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Charles D. and Mary Vaux Walcott
Research Fund

ECHINOID DISTRIBUTION AND HABITS,
KEY LARGO CORAL REEF
PRESERVE, FLORIDA

(WITH 16 PLATES)

By

PORTER M. KIER

U. S. National Museum, Smithsonian Institution

and

RICHARD E. GRANT

U. S. Geological Survey, Washington, D. C.



(PUBLICATION 4649)

CITY OF WASHINGTON
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LARGO CORAL REEF PRESERVE, FLORIDA

By

PORTER M. KIER, *U. S. National Museum, Smithsonian Institution*, and
RICHARD E. GRANT, *U. S. Geological Survey, Washington, D. C.*

(WITH 16 PLATES)

ABSTRACT

SEVENTEEN SPECIES of echinoids were found between the shore and a depth of 110 feet seaward from the living reef. All but one were encountered alive, and observed in their habitats. *Eucidaris tribuloides* (Lamarck) is solitary, widely and sparsely distributed in rocky niches and turtle grass. *Echinometra lucunter* (Linnaeus) is abundant in rock niches just below low tide, and less abundant in isolated clumps of coral and sponge on sand. *E. viridis* Agassiz is less abundant in the same habitats, and extends to greater depth on the reef. *Arbacia punctulata* (Lamarck) similarly inhabits rocky niches along the shore, and also clusters near sponges and corals elsewhere. *Diadema antillarum* Phillipi is ubiquitous, living at all observed depths in rocky niches along the shore and on the reef, in large flocks in turtle grass, but not on clean sand. *Astropyga magnifica* Clark moves in groups over open sand areas at relatively greater depth. *Lytechinus variegatus* (Lamarck) and *Tripneustes ventricosus* (Lamarck) occupy similar habitats in turtle grass, although *L. variegatus* is more abundant and its habitat includes rocky areas near shore.

The sand dollars *Leodia sexiesperforata* (Leske) and *Encope michelini* Agassiz burrow through the uppermost inch of sand, and are absent from rocky or grassy areas. Similarly, *Clypeaster subdepressus* (Gray) burrows through the upper part of the substrate, or occasionally merely covers itself with sand and shell debris and moves along the surface of the sand. The latter mode of life is normal for *Clypeaster rosaceus* (Linnaeus) which never was seen to burrow

and therefore can live in grassy areas. Less commonly it leaves the grass and moves over the surface of clean sand. *Meoma ventricosa* (Lamarck) normally burrows in areas of thick grassless sand relatively far from shore. It was observed rarely on the surface of the substrate, in grass or on clean sand, with debris held onto the test in the manner of *C. rosaceus*. *Plagiobrissus grandis* (Gmelin) burrows in clean sand, and was never observed at the surface. *Brissus unicolor* (Leske) and *Echinoneus cyclostomus* Leske live in coarse sand beneath rocks in the vicinity of the reef.

The only species not observed alive is *Schizaster (Paraster) floridensis* n. sp., which also has been found off the coast of the island of Dominica in the southern Caribbean.

INTRODUCTION

Echinoids are important constituents of the near-shore marine biota, contributing significantly to the food-chain and to modification of the substrate. In some areas they are among the most abundant megascopic animals. Similarly, their remains are abundant as fossils, especially in younger geologic strata, and as such they have become important indicators of the ages and environments of deposition of many Tertiary formations. These animals have been studied by zoologists and paleontologists since the beginnings of those sciences, and much has been learned about their evolution, gross areal distribution, general biology, habitat preferences, and especially their taxonomy. Nevertheless, until the invention of self-contained underwater breathing apparatus it remained virtually impossible to observe in detail the living habits and local habitat preferences of any but intertidal species. The authors are paleontologists whose prime concern is to interpret the ecology and life-habits of fossil animals, normally through recourse to the literature of biology and ecology. However, detailed data on the habits and habitats of living echinoids is scarce, therefore it was necessary to make firsthand observations.

The results of this preliminary study are presented in order to provide a broad ecological framework for further such studies in other areas, and for more detailed and comprehensive investigations of individual species.

Location and methods.—The Key Largo Coral Reef Preserve is an area almost completely under water which has been set aside by the governments of the United States and Florida for the preservation of a living coral reef and its surroundings (fig. 1). The administration is under the State of Florida, which has named its on-shore facilities

and the underwater portion that lies within its jurisdiction the John Pennkamp State Park. The Reef Preserve lies in the Atlantic Ocean,

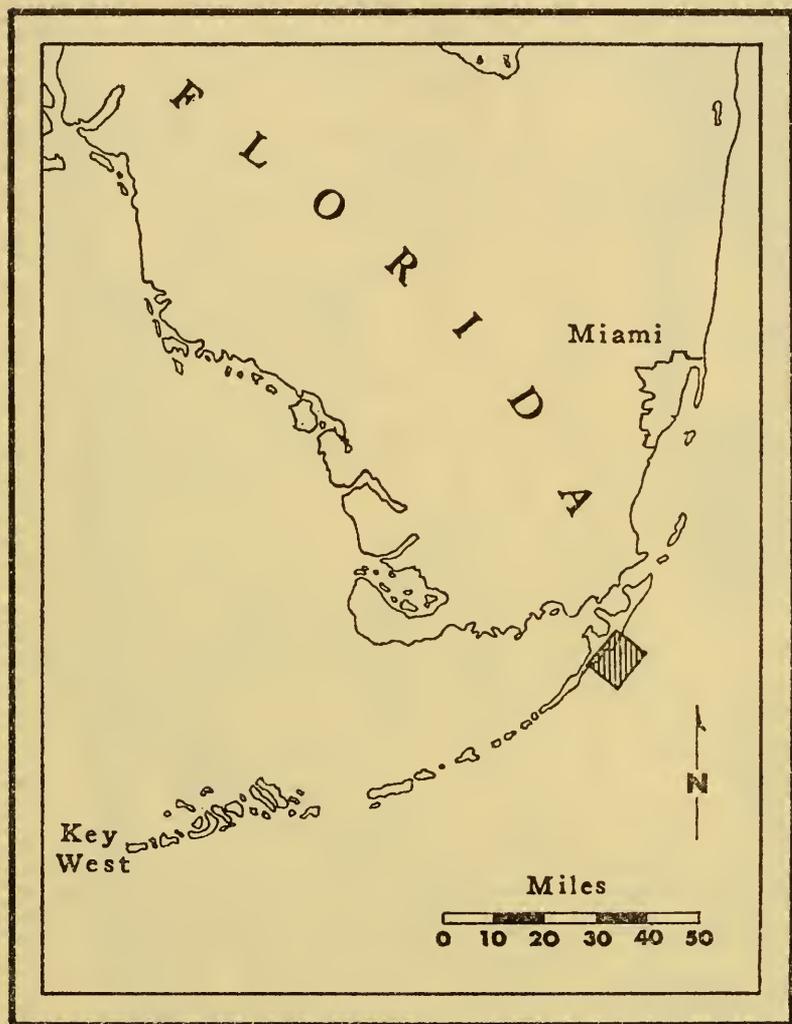


Fig. 1.—Map of southern Florida and the Keys; shaded rectangle indicates area shown on figure 2, in southern part of Key Largo Coral Reef Preserve.

southeast of the middle part of Key Largo, extending from about 1.5 miles offshore to just beyond the living coral reef about 5.5 miles offshore, for a length of about 20 miles. The area of this study ex-

tends from the shore to just beyond the outer boundary of the Reef Preserve, between the Grecian Rocks and the Molasses Reef Light, an area of about 55 square miles (fig. 2).

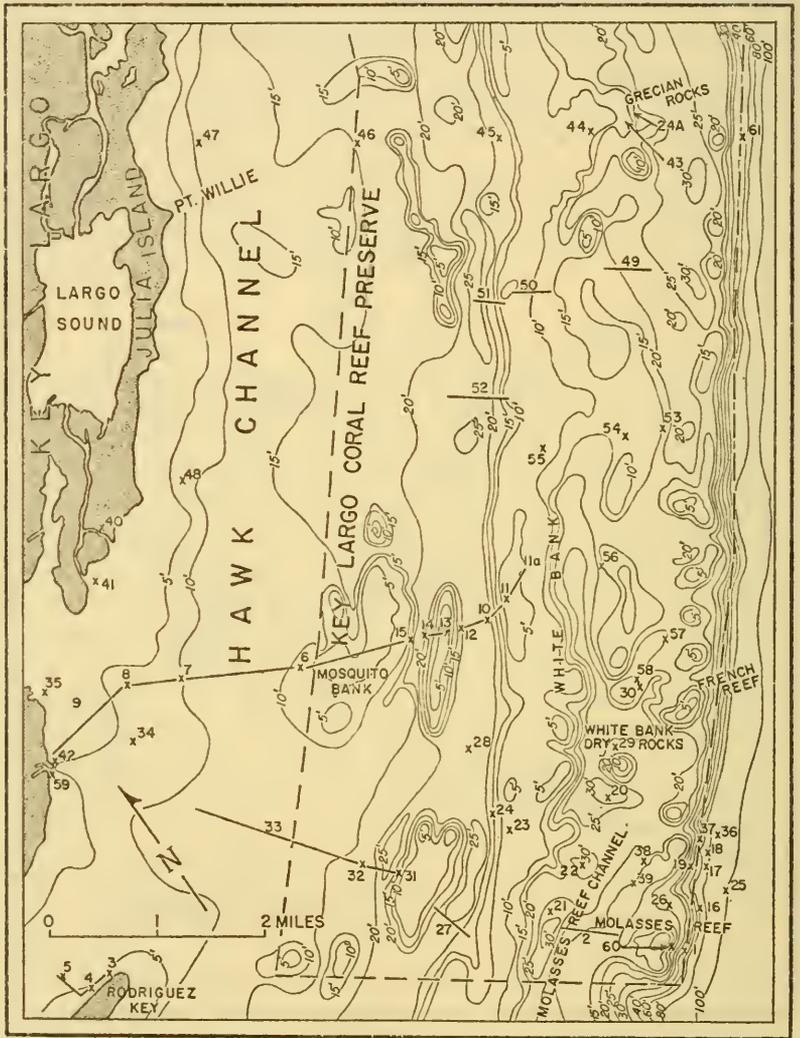


Fig. 2.—Contour map of area studied; depth contours in feet; numbers refer to stations; numbered straight lines are traverses. Map adapted from U. S. Coast and Geodetic Survey chart 1249.

Several different environments are present in this area; each that has a bearing on the distribution of the echinoids is described below

and its echinoid fauna discussed (fig. 3). Depths that were explored range from intertidal along the shore and at exposed parts of the reef, to 110 feet seaward from Molasses Reef. The investigation included the making of several traverses across the various channels, reefs, and sand flats, detailed census-taking in selected small areas, and the less detailed investigation of numerous stations in each of the various environments.

The echinoid fauna.—Seventeen species of echinoids were observed in the area of study. They belong to several of the major echinoid groups, and inhabit many different environments (table 1):

“Regular” echinoids

- Eucidaris tribuloides* (Lamarck)
- Diadema antillarum* Philippi
- Astropygys magna* Clark
- Arbacia punctulata* (Lamarck)
- Echinometra lucunter* (Linnaeus)
- Echinometra viridis* Agassiz
- Tripneustes ventricosus* (Lamarck)
- Lytechinus variegatus* (Lamarck)

“Irregular” echinoids

Holactypoida

- Echinoneus cyclostomus* Leske

Clypeasteroida

- Clypeaster rosaceus* (Linnaeus)
- Clypeaster subdepressus* (Gray)
- Leodia sexiesperforata* (Leske)
- Encope michelini* Agassiz

Spatangoida

- Plagiobrissus grandis* (Gmelin)
- Brissus unicolor* (Leske)
- Meoma ventricosa* (Lamarck)
- Schizaster (Paraster) floridiensis* new species

Living specimens of all these species were observed except *Schizaster (Paraster) floridiensis*. Although we saw only a few specimens of *Brissus unicolor* and *Echinoneus cyclostomus*, all the other species were abundantly represented by living individuals.

Acknowledgments.—It is a pleasure to acknowledge the interest and encouragement of the Smithsonian Institution and the U.S. Geological Survey which gave permission for the publication of this paper, and the financial support of the National Science Foundation by a grant to P. M. Kier through the Smithsonian Institution. John Harms of the Marathon Oil Company, Boulder, Colo., accompanied the authors on most of the dives, and helped greatly in determination of the types of bottom sediments as well as in collecting echinoid

TABLE 1.—Occurrence of Echinoids

| Depth and location | | Bottom type | Sand bottom | |
|---|----------------------------|-------------|---|--|
| | | | Bare sand | Turtle grass |
| INTER-TIDAL 2-6' | NEAR SHORE | | | |
| | OFF SHORE | | | |
| NEAR SHORE 4-8' | | | Clypeaster rosaceus | Clypeaster rosaceus Lytechinus variegatus |
| INSHORE EDGE HAWK CHANNEL, RODRIQUEZ KEY 4-15' | | | | Clypeaster rosaceus Diadema antillarum Echinometra lucunter Echinometra viridis Lytechinus variegatus |
| HAWK CHANNEL 10-18' | | | | Arbacia punctulata Clypeaster rosaceus Diadema antillarum * Lytechinus variegatus |
| BACK REEF CHANNEL 10-20' | | | | Arbacia punctulata Clypeaster rosaceus Diadema antillarum Eucidaris tribuloides Lytechinus variegatus Tripneustes ventricosus * |
| WHITE BANK 10-12' | | | Clypeaster rosaceus Clypeaster subdepressus Encope michelini Leodia sexiesperforata Meoma ventricosa Plagiobrissus grandis * | Clypeaster rosaceus Diadema antillarum Eucidaris tribuloides Lytechinus variegatus Tripneustes ventricosus |
| INTERREEF CHANNEL 15-35' | | | Clypeaster rosaceus Clypeaster subdepressus Encope michelini Leodia sexiesperforata Lytechinus variegatus * Meoma ventricosa Plagiobrissus grandis * Schizaster (P.) floridiensis * Tripneustes ventricosus * | Brissus unicolor * Clypeaster rosaceus Diadema antillarum Eucidaris tribuloides Lytechinus variegatus Meoma ventricosa Tripneustes ventricosus |
| R E E F | SHOREWARD PATCHES 5-10' | | | Clypeaster rosaceus |
| | MAIN REEF 10-35' | | Clypeaster subdepressus Diadema antillarum Meoma ventricosa Schizaster (P.) floridiensis | |
| | SEAWARD PATCHES 110' | | | |
| SEAWARD TERRACE 80-85' | | | Astropyga magna Clypeaster subdepressus Diadema antillarum Eucidaris tribuloides Meoma ventricosa Plagiobrissus grandis * Schizaster (P.) floridiensis * | |

* Rare.

TABLE 1.—Occurrence of Echinoids

| Rock bottom | | |
|--|---|--|
| Living coral | Rock and dead coral | Broken rock |
| | Diadema antillarum Echinometra lucunter Lytechinus variegatus | Diadema antillarum Echinometra lucunter Lytechinus variegatus |
| | | Diadema antillarum Echinometra lucunter Eucidaris tribuloides Tripneustes ventricosus |
| | | |
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| | | |
| | | |
| | | |
| | | |
| Arbacia punctulata Diadema antillarum Echinometra lucunter | | |
| Diadema antillarum | Diadema antillarum Echinometra viridis | Brissus unicolor Echinoneus cyclostomus Eucidaris tribuloides |
| Diadema antillarum | | |
| | | Diadema antillarum |

specimens. Norman F. Sohl of the U.S. Geological Survey dove with P. M. Kier on an earlier expedition to the keys during which a preliminary study of the echinoid fauna was made. Craig Pontin of the Sea Center, Key Largo, ran the boat, provided accurate determinations of location for each station, and made available his extensive and detailed knowledge of bottom conditions and depths. Herb Pontin was most kind in permitting use of his larger boat during rough weather. The State of Florida gave permission to collect specimens in John Pennekamp State Park. We thank Thomas Phelan, research assistant at the U.S. National Museum, who helped in the preparation and study of the collected specimens. The fish were identified by John E. Randall, University of Puerto Rico Institute of Marine Biology.

The manuscript was reviewed critically by Dr. J. Wyatt Durham, University of California, Dr. Peter Glynn, University of Puerto Rico Institute of Marine Biology, and Dr. Richard S. Boardman, U.S. National Museum, whom we thank for their many valuable suggestions.

ECHINOID DISTRIBUTION

The southern part of the Key Largo Coral Reef Preserve and its shoreward extension divide naturally into several major types of environments determined by the nature of the bottom, depth of the water, and distance from shore (table 1). These major environments form bands between and roughly parallel to the shoreline and the outer edge of the living coral reef. Hawk Channel, White Bank, and various parts of the reef have formal names (fig. 2); other areas have been given convenient field designations for purposes of this discussion (fig.3).

MAJOR ENVIRONMENTS

Intertidal (rocky shore and exposed reef).—Rocky shore (stations 35, 42, 59, inshore end of station 9) depth (just off seawall) 2-4 feet at midtide; very steep, large rocks of dead coral, living alcyonarian and anthozoan corals, large loggerhead sponges, sparse green algae, abundant coralline algae and turtle grass extending to tidal edge. *Echinometra lucunter* is abundant at station 59, in depths as shallow as one foot at low tide; *Lytechinus variegatus* and *Diadema antillarum* also occupy the steep rock intertidal shore edge.

Exposed reef (station 38) depth 2-6 feet, high tide; gently sloping rocky bottom, rocks covered with thin algal slime. Echinoids are

Eucidaris tribuloides (on and under rocks), *Echinometra lucunter* (numerous in holes in rocks, and under rocks), *Diadema antillarum* (relatively small, numerous under rocks and around edges of rocks), *Tripneustes ventricosus* (one juvenile under rock). In addition, each rock that was turned over revealed several active brittle stars scurrying for cover.

Permanently underwater, just offshore.—(Stations 7, 8, 9, 34, 35, 48) nearly flat rock bottom covered with thin layer of calcareous sand; water depth 4-8 feet; numerous loggerhead and basket sponges, alcyonarian and large and small scleractinian corals, patches of sparse turtle grass (*Thalassia*), patches of algae. Echinoids: *Lytechinus variegatus* (in grass), *Clypeaster rosaceus* (in grass and on sand).

Rock bottom of artificial channel at station 40; depth about 6 feet, edged by mangroves, has numerous *Diadema antillarum* attaining large size, living in recesses on bottom, and on vertical rocky irregular sides, and among lower parts of mangrove roots; this is partly intertidal.

Inshore edge of Hawk Channel.—(Stations 33, 47) sand bottom, mostly covered with turtle grass, few bare patches; depth 10-15 feet; water typically murky; echinoids: *Lytechinus variegatus* and *Clypeaster rosaceus* abundant in grass, a few small solitary *Diadema antillarum*.

Shallows just inshore from Rodriguez Key; (stations 3, 4, 5) depth 4-10 feet; sand bottom with large areas of turtle grass (*Thalassia*), calcareous algae (*Halimeda*), merman's brush (*Pennicillus*), brown algae, widely scattered loggerhead and basket sponges, small staghorn and brain corals imbedded in sand, buried clams (*Arca*), holothurians, brittle stars, and echinoids: *Diadema antillarum* (solitary and in groups of up to 50), *Lytechinus variegatus* (in grass), *Echinometra lucunter* and *E. viridis* (under clumps of sponge, coral, and shells), *Clypeaster rosaceus* (in grass and on bare sand). Detailed survey of 100 square feet in sparse turtle grass at station 3 (depth 4 feet) produced the following echinoids:

Lytechinus variegatus—7 alive

Echinometra lucunter and *E. viridis*—5 alive, under clumps

Clypeaster rosaceus—4 alive, 2 dead

L. variegatus and *C. rosaceus* live on the sand bottom, individuals about 1.5-2 feet apart but without apparent segregation as to species. About 20 feet from this surveyed area, in an area 15×5 feet, at the same depth (4 feet) were 90 small and medium size *D. antillarum*, in one group of 50, one of 20, and two groups of about 10 each, living on the sand bottom in short, sparse turtle grass (pl. 2, fig. 4).

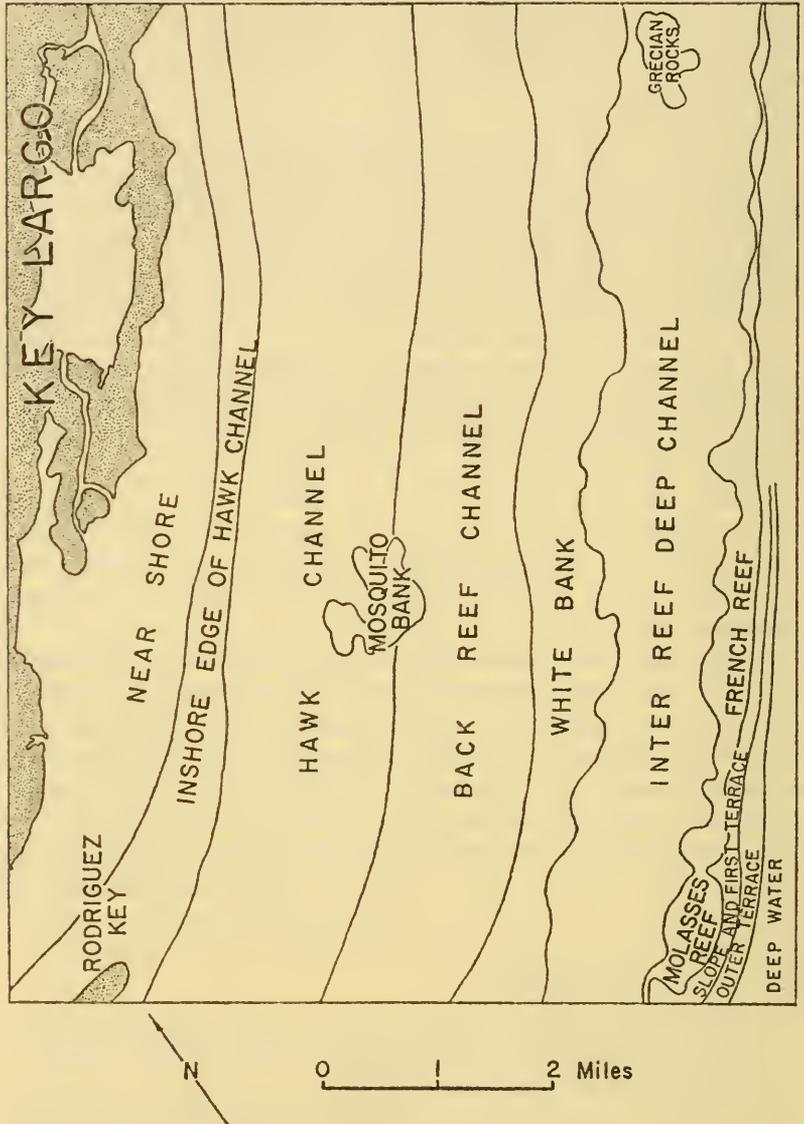


Fig. 3.—Locations of major environments mentioned in text.

Hawk Channel and its offshore edge.—(Stations 6, 32, 33, 46) cloudy water, fine sand and silt bottom with dense turtle grass; depth 10-18 feet; numerous worm burrows and mounds, small free-living scleractinian corals, crabs, starfish (*Linckia*); echinoids: *Lytechinus variegatus* (very abundant, about 1.5-2 feet apart, small), *Arbacia punctulata*, *Diadema antillarum* (rare), *Clypeaster rosaceus* (less abundant than *L. variegatus*).

Back reef channel.—(Stations 10, 12, 14, 15, 24, 27, 28, 31, 51, 52) sand and silt bottom, grassless patches and patches of turtle grass (small reef patches discussed separately); depth 10-26 feet (shoaling to reef patches); water normally cloudy, turtle grass covered with "dust"; small sponges and scleractinian corals, numerous holothurians, worm burrows; echinoids: *Eucidaris tribuloides* (few), *Lytechinus variegatus* (abundant), *Tripneustes ventricosus* (few), *Arbacia punctulata* (few), *Diadema antillarum* (many, in groups of 3-5), *Clypeaster rosaceus*. Station 14 is clean sand with no echinoids.

Reef patches in back reef channel.—(Stations 13, 15, 27) hard rock bottom with patches of thin sand; depth 5-10 feet; many corals and sponges, fish; echinoids: *Echinometra lucunter* (on coral), *Arbacia punctulata* (under edge of sponge), *Diadema antillarum*, *Clypeaster rosaceus* (on sand patches).

White Bank.—(Stations 11, 11a, 23, 24, 45, 50 and offshore ends of stations 27, 51, 52) depth 10-12 feet, 3-6 feet over shoals; broad areas of white, rippled sand, patches of sparse turtle grass; echinoids: *Eucidaris tribuloides* (few), *Lytechinus variegatus* (abundant, in grass), *Tripneustes ventricosus* (few in grass), *Diadema antillarum* (few, in grass and on rock at station 50), *Leodia sexiesperforata* (in sand), *Encope michelini* (in sand), *Clypeaster subdepressus* (in sand), *C. rosaceus* (in grass and on sand), *Plagiobrissus grandis* (in sand), *Meoma ventricosa* (in sand).

Interreef channel.—(Stations 2, 20, 21, 22, 29, 30, 39, 44, 49, 53, 54, 56, 57, 58) depth 15-35 feet; broad areas of clean, white, rippled sand, with large irregular, slightly elevated patches of turtle grass; echinoids in sand areas: *Encope michelini*, *Leodia sexiesperforata*, *Clypeaster subdepressus*, *C. rosaceus* (near edges), *Meoma ventricosa* (large), *Plagiobrissus grandis*, *Schizaster (Paraster) floridiensis* (dead), tiny *Lytechinus variegatus* and *Tripneustes ventricosus* in clumps. Echinoids in turtle grass: *Eucidaris tribuloides*, *Lytechinus variegatus*, *Tripneustes ventricosus*, *Diadema antillarum*, *Clypeaster rosaceus*, *Brissus unicolor* (dead), *Meoma ventricosa* (small).

