 ppm; the greater the concentration, the shorter the latent period.

There has been much speculation with reference to possible modes of action of detergents (Crisp et al. 1967; Manwell and Baker 1967; Corner et al. 1968). Some believe that enzyme inhibition and/or denaturation are caused by the presence of detergents. Others (Corner et al. 1968) think that toxic effects of detergents in low concentrations are due to causes other than enzyme inhibition and that some physical (presumably as opposed to chemical) effect is involved.

My observations suggest that toxicity exerts its greatest effect on loosely-bound epithelial tissues. Cell membranes develop fissures and their granular components are liberated; superficial cells are detached from each other and the veliger's protective epithelium is destroyed. In low concentrations of LAS (i.e., <4 ppm), death apparently is not of the neurotoxic sort, --the latent period is too long for that possibility to deserve much consideration --rather it would seem to be a result of epithelial damage and internal destruction of membranes.

One of the chief functions of the cell membrane is to regulate the exchange of raw materials and waste products. In the absence of this function, metabolism ceases and death ensues. Another area of damage to the veligers apparently is caused by the capacity of the detergent to break links between cells. The mechanism by which this is brought about is unknown. Presumably, the detergent molecules compete more

favorably for the calcium ions which are constituents of the bridges

Detergents enter Kaneohe Bay primarily as a component of sewage effluent. Recent analyses of sewage provide values for detergents in sewage (Gray and Lau 1970; Young et al. 1970).

Conclusions - Detergent Experiments

1) Toxicity of LAS in concentrations under these experimental conditions begins to lessen 43-65 hours after the LAS stock solution is mixed with sea water. Presumably LAS is degraded noticeably after 43 hours.

2) The process of toxification by LAS is, in some cases, a reversible phenomenon; if veligers are removed to fresh sea water lacking detergent, some recover if the transfer is effected before the velum is critically damaged. There are few, if any, abeyant responses as a result of exposure to LAS.

3) The toxicity associated with LAS-in-sea-water concentrations of 3.3 ppm or greater is too great for any exposed veligers to outlive the duration of toxicity.

4) Concentrations critical to the survvival of Crucibulum spinosum veligers lie between two and four ppm for exposure times of approximately 48 hours at 25°C. If the larvae survive this period, they generally survive until the end of the experiment.

5) The latent period associated with exposure to LAS is short and varies inversely with the concentration.

Growth in Carnivorous Juveniles.

Information is available on growth rates of adult and subadult mollusks (see reviews and articles by Wilbur and Owen 1964; Loosanoff and Nomejko 1949; Dehnel 1955; Frank 1969), feeding mechanisms of larvae (Fretter and Montgomery 1968; Pilkington and Fretter 1971) and growth of molluscan herbivores (Loosanoff et al. 1951; Struhsaker and Costlow 1968). In contrast, little is known about growth rates and patterns in larval and juvenile gastropods. In particular, little is known about growth in newly-settled carnivorous gastropods whose larvae are planktonic.

The principal reason why this subject has received so little experimental attention is that carnivores are more difficult to rear than are herbivores. If adequate food is not supplied regularly, carnivores may resort to cannibalism. The quality and quantity of food requirements must be ascertained. Prey species must be kept in culture or harvested regularly. Food supply must be monitored and replenished frequently. Carrion contaminates the in vitro environment of carnivorous juveniles and invites microbial increase; accordingly, culture media must be refreshed constantly.

Many estimates of the life expectancy and replacement rates of gastropod populations are based on growth rates obtained by measuring the rate of increase in size of adults and subadults. Many investigators display a tendency to gather a few data points relating increase in size to time and to fit those points to an ortholinear growth curve. Recently, Frank (1969) pointed out that inclusion of three an-

imals smaller than 2 cm changed an apparently ortholinear growth curve into a more complex curve; his remark suggests that an effort should be made to include juveniles and younger stages of the life cycle in studies of growth. The more information amassed relating to growth patterns and growth rates of all portions of the gastropod life cycle, the more refined and reliable can be estimates of population density and productivity obtained from mathematical models.

Many of the predatory species encountered as larvae in the plankton during this study survived the critical period of metamorphosis and subsequently grew at a continuous rate in apparent good health. Growth data were recorded on as many individuals as possible from the size at metamorphosis to the size (4-8 mm) attained when ecologists begin to find them in the field and include them in their studies of growth (see Table 39). These data represent growth as it occurs under laboratory conditions when provided with an abundance of acceptable food which the juveniles may, or may not, normally encounter in situ, and under water temperatures at variance with in situ temperatures; therefore, it should be recognized that these growth rates may not parallel those occurring in nature.

Of the many reports and articles which discuss problems encountered in the analysis of growth data, several (Huxley 1932; Medawar 1945; Walford 1946; von Bertalanffy 1960 and Conway et al. 1970) were particularly helpful because they include graphical and mathematical methods useful in summarizing growth.

The composition of the plankton of different regions of Kaneohe

Table 39

Species Reared for Several Weeks to Several Months

Scientific name	Family	Maximum size (mm)
1. Phenacolepas scobinata	Phenacolepadidae	4.8
2. Theodoxus neglectus	Neritidae	7.6
3. Nerita picea	"	6.2
4. Smaragdia bryanae	"	3.6
5. Littorina pintado	Littorinidae	6.4
6. Rissoina miltozona	Rissoinidae	3.4
7. Rissoella sp.	Rissoellidae	1.5
8. Heliacus variegatus	Architectonicidae	7.8
9. Philippia oxytropis	"	10.2
10. Petaloconchus keenae	Vermetidae	2.8
11. Vermetus alii	"	1.8
12. Serpulorbis variabilis	"	2.3
13. Dendropoma platypus	"	3.4
14. Dendropoma gregaria	"	2.2
15. Dendropoma meroclista	"	1.8
16. Vermetid sp.	"	2.8
17. Cithna sp.	[Cerithiacea]	2.0
18. Litiopa melanostoma	Litiopidae	3.1
19. Alaba goniochila	[Cerithiacea]	4.5
20. Cerithium atromarginatum	Cerithiidae	18.4
21. Cerithium echinatum	"	21.6
22. Epitonium ulu	Epitoniidae	19.3
23. Epitonium gazeoides	"	13.5
24. Epitonium fucatum	"	11.2
25. Strombus maculatus	Strombidae	8.2
26. Hipponix trigona	Hipponicidae	6.8
27. Hipponix imbricatus	"	6.3
28. Sabia conica	"	4.3
29. Cheilea dillwyni	Calyptraeidae	9.5
30. Crucibulum spinosum	"	10.75

tube diameter at aperture

Table 39 (cont.)

31. Crepidula aculeata	"	9.2
32. Lamellaria sp.	"	7.6
33. Natica gualtieriana	Naticidae	18.0
34. Bursa cruentata	Bursidae	8.0
35. Morula granulata	Thaisidae	4.9
36. Morula spectrum	"	3.37
37. Morula ochrostoma	"	5.33
38. Morula uva	"	7.2
39. Vexilla taeniata	"	2.1
40. Vexilla fusconigra	"	2.55
41. Pinaxia versicolor	"	3.55
42. Euplica varians	Pyrenidae	1.81
43. Mitrella margarita	"	2.26
44. Mitrella fusiformis	"	5.2
45. Seminella varia	"	4.8
46. Seminella smithi	"	3.4
47. Mitrella bella	"	6.1
48. Nassarius ravidus	Nassariidae	3.39
49. Nassarius dermestina	"	1.77
50. Mitra auriculoides	Mitridae	7.6
51. Vexillum approximatum	"	8.4
52. Vexillum consanguineum	"	2.59
53. Vexillum interruptum	"	3.0
54. Vexillum piceum	"	3.29
55. Vexillum rubrum	"	4.04
56. Vexillum tusum	"	5.17
57. Vexillum unifascialis	"	3.23
58. Conus vexillum	Conidae	8.1
59. Bittium zebrum	Cerithiidae	6.5

Bay varies due to a variety of ecological factors. Greatest yield of veligers was obtained just prior to high tide. The most diverse sample of veligers was netted in Sampan Channel, although a greater abundance of veligers often occurred in the southeast part of Kaneohe Bay (see pendix A). These considerations dictated the time and area in which plankton tows were conducted.

Immediately after completing a plankton tow, veligers were separated from the other constituents of the plankton by swirling a bucket containing a depth of 3-4 cm of plankton sample (see pp.7-8), and deposited in appropriate containers. Prosobranch veligers were selected during sorting and transferred to appropriate dishes. The number of individuals put into a petri dish varied with the size of the veligers. Three or four of the veligers larger than 1400 μm, 8-10 in the 800-1400 μm size groups and more than 50 veligers under 800 μm were the usual numbers of the same types put into a single petri dish. At these population densities metamorphosis is more likely to occur than at lower densities. Veligers which can accomplish metamorphosis within two weeks after capture are more likely to grow to sizes large enough to permit tagging and recognition after subsequent release in sea water tables than are individuals which are still veligers a week or two after being collected.

The type of substratum included in the petri dish can be important in terms of providing territory, hiding places, shelter from light and other organisms and in providing nutrition. Sand-dwellers (Natica, Polinices, Terebra) were esconced in fine, clean sand from Sampan Channel . Rock dwellers were provided with clean, non-living coral chips.

Veligers in the plankton reportedly feed on either (1) yolk (and are termed lecithotrophic), (2) nannophytoplanktonic components (presumed usually to be unicellular algae such as diatoms or chlorophytes) or (3) a combination of both food supplies (Fretter and Graham 1962; Fretter and Montgomery 1968; Fretter 1967; Pilkington and Fretter 1971).

In addition to unicellular algae, bacteria may also be an important component of the planktonic diet of some veligers. During the summer of 1970, Dr. Yuri Sorokin, a Russian microbiologist studied the ecological role of bacteria in tropical waters while at H.I.M.B. In the interests of determining the relative amounts of bacteria ingested by planktonic constituents, equal numbers of larval types that happened to be plentiful in the plankton at that time were collected: veligers of Crucibulum spinosum, Serpulorbis variabilis and an unidentified opisthobranch and the modified trochophore larvae of Loxosoma sp., an entoproct. Dr. Sorokin exposed each group for three hours to identical concentrations of a variety of Kaneohe Bay bacteria which had been labelled with an isotopic tracer. They were then fixed, washed and filtered and the radioactive emissions were counted with a Geiger detector. From most efficient to least efficient, the larvae were ranked as follows: C. spinosum, S. variabilis, the unidentified opisthobranch veligers and finally the larvae of Loxosoma sp. This small study revealed that veligers consume significant amounts of bacteria (Sorokin, pers. comm.). The presence of large numbers of C. spinosum in the plankton of the southeast part of Kaneohe Bay may constitute an important factor in the continual consumption of bacteria in the Bay.

