DISTRIBUTION OF MACROSCOPIC REMAINS OF RECENT ANIMALS FROM MARINE SEDIMENTS OFF MASSACHUSETTS

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ABSTRACT

Macroscopic animal remains are common constituents of bottom sediments on the continental shelf and upper continental slope south of Cape Cod, Mass. The largest quantities are in sandy deposits in the vicinity of Nantucket Shoals, where they form nearly 30% by volume of the total substrate. The smallest quantities are along the outer continental shelf and upper slope, where animal remains generally make up less than 1% of the substrate. Representatives of all three major realms of aquatic animals contribute to the prefossil skeleton assemblages; benthic forms are the principal components, nektonic forms are common, and planktonic forms are rare. The quantitatively dominant taxonomic groups present in the sediments are: echinoderms, mollusks, and teleosts.

Typical specimens of all groups represented in the samples are illustrated. Charts and graphs show the geographic and bathymetric distributions of the common species.

Durable remains of recently (up to several thousand years) deceased animals and plants constitute an important, but frequently overlooked, link between living organisms and their fossils. Reconstruction of the marine environment that existed in past geological ages can be better approximated when present-day marine populations and processes are well understood. A conventional approach used in paleobiological investigations is to equate the habits, ecological requirements, and functional morphology of fossil species with their living relatives (Ladd, 1957; and others). Consequently, a thorough knowledge of existing life is valuable to geological advancement. Events during the transitional phase between death and fossilization may strongly influence the dispersal, shape, and associated species of fossil remains. Frequently these events must be clearly understood to interpret fossil findings correctly and completely. It is in this context that the prefossil stage is considered to be significant in determining the history of life.

A series of samples collected from the ocean bottom off southeastern Massachusetts provide an insight into the composition and the geographic distribution of macrobenthic, nektonic, and planktonic animal skeletons—or portions thereof—that occur in continental shelf bottom sediments and that are available for fossilization. Thus the purpose of this report is to describe qualitatively and quantitatively the macroscopic animal remains (durable portions of recently dead animals) in the bottom sediments of this representative portion of the continental shelf in New England.

To avoid undue repetition of the words "dead," "deceased," "remains," and similar descriptive terms throughout this report, it must be emphasized at the outset that all samples of animal materials dealt with in this report are the remains of dead animals. Accounts of the living organisms obtained in these collections will be dealt with in other reports.

Previous studies of paleontological interest pertaining to prefossil marine animal remains are very diverse in subject. A few examples of these studies include such dissimilar topics as: the composition and distribution of mollusk shell remains (Habe, 1956; and others), biological alteration of bottom sediments (Schäfer, 1956; Rhoads, 1966; and others), comparison

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of the feeding habits and sediment types inhabited by epifaunal and infaunal benthic animals (Craig and Jones, 1966), catastrophism in the sea (Gunter, 1947; and others), position of pelecypod shells in different environments (Emery, 1968), burial of mollusk shells (Johnson, 1957), radiocarbon dating of relict oyster shells (Merrill, Emery, and Rubin, 1965), and other related subjects. Most of these studies are restricted to one specific topic. The present study, likewise, has a limited objective: to describe the species composition and distribution of macroscopic prefossil animal remains.

Literature pertaining to present-day mollusk remains in marine bottom deposits is relatively common; see references in Habe (1956), Schäfer (1956), Johnson (1957), Belyaev (1970), and others. In contrast, however, a paucity of reports dealing with prefossil fish remains became strikingly evident during our literature search. Research on this subject tends to be regionally oriented. For example, the study by Jensen (1905) deals with otoliths from an Arctic basin. David (1947) and Soutar (1967) described fish remains from off southern California, and Belyaev and Glikman (1970) describe selachian teeth from a broad expanse of the Pacific Ocean. A major exception to this regional basis is the report by Brongersma-Sanders (1949), which summarizes the earlier literature pertaining to fish remains (albeit mostly fossil) from many parts of the world.

Prefossil remains of marine organisms are more easily obtained than are those of most terrestrial or aerial forms. Macrobenthic and nektonic organisms are usually abundant on continental and insular shelves, and their skeletal components are massive compared with those of microplanktonic pelagic forms. As a result, the "fossil assemblages" (Craig, 1953) of the continental shelf are dominated by macroscopic organisms, as opposed to planktonic forms that make up the bulk of deep-sea fossils. Likewise, the prefossil material of organic origin on continental and insular shelves is generally of a larger size, and the macrofaunal components are considerably more abundant than they are in the deep sea.

MATERIALS AND METHODS

Samples were collected 11-20 June 1962, from the Bureau of Commercial Fisheries (now the National Marine Fisheries Service) RV *Delaware* at 62 stations south of Martha's Vineyard, Mass. (Table 1; Figure 1). Stations were spaced at intervals of 16 km on a grid pattern having eight north-south transects at right angles to the depth contours. Quantitative bottom samples, including sediments and the constituent benthic fauna, were collected with a Smith-McIntyre grab sampler (Smith and McIntyre, 1954). This instrument effectively sampled a 0.1-m^2 area of bottom to a depth of about 10 to 17 cm. The volume of bottom material analyzed from individual samples averaged 8.9 liters. At sea, contents from the grab were washed on a 1-mm mesh sieving screen. Material remaining on the screen after washing was removed and preserved in a solution of neutral Formalin.[3] In the laboratory ashore.

[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

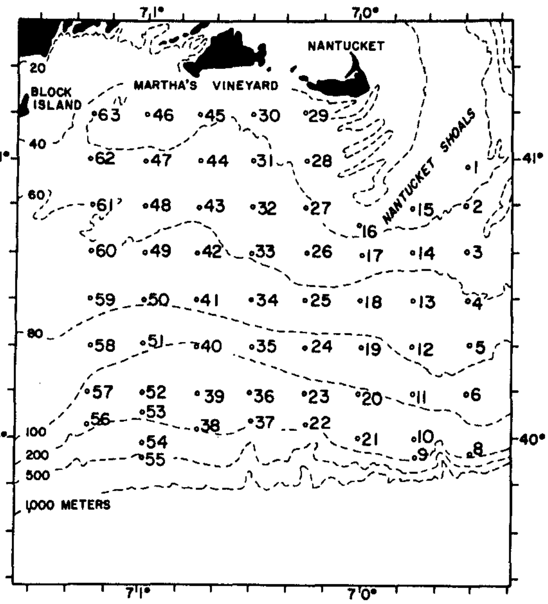

FIGURE 1.—Location of stations at which bottom samples were collected for determining the distribution of the remains of marine animals. Isobaths are indicated by dashed lines.

TABLE 1.—Station location, water depth, sediment type, and volume of bottom samples collected south of Martha's Vineyard, Mass., 11-20 June 1962.

Station number	Lat N	Long W	Water depth	Sediment type	Sample volume
			m		*liters*
1	40°58′	69°30′	46	Sand & gravel	2
2	40°51′	69°31′	46	Sand	4½
3	40°40′	69°31′	51	Sand	2¾
4	40°30′	69°29′	62	Sand	6¾
5	40°21′	69°30′	76	Sand	3¾
6	40°10′	69°31′	91	Sand	5¾
8	39°57′	69°30′	183	Sand	4¾
9	39°56′	69°45′	201	Sand	3¾
10	40°00′	69°45′	139	Silty sand	4¼
11	40°10′	69°45′	95	Silty sand	4¼
12	40°20′	69°46′	79	Sand	6¼
13	40°30′	69°45′	73	Sand	9¾
14	40°40′	69°45′	59	Sand	4½
15	40°50′	69°45′	37	Sand	6
16	40°46′	70°00′	38	Sand	2¾
17	40°39′	69°59′	49	Sand	4¾
18	40°30′	70°00′	73	Sand	11¾
19	40°20′	69°59′	91	Sand	7
20	40°10′	70°00′	117	Sand	¾
21	40°00′	70°00′	165	Sand	10¼
22	40°03′	70°15′	183	Silty sand	9¾
23	40°10′	70°15′	113	Silty sand	12¾
24	40°20′	70°15′	90	Silty sand	14¾
25	40°30′	70°15′	70	Sand	14
26	40°40′	70°15′	51	Sand	10
27	40°50′	70°15′	44	Sand	9¼
28	41°00′	70°15′	33	Sand	7¾
29	41°11′	70°16′	27	Sand	4¾
30	41°10′	70°30′	38	Sand	10
31	41°00′	70°30′	48	Sand	9¾
32	40°50′	70°30′	59	Sand	14¼
33	40°40′	70°30′	62	Silty sand	14¾
34	40°30′	70°30′	73	Sandy silt	13¾
35	40°20′	70°30′	97	Sandy silt	10¾
36	40°10′	70°30′	128	Silty sand	14¾
37	40°04′	70°29′	220	Sand	11½
38	40°02′	70°44′	194	Silty sand	5¾
39	40°10′	70°45′	132	Silty sand	14¾
40	40°20′	70°46′	106	Sand-silt-clay	14¾
41	40°30′	70°45′	79	Sandy silt	14¼
42	40°40′	70°45′	66	Silty sand	7½
43	40°50′	70°45′	55	Sand	9¾
44	41°00′	70°45′	51	Sand	7¾
45	41°10′	70°45′	38	Sand and gravel	5
46	41°10′	71°00′	40	Sand	6½
47	41°00′	71°00′	51	Sand and gravel	12¼
48	40°50′	71°00′	59	Sand	4¾
49	40°40′	71°00′	70	Sandy silt	14¾
50	40°30′	71°00′	84	Clayey silt	14
51	40°21′	71°00′	99	Sandy silt	14¾
52	40°10′	71°00′	146	Silty sand	4¾
53	40°06′	71°00′	179	Silty sand	11¾
54	39°59′	71°00′	366	Silt	11¾
55	39°56′	71°00′	567	Silt	10
56	40°03′	71°16′	183	Sand	10¾
57	40°10′	71°15′	110	Silty sand	7¾
58	40°20′	71°15′	91	Silty sand	14½
59	40°30′	71°15′	77	Silty sand	14¼
60	40°40′	71°15′	62	Sand	14½
61	40°50′	71°15′	62	Sand	12¾
62	41°01′	71°16′	48	Sand	¾
63	41°10′	71°15′	38	Sand	4¾

mineral matter and associated debris were removed by hand sorting, and the animals and animal remains were separated by species, identified, and counted. Only animal remains are considered in the present report.

Water depths at which samples were collected ranged from 27 to 567 m.

Sediment samples were collected at each station and at two localities equally spaced between stations along the cruise track. Of the 186 samples collected, 60 were analyzed in detail for particle size, and the remaining 126 were examined in the laboratory by field techniques. Names of the various sediment types are in accordance with the classification reported by Shepard (1954) and Emery (1960).

DESCRIPTION OF THE AREA

Three major physical features that have an important impact on the occurrence, distribution, and condition of the prefossil animal remains in this area are: physiography, bottom sediment composition, and hydrography. These features are briefly discussed below.

PHYSIOGRAPHY

The area studied is about 130 km square and extends across the continental shelf and the upper portion of the continental slope. Bottom configuration is moderately smooth; water depths increase gradually and rather uniformly from shore outward to the shelf break, which is at a depth of about 120 m. Beyond the shelf break, on the continental slope, the depth gradient is relatively steep, averaging 4°. Detailed bathymetric charts of this area having contour intervals of 1 fathom were published in 1967 by the U.S. Department of Commerce and U.S. Department of the Interior (Coast and Geodetic Survey, Bathymetric Maps numbers: 0708N-52 and 53; 0808N-51 and 52; and 0807N-51).

BOTTOM SEDIMENT COMPOSITION

Bottom sediments in the area are composed of relict glacial material—principally nonbiogenic sands and silts plus a few gravel patches

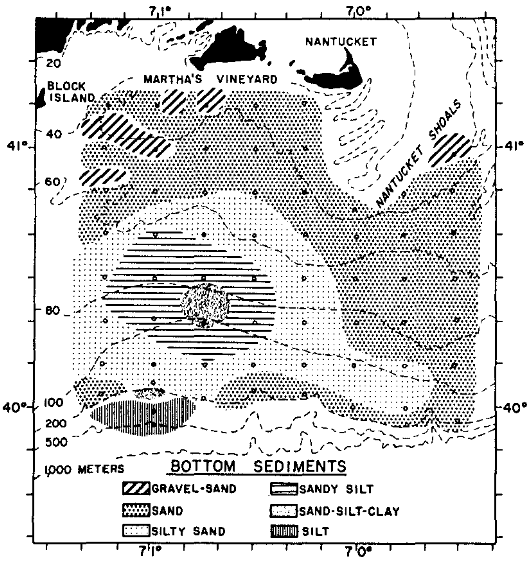

FIGURE 2.—Distribution of the various types of bottom sediments in the study area. Terminology is based on the classification reported by Shepard (1954) and Emery (1960).

of glacial erratics. Six major sediment types occur in the area (Figure 2). The terminology used is based on the standard Wentworth particle size classification (Twenhofel and Tyler, 1941; and others) and the nomenclature is that of Shepard (1954) and Emery (1960). Three types—sand, silty sand, and sandy silt—are distributed over a rather large area; the other three—gravel-sand, sand-silt-clay, and silt—have limited areal distributions. Sands cover more than half of the area. They occur mainly in shallow water (less than 60 to 80 m), except in the eastern sector and in a narrow (6 km) band parallel to the isobaths just below the outer periphery of the continental shelf. Sands and silts in the vicinity of the shelf break are primarily glauconitic. In shallow waters near Nantucket and Martha's Vineyard and in the vicinity of Nantucket Shoals, the sands are silt free and occasionally mixed with large quantities of shell. Mixtures of sand and gravel also occur in scattered patches in the shallower waters of the northwest sector and in Nantucket Shoals. Limonitic pellets and sand particles heavily stained with iron oxide are common in the northwest sector. Admixtures of silt occur with the sand over most of the remaining area.

A large (80 by 100 km) area of fine-grained sediments is situated in the southwestern sector. A relatively small circular area of sand-silt-clay near its center is surrounded by an inner band of sandy silt and an outer band of silty sand. Characteristically, the relatively large sand grains throughout the area of fine-textured sediments are frosted rounded quartz particles. Pyrite-filled foraminiferal tests occur in the eastern portion.

On the continental slope below the sand zone, the dominant sediment component is silt.

Additional information concerning sediments of this area and references to the geological literature were given by Uchupi (1963), Wigley and McIntyre (1964), Emery, Merrill, and Trumbull (1965), Emery (1966), Garrison and McMaster (1966), McMaster and Garrison (1966), and Wigley and Emery (1967).

HYDROGRAPHY

Within the area the water temperature regime is typically warm-temperate, although the boreal influence is seasonally significant. Surface temperatures are substantially higher than bottom temperatures; offshore surface waters are somewhat warmer than inshore waters throughout most of the year; temperatures of the entire water column change seasonally and to some extent from year to year. Most pertinent to the subject of this report are bottom water temperatures and nontidal currents.

A cell of cold (6.6°C in June 1962) bottom water extends in an east-west band from the New York region eastward to long 70°W (eastern Nantucket Island). This cell occurs at depths of about 40 to 80 m, which is roughly the midshelf region. At 300 to 600 m the bottom water temperatures are low and nearly constant throughout the year; they generally range between 4° and 7°C. Near the shelf break and upper continental slope the bottom temperatures are substantially higher, but also nearly constant; values range near 10° to 12°C throughout the year. Offshore shelf waters, especially in shallow sectors, may range from 3°C in February-March to 14°C in September-November. Temperatures of inshore surface waters substantially exceed these values.

Nontidal movements of water masses on the continental shelf within the area are generally westward. Water in the Gulf of Maine and Nantucket Sound tends to flow southwesterly across Nantucket Shoals and into the area. Conversely, surface waters offshore beyond the continental shelf flow easterly. Authors who have published further information on the hydrography of the area include Bigelow (1927, 1933), Bumpus and Day (1957), Bumpus et al (1957), Day (1958), and Colton (1964, 1968, 1969).

ORDER OF DISCUSSION

The most common animal remains in the samples studied were echinoderms, mollusks, and fish. Considerably less common than the foregoing were remains of crustaceans and coelenterates. The order in which these groups are discussed below is according to the abundance of remains in each major group, namely, echinoderms, mollusks, fish, and crustaceans and coelenterates.

REMAINS OF ECHINODERMS

Echinoderms were the most numerous and quantitatively dominant group of animal remains occurring in the area. The sole contributors in this group were the echinoids. Spines and test fragments were rare to very abundant and were widely distributed. Presumably the skeletal fragments of asteroids and ophiuroids, of which living members of both groups are common in this region, were generally too small to be recovered using the 1-mm mesh screen. Of all macroscopic animals in the samples, the common sand dollar, *Echinarachnius parma* (discussed in the following subsection), was by far the leading component. Spines were the principal structures recovered from heart urchins and sea urchins. Some examples of typical echinoderm remains are illustrated in Figure 3.

The size of fragments of most organisms discussed in this section ranged from 1 mm (sand size) to 1 cm or more. The largest remains were tests of whole or nearly whole *E. parma*. Adult size of living members of this species (about 7 cm) is less than some of the other nonmolluskan species, but the comparatively strong, compact test is much more resistant to fracture. This durability, plus the enormous supply in the form of living individuals, contributed to the abundance of fragments of this species in the sediments. Counting the *E. parma* and other echinoids was impractical owing to the enormous numbers of small fragments, plus a gradation in size that precluded the separation of major fractions from minor ones. Occurrence of *Brisaster fragilis, Echinarachnius parma,* and *Strongylocentrotus drobachiensis* are listed by stations in Table 2.

ECHINARACHNIUS PARMA

Remains of *E. parma* were widespread (Table 2) and numerous. This species ranked first in volume and number of fragments of all organic remains in the study area; it occurred at 73% of the stations. It was most abundant in the vicinity of Nantucket Shoals (stations 2, 3, and 16). *E. parma* fragments made up nearly 30% (by volume) of the substrate near station 3. In deepwater areas in the vicinity of the middle and outer shelf, the density of fragments was low—occasionally less than 50/m^2 or about 0.01% by volume. (All animal remains combined generally formed less than 1% by volume of the substrates of the outer shelf and slope.)