Living coral reef.—(Stations 1, 26, 43, 60) depth 10-25 feet, high relief; abundant niches in both living and dead parts of reef, in-

habited by large individuals of *Diadema antillarum*. Sandy patches in large depressions and grooves contain few *Clypeaster subdepressus*. *Echinoneus cyclostomus* and *Brissus unicolor* live under slabs of reef debris in and near the reef.

Outer edge of reef, and sandy terrace.—(Stations 16, 18, 19, 37, 61) depth 25-50 feet; tongues of sand extending from sandy terrace up through steep-sided grooves in lower edge of reef; sand fairly clean, with rocky patches, burrows by burrowing fish, some algae, broad ripples. Echinoids in sand: *Clypeaster subdepressus* (buried deeply), *Meoma ventricosa*, *Schizaster (Paraster) floridiensis*, *Brissus unicolor*, *Echinoneus cyclostomus*. Echinoids in holes in rock: *Diadema antillarum* (abundant), *Echinometra viridis* (one specimen).

Level sand flats beyond reef.—(Stations 17, 17a, 36) depth 80-85 feet; bare sand with thin cover of algae in patches, rocky holes of burrowing fish, small piles of rock supporting sponges and small corals; echinoids: *Eucidaris tribuloides*, *Diadema antillarum* (small, among rock and sponges), *Astropyga magnifica* (in groups, on sand), *Clypeaster subdepressus* (small, many dead, few alive), *Meoma ventricosa*, *Plagiobrissus grandis* (dead), *Brissus unicolor*, *Schizaster (Paraster) floridiensis* (dead).

Deep water beyond 85-foot terrace.—(Station 25) depth 105-110 feet; large mounds of living coral, with sponges, fish, crinoids, basket stars, mounds about 50 feet long, 12 feet high, surrounded by coarse sand of shell and calcareous algal debris. Very large *Diadema antillarum* in niches in coral mounds; no echinoids observed in sand.

SYSTEMATIC DISCUSSION OF SPECIES

Descriptions, synonymys, and illustrations of the species discussed below can be found in Mortensen (1928-1951).

Order CIDAROIDA Claus

Family CIDARIDAE Gray

Genus EUCIDARIS Pomel

EUCIDARIS TRIBULOIDES (Lamarck)

Plate 2, figures 1-3; text figure 7

This large brown urchin is easily recognized by its long thick spines arranged in 10 vertical series. It has a globular shape and is locally known as the mine or satellite urchin. An adult is approximately 100 mm. in horizontal diameter with its spines, 50 mm. without. The naked test is characterized by straight, narrow poriferous zones with only two vertical rows of pore-pairs in each ambulacrum, and broad interambulacral areas with 10 vertical series of large tubercles.

Occurrence.—*Eucidaris tribuloides* was found only seaward from the “back-reef channel,” although it was found much nearer shore farther south off Molasses Key. It is widespread but not abundant in the Coral Reef Preserve, occurring in depths from intertidal to at least 85 feet. It lives on sandy or rocky bottoms (pl. 2, figs. 1-3) but was not found on clean sand where grass or algae were absent. This species lives in the same kind of environment as *Lytechinus variegatus*, *Tripneustes ventricosus*, and *Arbacia punctulata*, but its distribution seems to be most nearly coincident with that of *T. ventricosus* in this area; it is not as widespread as *L. variegatus* (fig. 7). Normally it is solitary and well camouflaged, so in light of observed occurrences elsewhere in the Keys, we believe that an intensive search for this species would extend its range in the Coral Reef Preserve to the region nearer shore.

This species was found at stations 1, 2, 10, 11, 12, 22, 24, 30, 36, 38, 51, 52, and 53.

Behavior.—*Eucidaris tribuloides* lives unburied, on rocky (pl. 2, fig. 1) or sandy bottoms (pl. 2, figs. 2, 3) but not in areas of clean, grass-free sand. Specimens were found in dense and sparse turtle grass, normally with their upper and lateral primary spines covered by sheaths of living algae which render the animal nearly invisible (pl. 2, figs. 2, 3). Individuals living in grass normally were solitary, whereas those living on rock, under the overhang of a sponge or coral were more typically clustered in favorable niches. Some lived under slabs of rock in shallow water, and in deeper water where slabs had fallen into deep “grooves” between spurs of the reef.

Mortensen (1928, p. 404) reports that this species feeds on algae and Bryozoa. Its abundant presence in areas of turtle grass leads us to suspect that it also eats grass, although no direct observations of its feeding habits were made. This species is relatively immobile during the day; its nocturnal behavior is unknown. We observed no trails, and did not see undisturbed specimens in motion.

Order DIADEMATOIDA Duncan

Family DIADEMATIDAE Peters

Genus DIADEMA Gray

DIADEMA ANTILLARUM Philippi

Plate 2, figures 4-7

This black urchin has extremely long, slender hollow spines the tips of which are mildly venomous. The urchin is very large, many adults

being more than 200 mm. in horizontal diameter with spines, 100 mm. without. The bare test is flattened and the apical system and medial areas of the interambulacra are depressed. The ambulacra are narrow, inflated with the pore-pairs in two fairly straight series in each area. Spines of mature specimens are black, but those of juveniles are annularly banded black and white. Kristensen (1964, p. 15) reports that adults with gray or banded (or white) spines occur in areas of low light intensity, either deep or turbid water.

Occurrence.—*Diadema antillarum* is the most ubiquitous echinoid in the area of the Coral Reef Preserve. It occurs in the entire depth range studied, and extends from intertidal slopes of South Sound Creek leading from Largo Sound, to a depth of 110 feet on the seaward side of the main reef, and undoubtedly much deeper. Mortensen (1940, p. 274) reports it from depths as great as 1,200 feet. It was found among mangrove roots in South Sound Creek (station 40) and in irregularities in the limestone bottom of that creek, in sparse grass on open sand in large flocks near Rodriguez Key, in denser grass in Hawk Channel where the water is cloudy with suspended silt, in isolated reef patches within the sandy areas, in clear water at all depths on the main part of the reef, on sand terraces beyond the reef, and on discontinuous reef mounds in deep water beyond the reef. The only environment from which *D. antillarum* was absent is open grassless sand, the areas primarily inhabited by sand dollars and *Meoma ventricosa*.

This species was found at stations 1, 3, 4, 10, 11, 11a, 12, 13, 15, 16, 17, 17a, 18, 22, 25, 26, 27, 28, 31, 32, 36, 38, 40, 43, 50, 52, and 59.

Behavior.—*Diadema antillarum* remains relatively immobile during the day. It occupies niches and recesses in the reef or other rock, rests among mangrove roots (even on nearly vertical sides of creeks), hides under rock slabs in shallow water where dead reef is broken by wave action, or in deeper water between reef masses, or it gathers into clusters and spends the day on the sand among sparse turtle grass and other vegetation. Specimens were found around the bases of isolated sponges or corals, and even living inside the cups of larger basket sponges.

Individuals remain in their niches, gently waving their long spines (or having them waved by the surge of water), with small white mysid shrimps swimming among the spines. Upon approach of

danger, presumably sensed by motion or the shadow cast by the potentially dangerous object, *D. antillarum* begins to wave its spines rather rapidly. When the potential danger is a diver, they seem to point many of the spines at him; presumably this is their reaction to other dangers as well. Specimens that are in the open on grassy sand group their upper spines into five cone-shaped bundles and point them at the intruder, after the fashion observed in *Astropyga magnifica* (pl. 1).

Shroeder and Stark (1964) report that *D. antillarum* becomes much more active at night, leaving its niches and wandering about on the reef. Presumably the groups that rest on the grassy sand during the day also become active and more mobile during the night. Other similarities in habit suggest that perhaps the groups remain intact as they move, as do clusters of *A. magnifica* during the day.

A few individuals were seen living singly on grassy sand, away from reef mounds or other places with available niches. Many of these isolated specimens (pl. 2, fig. 5) were small, with the black and white banded spines characteristic of juveniles. A few adults also were seen alone on sand, but this mode of life seemed to be more typical of the juveniles.

Genus ASTROPYGA Gray

ASTROPYGA MAGNIFICA Clark

Plate 1, figures 1-5

This echinoid is striking in appearance with its large test (205 mm. in horizontal diameter including spines) and its radiating color pattern. Under water the interambulacra are yellow, the ambulacra brown with brilliant iridescent blue spots bordering the ambulacra. At the surface in natural light unfiltered by the water, the specimens have purplish red (mallow) ambulacra and yellow-white interambulacra. The spines are banded with the same colors. A large anal tube was present on all the living specimens. In shape and size of its test, length and thickness of its spines, this species strongly resembles *Diadema antillarum*, but is easily distinguished by its color.

Occurrence.—*Astropyga magnifica* was found only on the sand terrace on the seaward side of the reef, at a depth of 80-85 feet. Mortensen (1940, p. 207) reports it from a depth of 88 meters off Dry Tortugas, Fla. We observed it on nearly flat grassless sand which

was bound in places by patches of algae. The vegetation was sparse, and the topography unbroken except by small sponges and corals, and by the burrows of fish which piled pebbles, shells, and echinoid tests around the entrances of their burrows.

Too few samples were obtained to establish the range of this species in this area, but extensive searches at depths near 65 feet, and briefer searching at 110 feet revealed no specimens. After the first specimen, a juvenile, was found on the 85-foot terrace, a return to that depth produced a good collection, so we infer that the species at least does not live in shallower depths; Mortensen's report indicates that it does inhabit deeper waters.

This species was found at stations 17a and 36.

Behavior.—Mortensen (1940, p. 207) emphasized the extreme rarity of *Astropyga magnifica* in collections made by dredge hauls, and correctly deduced that its distribution was spotty because individuals grouped together and traveled over the surface of the sand in small groups. He was precisely correct. This species is highly mobile; it was observed moving across the sand flats single-file in groups of two to five, at a speed of approximately 3 feet per minute. Only one isolated individual was found, a juvenile at station 17a; all others were in groups.

This species moves about on its relatively short ventral spines, with all other spines radiating rather uniformly, although waving slightly with motion of the animal. Small fish, identified by J. E. Randall as a species of the cardinal fish *Apogon*, swim among the spines, keeping up with the echinoids as they move along (pl. 1, fig. 4). The anal sac is fully inflated (pl. 1, figs. 1-5), and the iridescent blue spots along the edges of the ambulacra reflect enough light to appear to glow (pl. 1, figs. 2, 3, 5). Upon the approach of danger, presumably sensed by changes in light intensity, the spines group together into five cone-shaped bundles, thus producing a strong and formidable defense (pl. 1, figs. 1-3, 5).

The gregarious habits, acute sensitivity to changes in light, waving and then bundling of spines, are modes of behavior that recall *Diadema antillarum*. That species is much less mobile during the day, normally remaining in groups on the open sea bottom or hidden in niches in coral, sponge, or rock. *D. antillarum* is active at night, however, and then its behavior is yet more strikingly similar to that of *A. magnifica* (Schroeder and Stark, 1964, p. 133).

Order ARBACIOIDA Gregory

Family ARBACIIDAE Gray

Genus ARBACIA Gray

ARBACIA PUNCTULATA (Lamarck)

Plate 2, figures 8-9; plate 10, figure 5; text figure 4

This dark brown urchin is characterized by its long slender spines and circular ambital outline. An adult is approximately 90 mm. in horizontal diameter with spines, 45 mm. without. The area around the apical system is naked and there are usually four large periproctal plates. The dead test is reddish brown, with narrow ambulacra, and pore-pairs arranged in simple vertical series. The tubercles on the interambulacra are of the same size and are arranged in oblique series slanted up to the middle of each area. This species can be confused with *Echinometra lucunter* from which it is distinguished by its longer slenderer spines and round test, and with *Diadema antillarum* from which it differs in having thicker solid spines, and a smaller, higher test with a larger peristome.

Occurrence.—*Arbacia punctulata* was found primarily in areas of turtle grass, commonly associated with *Lytechinus variegatus* and *Tripneustes ventricosus*. During the day it stays in the shadow of an overhanging sponge or clump of coral (pl. 2, figs. 8, 9) although rarely it was merely in grass like the above two species. The species also occurred rarely on sandy areas with little or no turtle grass, although there it stays near corals or sponges.

This species was rare in the area of study. Its range apparently coincides rather closely with that of *Tripneustes ventricosus*, but more observations would be necessary in order to establish its limits precisely (fig. 4). It was found in the "back-reef channel" and in Hawk Channel, in depths ranging from 10 to 20 feet.

Sharp and Gray (1962, p. 309) report *A. punctulata* living on rocky bottom in about 12 to 20 feet of water off the coast of North Carolina. We encountered large numbers along the rocky shore of Molasses Key, a few miles south of the Coral Reef Preserve. Similarly, Kier has found it on the rocky coast of Dominica in the Lesser Antilles. Only one specimen was found in a rocky habitat in the Key Largo Coral Reef Preserve, exposed and uncovered on bare rock within a large grassy area at station 51. The species obviously inhabits a variety of environments, but seems to have a clear preference for

niches that offer some protection, either from predators or from sunlight (Sharp and Gray, 1962).

This species was found at stations 24, 27, 46, and 51.

Behavior.—*Arbacia punctulata* was not observed to cover itself with objects from the substrate. Sharp and Gray (1962) studied its reaction to various kinds of light, including sunlight, and concluded that it tends to negative phototaxis, although much less strongly than *Lytechinus variegatus*. They report also that *A. punctulata* is highly variable in its response to light, with some specimens remaining at water level during low tide, in the full light of the sun. This variability would account for our finding the species clustering under overhanging edges of coral or sponge, and also finding rare individuals on bare rock or uncovered in sparse grass.

Order ECHINOIDA Claus

Family ECHINOMETRIDAE Gray

Genus ECHINOMETRA Gray

ECHINOMETRA LUCUNTER (Linnaeus)

Plate 16, figures 1-4

The living test is reddish to dark brown, usually slightly oblong, with adults from 80 to 100 mm. long although a few specimens are considerably larger. The spines are long and slender, but moderately thick near their bases. The bare test has large tubercles, two rows of which are larger in each interambulacrum and ambulacrum. The pore-pairs are arranged in arcs, and the peristome is large. This species can be confused with *Echinometra viridis* Agassiz (distinguished below) and with *Arbacia punctulata* (Lamarck). It differs from *A. punctulata* in having thicker spines, usually an oblong test, fewer large tubercles, and many periproctal plates.

Occurrence.—*Echinometra lucunter* was found in shallow water (2-8 feet), both near shore and on shoals far from shore. Normally it was on hard bottom, either among slabs of dead reef limestone or on small patch reefs in sandy areas. Some were found in sand away from hard substrate, but these were near sponges or small corals, or under clumps of shells, coral, and sponge. The species ranges from the shoreline to exposed parts of the reef. It was found among the rocks along the shore at station 60, and was present in sand in shallow water near Rodriguez Key. In addition, many specimens were found on rock in the shoreline intertidal zone farther south at Molasses Key, where it was found to a depth of 10 feet.

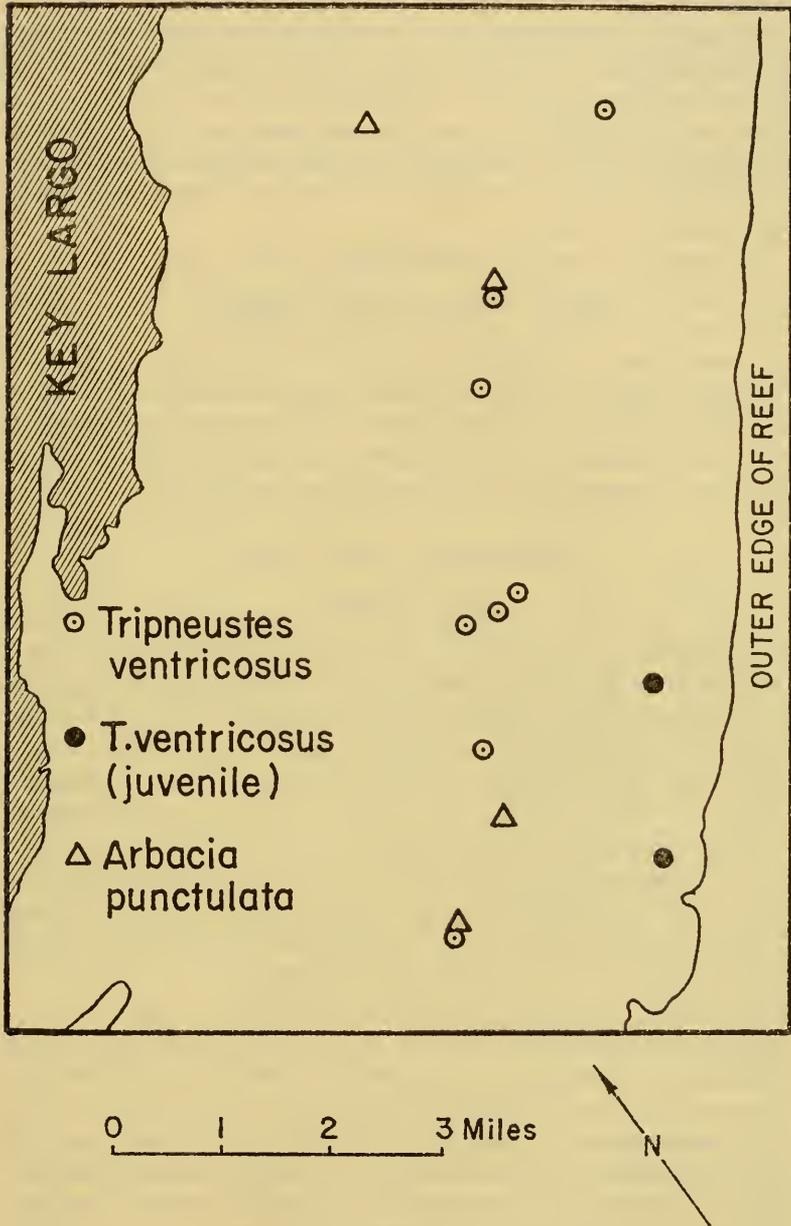


Fig. 4.—Sketch map of area studied, showing distribution of *Tripneustes ventricosus* and *Arbacia punctulata*.

This species occurs at stations 3, 13, 15, 38, and 59.

Behavior.—This species lives in protected niches. It inhabits holes or shallow recesses in rock, clings to the bases of sponges or coral heads, works its way under detached slabs of rock, or gets under clumps of shell and broken coral that are bound together by growths of algae and sponge. It has been found in the same environments, living closely associated with *E. viridis*, although the depth range of that species is greater.

The species was seen in great numbers living in holes in rock at station 60 and along the shore of Molasses Key, but did not appear to be trapped in the holes. Some regular echinoids are reported to enter small holes in rock as juveniles, and to enlarge the holes as they grow, finally becoming too large to pass through the entrance. *E. lucunter* inhabited holes and niches with openings large enough to permit exit; possibly they leave their protected habitats at night, and travel over the substrate as does *Diadema antillarum*.

ECHINOMETRA VIRIDIS Agassiz

Plate 10, figure 6

This species is very similar to *E. lucunter* but differs in having a smaller test, purple, gray, or blue tips on its spines, and fewer spines in the apical system. Both species occur together at some localities.

Occurrence.—*Echinometra viridis* was found in shallow water associated with *E. lucunter*, and also as deep as 40 feet on the main reef. In the shallow areas it was on rock or in sandy areas in clumps of shell and coral debris held together by growth of algae and sponge. One specimen was found in deeper water on rock at the edge of the reef. Its range extends from the shoreline (observed at Molasses Key, not in the area of this study) to the outer edge of the main reef; from intertidal to 40 feet and possibly deeper.

This species was found at stations 3 and 37.

Behavior.—Specimens living in the shoreline intertidal zone on Molasses Key were in holes in the rock. These holes appeared to be large enough to permit the urchin to enter and leave. Specimens living on sandy bottom in the area of study, just off Rodriguez Key, clustered together with individuals of *E. lucunter* among clumps of coral and shell debris bound together by living sponge. In these two shallow water habitats the two species of *Echinometra* lived together, with no apparent differences in habitat or behavior. Further research into this matter is intended, to examine the basis upon which they

are classed as separate species. For purposes of this paper they are considered separate, following Mortensen (1943, p. 365).

The one specimen that was found at the depth of 40 feet was in an elongate hole in the edge of a spur on the offshore side of the main reef (station 37). Although the specimen was difficult to remove from its niche, the aperture of the hole appeared to be sufficiently large to allow the animal to enter and leave freely.

Genus *LYTECHINUS* Agassiz

LYTECHINUS VARIEGATUS (Lamarck)

Plate 3, figure 1; text figure 5

The color of the test and spines of this species ranges from green, to red, purple, or white. An adult is approximately 90 mm. in horizontal diameter with spines. The bare test is high domed with smoothly curving sides, and a relatively small peristome. The ambulacra are moderately wide with the pore-pairs arranged in two series in each ambulacrum; each series with the pore-pairs in units of three. The pedicellariae are very conspicuous on a living specimen. The tubercles in the interambulacra are small and arranged in horizontal rows with approximately four in each half-interambulacrum. This species is distinguished from *Tripneustes ventricosus*, a species associated with it and somewhat similar in appearance, by its generally smaller test, variable color, more conspicuous pedicellariae, more numerous and shorter spines, and more compactly arranged pore-pairs in each poriferous zone.

Occurrence.—*Lytechinus variegatus* was abundant in areas of turtle grass, rare on bare sand near turtle grass and on alga encrusted rock along the shoreline, and absent from broad expanses of clean, grassless sand. It occurred in water ranging in depth from about 4 to 35 feet (fig. 5). Sharp and Gray (1962, p. 309) report its presence on shelly sand bottom off the coast of North Carolina, and its absence from grassy areas. Our findings are more similar to those of Clark (1933) who found this species in grass off Puerto Rico, and Moore, et al. (1963) who also found it in grass and absent from clean sand or gravel off Key Largo. Clark (1933) found juveniles living under and among rocks outside of grassy areas. We found them living similarly, along with juveniles of *Tripneustes ventricosus*, in sandy areas near grass patches, clustered together in aggregates of shells, algae, and especially small sponges. Extensive search of the adjacent grassy areas revealed only one juvenile *L. variegatus*.

Moore et al. (1963, p. 24) state that *L. variegatus* is intolerant of suspended silt in the water. However, we found the species to be abundant in the Hawk Channel where the water is continuously cloudy with suspended silt, at least during the summer (C. Pontin, personal communication).

The pattern of distribution of *L. variegatus* is remarkably similar to that of *Clypeaster rosaceus*, another grass-dwelling species (figs. 5, 6). On the other hand, it shows little overlap with the distribution of *C. subdepressus* or *Meoma ventricosa*, two species that prefer the clean sand habitat, and apparently prefer to live somewhat farther off shore.

According to Moore, et al. (1963) the minimum depth range of this species may be determined by two factors. One is that specimens exposed at low tide are seized by gulls which carry them to a height and drop them to crack them and expose their edible insides. The other is that the species is remarkably sensitive to short ultraviolet rays, which are filtered out by a few inches of water, as shown by Sharp and Gray (1962). Therefore, the net effect is to keep the population of *L. variegatus* confined to depths greater than those exposed at low spring tides.

The maximum depth at which this species lives probably is determined by the depth range of turtle grass (*Thalassia*), which is about 35 feet (Moore, et al., 1963). We found the species only in waters shallower than that depth, and essentially inshore from the "interreef deep channel."

This species was found at stations 2, 3, 4, 6, 7, 8, 9, 10, 11, 22, 24, 27, 28, 29, 30, 31, 33, 35, 46, 48, 51, 52 and 59.

Behavior.—*Lytechinus variegatus* lives above the surface of the sand, moving over the sand and the turtle grass, and climbing up among the blades of grass. Dissections of several specimens, and observation of activities of others, confirm that this species feeds mainly on turtle grass (Moore, et al., 1963).