The critical problem in rearing the juvenile stages of the metamorphosed veligers is to determine how to rear or collect the supportive food supply. Determining the quality and quantity of food for carnivorous juveniles was in most cases a matter of trial and error. Fretter and Graham (1962, pp. 261-62) provide some clues relative to which foods are preferred by various British species of gastropod adults; however, little is known of the nutrition of juvenile gastropods resident in tropical and subtropical areas.

Herbivorous juveniles may be classified into three main groups; (1) those that feed largely on phytoplankton, (2) those that feed on algal films, encrusting algae or detritus and (3) those that feed primarily on upright branching or filamentous algae.

Among the juveniles which feed on phytoplankton are those of C. spinosum, Crepidula aculeata, Capulus bicarinatus and some vermetids. These species were reared using cultures of algae (Phaeodactylum tricornutum and Dunaliella tertiolecta) which are maintained by the aquaculture program of the Hawaii Institute of Marine Biology.

Herbivorous gastropods which feed on algal films, encrusting algae or algal detritus include Rissoella sp., Cithna sp., Phenacolepas scobinata, nerites, rissoids and various species of Bittium. A water table arranged as in Fig. 10 promoted rich algal growth on the inside and outside of the plastic aquarium and a fair to moderate growth on sides of the water table. Some growth also was maintained on the aquarium rocks. Juveniles of Rissoella, Cithna and Bittium are acceptable as food for many gastropod species which are carnivorous as juveniles. Initial populations of these prey species are established by collec-

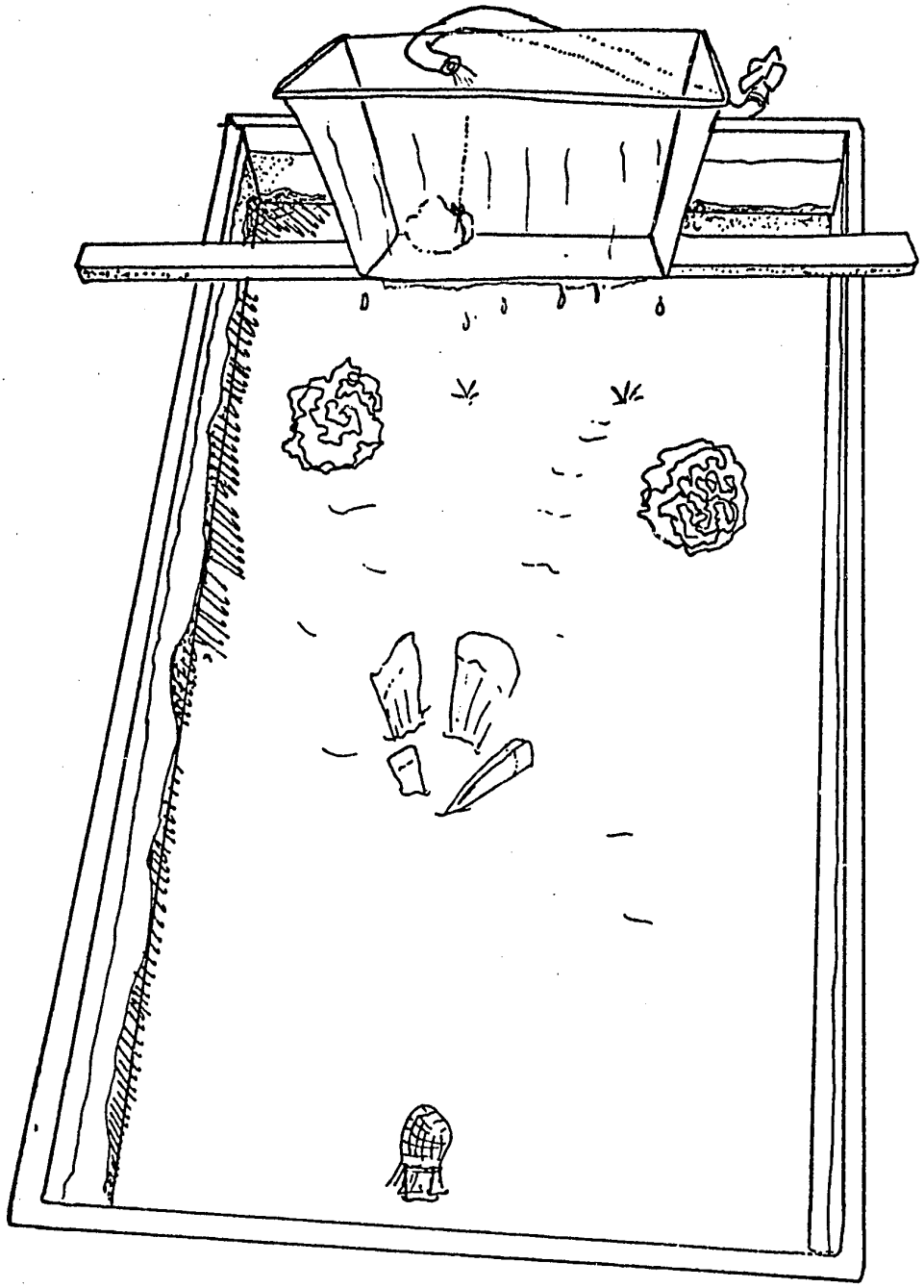


Figure 10. The water table arrangement used in the growth studies.

ting from the field 50-100 adults of the prey species and adding them to the sea water table. Because Rissoella sp. individuals are small (2 mm or less), finding them is difficult if they are placed in a large sea water table; the adults are placed in a bucket with some rocks and an inlet tube for water and subsequent harvesting is accomplished easily.

Members of the third group, which includes hipponicids, some cerithiids, Styliferina goniochila, Litiopa melanostoma, Strombus maculatus and other browsers, feed primarily on upright branching or filamentous algae. For juveniles of these groups, algal samples were collected from beneath the floating docks and from the highly productive sea water tables of the H.I.M.B. laboratory. When algal growth on the plastic aquarium became abundant, it was scraped off and added to the water table below.

Providing food for carnivorous juveniles is somewhat more difficult than rearing herbivores. Carnivorous juveniles that found small gastropods acceptable as food (most naticids, thaisids, columbellids, miters of the Vexillum type and Nassarius dermestina) first were offered Rissoella sp., then Cithna sp., and finally Bittium parcum and B. zebra.

Juvenile bivalves (Pinna, Crassostrea, Tapes) were reared as food for juvenile gastropods such as Bursa cruentata and Nassarius splendidulus. The simple way to culture bivalves is to sort their larvae from the plankton, wait until metamorphosis has occurred and then transfer them to sea water tables with a moderate rate of inflowing water. As these juveniles get older, they augment their earlier nutrition of phy-

toplankton with small zooplankters. Spurts of growth in bivalves were evident one or two days after zooplankton was added to the water tables. Cultures of algae (P. tricornutum and D. tertioplecta) from the aquaculture program were added sporadically to the water tables containing the bivalves. During periods when no suitably-sized bivalves were in culture, benthic grab samples were obtained and sorted for small (1 cm or less) bivalves.

Juveniles which require coelenterates as food (Epitonium and the architectonicids) were offered the anemone Aiptasia pulchella. Occasionally stony corals such as Fungia and small chunks of living Pocillopora damicornis and Porites lobata were included for short periods in the sea water table. Aiptasia is in many of the sea water tables at H.I.M.B. in which growth of sessile organisms is not discouraged and also appears to be the most abundant sea anemone on the hulls of the floating docks.

Small sponges and colonial tunicates were collected regularly to accommodate those gastropods which are thought to feed on them (Lamellaria, Triviidae, Triphoridae, Cerithiopsidae). These groups seem to prefer as food species of Perophora which are tiny, transparent, colonial tunicates. Juveniles of Lamellaria did not feed on Symplegma viridis or solitary tunicates when offered them. Trivia spp. are often collected in masses of crustose algae such as Dictyosphaerium cavernosum and are thought to feed on either sponges or tunicates.

Polychaetes, opisthobranchs, echiuroids and enteropneusts are thought to constitute much of the diet of some miters, cones and terebrids (A.J.Kohn 1959; Bruce Miller 1970). These prey types were not

kept in culture although their larvae are frequently in the plankton and they might have been reared fairly easily in sea water tables. Rearing these prey species is a much-neglected area of study which remains for future investigation.

The rearing procedure varied little from the following description. Prosobranch juveniles were transferred to clean petri dishes with clean substratum, clean sea water and additional food every other day. In feeding carnivorous juveniles, enough biomass of prey species was provided so that supply exceeded demand. No more than two days intervened in the refreshment of culture conditions; otherwise, the increase in waste products was detrimental to the well-being of the juveniles. Few species larger than 3-4 mm fare well under these conditions; juveniles which had reached a length of 3 mm were transferred to appropriate quarters in a water table with Kaneohe Bay sea water flowing in at a slow rate.

Annual temperature variation in the laboratory sea water system was from 24°C. to 28°C. Temperature in the sea water table varied from 22°C. to 30°C. during the course of the investigation.

All measurements were made with an ocular reticle in the system already described (p. 9); all camera lucida drawings yielded magnifications of 58x and preserved the scale which enabled differing protoconchs to be compared easily. Identifications were made by 1) superimposition of drawings of larval protoconchs with drawings of protoconchs on adult shells, 2) rearing juveniles to a size which permitted identification with certainty or 3) finding the pre-settlement veligers still in the oviducts of the mother and identifying the species of the

mother.

Naticid shells were measured at their greatest diameter with the aperture facing downward. All other carnivores were measured by columellar length, i.e., from the apical tip to the tip of the siphonal canal (or analogous area).

Mathematical analysis was carried out using the Kentron time-sharing system at the H.I.M.B. terminal which uses the BASIC language. The "Least Squares Curve Fit" program (AppendixG) enables one to select the curve which best fits a mass of data. Standard deviations were calculated on a small Wang desk computer according to a formula provided by Snedecor and Cochran (1967, p. 44).

Measurements of greatest diameter were begun on 33 veligers of Natica gualtieriana collected during the course of a year. Eighteen which attained lengths greater than 3.3 mm were given to Mr. Eric Guinther, who measured their subsequent growth. Five individuals died when they had reached lengths between 2.5 and 3.3 mm; causes of their demise are unknown. Data on these five individuals were included in the graphs of individual growth (Fig. 11) because their growth patterns paralleled growth in the eighteen healthy specimens. Ten individuals did not attain a diameter of 2.5 mm; data from their growth histories are not included in Fig. 12 .