The distribution of *E. parma* extended from the shallow inshore areas across the entire shelf to the upper portion of the continental slope (Figure 4). Surprisingly, it was rather sparse near the middle of the shelf. Fragments from inshore areas were different in size, color, and sphericity from those collected offshore. Test fragments from the inshore zone, which extends out to 50 or 70 m, were whitish, usually larger than 5 mm in greatest dimension, and had sharp and angular edges and apexes (Figure 3A). Fragments from depths of about 80 m or more were greenish-brown, commonly less than 5 mm long, and had rounded edges. In contrast to the fresh, new appearance of the test fragments

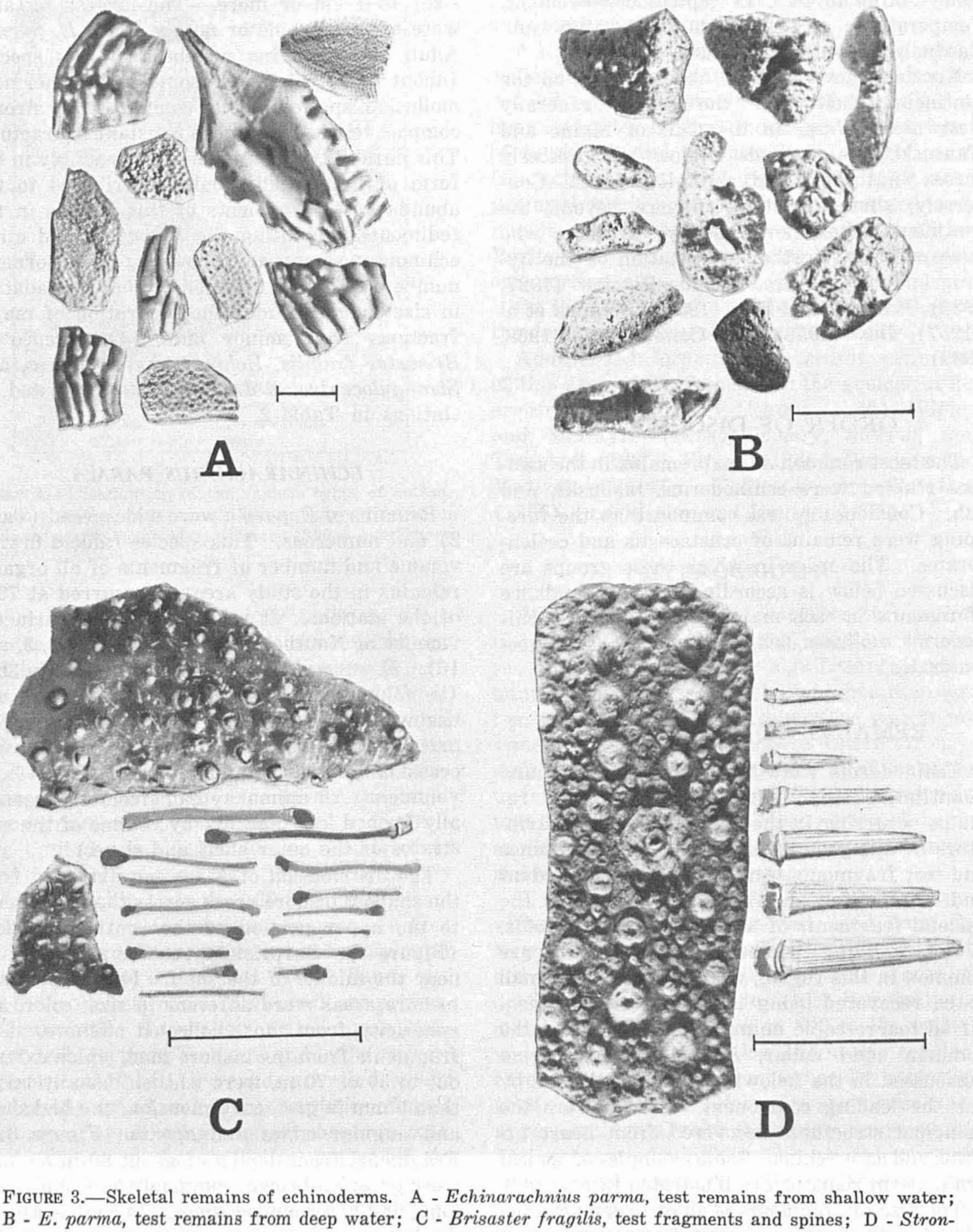

FIGURE 3.—Skeletal remains of echinoderms. A - *Echinarachnius parma*, test remains from shallow water; B - *E. parma*, test remains from deep water; C - *Brisaster fragilis*, test fragments and spines; D - *Strongylocentrotus drobachiensis*, test fragments and spines. Each scale bar is 5 mm.

TABLE 2.—Occurrence, by station, of the remains of three species of echinoderms. Present (+), absent (−).

Station number	*Echina rachnius parma*	*Brisaster fragilis*[1]	*Strongylo-centrotus drobachensis*
1	+	−	+
2	+	−	−
3	+	−	−
4	+	−	−
5	+	−	−
6	+	−	−
8	−	+	−
9	+	−	+
10	+	−	−
11	+	+	−
13	+	−	−
14	+	−	−
15	+	−	−
16	+	−	+
17	+	−	−
18	+	−	−
20	−	+	−
21	+	+	−
22	+	+	−
23	+	+	−
24	+	+	−
26	+	−	−
27	+	−	−
28	+	−	−
29	+	−	−
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35	+	+	−
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37	−	+	−
38	+	+	+
39	−	+	−
40	+	+	−
41	+	−	−
43	+	−	−
44	+	−	−
45	+	−	−
46	+	−	−
47	+	−	−
49	+	−	−
51	+	+	+
52	+	+	+
53	+	+	−
54	−	+	−
56	+	+	−
57	+	−	−
61	+	−	−
62	+	−	−
63	+	−	−

[1] May include some fragments of *Echinocardium* or *Schizaster*.

from the inshore zone, shells from deep water appeared old and worn (Figure 3B). The characteristics of specimens from the area between the two depth zones were intermediate.

OTHER SPECIES

Brisaster fragilis (Figure 3C) was distributed in a broad east-west band along the outer continental shelf and upper slope (Figure 5). The fragments were generally small and scattered. Even when all species are considered as a group, only a few spines or test fragments occurred in any one sample. Range in water depth for this echinoid was 90 to 366 m. Water depth range is compared with that of other species of echinoderms in Table 3 and illustrated in Figure 6.

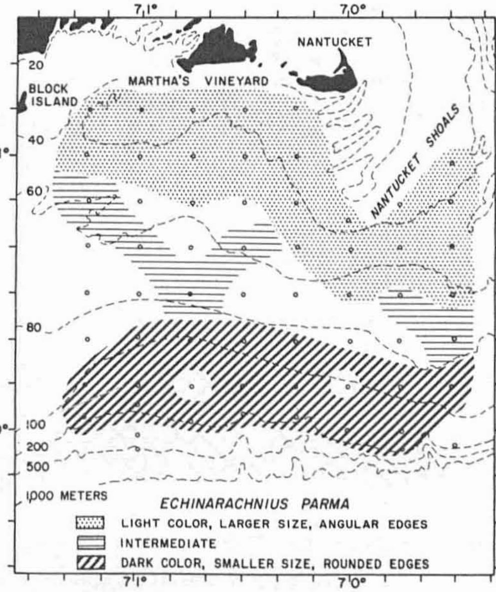

FIGURE 4.—Geographic distribution of remains of tests of *Echinarachnius parma*. Three categories of size, color, and sphericity are shown separately.

The green sea urchin, *Strongylocentrotus drobachiensis* (Figure 3D), was represented chiefly by spines and less commonly by test fragments. The remains were rather widely scattered among six stations; two were in the

TABLE 3.—Bathymetric distribution of three species of echinoderms and the number of stations at which each occurred.

Species	Water depth			Number of stations
	Minimum	Maximum	Mean	
	m	*m*	*m*	
Brisaster fragilis[1]	90	366	155	18
Echinarachnius parma	27	201	84	45
Strongylocentrotus drobachiensis	38	201	121	6

[1] May include some spines of *Echinocardium* and *Schizaster*.

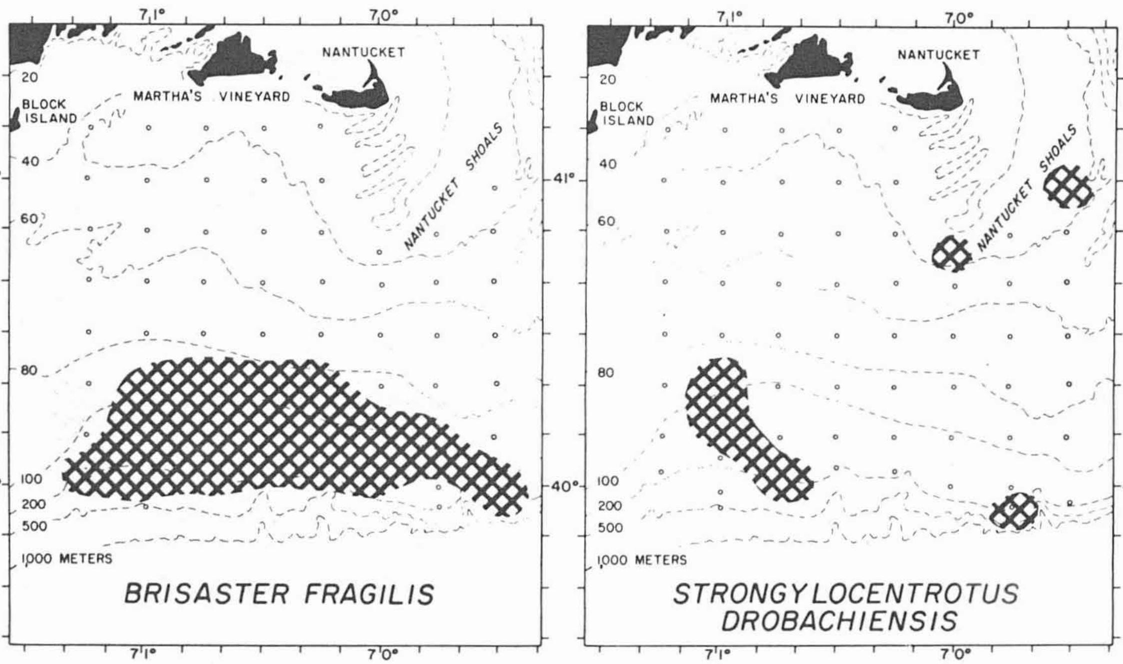

FIGURE 5.—Geographic distribution of skeletal remains of the echinoderms *Brisaster fragilis and Strongylocentrotus drobachiensis.*

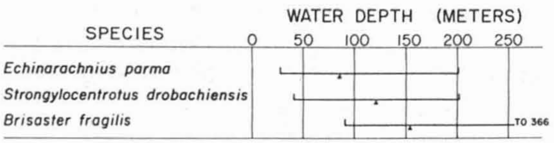

FIGURE 6.—Bathymetric range and mean depth of occurrence of echinoderm remains. (Mean values are listed in Table 3.)

shallow waters of Nantucket Shoals and the other four were in moderate to deep water near the shelf break (Figure 5). Bathymetric range at the locations where this species was found was from 38 to 201 m (Table 3, Figure 6).

REMAINS OF MOLLUSKS

Remains of mollusks were among the most common organic seabed constituents. In total abundance they ranked second; only the echinoderms were more plentiful. Four major groups of mollusks were represented in the material analyzed. Pelecypods were the most abundant molluscan group, gastropods ranked second, and the cephalopods and scaphopods were present in relatively small quantities. These groups are discussed below in the order of their abundance.

PELECYPODS

Pelecypod shells were abundant and conspicuous components of the prefossil animal remains. In addition to their relatively large size, often the color and texture of the shell surface contrasted sharply with the sediments in which they occurred. Size of the shells ranged from such large, robust species as *Spisula solidissima* (12 cm), *Arctica islandica* (10 cm), and *Placopecten magellanicus* (10 cm), to such small, fragile forms as *Thyasira gouldi, Nucula proxima, Bathyarca pectunculoides,* and others, all of which were 5 mm or less. A total of 57 species representing 40 genera were collected. Typical species are illustrated in Figure 7. Pelecypod remains were very widespread; they were collected at all stations except three (3, 47, and 62).

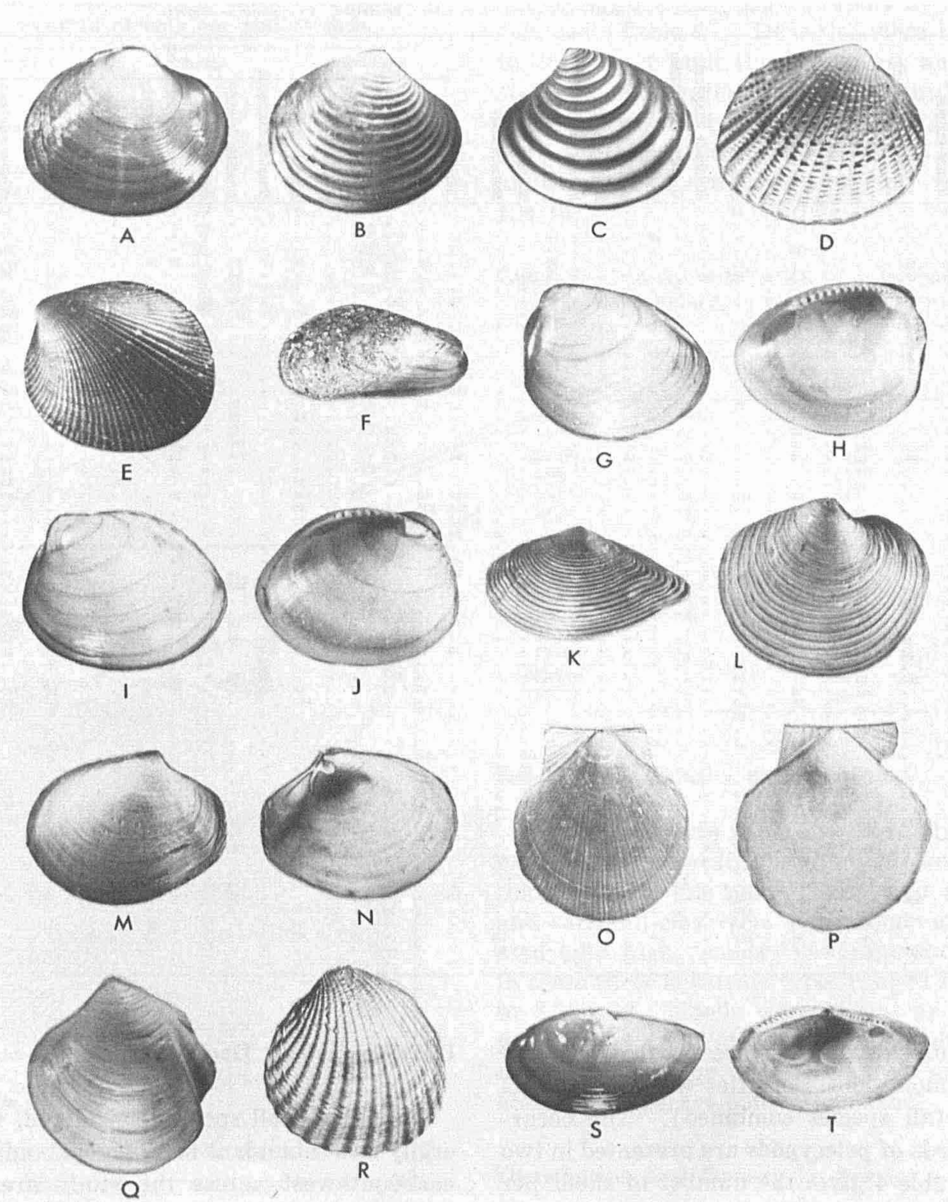

FIGURE 7.—Representative pelecypods from off southeastern Massachusetts. A - *Arctica islandica* (×0.7); B - *Astarte subequilatera* (×1); C - *Astarte undata* (×2); D - *Cerastoderma pinnulatum* (×2.6); E - *Crenella glandula* (×4); F - *Modiolus modiolus* (×0.7); G - *Nucula proxima* (×5); H - *Nucula proxima*, interior (×5); I - *Nucula tenuis* (×3.3); J - *Nucula tenuis*, interior (×3.3); K - *Nuculana acuta* (×4); L - *Phacoides filosus* (×2.6); M - *Periploma papyracea* (×2.6); N - *Periploma papyracea*, interior (×2.6); O - *Placopecten magellanicus*, left valve (×0.7); P - *Placopecten magellanicus*, right valve (×1); Q - *Thyasira trisinuata* (×3.3); R - *Venericardia borealis* (×1.3); S - *Yoldia sapotilla* (×2); T - *Yoldia sapotilla*, interior (×2).

Table 4.--Species and density (number per square meter), by station, of the common pelecypods.

Station number	Anomia aculeata	Arctica islandica	Astarte castanea	Astarte subequilatera	Astarte undata	Bathyarca pectunculoides	Cerastoderma pinnulatum	Crenella decussata	Crenella glandula	Cuspidaria perrostrata	Cyclopecten thalassinus	Ensis directus	Limatula subauriculata	Limopsis sulcata	Lyonsia hyalina	Mesodesma arctatum	Modiolus modiolus	Musculus niger	Nucula proxima	Nucula tenuis	Nuculana acuta	Pandora gouldiana	Periploma leanum	Periploma papyracea	Phacoides blakeensis	Phacoides filosus	Pitar morrhuana	Placopecten magellanicus	Spisula solidissima	Thyasira gouldi	Thyasira ovata	Thyasira plana	Thyasira trisinuata	Venericardia borealis	Yoldia sapotilla	Unidentified
1	20	-	150	-	-	-	-	-	10	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30
4	-	10	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	80	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-	40	10	-	60
6	30	160	10	1,560	-	-	-	-	110	-	10	-	-	-	-	30	-	-	-	10	-	10	-	30	-	90	-	30	30	-	-	-	150	2,120	160	60
8	30	-	-	30	10	70	110	-	50	10	20	-	-	-	-	-	-	-	-	-	170	-	-	-	-	90	-	-	-	-	-	100	20	10	90	160
9	70	-	-	-	110	-	-	-	-	-	-	-	40	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	10	-	-	-	-
10	10	-	-	100	660	20	-	-	-	-	-	-	-	40	-	-	-	-	10	-	160	-	-	-	-	250	20	-	-	-	-	-	20	200	30	-
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56	80	-	-	-	880	-	240	-	-	-	80	-	-	-	-	-	-	-	-	-	80	-	-	-	-	160	-	-	-	-	-	-	80	-	-	10
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60	-	20	60	-	390	-	30	-	170	-	-	-	-	-	-	-	-	10	-	-	-	30	-	50	-	-	-	-	70	-	240	-	30	120	70	-
61	-	10	-	10	70	-	10	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	30	-	80	30	60	-
63	-	-	50	-		-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	10	-	-	-	-	140	-	-

Members of this group were by far the most abundant mollusks. Densities were as high as 8,230/m² (all species combined). The occurrence records of pelecypods are presented in two tables: Table 4 gives the number of shells per square meter, by stations, for the 35 more common species and Table 5 lists the number of shells per square meter for each of the 22 species that occurred at only one station. Each pelecypod shell was counted separately. No attempt was made to enumerate the left and right valves separately, because of the fragmentary nature of many specimens.

Distribution and Density

Pelecypods, all species considered, were generally most abundant in a band extending northeast-southwest across the study area and in another narrower band parallel to the depth contours near the shelf break (Figure 8). Densities were frequently less in the northwest, northeast, and south-central sections of the continental shelf and along the continental slope. As expected, the density of the group was strongly influenced by a relatively few species that were both abundant and widely distributed.

TABLE 5.—Species and density, by stations, of pelecypods that occurred at only one station each.

Species	Station	Specimens
		No/m²
Abra longicallis	21	10
Aequipecten glyptus	10	10
Anadara ovalis	16	10
Axinopsis orbiculata	8	50
Bathyarca anomala	56	80
Crenella pectinula	33	20
Cuspidaria striata	8	20
Cyrtodaria siliqua	30	20
Liocyma fluctuosa	30	10
Macoma balthica	6	10
Modiolus demissus	46	10
Myonera limatula	8	10
Mytilus edulis	1	10
Nucula delphinodonta	11	10
Nuculana tenuisulcata	38	10
Panomya arctica	25	10
Periploma affinis	4	20
Siliqua costata	17	20
Solemya velum	4	10
Tellina agilis	29	10
Thracia conradi	13	40
Thracia myopsis	5	20

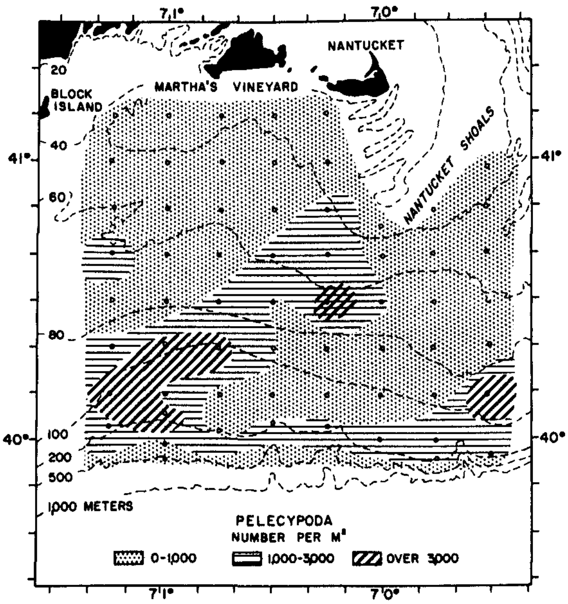

FIGURE 8.—Density distribution of pelecypod shells, all species combined.