This species, like some other nonburrowers, covers its test with objects from the bottom, holding them by its tube feet (pl. 3, fig. 1). Broad objects that cover much surface seem to be preferred. Individuals that live near shore nearly uniformly hold one or more mangrove leaves onto the test, and farther from shore where mangrove leaves are scarce, some individuals managed to find one. Others use complete clam valves, or other large fragments of shell, and many use the blades of turtle grass for cover. Experiments by Sharp and Gray (1962) suggest that this species covers itself to avoid sunlight, al-

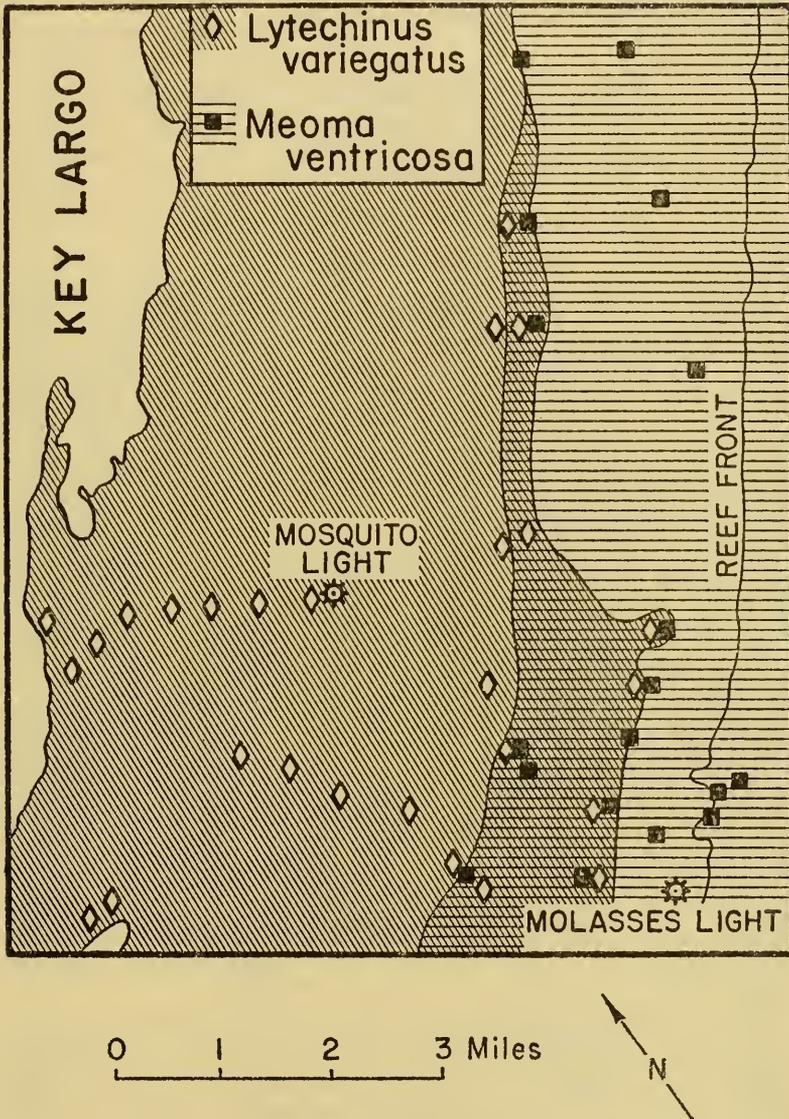


Fig. 5.—Map of area studied, showing only slightly overlapping ranges of grass and rock dwelling *L. variegatus* and sand dwelling *M. ventricosa*.

though the practice also produces a camouflage that appears to be effective and probably necessary during the daylight hours (for further discussion, see *Clypeaster rosaceus*).

Order TEMNOPLEUROIDA Mortensen

Family TOXOPNEUSTIDAE Troschel

Genus *Tripneustes* Agassiz

TRIPNEUSTES VENTRICOSUS (Lamarck)

Plate 3, figure 2; text figure 4

The test of this urchin is large—an adult approximately 110 mm. in horizontal diameter. It is brown and has numerous short, white spines. The bottom of the test is relatively flat, the top domed with smoothly curving sides. The bare test is characterized by broad ambulacra with six vertical rows of pore-pairs in each area. The interambulacra are slightly wider than the ambulacra and have many small tubercles arranged in horizontal rows. This species resembles *Lytechinus variegatus* with which it is associated and often confused, but differs in its generally larger test, persistent brown color in living specimens, less conspicuous pedicellariae, and more numerous and shorter spines. Its bare test is distinguished by its white color, and its more widely separated pore-pairs in each poriferous zone.

Occurrence.—*Tripneustes ventricosus* was found in grassy areas on sand bottoms. Its habitat is similar to that of *Lytechinus variegatus*, but seems to be more restricted in this area. Where the two species occur together, *T. ventricosus* is much less abundant. *L. variegatus* occurred at nearly all stations where turtle grass was abundant, but *T. ventricosus* was found only in the offshore grassy areas, on the White Bank, in the “back-reef channel” and in the “interreef deep channel” (figs. 3, 4). Depth does not appear to be the controlling factor, because the species was found in waters from 5 to 35 feet deep, a range very similar to that of *L. variegatus*.

Immature individuals about an inch in diameter were found on open sand near an extensive patch of grass at station 30, clustered together with immature *L. variegatus* in clumps of algae, broken shells, and small sponges and sponge fragments. Similar juveniles were found under rocks in only 5 feet of water at station 38, in absence of *L. variegatus*. Lewis (1958, p. 607) found mature specimens as well as immature ones on rocky bottoms off the coast of Barbados, B.W.I. *Lytechinus variegatus* was absent from this habitat in the study area and has not been reported with certainty from Barbados.

Lewis (1958) mentions the similarity in occurrence and habitat of these two species, but apparently some rather important differences in requirements also exist.

This species was found at stations 10, 11, 12, 27, 28, 29, 30 (juveniles), 38 (juveniles), 44, 51, and 52.

Behavior.—*Tripneustes ventricosus* lives on the sandy bottom among the turtle grass, and also climbs up the grass blades for a short distance above the bottom. According to Lewis (1958) it feeds almost exclusively on algae that grows on and among the rocks near shore. We made no systematic observations on the feeding habits of this species, but its association with *L. variegatus* in turtle grass, and its habit of climbing in the grass, indicate that it may eat turtle grass as well as algae. However, blades of *Thalassia* are frequently coated with a thin floral slime and it may be that *T. ventricosus* climbs on the grass in order to feed on the slime. Lewis reports that it rejects calcareous algae such as *Halimeda*. Kier has observed the same species living on rock near the shore of the island of Dominica, in an environment similar to that described by Lewis off Barbados. There likewise the available food was algae growing upon rock.

The habit of covering the test with shells, leaves, or other objects is much less strongly developed in this species than in *L. variegatus* (pl. 3, fig. 2). Individuals of the two species living within a foot or two of one another exhibited greatly differing amounts of cover, with *T. ventricosus* normally nearly uncovered, and *L. variegatus* ranging from sparsely covered to almost entirely concealed. Small individuals on the other hand, seemed to seek protected places under rocks, or in clumps with other small specimens (of this species and *L. variegatus*) with elaborate coverings of shells, sponges, and other objects in an intricate tangle. It would be interesting to discover whether they can drop or abandon this cover at night, and regain or reconstruct it each day, as reported for normal size *L. variegatus* by Sharp and Gray (1962).

Order HOLECTYPOIDA Duncan

Family ECHINONEIDAE Wright

Genus ECHINONEUS Leske

ECHINONEUS CYCLOSTOMUS Leske

Plate 15, figure 1

The only holectypoid found, this species is easily identified because of its large oblique peristome, with the large periproct situated just

posterior to it. A live specimen is white with very short spines and red tube-feet. Most of the specimens are small, around 30 mm. long, elongate, with narrow, simple poriferous zones, and small, equal-size tubercles. The species occurs with *Brissus unicolor*, from which it is easily distinguished by lack of petals, lower test, shorter spines, oblique peristome, and position of periproct near the peristome.

Occurrence.—Dead tests of *Echinoneus cyclostomus* were found on the sand below Molasses Reef and Grecian Rocks, among debris eroded from the reefs. These occurrences are well offshore, in depths from 20 to 40 feet. Mortensen (1948, p. 78) reports that this species lives among slabs of rock, normally clinging to undersurfaces, and eats organic material adhering to rather coarse grains of sand and shell fragments. It has been found in waters as deep as 350 feet.

We found few living specimens of this species; these did not seem to be clinging to the undersurfaces of rocks, but appeared to be living in coarse sand beneath the rocks. Unfortunately, the surge of waves removed the specimens from their habitats as soon as the rocks were overturned, so it was not possible to observe the echinoid in place.

Dead tests were found at stations 19 and 43, living specimens at station 60.

Order CLYPEASTEROIDA Agassiz

Family CLYPEASTERIDAE Agassiz

Genus CLYPEASTER Lamarck

CLYPEASTER ROSACEUS (Linnaeus)

Plate 4, figures 1-7; plate 6, figure 7; text figure 6

The test of a living specimen is dark brown, elongate, with inflated petals of equal length. An adult is approximately 130 mm. long, and is deeply invaginated around the mouth. Locally, this species is called a sea biscuit. It is a distinctive species and is easily distinguished from *Clypeaster subdepressus*, a species often occurring near it, by its much higher test, impressed mouth, and darker color.

Occurrence.—*Clypeaster rosaceus* lives in areas of thick sand, either in grassy areas or on relatively grassless patches within grassy areas. It is most characteristically associated with *Lytechinus variegatus* and *Tripneustes ventricosus* in the turtle grass, but also was found commonly with *Clypeaster subdepressus* and *Meoma ventricosa* in the cleaner sand areas near grassy patches. Its range extends from near shore to just inshore from the main body of the reef, and some speci-

mens were found in sandy patches that supported a growth of grass within the reef. The species was found in depths ranging from 4 to 40 feet, and its abundance did not seem to be directly affected by depth of water, but rather by the presence of turtle grass.

The distribution of this species (fig. 6) slightly overlaps with that of *C. subdepressus*. The two species occur together in the southern part of the area investigated, where irregular patches of grass and grassless sand are interspersed.

This species was found at stations 2, 3, 4, 6, 7, 8, 9, 10, 11, 11a, 12, 13, 15, 19 (dead), 20, 21, 22, 23, 24, 26, 27, 29, 30, 33, 34, 44 (dead), 45, 47, 48, 50, 51, 52, and 53.

Behavior—*Clypeaster rosaceus* does not burrow in the sand, but travels on its surface. Normally it lives in fairly dense turtle grass, where the tangled root systems just below the surface of the sand prevent effective burrowing (pl. 3, fig. 3). Where individuals of this species wander away from grass onto clean sand, they remain on the surface and do not burrow.

This species normally covers the upper surface of the test with locally available coarse objects (pl. 4, figs. 1-7). The grassy habitat provides a ready supply of blades of turtle grass, and the majority of individuals used them for cover (pl. 4, figs. 1, 3, 6, 7). Most also attached a few shells or shell fragments to themselves (pl. 4, figs. 3, 7) along with the grass or mangrove leaves and a little sand. Those that were found away from the grass on sandy patches used shells, shell fragments, sponges, and sand grains (pl. 4, figs. 2, 4, 5), but some that were in relatively clean sand immediately adjacent to grassy patches used a combination of grass and shell debris (pl. 4, figs. 1, 2, 4, 7). *C. rosaceus* is rare on sand that is completely free of grass, but when a specimen wanders far from its normal habitat it does cover itself with sand exclusively, although it sorts it and uses the coarsest grains (pl. 4, fig. 5).

The purpose of the habit of holding grass, shells, or other objects to the test has been a subject for controversy. Sharp and Gray (1962) conducted a series of experiments on *Lytechinus variegatus* and *Arbacia punctulata* to determine whether the habit of heaping shells onto the test was related to sensitivity to light. They conclude that *L. variegatus* is negatively phototactic, and that the habit of heaping shells and other objects onto the test in the daylight is definitely related to that character. They cite Boone (1928) to the contrary, who contended that the purpose of the covering habit was to effect camouflage. More studies such as that by Sharp and Gray, on more different kinds

of echinoids, are necessary before it can be concluded that the habit of covering is for one purpose only, or that it is for the same purpose in all species. The cover of debris employed by *C. rosaceus* is elaborate compared to that of *L. variegatus* (pl. 3, fig. 1), and no matter what the triggering mechanism may be (e.g. sunlight) the debris serves as a remarkably effective camouflage, at least to the human eye. Species in which the covering habit has been studied drop the shells and grass each night, and pick up a new supply each day shortly after sunrise (summary in Nichols, 1964, p. 406). If *C. rosaceus* also does this, it would greatly enhance the effectiveness as camouflage, as local objects would be picked up each day. As mentioned above, individuals observed in grass used grass for cover, those on shelly sand used shells; all seemed to employ sand grains to a minor extent.

CLYPEASTER SUBDEPRESSUS (Gray)

Plate 5, figures 1-6, 8; plate 6, figures 1-10; plate 15, figure 8; text figure 6

This echinoid has a large, low test with only slightly inflated petals, a flat lower surface, and is yellow brown to tan in color when alive. It has no perforations (lunules) or indentations at its margin, which immediately distinguishes it from the sand dollars with which it is often associated. It differs from *Clypeaster rosaceus* of this genus which is often found nearby, in its flattened test with less inflated petals, flat lower surface, and lighter color.

Occurrence.—*Clypeaster subdepressus* was found in sandy areas with little or no grass or filamentous algae, normally where the sand was deep. Isolated specimens were encountered in small sandy basins within reefy areas where only 6 to 8 inches of sand overlay hard substrate. Apparently it prefers depths somewhat greater than those normally inhabited by the sand dollars, *Leodia sexiesperforata* and *Encope michelini*, because it is not consistently present on the broad sandy expanses in shallow water on the White Bank. Instead it is most frequent in the large sandy areas of the "interreef deep channel" in depths between 15 and 35 feet (fig. 6). Relatively small dead tests were abundant around the nests of burrowing fish, offshore from the reef at depths as great as 85 feet; living specimens were rare and small at that depth. The limits of depths at which live or dead specimens of this species were encountered are 12 and 85 feet, although the greatest abundance of living specimens occurred between 15 and 35 feet.

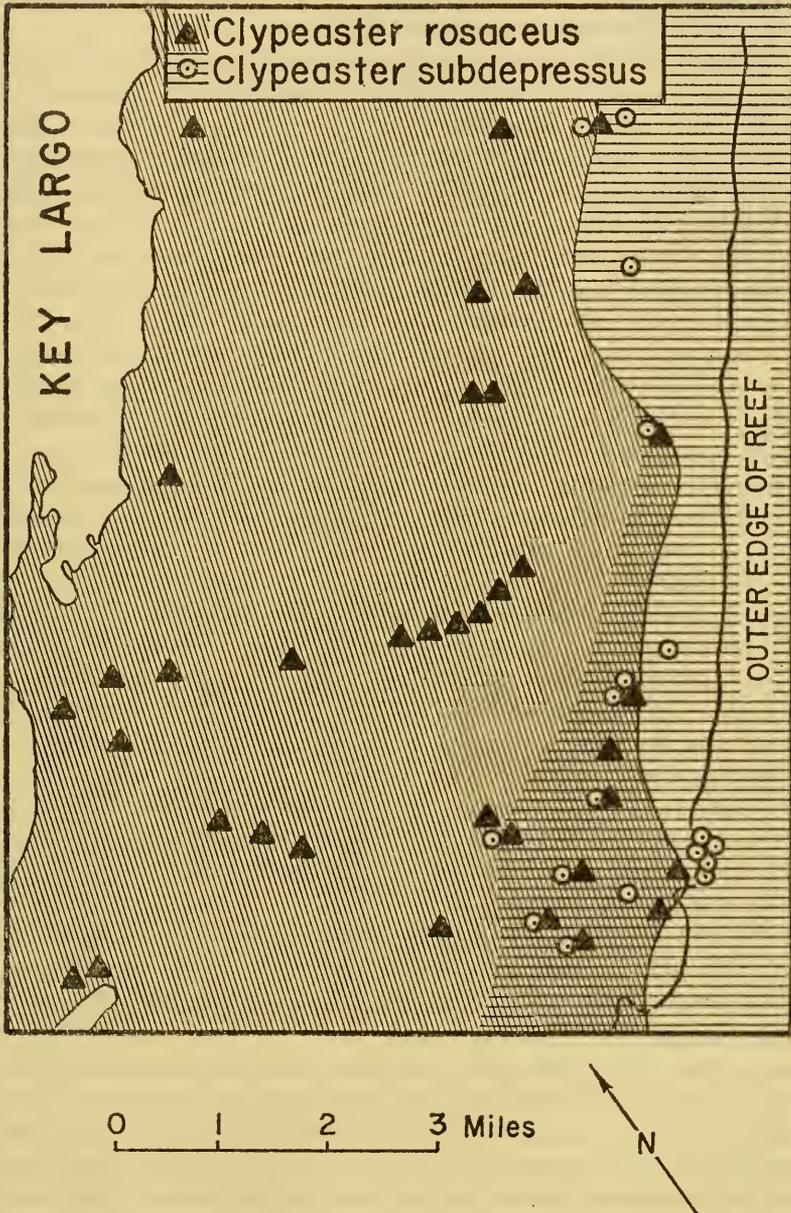


Fig. 6.—Map of area studied, showing distribution of *Clypeaster rosaceus* and *C. subdepressus*. Their ranges overlap in offshore areas where patches of grass and clean sand are intermixed.

This species was found at stations 17, 17a, 18, 19, 20, 21, 22, 23, 30, 36, 37, 39, 43, 44 (dead), 49, 53, 57, 58, and 61.

Behavior.—*Clypeaster subdepressus* burrows through grassless sand with its dorsal surface buried as deeply as 1 inch below the surface, or it moves along the top of the sand in areas where various algae tend to bind the sand, or where much of the sand is composed of coarse shell fragments. When it remains unburied, moving upon the surface of the sand, it covers itself with a layer of sand, shell fragments and other debris which it carries along as it moves (pl. 6, fig. 8). Normally shell fragments, leaves, or other coarse material are carried over the apical area, and finer sand over the remainder of the test.

When excavated from the sand, this species can re-bury or re-cover itself in about 6 to 12 minutes. The speed of burial, and of righting when overturned, seems to be related to size, with the smaller specimens accomplishing these activities somewhat faster than the larger ones. The manner of re-burial is illustrated on plate 5, figures 1-6, 8. The animal begins to move forward slowly, at the same time bringing sand up over the anterior and anterolateral parts of the test by means of the numerous locomotor spines that are abundant around the periphery, and the podia that are concentrated in the ambulacral areas of the dorsal surface, distal to the tips of the petals. The major portion of the sand on the test is brought up along these anterior areas, but at the same time the podia in the areas behind the two posterior petals also bring up sand grains in thin layers. The main two sheets of sand move back, coalescing with one another along the midline of the test, while two smaller, thinner sheets of sand move anteriorly from the posterolateral corners. Thus the test is effectively buried when all the sand sheets meet, which is accomplished before the animal has moved forward its own length.

This species can right itself after being overturned, although it does this in a different direction and at a slower rate than either *Leodia sexiesperforata* or *Encope michelini*. Small specimens manage to right themselves significantly faster than large ones. In one experiment where three specimens were placed near one another on their dorsal surfaces, a small one turned itself over and was buried before two larger ones raised themselves to 45 degrees (pl. 6, figs. 1-6). Sand is brought up onto the oral surface of an overturned specimen by the locomotor spines at the periphery, and the podia in the ambulacral areas. The sand comes up along one side, or one anterolateral area, thus this side is dug down into the sand. As it digs, increasing numbers of locomotor spines and podia on the oral surface are

brought into contact with the sand, and as that side digs in, the other is raised. It takes 45 minutes to an hour to achieve a vertical position, but once that is achieved, the remainder of the turnover, and complete burial are accomplished in an additional 5 to 15 minutes.

This sidewise method of overturning contrasts to that of *Leodia sexiesperforata* and *Encope michelini* which right themselves by turning on their anterior edges. Reasons for the differences probably are in the shapes of the tests, and the patterns of concentrations of spines. *L. sexiesperforata* and *E. michelini* are essentially circular, or at least their anterior portions are evenly arcuate. *C. subdepressus* is elongate, narrowest at the anterior, and has long, relatively straight sides with numerous locomotor spines along the edges, and in two interambulacral concentrations that radiate to the sides. The petal area of *C. subdepressus* projects high above the major portion of the test, and an overturned specimen that rests on this high convex hump tends to lean to one side. If all spines move, those in contact with the sand will begin to dig in, and they are the spines along the down side of the tilted test.

Family MELLITIDAE Stefanini

Genus LEODIA Gray

LEODIA SEXIESPERFORATA (Leske)

Plate 7, figures 6-8; text figure 7

This sand dollar is characterized by its very low test with thin margins, six slotlike lunules, and short petals of equal length. An adult is approximately 80 mm. in horizontal diameter and is yellow to light brown when alive, white when dead and denuded of spines. It differs from the other sand dollar associated with it, *Encope michelini*, in having a smaller thinner test, lighter color, shorter petals, and six perforations, rather than the five indentations and one perforation of *E. michelini*.

Occurrence.—*Leodia sexiesperforata* was found in areas of open sand where grass and filamentous algae were scarce or absent. The sand normally was rather deep (at least 1 foot) and at most localities its surface was strongly rippled, although on calm days the ripples were rapidly destroyed by burrowing of this and other species of echinoids. The species was most abundant on the broad calcareous sand expanses of the White Bank, nowhere as abundant as the other discoid species, *Encope michelini* and *Clypeaster subdepressus*

(fig. 7). The observed range extends from the shoreward edge of the White Bank to the sand patches just shoreward of the main reef (the area termed the interreef deep channel). Depths at which living specimens were found range from 10-25 feet, although dead tests were found on banks as shallow as 3 feet, and in the sand offshore from the reef at station 17a at 85 feet.

This species was found at stations 11a (dead), 17a (dead), (20) (dead), 23, 30, 39 (dead), 44, 45, 49, 55, 56, and 57.

Behavior.—*Leodia sexiesperforata* moves anteriorly through the sand at a depth of about 1 inch below the surface, just slightly deeper than the observed depth of burrowing of *Encope michelini*. Goodbody (1960, p. 80) observed the species near Jamaica at times burrowing so shallowly that its outline was discernible from above, and at other times burrowing somewhat deeper. The individual moves forward by means of locomotor spines which occur around the periphery of the test and in concentrations in the interambulacral areas of the ventral surface. The dorsal surface is covered with numerous short, club-shaped spines, and slightly shorter mucus-secreting spines (Goodbody, 1960, p. 83). These are used to pass sand grains up onto the dorsal surface. When a specimen is excavated from the sand it reburies itself in 5 to 7 minutes, normally accomplishing complete burial before having moved anteriorly more than one-half its own length. Burial is achieved partly by pushing forward into the sand, but mostly by passing sand grains onto the dorsal surface by the two kinds of spines. The grains are moved up along the anterior and the anterolateral edges, and passed backward over the test in two sheets which coalesce over the middle of the test (pl. 7, figs. 6-8). A few grains appear to be passed upward through the lunules, but these do not seem to play a large part in covering the test with sand.

Leodia sexiesperforata rights itself after being overturned by moving anteriorly or slightly anterolaterally into the sand. Locomotor spines are most densely concentrated along the anterior peripheral edge and in the two anterolateral interambulacral areas of the ventral surface (Goodbody, 1960, fig. 1). Action of these spines tends to move the oral surface into the sand at an increasingly steep angle until the test is vertical. Then the animal continues its forward motion and, by the aid of gravity, it is rapidly righted from the vertical position, and buried almost concurrently.

Goodbody (1960) described the mechanism by which food particles are moved toward the mouth of this species. Cilia at the bases of the club-shaped and the mucus-secreting spines on the dorsal surface set

up centrifugal currents that move the particles to the periphery and to the lunules. Cilia at the bases of spines on the ventral surface set up centripetal currents that are especially strong in the radial food tracts, moving the food particles medially toward the mouth. Thus the animal collects any food particles contained in any of the sand through which it passes, regardless of whether that sand passes over its ventral or oral surface.

Genus ENCOPE Agassiz

ENCOPE MICHELINI Agassiz

Plate 5, figure 7; plate 7, figures 1-8; plate 15, figure 7; text figure 7

When alive this sand dollar has a dark brown to reddish brown test covered with very short, dense spines. The test is flat, with one large slotlike lunule between the posterior petals, and usually five indentations in the ambulacra at the margin. An adult is approximately 100 mm. long. It is distinguished from the other sand dollar associated with it, *Leodia sexiesperforata*, by its larger, thicker test, longer petals, darker color, and presence of ambulacal indentations at the margin rather than perforations. It is similar to *E. emarginata* (Leske), with which it has been confused, but differs in having its adapical surface elevated posterior to the apical system whereas, in *E. emarginata* the test is flattened adapically. Furthermore, the indentations of *E. emarginata* are usually closed whereas those of *E. michelini* are open, where present. All the specimens we collected off the Keys had indentations, but they are absent on many of the specimens from the Gulf of Mexico. Thomas F. Phelan, research assistant at the U.S. National Museum, is currently making a study of the variation in these characters in the Carribbean and Gulf *Encope*.