Data from other carnivorous species are graphed using the same scale used in graphs of growth in N. gualtieriana (see Figs. 16 and 18). The number of individuals of species other than N. gualtieriana was insufficient to permit reliable statistical analysis. Growth in miters,

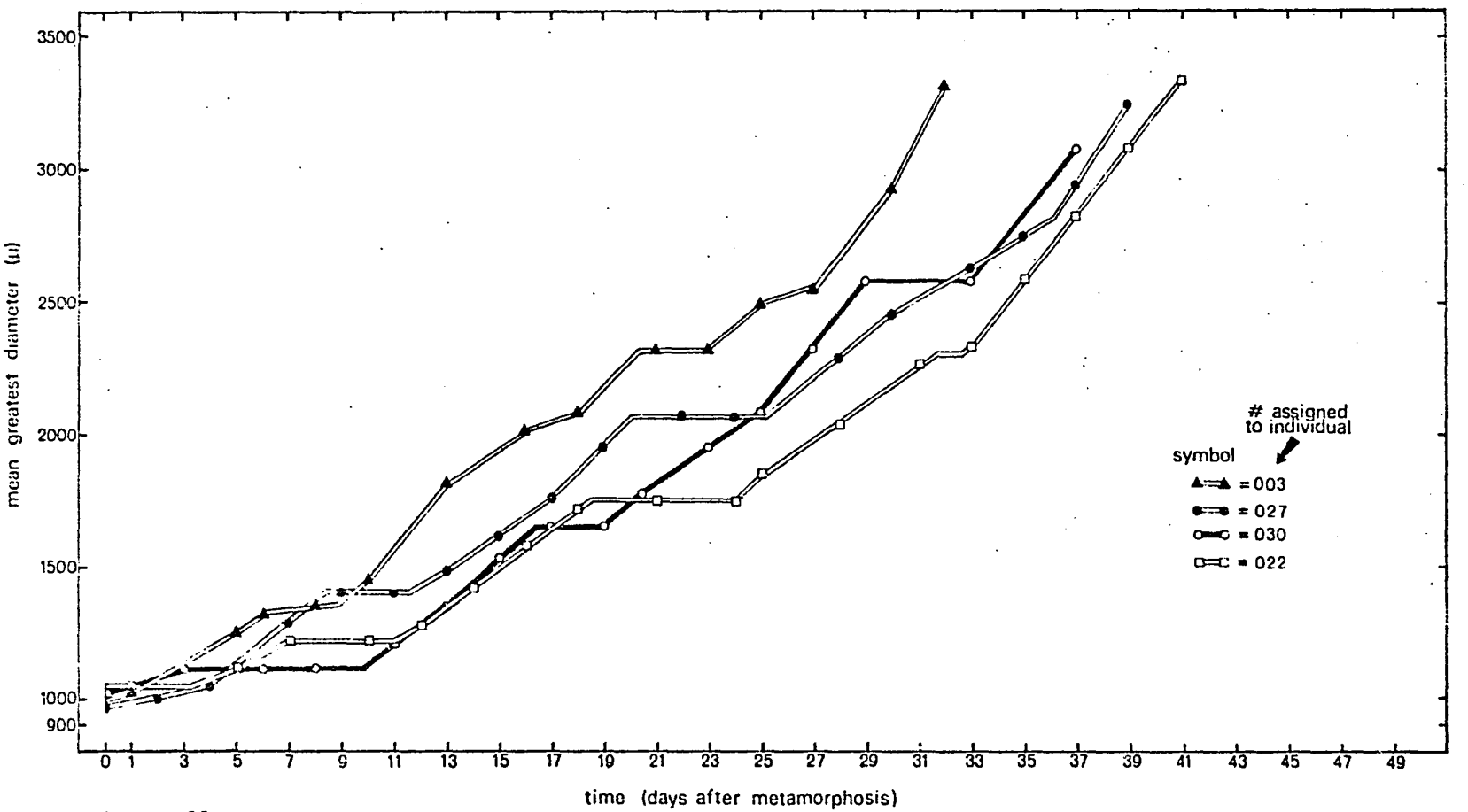


Figure 11.

GROWTH: INDIVIDUALS OF
Natica gualtieriana

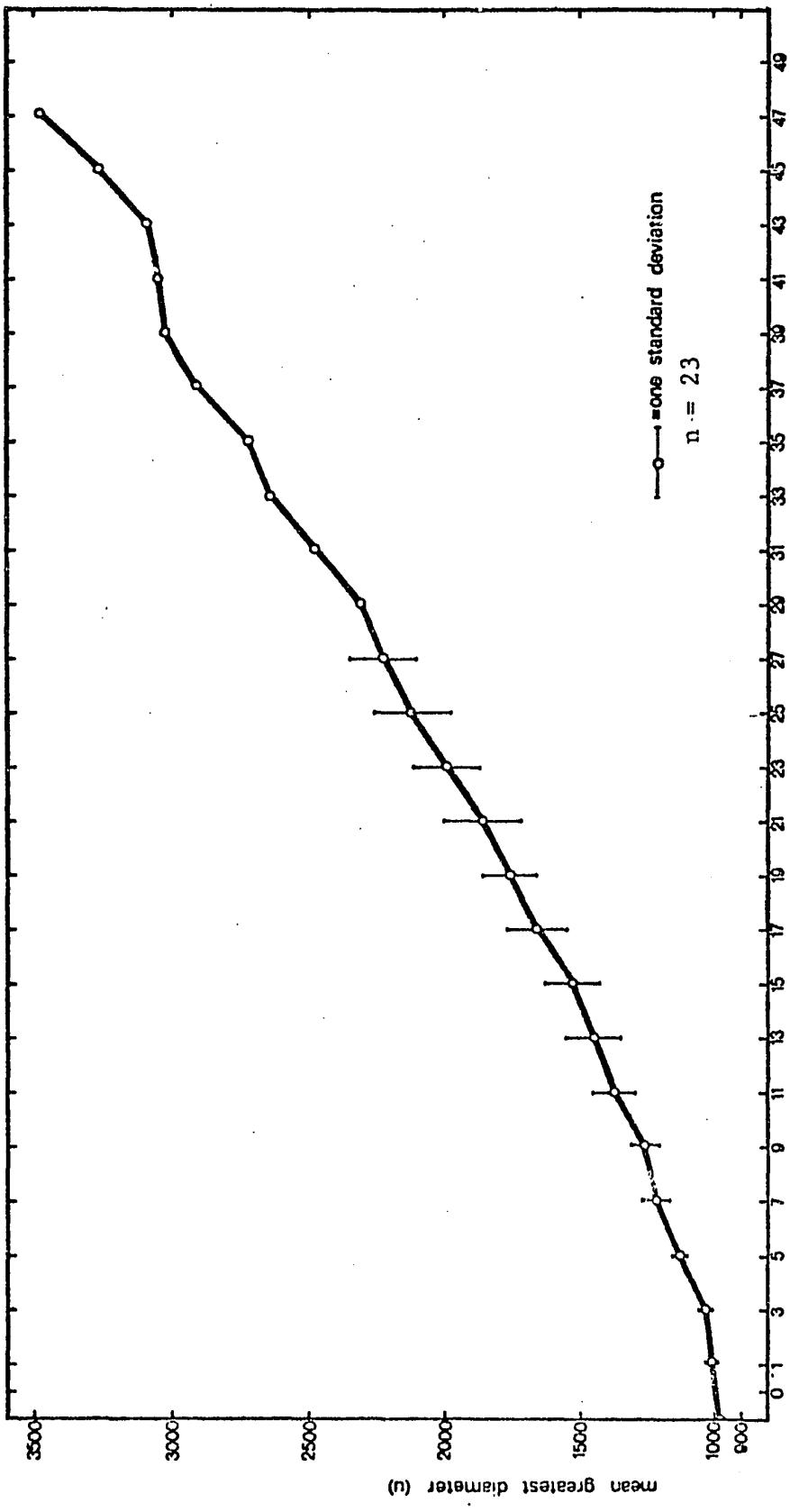


Figure 12. GROWTH: Natica gualtieriana

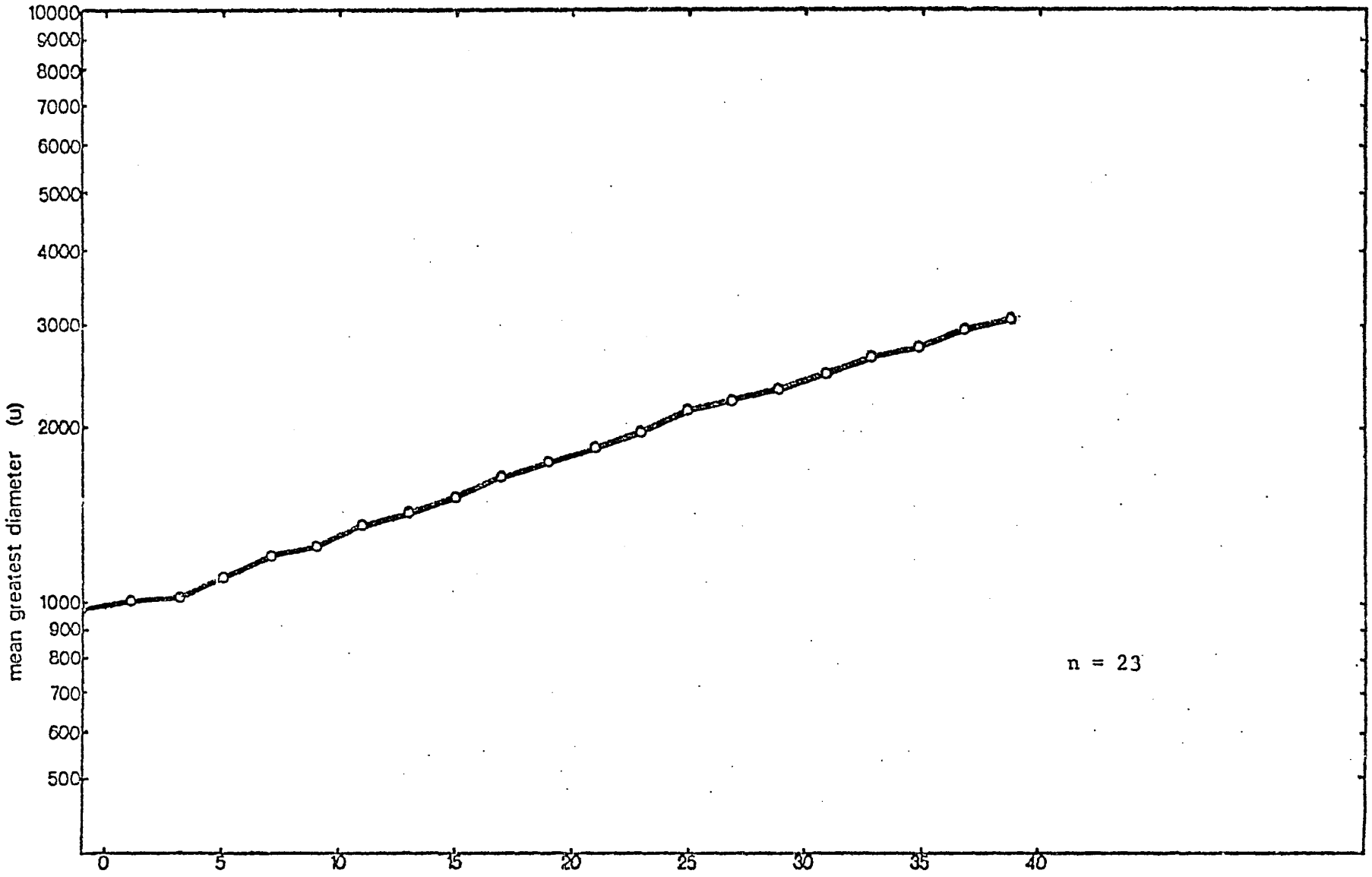


Figure 13.

