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Ecosystem Definition and Community Structure of the Macrobenthos of the NEMP Monitoring Station at Pigeon Hill in the Gulf of Maine

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
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The Pigeon Hill station forms part of the baseline ecosystem definition of the National Oceanic and Atmospheric Administration's Northeast Monitoring Program (NEMP). The monitoring effort has evolved into an integrated program providing a system of physical, chemical, and biological monitoring at selected stations in waters of the northeast continental shelf from the Gulf of Maine to Cape Hatteras. The purpose of this report is to provide a quantitative baseline description of the dominant faunal and floral components of the Pigeon Hill communities.

KEYWORDS: *Invertebrates, *Marine biology, *Ecology, *Water pollution, *Continental shelves, *Maine Gulf.

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LIST OF ABBREVIATIONS AND DEFINITIONS

Airlift	Underwater disruptive sampling apparatus
cm	Centimeter
°C	Degree Centigrade
df	Degrees of freedom
g	Gram
km	Kilometer
LAT	Latitude
LOG	Logarithm (base 10)
LONG	Longitude
m	Meter
m^2	Meter square area (100 cm x 100 cm)
mm	Millimeter
NEMP	Northeast Monitoring Program (NOAA)
No.	Number
NODC	National Oceanographic Data Center
P	Significance Level
PCB	Polychlorinated B.phenyl
ppb	Parts per billion
ppm	Parts per million
quadrat	Square sampling area
quadrupod	System to photograph a quadrat
r^2	Correlation coefficient
SD	Standard deviation
SE	Standard error of the mean
sp	Species
tagging	Permanent substrate marking system
temp	Temperature
wt. wgt.	Blotted wet weight
$\bar{X}$	Mean
$\bar{\bar{X}}$	Grand mean
>	Greater than
<	Less than

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1. EXECUTIVE SUMMARY

1.1 GENERAL

The Pigeon Hill station forms part of the baseline ecosystem definition of the National Oceanic and Atmospheric Administration's Northeast Monitoring Program (NEMP). Pigeon Hill, located off Cape Ann, Massachusetts (Figure 1) was set up as a permanent NEMP station in October, 1977. The site was chosen because it was relatively pristine and in the midst of a commercial fishery and heavy shipping traffic.

The purpose of this report is to provide a quantitative baseline description of the dominant faunal and floral components of the Pigeon Hill benthic communities. We have approached the problem of monitoring the communities using in-situ SCUBA techniques by first defining a quantitative baseline of the subhabitats, subsequently utilizing more cost-effective photographic tracking of "key indicator species." We utilize as biological indicators asteroids, brachiopods, tunicates, and algae.

1.2 METHODS

The station was marked and permanent transects were established utilizing a stratified sampling procedure with horizontal and vertical substrata and 33 and 42 m depths. We utilized primarily precise disruptive sampling techniques to establish descriptive community baselines and subsequently used quantitative photography for following the stability of the communities.

1.3 RESULTS

A total of 149 species have been identified from the disruptive samples. Differences in the species composition of horizontal and vertical communities as well as the changes with depth have been shown (Table 5). Horizontal communities are dominated by an algal-polychaete matrix offering a large amount of secondary substrate. Vertical surfaces are dominated by sponges, tunicates and brachiopods. The biological effects of increased depth are due primarily to the loss of algae which is near its extinction depth at 33 m.

The permanent transects have been photographed regularly since 1978 to monitor species composition and abundance and to determine the extent of the natural variability of the communities.

Body burdens of heavy metals, PCB's and anthropogenic hydrocarbons have been established for algae, asteroids, and tunicates and we will continue to augment the baseline data.

1.4 CONCLUSIONS

We have established a quantitative baseline of community parameters and have instituted the methodology for tracking the communities for time-series analysis. From this and other studies the biology of many of the important species is known. Computerized photo analysis, allowing quick data turnaround, and a knowledge of the biology of the dominant species should help in both quickly detecting and subdequently understanding potential future impacts. By extending the time-series analysis of the benthic communities, we will better understand the natural variability and hence lower the level of detectable impact.

Pigeon Hill, at present, is a healthy, relatively pristine location in the midst of a commercial fishery and heavy shipping traffic. The benthic communities at Pigeon Hill primarily are composed of boreal species of the exposed coast. Community dominants have been identified as indicator species and are being tracked using predominantly quantitative photographic techniques in very site-specific subhabitats.

2. INTRODUCTION

The Pigeon Hill station forms part of the baseline ecosystem definition of the National Oceanic and Atmospheric Administration's Northeast Monitoring Program (NEMP). The monitoring effort has evolved into an integrated program providing a system of physical, chemical, and biological monitoring at selected stations in waters of the northeast continental shelf from the Gulf of Maine to Cape Hatteras, (see NOAA Tech. Mem. NMFS-F/NEC10). The Northeast Monitoring Program is thus a multidisciplinary effort designed to monitor the health of marine communities over long periods of time. The program, as set up in selected marine communities along the Atlantic Coast, tracks the natural fluctuations in communities as well as the impact of man-produced pollutants.

A permanent NEMP research station to be monitored by SCUBA was set up in October 1977 in the Gulf of Maine on Jeffreys Ledge, Lat 42°46.5' N, Long 70°14,5'W. Pigeon Hill is a rocky knoll located 37 km off Cape Ann, Massachusetts (Figure 1), chosen because of its offshore location, relatively pristine environment, situation in the midst of a commercial fishing area, and a previous knowledge of the benthos, as well as a knowledge of similar Gulf of Maine communities.

The purpose of this report is to provide a quantitative baseline description of the dominant faunal and floral components of the Pigeon Hill communities. Where sufficient data was available we have statistically evaluated initial trends and differences observed in the field, and in the data. The report is based upon disruptive 0.25 m^2 samples from 1978 and 1979; quantitative 0.25 m^2 photographs from 1978, 1979, 1980, and 1981; contaminant samples from 1980 and 1981; and many qualitative observations.

We have approached the problem of monitoring the Pigeon Hill benthic communities by first defining a quantitative baseline analysis of the subhabitats from in-situ collections of benthos using qualitative and quantitative disruptive techniques. Subsequently we have utilized more cost-effective quantitative photographic techniques to study "key indicator" species that are identified for their community importance and photographic affinities. Information on the indicator species is then considered as reflective of the communities. Biological indicators can provide a natural integrating function and are often concentrators of environmental information. A parameter such as a species population structure can be considered as a dynamic equilibrium to the biotic and physical environments in which it lives (Hulbert, 1980a, 1980b, 1981a; Paine 1976).

There is relatively little information on temperate, offshore, hard substrate communities. In the Gulf of Maine there are only a few studies of similar communities and they tend to emphasize the interaction between macro algae and sea urchin disturbance (e.g., Breen and Mann, 1976; Harris, 1981; Mathieson, 1979). Sears and Cooper (1978) have described the algal components of the Pigeon Hill communities, but other research is minimal. Similar communities have been investigated at the Isles of Shoals, off the New Hampshire coast, since 1974 (Harris, Ms; Harris, et al., 1979; Harris et al. Ms; Harris and Irons, 1982; Hulbert, 1979, 1980a, 1980b, 1981a, 1981b;

Hulbert, Ms; Hulbert et al., 1981; Powers et al., 1977; Witman, 1979, 1980, 1981, 1982; Witman, et al., 1980, 1981). Few other long-term studies have been done in the Gulf of Maine on rocky substrates. The subtidal research of Mathieson (1979) and Sebens (Ms) and the intertidal research of Menge (1976a, 1978a, 1978b, 1979) constitute the bulk of the existing and recent local research.

Benthic communities in general, but especially on hard substrates where it is most apparent, form community zones delineated by depth. The zones are characterized by community dominants or by changing species abundances and are a direct result of changes in the physical and biotic environments with depth. Figure 2 illustrates several of the important factors which change with depth, although there are many other factors which may also interact in a synergistic manner on the local habitat. In the Gulf of Maine, and most areas of the world, temperature is more variable at the ocean surface than at depth, on both a yearly and daily basis. The shallow water organisms often are subjected to greater temperature extremes than their counterparts in deeper water. Deeper dwelling organisms live in a more stable environment over time and the diversity of species would be expected to be higher in deeper communities (Stability-Time Hypothesis, Sanders, 1968).

The effect on light is a purely physical one of direct attentuation of amount and quality of light with depth. Algae which need light for photosynthesis are limited to depths above their compensation limit, that is the depth at which photosynthesis equals respiration. Below the compensation depth of a species respiration utilizes more energy than photosynthesis produces and existence is not possible.

The integration of the effects of light and temperature on benthic communities is that high algal diversity is favored in shallow communities with relatively high light levels, while deeper communities favor high animal diversity due to the more stable physical environment. The areas of intermediate depths in the Gulf of Maine tend to be characterized by a series of community zones with depth. Each of the zones is typically dominated by a few species, and can be characterized by the dominants. Biotic interactions (i.e., predation, competition, recruitment, etc.) tend to be important in the establishment and maintenance of dominant species (see Connell, 1972, for a review of intertidal zonation; Hulbert, 1980b, for subtidal zonation in the Gulf of Maine).

The above discussion accompanied by Figure 2 are examples of the effects of only two variables, light and temperature; there are many more and the combined effects are synergistic. At Pigeon Hill the communities studied are at the lower depths shown in Figure 2, just above the extinction depth of the algae, (Sears and Cooper, 1978) where only one algal species (Ptilota serrata) predominates, and there is relatively high animal diversity (149 sp) (Hulbert, 1980b; Witman, Ms).

Within each community zone, smaller scale, micro-habitat, community differences are present. One of the more obvious subhabitat differences at Pigeon Hill is the effect of different substrate angles and the associated communities. Communities of horizontal substrates are characterized by algae, amphipods and polychaete worms which form an extensive matrix of tubes. Horizontal communities have a large amount of secondary substrate available to other organisms, both on the tubes and the algae. Communities of vertical substrates are dominated by sponges, tunicates and brachiopods, all suspension feeders. A factor that varies by substrate angle is the amount of light which reaches the surfaces (Figure 3). Algae are largely restricted to horizontal surfaces, probably directly because of the reduced amount of light.

An important aspect of the study was to develop criteria for and select potential indicator species. Some species are important because they form the physical structure of their communities, while other species are important because of their trophic status or potential for controlling prey species. We have approached each species in terms of its functional role (Sutherland, 1978), i.e., its importance in the community when considering it as a possible indicator species. The dynamics of communities are essential aspects for the interpretation of descriptive, baseline data, and future studies at Pigeon Hill should incorporate, as part of the monitoring effort, research on community processes (i.e., biological interactions). Such research would greatly enhance the predictive and interpretive value of the descriptive baseline data in documenting natural population fluctuations and in studying species interactions.

We monitor four indicator species at Pigeon Hill: the red alga, Ptilota serrata (a primary producer), the sea star Leptasterias sp. (a primary carnivore), the tunicate Ascidia callosa, and the brachiopod Terebratulina septentrionalis (both suspension feeders). The use of key indicators of complex communities allows a cost-effective, yet very precise in-situ analysis of their health and potential changes. The in-situ approach also allows observation of the biological interactions occurring, lending insight into the interpretation of future potential community changes based on the criteria of species population structure, trophic importance, and ease of quantitative photography.

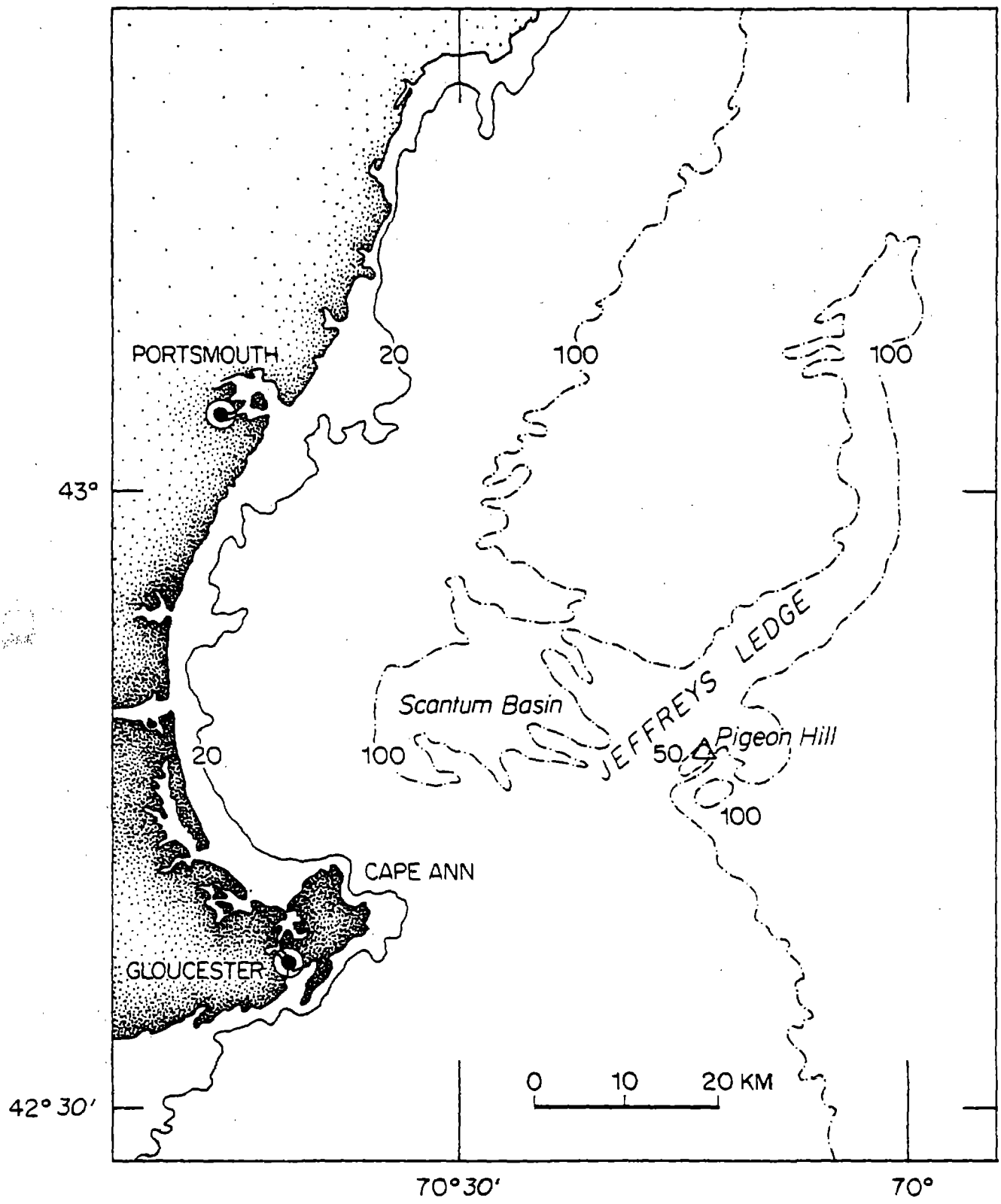
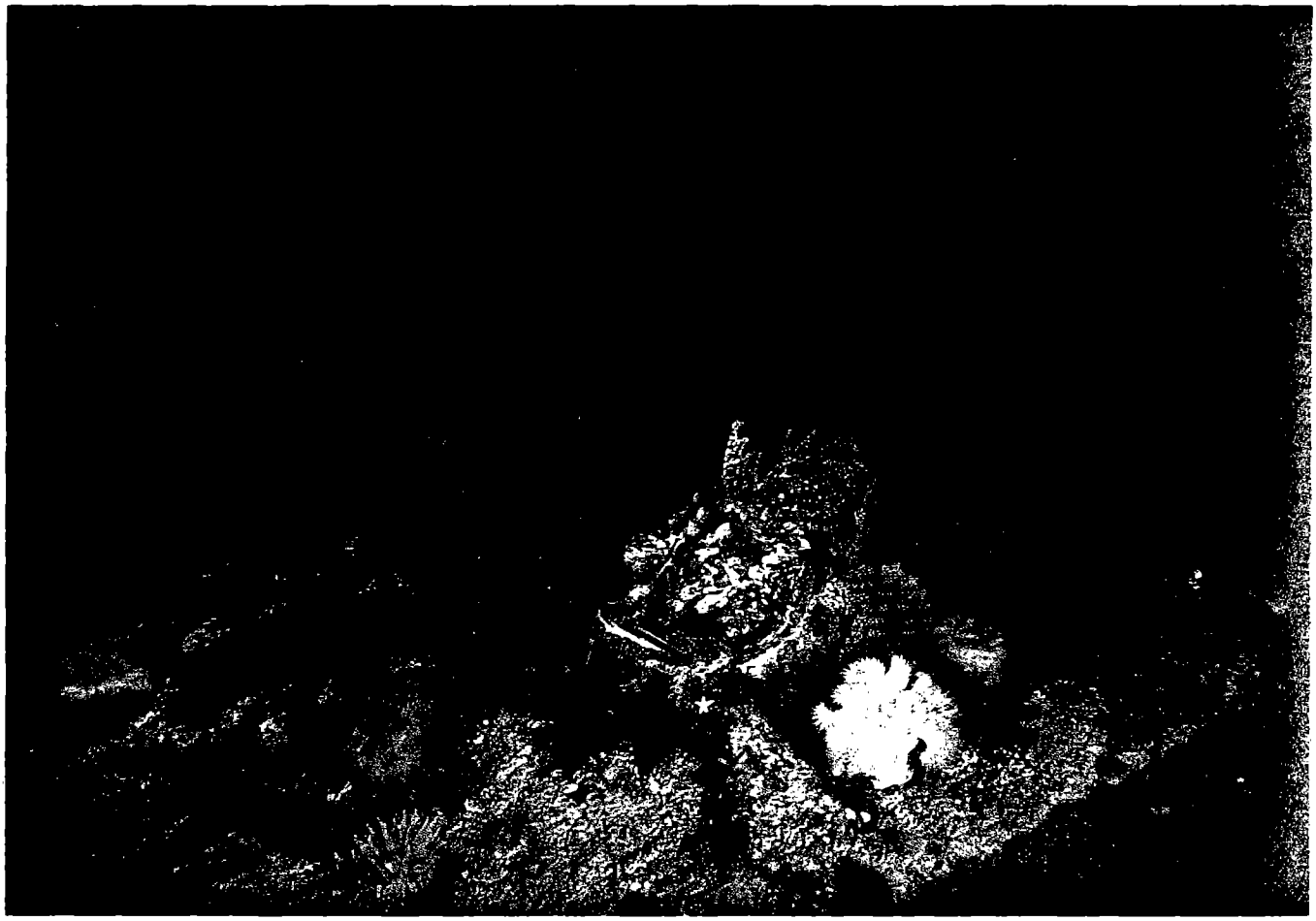


Figure 1: Map of the Jeffreys Ledge area off Cape Ann, Massachusetts, showing the Pigeon Hill monitoring site.

A closeup view of a horizontal community at 33 meters, showing the fleshy alga Ptilota serrata *and a blood star* (Henricia sanguinolenta)*—one of this community's suspension-feeding benthic invertebrates. See Section 4.1 for a detailed description of this community. Photograph by Alan W. Hulbert with Nikonos camera with 3.5:1 extension tube and Kodachrome-64 film. See note below on color photography/multicolor printing.*

Underwater photographic documentation necessitates high resolution and color contrast for resolving and identifying both faunal and floral species. The typical scene, at least in temperate waters, shows grayish blues, grayish greens, and grayish browns. Black-and-white (or gray-contrast) photographs of such scenes reveal an almost indistinguishable mass of gray.