Pelecypods were sparse (less than 50/m²) or absent at 8 stations, common (50 to 1,000/m²) at 32 stations, abundant (1,000 to 3,000/m²) at 16 stations, and very abundant (more than 3,000/m²) at 6 stations.

Pelecypod shells were present at all depths sampled (Table 6). Densities were lowest (30 to 40/m²) at both the shallowest and deepest stations; moderate (100 to 1,100/m²) between 30 and 89 m and between 200 and 249 m; high (greater than 1,100/m²) between 125 and 199 m; and highest (more than 2,000/m²) from 90 to 124 m.

TABLE 6.—Density distribution of pelecypod shells, all species combined, in relation to water depth.

Water depth class	Samples collected	Samples containing pelecypod shells	Mean number of shells
Meters	*Number*	*Percent*	*No/m²*
20-29	1	100	30
30-39	6	100	140
40-49	7	86	440
50-59	8	63	320
60-69	5	100	670
70-79	9	100	1,030
80-89	1	100	620
90-99	7	100	2,250
100-124	4	100	3,080
125-149	4	100	1,110
150-174	1	100	1,460
175-199	5	100	1,970
200-249	2	100	690
250-567	2	100	40

Relations of Density to Sediments

Pelecypods were generally more abundant in moderately fine-grained sediments than in either coarse or very fine types. Silty sand, sandy silt, and sand-silt-clay were most commonly associated with high density. Average shell density in these three substrate types ranged from 1,800 to 3,300/m². Shells were absent or sparse in gravel-sand substrates (average density 80/m²) and silts (average density 40/m²), and moderately low (average 650/m²) in sand.

Distribution and Density by Species

Geographic distributions of the 35 more common pelecypod species are illustrated in Figure 9. These charts are based on information listed in Table 4. No two species had identical distributions, but the distribution of a number of species in east-west bands across the study area suggests correlations with hydrographic features or bottom sediments, or both.

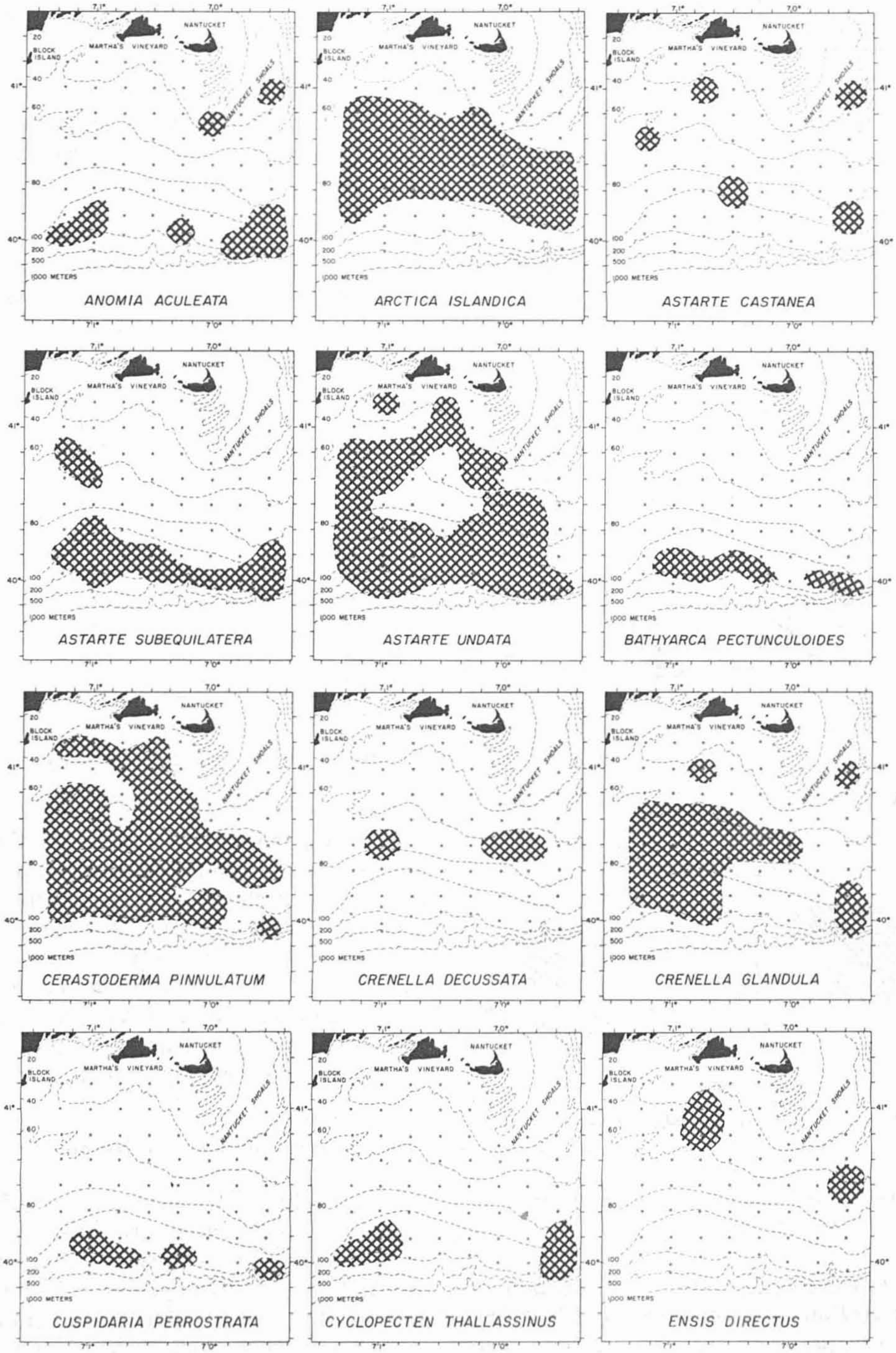

FIGURE 9.—Geographic distribution of the common pelecypods.

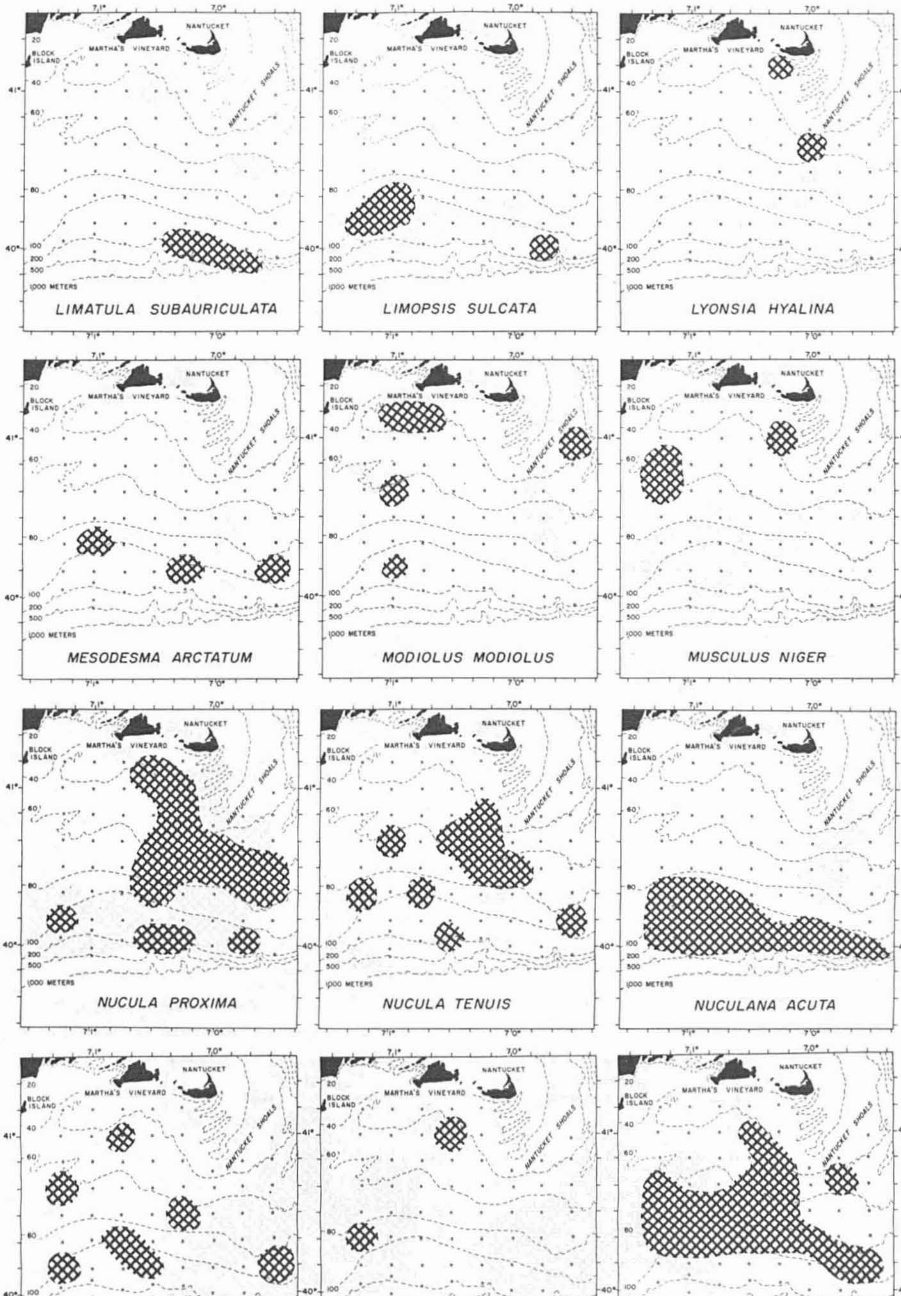

FIGURE 9.—Geographic distribution of the common pelecypods.—Continued.

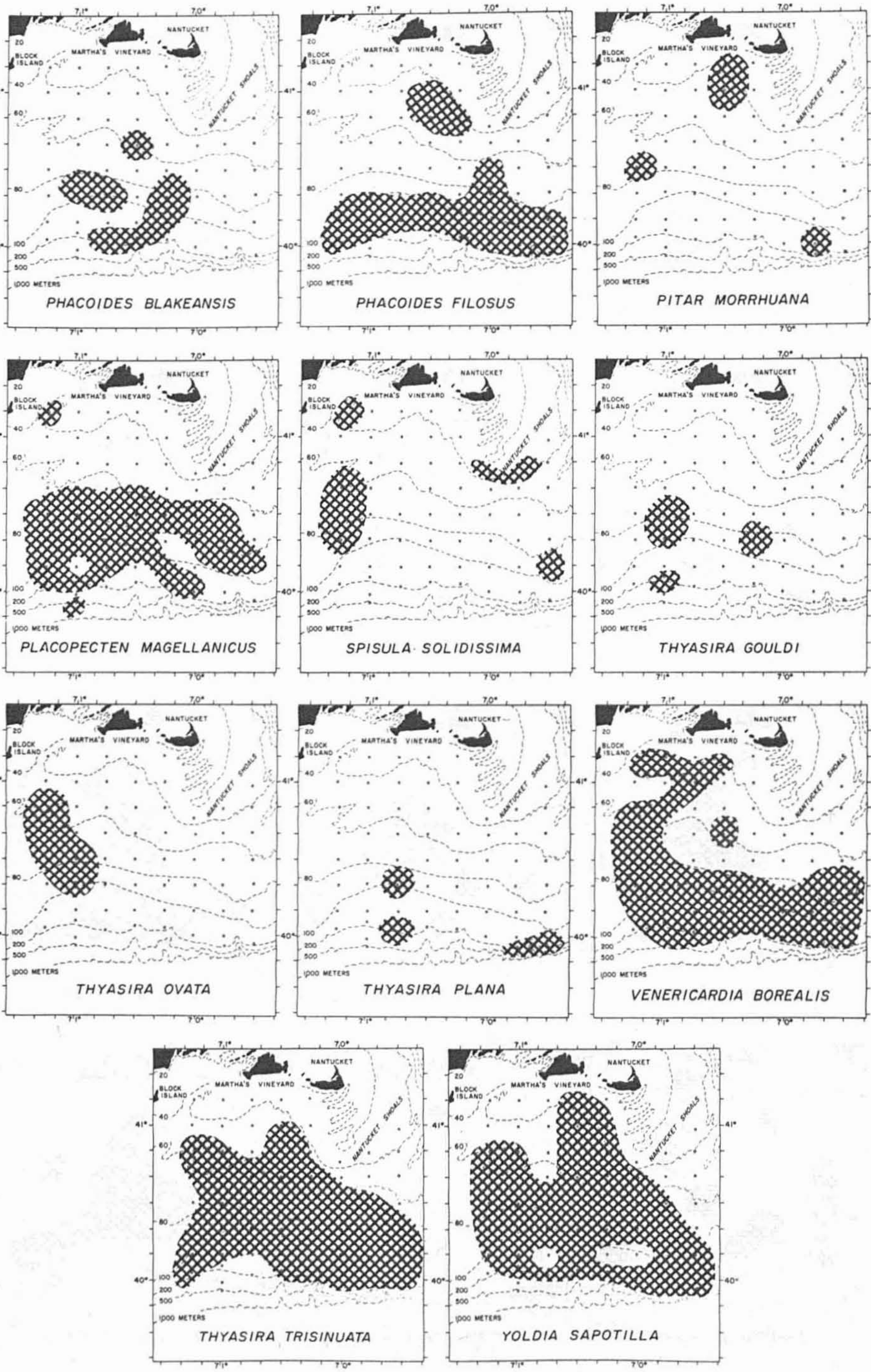

FIGURE 9.—Geographic distribution of the common pelecypods.—Continued.

The 10 most widely distributed species, in decreasing order, were: *Yoldia sapotilla, Cerastoderma pinnulatum, Astarte undata, Thyasira trisinuata, Venericardia borealis, Arctica islandica, Placopecten magellanicus, Phacoides filosus, Crenella glandula,* and *Nucula proxima.* All of these species inhabited rather broad east-west zones across the study area, except for *Nucula proxima,* which was absent in shallow water in the western sector. Its distribution was aligned in the north-south direction, and to some extent east-west.

Bathymetric distributions differed greatly among various pelecypod species. Depth range in which each species was found is listed in Table 7, and data for the most common species are plotted in Figure 10. Species dispersed over the widest depth range (38 to 567 m) were *Astarte undata* and *Placopecten magellanicus.* Depth ranges of 21 species were very narrow, but nearly all of these were based on few collections. Most of the species that occurred in two or more collections were taken over rather broad depth ranges.

Species found in shallow water (less than 50 m) were: *Anadara ovalis, Cyrtodaria siliqua, Liocyma fluctuosa, Lyonsia hyalina, Modiolus demissus, Mytilus edulis, Siliqua costata,* and *Tellina agilis.*

Species found in deep water (taken at depths greater than 200 m) were: *Anomia aculeata, Astarte subequilatera, A. undata, Cerastoderma pinnulatum, Limatula subauriculata, Nucula proxima, N. tenuis, Nuculana acuta, Phacoides blakeansis, P. filosus, Placopecten magellanicus, Thyasira plana, T. trisinuata, Venericardia borealis,* and *Yoldia sapotilla.*

Density of shells of individual pelecypod species ranged from 10/m² to 4,600/m² (Table 4). Densities tended to be high for the more widely distributed species and low for species with a restricted geographic distribution. Species found in greatest density were: *Venericardia borealis* —4,600/m², *Arctica islandica*—2,080/m², *Astarte subequilatera*—1,560/m², *Nucula proxima* —1,360/m², *Astarte undata*—1,440/m², and *Thyasira trisinuata*—1,160/m². All of these, except *Astarte subequilatera,* were among the 10 species with the widest geographic distribution. Among the species collected at 10 stations or less, few occurred in densities greater than

TABLE 7.—Bathymetric distributions of 57 species of pelecypods and the number of stations at which each occurred.

Species	Water depth			Number of stations
	Minimum	Maximum	Mean	
	m	*m*	*m*	
Abra longicallis	165	165	165	1
Aequipecten glyptus	139	139	139	1
Anadara ovalis	38	38	38	1
Anomia aculeata	38	201	139	10
Arctica islandica	44	110	75	27
Astarte castanea	38	97	64	6
Astarte subequilatera	62	366	152	15
Astarte undata	38	567	123	36
Axinopsis orbiculata	183	183	183	1
Bathyarca anomala	183	183	183	1
Bathyarca pectunculoides	128	194	164	7
Cerastoderma pinnulatum	38	220	96	38
Crenella decussata	73	84	77	3
Crenella glandula	46	194	99	20
Crenella pectinula	62	62	62	1
Cuspidaria perrostrata	146	194	177	5
Cuspidaria striata	183	183	183	1
Cyclopecten thallassinus	91	183	156	5
Cyrtodaria siliqua	38	38	38	1
Ensis directus	51	62	56	3
Limatula subauriculata	165	201	183	3
Limopsis sulcata	99	146	124	4
Liocyma fluctuosa	38	38	38	1
Lyonsia hyalina	27	49	38	2
Macoma balthica	91	91	91	1
Mesodesma arctatum	91	113	101	3
Modiolus demissus	40	40	40	1
Modiolus modiolus	38	146	68	5
Musculus niger	33	62	52	3
Myonera limatula	183	183	183	1
Mytilus edulis	46	46	46	1
Nucula delphinodonta	95	95	95	1
Nucula proxima	33	220	83	19
Nucula tenuis	44	220	88	10
Nuculana acuta	91	366	161	17
Nuculana tenuisulcata	194	194	194	1
Pandora gouldiana	51	110	88	7
Panomya arctica	70	70	70	1
Periploma affinis	62	62	62	1
Periploma leanum	48	91	70	2
Periploma papyracea	44	106	77	19
Phacoides blakeansis	62	220	126	7
Phacoides filosus	44	201	122	22
Pitar morrhuana	38	139	88	4
Placopecten magellanicus	38	567	116	25
Siliqua costata	49	49	49	1
Solemya velum	62	62	62	1
Spisula solidissima	37	91	62	7
Tellina agilis	27	27	27	1
Thracia conradi	73	73	73	1
Thracia myopsis	76	76	76	1
Thyasira gouldi	84	179	113	4
Thyasira ovata	62	99	77	5
Thyasira plana	106	201	171	4
Thyasira trisinuata	48	220	100	36
Venericardia borealis	38	366	116	33
Yoldia sapotilla	33	220	96	38

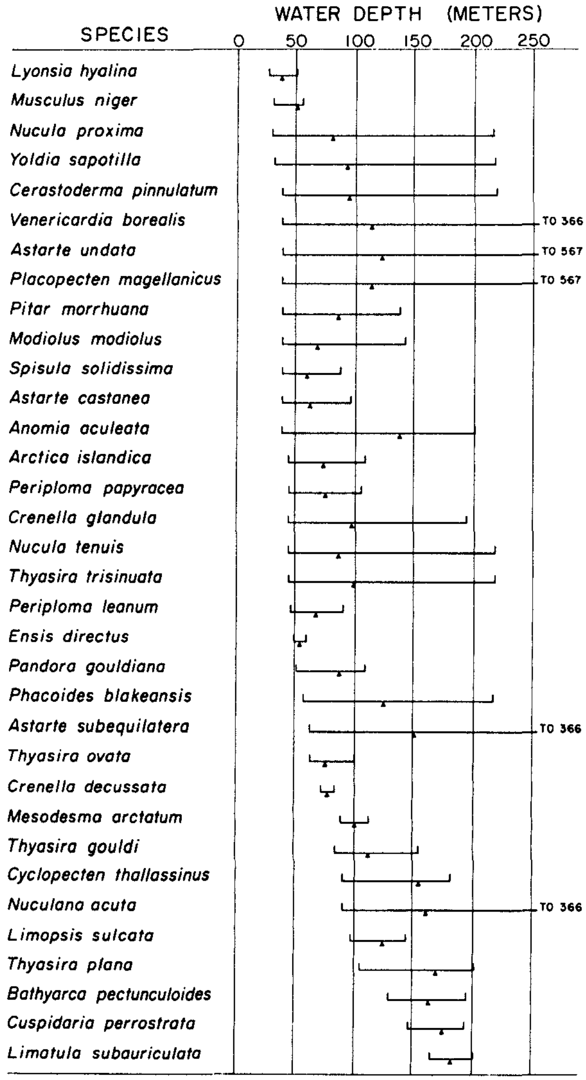

FIGURE 10.—Bathymetric range and mean depth of occurrence of the common pelecypods. (Observed values are listed in Table 7.)