GROWTH: Natica gualtieriana

nassariids and thaisids is graphed to allow comparison of intra-family growth patterns (see Figs. 15, 16, 17, 18 and 19) Data for members of Epitoniidae, Columbellidae, Bursidae, Strombidae and for naticids other than N. gualtieriana are graphed in Figs. 14 and 20.

Data on N. gualtieriana were treated in the following manner. Measurements of greatest diameter were divided into ranks of two-day groups, i.e., all measurements obtained during a two-day period were grouped into one rank.The mean and standard deviation calculated for each rank are graphed using axes identical to those of Fig. 12.

The data fit equations (a) and (b) with very high indices of determination (r^2, the square of the correlation coefficient, see Table 40 below). The data also fit equation (c) with a high r^2 value. Appendix F). With the appropriate values of A and B (the interceptor and slope, respectively) substituted into the equations, they are as follows:

Table 40. Equations used in the least squares curve fit program.

Equation	General Equation	A	B	r^2
(a)	$Y=Ae^{(BX)}$	$Y= 966.519e^{(.0313176X)}$		.854454
(b)	$Y=1/ (A+BX)$	$Y= 1/ (9.73538^{-4} - 1.96208^{-5}X)$		.850549
(c)	$Y=A+BX$	$Y= 829.926 + 53.2156X$		.822169

Equation (a) is an exponential function, (b) is a hyperbolic function

and (c) is a linear function. The data fit the exponential equation (a) significantly better ($p = .05$) than equation (c); for the relevant calculations, see Appendices F and G.

While graphing the growth patterns of individuals of Natica gualtieriana, I noticed that pauses in growth occurred in 20 of 23 individuals. "Pause in growth" is arbitrarily defined as a period of three to twelve days unaccompanied by an increase in diameter of more than 34 µm. 34 µm is the distance between the closest lines on the ocular reticle. Eleven of the 23 individuals underwent two or more pauses in growth. Ten of these exhibited at least one interval of either seven or 13-14 days between pauses.

The instantaneous growth rate equals 0.3575 (Appendix H) and was calculated by determining the natural logarithm of the ratio of the final length (13 days) to the initial length (0 days) for a time period of 13 days. This 13-day period was chosen for comparison with the instantaneous growth rate of Epitonium ulu. Although growth was followed for a period greater than 33 days, sample size drops sharply after day 33 as individuals having reached 3.3 mm were transferred to sea water tables; the means, as a result, are depressed and the validity of these statistics is decreased.

Fig. 13. which represents the growth pattern in post-metamorphic juveniles of N. gualtieriana, is derived from data on 23 individuals; therefore, it does not portray the detailed growth pattern of individual specimens.

The amount of growth data compiled from observations on the juveniles of N. gualtieriana was insufficient to determine whether growth during the period studied is essentially exponential or hyperbolic.

A growth periodicity of seven or fourteen days in juveniles which are reared in an environment presumably free from tidal or lunar influences is a phenomenon that presents no ready explanation. Usually, rhythms cued by environmental stimuli are lost within a week after capture when organisms are maintained under conditions lacking these stimuli (Struhsaker, pers. comm.). Juveniles of N. gualtieriana exhibited this periodicity long after a week had elapsed; therefore, it would appear that a genetically-determined basic metabolic rhythm is operative rather than one cued by an environmental stimulus. Semi-lunar rhythms are not unknown among mollusks; in Venus mercenaria (Bennett 1954) and Crassostrea virginica (Brown 1954), peaks in oxygen consumption occur with semi-lunar frequency and coincide with the spring tides.

Wilbur (1964, p. 268) suggests that five factors govern the rate of shell formation:

(1) the supply of calcium furnished to the mantle by the blood or external medium

(2) the rate of conversion of CO_2 and bicarbonate to carbonate

(3) the rate of synthesis of components of organic matrix

(4) the rate of secretion of calcium and components of the matrix by the mantle

(5) the alkalinity of extra-pallial fluid sufficient to permit deposition of $CaCO_3$

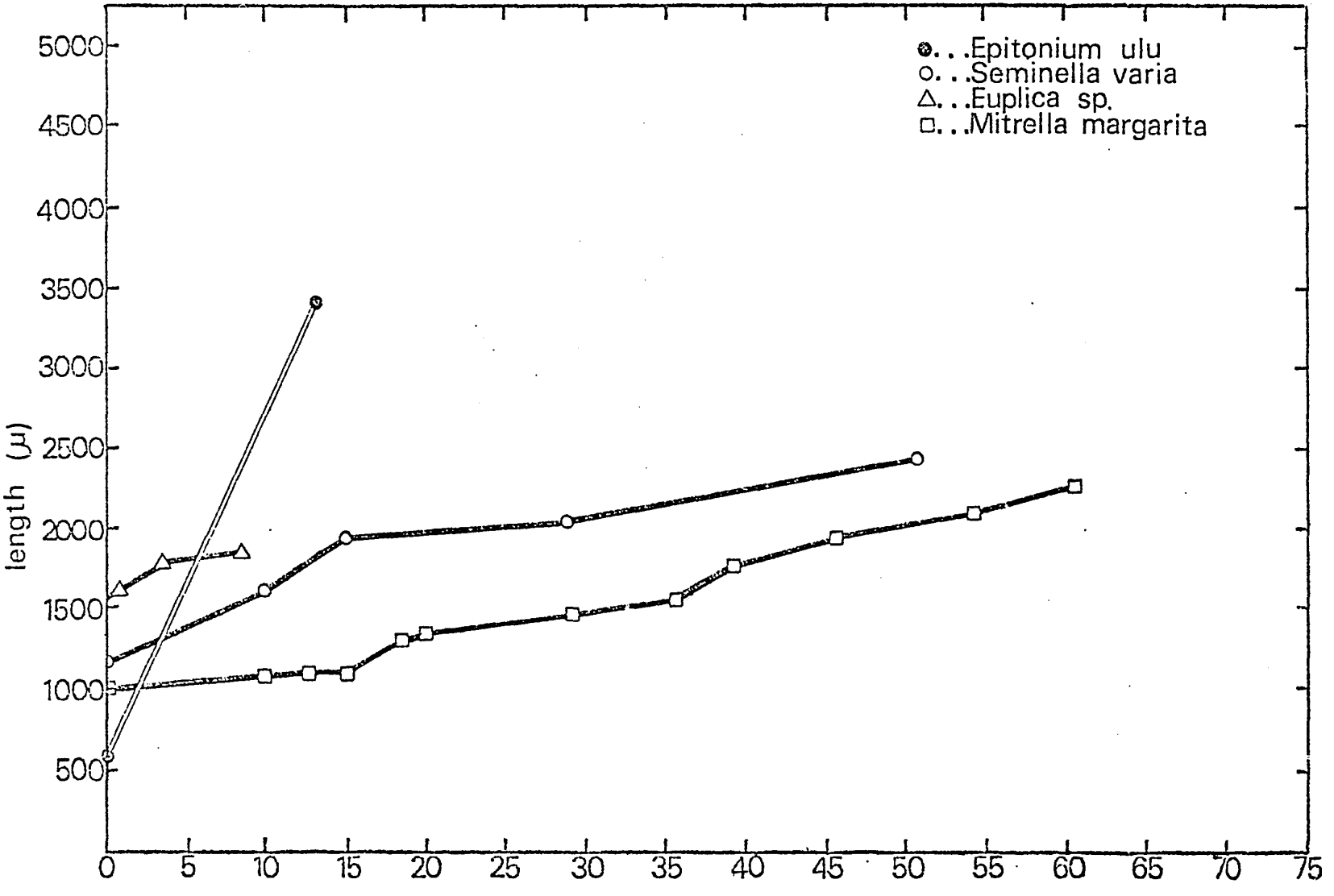


Figure 14.