A typical horizontal community at 33 meters, dominated by the fleshy alga Ptilota serrata *and inhabited by the sea raven* (Hemitripterus americanus)*—one of this community's commonly occurring benthic-feeding fishes. See Section 4.1 for a detailed description of this community. Photograph by Alan W. Hulbert with Nikonos camera with 15-millimeter lens and Kodachrome-64 film. See note on next page on color photography/multicolor printing.*

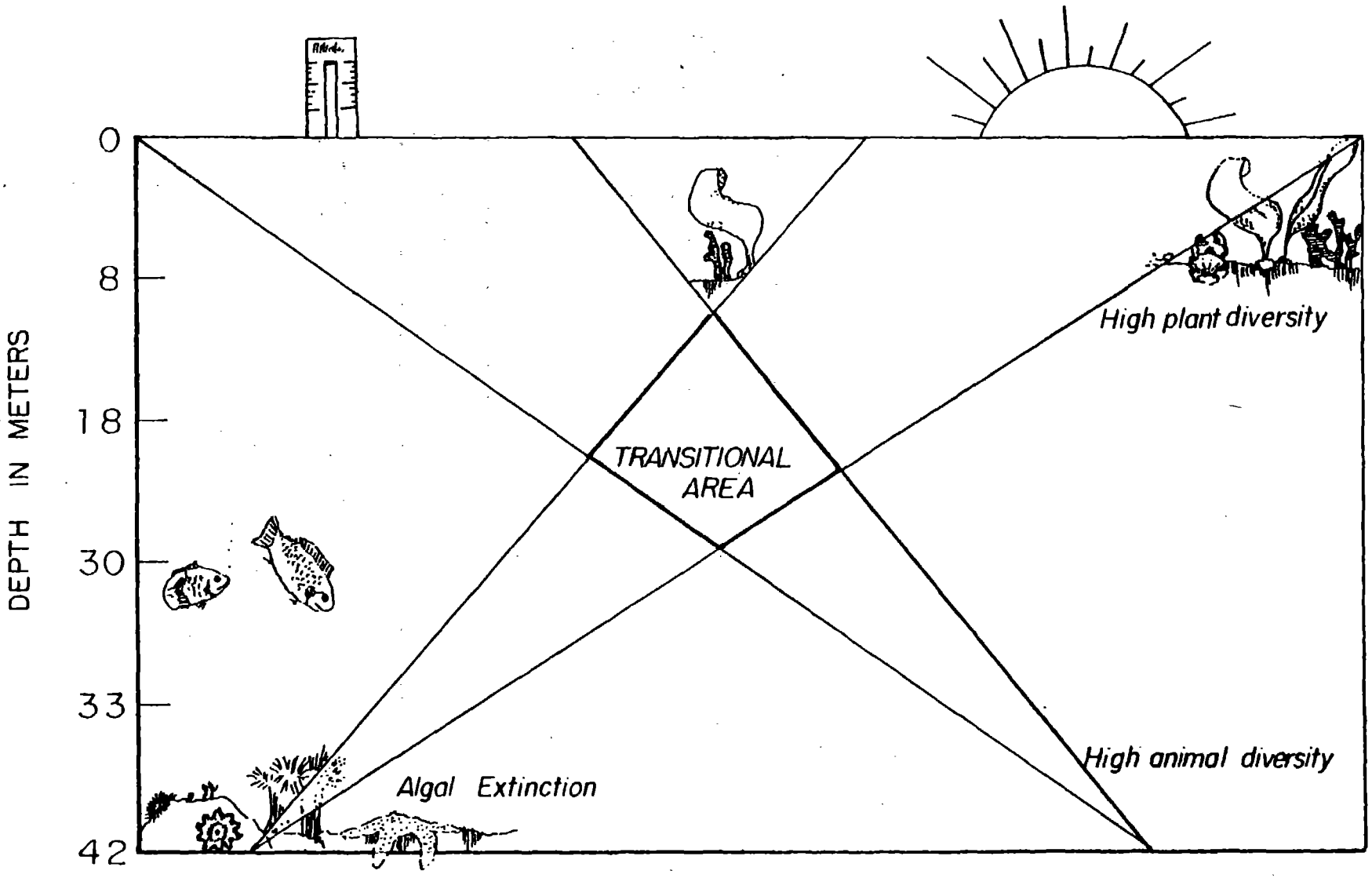


Figure 2: Schematic of interactions of only two physical variables, light and temperature, showing some of the effects on the benthic communities.

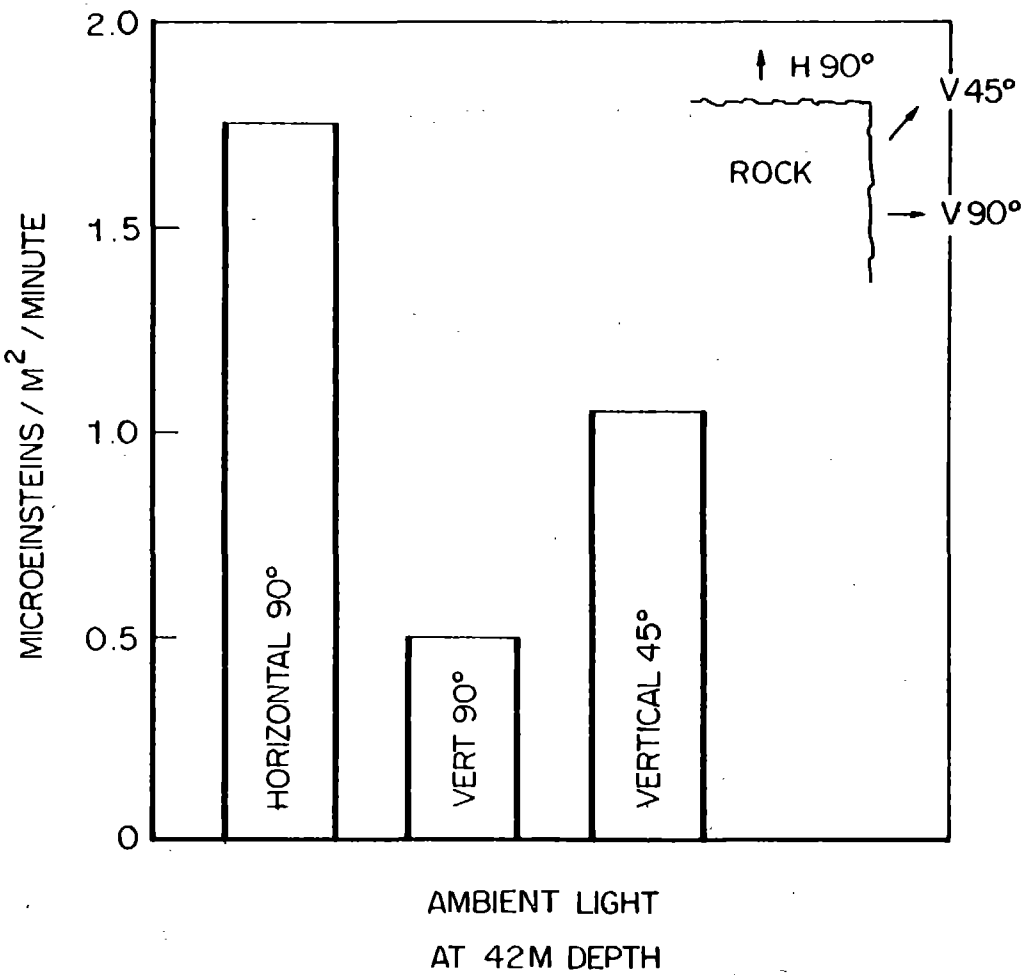


Figure 3: Averaged values of 20 total readings taken in-situ, on 10 July 1980, at midday, showing low overall light at 42 m and the differences in the amount of light reaching different substrata.

3. MATERIALS AND METHODS

A long-term environmental monitoring site was established in October 1977 at Pigeon Hill. Pigeon Hill is a glacially eroded offshore pinnacle located on the south-central portion of Jeffreys Ledge, 37 km off Cape Ann, Massachusetts (Lat 42°46.5'N, Long 70°14.5'W, Figure 1). The knoll rises from a mud bottom at 125 m to within 30 m of the surface. Several factors make Pigeon Hill a good monitoring station: 1) it is representative of deep, offshore rocky communities and relatively unimpacted by coastal pollution; 2) comparative baseline data exists for similar communities at the Isles of Shoals, New Hampshire; 3) it is located in a historically important commercial fishery; and 4) the distinctive topography of the knoll makes it easy to relocate. Initial observations indicated that the benthic communities varied with depth and substrate orientation. Therefore, a stratified sampling design was established with depth and substrate angle corresponding to strata. The depth strata designated were 33 and 42 m, and the substrate angle strata were horizontal and vertical.

Permanent stations were established with an array of two 5,000 pound cement blocks connected by 100 m of wire cable at 33 m and 42 m (Figures 4 and 5). These site markers and five-year acoustic pingers enabled the stations to be readily relocated. The initial 1977 three-week fall cruise was utilized to define the site-specific locations of the substations based on previous observations and reconnaissance dives. Qualitative observations, photographs, and voucher collections were also taken at the sites. The benchmark study was begun during the six-week 1978 fall cruise. The sampling program consisted of both photographic and disruptive airlift sampling as outlined below:

3.1 DISRUPTIVE QUADRATS

Random 0.25 m^2 quadrats on both horizontal and vertical substrata were first photographed, then disruptively sampled and subsequently re-photographed. The rock surfaces were scraped with a putty knife and the organisms collected with an airlift which sucked them into a fine mesh bag (1 mm mesh size). Figure 6 illustrates the airlift which consists of a PVC pipe 1.2 m long and 10 cm in diameter with a collection bag attached to the upper end. Compressed air from a SCUBA tank is forced into a perforated collar at the lower end, creating a strong suction which sucks the organisms up the pipe and into the collecting bag. The airlift system is easily and efficiently operated by a diver. The benthic samples were initially preserved in buffered 10% formalin, and later transferred to 70% alcohol. In the laboratory, the samples were presorted to major taxonomic groups (Phylum or Class) and later identified to species. Data on density, size and biomass was obtained from the samples, and coded for subsequent computer analysis.

3.2 PERMANENT PHOTOGRAPHIC TRANSECTS

Permanent photographic transects were set up at the 33 m station using eyebolts and marine cement (Maricrete). The transects, located by 30 m sections of nylon rope marked at meter intervals, were established on an

upper horizontal rock surface and a vertical rock wall. The transects were then photographed along their entire 30 m length with a standardized photographic device called a "quadrupod" (Figure 7). The quadrupod is a specially designed aluminum camera frame for quantitative photographic sampling of macrobenthic communities. It was designed to hold a Nikonos 35 mm camera with a 15 mm lens and two electronic strobes in position to photograph a 0.25 m^2 area of ocean bottom. Both density and percent cover of the dominant organisms were measured from the photographs. Percent cover, which is an estimate of the percentage of the primary substratum occupied by an organism, was measured with an electronic planimeter at the National Marine Fisheries Service Laboratory, Woods Hole, Massachusetts. The photographs taken along the permanent horizontal and vertical transects were also utilized to reconstruct the benthic communities.

3.3 RANDOM PHOTOGRAPHS

Random quantitative photographs were taken with a quadrupod on adjacent horizontal and vertical substrata for comparison with the results of the permanent transect surveys and from studies on selected species. The purpose of the comparative method was to assure the representative nature and generality of the data from the permanent photographic transects.

3.4 MONITORED QUADRATS

Four of the disruptively sampled quadrats were marked to monitor the subsequent redevelopment of a community on the cleared substrate. Unaltered one-meter square control quadrats were also marked and photographed as controls to follow natural changes in the communities and indicator species.

3.5 PERMANENT QUADRATS

A system of marking permanent 0.25 m^2 quadrats was developed utilizing an underwater drill system in the 1981 monitoring program. A series of holes were drilled into the granite substrate and large numbered plastic tags were screwed to the bottom. The screws formed a template for a quantitative photographic system. Thus specific bottom quadrats can be followed for time-series analysis utilizing photographic techniques (Figure 8).

3.6 FOULING PANELS

A new fouling panel study was implemented in 1981 to test recruitment of the dominant algae (Ptilota serrata) on different substrates. We have observed that fragments of Ptilota often are torn loose and roll along the bottom becoming caught on bottom obstructions such as worm tubes or rough substrate. The colonization experiments were designed to determine the extent and mechanism of recruitment in P. serrata.

3.7 CONTAMINANT ANALYSIS

Samples of asteroids, tunicates, and algae were collected from the research site, using sterile techniques, and immediately frozen on the ship for later baseline body burden analysis of trace metals, hydrocarbons and PCB's.

3.8 GENERAL OBSERVATIONS

At the end of each dive, all divers were debriefed. Qualitative information on species abundances, interactions, movements and general community observations were recorded.

3.9 FISH FOOD HABITS INFORMATION

Concurrent with the benthic sampling program, a survey was conducted (NMFS Woods Hole) to determine the food habits of the major benthic feeding demersal fish species at the Pigeon Hill site. The fish were obtained with a commercial stern trawler, which fished the sides of Pigeon Hill. The information obtained was directly relevant to this study because it indicated which components of the benthic invertebrate communities were preyed on by demersal fish.

3.10 DATA ANALYSIS

The results presented are based on the analysis of 441 0.25 m^2 photographic quadrats and 31 0.25 m^2 disruptive samples collected with the airlift, as well as the synthesis of many qualitative observations. The data were analyzed utilizing a multiple regression forumlation [Log (x+1) transformation] of the general model:

$$y + B_0 + B_1X_1 + B_3X_3 \ldots + B_kX_k + E$$

where B's are regression coefficients to be estimated from the independent variables X_1, X_2, X_3, $\ldots X_k$. The two depths (33 and 42 m) and the two substrate angles (horizontal and vertical) were coded as dummy variables for the analyses (Kleinbaum and Kupper, 1978). The analyses were accomplished utilizing the multiple regression programs of the MINITAB II Statistical Package (Ryan, 1976), as adapted to the DEC 1090 computer system at the University of New Hampshire.

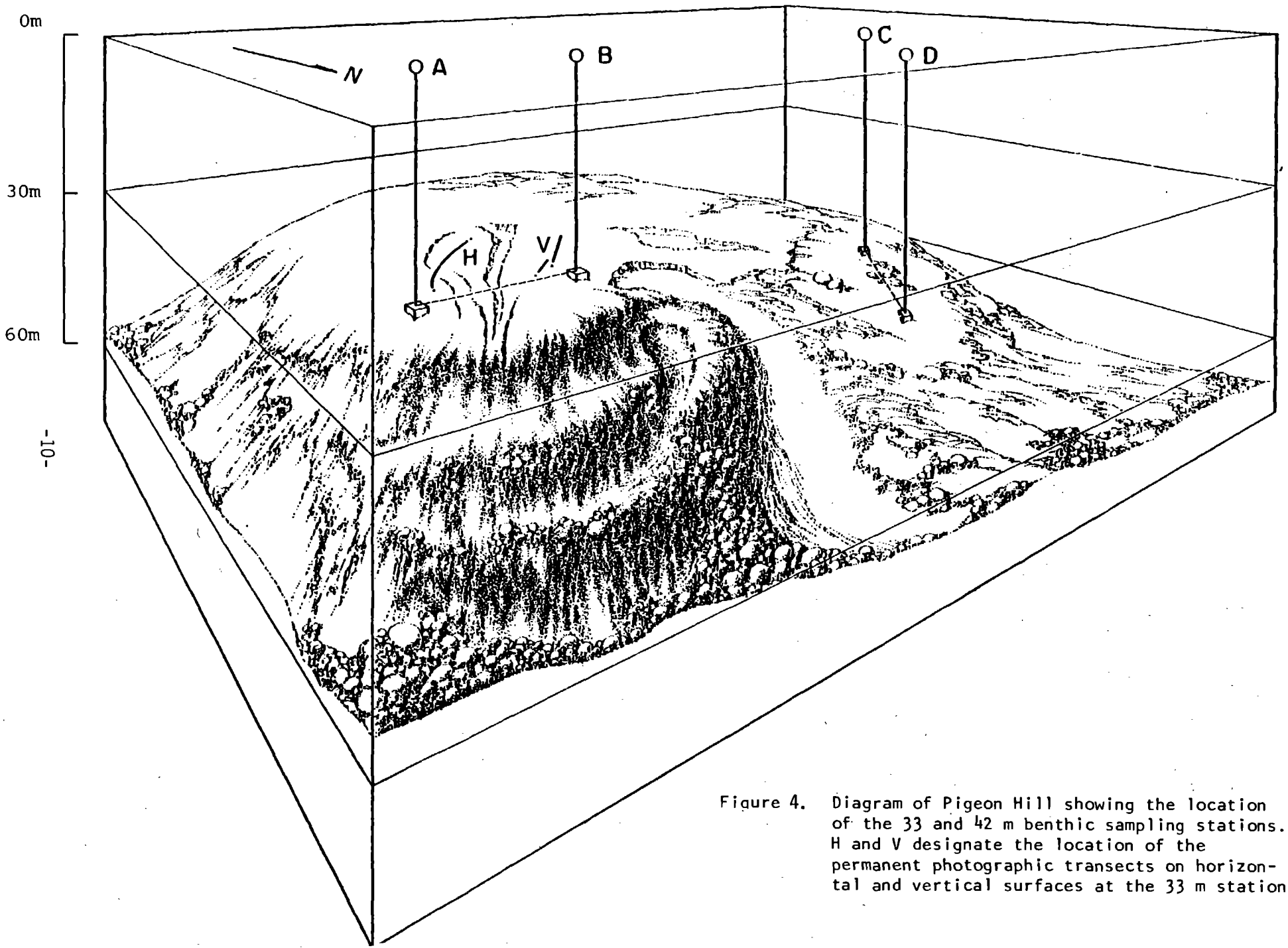


Figure 4. Diagram of Pigeon Hill showing the location of the 33 and 42 m benthic sampling stations. H and V designate the location of the permanent photographic transects on horizontal and vertical surfaces at the 33 m station.

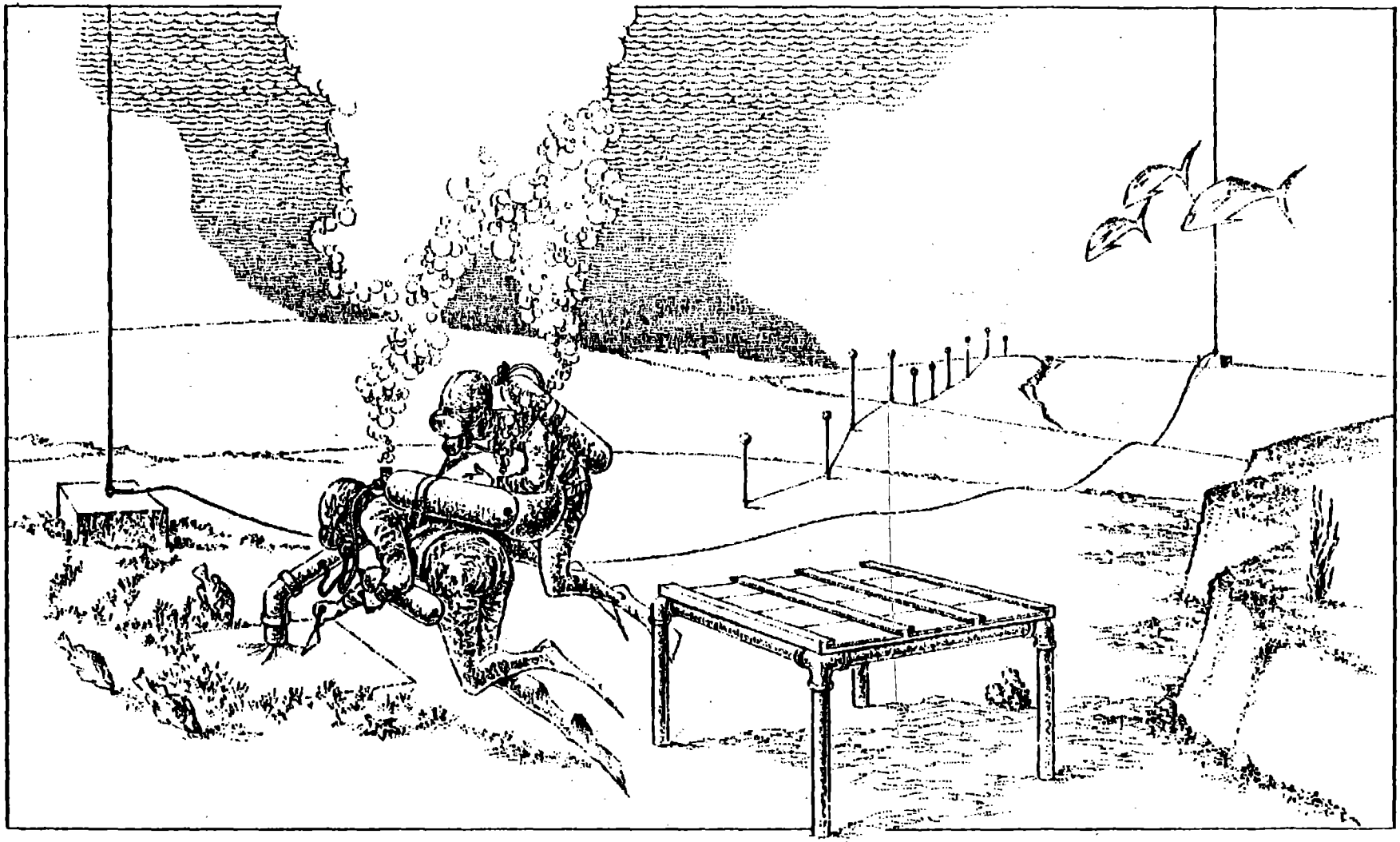


Figure 5. An artist's rendition of divers collecting benthic samples with an airlift at the Pigeon Hill research station. The buoyed line in the background marks the location of one of the permanent photographic transects.