Occurrence.—*Encope michelini* was found only in areas of deep sand with little or no turtle grass or filamentous algae. The surface of the sand normally is marked by large ripples up to 4 inches high and 12-16 inches between crests, although these are a function of wave oscillation and are rapidly destroyed by the echinoids on calm days. The species normally burrows through the upper surface of the sand, rarely covering its upper surface to a depth of more than one-quarter inch. Normally *E. michelini* is associated with *Leodia sexiesperforata* on the broad sandy reaches of the White Bank (fig. 7). Although it is much more abundant than *L. sexiesperforata*

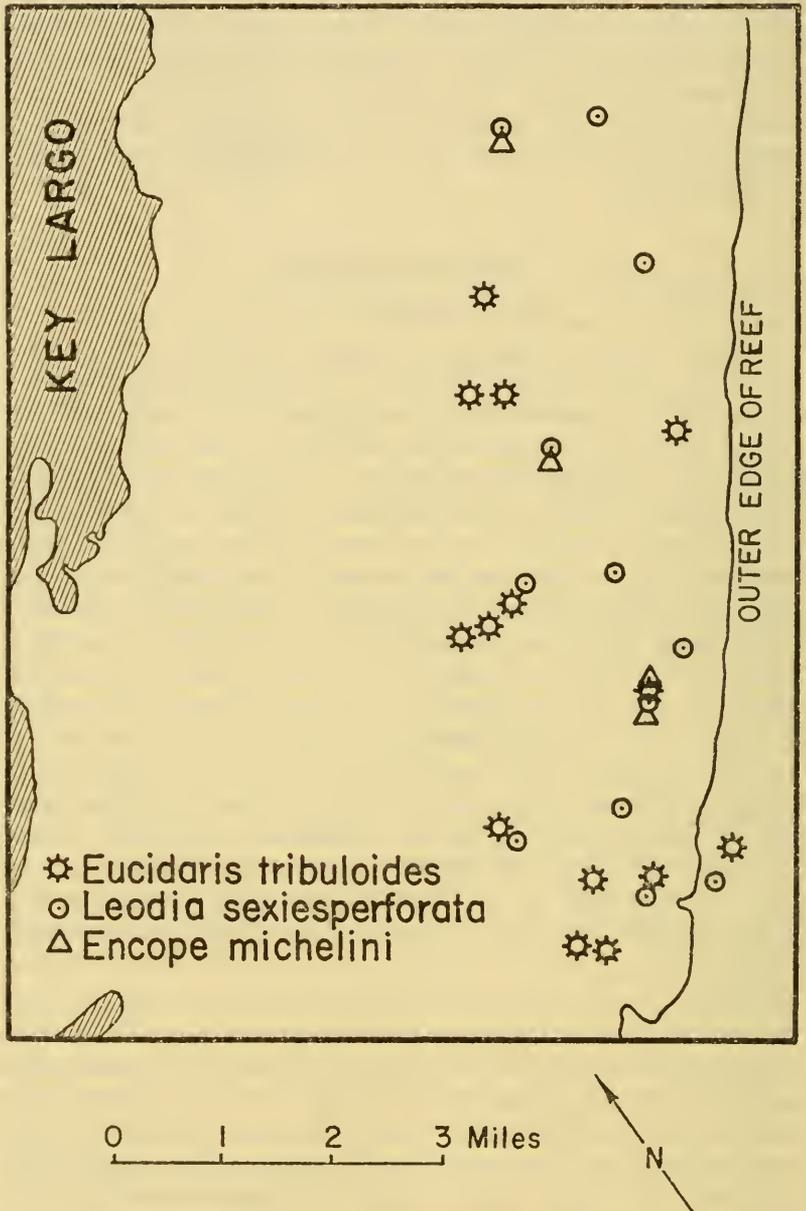


Fig. 7.—Map of area studied, showing distribution of *Eucidaris tribuloides*, *Leodia sexiesperforata*, and *Encope michelini*.

wherever it occurs, it was found only at a few localities. The range of depth of *E. michelini* in this area is between 10 and 20 feet.

This species was found at stations 23, 30, 45, 55, and 58.

Behavior.—*Encope michelini* is the most active of the clypeasteroids in this area. When actively burrowing it moves anteriorly through the upper surface of the sand at the rate slightly less than an inch per minute, a speed about twice that of *Leodia sexiesperforata*. It buries itself in about four minutes which is about half the time required by *L. sexiesperforata* and about a fourth of the time required by *Clypeaster subdepressus*. The outlines of most specimens are plainly visible as they move through the sand, and the trails that they leave have two low parallel lateral ridges produced by the posterolateral notches, and occasionally a median one produced by the posterior lunule (pl. 5, fig. 7).

The distribution of spines in this species is similar to that described for *L. sexiesperforata* by Goodbody (1960). The dorsal surface has only club-shaped and miliary spines; all ambulatory spines are around the periphery of the test and in radiating concentrations in the interambulacral areas of the oral surface, and one transverse concentration just posterior to the posterior lunule. Therefore, the manner of burial and of turning over is similar in the two species. *E. michelini* buries itself by passing sand grains onto the dorsal surface in two coalescing sheets from the anterior and the anterolateral edges. These grains are moved progressively toward the posterior end by nonambulatory spines, and the test is effectively covered by sand before it has moved anteriorly more than three-fourths of its own length (pl. 7, figs. 6-8). Similarly, when this species is turned onto its dorsal surface, it rights itself by the same activity of ambulatory spines that normally produces forward motion. Inasmuch as these spines are concentrated on the periphery and on the oral surface of the test, the result is to bury the anterior portion of the test progressively deeper, pulling the test into an increasingly upright position (pl. 7, figs. 1-5) until it turns over. Then as it continues this motion of spines, gravity brings an increasing number of the ambulatory spines into contact with the sand, and the animal moves anteriorly through the sand into the normal position.

Feeding habits of this species were not observed, but the distribution of spines, podia, lunules (and notches), and food tracts is so similar to that of *Leodia sexiesperforata* that it undoubtedly feeds in the same manner.

Order SPATANGOIDA Claus

Family BRISSIDAE Gray

Genus PLAGIOBRISSUS Pomei

PLAGIOBRISSUS GRANDIS (Gmelin)

Plate 8, figures 1-6; plate 15, figures 2, 3

This species is characterized by its large low test, often more than 200 mm. long, tan color, and extremely long spines which curve back over the upper surface. The bare test is distinguished by the large tubercles on the upper surface, the four slightly depressed curving petals of unequal length (anterior shorter) the narrow plastron, and the thinness of the plates of the test. It differs from the other large spatangoid, *Meoma ventricosa*, with which it is often associated, by its lower, lighter test, long spines and large tubercles on the upper surface, lighter color, and narrower plastron.

Juvenile morphology.—A denuded specimen only 35 mm. long (pl. 15, fig. 2) was collected at locality 30. This specimen differs from an adult in many of the same ways that young *Meoma ventricosa* (described below) differs as a juvenile. It is relatively higher and less angular than the adult, its petals are less depressed, and the periproct is not visible adorally. The posterior petals are much shorter proportionately, extending only half the distance from the apical system to the margin. This contrasts to the proportionately long petals in adults which extend more than two-thirds that distance. The anterior petals are more divergent, and all petals are relatively wider and straighter in the young specimen. The peristome is larger relative to the size of the test, and the labrum less strongly developed. Unfortunately, no spines are preserved on this small specimen, so it is impossible to determine the relative change in their length with growth of the test. Genital pores are present in this small specimen, suggesting that *P. grandis* reaches sexual maturity at a smaller size than *M. ventricosa*.

Occurrence.—*Plagiobrissus grandis* is found in sandy areas where grass and algae are sparse or absent, associated with other sand dwellers such as *Meoma ventricosa*, *Clypeaster subdepressus*, *Encope michelini* and *Leodia sexesperforata*. Specimens of this species are relatively rare (or at least, infrequently found) so their habitat could not be determined accurately; they seemed to be most common at the edges of the grassless areas,

The species was found only well offshore, from the White Bank

outward to the sandy terraces beyond the main reef. It occurred in depths from 12 to 85 feet, although only dead tests were found at the greater depths. It was present only in relatively deep sand, not in the shallow basins of sand between reef spurs, or patches within reef masses.

This species was found at stations 17 (dead), 17a (dead), 20 (dead), 23, and 30.

Behavior.—*Plagiobrissus grandis* burrows through the sand, buried just beneath the surface or as deeply as 2 inches. The long spines on its dorsal surface lie back as the animal burrows anteriorly, but stand straighter with the tips reaching the surface of the sand when forward motion ceases. The trail left by this species is less conspicuous than that of *Meoma ventricosa*, because it burrows deeper than that species. However, weak trails were visible, although normally mistaken for less fresh trails of *M. ventricosa*. Living specimens were discovered by digging at the ends of these trails, normally with the expectation of finding *M. ventricosa*.

When excavated, *P. grandis* moved rapidly over the surface of the sand with a zig-zag or "fishtailing" motion, at a speed of about 1 foot in 3 seconds. After moving about 3 feet away from an antagonist, or to a patch of sand suitable for burrowing, it begins to bury itself in a manner similar to that of *M. ventricosa*, only much more rapidly. It moves sand away from its ventral surface (pl. 8, figs. 1-3) and up along its sides into two crescentic mounds. When its dorsal surface is lowered nearly to the surface of the sand, it brings sand up onto that surface (pl. 8, figs. 4, 5), thus becoming effectively covered before the two lateral crescents of sand actually coalesce over the test. It takes only about 3 minutes to bury to a depth of about half the thickness of the test, and another 5 minutes to descend nearly to the level of the surface of the sand. Complete burial can be accomplished in 10 minutes or slightly more or less, depending upon the individual. The animal does not attempt to move forward until burial is complete or nearly so.

Predation.—Moore (1956) reports that *P. grandis* is frequently preyed upon by species of the helmet conch, *Cassis*. Many of the dead tests in our collection show the small circular hole that is the mark of predation by a gastropod. Dead tests and living specimens were most abundant at station 30, and there two specimens of *Cassis* were observed, a large one about 12 inches long, and a smaller one 4 inches long that was buried with its dorsal surface about 4 inches below the surface of the sand. These associations led us to suspect that *Cassis*

probably preyed upon *P. grandis* by burrowing, a surmise supported by Moore's extensive observations on this activity.

Genus **BRISSUS** Gray

BRISSUS UNICOLOR (Leske)

Plate 15; figures 4, 5

This small spatangoid, usually around 50 mm. long, has an elongated test inflated posteriorly, a blunt anterior margin, and a rather pointed posterior margin. The living test is white to light tan, has short spines, and very obvious black pedicellariae. Only four petals are present, the anterior pair are short and diverge 180 degrees. This species differs from the only other small spatangoid found with it, *Schizaster (Paraster) floridiensis*, by its more elongate test, shorter spines, longer posterior and shorter anterior petals, and less depressed anterior ambulacrum.

Occurrence.—This relatively rare species was found living under rock slabs in and near the reef. Dead tests were found in sandy areas near the reef, except for one found near an almost completely disintegrated shipwreck supporting an incipient growth of coral, sponge, and algae that probably was the ecological equivalent of a small reef patch. Living specimens on the reef occurred in about 15 feet of water, but dead tests were encountered in depths from 18-80 feet.

Mortensen (1951, p. 512) suggested that the species lives buried, which accounts for its apparent rarity. We found it living under rocks, but could not determine confidently whether it was clinging to the undersurfaces of the rocks, or was in the sand beneath them. The ease with which they drifted out of the hole that was left when a slab was overturned suggests that they were not clinging to the rock, but were living in the coarse sand under it.

Dead tests were found at stations 17a, 19, 21, 30, and 44; living specimens at station 60.

Genus **MEOMA** Gray

MEOMA VENTRICOSA (Lamarck)

Plate 3, figures 4, 5; plate 9, figures 1-4; plate 10, figures 1-4; plate 11 figures 1-6; plate 12, figures 1-4; plate 13, figures 1-3; plate 15, figure 6; plate 16, figures 5, 6; text figures 8-14

This large spatangoid (150 mm. long) has a high brown test covered with relatively short spines. The bare dead test is white and has

only four petals, all of which are approximately equal in length and well depressed below the surface of the test. The tubercles are all small, and the plastron is narrow. This species is distinguished from the other large spatangoid that often occurs with it, *Plagiobrissus grandis*, by its higher heavier test, lack of long spines on the upper surface, more depressed petals, darker color, and wider plastron.

Growth.—Two small spatangoids, 22 and 44 mm. long, seemed different from all the other spatangoids known from the Keys. These specimens differ from all other species in the length of their spines, shape of test, arrangement and relative length of the petals, size of peristome, and occurrence of fascioles. After considerable study, however, these specimens were recognized as immature *Meoma ventricosa*, unusual in that the growth changes that normally occur in specimens much smaller than 22 mm. in other spatangoids are postponed in this species. Presumably it is because this species becomes so large that even very young specimens are as large as adults of other species. The young of this species would be large enough to be considered adults if no larger specimens were available. Therefore, to clarify the relationships, these growth changes are described in detail below. This information should make possible a reasonably accurate prediction of the appearance of the young of other large spatangoids.

Shape.—The shape of the test changes considerably during growth. As the test increases in size it becomes relatively lower. The height of the smallest specimen (pl. 9, fig. 1), 22 mm. long, is 67 percent of the length, but only 53 percent in a specimen 71 mm. long (pl. 9, fig. 3), and only 50 percent in a specimen 144 mm. long (pl. 9, fig. 4). The ratio of the height to the length does not change, as shown by the fairly straight line in the distribution of points in the scatter diagram (fig. 8). The relative width of the test is constant throughout growth; in the smallest test the width is 87 percent of the length, and in a large specimen it is 88 percent (fig. 8).

The petals are only slightly depressed in the two specimens 22 and 44 mm. long (pl. 9, figs. 1, 2) but in a specimen 71 mm. long (pl. 9, fig. 3) they are considerably depressed, and in a full size specimen, 144 mm. long (pl. 9, fig. 4), they are deeply depressed. Likewise the anterior ambulacral groove is shallow in the smallest specimen, slightly more depressed in a specimen 71 mm. long, and deeply depressed in a large specimen. Because of depression of the ambulacra, the adapical interambulacra appear more inflated in the adults.

The periproct on the smaller specimens is situated high on the posterior truncation, and because this truncation is nearly vertical on

these smaller specimens (pl. 9, fig. 1) the periproctal opening is not visible from the adoral side. The opening is lower on the larger tests and the truncation is tilted so that the opening is partially visible from the adoral side on a specimen 71 mm. long (pl. 9, fig. 3), and completely visible on a full-size adult (pl. 9, fig. 4).

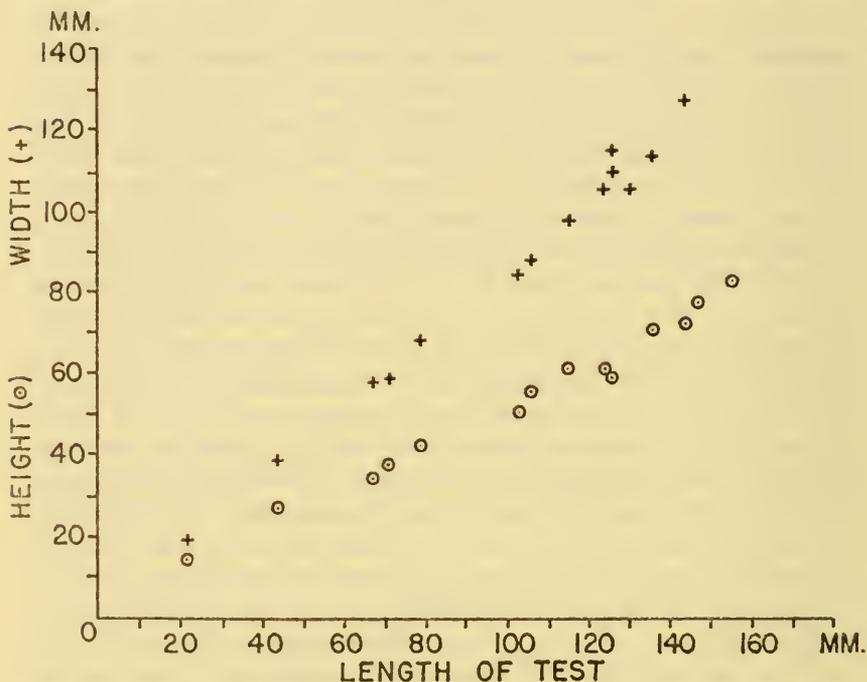


Fig. 8.—*Meoma ventricosa* (Lamarck). Scatter diagram showing rates of increase in height and width of test as length increases.

The dorsal posterior surface of the smallest specimen is highly inflated (pl. 9, fig. 1), but on larger specimens (pl. 9, figs. 3, 4) it is depressed and slopes steeply posteriorly. Anteriorly the situation is reversed, with the front steep in the smallest specimen, but more gently sloping in the larger.

Petals.—One of the most striking differences between small and large *Meoma ventricosa* is in the relative length of the posterior petals. In the smallest specimen available (pl. 9, fig. 1), 22 mm. long, the posterior petals extend only one-half the distance from the apical system to the margin, whereas in a specimen 144 mm. long (pl. 9, fig. 4), they extend 83 percent of this distance. A scatter diagram

(fig. 9) of this relative length of the petal to the length of the test illustrates that in specimens up to 65 mm. long the rate of increase in petal length is much greater than in specimens longer than 65 mm. The rate of introduction of new pore-pairs in the petals decreases correspondingly during growth (fig. 10). Between the lengths of 22 mm. and approximately 100 mm. 8-10 new pore-pairs are added for each doubling of the length of the test. For example, a specimen 44

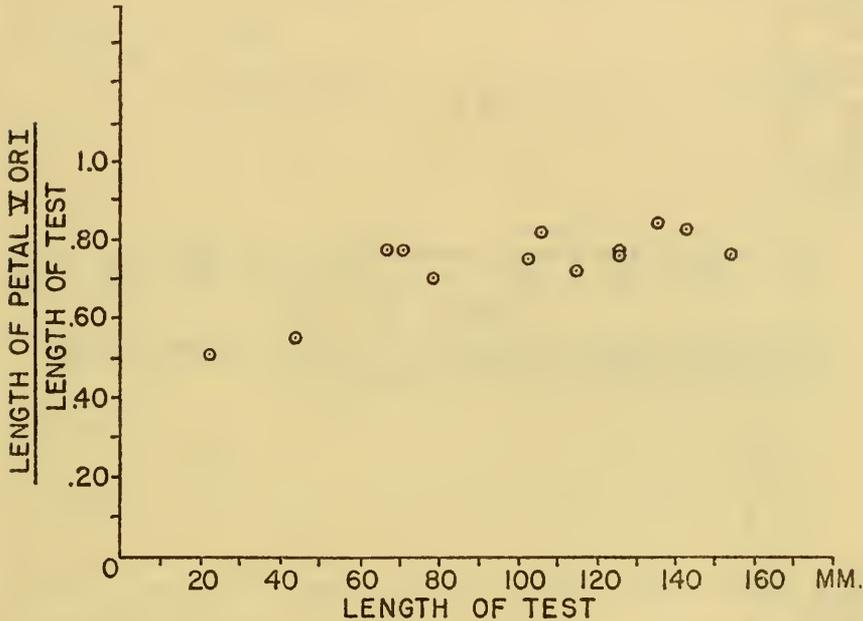


Fig. 9.—*Meoma ventricosa* (Lamarck). Scatter diagram showing proportionate increase in length of petals with increase in size of test. This trend is illustrated in a series of photographs on plate 9.

mm. long has 10 more pore-pairs in a single poriferous zone than a specimen only 22 mm. long. In specimens over 100 mm. long, production of new pore-pairs has almost ceased, with approximately 41 pore-pairs in each poriferous zone of each of the four petals.

The shape of the anterior petals also changes. In the smallest specimen (pl. 9, fig. 1) these petals are straight, but in the larger specimen (pl. 9, fig. 4) their ends curve anteriorly. The posterior petals curve slightly posteriorly in the smaller specimens but slightly anteriorly in the larger. Furthermore, the anterior petals are more divergent in the smaller specimen where they subtend an angle of 162 degrees than

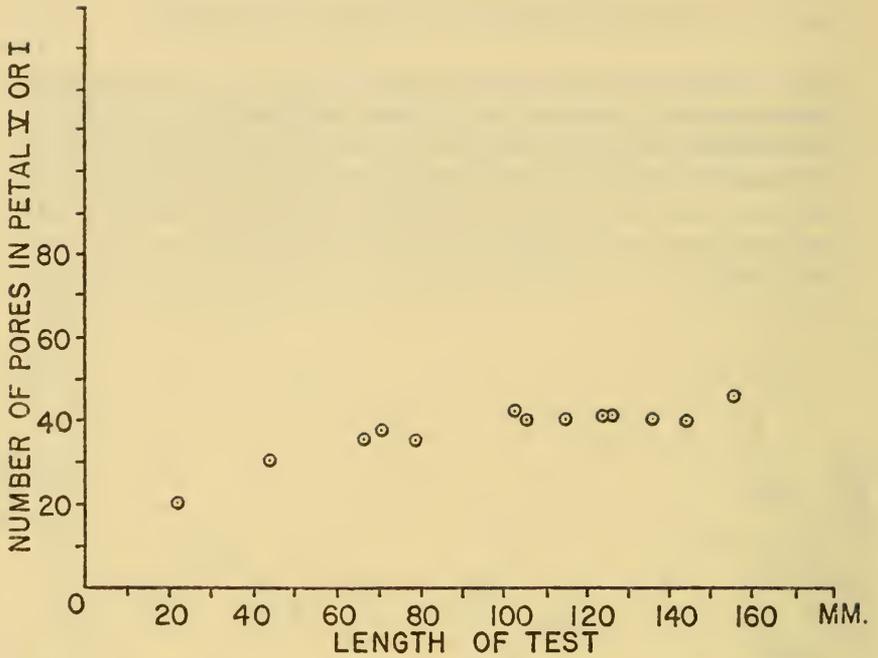


Fig. 10.—*Meoma ventricosa* (Lamarck). Scatter diagram showing increase in number of pores in petals with growth of test.

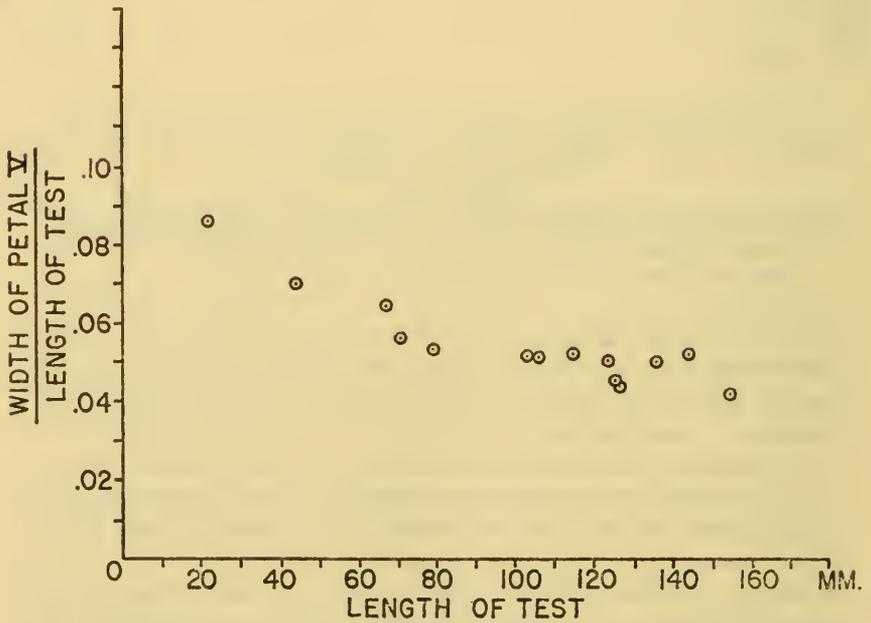


Fig. 11.—*Meoma ventricosa* (Lamarck). Scatter diagram showing proportionate decrease in width of petal V with increase in length of test.

in the larger with an angle of 135 degrees. The posterior petals are less divergent, having an angle of 56 degrees in the smallest specimen as opposed to 65 degrees in a large specimen.

The petals are relatively much wider in the smaller specimens than in the larger (see pl. 9). In the smallest specimen, 22 mm. long, the width of one of the posterior petals is 8.6 percent of the length of the test, but only 5.3 percent in a specimen 79 mm. long and only 4.2 percent in the largest one studied, 155 mm. long. The greatest rate of change (fig. 11) in the width of the petals occurs in the specimens under 80 mm. in length.

Phyllodes.—Phyllodes are well developed in the smallest specimen, and do not change significantly during growth except by the addition of pores. In the smallest specimen 6 pores occur in each of the poriferous zones of the anterior paired phyllodes, whereas 9-11 occur there in specimens over 66 mm. long. Presumably these additional pores were produced by enlargement and alteration of the small pores in the ambulacral plates immediately adapical to the phyllodes. The small sensory tubefeet that passed through these small pores must have changed into the pencillate tubefeet found in the phyllodes.

Peristome.—The outline of the peristome changes considerably during growth. In the smallest specimen it is proportionately large, with a length 22 percent of the length of the test, whereas in a large specimen its length is only 15 percent of the test length. In the smallest specimen (pl. 9, fig. 1) the peristomal opening is high, but as the echinoid grows the labrum enlarges and extends anteriorly (pl. 9, fig. 3) until in a large specimen (pl. 9, fig. 4) it extends nearly to the anterior margin of the peristome. This development of the labrum is also apparent in the profile views on the same plate.

Periproct.—Besides changing its position, as described in the section on shape, the relative size of the periproct changes during the growth of the test. The periproct of the smallest specimen is proportionately larger, with a height 23.8 percent of the length of the test, whereas the periproct of the largest specimen is only 14.2 percent of the test length. A scatter diagram (fig. 12) illustrates that the rate of change in the relative size of the periproct opening is greatest in the smaller specimens, with almost no change in rate in specimens over 100 mm. long.

Spines.—The spines are relatively much longer on smaller specimens, particularly spines within the peripetalous fasciole (see pl. 10). One measured spine is 5.1 mm. long in the smallest specimen, or 23 percent of the length of the test, whereas on a large specimen, one

is 7.4 mm. long or only 5 percent of the length of the test. Spines of juveniles, therefore, are more than 4 times as long relative to the size of the test as are spines of large specimens. Similarly, the large adoral spines are proportionately 2.5 times larger on the smallest specimen.