GROWTH PATTERNS: MISCELLANEOUS

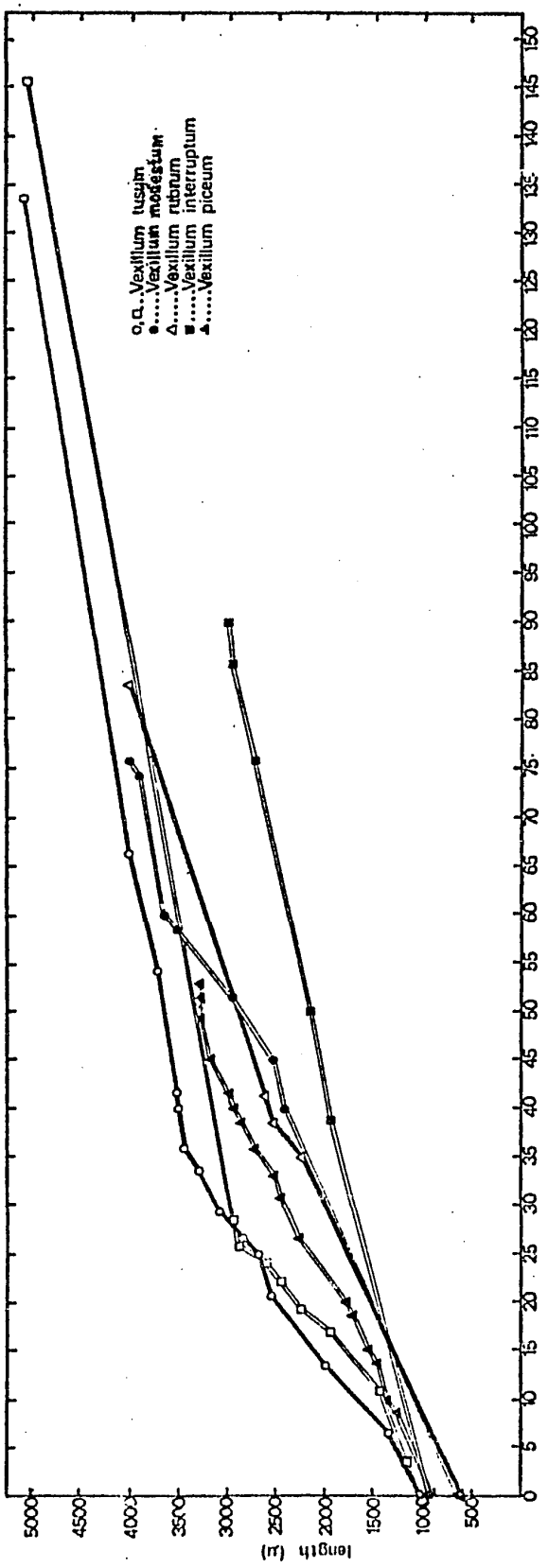


figure 15. GROWTH PATTERNS: MITRIDAE

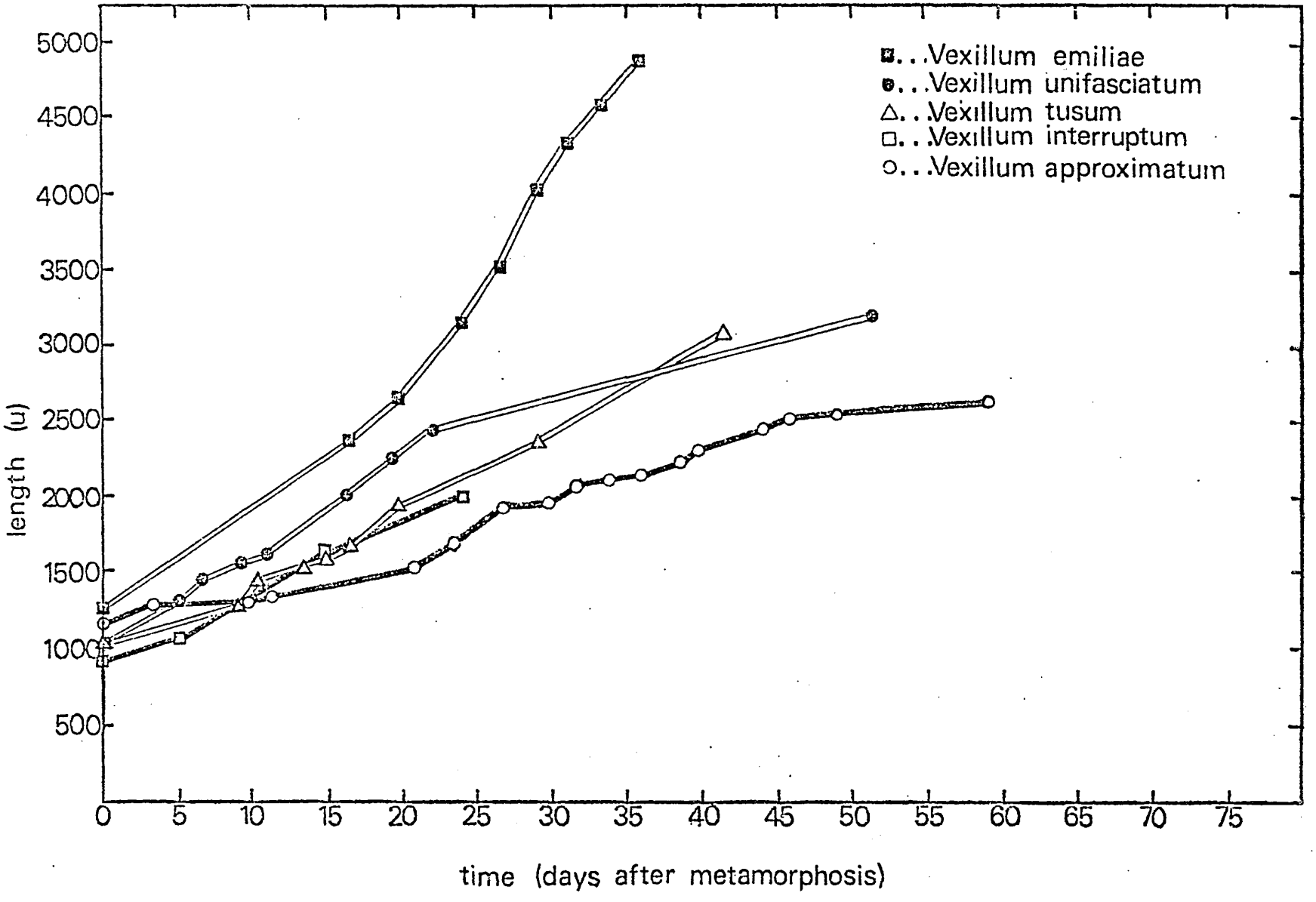


Figure 16.

GROWTH PATTERNS: MITRIDAE

Figure 17. Growth patterns: Thaididae.

Morula spectrum: each filled-in circle represents the average of values for three individuals (n=3).

M. ochrostoma (=Drupella ochrostoma): each circle represents the average of values for five individuals (n=5).

Vexilla fusconigra: each triangle represents the datum for one individual (n=1).

Morula granulata: each square represents the datum for one individual (n=1).