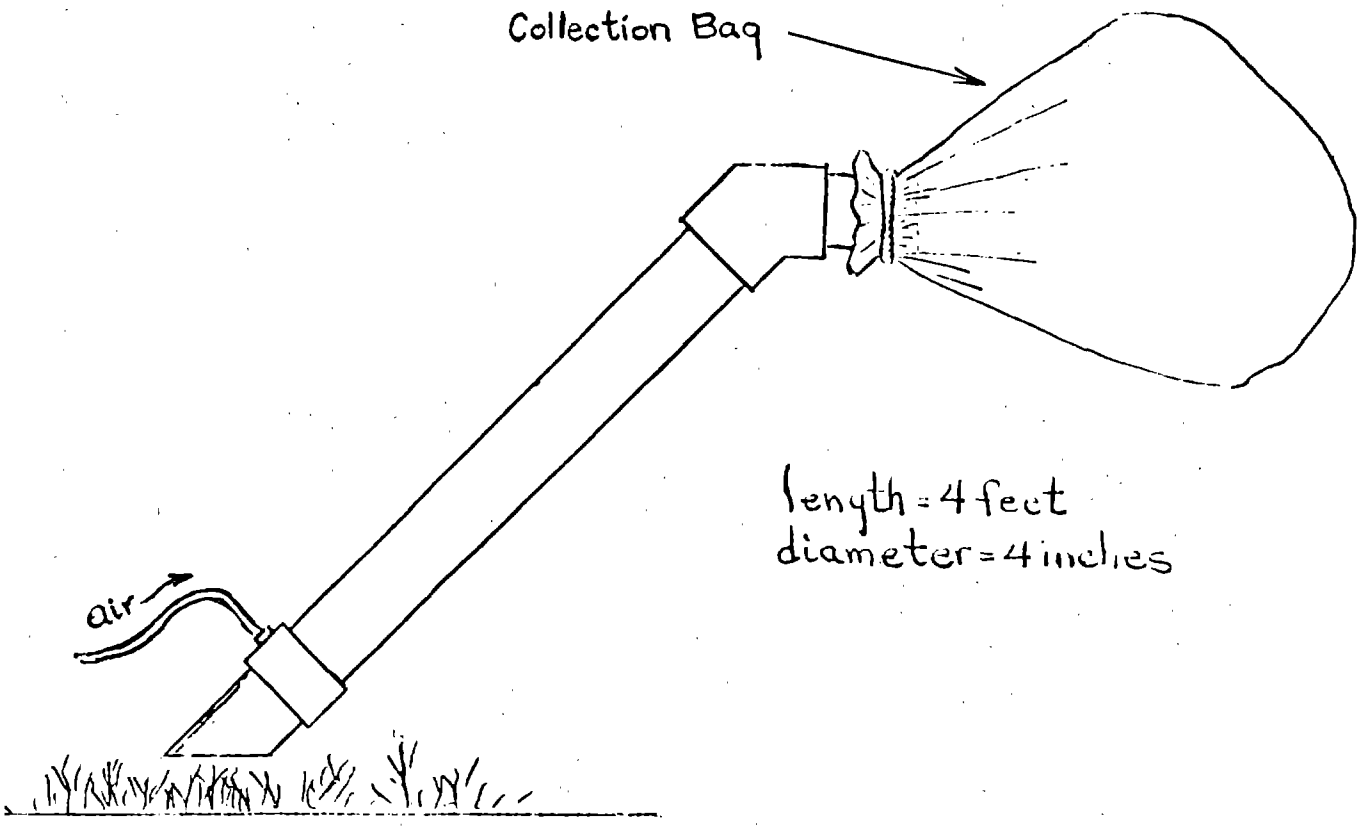
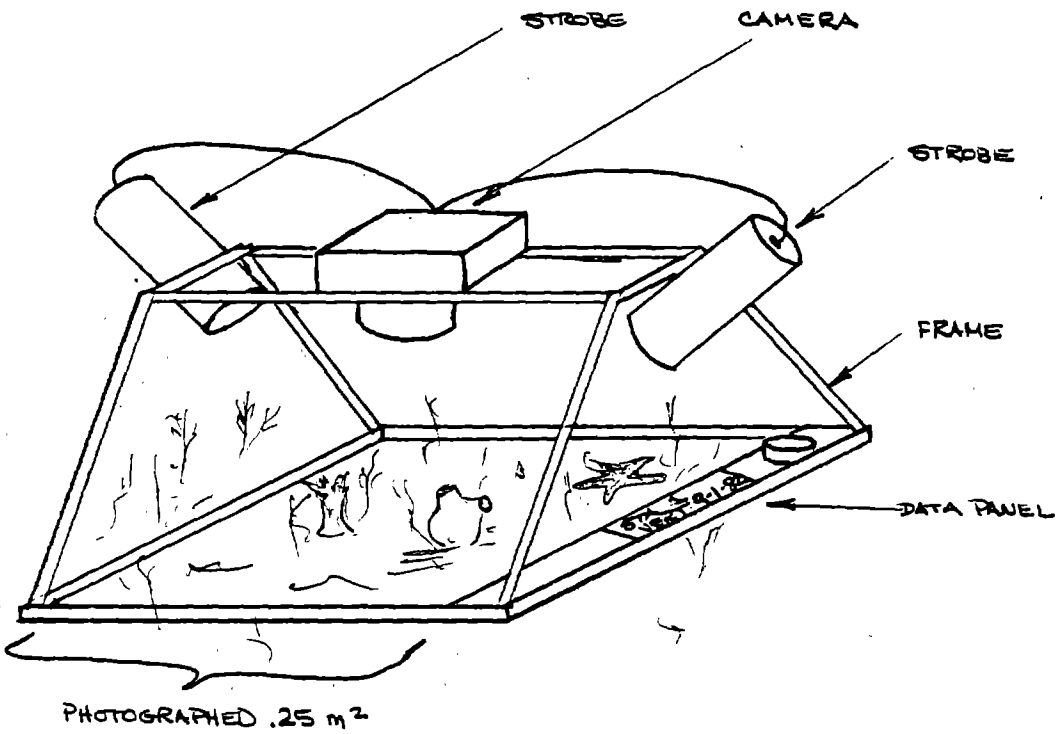


Figure 6. Airlift for in-situ disruptive sampling.

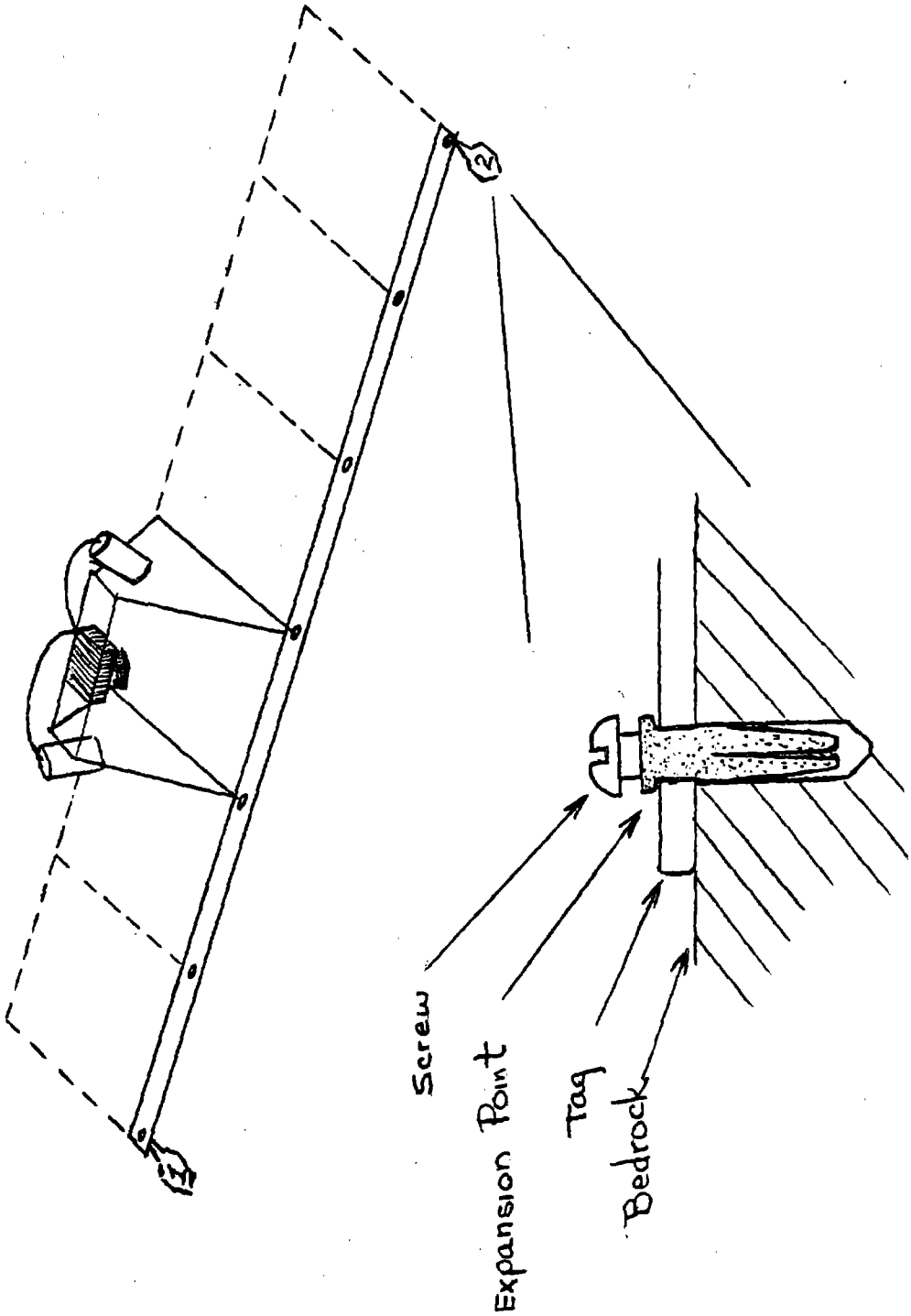


Specifications for Nikor 15 mm lens.

Focal distance	Side "A"	Side "B"	Area included (cm^2)	Proportion of meter sq.
10 cm	20 cm	13.6 cm	272.0	.0272
20	40	27.2	1088.0	.1088
25	50	34.0	1700.0	.1700
30	60	40.8	2448.0	.2448
32.5	65	44.2	2873.0	.2873
35	70	47.6	3332.0	.3332
40	80	54.4	4352.0	.4352
45	90	61.2	5508.0	.5508
50	100	68.0	6800.0	.6800
55	110	74.8	8228.0	.8228
60	120	81.6	9792.0	.9792
62.5	125	85.0	10625.0	1.0625
65	130	88.4	11492.0	1.1492
70	140	95.2	13328.0	1.3328
80	160	108.8	17408.0	1.7408
90	180	122.4	22032.0	2.2032
100	200	136.0	27200.0	2.7200
110	220	149.6	32912.0	3.2912
120	240	163.2	39168.0	3.9168

Figure 7. Quadrupod schematic and specifications.

Figure 8. Permanent Transect Marking System



4. RESULTS

A total of 149 species have been collected from the two depth stations on Pigeon Hill. A species list based on the disruptive samples is presented in Appendix G. The identification of some species in several groups (sponges, ectoprocts, and polychaetes) are still being verified by experts. The species at Pigeon Hill form two major and ecologically distinct benthic communities: an algal-polychaete community and a sponge-tunicate community. The local distribution of the two major communities is differentiated by substrate angle. The algal-polychaete community is largely restricted to horizontal rock surfaces and the sponge-tunicate community to vertical rock walls. Regionally the algal-polychaete horizontal community and sponge-tunicate vertical community are uniformly distributed throughout the Gulf of Maine on hard substrata at depths beyond 30 m. The two communities are further described below. Quantitative photography was taken annually (Tables 7 and 8) and contaminant analyses were done to establish baseline body burdens for the indicator species (Table 10).

4.1 ALGAL-POLYCHAETE COMMUNITY

The dominant species of the algal-polychaete community are the red alga, Ptilota serrata, the sabellid polychaete Chone infundibuliformis and the terebellid polychaete Thelepus cincinnatus. On the average Ptilota serrata covers 66.1% of the substratum on horizontal surfaces at the 33 m station (Table 8, Figures 9 and 15). The mean densities of Chone infundibuliformis and Thelepus cincinnatus on horizontal surfaces at 33 m are 254/0.25 m^2 and 164/0.25 m^2, respectively. Ptilota, Chone, and Thelepus form an important three dimensional habitat structure and provide secondary substrate on horizontal rock surfaces. Ptilota serrata is a fleshy, macroscopic alga with a bushy, upright growth form. Both Chone and Thelepus are tube dwellers and they construct a matrix of sand tubes that is several centimeters thick. The tubicolous amphipods Corophium crassicorne, Ischyrocerus anguipes and Haploops tubicola also form part of the tube matrix on horizontal surfaces. A diverse invertebrate fauna inhabits the secondary substratum layer of bushy red algae and polychaete tubes. Amphipods, caprellids, small asteroids, ophiuroids, brachiopods and ectoproct colonies are the most obvious organisms found on the Ptilota serrata. Tunicates and brachiopods attach to the polychaete tubes. There are nine species of bivalves, 19 species of gastropods, three species of ophiuroids, and at least five species of errant polychaetes living amongst the sediment trapped by the polychaete tubes. Crustose coralline algae cover much of the primary substratum beneath the sediment and tube matrix. The ophiuroids are by far the numerically dominant group associated with the algal-polychaete structure. On upper horizontal surfaces at 33 m, the mean density of Ophiura robusta is 447/0.25 m^2 and the mean density of Ophiopholis aculeata is 127/0.25 m^2.

There is a change in the composition of the algal-polychaete community with depth. Below 38 m the red alga, Ptilota serrata does not occur because light levels are too low to support growth (Sears and Cooper, 1978). Polychaetes remain as the dominant macrobenthic component of the community on upper horizontal surfaces at 42 m. There is an increase in the densities of brachiopods, bivalves and gastropods living on horizontal rock surfaces at 42 m. (See Appendix A for additional documentation.)

4.2 SPONGE-TUNICATE COMMUNITY

The most obvious differences between horizontal and vertical surfaces are that the alga, Ptilota serrata is virtually absent on vertical walls and the primary substratum is relatively free of sediment. At the 33 m station crustose coralline algae cover much of the primary substratum on upper vertical rock walls, surviving overgrowth by sponges and tunicates. Brachiopods (Terebratulina septentrionalis), are most abundant on vertical surfaces with a patchy spatial distribution.

The sponge component of the community is represented by at least nine species, although the actual number of species that occur at Pigeon Hill is probably several times greater. The sponge colonies have several major growth forms. They are: the thin, sheetlike encrustations of Hymedesmia sp. and Halichondria panicea, the rounded globose form of Myxilla fimbricata, Plocamionida ambigua and Iophon pattersoni, and the upright branching form of Haliclona palmata and Haliclona oculata. The mean percent cover by sponges is 17.3% and tunicates cover 6% of vertical surfaces at 33 m. The tunicate fauna is represented by at least seven species. Thus horizontal communities are dominated by fleshy algae and a polychaete tube matrix which provide vertical structure, secondary substrate and trap sediment. Vertical communities are dominated by the colonial growth forms of sponges and tunicates which trap little sediment and have few secondary encrustations. (See Appendix A for additional documentation.)

4.3 FEEDING TYPES

A preliminary trophic classification of the benthic assemblages at Pigeon Hill is presented in Figure 11. The classification was based on the number of species of each feeding type according to the definitions of Fedra et al. (1976). The community consisted of 42% suspension feeders (57 sp), 5% deposit feeders (7 sp), 21% species that were both deposit feeders and herbivores (30 sp), 8% species that feed on two trophic levels; deposit feeders and carnivores (12 sp), and 18% motile carnivores (25 sp). Suspension feeders dominate, which indicates the dependence of the benthos on the input of organic material from the water column. Suspension feeders were distributed on both horizontal and vertical surfaces, however, they were more abundant on vertical surfaces. The motile invertebrate carnivores consisted of asteroids, nudibranchs, errant polychaetes and small crustaceans which were widely distributed. Primary consumers comprised 69% of the species while secondary consumers comprised 18% of the species.

4.4 DISRUPTIVE QUADRAT RESULTS

4.41 Dominant Species

The abundance of 18 dominant invertebrate species was statistically analyzed by depth and substrate angle in addition to the size structure of five of the species (Table 5). Findings for the dominant species are presented below based on the 1978 disruptive samples (Tables 2 and 4). The 1979 samples were similar in most instances (Table 6).

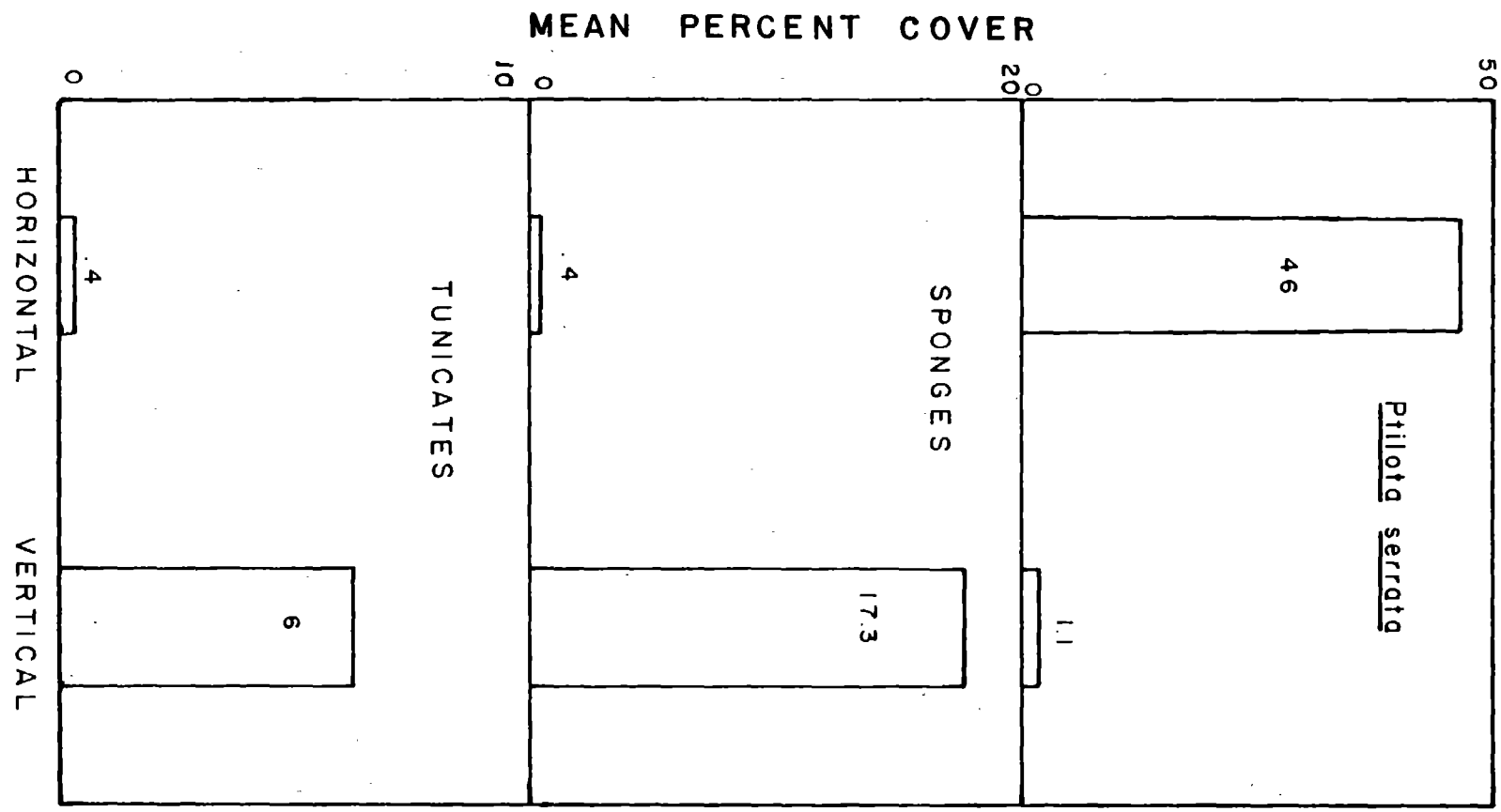


Figure 9. Histogram of mean percent cover of Ptilota, sponges, and tunicates on horizontal and vertical surfaces at 33 m.