Fascioles.—Although the peripetalous fasciole changes little during the growth of the echinoid, the subanal fasciole undergoes a striking change. In the smallest specimen (fig. 13A) that portion of the

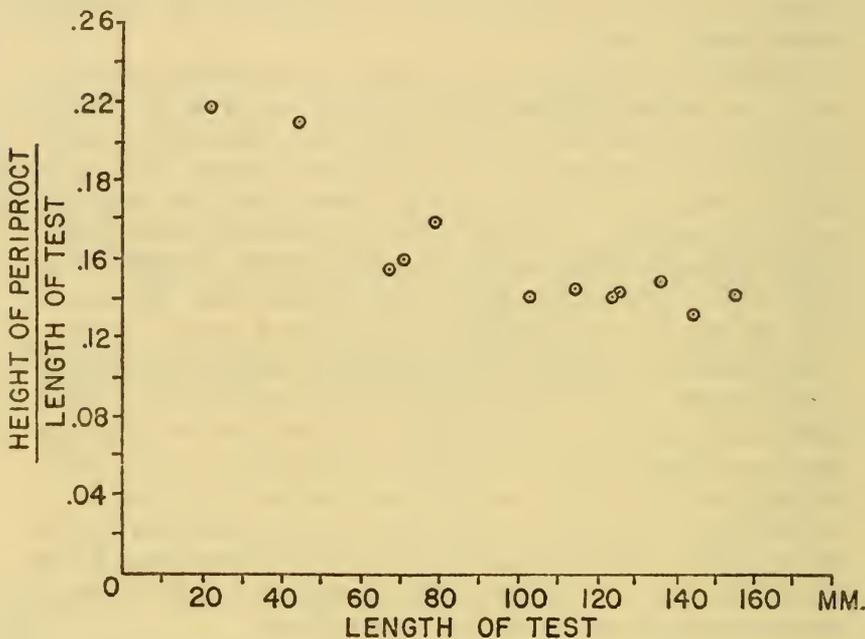


Fig. 12.—Scatter diagram showing proportionate decrease in height of periproct with increase in size of test.

fasciole nearest the periproct is wide, but in a specimen 44 mm. long (fig. 13B) it is much narrower, and finally in a specimen 71 mm. long (fig. 13C) it is completely absent. Mortensen (1951, p. 528) reports the same loss of this portion of the fasciole in *Meoma grandis* Gray.

Apical system.—No genital pores are present in the smallest specimen, but in a specimen 44 mm. long (fig. 14A) three very small pores are present, but none in genital plate 2, the madreporite. In the next larger specimen available, 71 mm. long (fig. 14B), the genital pores are fully open and all four are present. In a large specimen 144 mm. long (fig. 14C), the madreporite is greatly expanded posteriorly,

widely separating the posterior oculars. Some madreporitic pores also occur in genital plate 1. Mortensen (1951, p. 529) reports that genital pores appear in *Meoma grandis* Gray when the echinoid is about 50 mm. long.

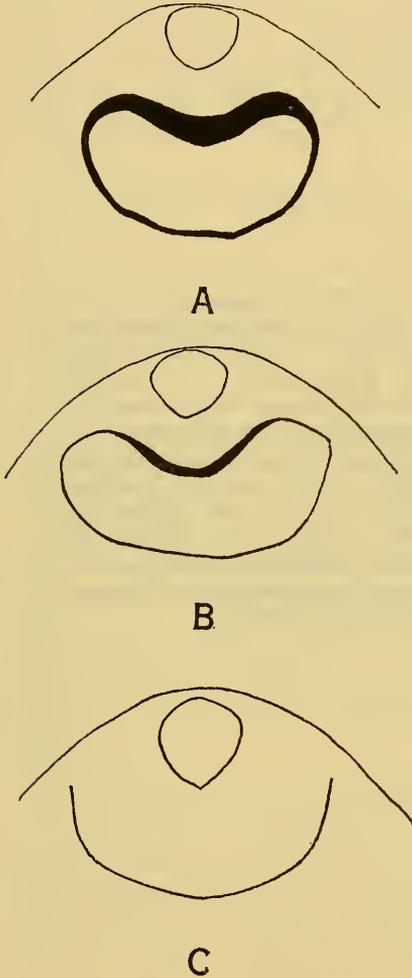
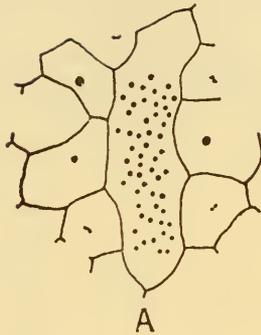
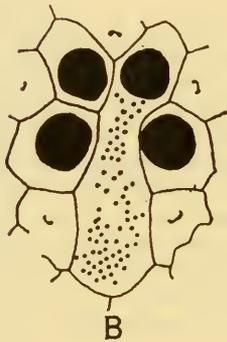


Fig. 13.—Change in subanal fasciole during growth of *Meoma ventricosa* (Lamarck). In the smallest specimen, 22 mm. long, that portion of the fasciole near the periproct is broad but decreases in width during the growth of the echinoid and is absent in an adult. A. USNM E10315; station 19; 22 mm. long; $\times 3$; B. USNM E10314; station 17; 44 mm. long; $\times 1.7$; C. USNM E10313; station 30; 71 mm. long; $\times 1$.

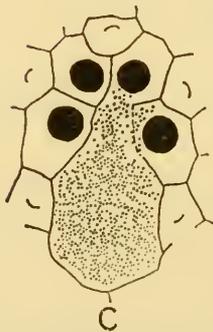
In one of the larger specimens, 144 mm. long, the last plates (adapical) in the posterior interambulacrum are not in contact with the posterior oculars. As shown by Kier (1956, p. 971) this separation indicates that production of new interambulacral plates has ceased in this area.



A



B



C

Fig. 14.—Growth changes in the apical system of *Meoma ventricosa* (Lamarck). Only three small genital pores present; A. specimen 44 mm. long ($\times 16$); station 17; USNM E10314. B. Madreporite beginning to expand posteriorly; all genital pores present; specimen 71 mm. long ($\times 10$); station 30; USNM E10313. C. Madreporite greatly expanded posteriorly; specimen 144 mm. long ($\times 5.3$); station 17b; USNM E10312.

Summary.—The following changes occur during the growth from 22 mm. in length to full size:

1. Test becomes lower, more angular, petals become depressed, posterior truncation tilts so that periproct is visible adorally.

2. Posterior petals become much longer, all petals become relatively narrower and curved at the ends.

3. The peristome becomes smaller relative to the length of the test, and the labrum enlarges and extends anteriorly.

4. The spines become more equal in size, and proportionately much shorter.

5. The subanal fasciole becomes discontinuous because of the elimination of that portion of the fasciole nearest the periproct.

6. Genital pores are introduced when a specimen is approximately 40-60 mm. long.

Most of these growth changes also occur in *Plagiobrissus grandis* (Gmelin).

Occurrence.—*Meoma ventricosa* occurs in sandy areas relatively far from shore. It is most abundant, and reaches its maximum size, in areas of clean sand that are free or nearly free of grass or dense patches of algae. However, specimens somewhat below the normal size were found in turtle grass, along with *Clypeaster rosaceus*. Their range extends from the inshore edge of the White Bank to the sandy terraces offshore from the main reef (and possibly also beyond, outside our area of study). It is most abundant on the White Bank and in the "interreef deep channel," and rare on the deep terraces beyond the reef. The inshore limit of its range overlaps only slightly with the outerlimit of *Lytechinus variegatus*; the two are seldom found together (fig. 5).

The depth range of *M. ventricosus* is between 10 and 85 feet; specimens were not found at 110 feet, but a wider search at that depth might disclose them. The species is most abundant in depths between 20 and 40 feet, and in some areas within that depth range a specimen can be dug up about every two or three feet of traverse. An area 40 feet by 40 feet at station 19, in 40 feet of water produced 40 specimens of *M. ventricosa* in about 20 minutes of searching, during which time only 6 specimens of *Clypeaster subdepressus* were discovered in the same area.

This large and thick species requires rather deep sand for its burrowing, so it was absent from small patches of sand within rocky or reefy areas where a few *C. subdepressus* could survive.

This species was found at stations 17, 17b, 19, 20, 21, 22, 23, 24 (dead), 27, 29, 30, 36 (dead), 37, 39, 44, 45, 49, 51, 52, and 53.

Behavior.—*Meoma ventricosa* burrows through the sand with the dorsal surface of the test covered to a depth of as much as 1.5 inches. Most dig less deeply than that, and many keep the uppermost part of dorsal surface nearly at the surface of the sand. These sort the sand slightly, to keep relatively coarse grains and shell fragments over the petal areas, and are visible from above (pl. 11, fig. 6). Some specimens seemed to burrow steadily through the sand, leaving even trails, each with a narrow row of coarse sand in the middle. Others apparently moved more sporadically, leaving trails that consisted of connected series of low mounds marking where individuals repeatedly stopped and again moved forward.

Some specimens were found in areas of dense turtle grass (pl. 3, fig. 4), where the tangled root systems made burrowing impossible. These were smaller than the average adult living in clean sand, and they lived above the surface of the sand covered with shell fragments, sand grains, and a few blades of grass, much in the manner of *Clypeaster rosaceus*, and associated with that species. Blades of turtle grass were preferred for cover by *C. rosaceus* in grassy areas, but in the same areas *M. ventricosa* used mostly sand and coarse sand size shell fragments, and only a few blades of grass (pl. 3, figs. 4, 5).

When excavated and placed on the surface of the sand, *M. ventricosa* buries itself without moving forward. It brings sand laterally away from the ventral surface (pl. 11, figs. 4, 5), and up along the sides, thus displacing the sand and moving the test directly downward into the sand. The displaced sand forms two low, crescent-shaped mounds, one on each side, and these ultimately coalesce over the dorsal surface of the test. However, before they meet, the test is already effectively covered by a thin layer of sand that has been brought up onto the petal area (pl. 11, fig. 5). The process of burial is lengthy, and gradually slowing. The excavated animal is reburied to about half its height in about 7 to 9 minutes, but only about 75 percent covered after 20 minutes. From then the process slows even further, although the test may be effectively covered by the thin layer over the petals after about 30 minutes. The individual is buried to "burrowing depth" after 40 to 50 minutes, and then may begin to move forward. This process is much slower than the reburial of the thin sand dollars *Encope michelini* and *Leodia sexiesperforata*, and also somewhat slower than that of the thicker form, *Clypeaster subdepressus*. It is also much slower than the burial process of the similarly large

but much more active spatangoid *Plagiobrissus grandis*, which can bury itself in a little over 10 minutes.

Meoma ventricosa is able to right itself relatively rapidly when overturned. An excavated specimen was placed on the sand on its dorsal surface, along with three specimens of *Clypeaster subdepressus*, two of which are illustrated on plate 6, figures 1-6. The process of righting began at 10:15. By 10:30 *M. ventricosa* had achieved a strong tilt while two of the *C. subdepressus* were barely moved, and one small one slightly tilted. The *M. ventricosa* was nearly on edge by 10:35, but the most rapid *C. subdepressus* (pl. 6, fig. 2) did not attain an angle of 45 degrees until 10:50. The *M. ventricosa* had righted itself by 10:40, in contrast, the most rapid of the *C. subdepressus* did not become completely righted until about 11:15, but then was completely buried and actively burrowing only three minutes later. At that time the slower two *C. subdepressus* nearby had only raised to about 45 degrees, when the observations were terminated.

Meoma ventricosa turns over on its anterolateral edge, in a direction similar to that of *C. subdepressus*, and in contrast to the anterior direction of overturning of *Encope michelini* and *Leodia sexiesperforata*. However, it does not dig that edge into the sand as does *C. subdepressus*, but seems merely to "walk" itself over on its spines, while remaining on the surface of the sand.

This species apparently feeds by passing sand through its system and extracting whatever nutrient particles are included. A dissected specimen 144 mm. in length was nearly entirely full of sand; the entire contents of the test had a dry weight of 191 grams. The mouth remains open as the animal moves anteriorly through the sand, the labrum serves as a scoop, and sand is forced into the mouth by the anterior motion of the whole animal.

Predation.—*Meoma ventricosa* seems to be rather frequently victimized by the starfish *Oreaster reticulatus* (Linnaeus). One such incident was observed directly (pl. 12, figs. 1, 2). The urchin was unburied, on the surface of the sand, and the starfish was draped over its dorsal surface. When the starfish was lifted off, its extruded gut was seen to retract. The area of the urchin that had been covered by the gut of the star was devoid of spines, and the test was comparatively thin (pl. 13, figs. 1-3) demonstrating local digestive dissolution. As soon as the starfish was removed, the urchin began to move its spines in the normal burrowing or reburying motion, but while the starfish was on it, the urchin did not move. Possibly the starfish secreted some form of mild narcotic agent along with whatever fluids

were dissolving spines and the test of the urchin. Previously, many specimens had been observed with large or small areas that were free of spines, and which, as a consequence, were but poorly covered by sand (pl. 11, figs. 2, 3). Later examination of specimens in the laboratory showed others, each with the spineless area stained a brownish purple where the digestive fluids of the starfish had been active. Apparently *M. ventricosa* is a frequent victim of *O. reticulatus*. Some individuals obviously were able to escape alive, but with some portion of the test stripped of spines.

Several specimens of *M. ventricosa* with bare areas devoid of spines were observed at station 21. These lay buried just below the surface of the sand, and the spineless areas remained uncovered by sand. A small fish, identified by J. E. Randall as the red band parrot fish *Sparisoma aurofrenatum* (Valenciennes), was seen to swim to the urchin and nip at the exposed areas. Some of the specimens were dug up and placed on the surface of the sand, and the parrot fish photographed as it nipped them (pl. 11, fig. 1). The spineless areas in these specimens differ from those in which the spines had been removed by dissolution by *Oreaster reticulatus*. No spines were partly dissolved, or "thinned" as in a second specimen taken from station 23 where the starfish was observed in process of attacking an urchin, and there was no sign of partial dissolution of the test. Furthermore, the depressed petalous areas retained their spines, and only the highly convex areas between petals were denuded. Possibly these are specimens that were attacked by *O. reticulatus*, but made good their escape, with the fish then taking advantage by nipping at the areas that lacked spines and therefore were not covered by sand. However, the difference in the bare areas, cited above, suggests that they were due to the grazing of the fish.

Family SCHIZASTERIDAE Lambert

Genus SCHIZASTER Agassiz

Subgenus PARASTER Pomel

SCHIZASTER (PARASTER) FLORIDIENSIS Kier and Grant, new species

Plate 13, figures 4-6; plate 14, figures 1-9; text figure 15

Diagnosis.—Species characterized by central apical system, narrow ambulacrum III, and flexuous anterior petals.

Material.—Four denuded tests, one incomplete specimen with spines.

Measurements.—

| <i>Length</i> | <i>Width</i> | <i>Height</i> |
|---------------|--------------|---------------|
| 40.0 | 39.5 | 27.0 |
| 36.9 | 35.4 | 28.9 |
| 21.6 | 20.6 | 17.0 |
| 21.1 | 19.6 | 16.2 |

Shape.—Test subglobular, nearly as wide as long with greatest width near center, test high, with height 70-80 percent of length; anterior margin indented, posterior slightly truncated, margin slightly angular particularly in larger specimens; in side view anterior profile sloping steeply, posterior nearly vertical, indented at and immediately below periproct; node present on most interambulacral plates on adapical surface, nodes on interambulacral plates where crossed by fasciole; adorally test slightly convex, plastron more convex.

Apical system.—Central to slightly posterior to center; depressed below interambulacra; four genital pores (pl. 13, fig. 5), anterior pair much smaller than posterior, circular to slightly elongated into interambulacra; system ethmolytic with madreporite extending considerable distance posterior to posterior oculars, very narrow where passing between posterior genitals; ocular plate of ambulacrum III small, higher than wide, deeply inserted between genitals 2 and 3; other oculars large, approximately equal in size, roughly pentagonal.

Ambulacra.—Ambulacrum III deeply depressed with groove extending over ambitus to peristome; adorally, bottom of groove slightly concave, sides sloping, not vertical; adapically sides steep, almost vertical; pore-pairs arranged in simple regular series near edge of ambulacral groove (pl. 13, fig. p); pores oblique with inner pore of each pair more anterior, smaller, and more elongate than outer; pores near apical system very small, increasing in size anteriorly, last 2 or 3 pore-pairs very small; 15 pore-pairs in poriferous zone in specimen 21.1 mm. long, 18 in specimen 40.0 mm. long; pores beyond axis extending longitudinally to ambulacrum III; petals II and IV long, extending $\frac{4}{5}$ distance from apical system to margin, curved distally with greatest width $\frac{2}{3}$ distance from apical system to end of petal; both pores of each pair approximately same size, outer pore more slitlike than inner; interporiferous zone narrow, approximately same width as distance between pores of pore-pair; 22 pore-pairs in each poriferous zone in specimen 21.1 mm. long, 26 in specimen 40.0 mm. long; posterior petals V and I short, extending less than $\frac{1}{2}$ distance from the apical system to the margin, one-half as long as petals II and IV, greatest width near midlength of petal; interporiferous zones approxi-

mately same width as distance between pores of pair; 14 pore-pairs in poriferous zone of specimen 21.1 mm. long, 19 in specimen 40.0 mm. long; pores beyond all petals single, slitlike, situated on adoral edge of plate.

Phyllodes.—Broad (pl. 13, fig. 4) pores single, large, on adoral edge of oval depression; three pores in ambulacrum III, 7-8 in ambulacra II and IV, 6-7 in ambulacra V and I.

Peristome.—Anterior, located 70 percent anterior of distance between posterior and anterior margins; opening wide, low, crescent shaped.

Spines.—Preserved only on one incomplete small specimen (pl. 14, figs. 4, 5), originally approximately 23 mm. long; adapically most of specimen missing, spines expanded at tips, spines near ambulacra curving over ambulacra; adorally, plastron spines (pl. 14, fig. 9) very distinct, long, 4.5 mm. long, flattened and expanded at tips transverse to length of test, tips curving anteriorly, similar spines but longer (6 mm. long) on edge of posterior interambulacra adjacent to ambulacra V, I; no long spines in phyllodes or most of posterior ambulacra; few minute spines, 0.5 mm. long, scattered over otherwise bare surface; long tapering, pointed tipped spines (6 mm. long) in anterior interambulacra and a few in ambulacrum III.

Sphaeridia.—Many sphaeridia present along full length of posterior ambulacra on adoral side; a few in phyllodes of the other three ambulacra.

Periproct.—Longitudinal, high on posterior truncation.

Tuberculation.—Adapically, tubercles inside and outside of peripetalous fasciole of approximately same size; adorally tubercles on plastron situated anteriorly on raised oval platforms, centrally in other areas; peripetalous and lateroanal fascioles present; peripetalous fasciole passing close to extremities of petals, (pl. 14, fig. 3), curving sharply inward in all interambulacra except interambulacrum 5, fasciole widest at extremity of petals II and IV (anterior paired petals), narrowest at indentations in interambulacra; lateroanal fasciole leaving peripetalous fasciole in posterior paired interambulacra and passing down under periproct; narrowest at peripetalous fasciole, greatest width directly under periproct.

Pedicellariae.—(Fig. 15). Only two pedicellariae found on single specimen with spines, both globiferous (pl. 14, figs. 6-8; text fig. 15) with valves, 0.4 mm. in length; base of valve relatively broad, tapering to slender, tubular blade above apophyses; two lateral articulating teeth present on articular face, just above the median apophysis rises

vertically one-third length of valve, then angles back to join lower portion of tubular blade; valves in contact distally only at terminal teeth; two terminal teeth of each valve forming horizontal fork; each valve containing internal poison chamber. Small terminal opening between teeth.

Internal calcareous process.—Support on interambulacrum 4 narrow, erect, almost vertical, sloping slightly sideways and posteriorly.

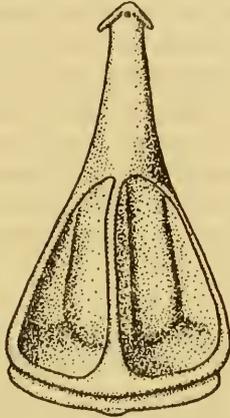


Fig. 15.—*Schizaster (Paraster) floridiensis*. Valve of pedicellaria from figured paratype USNM E10303; $\times 94$.

Comparison with other species.—This species is easily distinguished from the three living species of the subgenus *Schizaster (Paraster)*. It differs from *S. (Paraster) gibberulus* (L. Agassiz) from the Red Sea and Indian Ocean in its more anterior apical system, more flexuous anterior petals, narrower ambulacrum III, and lack of transverse ridges in ambulacrum III. It is distinguished from *S. (Paraster) compactus* Koehler from the Bay of Bengal by having the pores in the anterior ambulacrum oblique to each other, a wider higher test, shorter wider posterior petals, and more divergent anterior paired petals. It differs from *S. (Paraster) rotundatus* Doderlein, a Pacific species, in having a more anterior apical system, its posterior petals not extending as near to the posterior margin, and in having more divergent and more flexuous anterior petals.

S. (Paraster) floridiensis is distinguished from the West Indian species *Schizaster orbignyianus* Agassiz by its more central apical sys-

tem with four instead of two genital pores, higher, wider test, wider paired petals, more divergent anterior paired petals, and wider peristome. It differs from the Late Pleistocene *S. (Paraster) eustatii* Engel (1961, p. 3) from St. Eustatius in the West Indies by its more anterior apical system, narrower ambulacrum III, and more flexuous anterior petals.

Type.—Holotype USNM E10302.

Occurrence.—This rare species was not found alive in its habitat. Dead tests were found near the reef in about 35 feet of water (station 19), well beyond the reef on a sandy terrace in 80 feet of water (station 17a), and landward of the reef on sandy bottom in only 15 feet depth at station 30. Probably it lives buried beneath rocks or clumps of sponge and coral, in a manner similar to that of *Brissus unicolor* and *Echinoneus cyclostomus*, and therefore is rarely encountered.

Kier found a dead test of the same species on a sandy bottom at 85 feet depth off the southern Caribbean island of Dominica. Because the species has never been taken alive, its habitat preferences remain unknown.

ENEMIES OF ECHINOIDS

No general survey of the predator-prey relationships of echinoids is intended here, but our observations of victimization of echinoids by other animals are significant enough to warrant emphasis. The most incontrovertible attack observed was that by the starfish *Oreaster reticulatus* upon *Meoma ventricosa*, as described above in the discussion of that species (pl. 12, figs. 1, 2). To our knowledge, this is the first record that *O. reticulatus* may feed upon *M. ventricosa*. This urchin also is attacked by the red band parrot fish (*Sparisoma aurofrenatum*) which nibbles away spines on the dorsal surface that are not completely protected by a cover of sand (pl. 11, fig. 1).

Other examples of fish predation were noted when specimens of the thin sand dollars *Encope michelini* and *Leodia sexiesperforata* were overturned to see how they right themselves. When the urchins were nearly vertical, in the process of righting themselves, a little burrowing fish nipped at the upturned edges. Many injured specimens of these thin sand dollars were seen, some with nearly one-quarter of the test broken away, but nevertheless healed and bearing spines. Undoubtedly this breakage could have resulted from several causes, one of which may be biting by fish.

Predation of *Plagiobrissus grandis* by species of the helmet conch *Cassia* has been noted above in the discussion of that species. One observation led us to believe that *Cassia* preys upon other species of echinoids as well. A specimen of *Clypeaster subdepressus* at station 57 on sand in 18 feet of water was crushed as though it had been stepped upon by a heavy foot. About 6 feet away, on the surface of the sand, was a live specimen of *Cassia madagascariensis* Lamarck about 7 inches long. Possibly the large gastropod had eaten the urchin, and had broken up the test by action of its foot, which was about the same diameter as the echinoid. If this happened, it contrasts strongly with the manner in which *C. madagascariensis* drills into the fragile test of *P. grandis* by means of its radula, leaving the test unbroken, and only the small circular drill-hole as evidence of its predation. However, that process occurs beneath the surface of the sand, with both the gastropod and the victim remaining buried. The *C. subdepressus* was on the surface, near where it normally lives, and the *Cassia* shell was smooth and clean of encrusting algae except for an area of about 4 square inches on its highest dorsal elevation, indicating that it was out of its normal buried habitat. Until this type of predation by *Cassia* is actually observed, it must be regarded merely as an inference from circumstantial evidence.

Dead tests of the small burrowing spatangoid *Brissus unicolor* also had the small circular hole that indicates predation by a gastropod. As *C. madagascariensis* is an efficient burrower, and a known predator of burrowing echinoids, possibly it also feeds upon *B. unicolor*.

Several dead tests of *Clypeaster subdepressus* were collected, in which the ventral surface was almost completely excavated, and the remaining rim marked by numerous short radiating scratches (pl. 15, fig. 8). The organism that preyed upon the urchin was not observed, but presumably it was a fish.

RELATION OF TEST SHAPE TO LIVING HABIT

Thin discoid species such as *Leodia sexiesperforata* and *Encope michelini* normally inhabit the upper part of the sand substrate. They burrow to a depth of only about a quarter of an inch under normal circumstances, although in some areas they were found slightly deeper. Hyman (1955, p. 556) cites studies that indicate that sand dollars dig deeper in stormy weather. The thicker and less completely flattened *Clypeaster subdepressus* also lives very near the surface of the

sand, and some specimens were observed to cover themselves with a layer of sand and carry it with them as they move over the surface without burrowing. This species has the flat ventral surface that characterizes species that burrow.

The other common *Clypeaster* in the Coral Reef Preserve is *C. rosaceus* which we did not find buried, and whose shape is greatly different from that of *C. subdepressus*. The test is strongly convex dorsally, a feature in common with burrowing spatangoids, but the oral surface is deeply concave, a shape not found in burrowers. The concavity of the oral surface keeps the nearly centrally located mouth raised somewhat above the sand as the animal moves over the surface. This shape would be an impediment to motion in a burrowing species, but probably is advantageous to *C. rosaceus* in allowing the test to ride over tufts of grass, and then to fill the concave underside as the animal stops to feed.

Thick or tumid forms such as *Meoma ventricosa* and *Plagiobrissus grandis* are somewhat streamlined and have the ventral surface flat. This shape is efficient for burrowing deeper than do the flat sand dollars, and size probably is no impediment to motion, providing the thickness of sand is sufficient.