500/m²; the maximum density for most of these species was less than 100/m².

Exceptions to the direct relation between high density and wide distribution were two types: (1) species widely distributed, but present in low density, such as *Cerastoderma pinnulatum*, *Crenella glandula*, *Placopecten magellanicus*, and *Yoldia sapotilla;* and (2) geographically restricted species of relatively high local densities, such as *Bathyarca pectunculoides* and *Thyasira ovata* (shells of these two species occurred at only seven and five stations each, but densities were as high as 300 and 430/m²).

Four patterns of geographic distribution revealed by these samples are: (1) Narrow band extending east-west across the area, such as: *Bathyarca pectunculoides, Crenella decussata, Cuspidaria perrostrata, Cyclopecten thallassinus, Limatula subauriculata, Mesodesma arctatum,* and *Nuculana acuta.* (2) Broad east-west band exemplified by: *Arctica islandica, Periploma papyracea, Placopecten magellanicus,* and *Thyasira trisinuata.* (3) Encircling distribution surrounding the center of the area, illustrated by *Astarte undata.* (4) Wide inshore-offshore distribution, as typified by: *Anomia aculeata, Cerastoderma pinnulatum, Crenella glandula, Nucula proxima, Venericardia borealis,* and *Yoldia sapotilla.*

Hydrographic conditions and the type of bottom sediments appear to have a substantial influence on the suitability of a habitat for some species of bivalves in this region. Unfortunately the common co-occurrence of fine-grained sediments in areas of low energy and relatively stable water temperature, as opposed to coarse sediments in high-energy and changeable water temperature does not lend itself to an evaluation of the specific conditions that limit the occurrence of the various species. Additionally, the presence of fossil shells invalidates a detailed evaluation of inferred habitat based on the presence of shell remains. For example, the shells of *Mesodesma arctatum* from depths of 91 to 113 m probably are remains of populations that inhabited nearshore areas during the rapid rise in sea level of the post-Pleistocene period. Radiocarbon age determinations for shells collected in this region at depths between 86 to 130 m, studied by Emery and Garrison (1967), range from 10,850 ± 150 to 14,850 ± 250 years before present.

Species that occurred in moderately deep waters and appeared to require a stenothermic habitat were: *Arctica islandica, Nuculana acuta, Thyasira plana,* and *Thyasira trisinuata* (Figure 9). Species that inhabited stenothermic waters, but also showed special sediment requirements, were: *Bathyarca pectunculoides, Cuspidaria perrostrata, Limatula subauriculata,* and *Thyasira gouldi.* Conversely, those bivalves that occurred in eurythermic habitats (and coarse sediments) were: *Ensis directus, Lyonsia hyalina,* and *Musculus niger.*

Relations of pelecypod distributions with bottom sediments are discussed below.

Species-Sediment Relations

Shells from 89% of the 35 more common pelecypod species represented in the area were found in several different sediment types; only 11% were associated exclusively with one sediment type. All of the common species were primarily in sediments in which sand or silt was the chief constituent. Species frequently taken in sand sediments were: *Ensis directus, Limatula subauriculata, Lyonsia hyalina,* and *Musculus niger.* Species most commonly found in silty sand and sand were: *Bathyarca pectunculoides, Cuspidaria perrostrata, Cyclopecten thallasinus, Limopsis sulcata, Nucula proxima, N. tenuis, Nuculana acuta, Pandora gouldiana, Phacoides filosus, Pitar morrhuana, Spisula solidissima. Thyasira plana,* and *Venericardia borealis.* The only two species found mainly in sandy silt or silty sand were *Limopsis sulcata* and *Thyasira gouldi.* The absence of *Astarte undata* in the center of the area is probably due to the presence of fine-grained sediments there. All the remaining common species were collected from several different sediment types.

The presence of a narrow band of sand extending parallel to the depth contours near the outer margin of the shelf (Figure 2) appears to be a major feature affecting the distribution of many species having a narrow-band distribution (Figure 9).

GASTROPODS

Remains of gastropods formed an important component of organic origin, but compared with other mollusks they were far less common than pelecypods, but considerably more abundant than scaphopods and cephalopods. Gastropods were widely distributed throughout the area and ranged in density (all species combined) from 0 to slightly over 1,000/m^2. All remains were shells, except for one operculum of *Polinices duplicata.*

Forty-four species of gastropods were found in the samples. Some typical examples are shown in Figure 11. A large majority of specimens were small, less than 1 cm in shell height. Some of the smallest specimens, averaging between 2 and 5 mm, were *Alvania carinata, Cylichna alba, Retusa obtusa,* and larval forms, presumably of *Thais.* The larger species, averaging between 1 and 5 cm in greatest dimension, were: *Buccinum undatum, Colus pygmaeus, Crucibulum striatum, Crepidula fornicata,* and *Nassarius trivittatus.*

Gastropod occurrence records are listed in Tables 8 and 9. Table 8 gives the species-station record for the 24 more common species. Table 9 lists the occurrence record for species taken at only one station.

Distribution and Density

Gastropod shells (all species combined) were rather widely distributed throughout the area, occurring at 80% of the stations. Highest concentrations (250 to 1,050/m^2) were in the central part of the area in a lens-shaped patch at depths between 40 and 80 m (Figure 12).

Although gastropod shells were collected at all depths, the average concentration increased in each 10-m depth class from 20 m down to about 80 m (Table 10). Concentrations were lower in deeper water, except for a zone of greater density between 175 and 250 m. *Alvania carinata* and *Cylichna gouldi* made up the bulk of the gastropod remains in the shallowwater zone: *Mitrella zonalis,* a gastropod larva, and a variety of species accounted for the high abundance in the deepwater zone.

Relations of Density to Sediments

The density of gastropod shells as a group was related to sediment type only in a rather general way. No gastropod shells were found in the coarse sand or gravel-sand substrates. Concen-

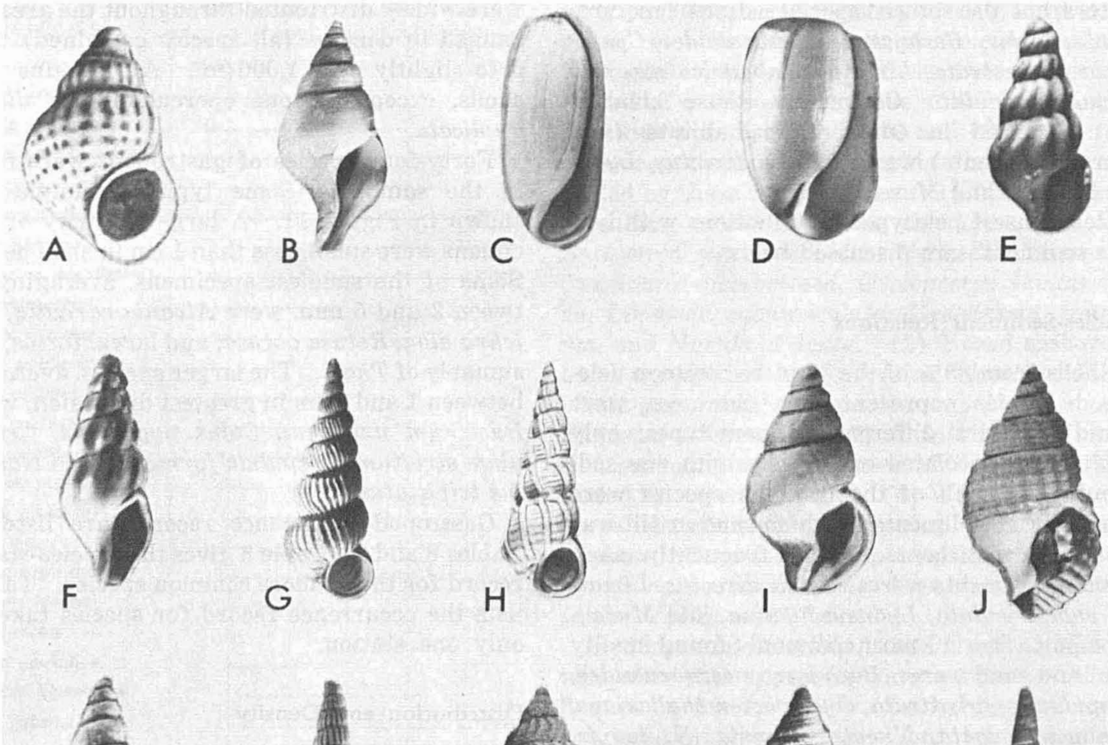

FIGURE 11.—Representative gastropods from off southeastern Massachusetts. A - *Alvania carinata* (×14); B - *Colus pygmaeus* (×1.5); C - *Cylichna alba* (×4); D - *Cylichna gouldi* (×11.7); E - *Drillia lissotropis* (×5.5); F - *Drillia* sp. (×4.7); G - *Epitonium dallianum* (×3); H - *Epitonium groenlandicum* (×0.8); I - *Mitrella zonalis* (×7); J - *Nassarius trivittatus* (×2.3); K - *Odostomia canaliculata* (×7); L - *Turbonilla interrupta* (×4.7); M - *Buccinum undatum* (×1); N - *Neptunea decemcostata* (×0.8); O - *Eulimella smithi* (×2.3); P - *Polinices duplicata* (×1); Q - *Crepidula fornicata* (×0.8); R - *Crepidula fornicata* (×0.8).

Table 8.--Species and density (number per square meter), by station, of the common gastropods.

Station number	*Alvania carinata*	*Anachis costulata*	*Balcis intermedia*	*Buccinum undatum*	*Colus pygmaeus*	*Crepidula fornicata*	*Crucibulum striatum*	*Cylichna alba*	*Cylichna gouldi*	*Drillia lissotropis*	*Epitonium dallianum*	*Epitonium novangliae*	*Lunatia levicula*	*Mitrella zonalis*	*Mitrella* sp.	*Nassarius trivittatus*	*Odostomia canaliculata*	*Polinices duplicata*	*Rissoa* sp.	Trochidae	*Turbonilla interrupta*	*Turbonilla* sp.	Gastropod larva	Unidentified
4	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	-	-	-	-	-
6	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-
8	20	-	20	-	-	-	-	20	-	-	-	10	-	50	-	-	10	-	-	-	-	-	-	-
9	-	30	-	-	-	-	-	-	-	10	40	-	-	-	-	-	-	-	-	-	50	-	10	-
10	-	-	10	-	-	-	-	-	-	-	10	-	-	20	-	-	-	-	-	10	40	10	-	-
11	60	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	20	-	-	-	-	20	-	-	20	-	-	-	-	-	-	-
13	-	-	-	-	60	-	-	-	10	-	-	-	-	-	-	-	10	-	30	-	-	-	-	-
14	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-
15	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	40	-	10	-	-	-	-	-	-
17	-	-	-	-	40	-	-	10	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-
18	200	-	-	-	10	-	-	-	100	-	-	-	-	40	-	-	30	-	-	-	10	-	10	20
19	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	10	-
20	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	10	-	-	-	-	-	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	10	-
22	-	-	-	-	-	-	-	10	-	-	10	-	-	10	-	-	10	-	-	-	10	-	20	-
23	20	-	-	-	-	-	-	-	-	20	-	-	-	10	-	-	-	-	-	-	50	-	10	-
24	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	630	-	-	-	10	-	-	-	410	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	530	-	-	-	-	-	-	20	-	-	-	-	-	10	-	-
27	-	-	-	-	-	10	-	-	70	-	-	-	-	-	-	130	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-
30	-	-	-	-	20	-	-	-	10	-	-	-	-	-	-	50	-	10	-	-	-	-	-	-
31	-	-	-	-	20	10	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	90	-	-	10	-	-	-	-	40	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
33	600	-	-	-	10	-	-	-	150	-	-	-	-	20	-	10	-	-	-	-	-	-	-	-
34	40	-	-	-	-	-	-	-	40	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-
35	80	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	20	-
36	50	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	10	-	-	-	-	-	30	-
37	10	-	-	-	-	-	-	10	-	-	-	-	-	10	-	-	10	-	-	-	-	-	30	-
38	10	-	-	-	-	-	-	10	-	10	30	-	-	20	10	-	-	-	10	-	10	-	-	-
40	20	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	10	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	30	10	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	80	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-
51	10	-	-	-	-	-	-	-	-	-	10	-	-	10	-	-	-	-	-	-	-	-	-	10
52	-	-	10	10	-	-	10	-	-	-	30	-	-	-	-	-	20	-	-	-	10	-	-	-
53	10	-	-	-	-	-	-	10	-	-	20	-	-	30	10	-	-	-	-	-	-	-	-	10
54	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	30	-
55	-	10	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	10	-	-	40	-
56	-	-	-	-	-	-	-	-	-	10	-	-	-	10	-	-	-	-	-	-	20	-	-	-
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60	-	-	-	-	-	-	-	10	-	-	-	-	-	10	-	-	-	-	10	-	-	-	-	-
61	10	-	-	-	10	-	-	30	10	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
62	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	20	-	-	-	-	-	-	-	-

trations were high in silty sand in some areas but were intermediate or low in other locations at similar depths. Densities of gastropod shells were high, intermediate, and low in sand, with no apparent correlation.

Distribution and Density by Species

The geographic distributions of the 24 most common forms of gastropods are shown in Figure 13. These charts are based on the data in

TABLE 9.—Species and density, by station, of gastropods that occurred at only one station each.

Species	Station	Specimens
		No/m²
Alvania janmayeni	55	20
Calliostoma occidentalis	23	20
Calliostoma sp.	53	10
Cavolina longirostris	51	10
Cavolina tridentata	53	20
Epitonium groenlandicum	52	10
Epitonium multistriatum	23	30
Eulimella smithi	37	10
Eulimella sp.	6	20
Eupleura caudata	29	10
Fossarus elegans	52	10
Lunatia heros	1	10
Mitrella lunata	27	10
Neptunea decemcostata	31	10
Odostomia gibbosa	1	40
Pseudorotella solida	38	40
Pyramidella sp.	21	10
Retusa obtusa	5	40
Solariella iris	9	30
Taranis cirrata	9	10
Turrtellopsis acicula	37	10

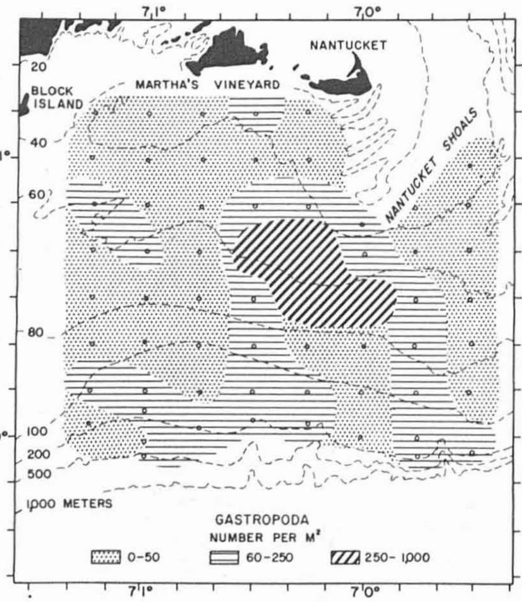


FIGURE 12.—Density distribution of gastropod shells, all species combined.

Table 8. Species with a wide geographic distribution were, in decreasing order: *Alvania carinata, Mitrella zonalis, Cylichna gouldi, Colus pygmaeus, Odostomia canaliculata, Epitonium*

TABLE 10.—Density distribution of gastropod shells, all species combined, in relation to water depth.

Water depth	Samples collected	Samples containing gastropod shells	Mean number of shells
Meters	*Number*	*Percent*	*No/m²*
20-29	1	100	10
30-39	6	83	35
40-49	7	71	84
50-59	8	63	96
60-69	5	100	190
70-79	9	89	221
80-89	1	0	0
90-99	7	100	51
100-124	4	100	72
125-149	4	75	80
150-174	1	100	60
175-199	5	100	102
200-249	2	100	140
250-567	2	100	65

dallianum, Cylichna alba, Nassarius trivittatus, and *Turbonilla interrupta.*

Four patterns of geographical distribution are revealed: (1) The most common is a relatively narrow east-west band across the area in either shallow or deep water, typified by *Balcis intermedia, Crepidula fornicata, Drillia lissotropis, Epitonium dallianum,* and others. (2) Comparatively broad east-west bands across the area are illustrated by *Mitrella zonalis* and *Turbonilla interrupta.* (3) Peripherial occurrence around the fine-grained bottom sediments located in the center of the area is illustrated by *Cylichna alba, Odostomia canaliculata,* and to some extent by *Rissoa* sp. (4) Distribution in the central part of the area, a pattern nearly opposite that of peripheral distribution (pattern number 3), is illustrated by *Alvania carinata.*

Bathymetric range differed markedly among species. The minimum, maximum, and mean depth of occurrence for each species is listed in Table 11 and illustrated for the more common species in Figure 14. *Mitrella zonalis* was the only species taken over a wide range of water depths (62 to 567 m). Species that had a moderately wide depth range were: *Buccinum undatum, Cylichna alba, Epitonium novangliae, Odostomia canaliculata,* and *Rissoa* sp.