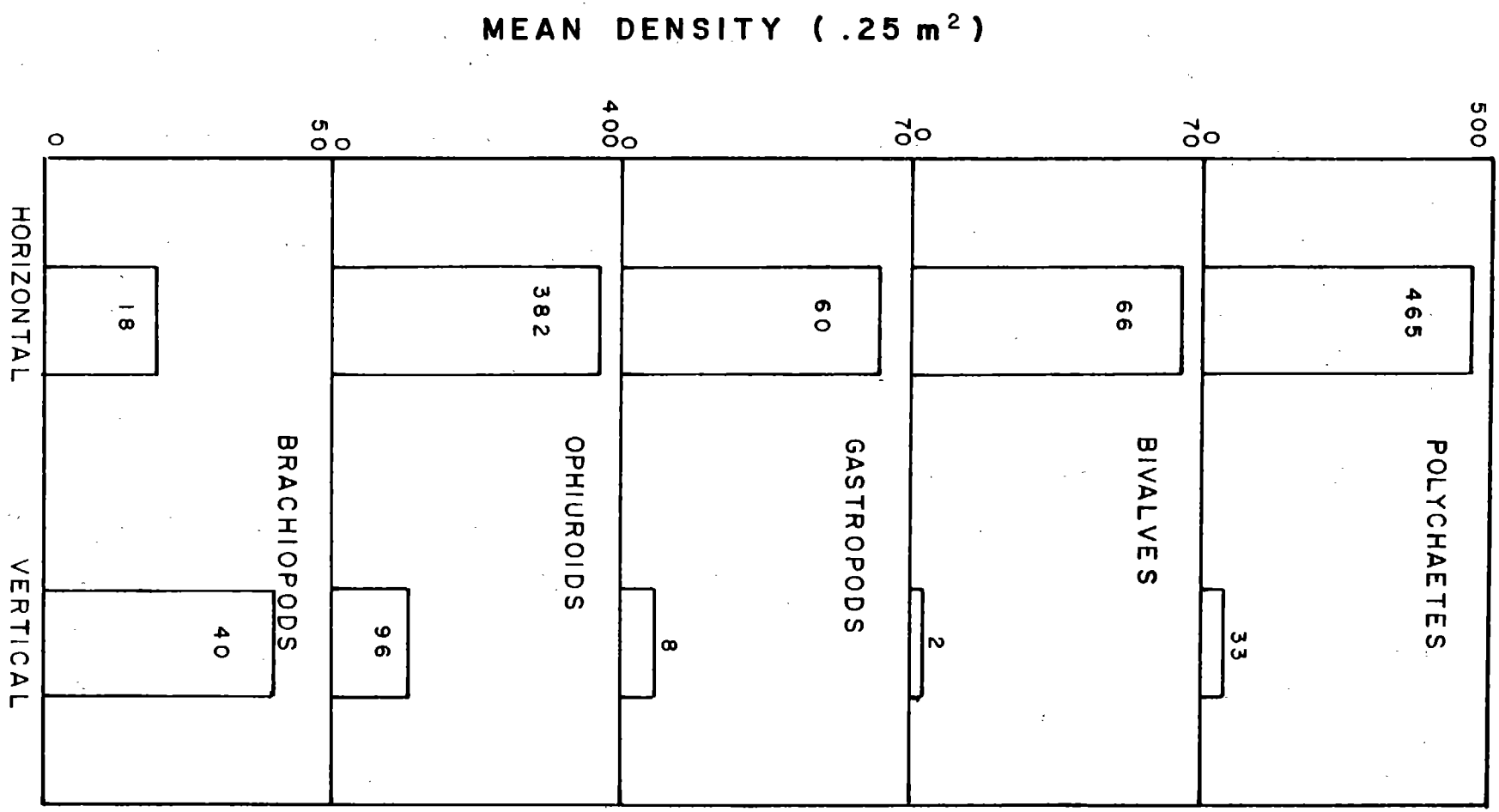


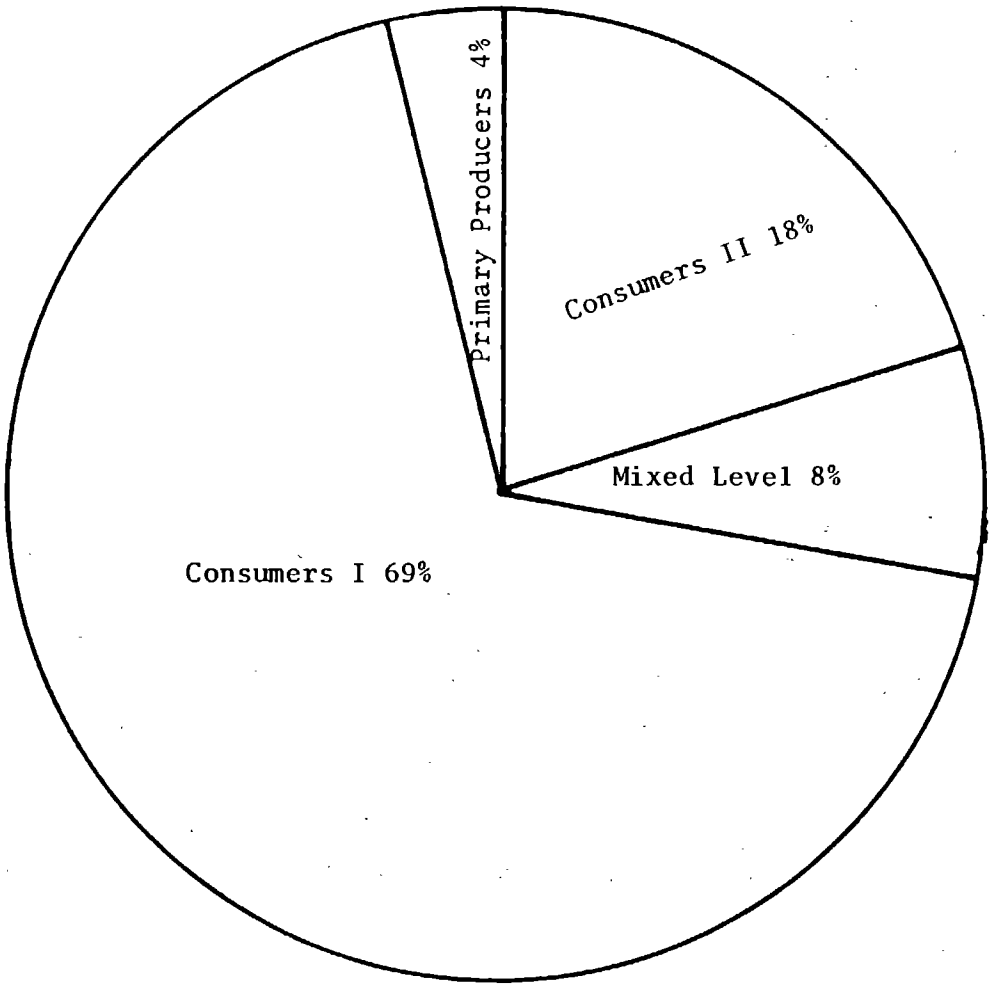
Figure 10. Histogram of mean densities of polychaetes, bivalves, gastropods, ophiuroids, and brachiopods on horizontal and vertical surfaces at 33 m.

Table 1. Abundance of organisms in different macrobenthic taxa (recorded as numbers/0.25 m^2 and percent cover, from the 1978 data) at the 33 m station.

Taxon	Horizontal Surfaces $\bar{x}$ density	Horizontal Surfaces % cover	Vertical Surfaces $\bar{x}$ density	Vertical Surfaces % cover	Statistical Analysis ANOVA
Rhodophyta (Ptilota)		46.0		1.1	***
Porifera	1	0.4	38	17.3	***
Brachiopoda	18		40		**
Annelida Polychaeta	465		33		***
Mollusca: Polyplacophora	2		1		*
Gastropoda	60		8		**
Bivalvia	66		2		*
Arthropoda: Amphipoda	90		155		NS
Caprellidea	83		56		***
Echinodermata: Echinoidea	18		6		**
Asteroidea	5		10		NS
Ophiuroidea	382		96		***
Chordata: Ascidacea	2	0.4	17	6.0	***
Total Density	1192		462		* $p \leq .05$
					** $p \leq .01$
Number of Samples	12	55.0	7	53.0	*** $p \leq .001$

Figure 11. Preliminary trophic classification of the benthic assemblages at Pigeon Hill

PRIMARY PRODUCERS	
Rhodophyta	6 sp
CONSUMERS I	
Suspension Feeders	57 sp
Deposit Feeders	7 sp
Deposit/Herbivores	30 sp
MIXED LEVEL	
Deposit/Carnivores	12 sp
CONSUMERS II	
Motile Carnivores	25 sp



4.411 Brachiopods

The most common articulate brachiopod in the Gulf of Maine is Terebratulina septentrionalis. In shallow water, T. septentrionalis is usually found on vertical and undercut rock walls (Noble, Logan and Webb, 1976). At depths beyond 50 m, it occurs on both horizontal and vertical rock surfaces in high densities (personal observations, AWH, JDW, LGH). The overall mean density at Pigeon Hill was 32/0.25 m^2 and the mean shell length was .99 cm (Table 3). The highest brachiopod density (77/0.25 m^2) occurred on the vertical surface at the 42 m station. Brachiopods living on vertical rock walls were significantly larger than those on upper horizontal surfaces (Table 5). There is a trend of increasing brachiopod abundance with increasing depth (33 to >42 m). Within a particular depth zone, T. septentrionalis is significantly more abundant on vertical surfaces than horizontal (Table 5). Little is known about the ecology of recent brachiopods. Thayer (1975) and Doherty (1979) have found that brachiopods have few predators. Personal observations at Pigeon Hill indicate that the asteroids Asterias vulgaris and Leptasterias sp. both feed on T. septentrionalis, but the extent of predation is unknown. Many of the brachiopods are encrusted with the sponges Iophon nigricans, Iophon pattersoni, and Plocaminionida ambigua. There may be an advantage to a sponge covering as a deterrent from asteroid predation similar to that found for bivalves (Bloom, 1975; Vance, 1978). the sponge may add a porous layer to the brachiopod valves which makes it difficult for asteroid tubefeet to form a proper suction for prey capture. Generally, the size frequency distributions for each strata are bimodal with high frequencies of individuals less than 0.4 cm shell length, and a second node at 1.9 cm shell length in the vertical communities. Most brachiopods settled directly on rock in 1978, but there is a tendency for T. septentrionalis to settle on other substrata such as Ptilota, Sabellid and Serpulid tubes and other brachiopods (Witman, 1982). The brachiopods settling out on the secondary substrata are not as large as those settling directly on rock, possibly indicating that they have lower survival rates. (See Appendix B for additional documentation.)

4.412 Polychaetes

Two polychaete samples were completely analyzed, but for the remaining samples the polychaetes were subsampled from the 0.25 m^2 pre-sorted samples to obtain estimates of biomass and abundance. The total weight of the polychaetes collected from the 1978 cruise was 3540 grams of which 456 grams were analyzed (13% of total material). Nineteen species of polychaetes comprising 11 families were found. Chone infundibuliformis, a sabellid; and Thelepus cincinnatus, a terebellid; both tube builders, comprised 96% of the polychaete fauna. Polychaetes were most abundant on horizontal substrates (Table 3)

where they formed a major part of the three dimensional structure of the community. Tubicolous polychaetes are an important food source for demersal fish species (NMFS data; personal observations, AWH, JDW).

Chone infundibuliformis: The most abundant polychaete occurred in mean densities of 254/0.25 m^2 at 33 m and 236/0.25 m^2 at 42 m on horizontal surfaces (Table 3). This sabellid was significantly more abundant on horizontal surfaces and there were no differences in mean density with depth (Table 5).

Thelepus cincinnatus: On horizontal substrata at 33 and 42 m, this terebellid occurred in mean densities of 164/0.25 m^2 and 32/0.25 m^2, respectively. Thelepus was significantly more abundant at the 33 m station and on horizontal surfaces (Table 5).

Nereis pelagica: An errant, predatory polychaete, Nereis was equally abundant on vertical and horizontal substrata at both depths. The mean densities of the species did not differ significantly by depth or substrate angle (Table 5).

Benthic feeding fish are important predators on polychaete worms. The concurrent fish stomach analysis showed large numbers of polychaetes in the stomachs of yellowtail and winter flounder, and cod and haddock that were less than 30 cm in length. (See Appendix C for additional documentation.)

4.413 Molluscs

There were 40 species of molluscs collected (comprised of two species of chitons, 19 species of prosobranchs, eight species of opisthobranchs and nine bivalve species), of which seven were sufficiently abundant to analyze statistically (Table 5). The dominant species were the prosobranchs Margarites costalis, Anachis lafresnayi, Colus pygmaeus, and the bivalves Hiatella arctica, Cerastoderma pinnulatum, Modiolus modiolus and Musculus niger. All of the dominant species were significantly more abundant on upper horizontal substrata (Table 5). Only the densities of Cerastoderma and Modiolus varried significantly with depth; both species were more abundant at 42 m than at 33 m (Table 5).

Margarites costalis: Maximum denties of 14/0.25 m^2 occurred on horizontal substrata at 33 m. The overall mean density was 4.7/0.25 m^2 (Table 3).

Anachis lafresnayi: The most abundant prosobranch gastropod at Pigeon Hill, it occurred in densities of 50 individuals/0.25 m^2 on horizontal surfaces at 33 m with an overall mean density of 20/0.25 m^2 (Table 3). It is likely that Anachis preys on Cerastoderma pinnulatum, as many drilled Cerastoderma were collected.

Colus pygmaeus: Colus was significantly more abundant on horizontal substrata at both 33 and 42 m, where mean densities of 6.8 and 15.6/0.25 m2 occurred (Table 3 and 5). Colus may also drill Cerastoderma.

Hiatella arctica: Most abundant in the polychaete tube matrix on horizontal surfaces at 33 and 42 m, Hiatella had mean densities of 12.6/0.25 m^2 at 33 m, and 11.3/0.25 m^2 at 42 m. It was not found on vertical surfaces at 42 m.

Cerastoderma pinnulatum: The most abundant bivalve at Pigeon Hill had significantly higher densities on horizontal substrata and a significant trend of increasing abundance with depth (Table 5). Mean densities of 30.8/0.25 m^2 and 93/0.25 m^2 occurred on horizontal surfaces at 33 and 42 m, respectively (Table 3).

Modiolus modiolus: The mussel was virtually absent on vertical surfaces, while small individuals were patchily distributed in the sediment layer on horizontal surfaces. Mean densities were 14.8/0.25 m^2 at 33 m and 19.5/0.25 m^2 at 42 m (Table 3). The size frequency histogram of the Modiolus population (Appendix E) has a mode at 1-3 mm shell length, indicating the overall small size of individuals. Adult Modiolus are rare at Pigeon Hill, occurring only rarely in crevices at the base of vertical walls. At similar depths and communities at the Isles of Shoals, adult Modiolus are more abundant (Witman, 1979). The scarcity of adult Modiolus modiolus at Pigeon Hill is presently unexplained, but may be related to predation, since many empty shells can be found.

Musculus niger: Musculus, a mytilid bivalve, was significantly more abundant in the sediment layer on horizontal surfaces (Table 5) than in vertical communities. Mean densities on horizontal surfaces were 6.6/0.25 m^2 at 33 m and 4.3/0.25 m^2 at 42 m (Table 3). (See Appendix D for additional documentation.)

4.414 Crustaceans

Amphipods: There were 2412 amphipods in the 24 disruptive samples from 1978 comprising 27 species. Unidentifiable individuals comprised 15% of the total (364 individuals). Average densities were 155/0.25 m^2 at 33 m and 55/0.25 m^2 at 42 m for the vertical walls and 90/0.25 m^2 at 33 m and 45/0.25 m^2 at 42 m for horizontal surfaces (Table 3). Amphipods were most abundant at the 33 m station and on vertical surfaces (Table 3). Two species, Pleusymtes glaber and Pontogeneia inermis, common on both horizontal and vertical substrata, comprised 67% of the overall amphipod abundance. Two species, Corophium crassicorne and Phoxocephalus halboli were common only on horizontal surfaces and two others were common only on vertical surfaces (Amphithopsis longicaudata and Dyopedos porrecta).

Three species, Corophium, Pontogeneia, and Plausymtes were sufficiently common to allow statistical analysis (Table 5).

Corophium crassicorne: Corophium was significantly more abundant on horizontal substrata (Table 5) and there were no discernible abundance differences between depths. Overall mean density was 4.7/0.25 m^2.

Pontogeneia inermis: The overall mean density of Pontogeneia was 37.5/0.25 m^2, making it the most abundant species of amphipod. Densities were significantly higher at 33 m than 42 m and there were no differences attributable to substrate angle (Table 5).

Pleusymtes glaber: The overall mean density of Pleusymtes was 29.5/0.25 m^2. Pleusymtes was significantly more abundant at 33 m than 42 m, and there were no significant differences in abundance between vertical and horizontal substrata (Table 5).

Caprellids: Caprellids are abundant on secondary substrates, such as algae or sponges, where they function as micro-predators catching small planktonic organisms. Two species are common, Caprella linearis and Aegina longicuris. Although biomass is low for caprellids ($\bar{x}$ = 0.2 gram/0.25 m^2; Table 4) they occur in high densities of small individuals.

Crabs and lobsters: Crabs and lobsters occur as upper level predators at Pigeon Hill, but their abundances are low, approximately one cancer crab/100 m^2 and one lobster/500 m^2 of bottom area. Hyas coarctatus, a small spider crab, was found in two 0.25 m^2 disruptive samples (Table 2).

Crustaceans are important as food for many demersal fish. The concurrent fish stomach analysis showed large numbers of amphipods and caprellids in the stomachs of small cod and haddock. The micro-predators are probably very important in energy transfer between trophic links in the communities at Pigeon Hill. (See Appendix E for additional documentation.)

4.415 Echinoderms

The echinoderms were numberically dominant in both vertical and horizontal communities at 33 m and 42 m. Fourteen species were collected of which five were common enough for statistical analysis. The rare species included: the sea cucumbers Psolus fabricii and Cucumaria frondosa; the ophiuroid Axiognathus squamatus; and the sea stars Asterias vulgaris, Henricia sanguinolenta, Crossaster papposus, Solaster endeca, Hippasteria phrygiana and Porania insignis (Table 2). Pteraster militaris was also present but was not found in the disruptive samples.

The two species of sea cucumber are suspension feeders which feed by spreading the tentacles into the current and catching planktonic prey. Psolus is commonly found attached in an exposed position while Cucumaria typically utilizes a refuge such as a crack or algal holdfast from which it extends its feeding tentacles.

Of the rare asteroids at Pigeon Hill, Asterias and Henricia are ubiquitous species at all depths throughout the Gulf of Maine. Crossaster, Solaster, Hippasteria, and Porania are boreal species found typically only in the deeper, colder waters (below 30 m). Asterias is a generalist which is a dominant in most Gulf of Maine benthic communities where it feeds upon a variety of prey, generally in relation to availability within a subhabitat, within overriding predator-prey size constraints. Henricia functions either as a suspension feeder curling back its arms and catching plankton while sitting in an exposed position, or a predator on ectoprocts, sponges, and occasionally on sea urchins. Crossaster is a predatory asteroid which has been observed feeding upon Asterias and sea urchins. In the eastern Atlantic Crossaster's preferred prey is Asterias (Hancock, 1974). Solaster is another predatory asteroid which has been observed feeding upon Asterias and Psolus. In the subhabitats where it is available Solaster preys almost exclusively on Psolus. The low densities of Asterias, typically a dominant in benthic communities, may well be related to predation by Crossaster and Solaster at Pigeon Hill. Hippasteria is typically a soft coral predator. Hippasteria has been observed feeding upon Gersemia, a soft coral, and Metridium, a sea anemone, but the species is rare at Pigeon Hill and few direct observations have been made.

The five common species of Echinoderms are discussed below:

Strongylocentrotus droebachiensis: Only one species of sea urchin occurs at Pigeon Hill, and it was common in all samples. Mean size, measured as the diameter of the test, was 0.52 cm, and mean density was 14/0.25 m^2 (Table 3). No statistical difference existed in mean size or abundance between the 33 m and 42 m stations, but the mean size of individuals on vertical walls was larger than of those on horizontal surfaces (Table 5). The mean densities of urchins tended to be higher on horizontal surfaces. Thus there were more urchins in the horizontal communities, but they were smaller, however, the habitats were supporting the same urchin biomass. The average biomass was 1.10 grams/0.25 m^2 (SD = 0.79) and 0.89 (SD = 0.47) for vertical and horizontal surfaces, respectively, giving totally overlapping 95% confidence limits. Small urchins are an important food source for many demersal fish species (NMFS data, unpublished; personal observations, AWH, JDW). A blotted wet weight (biomass) to diameter of urchin (size) size regression equation (Hulbert, unpublished

data), for convertability of data for Stronglyocentrotus droebachiensis is: Log weight = 0.135 + 2.30 Log Size (r^2 = 96.3%, P < .001, df = 155).

Ophiuroids: Two species of brittle stars were present in high densities. Ophiopholis aculeata occurred in mean densities of 80/0.25 m^2 with no difference in density with depth or substrate angle (Tables 3 and 5). Ophiura robusta occurred in mean densities of 220/0.25 m^2 and, although there were no depth differences found, they were more abundant in the horizontal communities (Table 5). The brittle stars are a major component of the communities and perform an important energy transfer from the pelagos to the benthos by capturing planktonic prey and assimilating it. The brittle stars are a major food source of demersal fish species. During fall 1978, 83% of the adult haddock (Melanogrammus aeglefinus) we caught on Pigeon Hill contained brittle stars in their stomachs. Cod (Gadus morhua) and cunner (Tautogalabrus adspersus), also had many brittle stars in their stomachs (unpublished data, NMFS; personal observations, AWH, JDW).

Asteroids: Two species of sea stars were common at Pigeon Hill, Stephanasterias albula and Leptasterias sp. Stephanasterias albula was the most abundant asteroid ($\bar{x}$ = 6.9 individuals/0.25 m^2). They were all small (< 1.0 cm) as measured from the tip of the largest arm across the disc to the opposite interadii (mean size = 0.66 cm). Stephanasterias is a fissiparous asteroid that reproduces by breaking off arms, which then regenerate new individuals. Gonads have never been observed in the species. The number of arms per individual ranged from one to eight. Frequently there were one or two larger arms and a number of smaller incipient arms. Higher densities of Stephanasterias occurred in the deeper communities and individuals were larger in the horizontal communities (Table 5). Virtually nothing is known about the species. Generally, it is extremely rare in the Gulf of Maine, occurring at Eastport, Maine (unpublished data, Charles Walker, University of New Hampshire), and the Isles of Shoals, New Hampshire (personal observations, AWH). It was observed feeding upon small bivalves in the polychaete tube matrix at the 33 m Pigeon Hill station, but its functional role in the communities is unknown.