All the regular echinoids we saw lived above the surface of the sand. Some such as *Echinometra lucunter* may live in deep niches in rock. We noted no preferred direction of motion of active regulars such as *Lytechinus variegatus* or *Tripneustes ventricosus*, an observation corroborated by Hyman (1955, p. 550) who reports that *L. variegatus* can walk with any ray forward, and cites Parker (1936) to the effect that the axis of forward motion frequently changes as the animal progresses.

Sand dwelling regular echinoids live above its surface, and some like *Astropyga magnifica* (and the presumably nocturnal *Diadema antillarum*) are surprisingly mobile.

ABNORMAL SPECIMENS

One tetramerous variant of *Meoma ventricosa* was found alive at locality 23. This specimen (pl. 16, figs. 5-6) lacks ambulacrum IV (left anterior) and its two associated half-interambulacra. Ocular IV and genital 3 are missing from the apical system. This variant is typical of the tetramerous variant group 4 as described by Jackson (1927, p. 502). Because only four ambulacra are present at the peristome (where the oldest, first-produced plates occur), it is apparent

that this abnormality dates from a stage before any skeletal parts had formed. With ocular IV absent, no plates could be introduced for ambulacrum IV and its two adjacent half-interambulacra for as shown by Jackson (1912, p. 26; 1927, p. 491) new plates are introduced at the edges of the ocular plates. This prospective gap was filled by the joining of the anterior half of interambulacrum 3 with the posterior half of interambulacrum 4. Ambulacrum III which is normally anterior shifted to the side of the test with its phyllode entering the side of the peristome instead of the front (pl. 16, fig. 6). The calcareous process that normally occurs in the interior at the edge of the peristome, attached to the first plate of interambulacrum 4, also is absent because that plate is missing. It is significant that the echinoid was able to live without this process. We have been able to find little in the literature concerning this structure, but from our study of dissected specimens of *Meoma ventricosa*, and as figured in the *Traité de Zoologie* (Grasse, 1948, vol. 11 p. 157, fig. 183) in *Spatangus purpureus* Müller, the esophagus is attached to this process by numerous mesenteries. Presumably this process keeps the esophagus from being pushed posteriorly by motion of sand through it as the echinoid moves anteriorly.

One tetramerous variant of *Encope michelini* also is referable to Jackson's group 4; it lacks ambulacrum IV and the two associated half-ambulacra. In this specimen (pl. 15, fig. 7) the anterior petal is shifted to the left. Because only four ambulacra occur at the peristome, and the lantern consists of only four jaws, teeth, and other parts, this abnormality also predates the development of any skeletal parts.

In contrast to the previous two variants, which are probably mutational, one specimen of *Echinometra lucunter* is incompletely tetramerous, probably because of post-embryonic injury. Adapically (pl. 16, fig. 2), only four ambulacra and four interambulacra are present, with ambulacrum I and its associated half-interambulacra missing. Adorally (pl. 16, fig. 1), all five ambulacra and five interambulacra are present but ambulacrum I and its half-interambulacra (pl. 16, fig. 4) terminate a short distance from the peristome and their place is filled by interambulacral plates from oculars V and II. The lantern is normal with five components of each structure, and there are five auricles. Apparently, therefore, the production of plates for ambulacrum I and its half-interambulacra ceased when the echinoid was small and had produced only a few plates in each column. This cessa-

tion could have been caused by an injury near ocular I where new plates are produced. The posterior genital plates, 5 and 1, have no pores, but two large pores in ocular I presumably are the pores normally found in those genital plates (pl. 16, fig. 3).

CONCLUSIONS

Echinoids studied here seem to show definite habitat preferences that could provide significant clues to interpretation of conditions in ancient seas by paleoecologists. Moreover, they could be valuable to the modern ecologist or sedimentologist who retrieves samples by dredge or trawl. For example, *Clypeaster rosaceus* dredged from clean sand would indicate that grassy areas were nearby, as grassy sand is the preferred habitat of that species. In addition, the material that this species carries on its back is a clear indication of the nature of the bottom. Similarly, the paleoecologist who found a fossil of this species or a species of similar shape, such as *Clypeaster antillarum* Cotteau from the Tertiary of the Caribbean area, could infer the presence of turtle grass on the former sea bottom. This in turn gives an indication of limits of depth at which the Tertiary formation was deposited, because this grass does not thrive much below 40 feet.

Many of the species that live in the Coral Reef Preserve occur as fossils, and others have near relatives that are known from Tertiary and Quaternary formations. A fossil assemblage that contains *Lytechinus variegatus*, with *Arbacia punctulata* (or similar *A. improcera* (Conrad)) and *Euclidaris tribuloides* or a similar form, indicates a sandy bottom with dense turtle grass, at depths as great as 40 feet, but relatively near shore. Admixtures of *Clypeaster subdepressus*, or the similar fossil *C. sunnilandensis* Kier, and some of the thin sand dollars indicate patches of clean, grassless sand among the turtle grass.

Meoma ventricosa has not been reported as a fossil. However, species similar to it in shape, such *Rhyncholampas evergladensis* (Mansfield) which occurs in the Tamiami Formation of Florida (Kier, 1963), probably had similar living habits. These forms indicate a sandy bottom with little or no turtle grass, located relatively far from shore. Likewise, a sandy, grassless bottom could be inferred from presence of *M. ventricosa* or similar forms in a dredge haul.

Some species of regular echinoids seek rocky or reefy environments, where niches and rock slabs provide cover. All large *Diadema antillarum* observed in the Coral Reef Preserve were on rocky sub-

strate, only small and medium-size individuals were congregated in groups on the sand. Therefore, a fossil assemblage consisting of large *D. antillarum*, along with *Echinometra viridis* and perhaps *Eucidaris tribuloides*, would suggest a hard substrate, possibly a reef or rocky shore. *Echinometra lucunter*, on the other hand, lives only in the intertidal zone, so its presence would suggest either a shoreline environment, or a shoal.

Factors controlling echinoid distribution.—Three major factors seem to control the distribution of the echinoid species in the area studied. These are depth, substrate, and distance from shore. Other possible influences, such as light penetration, wave agitation, current direction, water temperature, and food supply, either are functions of the three major factors, or were influences which we were unable to evaluate.

Species controlled by depth.—*Echinometra lucunter* inhabits rock just below low tide, whether along the shore of Key Largo, or on exposed parts of the reef several miles from shore. Although it inhabits rocky substrates, it is absent from rocks at depths greater than about 10 feet.

Species that inhabit turtle grass are controlled indirectly by the depth of water. Turtle grass does not survive at depths greater than about 40 feet; *Lytechinus variegatus*, *Tripneustes ventricosus*, and *Clypeaster rosaceus* seem to be confined to waters shallower than that depth. Turbidity seems not to have had great influence, as these species were found in clear water as well as in the extremely murky waters of Hawk Channel.

Astropyga magnifica was found only deeper than 75 feet. Its distribution may depend on other factors, such as the nature of the substrate, but depth also seems to be a major factor.

Species controlled by substrate.—The sand dwellers, *Encope michelini*, *Leodia sexiesperforata*, *Clypeaster subdepressus*, *Meoma ventricosa*, and *Plagiobrissus grandis* are confined by their necessity to burrow. They must have relatively grassless sand, where they are unobstructed by the tangle of roots. The few specimens of *M. ventricosa* found in turtle grass were unable to burrow, and were living on the surface of the substrate, covered by objects they held onto the test in the manner of *Clypeaster rosaceus*.

Brissus unicolor and *Echinoneus cyclostomus* were found only under detached pieces of rock in areas of coarse sand, and perhaps their distribution is confined to such areas. However, too few specimens were observed to be sure of this relationship.

Species whose distribution is controlled by the distribution of turtle grass might be said to depend on substrate, but as depth controls the turtle grass, it also indirectly controls the echinoids.

Species controlled by distance from shore.—*Meoma ventricosa* inhabits waters of greatly varying depth, but was not encountered nearer than about 4 miles from shore, just a short distance landward from the reef. Although it was found in shallow water on White Bank, it was not found in deeper water nearer shore.

Species not evaluated.—Factors controlling the distribution of *Diadema antillarum* could not be evaluated within the area studied. The species was found in all depths, on all substrates and its range extends from shore to the seaward limit of the area.

The habitat of *Echinometra viridis* is not well enough known to evaluate factors controlling its distribution. At present it seems to inhabit only niches in rock, and the shadows of sponge and coral heads, in the manner of *Arbacia punctulata*. Furthermore, its depth tolerances are unknown.

Echinoid associations.—Certain echinoid species characteristically occur near one another as inhabitants of similar or contiguous environments. Five such associations were encountered in the area studied.

1. *Echinometra lucunter* and *E. viridis* live in holes in rock near shore, and under the shadows of corals and sponges in shallow water just offshore.

2. *Lytechinus variegatus*, *Tripneustes ventricosus*, *Clypeaster rosaceus* and *Eucidaris tribuloides* live above the surface of the sand in turtle grass. In addition, *Arbacia punctulata* and *Eucidaris tribuloides* cluster around isolated mounds of coral or sponge within these grassy areas. *Diadema antillarum* also inhabits the turtle grass, with adults assembled into groups, and juveniles living singly.

3. *Clypeaster subdepressus*, *Encope michelini* and *Leodia sexiesperforata* inhabit the upper layer of clean grassless sand, and frequently are found together. *Meoma ventricosa* and *Plagiobrissus grandis* inhabit the same areas, although they burrow more deeply. *Clypeaster rosaceus* also may be encountered on the same grassless sand, but normally only where grassy patches occur in the vicinity.

4. *Diadema antillarum* appeared to be nearly the sole inhabitant of niches within the main body of the reef, although one specimen of *Echinometra viridis* was found in a hole in the reef.

5. *Brissus unicolor* and *Echinoneus cyclostomus* live under detached rocks in sandy patches within the reef area.

Further study in other areas of the Caribbean is necessary to test the consistency of these associations, establish other such associations of different species, and to assess their significance as ecological indicators. When a sufficient body of such associational information has been assembled, it should be of value of paleoecologists in interpreting past environments.

LITERATURE CITED

- BOONE, L.
1928. Scientific results of the first oceanographic expedition of the "Pownee" 1925, Echinodermata from tropical east American seas: The Bingham oceanographic coll., vol. 1, art. 4, p. 1-22, pl. 1-8, text figs. 1-8.
- CLARK, H. L.
1933. A handbook of the littoral echinoderms of Porto Rico and the other West Indian Islands: N. Y. Acad. of Sci., Sci. surv. of Porto Rico and the V. I., vol. 16, pt. 1, 147 p., 7 pls.
- ENGEL, H.
1961. Some fossil Clypeastrids (Echinoidea) from Brimstone Hill (St. Kitts) and Sugar Leaf (St. Eustatius), Lesser Antilles: *Beaufortia*, vol. 9, No. 94, 6 p., 4 figs.
- GOODBODY, IVAN
1960. The feeding mechanism in the sand dollar *Mellita sexiesperforata* (Leske): *Biol. Bull.*, vol. 119, No. 1, p. 80-86, 3 text figs.
- GRASSE, P. P.
1948. *Traité de Zoologie*: vol. 11, Echinodermes, stomocordes, procordes, 1077 p., 460 figs., Paris, Masson et C^o.
- HYMAN, L. H.
1955. Echinodermata. The coelomate Bilateria: *The Invertebrates*, vol. 4, 763 p., 280 text figs., New York, McGraw-Hill Book Co., Inc.
- JACKSON, R. T.
1912. Phylogeny of the Echini, with a revision of Palaeozoic species: *Mem. of the Boston Soc. of Nat. Hist.*, vol. 7, 491 p., 76 pls., 255 text figs.
1927. Studies of *Arbacia punctulata* and allies, and of nonpentamerous Echini: *Mem. of the Boston Soc. of Nat. Hist.*, vol. 8, No. 4, p. 435-565, text figs. 1-75.
- KIER, P. M.
1956. Separation of interambulacral columns from the apical system in Echinoidea: *Journ. of Paleontology*, vol. 30, No. 4, p. 971-974, 3 text figs.
1963. Tertiary echinoids from the Caloosahatchee and Tamiami formations of Florida: *Smithsonian Misc. Coll.*, vol. 145, No. 5, 63 p., 18 pl., 58 text figs.
- KRISTENSEN, I.
1964. Low light intensity inducing cave characteristics in *Diadema*: *Assoc. Island Marine Laboratories Caribbean*, 5th meeting, 26 pp.

LEWIS, J. B.

1958. The biology of the tropical sea urchin *Tripneustes esculentus* Leske in Barbados, British West Indies: Canadian Journ. Zoology, vol. 36, No. 4, p. 607-621, pls. 8-9, 7 text figs.

MOORE, D. R.

1956. Observations of predation on echinoderms by three species of Casididae: The Nautilus, vol. 69, No. 3, p. 73-76.

MOORE, H. B., JUTARE, THELMA, BAUER, J. C., and JONES, J. A.

1963. The biology of *Lytechinus variegatus*: Bull. of Marine Sci. of the Gulf of Mex., vol. 13, No. 1, p. 23-53, 22 text figs.

MORTENSEN, TH.

- 1928-1951. A monograph of the Echinoidea: 5 vols. and index, Copenhagen, C. A. Reitzel publisher.

NICHOLS, DAVID.

1964. Echinoderms: experimental and ecological: Oceanography and Mar. Biol. Ann. Rev., vol. 2, p. 393-423, 6 text figs.

PARKER, G. H.

1936. Direction and means of locomotion in the regular sea urchin *Lytechinus*: Mem. Mus. Hist. nat., Belg., (2) vol. 3, p. 197-208, 6 text figs.

SHARP, D. T., and GRAY, I. E.

1962. Studies on factors affecting the local distribution of two sea urchins, *Arbacia punctulata* and *Lytechinus variegatus*: Ecology, vol. 43, No. 2, p. 309-313, 2 text figs.

SHROEDER, R. E., and STARK, W. A., II.

1964. Photographing the night creatures of Alligator Reef: Natl. Geog. Mag., vol. 125, No. 1, p. 128-154, ill.

Manuscript received for publication February 19, 1965

EXPLANATION OF PLATES

PLATE 1. *ASTROPYGA MAGNIFICA* IN ITS HABITAT

- 1-5. *Astropyga magnifica* Clark at station 36 (depth 85 feet) on flat sand terrace.
1. Oblique view of specimen with spines grouped in defensive posture; inflated anal sac visible.
 2. Nearly vertical view from above, dorsal spines bundled for defense, anal sac visible, iridescent spots along ambulacra apparent.
 3. Two specimens showing bundled spines, anal sacs, and iridescent spots; glove at top gives scale.
 4. Small fish (*Apogon*) which characteristically swims among spines of this species.
 5. Same individuals as figure 3, seen from side with black glove in background, showing bundled upper spines, inflated anal sac, iridescent spots, color-banding of spines.

PLATE 2. HABITATS OF *EUCIDARIS TRIBULOIDES*, *DIADEMA ANTILLARUM*, AND *ARBACIA PUNCTULATA*

- 1-3. *Eucidaris tribuloides* (Lamarck).
1. Station 36 (depth 85 feet) in niche between boulders.
 2. Station 28 (depth 22 feet) in dense turtle grass.
 3. Station 22 (depth 30 feet) on sand in sparse turtle grass.
- 4-7. *Diadema antillarum* Phillipi.
4. Station 28 (depth 22 feet) flock of medium size specimens on fine sand in sparse turtle grass. One in bottom center of photograph shows inflated anal sac; small striped fish swim among spines in upper right.
 5. Station 22 (depth 30 feet) solitary juvenile with banded spines on sand in moderately dense turtle grass.
 6. Station 25 (depth 110 feet) large specimen in niche in living coral bank.
 7. Station 60 (depth 20 feet) medium size specimens in niches among living coral on reef.
- 8-9. *Arbacia punctulata* (Lamarck).
8. Station 28 (depth 22 feet) clinging to base of isolated sponge on sand in sparse turtle grass. White specks are small mysid shrimps which inhabit area protected by spines of this species and *D. antillarum*.
 9. Station 28 (depth 22 feet) two specimens clinging to base of small clump of corals and sponges, on sand in sparse grass.

PLATE 3. HABITATS OF *LYTECHINUS VARIEGATUS*, *TRIPNEUSTES VENTRICOSUS*, AND *MEOMA VENTRICOSA*

1. *Lytechinus variegatus* (Lamarck) station 28 (depth 22 feet), specimen in turtle grass completely camouflaged by shells and blades of grass held onto test by tube feet.

2. *Tripneustes ventricosus* (Lamarck) station 44 (depth 10 feet), on sand in sparse turtle grass, with a few blades of grass held onto test; typically much less completely covered than *L. variegatus*.
3. Eroded bank about 1.5 feet high, showing exposed roots of turtle grass at station 30 (depth 15 feet). The tangled mat of roots prevents echinoids from burrowing in grassy areas.
4. *Meoma ventricosa* (Lamarck) station 21 (depth 25 feet), two specimens in turtle grass where their normal habit of burrowing is impossible, hence they are covered by sand grains, except along the petals, in a manner similar to *Clypeaster rosaceus*.
5. *Meoma ventricosa* in sand at station 29 (depth 25 feet) living on the surface in the manner of *C. rosaceus*, partly covered by grains of sand and blades of grass; a rare habitat for this species.

PLATE 4. CAMOUFLAGED *CLYPEASTER ROSACEUS*

1-7. *Clypeaster rosaceus* (Linnaeus).

1. Station 22 (depth 30 feet), on sand near edge of grass, holding grass and coarse sand on test.
2. Station 30 (depth 15 feet), far from grass, on coarse sand bottom, holding coarse sand grains, shells and shell debris, and worm tubes onto test.
3. Station 21 (depth 25 feet), in sparse grass, covered by shell fragments, coarse sand grains, and a few blades of grass.
4. Station 29 (depth 25 feet), on coarse sandy bottom, covered with sand and shells including dead test of *Brisus unicolor*.
5. Station 20 (depth 35 feet), on clean, fine- to medium-grained sand, partly covered by sand grains, standing immediately to right of faint outline of buried specimen of *C. subdepressus*.
6. Station 29 (depth 25 feet), in dense grass, covered almost exclusively by blades of grass.
7. Station 21 (depth 25 feet), in coarse sand near grassy patch, test sparsely covered by coarse sand grains and grass, moving by plowing through sand rather than by normal habit of moving on surface.

PLATE 5. MODE OF BURIAL OF *CLYPEASTER SUBDEPRESSUS*,
AND TRAIL OF *ENCOPE MICHELINI*

1-6, 8. *Clypeaster subdepressus* (Gray)

1. Excavated specimen at station 20 (depth 35 feet) begins to rebury itself by passing sand onto the dorsal surface at the anterior, and by moving forward slightly.
- 2-4. Forward motion away from knife blade is apparent; sand is passed onto dorsal surface at ends of petals 3 and 4 as well as being passed backward from the anterior.
5. Burial is complete as specimen has moved forward about one length.
- 6, 8. Specimen at station 49 (depth 20 feet) buries with minimal forward motion, completing burial in about 4 minutes by passing sand onto dorsal surface along petalous areas.

7. *Encope michelini* Agassiz. Station 30 (depth 15 feet). Roughly triangular trail in calcareous sand, showing low parallel ridges made by posterolateral notches, and median row of sand grains aligned by posterior lunule; specimen at top center of photograph.

PLATE 6. OVERTURNING, HABITATS AND ASSOCIATES OF
CLYPEASTER SUBDEPRESSUS

- 1-6. Station 22 (depth 30 feet), timed series illustrating righting of *C. subdepressus* after being overturned.
1. Time 10:30. Small and large specimens overturned, begin righting by action of spines along edge near anterolateral ambulacrum.
 2. Time 10:50. Small specimen at angle near 45 degrees; larger one barely raised (subsequent illustrations show only the smaller specimen; at end of series 45 minutes later, larger specimen still had not attained vertical position).
 3. Time 11:04. Small specimen (at left in figure 2) nearly vertical, with right side dug into sand.
 4. Time 11:10. Small specimen vertical.
 5. Time 11:13. Small specimen rapidly lowering to normal horizontal position.
 6. Time 11:18. Specimen horizontal and buried, beginning to move forward.
7. *Clypeaster subdepressus* and *C. rosaceus*, station 30 (depth 15 feet). Both somewhat out of normal habitat, with tests covered. *C. subdepressus* here moving on surface of sand, with coarse particles held over petal area (this species normally burrows in topmost layer of sand). *C. rosaceus* covered by shells and some grass (this species normally lives in grassy areas).
8. *Clypeaster subdepressus*, station 22 (depth 30 feet), plowing through topmost layer of sand, with broad flat objects held over petals.
- 9-10. *Clypeaster subdepressus* and *Encope michelini*, station 30, depth 15 feet.
9. Two specimens of *C. subdepressus* and one of *E. michelini* covered by thin layer of sand, occupying essentially the same habitats.
 10. The same three specimens uncovered.

PLATE 7. OVERTURNING OF *ENCOPE MICHELINI*, AND BURIAL
OF *E. MICHELINI* AND *LEODIA SEXIESPERFORATA*

- 1-5. *Encope michelini* Agassiz, station 30 (depth 15 feet).
1. Inverted specimen digs anterior edge into sand.
 2. Side view showing specimen about 45 degrees to surface of sand.
 3. Specimen nearly vertical, without having dug deeper into sand than in figure 2.
 4. Righted specimen lowers posterior edge toward sand.
 5. Nearly horizontal, specimen buries itself rapidly by passing sand backward along dorsal surface, and by moving forward into sand.
- 6-8. *E. michelini* and *Leodia sexiesperforata* (Leske), station 30 (depth 15 feet).
6. Excavated specimen of each species begins to bury by moving forward into sand, passing sand backward along dorsal surface from anterior, and

by passing sand up through notches and lunules (time: 2:31). Both species started at watch band.

7. Both specimens have achieved nearly the same proportion of cover, but *E. michelini* has moved farther forward (time 2:34).

8. Both nearly buried; *E. michelini* moved forward about one length, (time: 2:35).

PLATE 8. *PLAGIOBRISSUS GRANDIS* BURYING

- 1-4. Timed series illustrating manner and speed by which excavated specimen of *Plagiobrissus grandis* (Gmelin) buries itself, station 30 (depth 15 feet).
 1. Time 3:09. Sand beginning to form ridge around specimen; process began about 1 minute earlier.
 2. Time 3:10. Specimen buried to nearly half its own thickness, pushing up large rim of displaced sand.
 3. Time 3:12. Upper surface of specimen at level of surface of sand; sand from rim being drawn onto test.
 4. Time 3:15. Test nearly covered, long dorsal spines projecting through sand.
5. Partly buried specimen at station 30 (depth 15 feet), showing long dorsal spines.
6. Side view of partly buried specimen at station 23 (depth 12 feet) showing backward curvature of long dorsal spines; rim of displaced sand destroying small ripple.

PLATE 9. GROWTH SERIES IN *MEOMA VENTRICOSA*

- 1-4. Specimens showing change in test shape, length and arrangement of petals, size of peristome, and size of tubercles during growth.
 1. Specimen 22 mm. long ($\times 2$); station 19; USNM E10315.
 2. Specimen 44 mm. long ($\times 1$); station 17; USNM E10314.
 3. Specimen 71 mm. long ($\times 0.6$); station 30; USNM E10313.
 4. Specimen 144 mm. long ($\times 0.3$); station 17b; USNM E10312.

PLATE 10. *MEOMA VENTRICOSA*

- 1-4. *Meoma ventricosa* (Lamarck)
 - 1, 2, 3. Adapical, adoral, right side of immature specimen, 22 mm. long, showing spines ($\times 2.5$); station 19; USNM E10315.
 4. Adoral view of adult showing difference in length of spines from immature specimen ($\times 2.6$); station 17b; USNM E10312.
5. *Arbacia punctulata* (Lamarck). Station 27; USNM E10320. Adapical view of naked test ($\times 1\frac{1}{2}$).
6. *Echinometra viridis* Agassiz. Station 3; USNM E10319. Adapical view of dried specimen ($\times 1$).

PLATE 11. *MEOMA VENTRICOSA* IN SAND

- 1-6. *Meoma ventricosa* (Lamarck) burrowing in sandy bottoms.
 1. Partly buried specimen with depressed petal area being nipped by small parrot fish (*Sparisoma aurofrenatum*). Others nearby with dorsal

spines missing. Shallow sand at station 21 (depth of water 25 feet) at edge of sandy area prevents *M. ventricosa* from burrowing deeply enough to protect themselves.

2. Specimen at station 21 (depth 25 feet) with spines missing near petals, preventing complete burial.

3. Specimen at station 21 (depth 25 feet) with spines missing on posterior lateral surface, preventing complete cover by sand, thus inviting further predation.

4-5. Station 22 (30 feet), timed pair of photographs, indicating speed of burial.

4. Time 10:20. Specimen buried to ends of petals.

5. Time 10:30. Sand being brought up onto test before specimen has burrowed deeply enough for complete burial.

6. Station 18. Normal specimen in normal habitat, showing manner of leaving petals uncovered (or covered only by coarse particles) to allow free circulation of water for respiration.

PLATE 12. *OREASTER RETICULATUS* PREYING ON
MEOMA VENTRICOSA

1. As first observed, station 23 (depth 12 feet), *Oreaster reticulatus* (Linnaeus) draped over an immobile specimen of *Meoma ventricosa* (Lamarck).
2. As the starfish was lifted off the urchin, its extruded gut was seen to contract back into its mouth, whereupon normal burrowing action of the urchin's spines began. Effects on *M. ventricosa* of this predation by the starfish are shown on plate 13.