Species found in shallow water—those restricted to depths of 50 m or less—were: *Crepidula fornicata, Eupleura caudata, Lunatia her-*

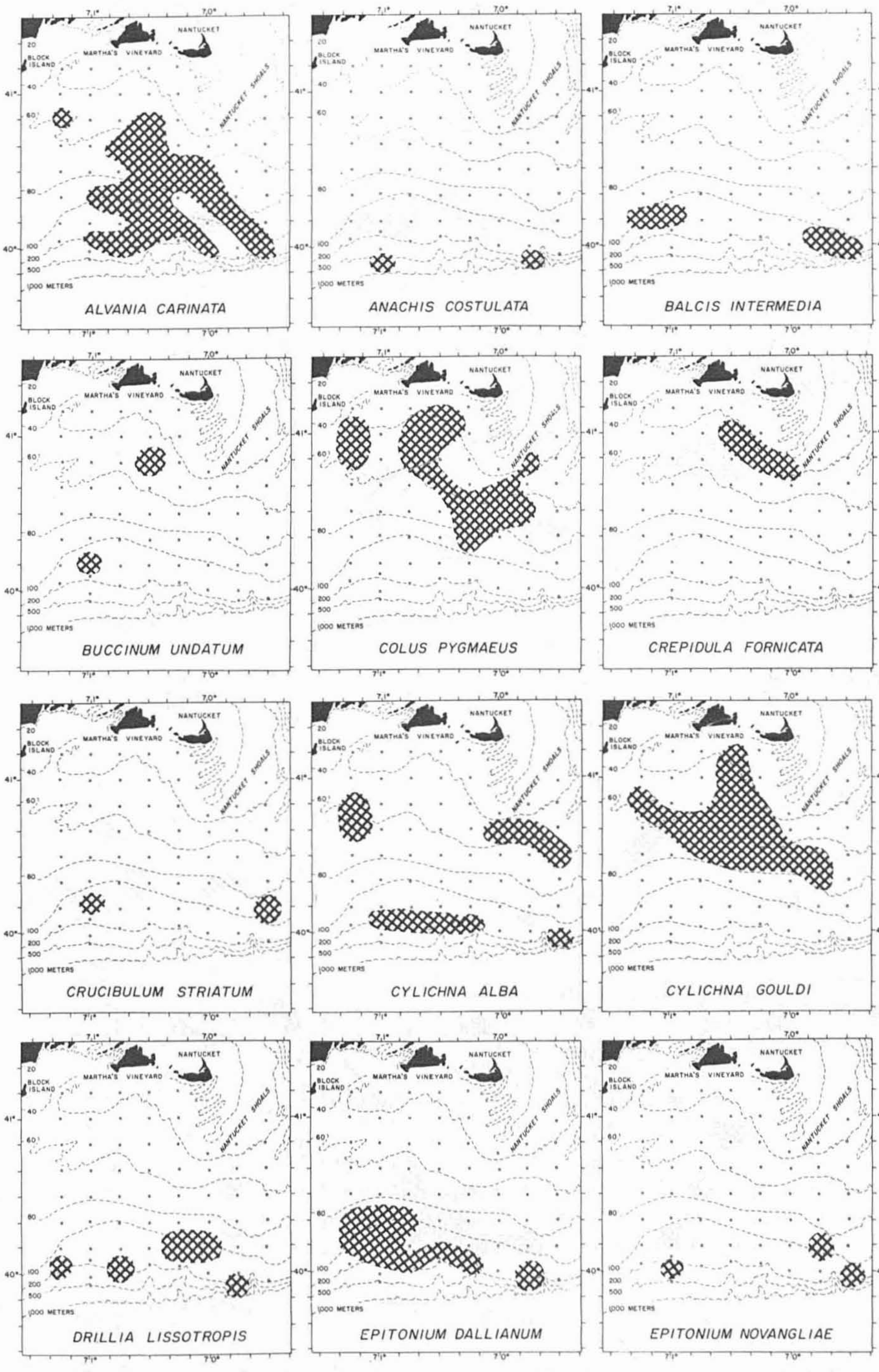


FIGURE 13.—Geographic distribution of the common gastropods.

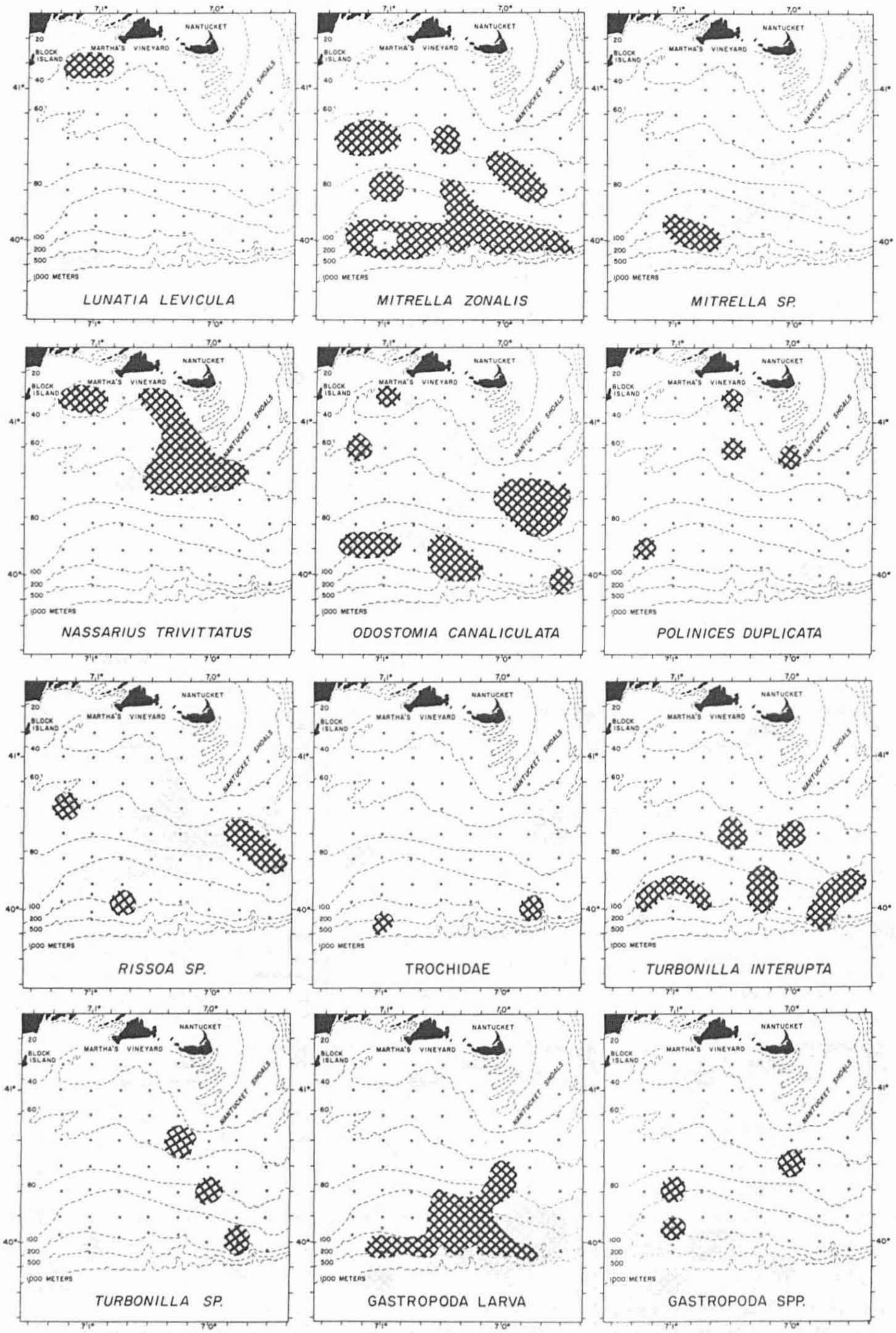


FIGURE 13.—Geographic distribution of the common gastropods.—Continued.

TABLE 11.—Bathymetric distributions of 44 gastropods and the number of stations at which each occurred.

Species	Water depth Minimum	Water depth Maximum	Water depth Mean	Number of stations
	m	m	m	
Alvania carinata	59	220	112	19
Alvania janmayeni	567	567	567	1
Anachis costulata	201	567	384	2
Balcis intermedia	110	183	144	4
Buccinum undatum	59	146	102	2
Calliostoma occidentalis	113	113	113	1
Calliostoma sp.	179	179	179	1
Cavolina longirostris	99	99	99	1
Cavolina tridentata	179	179	179	1
Colus pygmaeus	37	90	58	13
Crepidula fornicata	38	48	43	3
Crucibulum striatum	91	146	118	2
Cylichna alba	49	220	125	10
Cylichna gouldi	38	79	63	15
Drillia lissotropis	113	201	162	5
Epitonium dallianum	91	201	143	11
Epitonium groenlandicum	146	146	146	1
Epitonium multistriatum	113	113	113	1
Epitonium novangliae	95	366	215	3
Eulimella smithi	220	220	220	1
Eulimella sp.	91	91	91	1
Eupleura caudata	27	27	27	1
Fossarus elegans	146	146	146	1
Lunatia heros	46	46	46	1
Lunatia levicula	38	40	39	2
Mitrella lunata	44	44	44	1
Mitrella zonalis	62	567	157	17
Mitrella sp.	179	194	186	2
Nassarius trivittatus	33	62	45	10
Neptunea decemcostata	48	48	48	1
Odostomia canaliculata	40	220	113	12
Odostomia gibbosa	46	46	46	1
Polinices duplicata	38	110	61	4
Pseudorotella solida Dall	194	194	194	1
Pyramidella sp.	165	165	165	1
Retusa obtusa	76	76	76	1
Rissoa sp.	62	194	101	4
Solariella iris	201	201	201	1
Solariella sp.	139	139	139	1
Taranis cirrata	201	201	201	1
Turbonilla interrupta	73	201	140	10
Turbonilla sp.	51	139	70	3
Turrtellopsis acicula	220	220	220	1
Gastropod larva[1]	73	567	200	11

[1] Only one species appeared to be represented—possibly a *Thais*.

os, *L. levicula, Mitrella lunata, Neptunea decemcostata,* and *Odostomia* sp.

Species taken only in deep water—those restricted to depths greater than 200 m—were: *Alvania janmayeni, Anachis costulata, Eulimella smithi, Taranis cirrata,* and *Turrtellopsis acicula.* All these species were taken at only one station, except *Anachis costulata,* which occurred at two stations.

Shells of individual species of gastropods generally occurred at low or moderately low densities. Only three were found in high or moderately high concentrations: *Alvania carinata* ($630/m^2$), *Cylichna gouldi* ($530/m^2$), and *Nassarius trivittatus* ($130/m^2$). The density of other gastropods (41 species) was $60/m^2$ or less.

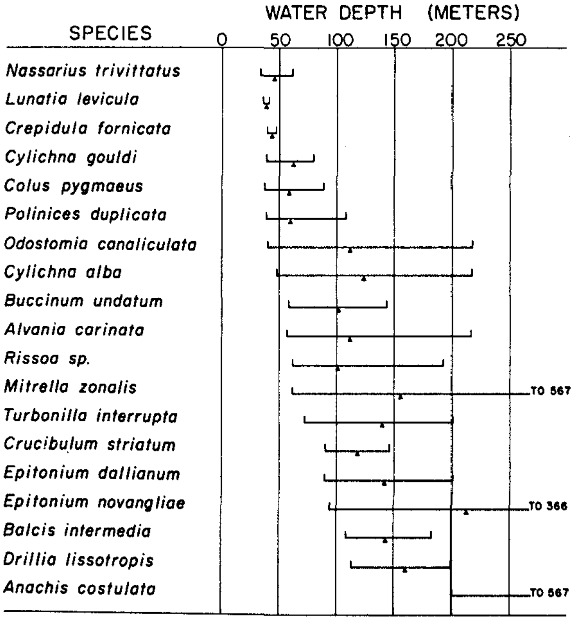


FIGURE 14.—Bathymetric range and mean depth of occurrence of the more common gastropod species. (Observed values are listed in Table 11).

Species-Sediment Relations

The majority of gastropod species occurred in sand and silty sand. None was in coarse sand or gravel-sand substrates, and none appeared to be restricted to silt. Widely distributed species generally occurred in a variety of sediment types ranging from medium sand to silt. A few species were associated with specific sediment types. Gastropods found chiefly in sand substrates were: *Colus pygmaeus, Crepidula fornicata, Cylichna alba, Lunatia levicula, Nassarius trivittatus,* and *Odostomia canaliculata.* The only species found principally in fine-grained sediments was *Epitonium dallianum;* it was mainly in silty sand.

CEPHALOPODS AND SCAPHOPODS

Remains of cephalopods and scaphopods were found in moderate to low densities, were small, and occurred in a relatively limited area. Only a few species of each group were represented in the samples. Illustrations of typical examples are shown in Figure 15.

Cephalopod remains consisted solely of beaks (jaws or mandibles) of Decapoda (squid). All were black and 4 to 6 mm long. The animals from which the beaks came were adults and probably rather small (less than about 10 cm in mantle length). Their uniformity in configuration and size suggests that only one or a few species are represented.

Scaphopod remains consisted only of shells or fragments of shells of a few species of the genus *Dentalium* (15 to 35 mm long) and one species of the genus *Cadulus* (mostly 10 to 13 mm long). Many *Dentalium* shells were inhabited by Sipunculida, whereas *Cadulus* shells were empty. Unbroken shells recovered from the samples included few of the thin-walled *Cadulus* but larger numbers of the thick-walled *Dentalium*.

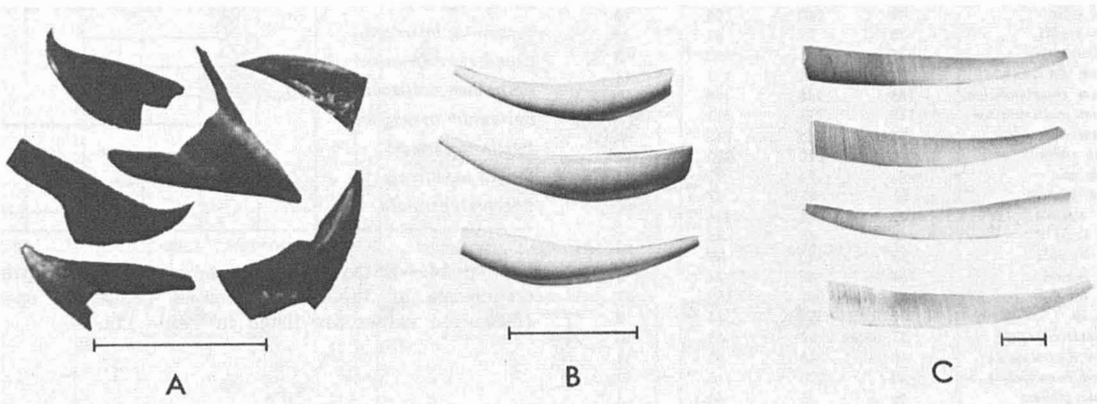


FIGURE 15.—Cephalopod mandibles and scaphopod shells from off southeastern Massachusetts. A - cephalopod beaks; B - shells of *Cadulus pandionis*; C - shells of *Dentalium* spp. Each scale bar is 5 mm.

TABLE 12.—Density of cephalopod beaks and scaphopod shells, by stations.

Station	Cephalopods[1]	Scaphopods: *Cadulus pandionis*	Scaphopods: *Dentalium* spp.
	No/m²	*No/m²*	*No/m²*
5	10	--	--
6	--	--	--
8	40	--	20
9	--	80	--
10	10	10	--
11	10	--	--
21	30	--	20
22	--	20	20
23	20	--	110
36	20	--	--
37	40	110	--
51	--	--	40
53	20	60	10
54	130	10	--
55	110	--	--
56	10	--	--
57	--	--	10

[1] Remains of mandibles.

Distribution and Density

The distribution of cephalopod and scaphopod remains was somewhat limited geographically and densities were low. Quantitative occurrence records for both groups (Table 12), geographic distributions (Figures 16 and 17), and depth of water inhabited (Table 13), disclose that both groups occur primarily in deep water, only on the continental slope and outer part of the shelf.

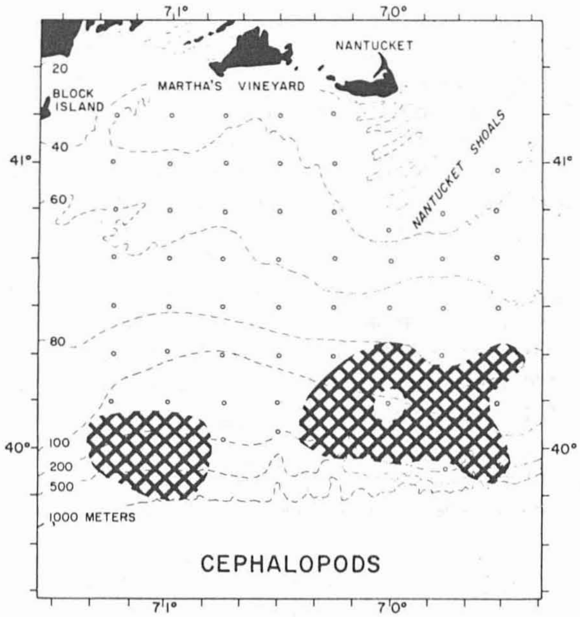


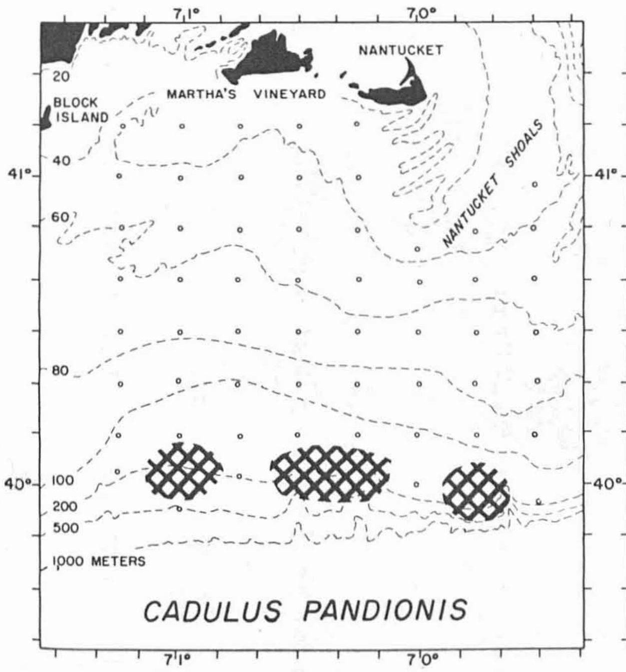
FIGURE 16.—Geographic distribution of cephalopod beaks.

Cephalopod beaks were present at 12 stations, at a depth range of 76 to 567 m. Their average density was 38/m², and maximum density 130/m². Highest densities were at the deepest stations sampled, stations 54 and 55, where water depths were 366 and 567 m.

Scaphopod shells were collected at 11 stations. *Cadulus pandionis* was present only on the continental slope at depths between 139 and 366 m. Average density at the six stations where it occurred was 41/m² and maximum density was 110/m². *Dentalium* spp. occurred along the continental shelf margin at depths of 91 to 183 m.

TABLE 13.—Bathymetric distribution of cephalopod beaks and scaphopod shells and the number of stations at which each occurred.

Species	Water depth			Number of stations
	Minimum	Maximum	Mean	
	m	*m*	*m*	
Cephalopods	76	567	201	12
Scaphopods				
Cadulus pandionis	139	366	213	6
Dentalium spp.	91	183	134	7



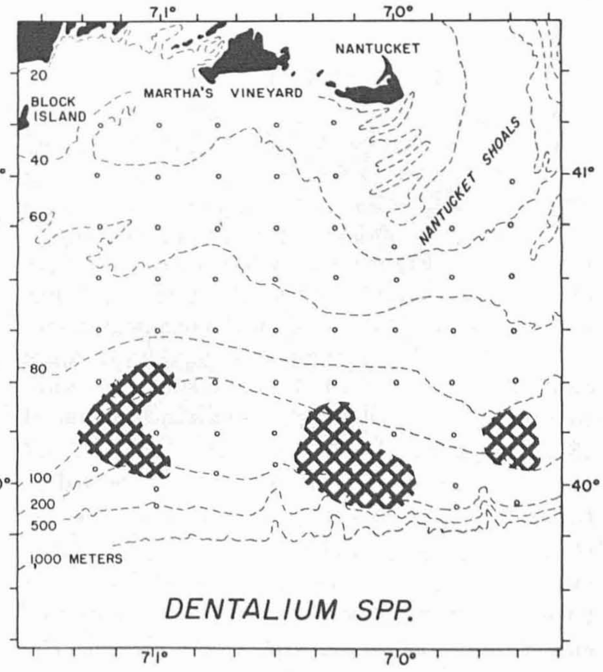


FIGURE 17.—Geographic distribution of shells of the scaphopods, *Cadulus pandionis* and *Dentalium* spp.