Leptasterias sp.: A species of Leptasterias is the second most abundant asteroid at Pigeon Hill ($\bar{x}$ = 2.2 individuals/0.25 m^2). There was no difference in the abundance of Leptasterias sp. with depth or substrate angle, but they were significantly larger on vertical walls (Table 5). All of the individuals were small (max size = $\approx$ 2.0 cm), as measured from the tip of the largest arm across the disc to the opposite interadii. Leptasterias sp. occurs throughout the Gulf of Maine on deeper rocky substrata and bears affinities to Leptasterias

littoralis, but it has a number of conservative traits (Hulbert, 1980a, 1980b). The species is sexually mature at 3-5 mm (as measured above), never reaches a large size (max = 7.0 cm) and broods embryos from December to March. A 5.0 mm individual frequently broods 16-18 embryos which crawl away from the adult after the yolk stalk is absorbed. They have been observed to eat small bivalves, polychaetes, and hydroids in the horizontal communities and brachiopods on the vertical walls.

As a group, the asteroids prey on sessile organisms in the benthic communities at Pigeon Hill. They are eaten by fish, but appear to be taken only incidentally to the intended food of the fish. A characteristic of the echinoderms in general at Pigeon Hill, and especially the urchins and asteroids, is the large number of very small individuals ($\bar{x}$ size $\tilde{\sim}$ 0.5 cm). (See Appendix F for additional documentation).

4.5 PERMANENT TRANSECT RESULTS - QUANTITATIVE PHOTOGRAPHY

The results of the photographic analysis of indicator species is shown in Table 7 and Figures 12, 13 and 14. The indicator species considered in this report are asteroids (predominantly Leptasterias sp.), brachiopods (Terebratulina septentrionalis), and solitary tunicates (predominantly Ascidia callosa).

The percent cover of algae (predominantly Ptilota serrata) is considered in a later section as another indicator of the horizontal community.

Vertical surfaces had higher abundances of the three indicator groups. The higher vertical abundances are in part due to enhanced photographic detectability in the absence of an algal canopy, but as shown for Leptasterias, Terebratulina and tunicates in the disruptive samples (Table 3) there are more individuals on vertical surfaces, and thus the higher abundances are a real aspect of the communities. Ascidians and brachiopods are an integral portion of the ecology of vertical surfaces, as discussed earlier, where they probably find a more suitable suspension feeding environment in the absence of the dense algal mat typical of the horizontal areas. Asteroids are motile predators and can be expected to range over both substrates. Part of the variability in results is due to the fine grained sampling strata relative to the range of the asteroids.

The 1978 results in Table 7 and Figures 12, 13 and 14 are derived from photos taken with a prototype quadrupod system which did not give the high resolution of the later system. The 1978 photographic results are, therefore, tentative when compared to the later three years.

Based on the relatively large number of 0.25 m^2 photographic samples per year (50-60), sampling at approximately the same time each year (June-July) and the precision of the stratified sampling protocol we feel we are seeing the true variability of the communities in the results presented here (Table 7). Discerning the internal variability is a key to the success of interpreting future external impacts.

4.6 ALGA PERCENT COVER AND BIOMASS

Yearly trends in algal abundance, based on 0.25 m^2 quadrats along a horizontal transect, determined from 0.25 m^2 photographs are shown in Table 8 and Figure 15. Analysis of quantitative photographs from the vertical transect showed low algal coverage (<2%) with very few Ptilota plants. Horizontal surfaces are dominated by a dense algal mat averaging 66.1% of the surface area over the period 1978-1981. Algal cover was 47% in 1978, increased to 73.4% in 1979, 76% in 1980, and decreased slightly to 68% in 1981. The general increase from 1978 may represent a natural fluctuation in coverage and growth, a restoration to a naturally high coverage following a reduction in 1978, or an abnormally high rate of algal growth in 1979 that is gradually returning to the 1978 level.

Two marked square meter areas which have been monitored since 1978 have shown the same trends in algal coverage as the transect results.

4.7 CONTAMINANT BODY BURDENS

Baseline body burdens of heavy metals, PCB's, and anthropogenic hydrocarbons were established from samples taken in July, 1980, from the Pigeon Hill site. The samples were processed by Cambridge Analytical Associates in Cambridge, Massachusetts, and their techniques are included in Appendices H and I. The results for heavy metals are shown in Table 10, Figure 16, and Appendix H; and for PCB's and hydrocarbons in Appendix I.

Cambridge Analytical Associates reports number ASD-80-127, 82-031, and 81-455B presented the findings from analysis of our samples on a wet weight basis. Results show low levels of hydrocarbons. Straight chain hydrocarbons of petroleum input were not present. Also, PCB's were not present at a 2 ppb limit of detection.

Levels of heavy metals were within normal limits. We note that barium was of a higher level than in specimens from offshore sites. Algae (Ptilota serrata) was resampled in 1981 for comparative purposes. Heavy metal body burdens were similar between years with the exception of cadmium which showed an increase from 0.04 ppm in 1980 to 0.56 ppm in 1981.

Table 2. Abundance, size, and biomass of common invertebrates and algae collected by airlift sampling in 1978. Density recorded as counts/0.25 m^2, biomass as grams/0.25 m^2, and mean size in centimeters.

Species	Parameter	Quadrat Sample Number H1	H2	H3	H6	H7	H8	H9	H10	H11	H12	H15	H16
POLYCHAETES	Biomass	103.16	185.33	133.16	207.55	469.96	178.77	202.02	576.83	232.67	98.10	172.91	76.41
Chone infundibuliformis	Density	168	210	249	85	353	353	162	697	107	86	253	334
Thelepus cincinnatus	Density	74	210	149	254	88	0	259	498	72	139	56	170
Nereis pelagica	Density	50	0	0	0	0		97	100	0	0	28	0
MOLLUSCS	Biomass	4.23	4.92	3.44	2.49	3.51	2.18	1.15	5.14	1.66	2.18	2.12	2.17
Hiatella arctica	Density	11	25	34	13	5	14	4	7	1	25	11	2
Cerastoderma pinnulatum	Density	13	33	50	121	8	44	18	18	24	31	6	3
Modiolus modiolus	Density	2	7	6	141	1	3	2	0	2	3	4	6
Musculus niger	Density	12	13	10	8	1	3	5	1	5	4	18	0
Margarites costalis	Density	4	17	18	10	6	5	8	9	0	5	13	5
Anachis lafresnayi	Density	28	56	73	59	40	33	10	38	20	6	17	13
Colus pygmaeus	Density	5	14	8	21	11	4	2	5	3	3	0	3
Mitrella rosacea	Density	0	0	0	0	0	3	6	1	10	4	7	7
Tonicella rubra	Density	0	6	3	0	1	6	3	2	0	19	6	5
CRUSTACEANS	Biomass	.03	.23	.16	.41	.37	.67	.40	.12	.02	.11	.33	.01
Pleusymtes glaber	Density	6	18	29	38	41	59	60	17	1	12	73	1
Pontogeneia intermis	Density	7	51	22	60	87	127	62	16	4	24	37	0
Corophium crassicorne	Density	0	10	3	22	3	10	17	1	0	0	1	0
CAPRELLIDS	Biomass	.20	.29	.34	.20	.17	.13	.28	.25	.06	.05	.75	.62
BRACHIOPOD	Biomass	13.01	7.35	6.58	1.21	4.98	10.11	2.89	11.75	4.69	1.51	1.52	5.43
Terebratulina septentrionalis	Density	34	18	27	25	8	10	13	21	8	11	18	18
	Size	.99	1.07	.75	4.15	1.08	.71	.93	1.14	1.30	.70	.61	.81
ECHINODERMS	Biomass	5.47	15.77	14.74	1.43	3.35	.84	4.90	1.13	1.19	.79	17.02	18.16
Strongylocentrotus droebachiensis	Density	20	23	37	36	9	15	12	13	9	14	30	4
	Size	.55	.41	.41	.34	.58	.43	.51	.47	.52	.54	.43	.63
	Biomass	1.71	.94	1.88	.39	.36	.80	1.09	.93	.62	.60	1.42	.39
Stephanasterias albula	Density	2	0	1	1	0	1	2	0	0	0	13	7
	Size	.6	0	.6	.9	0	.8	.65	0	0	0	.72	.94
Leptasterias sp.	Density	0	0	1	0	1	1	2	1	0	0	8	12
	Size	0	0	.6	0	1.2	.4	.5	1.5	0	0	.71	1.41
Ophipholis aculeata	Density	48	76	52	37	41	0	61	48	19	28	227	146
	Biomass	2.62	0 00	1.12	1.01	2.83	0.00	3.38	0.00	0.57	.18	13.41	6.85
Ophiura robusta	Density	415	389	505	271	359	140	389	450	366	160	91	273
	Biomass	0.00	0.00	9.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	3.85
ALGAE	Biomass	55.50	47.90	34.80	21.00	29.00	18.70	35.60	51.50	11.20	20.00	103.00	96.00
Total Biomass/0.25 m^2		215.06	290.01	221.32	247.93	515.55	244.21	260.48	649.67	256.17	131.50	333.79	220.14

Table 2.

Species	Parameter	V1	V2	V3	V4	V5	V6	V7	DH1	DH2	DH3	DV1	DV2
POLYCHAETES	Biomass	21.16	20.58	32.06	14.69	27.06	0.00	16.63	248.94	188.20	201.59	54.01	85.08
Chone infundibuliformis	Density	6	15	21	0	0	0		180	194	336	0	18
Thelepus cincinnatus	Density	25	10	0	8	36	8		216	0	180	0	0
Nereis pelagica	Density	0	0	36	4	7	0		36	0	9	15	18
MOLLUSCS	Biomass	.55	1.05	.26	1.97	.70	.27	.92	13.70	5.27	8.49	1.68	2.96
Hiatella arctica	Density	0	0	0	9	1	0	0	15	15	4	0	0
Cerastoderma pinnulatum	Density	0	0	0	0	0	0	0	112	65	101	0	6
Modiolus modiolus	Density	0	0	0	0	0	0	0	19	14	24	0	1
Musculus niger	Density	0	0	0	0	1	0	0	7	5	1	0	8
Margarites costalis	Density	0	0	0	1	0	0	0	8	2	0	0	2
Anachis lafresnayi	Density	0	0	0	22	14	0	0	4	4	11	0	34
Colus pygmaeus	Density	0	0	0	4	7	0	0	32	8	7	0	0
Mitrella rosacea	Density	0	0	0	0	0	0	0	0	6	0	0	4
Tonicella rubra	Density	0	0	0	0	2	0	0	0	0	1	0	0
CRUSTACEANS	Biomass	.61	.13	.24	.26	.82	.56	.25	.24	.08	.04	.14	.15
Pleusymtes glaber	Density	118	8	22	14	116	19	19	15	8	0	2	6
Pontogeneia intermis	Density	47	15	37	47	52	125	26	2	8	3	36	7
Corophium crassicorne	Density	0	0	0	1	0	0	0	41	3	1	0	0
CAPRELLIDS	Biomass	.14	.03	.26	.14	.06	.06	.65	.11	.07	.01	.01	.06
BRACHIOPOD	Biomass	42	33	42	47	46	20	49	51	60	25	75	77
Terebratulina septentrionalis	Density	1.24	1.29	1.27	1.06	1.22	.95	1.28	.98	.89	.10	1.05	1.06
	Size	34.72	15.17	71.86	37.41	30.89	9.02	37.03	28.33	23.21	9.67	53.47	46.49
ECHINODERMS	Biomass	5.79	11.18	11.42	8.27	12.59	5.20	8.79	16.49	11.59	10.75	15.54	16.92
Strongylocentrotus droebachiensis	Density	5	8	9	5	6	8	3	31	23	21	8	10
	Size	.52	.81	.51	.60	.42	.73	.77	.33	.39	.39	.71	.6
	Biomass	.20	1.90	.53	.59	2.19	.48	.53	.67	.87	.63	2.11	1.36
Stephanasterias albula	Density	5	4	7	7	6	1	13	38	25	13	8	14
	Size	.48	.5	.48	.57	.71	.4	.6	.75	.59	.66	.71	.67
Leptasterias sp.	Density	3	4	2	5	4	0	1	2	2	0	3	0
	Size	1.3	.90	1.5	1.2	1.5	0	2.1	.8	.4	0	.93	0
Ophipholis aculeata	Density	42	62	108	83	69	52	112	153	89	163	87	115
	Biomass	4.47	8.82	8.14	6.54	6.24	4.71	7.07	5.39	3.64	6.67	12.81	14.15
Ophiura robusta	Density	0	2	96	6	12	2	24	607	454	193	5	63
	Biomass	0.00	0.00	1.70	.07	.05	.02	.32	8.61	5.81	2.78	.06	.90
ALGAE	Biomass	1.00	0.00	1.00	1.00	5.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Biomass/0.25 m^2		90.03	120.05	297.23	73.99	154.70	51.83	148.93	340.66	292.39	268.03	445.57	315.05

Table 3. Descriptive statistics -"ABUNDANCE/0.25 m^2 from 1978 disruptive samples."

	33 m		42 m			
	hori.	vert.	hori.	vert.	Overall	
Species	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$	S.D.
POLYCHAETES						
Chone infundibuliformis	254/170	7/9	236/12	9/12.7	165.6	172
Thelepus cincinnatus	164/132	14.5/1.3	132/115	20/0	106.6	123
Nereis pelagica	22.9/38.6	7.8/14.0	15.0/18.7	16.5/2.1	16.6	29.6
MOLLUSCS						
Hiatella arctica	12.6/10.3	1.4/3.3	11.3/6.3	0	8.16	9.45
Cerastoderma pinnulatum	30.8/32	0	93/24	3/4.2	27	37
Modiolus modiolus	14.8/39	0	19.5/5	.5/.7	9.8	28.7
Musculus niger	6.6/6.0	.14/.37	4.3/3.0	4/5.6	4.5	5.0
Margarites castalis	8.3/5.4	.14/.37	3.3/4.1	1/1.41	4.7	5.5
Anachis lafresnayi	33/21	5.1/9	6.3/4	17/12	20.1	21.0
Colus pygmaeus	6.8/5.9	1.6/2.8	15.6/14.1	0	5.8	7.6
Mitrella rosacea	3.1/3.5	0	2/3.4	2/2.8	2.0	3.0
Tonicella rubra	4.2/5.2	.28/.75	.33/.58	0	2.25	4.1
AMPHIPODS						
Pleusymtes glaber	29.5/24	45.1/49	7.6/7.5	4/2.8	29.5	33.5
Pontogeneia intermis	41.4/38.0	49.8/35.6	4.3/3.2	21.5/20	37.5	35.5
Corophium crassicorne	5.6/7.5	.142/.37	15/22.5	0	4.7	9.6
BRACHIOPOD						
Terebratulina septentrionalis	17.6/8.1	39.8/10.2	45.3/18.2	76/1.4	32.4	20.2
(size)	.88/.25	1.19/.13	.96/.06	1.06/.01	.99	.25
ECHINODERMS						
Strongylocentrotus droebachiensis	18.5/10.9	6.3/2.1	25/5.3	9/1.4	14.9	10.3
(size)	.49/.08	.62/.15	.37/.03	.66/.08	.525	.134
Stephanasterias albula	2.25/3.9	6.14/3.7	24.7/12.6	11.0/4.2	6.9	8.9
(size)	.74/.14	.53/.1	.67/.08	.69/.03	.649	.140
Leptasterias sp.	2.1/3.8	3.1/1.4	1.3/1.15	1.5/2.1	2.16	2.8
(size)	.97/.46	1.4/.4	.6/.28	.93/0	1.06	.49
Ophiopholis aculeata	65.2/62.3	75.4/26.9	135/40	101/19.8	79.9	52.5
Ophiura robusta	317/130	20.3/34.4	418/209	34/41	219	194

Table 4. Biomass of species from disruptive samples, Pigeon Hill 1978 (all weights in grams/0.25 m^2).

Species	V1	V2	V3	V4	V5	V6	V7	H1
Echinoderms (Total)	5.791	11.179	11.419	8.271	12.591	5.204	8.790	5.467
Ophiopholis aculeata	4.473	8.818	8.140	6.544	6.241	4.706	7.069	2.620
Ophiura robusta	0.	0.	1.701	.069	.049	.019	.322	0.
Strongylocentrotus droehbachiensis	.201	1.898	.529	.587	2.190	.479	.534	1.712
Leptasterias sp.	1.017	.463	.765	.989	1.393	0.	.514	0.
Stephanasterias albula	0.	0.	0.	.082	.059	0.	.272	0.
Crossaster papposus	0.	0.	0.	0.	0.	0.	0.	0.
Solaster endeca	0.	0.	0.	0.	0.	0.	0.	0.
Asterias vulgaris	0.	0.	0.	0.	0.	0.	0.	1.135
Henricia sanguinolenta	.100	0.	.282	0.	2.659	0.	.079	0.
Brachiopoda								
Terebratulina septentrionalis	34.716	15.166	71.865	37.413	30.887	9.018	37.028	13.008
Mollusca (Total)	.554	1.048	.261	1.974	.700	.271	.918	4.230
Bivalvia	0.	0.	0.	.272	.251	0.	0.	1.120
Gastropoda	0.	0.	0.	1.702	0.	0.	.918	0.
Arthropoda (Total)	0.	3.504	.180	0.	0.	0.	0.	1.046
Caprella	.14	.03	.26	.14	.06	.06	.64	.20
Amphipoda	.61	.13	.24	.26	.82	.56	.25	.03
Porifera	15.84	16.14	145.85	0.	56.04	0.	14.19	0.
Bryozoa-Tunicata	4.43	41.09	22.68	0.	8.70	28.51	50.77	25.83
Annelida	21.16	20.58	32.06	14.69	27.06	0.	16.63	103.16
Algae								
Ptilota serrata	1.0	0.	1.0	0.	5.0	3.0	0.	55.5
Phycodres rubens				1.0				
TOTAL WEIGHTS (gm/0.25 m^2):	90.032	120.046	297.232	73.993	154.700	51.827	148.924	215.058

Table 4 (cont'd).

Species	H2	H3	H6	H7	H8	H9	H10	H11
Echinoderms (Total)	15.766	14.743	1.428	3.346	.841	4.904	1.129	1.192
Ophiopholis aculeata	0.	1.122	1.005	2.833	0.	3.378	0.	0.569
Ophiura robusta	0.	9.513	0.	0.	0.	0.	0.	0.
Strongylocentrotus droehbachiensis	.941	1.877	.388	.360	.804	1.094	.929	.622
Leptasterias sp.	0.	0.	0.	0.	0.	.039	0.	0.
Stephanasterias albula	0.	0.	.025	0.	0.	.033	0.	0.
Crossaster papposus	0.	0.	0.	0.	0.	0.	0.	0.
Solaster endeca	0.	0.	0.	0.	0.	0.	0.	0.
Asterias vulgaris	7.473	2.231	0.	.140	0.	0.	.192	.192
Henricia sanguinolenta	0.	0.	0.	.013	.037	0.	0.	0.
Brachiopoda								
Terebratulina septentrionalis	7.352	6.584	1.210	4.978	10.110	2.888	11.755	4.688
Mollusca (Total)	4.917	3.442	2.490	3.310	2.179	1.153	3.136	1.664
Bivalvia	0.	0.	0.	0.	0.	.614	.604	.443
Gastropoda	0.	0.	0.	0.	0.	.539	2.532	1.221
Arthropoda (Total)	0.	0.	0.	1.069	4.975	0.	0.	0.
Caprella	.29	.34	.20	.17	.13	.28	.25	.06
Amphipoda	.23	.16	.41	.37	.67	.40	.12	.02
Porifera	16.88	0.	10.9	0.		0.	0.	0.
Bryozoa-Tunicata	2.93	13.35	1.31	0.	7.99	7.18	0.69	1.83
Annelida	185.33	133.16	207.55	469.96	178.77	202.02	576.83	232.66
Algae								
Ptilota serrata	46.9	34.8	21.0	29.0	18.7	35.6	51.5	11.2
Phycodres rubens	1.0							
TOTAL WEIGHTS (gm/0.25 m^2):	290.009	221.322	247.926	515.549	244.206	260.482	649.667	256.169

Table 4. (cont'd).

Species	H12	H15	H16	DH1	DH2	DH3	DV1	DV2
Echinoderms (Total)	.789	17.016	18.163	16.489	11.591	10.749	15.537	16.915
Ophiopholis aculeata	.182	13.413	6.847	5.393	3.645	6.665	12.807	14.151
Ophiura robusta	0.	1.302	3.847	8.615	5.807	2.776	.059	.898
Strongylocentrotus droehbachiensis	.602	1.423	.388	.665	.867	.625	2.109	1.362
Leptasterias sp.	0.	.304	5.776	.110	0.	0.	.503	0.
Stephanasterias albula	0.	.574	.639	1.706	1.272	.554	.059	.504
Crossaster papposus	0.	0.	.666	0.	0.	0.	0.	0.
Solaster endeca	0.	0.	0.	0.	0.	.129	0.	0.
Asterias vulgaris	0.	0.	0.	0.	0.	0.	0.	0.
Henricia sanguinolenta	0.	0.	0.	0.	0.	0.	0.	0.
Brachiopoda								
Terebratulina septentrionalis	1.513	1.524	5.433	28.331	23.211	9.675	53.473	46.493
Mollusca (Total)	2.183	2.122	2.168	13.701	5.269	8.492	1.679	2.963
Bivalvia	1.154	.392	1.180	0.	4.040	7.372	0.	1.594
Gastropoda	1.029	1.730	.988	9.905	1.229	1.120	0.	1.369
Arthropoda (Total)	0.	0.	0.	6.453	0.	0.	0.	0.
Caprella	.05	.75	.62	.11	.07	.01	.01	.06
Amphipoda	.11	.33	.01	.24	.08	.04	.14	.15
Porifera	0.	0.	1.00	0.	44.01	3.81	199.96	46.43
Bryozoa-Tunicata	5.78	17.00	0.	0.	3.10	14.42	105.20	97.08
Annelida	98.10	172.91	76.41	248.94	188.20	201.59	54.01	85.08
Algae								
Ptilota serrata	20.0	103.00	96.00	0.		0.	0.	0.
Phycodres rubens								
TOTAL WEIGHTS (gm/0.25 m^2):	131.498	333.790	220.135	340.658	292.391	268.027	445.546	315.049

Table 5. Statistical Summary. - 1978 Disruptive Samples.