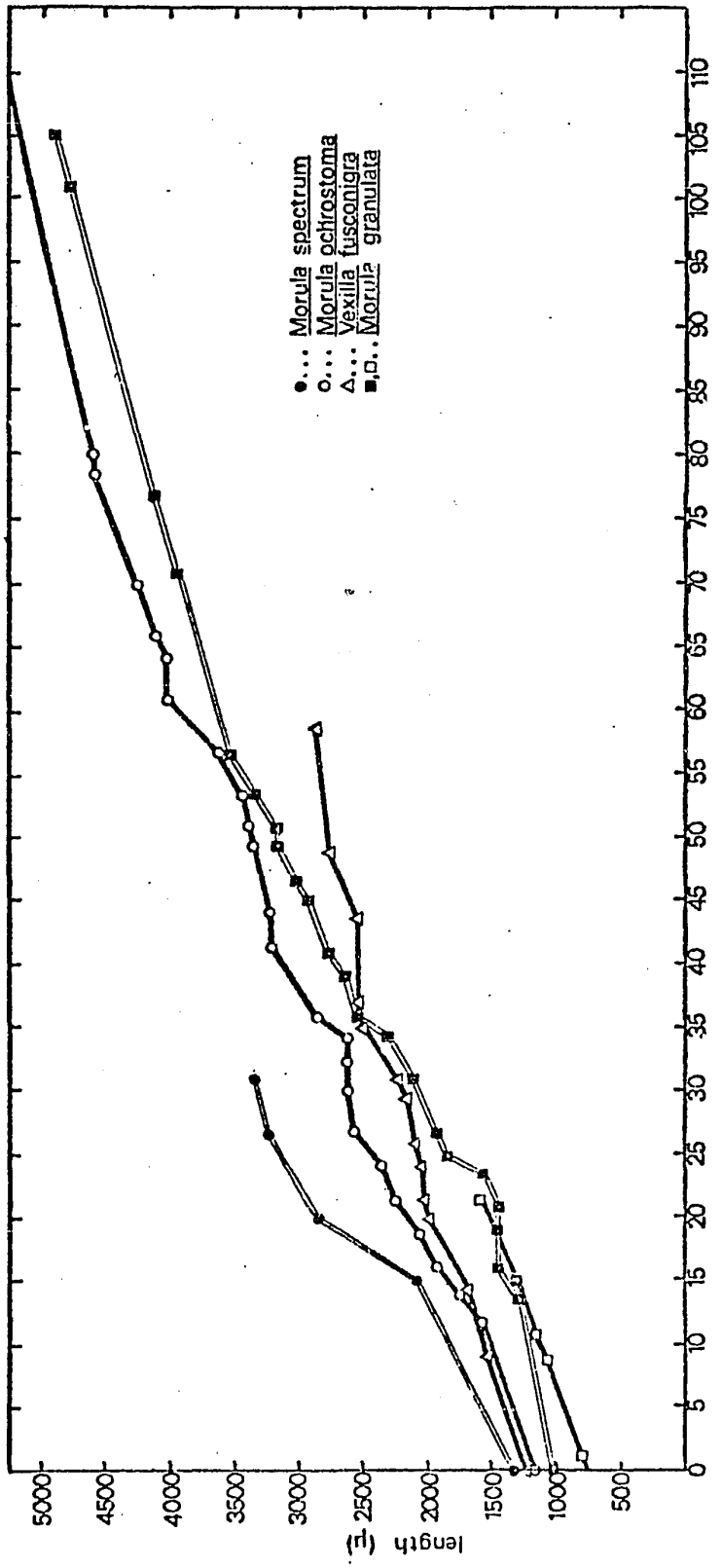


Figure 17. GROWTH PATTERNS: THAIDIDAE

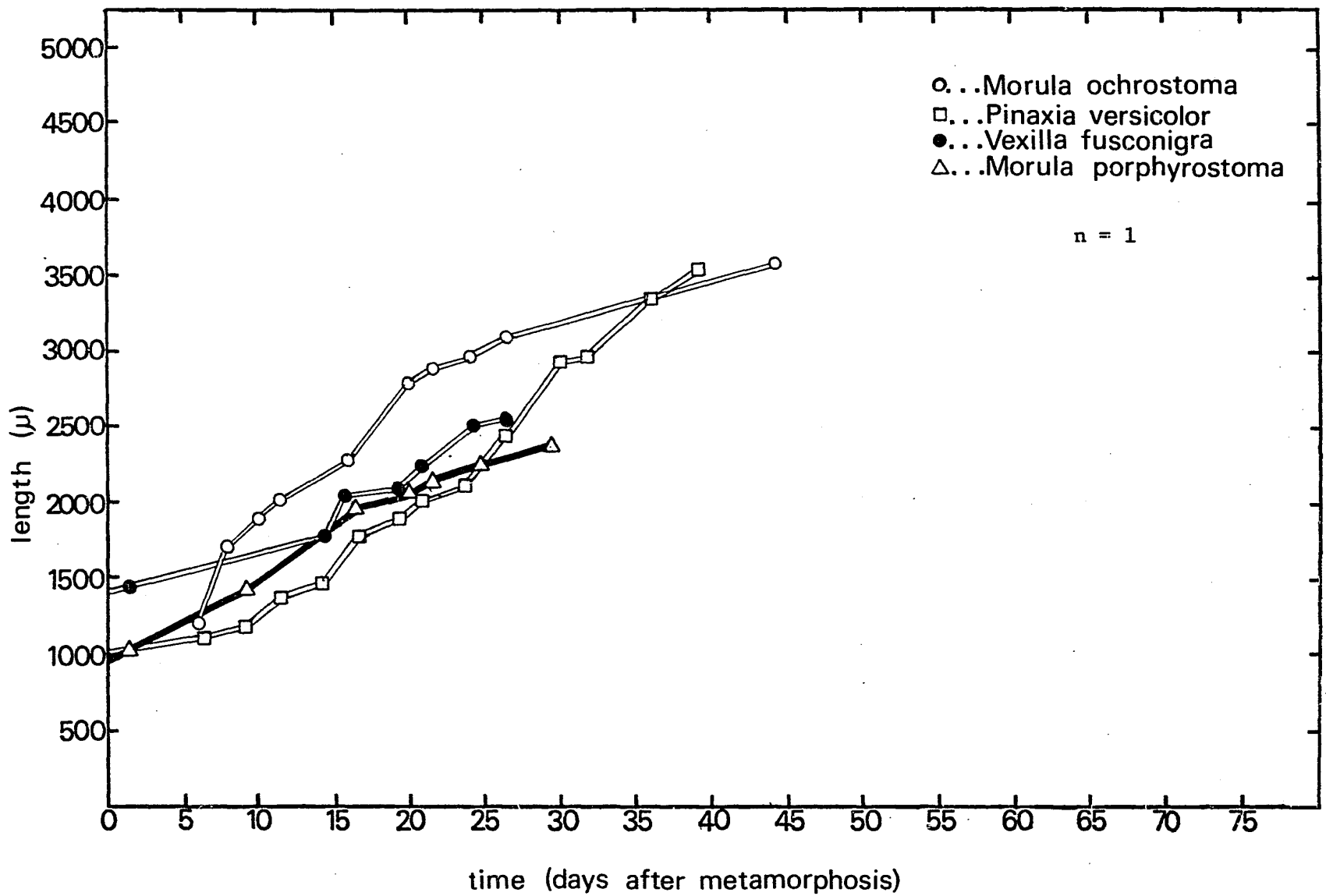


Figure 18. **GROWTH PATTERNS: THAIDIDAE**

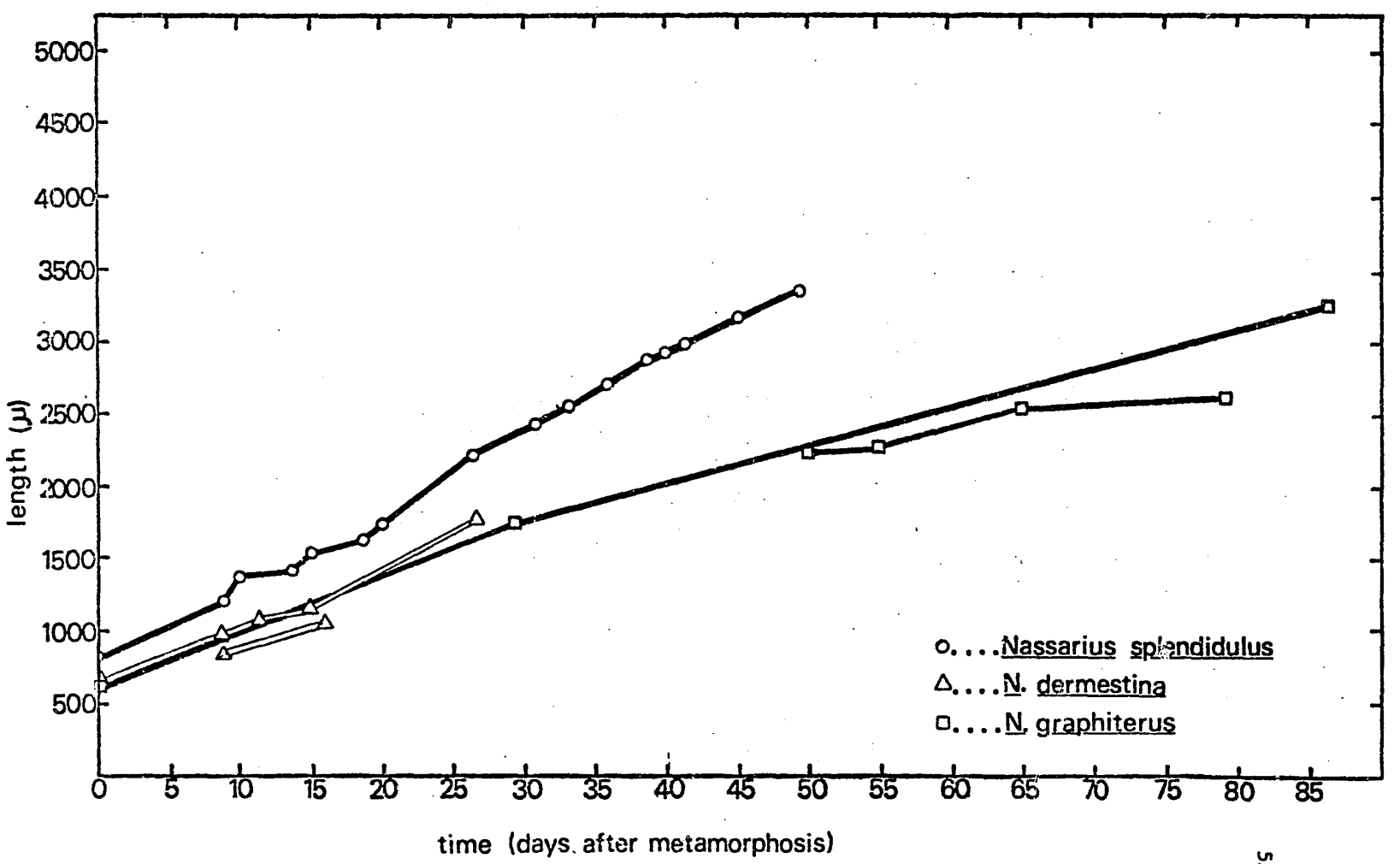


Figure 19. **GROWTH PATTERNS: NASSARIIDAE**

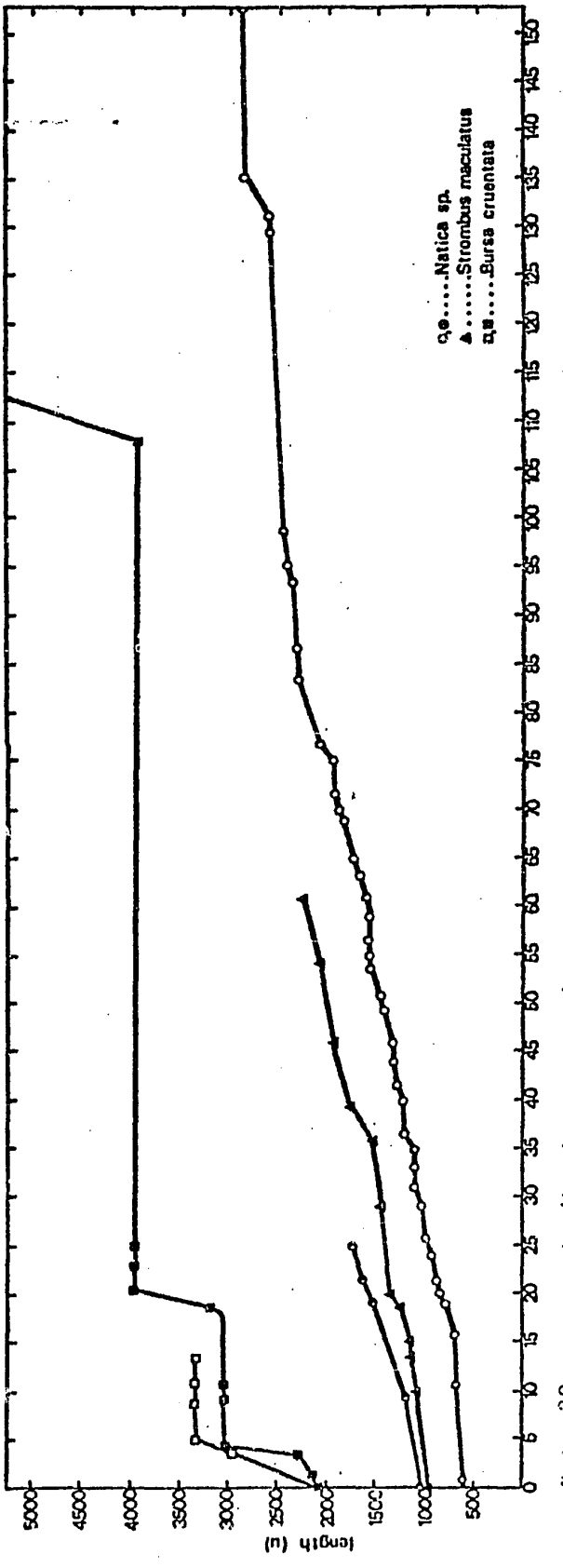


figure 20. GROWTH PATTERNS: BURSIDAE, STROMBIDAE, NATICIDAE

If one or more of these factors is limiting, the rate of shell deposition will be accelerated or stopped (i.e., as in pauses in growth). Apparently, a mechanism operates at intervals of 7 or 14 days which inhibits one or more of the above factors in many juveniles of Natica gualtieriana.

It is noted that the range of variation in growth rate in thaisids and miters studied varied approximately as much as range of variation in growth rate within the population of one species, N. gualtieriana. Most of the growth curves are clustered within a narrow range; this observation suggests that animals which feed on similar food supplies under similar environmental conditions tend to process and assimilate food at similar rates.

Three main growth patterns were observed: 1) that of molluscivorous juveniles described in the preceding paragraph, 2) discontinuous growth in Bursa cruentata and 3) the fast growth rate of Epitonium ulu. Growth in Bursa is discontinuous although feeding and consumption of molluscan flesh remains reasonably constant. Although only one individual of Epitonium ulu was actually measured, at least 30 individuals were reared to lengths greater than 2 cm; the growth rate of the measured individual did not appear to be be exceptional and the instantaneous growth rate is approximately 1.66 (Appendix H, for calculations). The instantaneous growth rate for Bursa cruentata during the short periods of growth varied from an average of 0.30 (at 4 days) to an average of 0.45 (at 5 days; see Appendix, ibid.).