PLATE 13. *MEOMA VENTRICOSA* AND *SCHIZASTER (PARASTER)*
FLORIDIENSIS

- 1-3. *Meoma ventricosa* (Lamarck). Station 23; USNM E10309.
 - 1, 2. Adapical, rear view of specimen attacked by starfish (see pl. 12, figs. 1, 2). Note black stain on anterior half of adapical surface ($\times \frac{1}{2}$).
 3. View of posterior of same specimen showing etching of plates by secretions of the starfish ($\times 1$).
- 4-6. *Schizaster (Paraster) floridiensis* Kier and Grant, new species.
 4. View of peristome and phyllodes of holotype ($\times 3$); Station 30; USNM E10302.
 5. Apical system of paratype ($\times 17$); Station 30; USNM E10303.
 6. Ambulacrum III of holotype ($\times 6$).

PLATE 14. *SCHIZASTER (PARASTER) FLORIDIENSIS*

- 1-9. *Schizaster (Paraster) floridiensis* Kier and Grant, new species.
 - 1, 2, 3. Left side, adoral, adapical view of holotype ($\times 1$); station 30; USNM E10302.
 - 4, 5. Left side, adoral view of paratype with spines ($\times 2$); station 17a; USNM E10303.
 - 6, 7, 8. Globiferous pedicellaria from specimen in figures 4, 5 ($\times 50$).
 9. Enlarged view of plastron spines of specimen in figures 4, 5 ($\times 18$).

PLATE 15. SIX SPECIES OF FLORIDA ECHINOIDS

1. *Echinoneus cyclostomus* Leske. Station 60; USNM E10318. Adapical view of specimen photographed in alcohol ($\times 2$).
- 2-3. *Plagiobrissus grandis* (Gmelin). Station 30.
 2. Adapical view of immature specimen (35 mm. long) for comparison with adult in figure 3 ($\times 1.5$); USNM E 10304.
 3. Adapical view of adult (140 mm. long), $\times 2.8$; USNM E10305.
- 4-5. *Brissus unicolor* (Leske).
 4. Adapical view of specimen photographed in alcohol ($\times 2$); station 60; USNM E10317.
 5. Adapical view of denuded test ($\times 1.5$); station 17a; USNM E10316.
6. *Meoma ventricosa* (Lamarck). Station 23. Pedicellaria clasping an ostracod ($\times 30$).
7. *Encope michelini* Agassiz. Station 45; USNM E10308. Tetramerous variant lacking ambulacrum IV and its associated half-interambulacra ($\times 1$).
8. *Clypeaster subdepressus* (Gray). Station 61; USNM E10307. Adoral view of specimen presumably attacked by a fish as evidenced by the teeth marks on the test. ($\times \frac{1}{2}$).

PLATE 16. ABNORMAL ECHINOIDS—TETRAMEROUS VARIANTS

- 1-4. *Echinometra lucunter* (Linnaeus). Molasses Key; USNM E10306.
 1. Adoral view showing five ambulacra, five interambulacra, but with ambulacrum I and its half-interambulacra terminating a short distance from peristome ($\times 1\frac{1}{2}$).
 2. Adapical view showing only four ambulacra and interambulacra ($\times 1\frac{1}{2}$).
 3. Apical system showing absence of pores in posterior genital plates, presence of two probable genital pores in ocular I ($\times 5$).
 4. Enlarged view showing total extent of ambulacrum I ($\times 5$).
- 5-6. *Meoma ventricosa* (Lamarck). Station 23; USNM E10311.
 5. Adapical view showing only three petals, the left anterior petal absent ($\times 0.6$).
 6. Adoral view showing absence of phylloche IV ($\times 0.6$).

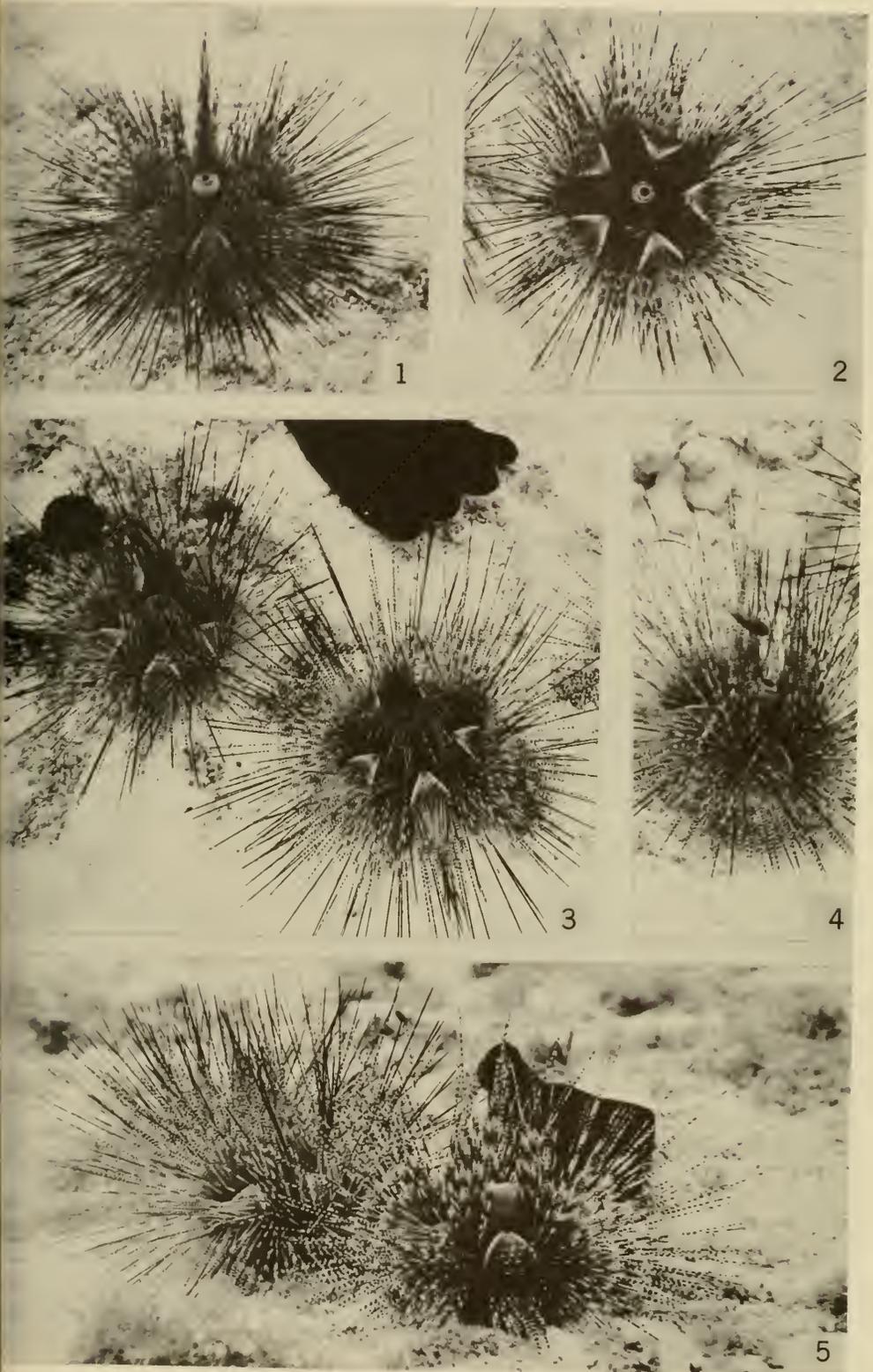


PLATE 1. *Astropyga magnifica* in its Habitat
(See explanation of plate at end of text.)

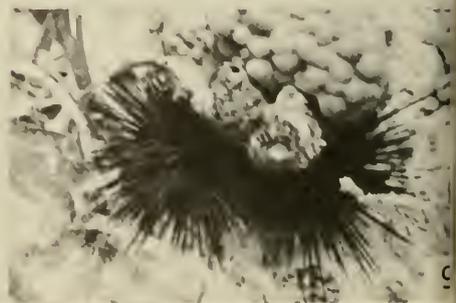
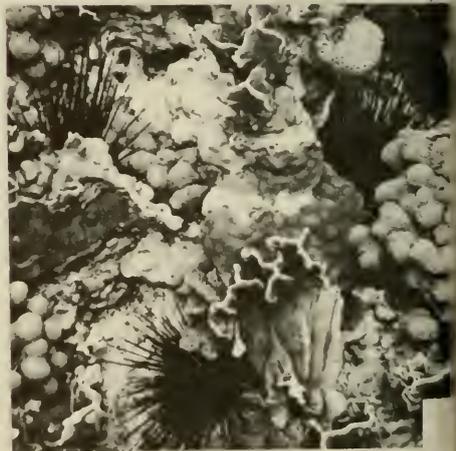
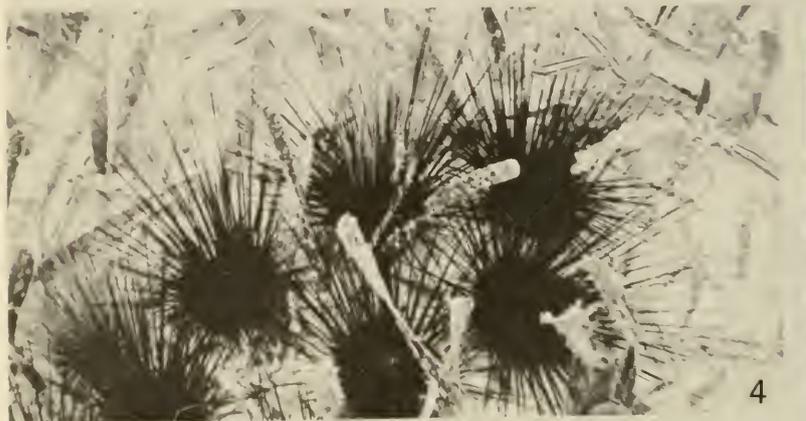
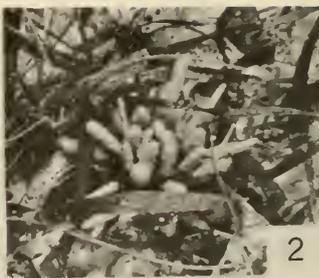


PLATE 2. Habitats of *Eucidaris tribuloides*, *Diadema antillarum*, and *Arbacia punctulata*
(See explanation of plate at end of text.)



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PLATE 3. Habitats of *Lytechinus variegatus*, *Tripneustes ventricosus*, and *Meoma ventricosa*
(See explanation of plate at end of text.)



PLATE 4. Camouflaged *Clypeaster rosaceus*
(See explanation of plate at end of text.)

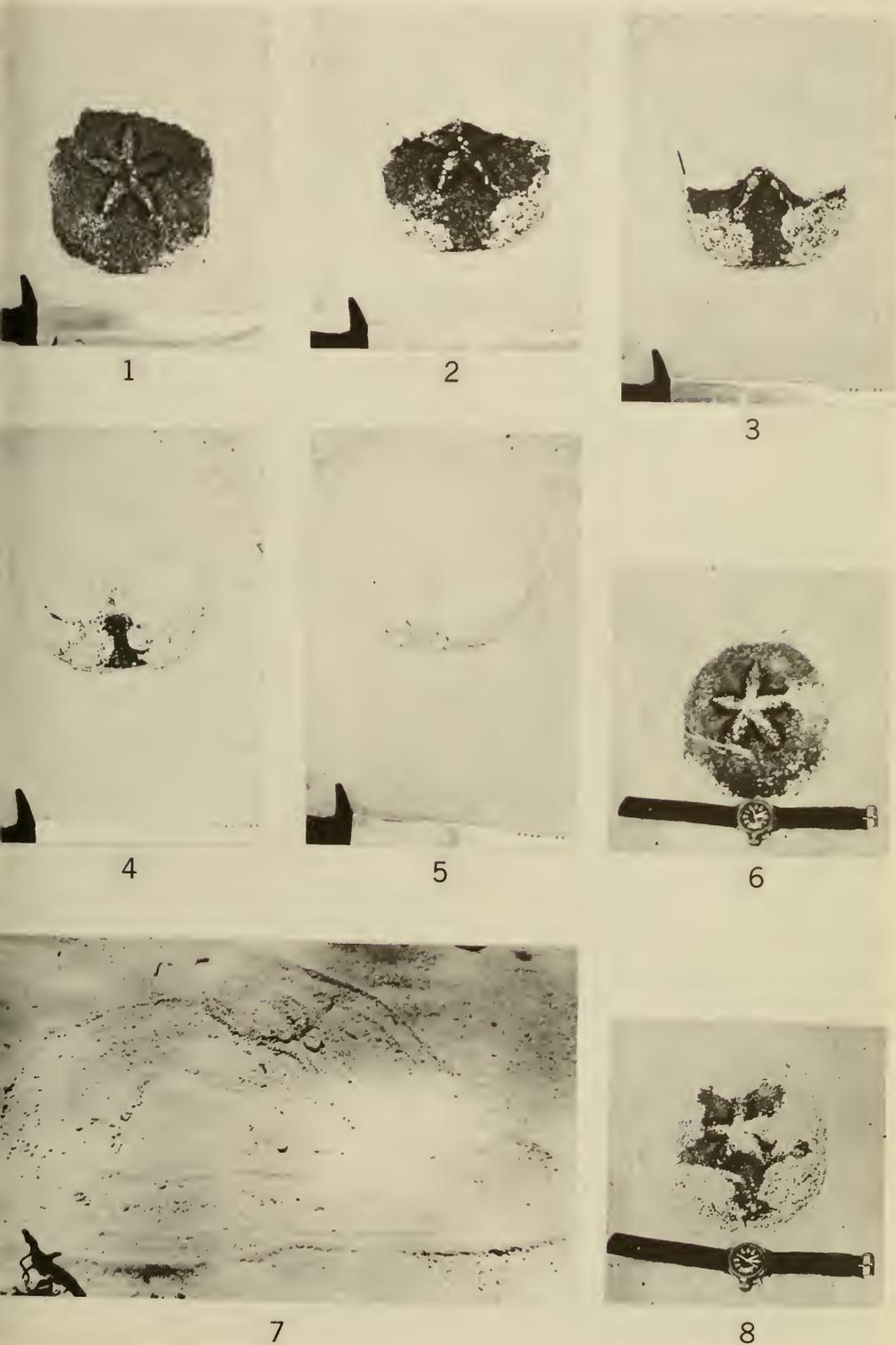


PLATE 5. Mode of Burial of *Clypeaster subdepressus*, and Trail of *Encope michelini*
(See explanation of plate at end of text.)

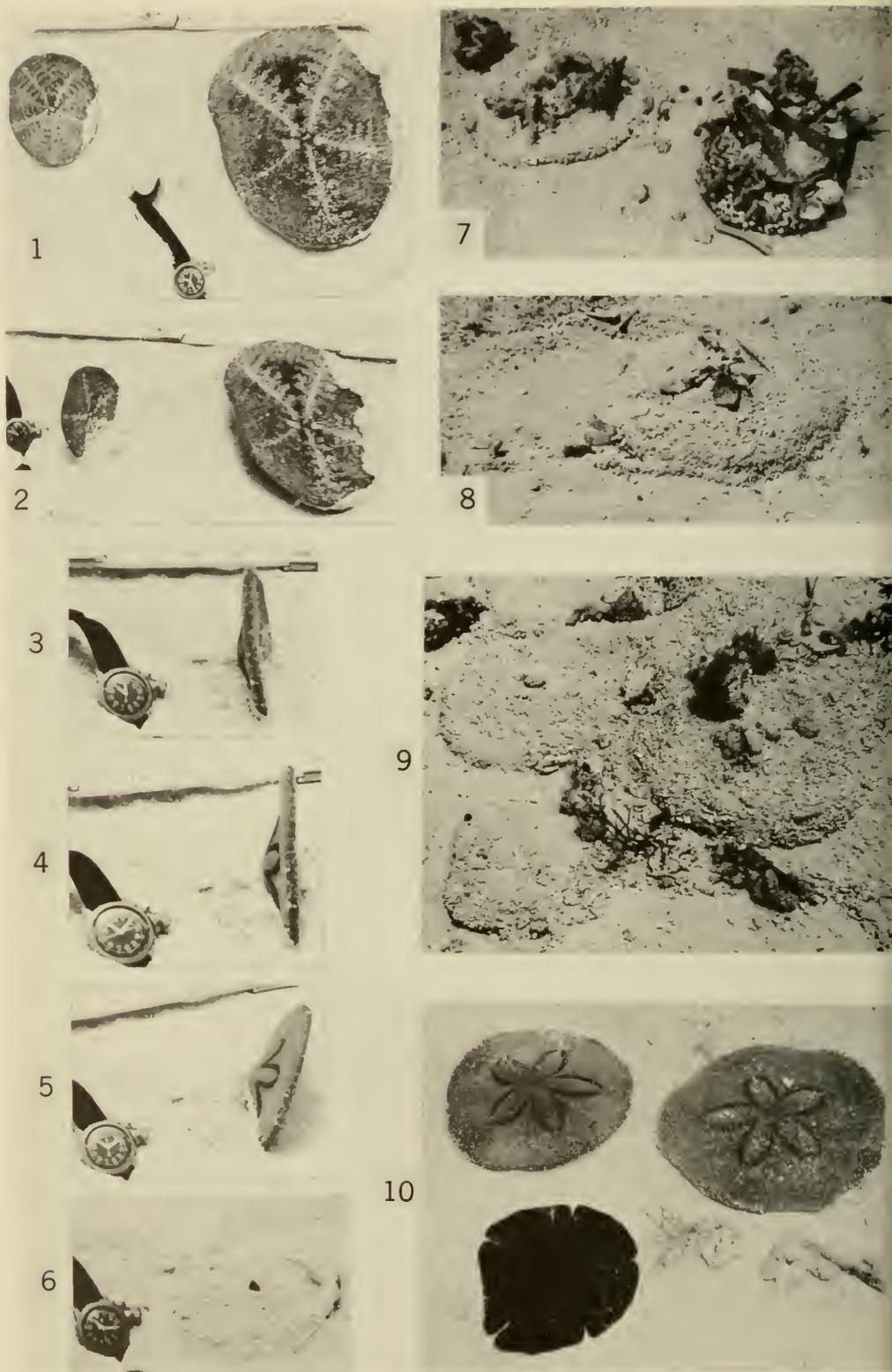


PLATE 6. Overturning, Habitats, and Associates of *Clypeaster subdepressus*
 (See explanation of plate at end of text.)

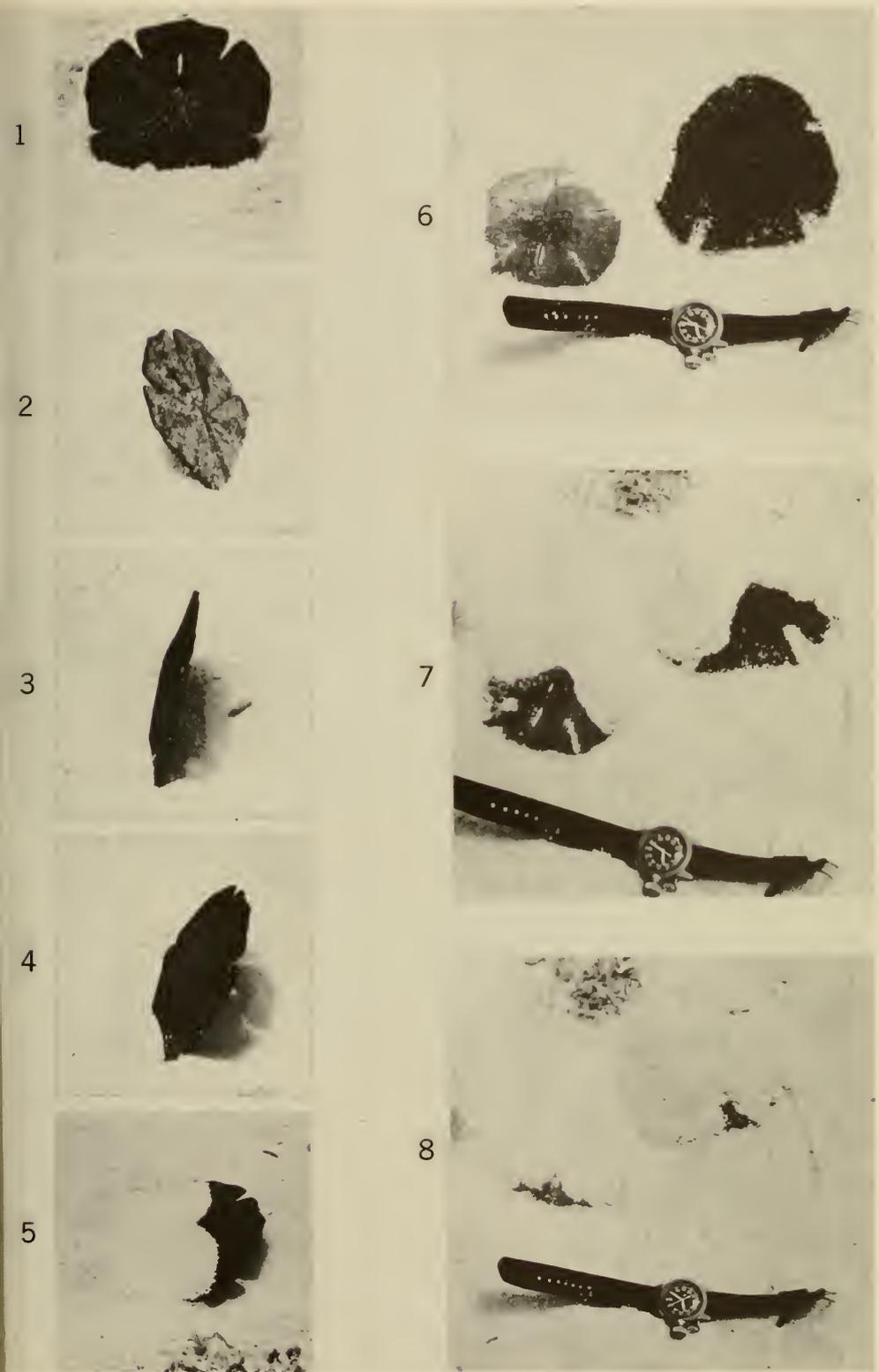


PLATE 7. Overturning of *Encope michelini*, and Burial of *E. michelini* and *Leodia sexiesperforata*
 (See explanation of plate at end of text.)

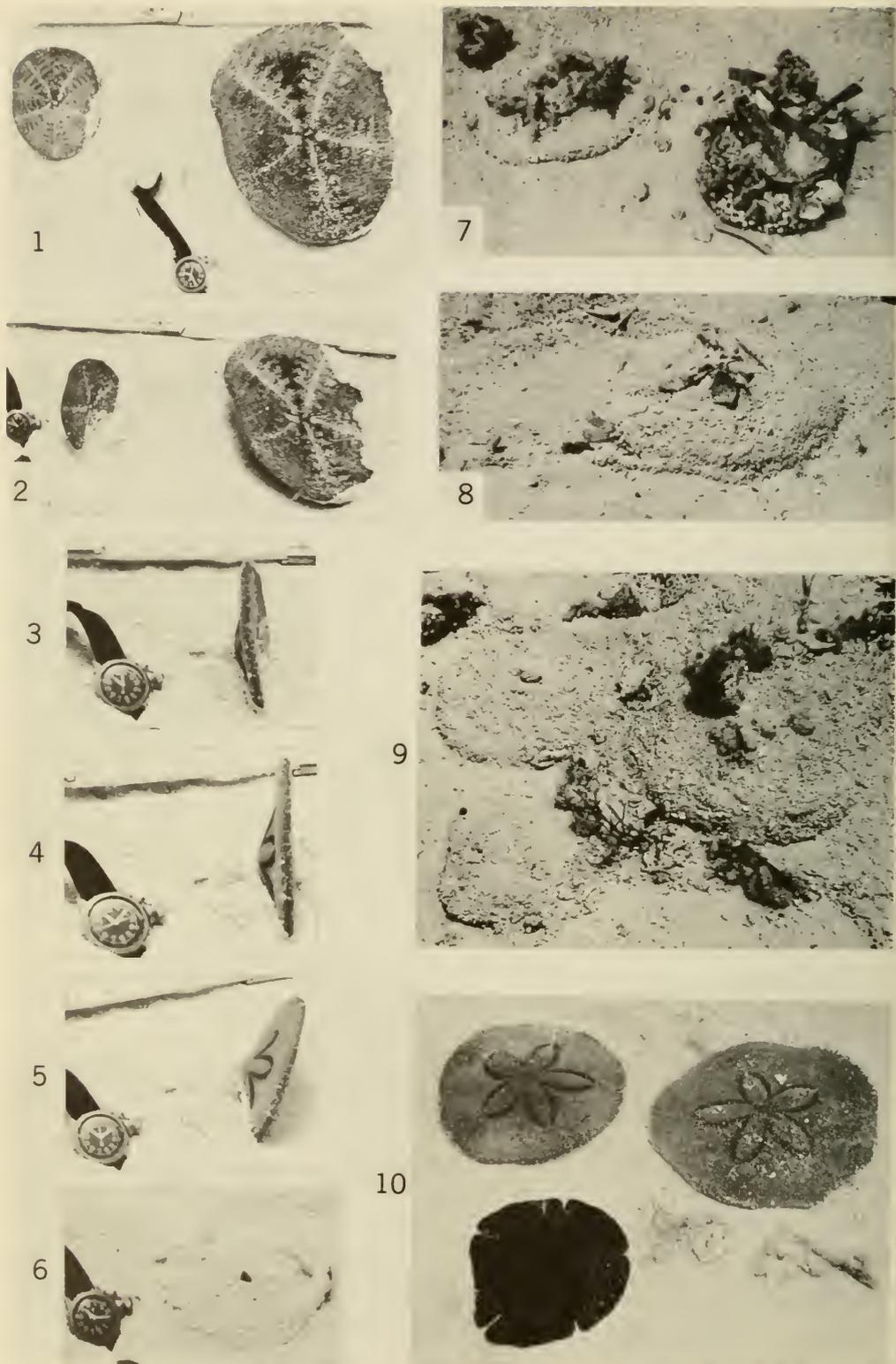


PLATE 6. Overturning, Habitats, and Associates of *Clypeaster subdepressus*
 (See explanation of plate at end of text.)