Species	Interactions	TEST: T-TEST	TEST: ANOVA	Result	SIGN. LEVEL: T-TEST	SIGN. LEVEL: ANOVA
Sponges (% cover)	S D	no data	F = 372.736			**
	V H	-19.31		↑ V	**	
Tunicates (% cover)	S D	no data	F = 167.866			**
	V H	-12.96		↑ V	**	
Algae (% cover)	S D	no data	F = 618.58			**
	V H	+24.88		↑ H	**	
Brachiopods (size)	S D	-.11	F = 4.56	NS	NS	*
	V H	3.01		↑ V	**	
Brachiopods (density)	S D	-4.21	F = 20.61	↑ D	**	*
	V H	4.73		↑ V	**	
Polychaete (density)	S D	1.47	F = 11.05	NS	NS	*
	V H	-5.05		↑ H	**	*
Polychaete (biomass)	S D	-1.98	F = 6.92	NS	NS	*
	V H	-8.40		↑ H	**	
Chone (density)	S D	1.85	F = 21.63	NS	NS	**
	V H	-6.49		↑ H	**	
Thelepus (density)	S D	2.22	F = 5.99	↑ S	*	*
	V H	-2.90		↑ H	**	
Nereis (density)	S D	-.45	F = 1.04	NS	NS	NS
	V H	.10		NS	NS	

Table 5. Statistical Summary (continued).

Species	Interactions	TEST: T-TEST	TEST: ANOVA	Result	SIGN. LEVEL: T-TEST	SIGN. LEVEL: ANOVA
Corophium (density)	S	- .74	F = 4.89	NS	NS	*
	D					
	V	-3.06		↑ H	**	
	H					
Pontogeneia (density)	S	2.40	F = 3.99	↑ S	*	NS
	D					
	V	1.56		NS	NS	
	H					
Pleusymtes (density)	S	2.56	F = 3.46	↑ S	*	NS
	D					
	V	.66		NS	NS	
	H					
Hiatella (density)	S	.29	F = 16.42	NS	NS	*
	D					
	V	-5.72		↑ H	*	
	H					
Cerastoderma (density)	S	-3.31	F = 53.9	↑ D	*	*
	D					
	V	-9.93		↑ H	*	
	H					
Modiolus (density)	S	-2.11	F = 13.38	↑ D	*	*
	D					
	V	-4.77		↑ H	**	
	H					
Musculus (density)	S	-.65	F = 7.92	NS	NS	*
	D					
	V	-3.95		↑ H	**	
	H					
Margarites (density)	S	1.02	F = 13.8	NS	NS	*
	D					
	V	-5.15		↑ H	**	
	H					
Anachis (density)	S	.80	F = 7.97	NS	NS	*
	D					
	V	-3.89		↑ H	**	
	H					
Colus (density)	S	-.67	F = 9.36	NS	NS	*
	D					
	V	-4.29		↑ H	**	
	H					

Table 5. Statistical Summary (continued).

Species	Interactions	TEST: T-TEST	TEST: ANOVA	Result	SIGN. LEVEL: T-TEST	SIGN. LEVEL: ANOVA
Strongylocentrotus (size)	S D	1.13	F = 7.49	NS	NS	*
	V H	3.73		↑ V	**	
Strongylocentrotus (density)	S D	-1.68	F = 11.18	NS	NS	*
	V H	-4.46		↑ H	**	
Ophiopholus (density)	S D	-1.67	F = 1.89	NS	NS	NS
	V H	.95		NS	NS	
Ophiura (density)	S D	-1.04	F = 33.72	NS	NS	*
	V H	-8.18		↑ H	**	
Stephanasterias (size)	S D	-.44	F = 3.266	NS	NS	NS
	V H	-2.69		↑ H	*	
Stephanasterias (density)	S D	-4.12	F = 10.75	↑ D	**	*
	V H	2.02		NS	NS	
Leptasterias (size)	S D	1.41	F = 4.433	NS	NS	*
	V H	2.47		↑ V	*	
Leptasterias (density)	S D	.46	F = .649	NS	NS	NS
	V H	1.05		NS	NS	

Code: NS = not significant interaction
* = sign. interaction at .05 level
** = highly sign. interaction at .01 level

S = shallow (33 m) area
D = deep (42 m) area
V = vertical communities
H = horizontal communities
D = more abundant or larger size in deep area

All samples were calculated at 21 d.f. except for the polychaetes which were figured at 20 d.f. and the sponges, tunicates, and algae which were figured at 106 d.f.

Table 6. Abundance of common invertebrates and algae collected by airlift sampling in July 1979. Density recorded as counts/0.25 m^2.

Species	Quadrat sample number H1	H2	H3	H4	H5	H6	$\bar{X}$	S.E.	V1	V2	V4	V5	V6	$\bar{X}$	S.E.
Polychaetes: (Total)	263	218	210	339	644	276	328.3	72.9	29	16	35	13	11	20.8	4.7
Molluscs:															
Bivalves	36	113	87	135	61	70	83.6	16.1	1	0	0	2	0	.6	.4
Gastropods	139	179	108	96	71	93	114.3	17.3	20	10	14	8	19	14.2	2.4
Chitons	13	18	4	6	5	7	8.8	2.5	3	2	3	1	2	2.2	.4
Crustaceans:															
Amphipods	471	270	131	178	218	269	256.2	59.0	15	9	33	17	23	19.4	4.1
Caprellids*	3825	2375	280	670	815	730	1450.8	614.6	91	49	63	59	86	69.6	8.1
Hyas	0	1	0	0	0	0	.2	.2	1	0	0	0	1	.4	.2
Evalis	2	4	0	0	1	2	1.3	.7	2	0	0	0	0	.4	.4
Brachiopods:															
Terebratulina	39	41	28	21	43	33	34.2	3.8	80	62	45	35	52	54.8	7.7
Echinoderms:															
Asteroids	62	51	1	6	15	3	23.0	11.9	10	8	12	1	5	7.2	1.9
Ophiopholis	151	249	93	35	104	102	122.3	32.3	69	7	144	114	117	90.2	24.0
Ophiura	403	421	466	222	299	333	357.3	40.0	2	2	9	36	8	11.6	6.3
Axiognathus	34	18	0	1	2	0	9.2	6.3	0	0	0	0	0	0	0
Strongylocentrotus	84	94	35	19	45	43	53.3	13.1	8	1	5	12	12	7.6	2.1
Tunicates:															
Ascidia callosa (density)	4	4	0	0	2	0	2.2	.8	4	0	24	9	19	11.2	4.51
(Biomass grams/0.25 m^2)	2.8	4.4	0	0	1.9	0	1.5	.8	2.3	0	63.9	5.0	5.0	20.9	12.3
Algae:															
Ptilota (Biomass grams/0.25 m^2)	213.8	177.1	21.2	23.0	60.3	81.1	96.1	36.3	.7	0	0	0	0	.1	.1
Total abundance/0.25 m^2 sample	5536.	4056.	1443.	1728.	2325.	1961.	2839.8[1]	1270.0	335	166	387	307	355	310.0[2]	38.3

*Caprellids were subsampled (1/5th counted).

[1] $\bar{X}$/Horizontal 0.25 m^2 samples.

[2] $\bar{X}$/Vertical 0.25 m^2 samples.

Table 7. Abundance of indicator species at Pigeon Hill from quantitative photographs

Year	Species Abundance (#/0.25 m^2)		
	Asteroids	Solitary Ascidians	Brachiopods
1978 Horizontal Transect N=55	$\bar{x}$ = 0.600 SD = 0.915 SE = 0.123	$\bar{x}$ = .0	$\bar{x}$ = 3.05 SD = 3.05 SE = 0.41
1978 Vertical Transect N=53	$\bar{x}$ = 3.660 SD = 2.480 SE = 2.935	$\bar{x}$ = 5.000 SD = 6.892 SE = 0.947	$\bar{x}$ = 44.208 SD = 19.183 SE = 2.635
1979 Horizontal Transect N=61	$\bar{x}$ = 2.131 SD = 1.830 SE = .234	$\bar{x}$ = .525 SD = .924 SE = .118	$\bar{x}$ = 4.689 SD = 5.946 SE = .761
1979 Vertical Transect N=50	$\bar{x}$ = 14.725 SD = 8.518 SE = 1.205	$\bar{x}$ = 14.140 SD = 8.028 SE = 1.135	$\bar{x}$ = 56.082 SD = 20.174 SE = 2.853
1980 Horizontal Transect N=60	$\bar{x}$ = 4.585 SD = 3.196 SE = .413	$\bar{x}$ = .246 SD = .471 SE = .061	$\bar{x}$ = 3.683 SD = 3.549 SE = .458
1980 Vertical Transect N=51	$\bar{x}$ = 37.588 SD = 17.875 SE = 2.503	$\bar{x}$ = 2.980 SD = 1.181 SE = .305	$\bar{x}$ = 28.680 SD = 16.358 SE = 2.291
1981 Horizontal Transect N=68	$\bar{x}$ = 7.95 SD = 4.50 SE = 0.55	$\bar{x}$ = 0.98 SD = 1.21 SE = 0.15	$\bar{x}$ = 0.41 SD = 1.07 SE = 0.13
1981 Vertical Transect N=43	$\bar{x}$ = 14.00 SD = 5.97 SE = 0.91	$\bar{x}$ = 7.79 SD = 4.49 SE = 0.68	$\bar{x}$ = 5.88 SD = 5.99 SE = 0.91

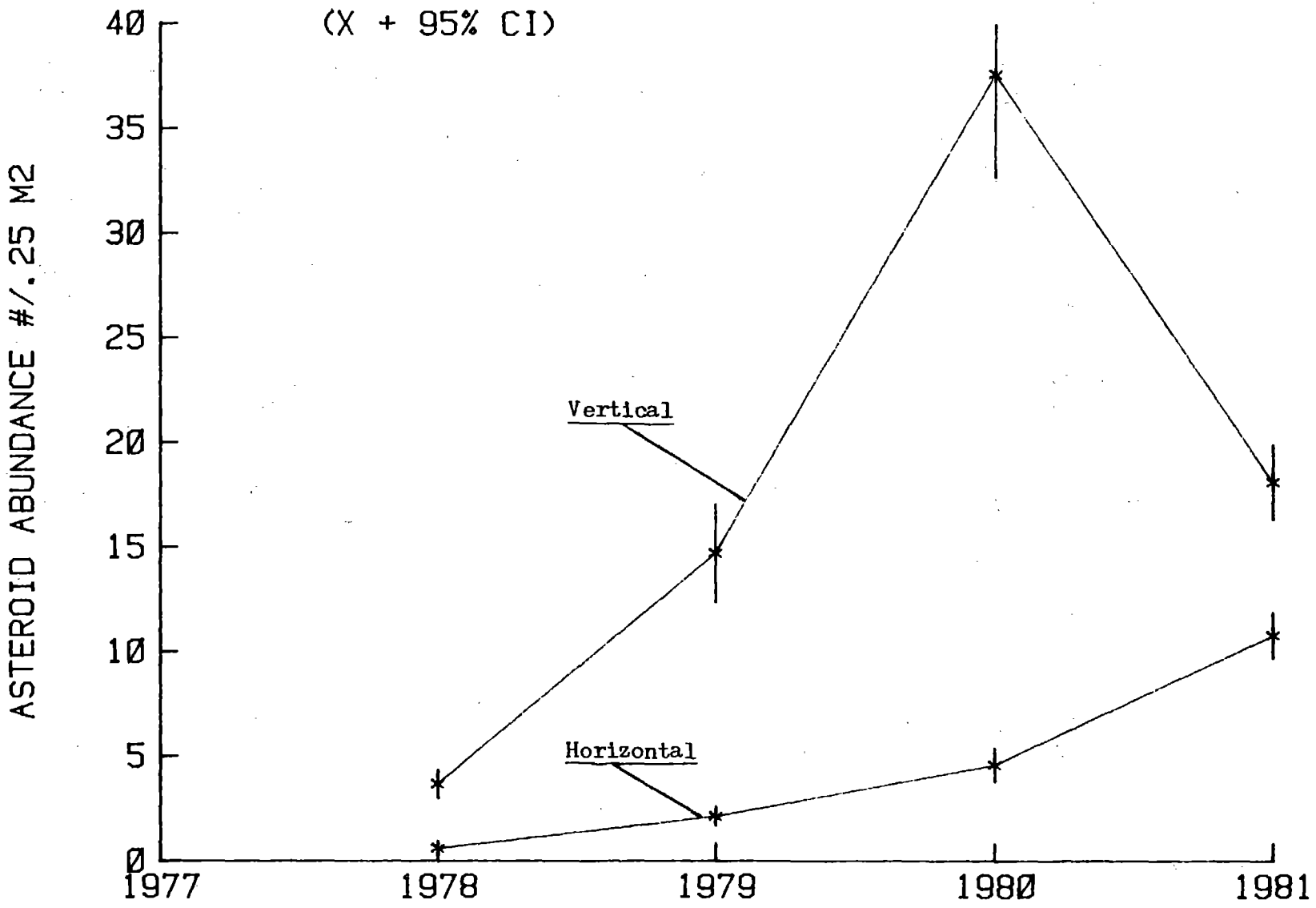


Figure 12. Asteroid Abundance from 0.25 m^2 Photographs

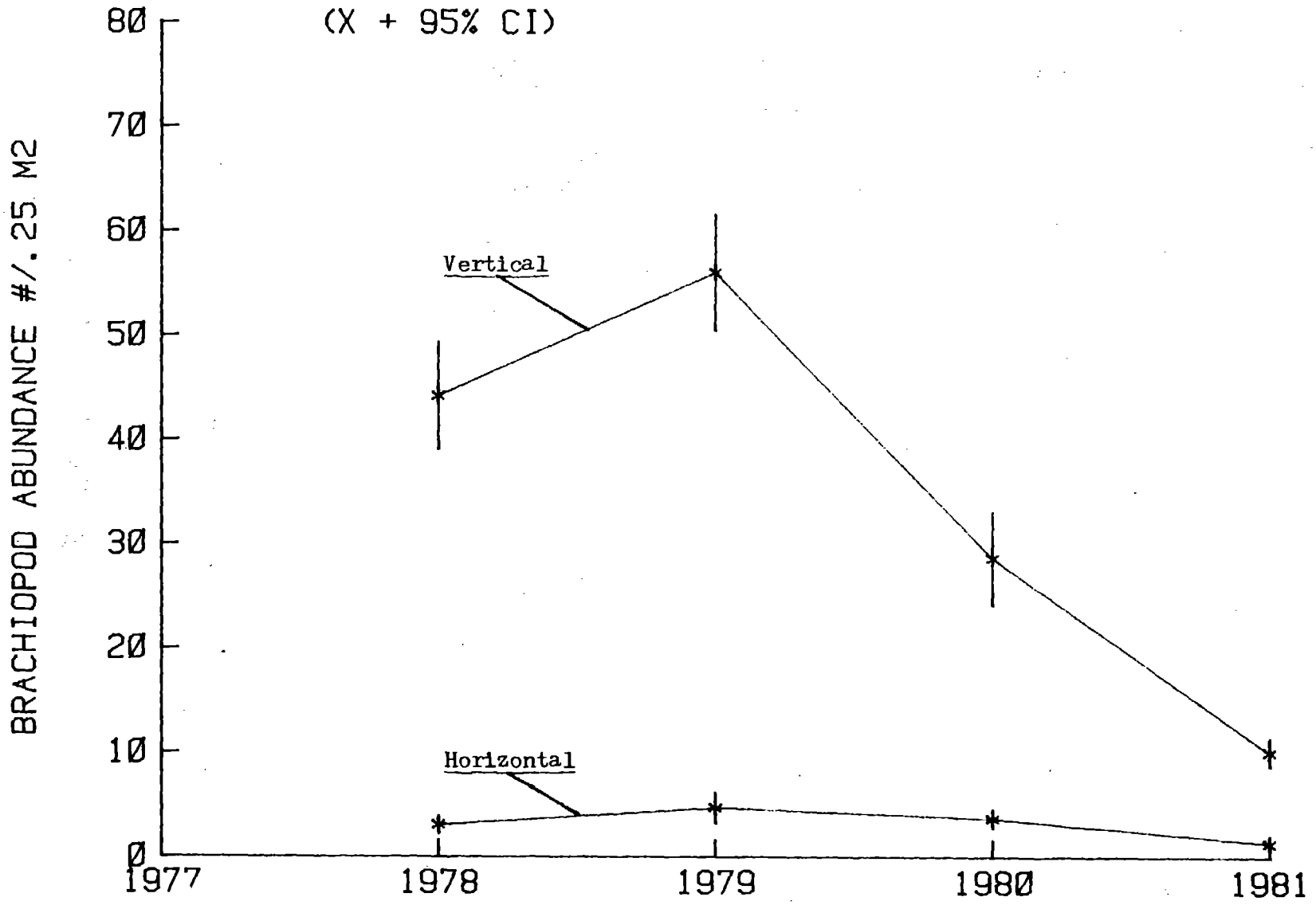


Figure 13. Brachiopod Abundance from 0.25 m^2 Photographs

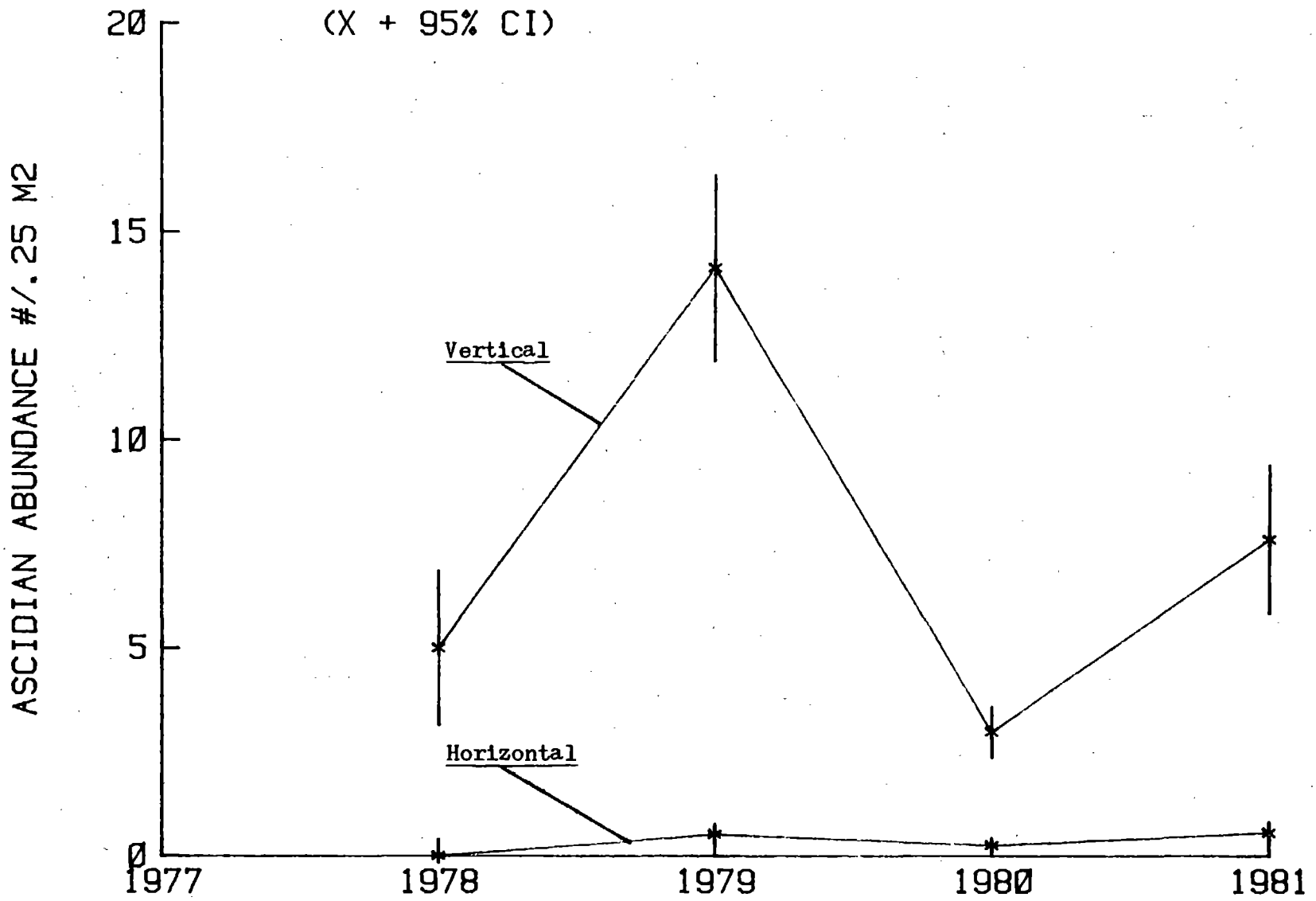


Figure 14. Ascidian Abundance from 0.25 m^2 Photographs

Table 8. Percent Coverage of Algae from 0.25 m^2 Quantitative Photographs of Horizontal Transects at Pigeon Hill. The Vertical Transects had <1% Algal Coverage.