Frank (1965) has noted that, although mathematical models developed by various authors (Walford 1946; Parker and Larkin 1959; von Bertalanf-

fy 1960) are consistent with some data obtained from organisms living *in situ*, these data are rarely obtained for the entire life cycle of an organism. He suggests that if growth during the entire life cycle is measured, it is likely to be described by more than one simple growth curve because environmental conditions, physiology of the animal, quality and quantity of food supply are not constant throughout the life span of most organisms. Perhaps examination of growth rates exemplified by juveniles in Hawaii will revise some of our estimates of normal life spans in tropical populations.

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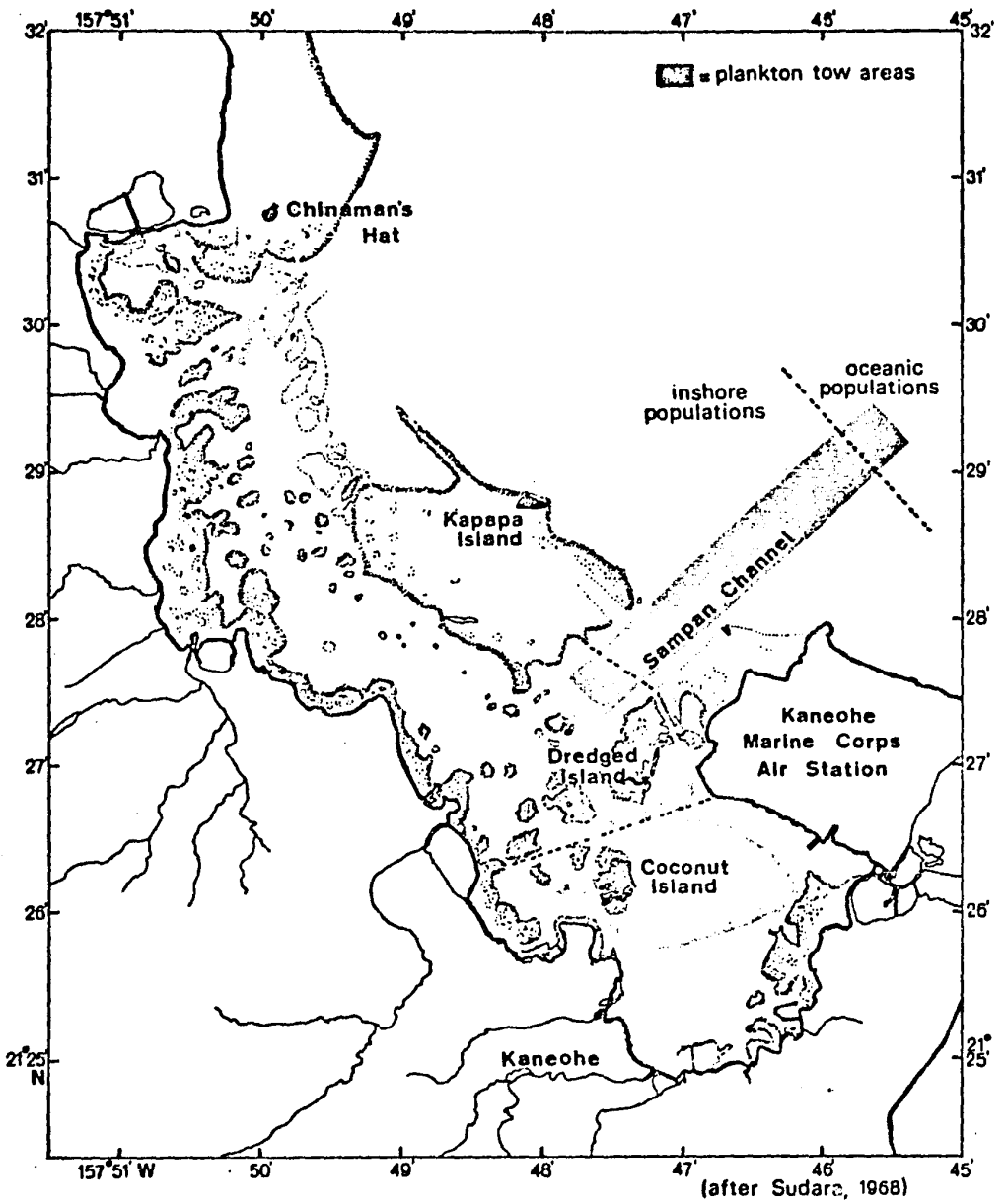
Appendix A. Kaneohe Bay, Oahu, Hawaii.



Appendix B

Distinctions and Definitions.

Detergents: surface active agents which, besides being good wetting agents, are capable of removing dirt (usually grease) from a variety of surfaces. Not all wetting agents are good detergents since the ability to prise the dirt away from its substrate and to hold it in sufficiently stable dispersion until it can be flushed away is an additional requirement not possessed by all wetting agents.

Surfactants (surface active agents): water, possessing powerful intermolecular forces of attraction, has a high surface tension (72.8 dynes/cm at 20°C.). Many soluble substances (mainly organic) when dissolved in water, even at low concentrations, considerably reduce surface tension. These surface active agents have weaker intermolecular attractive forces than the solvent, and therefore tend to concentrate in the surface at the expense of the water molecules. Surface active agents, which include certain dyestuffs, wetting agents, detergents, antibiotics, bactericides, etc., may be electrically neutral, non-dissociating substances (non-ionic), or they may ionize to give surface active anions or cations with small oppositely-charged counterions (usually metallic ions and halogen ions respectively).

Soaps: sodium or potassium salts of the fatty acids, particularly stearic, palmitic and oleic acids.

Appendix B (cont.).

Two ampoules of reference LAS (linear alkylate sulfonic acid) were obtained from the Soap and Detergent Association, Technical and Materials Division, 485 Madison Avenue, New York, N.Y. 10022. The following quotation describes the contents of the two ampoules.

"The reference LAS acids have been prepared by a plant-scale oleum sulfonation of a typical linear alkylate in current use in the United States and subsequent dilution of the washed sulfonic acids to the dilution stated. The LAS active analysis has been determined in replicate (N=6) by a single industrial laboratory by titration with Hyamine 1622 solution which has been standardized according to the procedure described by Gardner (1967). The molecular weight has been calculated from mass spectrometry data obtained on the starting linear alkylate. The sample contains approximately 0.4% free sulfuric acid in addition to the linear alkylate sulfonic acids." The information which accompanied the ampoules neglected to state whether the percent active LAS estimate was in terms of volume or weight.

Appendix C

Calculation of Total Error.

$\frac{0.30}{1000} \times 100 = 0.03\%$ $\frac{0.05}{50} \times 100 = 0.10\%$

$\frac{0.02}{10} \times 100 = 0.20\%$ $\frac{0.00\dot{2}}{1} \times 100 = 0.20\%$

$\frac{0.02}{50} \times 100 = 0.04\%$

0.03%
0.10%
0.20%
0.20%
0.04%
0.57% Total Error

Appendix D

Constituents of the experimental LAS solutions.

Solution (ppm LAS)	Constituents	
	FFSW (ml)	20 ppm SS (ml)
0	40	0
1	38	2
2	36	4
2.3	35.4	4.6
2.6	34.8	5.2
3	34	6
3.3	33.4	6.6
3.6	32.8	7.2
4	32	8
5	30	10

LAS = linear alkyl sulfonate

FFSW = freshly-filtered sea water

20 pp m SS = 20 ppm stock solution of LAS

Appendix E. LAS experiments: raw data.

Experiment began July 3, 1970, 2. p.m. Ambient tempertature: 20.7°C. Average temperature: 22.6±0.8°C.

Control Group. Two idenditical control groups run. All veligers remained alive through July 7, 5. p.m. except for one veliconcha that crawled out. No veligers in the controls metamorphosed.

Experimental groups. Each group (one per petri dish) contained 20 individuals at the beginning of experiment.

T (hrs)---->		20				30				40				46-48				64				72				116			
C (ppm)	R	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D
1	A	19	1	-	0	-	-	-	-	-	-	-	-	14	4	2	0	8	7	5	0	-	-	-	-	-	1	19	0
	B	17	1	2	0	-	-	-	-	-	-	-	-	13	3	3	1	7	8	4	1	-	-	-	-	1	2	16	1
	C	18	1	1	0	-	-	-	-	-	-	-	-	16	3	1	0	9	8	3	0	-	-	-	-	1	1	17	1
2	A	17	2	1	0	-	-	-	-	9	5	3	3	6	5	5	4	2	6	8	4	-	-	-	-	0	5	10	5
	B	12	4	3	1	-	-	-	-	10	4	4	2	8	1	6	5	5	1	9	5	-	-	-	-	3	-	12	5
	C	14	3	2	1	-	-	-	-	9	6	2	3	6	6	5	3	2	7	7	4	-	-	-	-	1	6	9	4
2.3	A	-	-	-	-	-	-	-	-	-	-	-	-	2	5	4	9	-	-	-	-	-	2	6	12	-	-	-	-
2.6	A	-	-	-	-	-	-	-	-	-	-	-	-	4	-	2	14	-	-	-	-	1	-	3	16	-	-	-	-
3	A	16	2	1	1	10	2	0	8	-	2	1	17	-	1	1	18	-	-	-	-	-	-	2	18	-	-	-	-
	B	10	4	5	1	7	4	-	9	-	1	-	19	-	-	-	20	-	-	-	-	-	-	-	20	-	-	-	-
	C	11	4	3	2	6	3	3	8	-	-	1	19	-	-	1	19	-	-	-	-	-	-	-	20	-	-	-	-
	D	14	4	2	0	8	3	2	7	-	8	2	10	-	2	1	17	-	-	-	-	-	-	2	18	-	-	-	-
	E	9	8	2	1	9	2	1	8	-	5	2	13	-	1	1	18	-	-	-	-	-	-	1	19	-	-	-	-
3.3	A	11	1	5	3	5	2	3	10	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B	9	5	2	4	4	1	2	13	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix E. LAS experiments: raw data (cont.).

T (hrs)---->		20				30				40				46-48				64				72				116			
C (ppm)	R	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D	P	B	J	D
4	A	-	1	1	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B	-	-	-	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	2	2	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	E	-	2	1	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	A	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	A	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	D	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Data expressing mortality as a function of time and LAS concentration are presented in Table 38 (p. 526).

C = concentration

R = replication number

P = number of living planktonic veligers

B = number of living benthic veligers

J = number of living juveniles

D = number of dead individuals

T = time elapsed since immersion of veligers in expweimental solution

APPENDIX F

Calculation of Probability

r^2	r	z	Equation
.854454	.9243	1.618	(a)
.850549	.9220	1.602	(b)
.822169	.9067	1.508	(c)

The r^2 value equals the index of determination on the computer print-out. Z values are obtained by interpolating z values listed in Table A12 of Snedecor and Cochran (1967 ed., p. 558), which transforms the correlation coefficient to values of z according to the following equation:

$$z = 1/2 \log_e (1+r)/(1-r)$$

The difference between the two z values under comparison was then divided by the standard error of z ($=\sigma_z$).