Average density at seven stations was 33/m², and maximum density was 110/m².

Relations with Sediments

The kinds of cephalopods that are abundant in this region are pelagic and their occurrence would not ordinarily be expected to be directly related to substrate composition. The fate of the remains of these animals that drop to the ocean floor may depend indirectly on sediment type because these species generally occur in deep or moderately deep water. Cephalopod remains were absent in coarse sand or gravel. Densities were moderate (10 to 40/m²) exclusively in silt.

Cadulus and *Dentalium* remains also were found only in fine-grained sediments; fine sand, silty sand, sandy silt, and silt. No areas of coarse sand, gravel, or mixtures of the two yielded scaphopod shells. A large majority were in areas where the sediments are fine sand and silty sand. *Cadulus* was densest in fine sand, and *Dentalium* in silty sand.

REMAINS OF FISH

Vertebrate remains in the bottom sediments were represented exclusively by fish otoliths and small numbers of bones, teeth, and scales (Table 14). Some examples of typical otoliths are illustrated in Figure 18. Otoliths were rather broadly distributed over much of the area but were particularly common in the deepwater section. The otolith density was strikingly high, 3,020/m², near the shelf break south of Nantucket Shoals. All samples combined included 18 genera and at least 26 species of fish; all but one were identified from otoliths. A record of the otoliths of each species recovered at different stations is given in Table 15. Eleven of the species are bottom-dwelling types, and 11 are epipelagic or mesopelagic (Table 16). Three species, *Merluccius albidus, M. bilinearis,* and *Peprilus triacanthus*, represented by otoliths range widely from the sea bottom to upper water levels; they remain unclassified for the purposes of this discussion. Clupeoids, scombroids, and other common pelagic groups were lacking. The collections included many more otoliths from pelagic species (1,288), however, than from groundfish (141); the average otolith density (based only on samples containing one or more otoliths), of pelagic species was 379/m², compared with 41/m² for groundfish. All fish remains were less than 2 cm in greatest dimension, and most were less than 3 mm. The sizes of fish from which these remains came ranged from lanternfish only a few centimeters long to sharks estimated to be 2 to 3 m long.

TABLE 14.—Density of fish remains[1], all species combined, by stations.

Station number	Otoliths	Bones
	No/m²	*No/m²*
4	10	--
5	10	--
6	30	--
8	3,020	--
9	1,250	--
10	360	10
11	10	20
12	10	--
13	--	10
16	--	10
17	10	--
18	--	10
20	20	--
21	760	10
22	2,200	10
23	170	40
24	--	10
25	--	30
27	30	10
31	10	--
33	10	--
34	10	10
35	40	10
36	30	10
37	1,460	80
38	1,270	--
39	150	10
40	20	10
41	20	20
50	--	60
51	50	10
52	50	--
53	830	--
54	870	40
55	580	--
56	1,380	--
57	60	10
58	10	--
59	10	--
61	10	--

[1] Scales occurred only at stations 11, 17, and 40 (10 to 20/m²) and teeth only at stations 53 and 54 (20 to 30/m²).

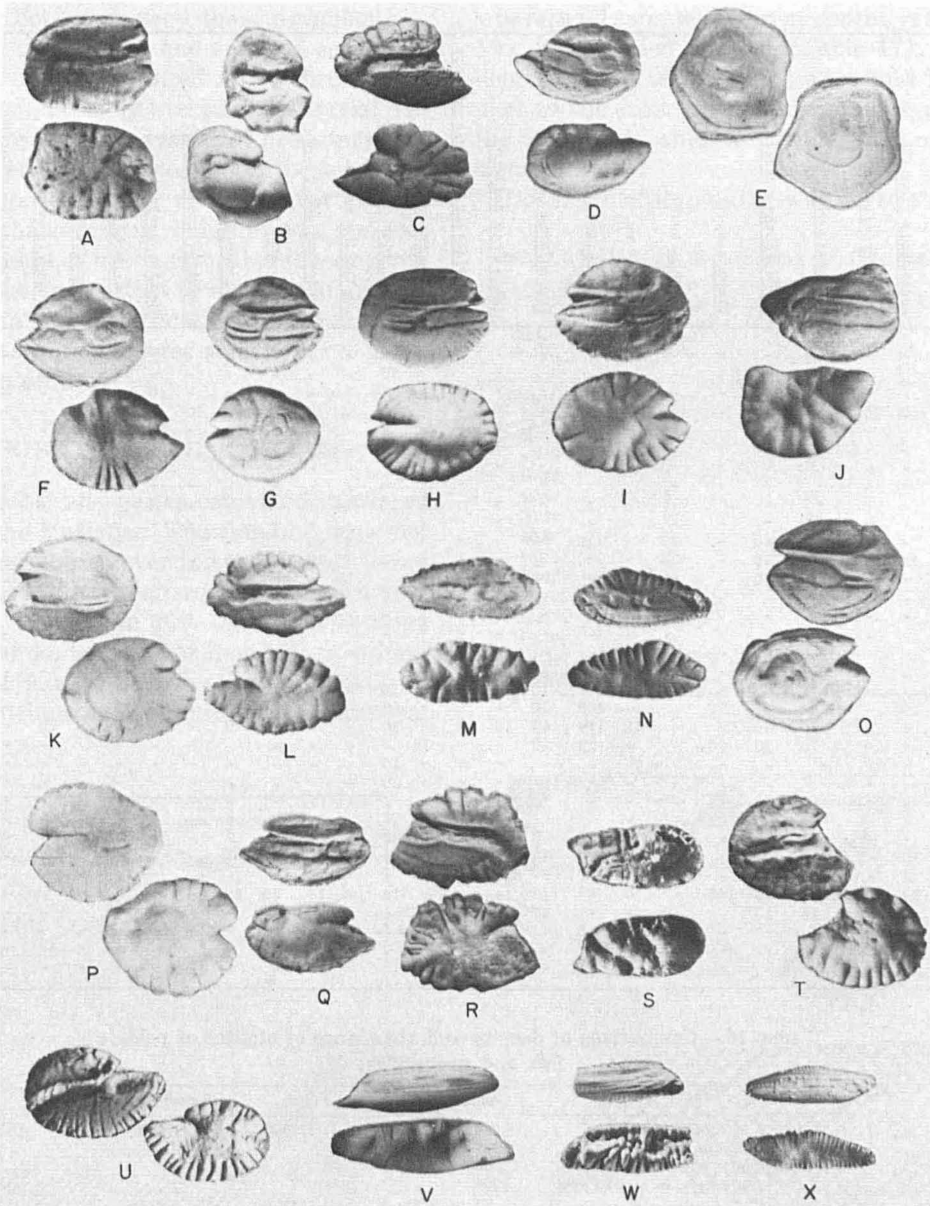


FIGURE 18.—Representative teleost otoliths from off southeastern Massachusetts. Inner face of otolith above, outer face below. A - Acanthuroidei sp.-1 (×10); B - *Benthosema glaciale* (×6.5); C - *Centropristis ocyurus* (×8); D - *Ceratoscopelus maderensis* (×4.5); E - *Citharichthys ?arctifrons* (×9); F - *Diaphus* sp.-1 (×2); G - *Diaphus* sp.-2 (×4.5); H - *Diaphus* sp.-3 (×4); I - *Diaphus* sp.-4 (×6.5); J - *Lepophidium cervinum* (×5.2); K - *Lobianchia dofleini* (×7); L - *Lopholatilus chamaeleonticeps* (×2.5); M - *Merluccius albidus* (×4.5); N - *Merluccius bilinearis* (×2); O - *Myctophum punctatum* (×4.5); P - *Myctophum* sp. (×6.5); Q - *?Notoscopelus* (×3.2); R - *Peprilus triacanthus* (×4.5); S - *Phycis chesteri* (×5.8); T - *Pomacanthus arcuatus* (×10); U - *"Stromateus"* (×5.8); V - *Urophycis chuss* (×2); W - *Urophycis ?floridanus* (×2); X - *Urophycis tenuis* (×1.3).

Table 15.--Species and density (number per square meter) of fish otoliths, by station.

Station number	Acanthuroidei sp.-1	Acanthuroidei sp.-2	Benthosema glaciale	Centropristis ocyurus	Ceratoscopelus maderensis	Citharichthys ?arctifrons	Diaphus sp.-1	Diaphus sp.-2	Diaphus sp.-3	Diaphus sp.-4	Lepophidium cervinum	Lobianchia dofleini	Lopholatilus chamaeleonticeps	Merluccius albidus	Merluccius bilinearis	Merluccius sp.	Myctophum punctatum	Myctophum sp.	?Notoscopelus	Peprilus triacanthus	Phycis chesteri	Pomacanthus arcuatus	"Stromateus"	Urophycis chuss	Urophycis ?floridanus	Urophycis tenuis	Urophycis sp.	Unidentified fragments
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	+
8	-	-	40	20	2,160	130	-	180	-	270	40	10	-	-	40	-	-	120	-	10	-	-	-	-	-	-	-	-
9	-	-	-	-	650	-	-	30	-	440	10	10	-	-	-	-	10	80	-	-	10	-	-	-	-	10	-	-
10	-	-	-	-	220	20	-	-	-	30	50	-	-	-	20	-	10	10	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	520	40	-	20	-	110	40	-	-	-	-	-	10	20	-	-	-	-	-	-	-	-	-	-
22	-	-	10	-	1,480	110	-	20	-	330	80	-	-	-	60	-	10	70	10	-	-	-	-	10	-	10	-	-
23	-	-	-	-	40	50	-	-	-	-	30	-	10	-	-	20	-	-	-	-	-	-	-	10	10	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	10	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-
35	-	-	-	-	-	10	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
36	-	-	-	-	10	-	-	-	-	-	10	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	1,100	-	20	-	-	200	20	-	-	-	60	-	-	-	20	-	30	10	-	-	-	-	-	-
38	-	-	-	-	970	40	-	-	10	110	40	10	-	-	50	-	-	20	10	-	-	-	-	10	-	-	-	-
39	-	-	-	-	70	30	10	-	-	20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	+
41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	10	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	-	-	-	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
53	10	10	-	-	460	50	-	20	-	160	80	-	-	-	20	-	-	20	-	-	-	-	-	-	-	-	-	-
54	-	-	10	-	820	-	-	-	-	20	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-
55	-	-	10	-	500	20	-	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	-	-	20	-	1,010	30	100	-	10	-	110	-	-	-	10	-	10	20	20	-	-	-	-	-	-	40	-	-
57	-	-	-	10	10	10	-	10	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	+
59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 16.—Comparison of density and abundance of otoliths of pelagic fish and groundfish.

Item	Pelagic	Groundfish	Unclassified
Number of otoliths	1,288 (87%)	141 (10%)	41 (3%)
Average otolith density (per m²)			
Including all samples (62)	208	23	7
Only samples with otoliths (34)	379	41	12
Number of species	11 (44%)	11 (44%)	3 (12%)

IDENTIFICATION OF OTOLITHS

Otoliths of relatively deepwater teleosts form the major portion of all species dealt with here; littoral species rarely occurred in the samples. Myctophids (lanternfishes) contributed most of the otoliths. Many of these have been referred tentatively to various genera in this group, but specific determinations are not possible in the absence of suitable identified material for comparison. It is very likely that the species are already in ichthyological collections, but most preserving fluids soon render the otoliths useless, if they do not destroy them completely.

Nearly all the otoliths had suffered some erosion that may have resulted from abrasion on the sea bottom, possibly preceded by partial dissolution in the digestive system of predatory animals and later by the reworking of bottom sediments by deposit-feeding benthic invertebrates such as polychaete worms, holothurians, starfish, and many others. One or several of these agents resulted in the destruction of the rostral area on all percoid otoliths. The outer rims of some merluccid otoliths were damaged sufficiently to make identification difficult.

DISTRIBUTION AND DENSITY

Fish remains, all species combined, occurred at 65% of the stations. The remains were not uniformly distributed over the area but occurred mainly in the southern, offshore sector (Figures 19 and 20). More than 90% of all fish remains were taken at depths greater than 150 m, whereas less than 1% came from depths less than 50 m. Only 36% of the samples collected at depths less than 100 m contained one or more otoliths, whereas all samples taken at depths greater than 100 m contained otoliths (Table 17). Highest densities, 500 to 3,030/m², were in a band parallel to the isobaths along the outer portion of the continental shelf and upper part of the continental slope.

Density of fish otoliths was correlated closely

TABLE 17.—Density distribution of fish otoliths in relation to water depth.

Water depth	Samples collected	Samples containing otoliths	Mean number of otoliths
Meters	*Number*	*Percent*	*No/m²*
20-29	1	0	0
30-39	6	0	0
40-49	7	43	7
50-59	8	0	0
60-69	5	60	6
70-79	9	56	7
80-89	1	0	0
90-99	7	71	20
100-124	4	100	70
125-149	4	100	142
150-174	1	100	740
175-199	5	100	1,724
200-249	2	100	1,365
250-567	2	100	735

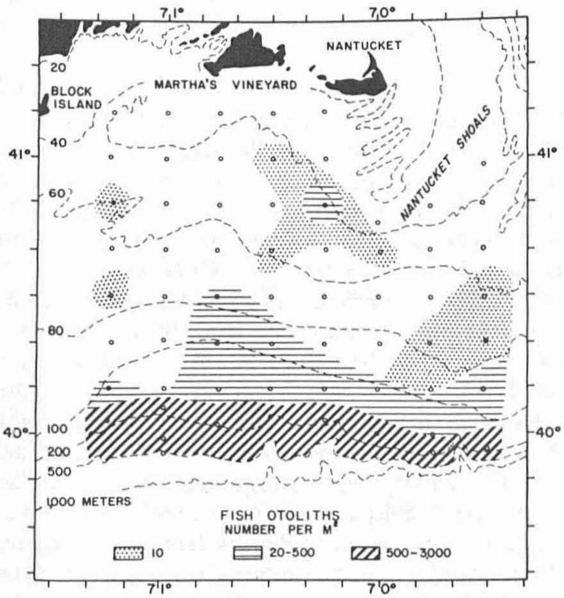


FIGURE 19.—Geographic distribution and density of fish otoliths, all species combined.

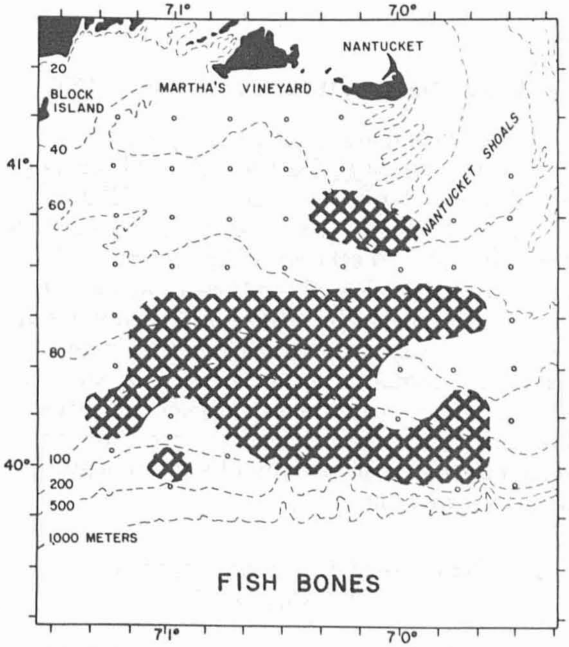


FIGURE 20.—Geographic distribution of fish bones.

with water depth (Table 17). Average densities ranged from 0 to 20/m² between 20 and 100 m and from 735 to 1,724/m² between 150 and 567 m.

Environmental features that contributed substantially to the observed correlations are the low energy environment combined with the relatively mild abrasive characteristics of the bottom sediments.

Densities of fish teeth, bones, and scales were low (80/m² or less). Teeth were recovered at only two stations (53 and 54), where water depths were 179 and 366 m; densities were 20 to 30/m². The teeth at station 53 were from the blue shark, *Prionace glauca,* a cosmopolitan species that commonly attains lengths of 2 to 3 m. Fish scales were found at three stations, at water depths of 49 to 106 m, and at densities of 10 to 20/m². Fish bones were detected at 22 stations (Figure 20). Vertebrae and rib bones were encountered most frequently but occasionally skeletal sections from the oral and branchial regions were taken. The small thin bones generally had a fresh appearance, whereas the larger thicker bones were often badly eroded and stained brown. Fish bones were collected at water depths from 38 to 366 m; densities ranged from 10 to 80/m².

RELATIONS OF DENSITY TO SEDIMENTS

A broad comparison of the geographic distribution and density of fish remains (Figures 19 and 20) with bottom sediment types (Figure 2) disclosed a moderately close correlation. The most obvious aspects were the absence of fish remains in gravel-sand mixtures, and an exceedingly low density in coarse and medium sand sediments. Conversely, fish remains were comparatively common in silt, sandy silt, and fine-grained sand. Otoliths had highest densities in the fine sand, whereas bones were common in sediments composed chiefly of silt and clay with admixtures of fine sand.

DISTRIBUTION AND DENSITY BY SPECIES

Of the 26 fish species whose remains were recovered from the bottom sediments, only six were abundant or moderately abundant; *Ceratoscopelus maderensis, Citharichthys ?arctifrons, Diaphus* sp.-4, *Lepophidium cervinum, Merluccius bilinearis,* and *Myctophum* sp. (Fish species represented by otoliths are listed by station in Table 15.) Each of these species occurred at eight or more stations, and maximum densities ranged from 60 to 2,160/m². Four of the six abundant species are pelagic forms (exceptions are *L. cervinum* and *M. bilinearis,* although *M. bilinearis* frequently is mesopelagic). The most common species was *Ceratoscopelus maderensis.* Otoliths of this species occurred at 19 stations and average density was 530/m².

Nearly all fish remains were collected in the southern half of the area. The geographic distribution of otoliths of different species is illustrated in Figure 21. With few exceptions, otoliths of individual species were geographically distributed in an east-west band across the area, roughly parallel to the depth contours. A major exception to this distribution was that for *M. bilinearis,* the most widely distributed species. It was found at 15 stations, most of which were located on the outer continental shelf, but a few otoliths occurred on the central and inner portions of the shelf. This species is one of the few whose remains were found in the inner-shelf region.