Year	Percent algal coverage	Number photos	Standard error	Standard deviation	Range (percent)	95% C.I.
	$\bar{x}$	N	S.E.	S.D.	R	$\bar{x}$ ±
1978	47	55	3.25	24.08	7-91	6.36
1979	73.4	60	4.09	31.7	50-99	8.02
1980	76	60	1.38	10.69	25-92	2.70
1981	68	68	1.93	15.9	9-96	3.78

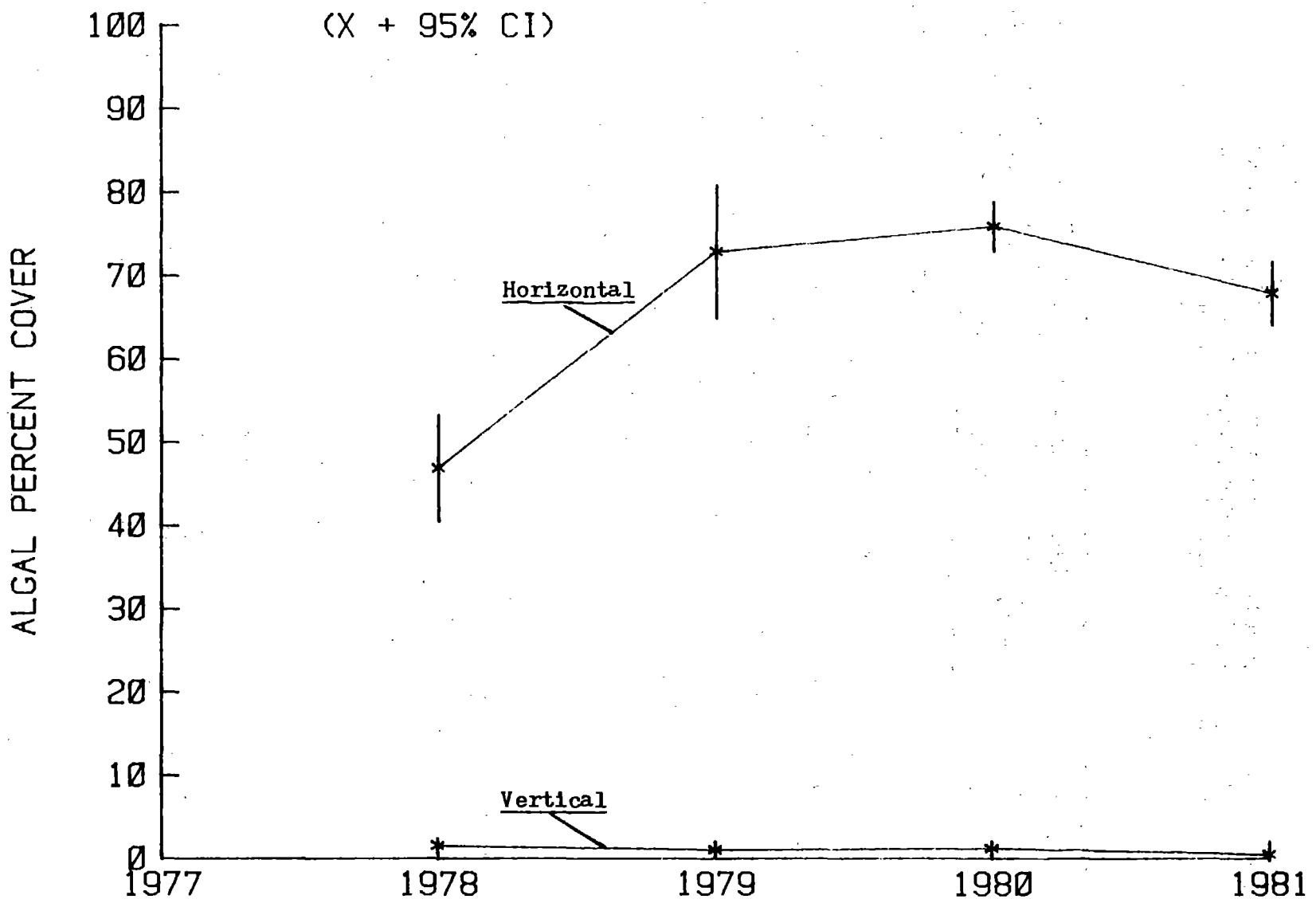


Figure 15. Ptilota serrata Percent Coverage of the Substratum from 0.25 m^2 Photographs

Table 9. 0.25 m^2 samples taken predominantly for algal analysis and biomass determinations, showing the predominance of Ptilota serrata, but also the presence of Phycodrys rubens. Ptilota makes up almost 50% of the total biomass including animals at 30 m on horizontal surfaces.

Date	Depth (m)	Sample #	Blotted wet weight (grams/0.25 m^2) Algae	Animal	Total	Comments
10/1978	30	1	157	203	366	Phycodrys 2 g Ptilota 155 g
10/1978	30	2	150	189	341	Phycodrys <1 g Ptilota >149 g
10/1978	30	3	162	260	422	Phycodrys <1 g Ptilota >161 g
10/1978	30	4	134	302	441	Phycodrys 3 g Ptilota 131 g
10/1978	30	5	199	321	520	Phycodrys 0 g Ptilota 199 g
10/1978	30	6	197	297	494	Phycodrys 1 g Ptilota 196 g
10/1978	30	7	197	204	401	Phycodrys 0 g Ptilota 197 g
10/1978	30	8	193	131	324	Phycodrys 1 g Ptilota 192 g
$\bar{x}$ Biomass/0.25 m^2			173.6	238.4	413.6	
S.E.			9.1	23.6	24.8	
7/1979	30	1	66	83	149	No Phycodrys
7/1979	30	2	140	156	296	No Phycodrys
7/1979	30	3	85	121	206	No Phycodrys
7/1979	30	4	173	204	377	No Phycodrys
7/1979	30	5	213	148	361	No Phycodrys
$\bar{x}$ Biomass/0.25 m^2			135.4	142.4	277.8	
S.E.			27.2	20.0	44.1	

Table 10. Heavy Metal Body Burdens at Pigeon Hill, 1980.

Species	Concentration (ppm wt. wgt.)						
	Ba	Cd	Cu	Cr	Hg	Pb	Zn
Sea stars	48.1	1.04	1.84	0.9	0.034	0.46	11.1
Algae	46.4	0.04	1.77	2.3	0.027	1.31	16.2
Tunicates	29.1	0.06	0.76	0.7	0.009	0.18	34.2

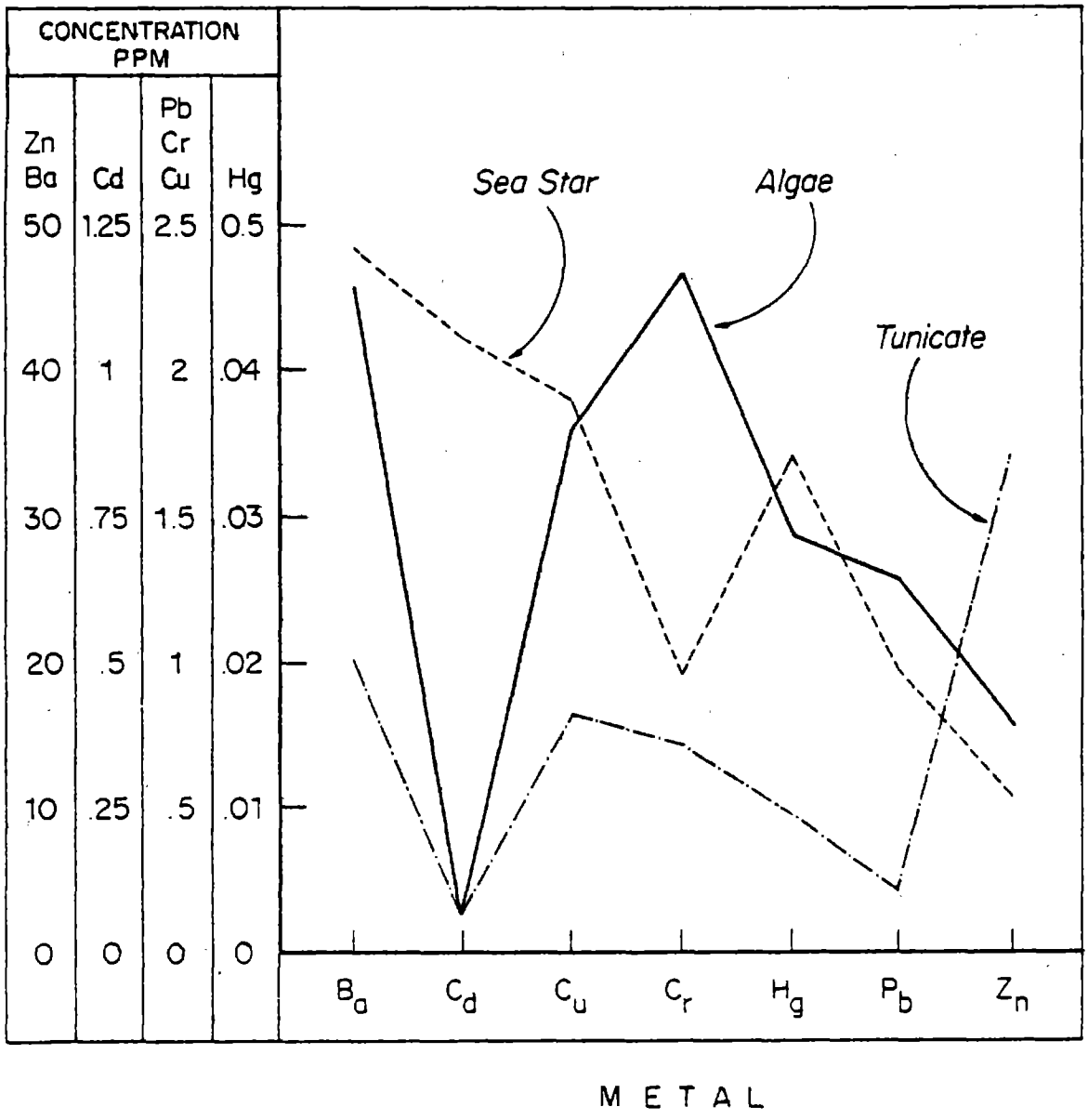
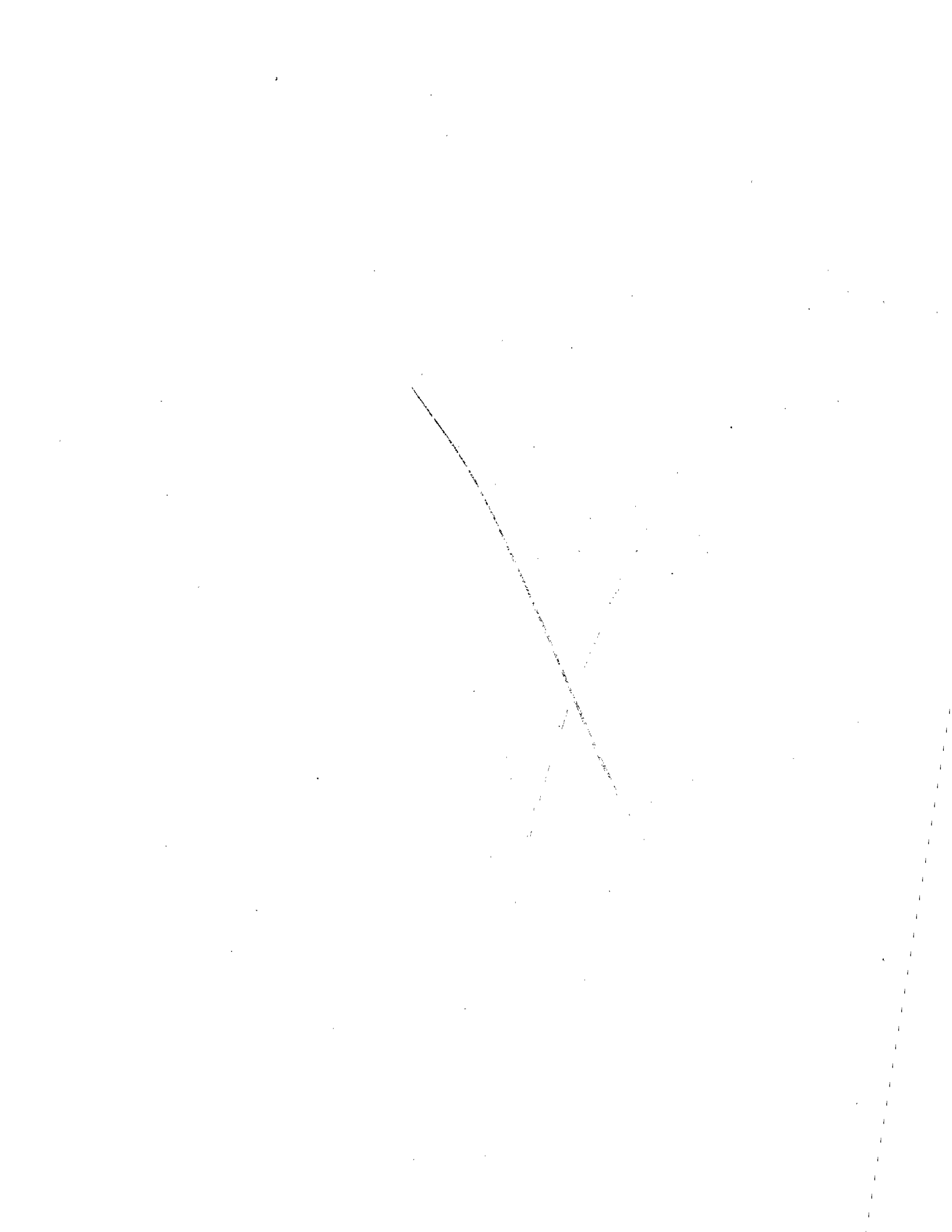


Figure 16. Plots of heavy metal body burdens in three species from Pigeon Hill, showing the highly variable nature of the data, both by species and by metal.



5. DISCUSSION

The primary goals of the study were to: 1) collect baseline data on the distribution and composition of subtidal benthic communities at Pigeon Hill, 2) identify biological indicator species and important community indices, and 3) establish methodologies for long-term biological monitoring of the communities. The indicator species are to be used as integrators of biological information to monitor the quality and state of the offshore benthic environment.

The results reported here indicate that the composition of the benthic community varies with differences in microhabitat. The two major community types are differentiated mainly on substratum orientation. Vertical relief in the rocky substratum leads to the development of a community dominated by sponges and tunicates, which is conspicuously different from the upper horizontal community dominated by algae and polychaetes. There are also changes in the composition of the benthic community with depth, mainly a reduction in the abundance of the red alga Ptilota serrata at 42 m, the other differences are less obvious than those caused by substratum orientation. The dominant species are widely distributed at both depth stations, but differences in the density and size structure of dominant species are greatest between horizontal and vertical substratum angles rather than by depth.

There is little information in the literature on rocky subtidal communities at the depths described (33 to 42 m). However, evidence for the existence of similar patterns of community structure in shallow hard substrate communities can be found in the literature. Sears and Cooper (1978) described in detail the distribution of algal populations at Pigeon Hill, but did not describe the macrofauna. One of the most comparable studies was conducted by Noble, Logan, and Webb (1976) in the rocky subtidal zone of the Bay of Fundy, Canada, at a depth range from 2 to 20 m. They described three communities; the upper surface community, the rock face community, and the cavity community as subcomponents of a major Terebratulina septentrionalis community. The upper surface and the rock face communities are analogous in terms of the dominant macrofaunal components to the upper horizontal and vertical surface communities described from Pigeon Hill. Algae, bivalves, chitons, and echinoids dominated the upper surface community and sponges and brachiopods predominated on vertical rock walls (Noble, Logan, and Webb, 1976). Differences in the specific composition of horizontal and vertical surface communities between the Bay of Fundy and the south central Gulf of Maine (Pigeon Hill) are probably attributable to the greater depth of the Pigeon Hill communities. Two major similarities are that the sponges are dominant on vertical rock walls and the distribution of macroalgae is restricted to upper rock surfaces in both subtidal regions. SCUBA studies of an upper horizontal community at 33 m at the Isles of Shoals (Harris, Hulbert, and Witman, MS) show strong parallels in community composition to the algal-polychaete community at Pigeon Hill. An extensive polychaete or amphipod tube matrix dominates much of the primary substratum at depths

beyond 30 m at the Isles of Shoals and the red alga Ptilota serrata is the dominant species of macroalgae. At depths shallower than 30 m, crustose coralline algae dominate primary space on upper horizontal surfaces. The biomass dominants in the shallow subtidal zones (1 to 20 m) are several species of macroalgae and the mussel Modiolus modiolus (Harris, Hulbert, and Witman, MS; Witman 1979, 1980). In general, the vertical wall sponge-tunicate community has a parallel in fouling communities which are well documented in the literature (Boyd, 1972; Fager, 1971; Harris and Irons, 1982; Jackson, 1977; Karlson, 1975, 1978; Keough and Butler, 1979; Sutherland, 1974; and Sutherland and Karlson, 1977). These communities are dominated by suspension feeding invertebrates such as sponges, cnidarians, ectoprocts, and tunicates. The benthos of vertical wall communities in the rocky subtidal zone of Scandinavia have been studied by Lundalv (1971) and Guilliksen (1978). Sponges and cnidarians were the dominant fauna of rock wall communities at depths of 5 to 25 m off the coast of Sweden (Lundalv, 1971). At depths of 8 to 12 m off northern Norway the vertical wall benthos was dominated by sponges, cnidarians, ectoprocts, and tunicates (Guilliksen, 1978). Guilliksen (1978) showed that algal cover was significantly reduced on vertical rock walls. Information from the literature and this study suggests that the differences in community composition by substrate angle (horizontal and vertical) are consistent worldwide patterns. The logical question is, what factors appear to be important in determining the differences?

Although it was not an objective of the benthic survey to determine the biotic and abiotic factors responsible for structuring the benthic assemblages at Pigeon Hill, the relative importance of the factors may be inferred from the literature and underwater observations. An experimental evaluation of the effect of physical and biological factors on the development of benthic communities is one of the goals of future work at the Pigeon Hill station. Biological mechanisms producing structure in marine communities include predation (Paine, 1966, 1974, 1976) and competition (Connell, 1961, 1972; Jackson, 1977). Important abiotic factors include light (Cinelli, et al., 1977; Norall, 1975), temperature (Golikov and Scarlato, 1968), sedimentation and water energy (Guilliksen, 1978; Noble, Logan, and Webb, 1976). For biological factors, the literature emphasizes the importance of predation on upper horizontal surfaces (Breen and Mann, 1976; Paine and Vadas, 1969). At Pigeon Hill it appears that the relative effect and type of predation varies between the upper horizontal algal-polychaete community, and the vertical wall sponge-tunicate community. Invertebrate predators such as urchins, prosobranch gastropods, crabs and lobsters are more common on horizontal surfaces. Polychaetes and ophiuroids in the upper horizontal community are heavily preyed on by demersal fish such as haddock and yellowtail flounder. Stomach contents of adult haddock caught at Pigeon Hill in 1978 indicated that 83% of the fish taken were feeding on polychaetes and ophiuroids. There are predators on vertical walls that feed on sponges and tunicates (i.e., Euphorsine borealis and Henricia sanguinolenta) but it is believed that their impact is not great. Of the physical factors, light is probably of major importance in controlling community differences. Light is a limiting factor for macroalgae in the low light environments of vertical walls, caves, and deep communities (Cinelli, et al., 1977; Guilliksen, 1978; and Sears and Cooper, 1978). Also light

influences the distribution of invertebrates with photonegative larvae such as Terebratulina septentrionalis (Noble, Logan, and Webb, 1976). The observed high densities of Terebratulina in the low light environments at Pigeon Hill (vertical walls and deep communities) may be related to the influence of light on the photosensitive larvae. Another physical factor that probably influences the distribution of invertebrates at Pigeon Hill is sedimentation. Sediment accumulates on upper horizontal surfaces, but not on vertical rock walls. Sediment may foul the surfaces of suspension feeding organisms such as sponges and tunicates, which may explain the low abundance of sponges and tunicates on upper horizontal surfaces.