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PLATE 7. Overturning of *Encope michelini*, and Burial of *E. michelini* and *Leodia sexiesperforata*
(See explanation of plate at end of text.)

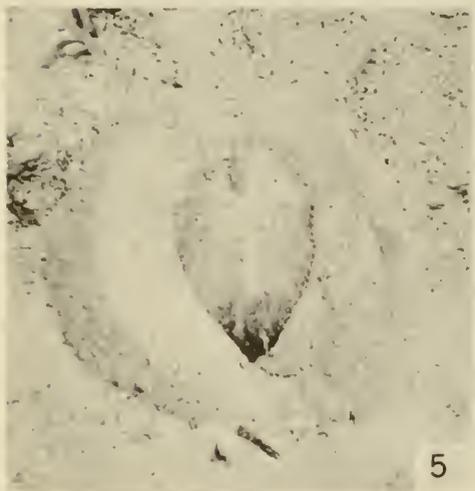


PLATE 8. *Plagiobrissus grandis* Burying
(See explanation of plate at end of text.)

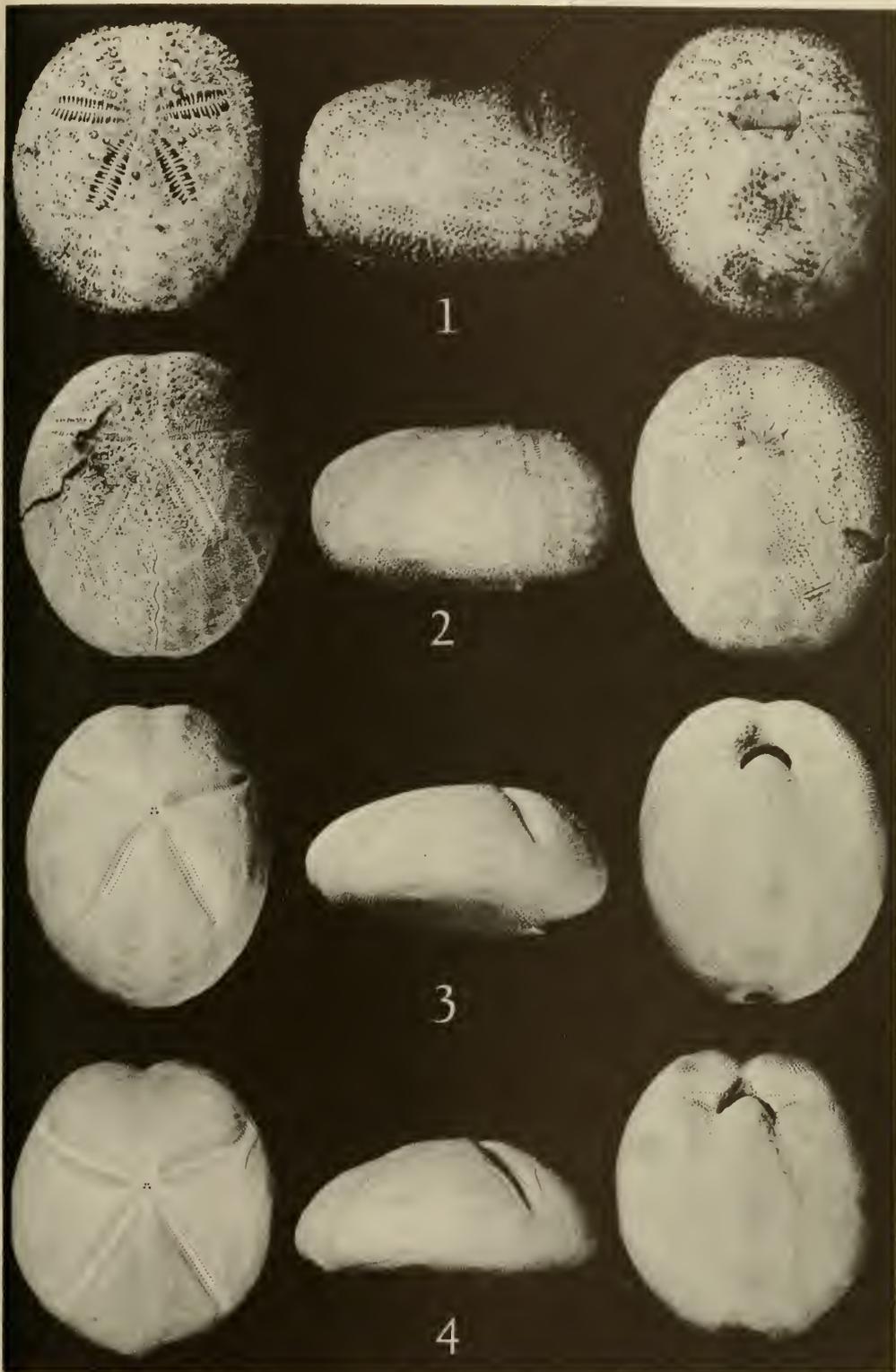


PLATE 9. Growth Series in *Meoma ventricosa*
(See explanation of plate at end of text.)

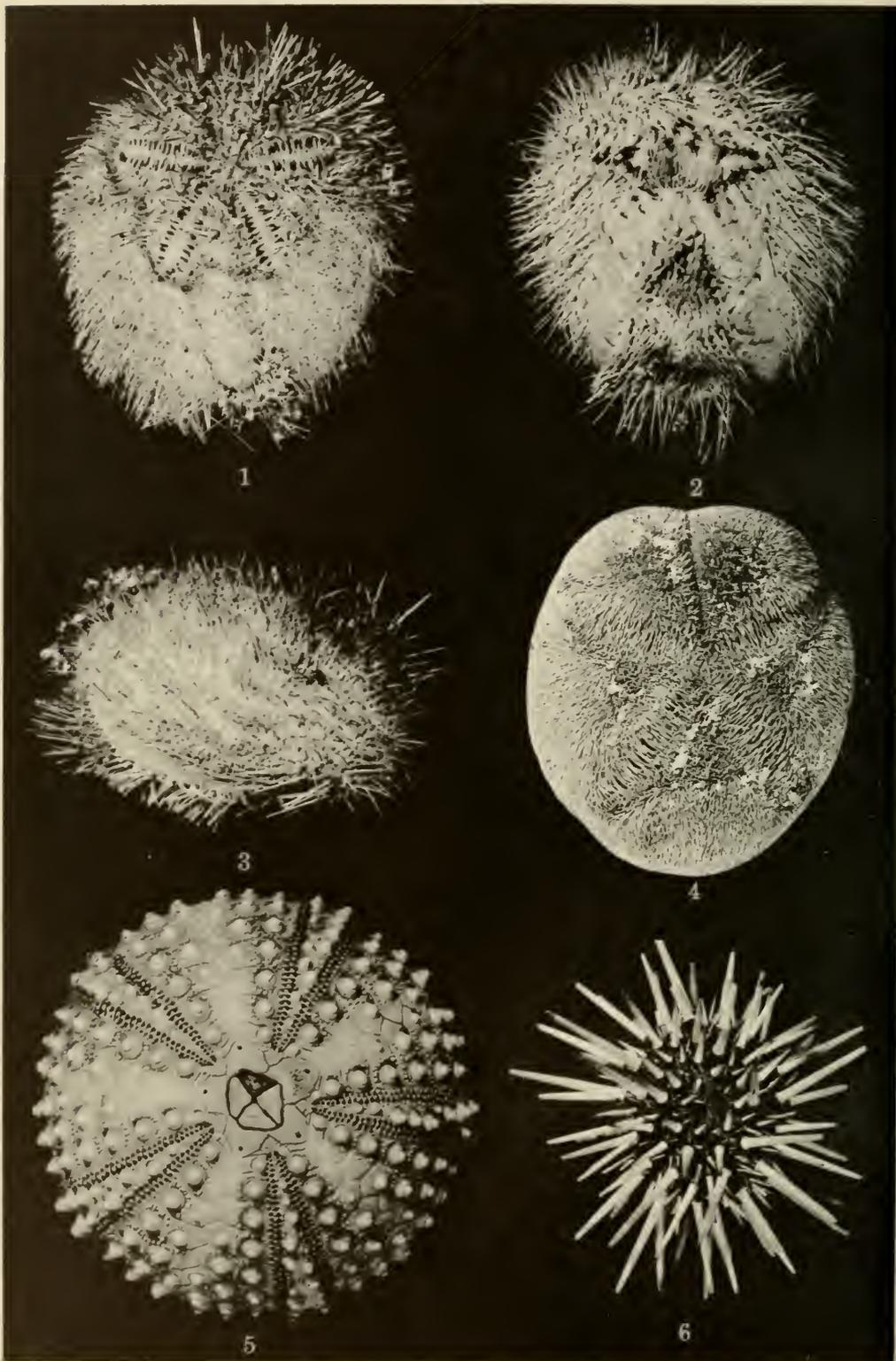


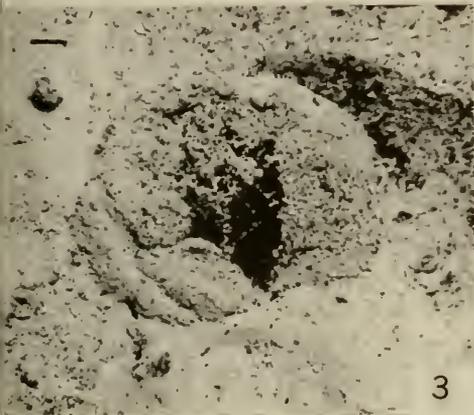
PLATE 10. *Meoma ventricosa*
(See explanation of plate at end of text.)



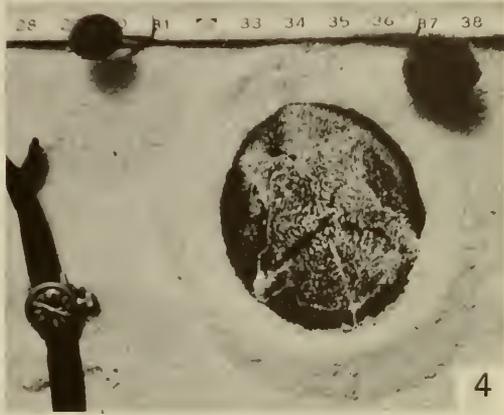
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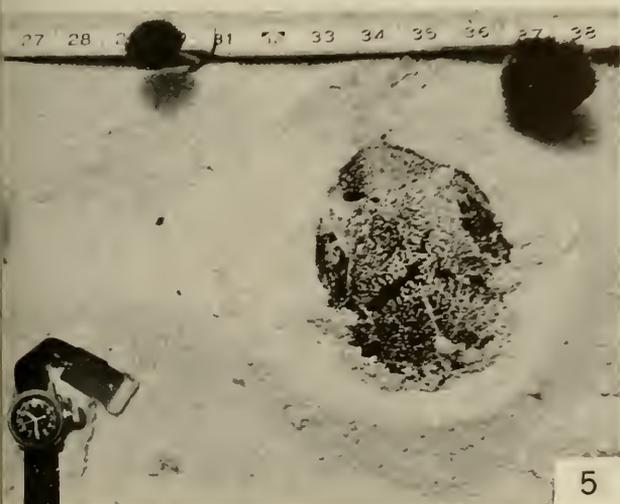
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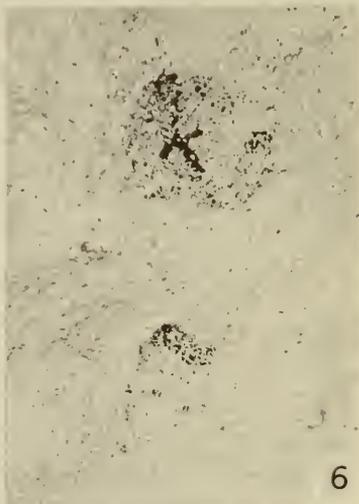
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PLATE 11. *Meoma ventricosa* in Sand
(See explanation of plate at end of text.)



PLATE 12. *Oreaster reticulatus* Preying on *Mcoma ventricosa*
(See explanation of plate at end of text.)



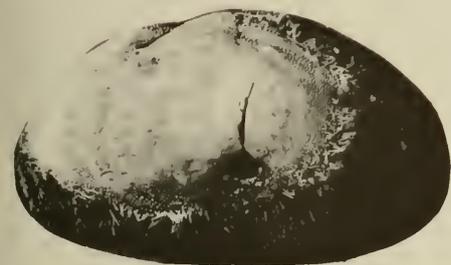
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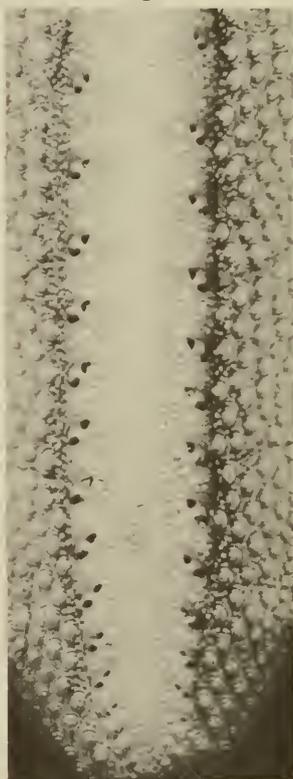
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PLATE 13. *Meoma ventricosa* and *Schizaster (Paraster) floridiensis*
(See explanation of plate at end of text.)

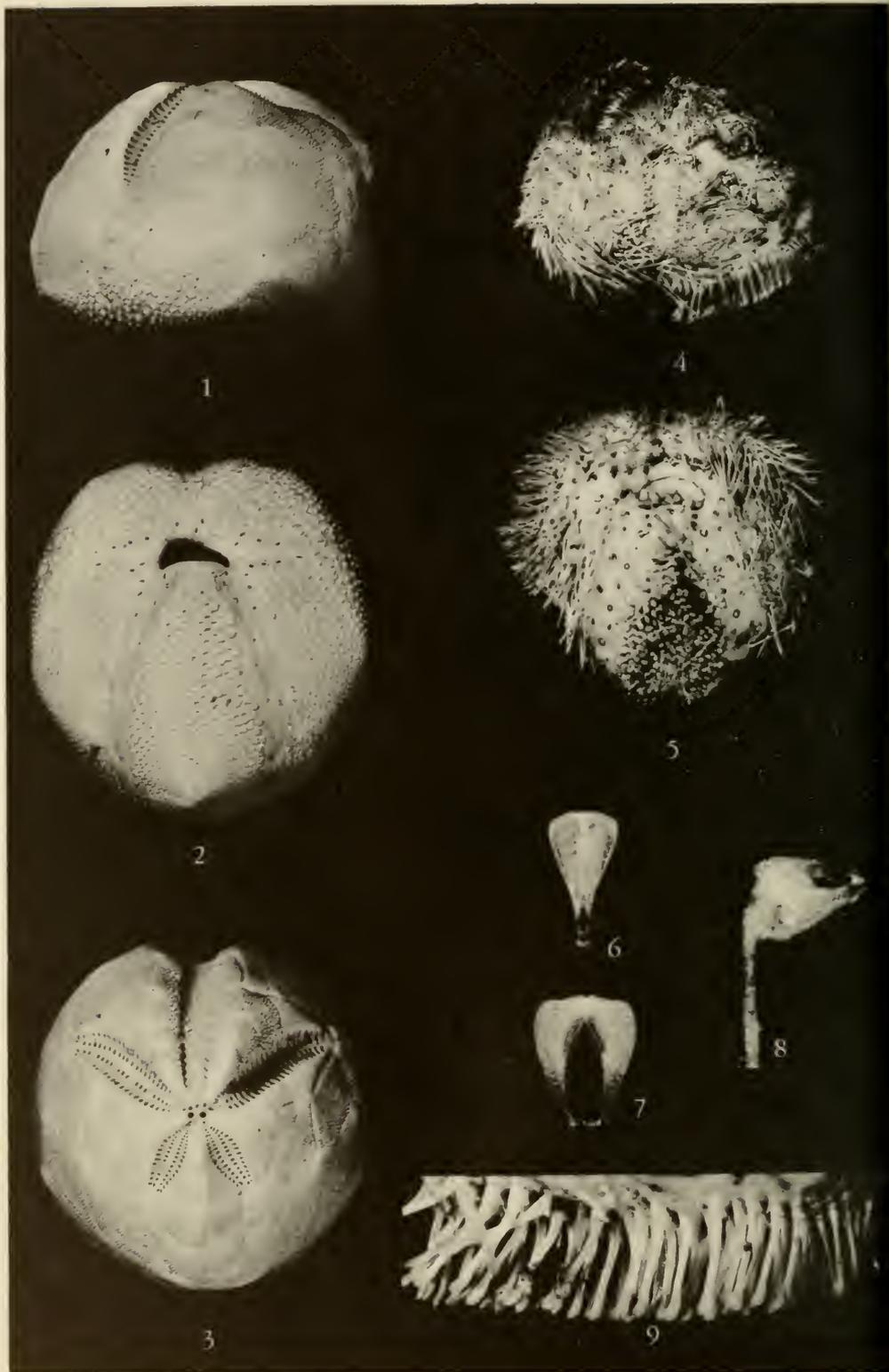


PLATE 14. *Schizaster (Paraster) floridiensis*
(See explanation of plate at end of text.)

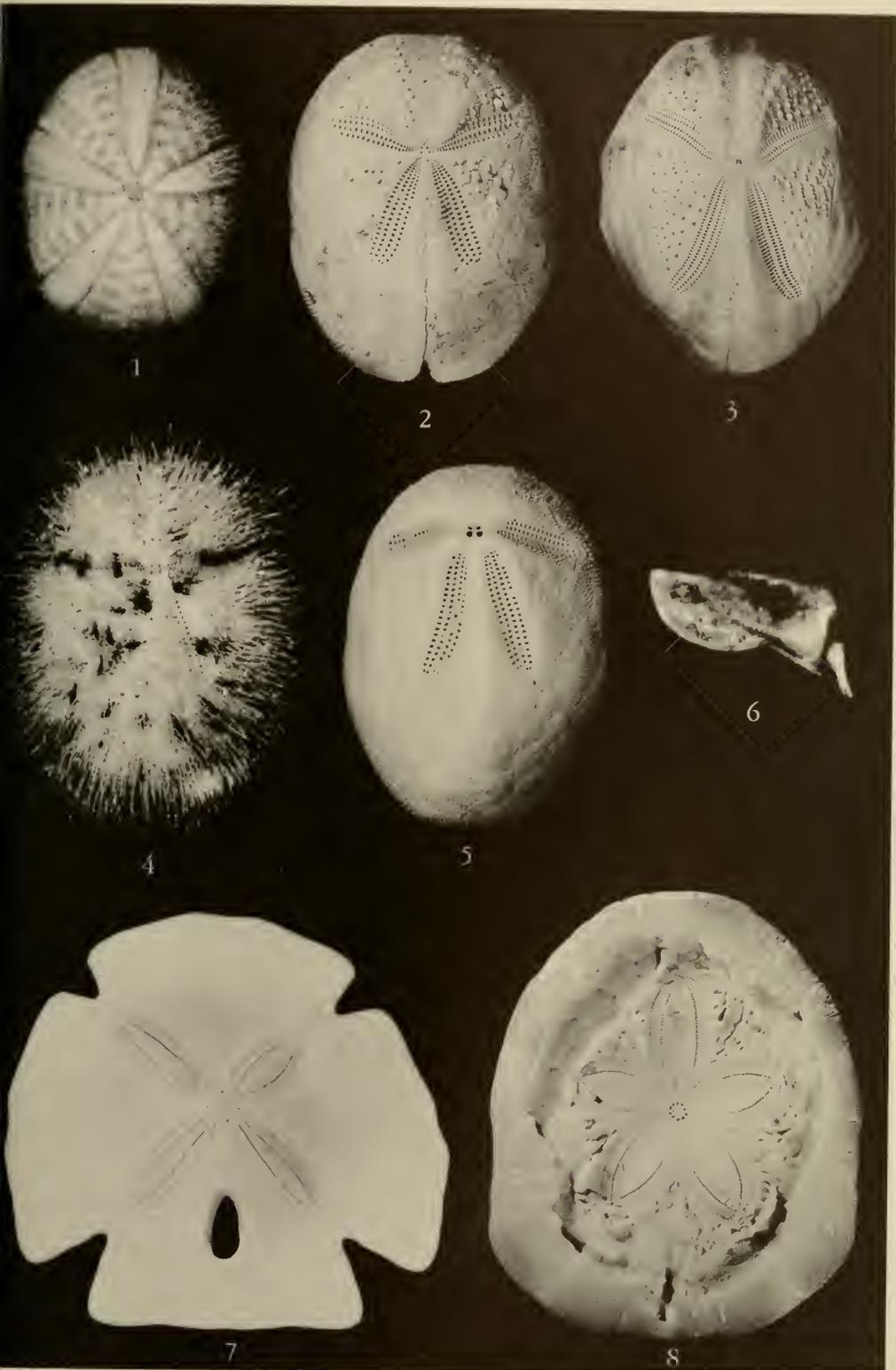


PLATE 15. Six Species of Florida Echinoids
(See explanation of plate at end of text.)

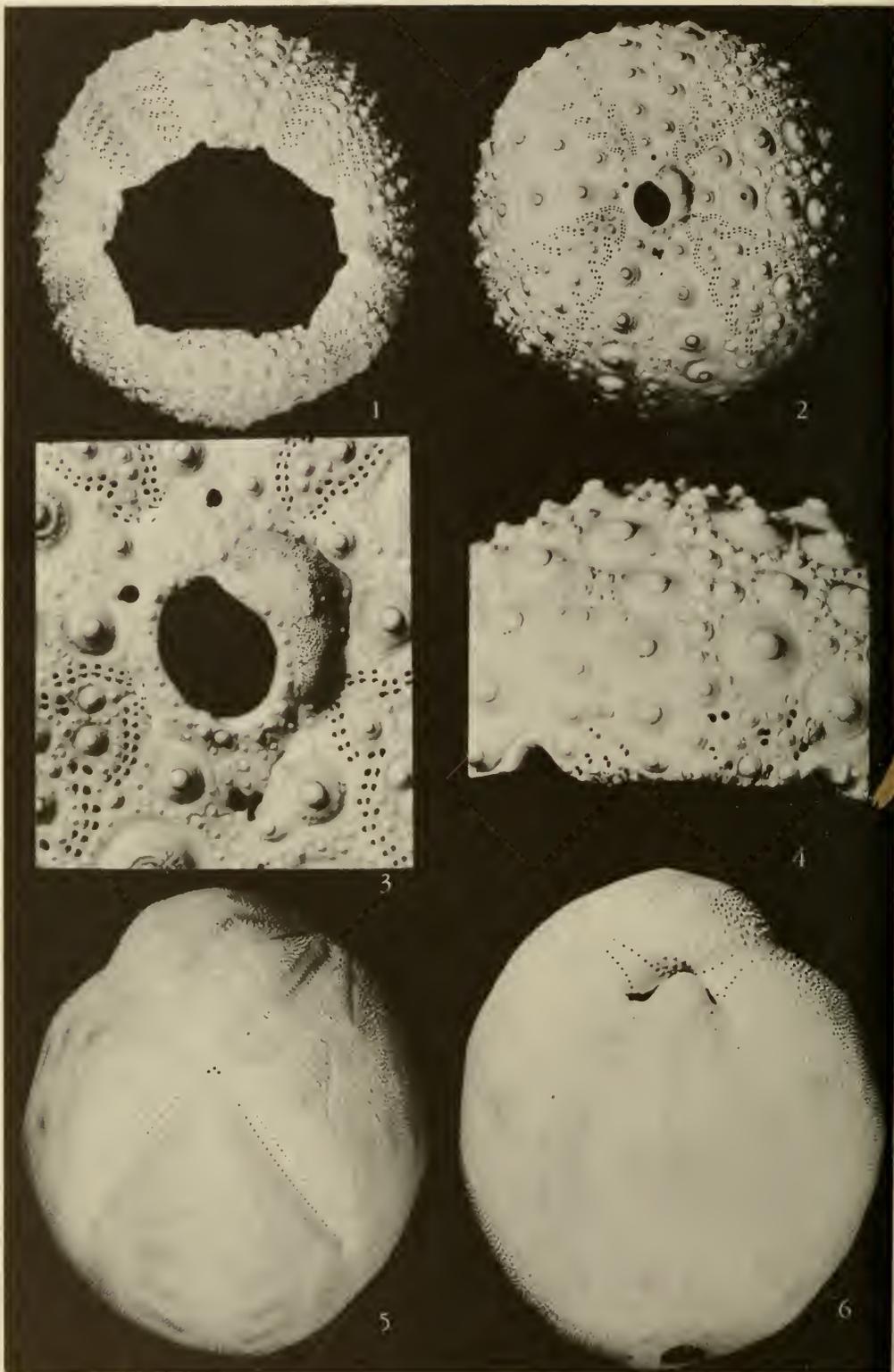


PLATE 16. Abnormal Echinoids—Tetramerous Variants
(See explanation of plate at end of text.)