Water depths at which remains of individual fish species occurred ranged from 44 to 567 m. Considerable differences in depth range were evident among species, probably in part because of the sparse representation of some. Depth-of-occurrence data, by species, are summarized in Table 18 and Figure 22. Only two species, "*Stromateus*" and *Merluccius bilinearis,* were found at depths shallower than 50 m, and only six occurred at less than 100 m. On the other hand, 15 species were recovered from depths greater than 200 m, and 6 from depths greater than 360 m. The species that were distributed over the widest depth range are *Ceratoscopelus maderensis* and *Citharichthys ?arctifrons;* their remains were taken at depths from 95 to 567 m. Other species whose remains were spread over a wide depth range are: *Benthosema glaciale, Diaphus* sp.-2, *Diaphus* sp.-4, and *Lepophidium cervinum.* About 61% of the species were found

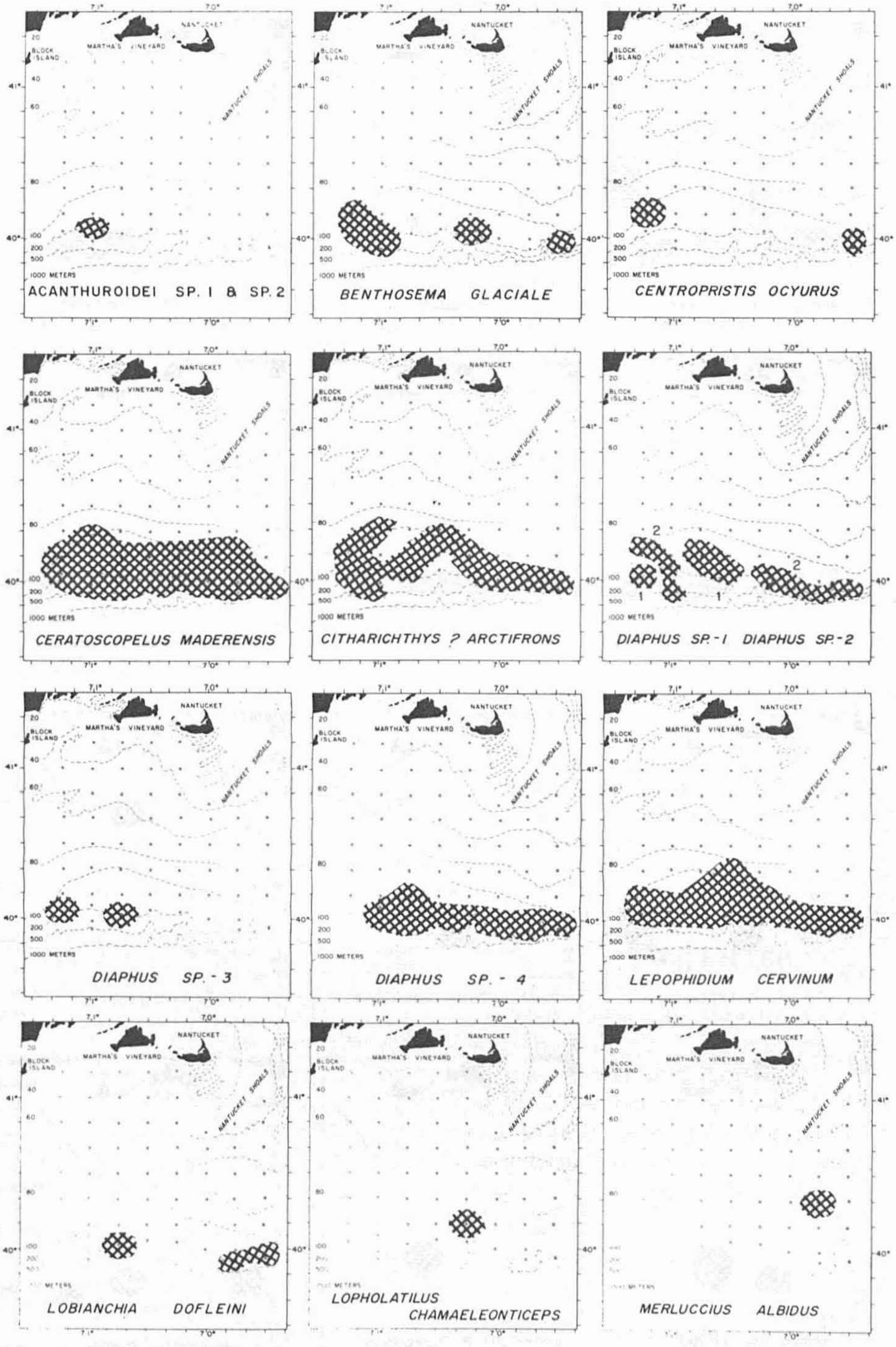


FIGURE 21.—Geographic distribution of fish otoliths, by species.

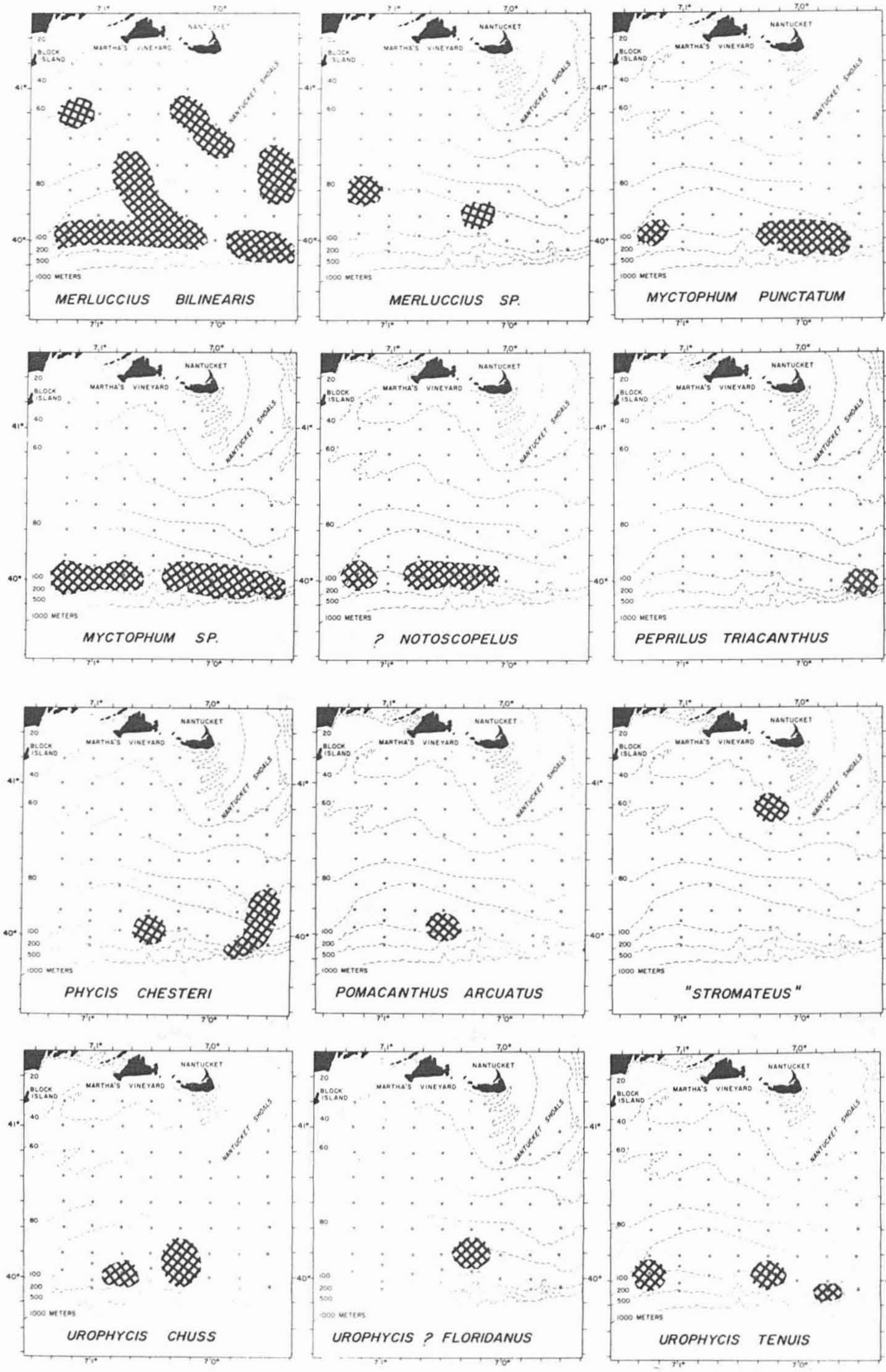


FIGURE 21.—Geographic distribution of fish otoliths, by species.—Continued.

TABLE 18.—Bathymetric distribution of teleost and selachian remains by species or higher taxon, and the number of stations at which each occurred. All entries are based on otoliths except *Prionace glauca*, which is represented by a tooth.
[P — pelagic, G — groundfish, and Un — unclassified.]

Species or higher taxon	Water depth: Minimum	Water depth: Maximum	Water depth: Mean	Number of stations	Environmental classification
	m	m	m		
Acanthuroidei sp.-1	179	179	179	1	G
Acanthuroidei sp.-2	179	179	179	1	G
Benthosema glaciale	183	567	296	5	P
Centropristis ocyurus	110	183	146	2	G
Ceratoscopelus maderensis	95	567	185	19	P
Citharichthys ?arctifrons	97	567	196	10	G
Diaphus sp.-1	132	220	176	3	P
Diaphus sp.-2	110	567	227	7	P
Diaphus sp.-3	183	194	188	2	P
Diaphus sp.-4	132	366	196	10	P
Lepophidium cervinum	97	366	169	17	G
Lobianchia dofleini	183	201	193	3	P
Lopholatilus chamaeleonticeps	113	113	113	1	G
Merluccius albidus	79	79	79	1	Un
Merluccius bilinearis	44	220	126	15	Un
Merluccius sp.	91	113	102	2	Un
Myctophum punctatum	139	201	174	5	P
Myctophum sp.	139	201	178	8	P
?Notoscopelus	183	220	195	4	P
Peprilus triacanthus	183	183	183	1	Un
Phycis chesteri	91	220	171	3	G
Pomacanthus arcuatus	220	220	220	1	G
Prionace glauca	179	179	179	1	Un
"*Stromateus*"	44	44	44	1	P
Urophycis chuss	113	194	163	3	G
Urophycis ?floridanus	113	113	113	1	G
Urophycis tenuis	183	201	189	3	G
Urophycis sp.	73	366	220	2	G

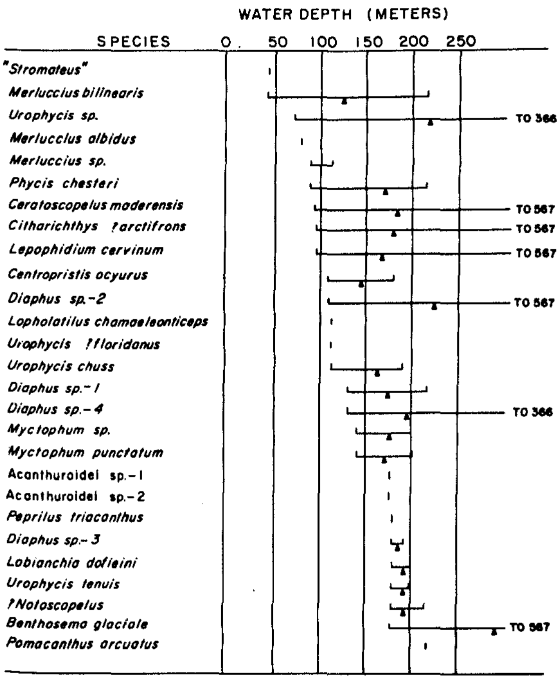


FIGURE 22.—Bathymetric range and mean depth of occurrence of fish species represented in the samples by otoliths. (Observed values are listed in Table 18.)

only in the general vicinity of the shelf break (100 to 220 m). None was restricted to a depth below 220 m.

REMAINS OF CRUSTACEANS AND COELENTERATES

Crustaceans and coelenterates were the least numerous of all taxonomic groups represented in the samples and formed only a small portion of the total macroscopic animal remains. These two groups differed markedly in geographic distribution, bathymetric distribution, and abundance. Thus, each is treated in a separate section below.

CRUSTACEANS

Remains of two groups of crustaceans—cirripedes and decapods—were present in the samples. Cirriped (barnacle) remains consisted of calcareous plates, primarily compartments (wall plates) plus a moderate proportion of opercular valves. Only balanomorph types were present, and generally the thicker, more durable portions were most numerous. Examples are illustrated in Figure 23. None of the chitinous parts of the skeleton, such as the covering of the appendages, was present. Decapod crustaceans were represented by anomuran (hermit) crabs and brachy-

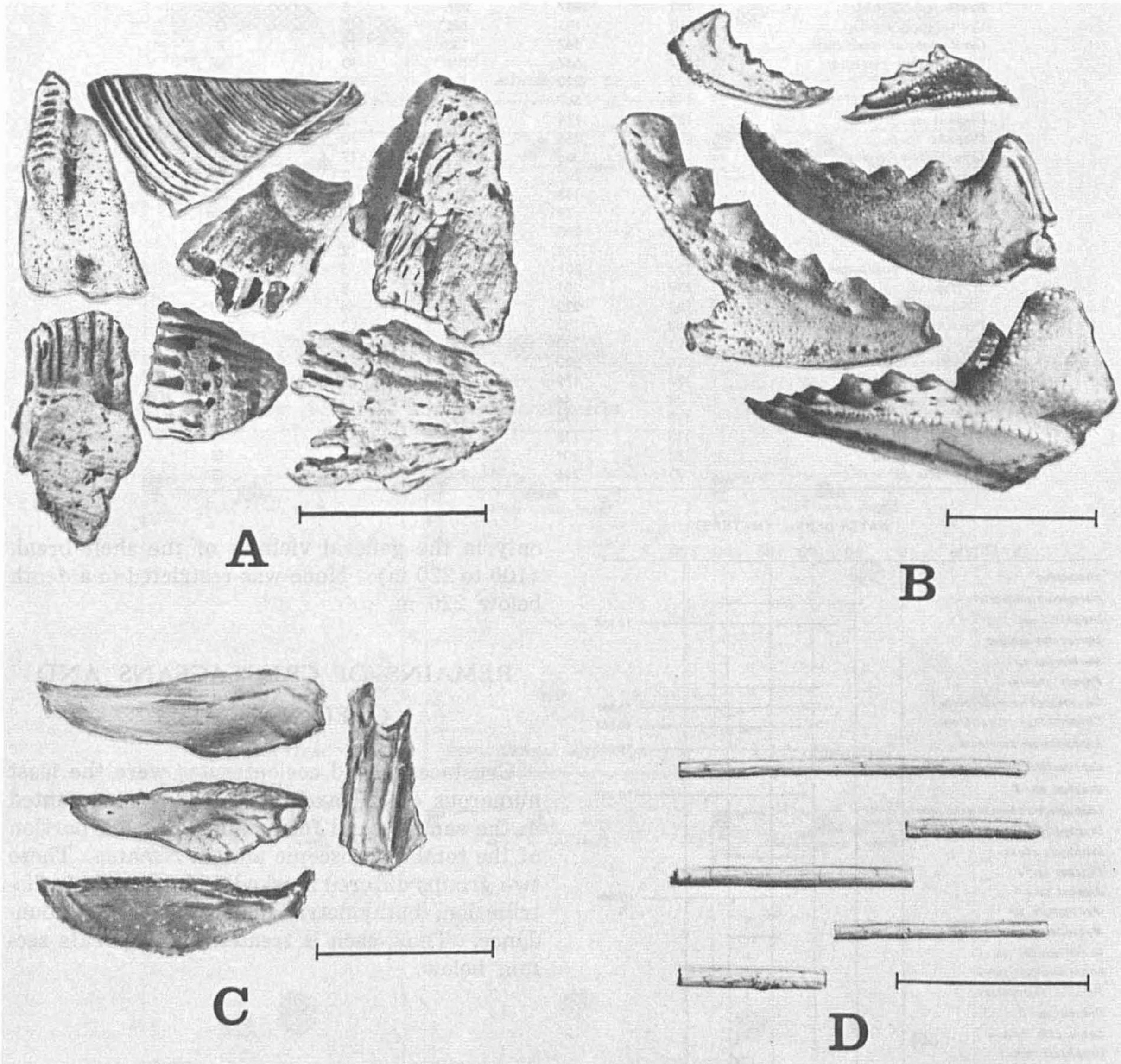


FIGURE 23.—Skeletal remains of crustaceans and coelenterates. A - cirripedes, scutum and compartments; B - anomuran and brachyuran, chelipod remains; C - *Flabellum*, corallite fragments; D - *Acanella* (?), axial skeleton remains. Each scale bar is 5 mm.

uran (true) crabs. Remains of the latter group consisted of the larger more massive and durable parts of the skeleton (mainly the carapace and chelipeds), and the anomuran remains consisted only of chelipeds. Occurrence records for both groups of crustaceans are included in Table 19; bathymetric data are given in Table 20. The geographic and bathymetric distributions are illustrated in Figures 24 and 25.

Remains of cirripedes (Figure 23A) were widely scattered over the area (Figure 24). The density of major fragments ranged from 10 to $90/m^2$; densities were substantially higher in shallow water than in deep water. The depth range was 27 to 567 m with the average depth at 123 m.

Remains of crustaceans carapaces and chelipeds were from anomuran and brachyuran crabs (Figure 23B). They were sparse to moderately dense and had a somewhat limited geographic distribution near the central part of the shelf (Figure 24) at depths from 51 to 113 m. Their distribution was much more restricted than that of cirripedes. Also, this part of the shelf is a low-energy region, as compared with the Nantucket Shoals and the shallow inshore areas where cirriped remains were prevalent.

TABLE 19.—Density of crustaceans and coelenterates, by station.

Station number	Crustaceans		Coelenterates	
	Cirripedes	Anomuran-brachyuran	*Flabellum*	*Acanella*(?)
	No/m^2	No/m^2	No/m^2	No/m^2
1	90	--	--	--
2	50	--	--	--
12	--	20	--	--
16	50	--	--	--
18	--	10	--	--
21	10	--	--	--
23	10	10	--	--
24	--	10	--	20
25	--	20	--	--
26	--	10	--	--
29	10	--	--	--
32	--	70	--	--
34	--	10	--	--
35	--	--	--	50
36	10	--	--	--
38	--	--	30	--
41	--	20	--	--
49	10	--	--	--
51	10	--	--	--
52	--	--	80	--
53	10	--	10	--
54	--	--	50	--
55	30	--	--	--
59	10	10	--	--
63	80	--	--	--

TABLE 20.—Bathymetric distribution of crustaceans and coelenterates, and the number of stations at which they occurred.

Group	Water depth			Number of stations
	Minimum	Maximum	Mean	
	m	*m*	*m*	
Crustaceans				
Cirripedes	27	567	123	13
Anomuran-brachyurans	51	113	76	10
Coelenterates				
Flabellum	146	366	221	4
Acanella (?)	90	97	94	2

COELENTERATES

Coelenterate remains were the rarest group of animals in the prefossil assemblage. They consisted solely of corals: *Flabellum alabastrum* (=*goodei* Verrill), a cup coral, and *Acanella* (?), a bush coral. Some examples of each kind are illustrated in Figure 23.

Flabellum, a solitary coral of the madreporian group, has a rather large (4 by 6 cm) polyp and a typical calcareous skeleton (corallite) with well-developed septae. Corallite remains contained a large proportion of septae and were commonly 4 to 8 mm long. This species occurred only in a limited area on the continental slope south of Martha's Vineyard (Figure 24) at depths of 146 to 366 m (Figure 25). Densities of fragments were as high as $80/m^2$, but the average density at the locations where they occurred was about $40/m^2$.

White calcareous rodlike structures about 0.5 mm in diameter and 0.5 to 1 cm in length (Figure 23D) were provisionally classified as *Acanella,* a colonial alcyonarian coral. The fragments appeared to be internodal portions of the axial skeletons. *Acanella normani* Verrill is not uncommon in the region. The multibranched colony of this species is composed of numerous slender, jointed segments. Total height of a full-grown colony is usually less than 30 cm. Remains of this coral were found at two stations near the center of the area (Figure 24) at depths of 90 to 97 m and in densities of 20 to $50/m^2$.