$\sigma_z = 1/(n-3) = 1/326 = 1/18.05$ In this case, n = 329.

We have

$$\frac{z_{(a)} - z_{(c)}}{1/18.05} = \frac{1.618 - 1.508}{1/18.05} = 0.110 \times 18.05 = 1.9855$$

1.9855 is greater than 1.96, the value listed for the five per cent level for ∞ degrees of freedom in the table of the distribution of t (ibid., p. 549), thus my data fit equation (a) significantly better ($p = .05$) than (c). The difference between the z values of equations (a) and (b) is small and my data do not fit (a) significantly better than (b).

```
9901 DATA 1023,1,990,1,1044,1,990,1,1056,1,1023,1,990,1,990,1
9902 DATA 1023,1,990,1,1056,1,1056,1,1130,1,969,1,939,1,1056,1
9903 DATA 969,1,1023,1,939,1,1056,1,
9903 DATA 969,1,1023,1,939,1,1056,1
9904 DATA 1089,3,1023,3,1122,3,1023,3,1056,3,1056,3,1089,3,1001,3
9905 DATA 969,3,1122,3,1034,3,1023,3,969,3,1122,3
9906 DATA 1254,5,1254,5,1155,5,1155,5,1188,5,1155,5,1188,5,1122,5
9907 DATA 1056,5,1023,5,1023,5,1122,5,1122,5,1089,5,1089,5,1066,5
9908 DATA 1066,5,1130,5,1056,5,1001,5,1155,5
9909 DATA 1320,7,1353,5,13
9909 DATA 1320,7,1353,7,1353,7,1320,7
TAPE
9003 DIM X[346],Y[346],U[346],V[346],A[6],B[6],C[6],S[6],F[6]
9900 DATA 346
9901 DATA 1,1023,1,990,1,1044,1,990,1,1056,1,1023,1,990,1,990
9902 DATA 1,1023,1,990,1,1056,1,1056,1,1130,1,969,1,939,1,1056
9903 DATA 1,969,1,1023,1,939,1,1056
9904 DATA 1,1089,1,1023,
9904 DATA 3,1089,3,1023,3,1122,3,1023,3,1056,3,1056,3,1056,3,1089
9904 DATA 3,1089,
9904 DATA 3,1089,3,1023,3,1122,3,1023,3,1056,3,1056,3,1089,3,1001
9905 DATA 3,969,3,1122,3,1034,3,1023,3,969,3,1122
9906 DATA 5,1254,5,1254,5,1155,5,1155,5,1188,5,1155,5,1188,5,1122
9907 DATA 5,1056,5,1023,5,1023,5,1122,5,1122,5,1089,5,1089,5,1066
9908 DATA 5,1066,5,1130,5,1056,5,1001,5,1155
9909 DATA 7,1320,7,1353,7,1320,7,1254,7,1122,7,1056,7,1023,7,1353
9910 DATA 7,1221,7,1122,7,1089,7,1292,7,1260,7,1122,7,1056,7,1130
9911 DATA 7,1254
9912 DATA 9,1353,9,1353,9,1320,9,1320,9,1320,9,1221,9,1122,9,1188
9913 DATA 9,1122,9,1188,9,1089,9,1260,9,1400,9,1421,9,1122,9,1324
9914 DATA 9,1089,9,1195
9915 DATA 11,1452,11,1617,11,1452,11,1419,11,1452,11,1353,11,1221
9916 DATA 11,1155,11,1122,11,1583,11,1400,11,1518,11,1221,11,1486
9917 DATA 11,1357,11,1315
9918 DATA 13,1815,13,1815,13,1419,13,1419,13,1584,13,1551,13,1650
9919 DATA 13,1419,13,1221,13,1221,13,1188,13,1287,13,1254,13,1188
9920 DATA 13,1674,13,1486,13,1712,13,1353,13,1583,13,1188,13,1454
9921 DATA 13,1485
9922 DATA 15,1881,15,1518,15,1584,15,1782,15,1782,15,1881,15,1650
9923 DATA 15,1353,15,1221,15,1188,15,1419,15,1353,15,1188,15,1712
9924 DATA 15,1615,15,1873,15,1551,15,1712,15,1188,15,1647,15,1518
9925 DATA 17,2013,17,1980,17,1617,17,1782,17,1980,17,1881,17,1980
9926 DATA 17,1749,17,1518,17,1386,17,1320,17,1584,17,1386,17,1221
9927 DATA 17,1353,17,1938,17,1777,17,2003,17,1650,17,1906,17,1221
9928 DATA 17,1777,17,1683
9929 DATA 19,2079,19,2079,19,1683,19,1914,19,2073,19,1980,19,2013
9930 DATA 19,1848,19,1650,19,1452,19,1419,19,1716,19,1584,17,1353
9931 DATA 19,1386,19,2099,19,183
9931 DATA 19,1386,19,2099,19,1938,19,2067,19,1650,19,1970,19,1320
9932 DATA 19,1970,19,1980
9933 DATA 21,2310,21,2145,21,1815,21,2178,21,2079,21,2079,21,2079
9934 DATA 21,1782,21,1749,21,1716,21,1749,21,1386,21,1485,21,1749
9935 DATA 21,2326,21,1782,21,2067,21,1485,21,2196,21,2040
9936 DATA 23,2310,21
9936 DATA 23,2310,23,2079,23,2343,23,2079,23,2277,23,2145,23,1914
9937 DATA 23,1848,23,1848,23,1848,23,1518,23,1617,23,2487,23,2067
9938 DATA 23,2067,23,1947,23,2326,23,2584,23,2467,23,2145
9939 DATA 25,2475,25,2541,25,2211,25,2079,25,2343,25,2343,25,2475
9940 DATA 25,2040,25,1848,25,1914,25,1647,25,1680,25,2680,25,2067
9941 DATA 25,2196,25,2079,25,2552,25,2519,25,2376
9942 DATA 27,2640,27,2376,27,2244,27,2475,27,2409,27,2211,27,2310
9943 DATA 27,2040,27,1980,27,2112,27,1815,27,1873,27,2390,27,2326
```

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 9944 DATA 27,2649 27,1815,27,2423
 9945 DATA 29,2409,29,2649,29,2541,29,2343,29,2244,29,2455,29,2358
 9946 DATA 29,2196,29,2132,29,2035,29,2178,29,2067,29,1970,29,3133
 9947 DATA 29,2293,29,2616,29,2584,29,285
 9947 DATA 29,2293,29,2616,29,2584,29,2842,29,3673,29,2519
 9948 DATA 31,3036,31,2640,31,2749,31,2541,31,2475,31,2745,31,2409
 9949 DATA 31,2487,31,2423,31,2229,31,2261,31,2261,31,2067,31,2261
 9950 DATA 31,3391,31,2423,31,2842,31,3068,31,2067
 9951 DATA 33,3300,33,2904,33,2871,33,2541,33,2607,33,2244,33,2475
 9952 DATA 33,2971,33,2713,33,2584,33,2326,33,2326,33,2358,33,2455
 9953 DATA 33,2196,33,2616,33,3068,33,2584,33,2196
 KEY
 9900 DATA 329
 RUN
 CURFIT
```

LEAST SQUARES CURVES FIT

CURVE TYPE	INDEX OF DETERMINATION	A	B
1. Y=A+(B*X)	.822169	829.926	53.2156
2. Y=A*EXP(B*X)	.854454	966.519	3.13176E-02
3. Y=A*(X^B)	.698328	763.932	.301016
4. Y=A+(B/X)	.256982	1917.31	-1241.6
5. Y=1/(A+B*X)	.850549	9.73538E-04	-1.96208E-05
6. Y=X/(A+B*X)	.396292	5.58916E-04	5.58629E-04

```
DETAILS FOR CURVE TYPE?2
   2. Y=A*EXP(B*X) IS AN EXPONENTIAL FUNCTION.  THE RESULTS
      OF A LEAST-SQUARES FIT OF ITS LINEAR TRANSFORM
      (SORTED IN ORDER OF ASCENDING VALUES OF X)
      ARE AS FOLLOWS:

X-ACTUAL        Y-ACTUAL        Y-CALC          PCT DIFFER

 1               1023           997.267              2.5
 1               990            997.267         -.7
 1               1044           997.267              4.6
 1               990            997.267         -.7
 1               1056           997.267              5.8
 1               1023           997.267              2.5
 1               990            997.267         -.7
 1               990            997.267         -.7
 1               1023           997.267              2.5
 1               990            997.267         -.7
 1               1056           997.267              5.8
 1
 1
 1
STOP
CONTINUE
???             DETAILS FOR CURVE TYPE?5
RUN                5. Y=1/(A+B*X)  IS A HYPERBOLIC FUNCTION.  THE RESULTS
CURFIT                OF A LEAST-SQUARES FIT OF ITS LINEAR TRANSFORM
                      (SORTED IN ORDER OF ASCENDING VALUES OF X)
                      ARE AS FOLLOWS:
```

APPENDIX H

Calculations of Instantaneous Growth Rates.

Instantaneous growth rate = $\ln \frac{\text{final length}}{\text{initial length}}$ for a unit of time.

1. Bursa-5 days..... $\frac{3366.0\ \mu m}{2133.0\ \mu m} = 1.578$, the ln thereof = 0.456

2. Bursa-5 days..... $\frac{3300.00\ \mu m}{2133.0\ \mu m} = 1.547$, the ln thereof = 0.436

3. Bursa-4 days..... $\frac{3066.0\ \mu m}{2100.0\ \mu m} = 1.460$, the ln thereof = 0.378

4. Bursa-4 days..... $\frac{3866.0\ \mu m}{3077.0\ \mu m} = 1.256$, the ln thereof = 0.228

5. Epitonium ulu-13 days.... $\frac{3400.0\ \mu m}{646.0\ \mu m} = 5.263$, the ln thereof = 1.661

6. Natica gualtieriana 13 days..... $\frac{1451.7\ \mu m}{1015.4\ \mu m} = 1.430$, the ln thereof = 0.358

7. N. gualtieriana-5 days... $\frac{1117.6\ \mu m}{1015.4\ \mu m} = 1.101$, the ln thereof = 0.096

8. Miters, thaisids combined-13 days..... $\frac{1475.1\ \mu m}{1001.3\ \mu m} = 1.473$, the ln thereof = 0.387

9. Miters, thaisids combined-5 days..... $\frac{1130.7\ \mu m}{1001.3\ \mu m} = 1.129$, the ln thereof = 0.122