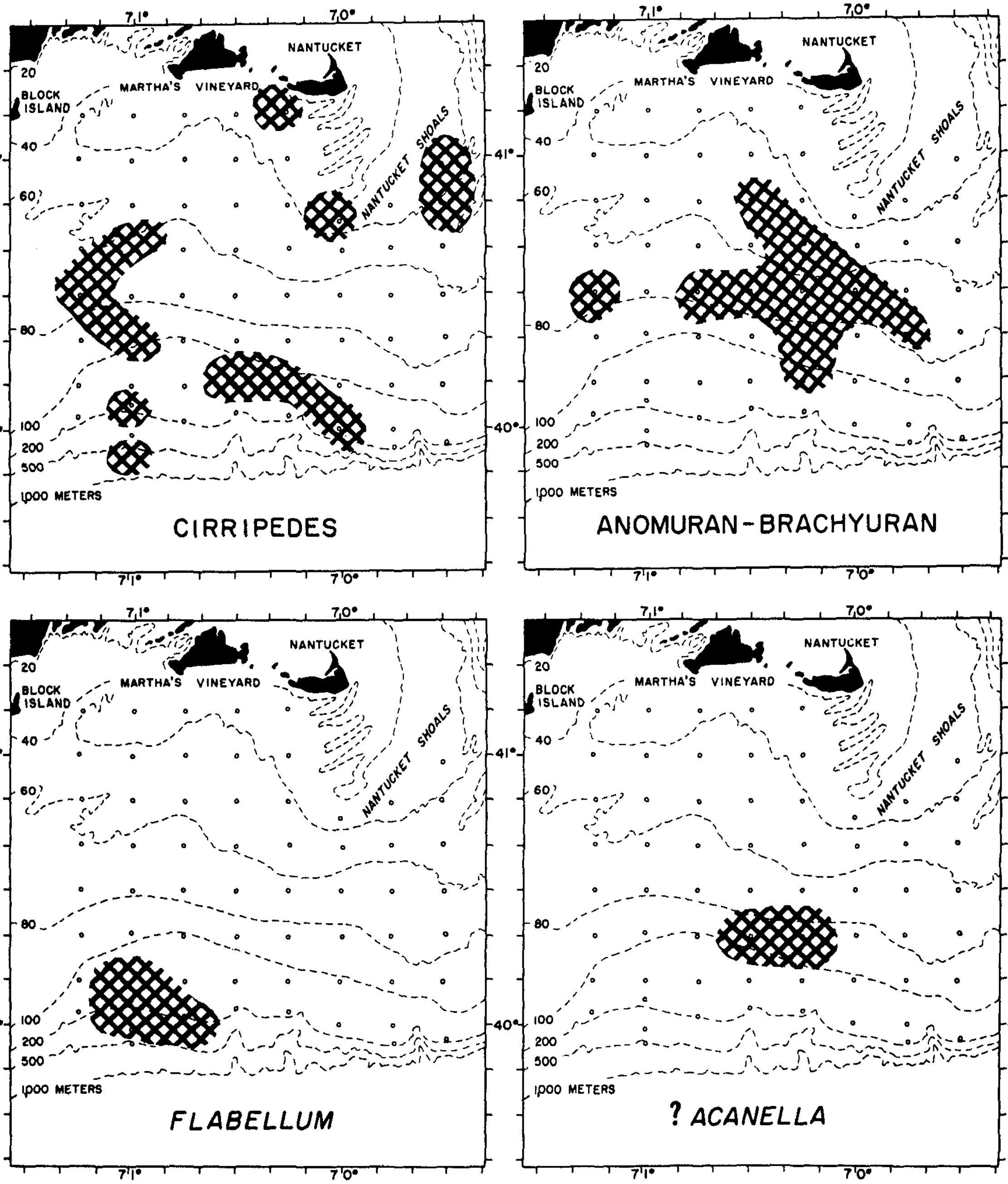


FIGURE 24.—Geographic distribution of skeletal remains of crustaceans and coelenterates.

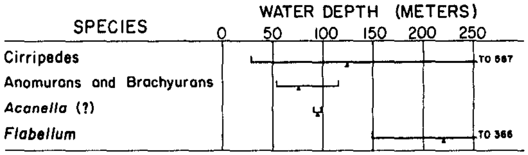


FIGURE 25.—Bathymetric distribution of skeletal remains of crustaceans and coelenterates.

COMPARATIVE DISTRIBUTION OF ALL TAXONOMIC GROUPS

The distribution of the principal animal remains in relation to each other, sediment type, and water depth, and, to a limited extent, their north-south geographical position on the continental shelf and slope are illustrated in Figure 26. This chart is a generalized profile of the study area with the inshore (north) section on the lefthand side and the offshore (south) section on the righthand side. Broad, diagonally striped bands indicate relatively high density, and narrow lines indicate low density. Animal groups whose centers of concentration were inshore in relatively shallow waters were cirripedes and *Echinarachnius parma.* The dominant midshelf and outer-shelf components were gastropods, pelecypods, and decapods. Pelecypods, scaphopods, *Brisaster*, and *Flabellum* were common along the outer portion of the continental shelf and upper portion of the continental slope. The chief components in deeper sections of the continental slope were fish otoliths and cephalopod mandibles.

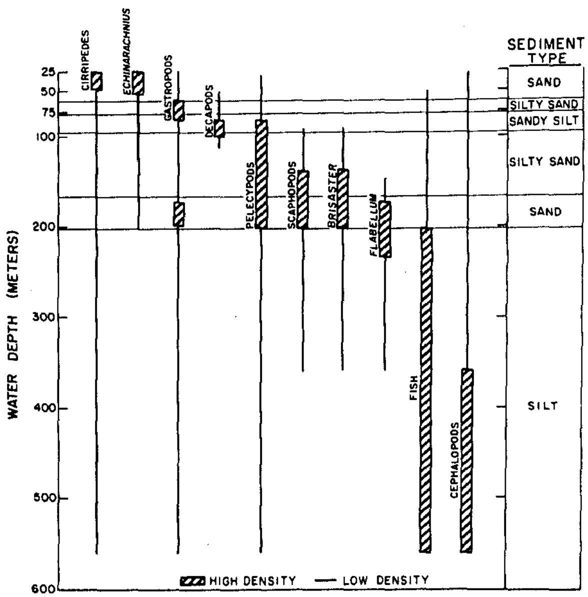


FIGURE 26.—Schematic diagram of the density distribution of macroscopic remains of the major animal groups represented in bottom sediments arranged according to water depth and sediment type (see text for details).

SUMMARY

Skeletal remains of deceased animals were common seabed components on the southern New England continental shelf and the upper part of the continental slope. In some sections, particularly in shallow water, skeletal remains constituted a substantial portion of the substrate volume—up to nearly 30% in the vicinity of Nantucket Shoals. Offshore, near the margin of the continental shelf and in the upper portion of the continental slope, macroscopic animal remains generally constituted less than 1% of the substrate.

Remains of benthic, pelagic, and nektonic organisms were present; benthic forms were dominant. Planktonic animals (represented only by pteropods) were sparse. Fish and cephalopods were the principal nektonic forms. They were rather abundant in the deeper waters, particularly on the outer portion of the continental shelf and on the continental slope.

The two animal groups that contributed the largest quantities of material to the substrate were echinoid echinoderms and pelecypod mollusks. Although remains of a wide variety of fish species were present, the quantity was moderate and the sizes small; consequently the volume of fish remains was rather small.

ECHINODERMS

The exceedingly abundant remains of echinoderms consisted exclusively of echinoids. Only one species—*Echinarachnius parma*—occurred in high densities and was the most abundant and widely distributed component of organic origin in the sediments. Geographically it had a wide distribution, occurring at 72% of the stations. Depth range was 27 to 201 m. Size, shape, and color of *Echinarachnius* fragments differed markedly with water depth and sediment type. The *E. parma* fragments in the inshore localities were whitish, relatively large, and had angular edges and corners; in offshore localities, the fragments were light greenish-brown, smaller, and had rounded edges. Densities of echinoids other than *Echinarachnius* were low, and except for *Brisaster*, remains were found at only a few localities. Density of *Brisaster* remains were low but the remains were rather widely distributed along the outer portion of the continental shelf. Remains of *Strongylocentrotus drobachiensis* were sparse and widely scattered in both shallow and deep water.

MOLLUSKS

Pelecypods ranked first in diversity of forms (57 species) and second in volume of remains in the bottom sediments. They were present at all depths sampled, from 27 to 567 m, and were widely distributed geographically. Densities were high in a wide band extending from Nantucket Shoals southwestward across the area, and in a narrow band parallel to the isobaths near the shelf break. Pelecypods were very abundant (more than 3,000/m^2) at 6 stations, most of which were along the outer margin of the continental shelf; common to abundant (50 to 3,000/m^2) at 48 stations; and sparse (less than 50/m^2) or absent at 8 stations. In general, the species with the broadest geographic distributions occurred in highest densities. The six most abundant and widely distributed pelecypods were: *Venericardia borealis, Arctica islandica, Astarte subequilatera, A. undata, Nucula proxima,* and *Thyasira trisinuata.* Pelecypod shells were more abundant in moderately fine-textured sediments than in either the coarse or very fine sediments. Silty sand, sandy silt, and sand-silt-clay yielded the highest densities of pelecypod shells. Size of shells ranged from 10 to 12 cm (*Spisula, Arctica, Placopecten*) to less than 5 mm (*Thyasira, Nucula, Bathyarca*).

Gastropods ranked third in volume of skeletal material in the substrates. Shells of gastropods were distributed widely throughout the area, but highest densities were near the center. A total of 44 species were present, but only 2 were generally abundant—*Alvania carinata* and *Cylichna gouldi.* Shells were taken at all depths, and were particularly common between 60 and 80 m and moderately common between 175 and 250 m. Density was correlated in a general way with bottom sediments. High densities were in silty sand and sand sediments, whereas shells were absent in coarse sand and mixtures of sand and gravel. A large majority of gastropod shells was less than 1 cm in height.

Cephalopod remains, consisting entirely of beaks, were present at only 12 stations, all of which were from the outer portion of the continental shelf and upper part of the continental slope at depths between 76 and 567 m. Densities were generally less than 40/m^2 at the shallower depths, but ranged to 130/m^2 at a depth of 366 m and 11/m^2 at 567 m. Remains of this group ranged in size from 4 to 6 mm and were relatively fragile. They were recovered only from fine-textured sediments.

Distributions of scaphopods were rather limited geographically and densities were low. The two genera collected, *Cadulus* and *Dentalum,* were present at 11 stations, geographically limited to the deepwater areas on the outer portion of the continental shelf and the upper continental slope. The bathymetric range was 139 to 366 m for *Cadulus,* and 91 to 183 m for *Dentalium.* Sediments at the scaphopod localities were generally fine-grained, but *Cadulus* occurred in slightly coarser sediments than *Dentalium.* Densities at the stations where they occurred averaged about 30 to 40/m^2; maximum density for both genera was 11/m^2. *Cadulus* shells were 10 to 13 mm long, and *Dentalium* shells were 15 to 35 mm.

FISH

Fish were the only vertebrates in the samples. Otoliths were the main component and bones were moderately common, but teeth and scales were rare. Remains of 26 species were collected, nearly half of which were from epipelagic or mesopelagic forms. Myctophids were the most numerous and widely distributed, and they contributed the greatest number of species. Thirty-six percent of the species and 87% of all otoliths were Myctophiformes. The six most abundant fish, based on otolith identifications, were: *Ceratoscopelus maderensis*, *Citharichthys ?arctifrons*, *Diaphus* sp.-4, *Lepophidium cervinum*, *Merluccius bilinearis*, and *Myctophum* sp. The estimated length of the fish whose remains were encountered ranged from a few centimeters to several meters. Remains of fish were at depths between 38 and 567 m, and an overwhelming majority was found at depths greater than 150 m. More than 90% of the otoliths were at depths below the 150-m isobath; bones were less common and more uniformly distributed, from 38 to 366 m. The remarkably high otolith density of 3,030/m^2 was found near the edge of the continental shelf south of Nantucket Shoals. Remains of most individual species were geographically distributed in east-west bands across the area, generally oriented parallel to the isobaths. Fish remains were absent in coarse-grained sediments, and most abundant in fine sands and silt-clay.

CRUSTACEANS AND COELENTERATES

Crustaceans and coelenterates were the only other nonmolluscan invertebrates, in addition to those previously described, that were present in the samples. The quantity of their remains was very small.

Crustaceans were generally sparse and rather widely distributed. Cirripedes consisted exclusively of shells of sessile forms; they were geographically scattered and were taken at all depths sampled. Cirripedes were only slightly more common in shallow water than in deep water. They were one of the few animal groups whose remains occurred in coarse-grained sediments. Fragments of skeletons of anomurans and brachyurans were encountered only in the midcontinental shelf in sediments primarily of silts and fine sands. They were collected between 51 and 113 m. Densities were low, from 10 to 70/m^2.

Remains of coelenterates occurred in low densities (10 to 80/m^2) and were geographically restricted to small areas in the south-central and southwestern sectors. Two genera—both corals—were represented, *Acanella* (?) (at 90 to 97 m) and *Flabellum* (between 146 and 366 m). Both kinds were restricted to fine-textured sediments.

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LITERATURE CITED

BELYAEV, G. M.
1970. The rostra of squids in the bottom sediments of the Pacific Ocean. [In Russian, English summ.] Tr. Inst. Okeanol. Akad. Nauk SSSR 88: 236-251.

BELYAEV, G. M., AND L. S. GLIKMAN.
1970. The teeth of sharks on the floor of the Pacific Ocean. [In Russian, English summ.] Tr. Inst. Okeanol. Akad. Nauk SSSR 88:252-276.

BIGELOW, H. B.
1927. Physical oceanography of the Gulf of Maine. U.S. Bur. Fish., Bull. 40(2):511-1027.
1933. Studies of the waters on the continental shelf, Cape Cod to Chesapeake Bay, I. The cycle of temperature. Pap. Phys. Oceanogr. Meteorol. 2:1-135.

BRONGERSMA-SANDERS, M.
1949. On the occurrence of fish remains in fossil and recent marine deposits. Bijdr. Dierkd. 28: 65-76.

BUMPUS, D. F., J. CHASE, C. G. DAY, D. H. FRANTZ, JR., D. D. KETCHUM, AND R. G. WALDEN.
1957. A new technique for studying non-tidal drift with results of experiments off Gay Head, Mass., and in the Bay of Fundy. J. Fish. Res. Board Can. 14:931-944.

BUMPUS, D. F., AND G. G. DAY.
1957. Drift bottle records for Gulf of Maine and Georges Bank, 1931-56. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 242, 61 p.

COLTON, J. B., JR.
1964. History of oceanography in the offshore waters of the Gulf of Maine. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 496, 15 p.
1968. Recent trends in subsurface temperatures in the Gulf of Maine and contiguous waters. J. Fish. Res. Board Can. 25:2427-2437.
1969. Temperature conditions in the Gulf of Maine and adjacent waters during 1968. J. Fish. Res. Board Can. 26:2746-2751.

CRAIG, G.
1953. Discussion: Fossil communities and assemblages. Am. J. Sci. 251:547-548.

CRAIG, G. Y., AND N. S. JONES.
1966. Marine benthos, substrate and palaeoecology. Palaeontology 9:30-38.

DAVID, L. R.
1947. Significance of fish remains in recent deposits off coast of southern California. Bull. Am. Assoc. Pet. Geol. 31:367-370.

DAY, C. G.
1958. Surface circulation in the Gulf of Maine as deduced from drift bottles. U.S. Fish. Wildl. Serv., Fish. Bull. 58:443-472.

EMERY, K. O.
1960. The sea off southern California, a modern habitat of petroleum. Wiley, Lond., 366 p.
1966. Atlantic continental shelf and slope of the United States, geologic background. U.S. Geol. Surv. Prof. Pap. 529-A:A1-A23.
1968. Positions of empty pelecypod valves on the continental shelf. J. Sediment. Pet. 38:1264-1269.

EMERY, K. O., AND L. E. GARRISON.
1967. Sea levels 7,000 to 20,000 years ago. Science (Wash., D.C.) 157:684-687.

EMERY, K. O., A. S. MERRILL, AND J. V. A. TRUMBULL.
1965. Geology and biology of the sea floor as deduced from simultaneous photographs and samples. Limnol. Oceanogr. 10:1-21.

GARRISON, L. E., AND R. L. MCMASTER.
1966. Sediments and geomorphology of the continental shelf off southern New England. Mar. Geol. 4:273-289.

GUNTER, G.
1947. Catastrophism in the sea and its paleontological significance, with special reference to the Gulf of Mexico. Am. J. Sci. 245:669-676.

HABE, T.
1956. Studies on the shell remains in þays. [In Japanese, English summ.] Contrib. Physiol. Ecol. (Kyoto Univ.) 77:1-31.

JENSEN, A. S.
1905. On fish-otoliths in the bottom-deposits of the sea. I. Otoliths of the Gadus-species deposited in the Polar Deep. Medd. Komm. Havunders., Ser.: Fisk. 1(7), 14 p.

JOHNSON, R. G.
1957. Experiments on the burial of shells. J. Geol. 65:527-535.

LADD, H. S.
1957. Introduction. *In* H. S. Ladd (editor), Treatise in marine ecology and paleoecology. Vol. 2, p. 1-29. Geol. Soc. Am., Mem. 67.

MCMASTER, R. L., AND L. E. GARRISON.
1966. Numerology and origin of southern New England shelf sediments. J. Sediment. Petrol. 36:1131-1142.

MERRILL, A. S., K. O. EMERY, M. RUBIN.
1965. Ancient oyster shells on the Atlantic Continental Shelf. Science (Wash., D.C.) 147:398-400.

RHOADS, D. C.
1966. Missing fossils and paleoecology. Discovery (New Haven) 2(1):19-22.

SCHÄFER, W.
1956. Wirkungen der Benthos-Organismen auf den jungen Schichtverband. Senckenb. Lethaea 37:183-263.

SHEPARD, F. P.
1954. Nomenclature based on sand-silt-clay ratios. J. Sediment. Petrol. 24:151-158.

SMITH, W., AND A. D. MCINTYRE.
1954. A spring-loaded bottom sampler. J. Mar. Biol. Assoc. U.K. 33:257-264.

SOUTAR, A.
1967. The accumulation of fish debris in certain California coastal sediments. Calif. Coop. Oceanic Fish. Invest., Rep. 11:136-139.

TWENHOFEL, W. H., AND S. A. TYLER.
1941. Methods of study of sediments. McGraw-Hill, N.Y., 183 p.

UCHUPI, E.
1963. Sediments on the continental margin off eastern United States. U.S. Geol. Surv. Prof. Pap. 475-C:C132-C137.

WIGLEY, R. L., AND K. O. EMERY.
1967. Benthic animals, particularly *Hyalinoecia* (Annelida) and *Ophiomusium* (Echinodermata), in sea-bottom photographs from the continental slope. *In* J. B. Hersey (editor), Deep-sea photography, p. 235-249. John Hopkins Oceanogr. Stud. 3.

WIGLEY, R. L., AND A. D. MCINTYRE.
1964. Some quantitative comparisons of offshore meiobenthos and macrobenthos south of Martha's Vineyard. Limnol. Oceanogr. 9:485-493.