The use of living organisms as "sentinel" or biological "indicator" species to monitor the effects of pollution in the marine environment is common in pollution research (i.e., Nichols, 1979; Mussel Watch). The underlying assumption is that the lethal and sub-lethal effects of pollution will be reflected in population or community level changes in abundance of the monitored organism and in bioaccumulation of pollutants. In order to detect the impact of pollution, it is necessary to document the magnitude of natural population density fluctuations of the indicator species. The significance of a potential change may then be interpreted by comparison to the background range of natural variability. Biological effects of pollution may also be assessed by monitoring contaminant levels in selected indicator species. This approach is most useful when the physiological response and tolerance of the organism to specific pollutants is known (Dalby, et al., 1979). Important criteria for the selection of an indicator species are: abundance, size, ease of sampling, trophic status, sensitivity to contaminants, and a knowledge of the ecological role of the species in the community in which it occurs. Based on a consideration of the above criteria and the quantitative analysis of dominant species distributions at Pigeon Hill, the following species could be effectively monitored as biological indicators of pollution, and we are presently utilizing quantitative photographic techniques for tracking the species:

Ptilota serrata: The most abundant macroscopic alga at Pigeon Hill, Ptilota serrata, comprises >99% of the algal biomass (Sears and Cooper, 1978). On the average, Ptilota covers approximately 66% of the substratum on horizontal surfaces at the 33 m station. As it is desirable to monitor representative species from all trophic levels (Nichols, 1979), Ptilota serrata is an indicator species because it is the dominant primary producer in the benthic ecosystem.

Chone infundibuliformis: The sand tube matrix on upper horizontal surfaces at 33 and 42 m is composed primarily of Chone tubes. Chone is an ecologically important polychaete because the microhabitat it forms provides secondary substrate and is inhabited by a variety of small invertebrates. Terebratulina larvae settle directly on Chone tubes, and the sediment trapped amongst the tubes is inhabited by errant polychaetes, ophiuroids, bivalves, and amphipods. The population densities of Chone are highly variable (i.e., a standard deviation of 170 about the mean of 254 individuals/0.25/m^2) which will make the detection of significant changes difficult. However, sufficient quantities of Chone could be easily obtained for contaminant analysis. The populations can possibly be tracked utilizing an index such as percent cover, rather than numerical abundance.

Terebratulina septentrionalis: The data indicate that Terebratulina is widely distributed in densities up to 77/0.25/m^2. An epifaunal species, the brachiopod is easily sampled by photographic and disruptive techniques. Linear regressions of field and photographic counts indicate that Terebratulina can be accurately censused from either 0.25/m^2 photo or disruptive quadrats (Witman, 1982b). In addition, sample size analysis showed that relatively few 0.25 m^2 quadrats are required to estimate population density at the .90 confidence level. An active suspension feeder, it is logical to assume that Terebratulina concentrates pollutants although this has not been investigated.

Ascidia collosa: Ascidia is a common solitary tunicate found regularly on vertical walls. Ascidia, a suspension feeder, probably has a relatively fast growth rate and concentrates contaminants, but very little information is presently available. We are utilizing Ascidia as an indicator predominantly because it is easily quantifiable from the photographs and provides additional community data.

Leptasterias sp.: Most of the organisms in the Pigeon Hill communities are suspension feeders and preliminary trophic classification shows that the primary consumer compartment is the largest trophic category. To monitor the effects of pollution at higher trophic levels, secondary consumers should be studied. Leptasterias sp. fulfills this requirement, as it is a carnivore known to feed on a variety of invertebrates (Hulbert, Ms). Leptasterias is common and occurs in overall mean densities of 2/0.25/m^2. It is also large enough to be easily sampled by photographic and disruptive techniques and for contaminant analysis. Most asteroids are indeterminate growers whose body sizes reflect local conditions. Observed population differences in size can be considered as dynamic equilibrium with the communities. The average local size reflects a complex interdependence between size-related metabolic needs, population density, characteristics of the prey, the predators, and the physical environment (Hulbert, 1980b, 1981b; Paine, 1976). The stable asteroid populations at the Isles of Shoals (Hulbert, 1980a, 1980b) suggest great longevity and low mortality. The population structure of asteroids (size and density) should make a sensitive functional indicator of community changes due to the complex dependence on the surrounding environment.

Thus, we are presently utilizing as indicators the percent cover of Ptilota serrata, the dominant primary producer; abundances of Terebratulina and Ascidia, both suspension feeders; and abundance of Leptasterias, a carnivore. We will also probably monitor the percent cover of Chone in the future because of its important structural role on horizontal surfaces. A great advantage of quantitative photography is that, once used, the samples are not lost, but they remain in their original state for restudy. Therefore, all of the potential data remains and further results can be extracted at future dates if new methods, indices, or changing interests necessitate. Essentially the photographic samples are stockpiled on the shelf for future use regardless of how many times they have been previously used.

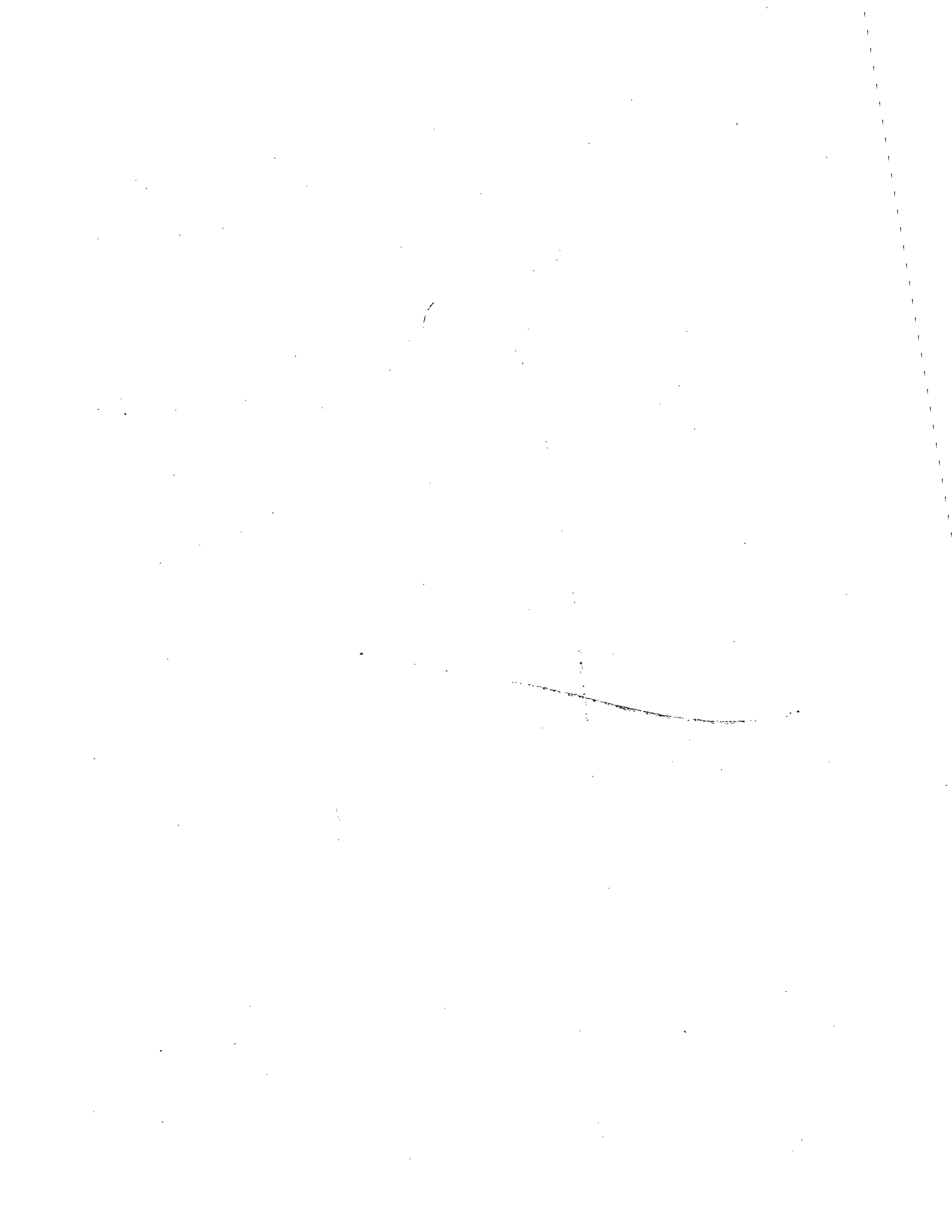
The "in-situ" approach allows the use of high resolution quantitative photography to monitor the site. The established permanent transects can be readily and precisely rephotographed to follow seasonal and yearly variation in community composition and growth. The epibenthic communities of the rough granite bottom cannot be adequately examined with the conventional surface oriented sampling equipment for soft substrates. Photography provides a highly cost-effective method to track the communities after a descriptive baseline is established, by more expensive disruptive techniques. Photographs can be taken, the results analyzed on a computerized digitizer, and a report available, from computer output, in a very short turnaround time for effective management.

An important aspect of such a study is to ascertain the internal variation of the system (the natural amount of change) in order to be able to detect an external impact. We believe we are beginning to see the limits of the real variability in the results of the photographs, and intend to subject our data base to more sophisticated statistical analyses in the near future. Obviously the longer we can build on the data base, the better our understanding of the naturally occurring community trends.

In the Gulf of Maine there are basically two benthic seasons, winter and summer. During 1981 and 1982 we are collecting seasonal data from the transects to document that there are in fact only two seasons, and to quantify the seasonal differences. We also intend to continue to collect samples for heavy metal analysis, to establish the variability of body burdens of metals. Although the analyses are very expensive we feel that they are important and should be continued.

In summary we are monitoring a site-specific location in the midst of a commercial fishery and in an area of heavy shipping traffic. We have very precise permanent transects on horizontal and vertical substrates on which we are tracking the communities utilizing biological indicators. Because we have stratified our sampling within what is already a small, well defined area, we are obtaining precise community information with a resolution virtually impossible in remote sampling schemes.

Pigeon Hill, at present, is a healthy, relatively pristine location. The benthic communities are composed of predominantly boreal exposed coast species, which can tolerate large amounts of disturbance, and there are observable and quantifiable differences between the communities of horizontal and vertical substrata and with depth.



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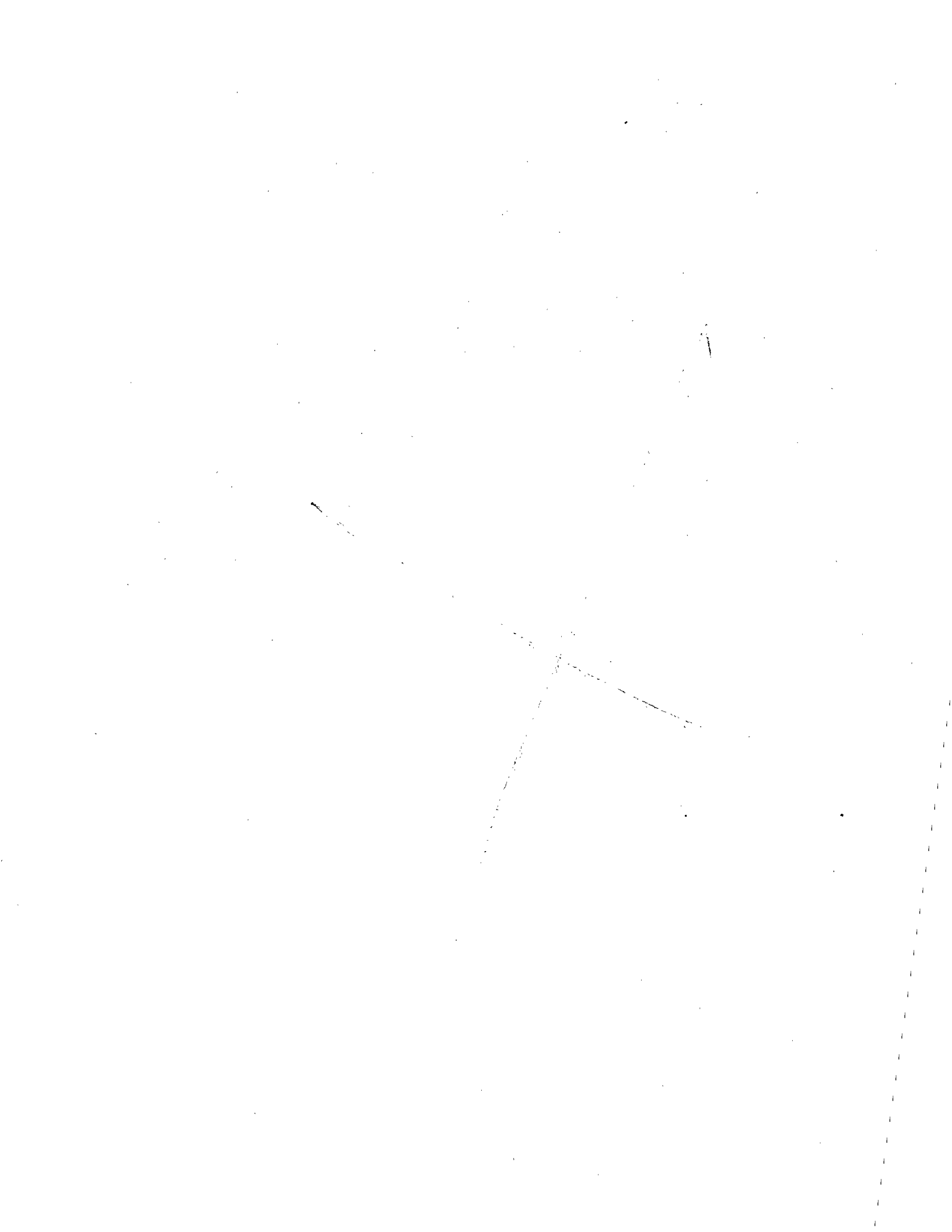
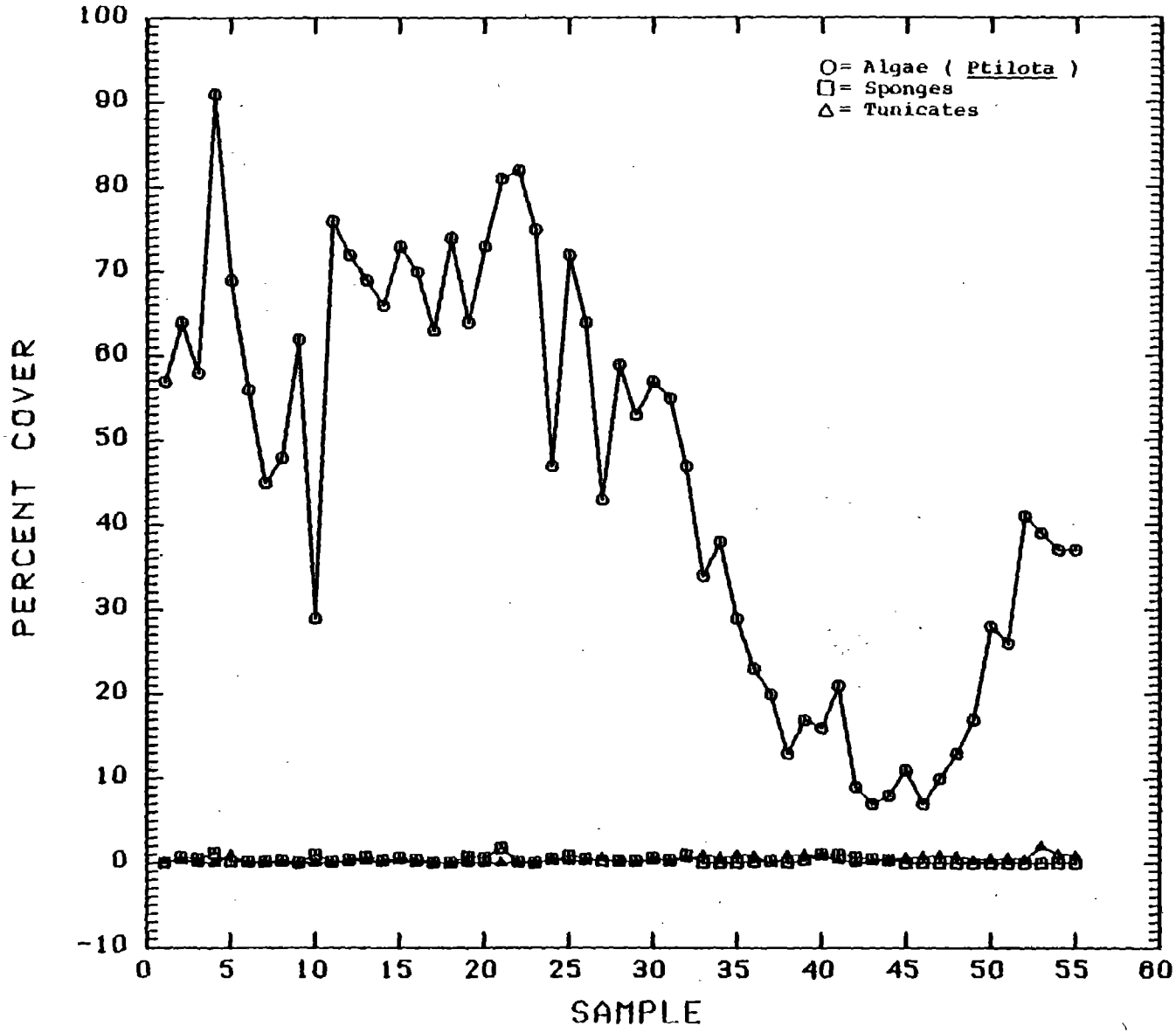


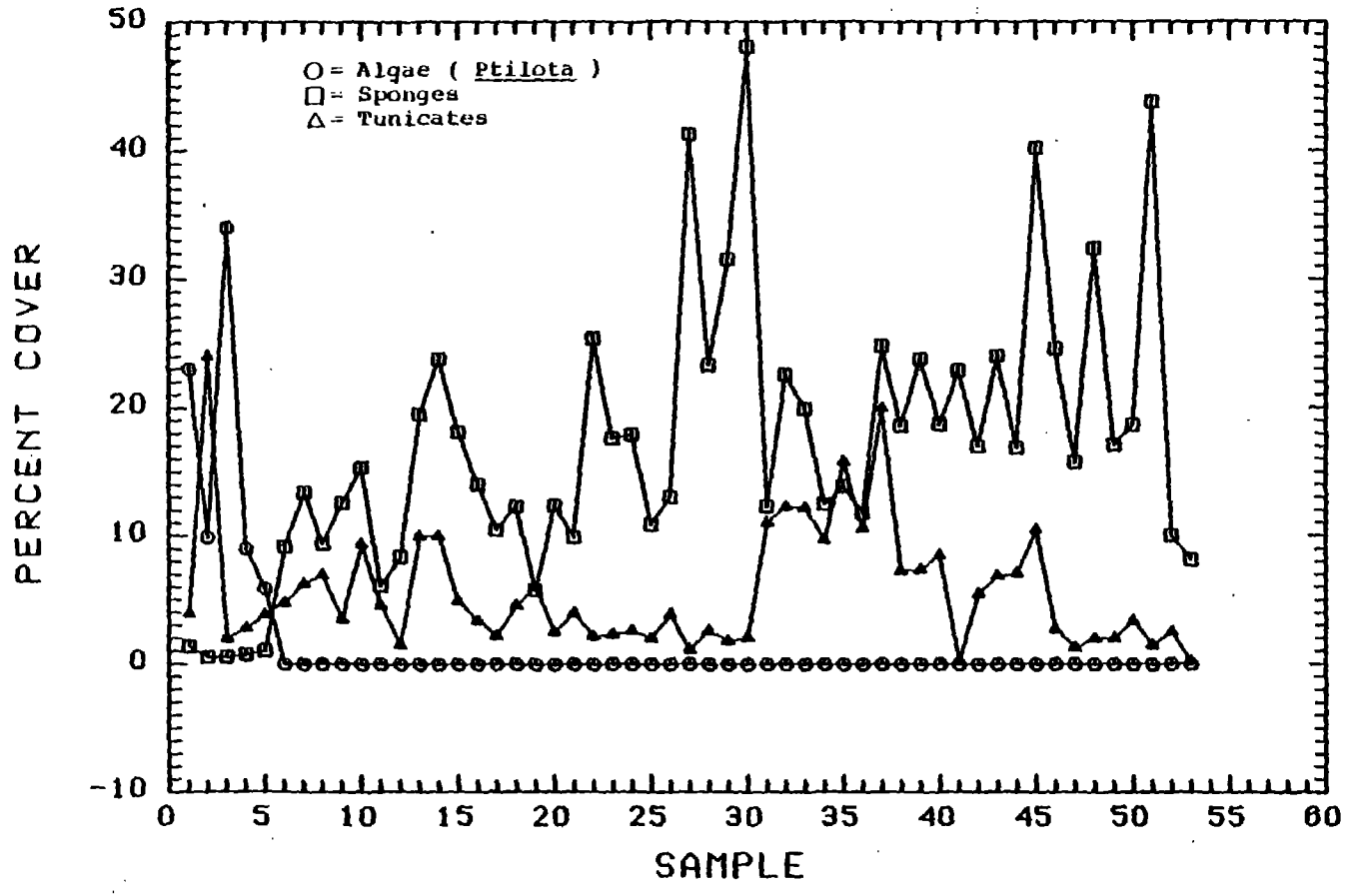
APPENDIX A

PERCENT COVER ESTIMATES OF THE MAJOR SPACE OCCUPYING GROUPS

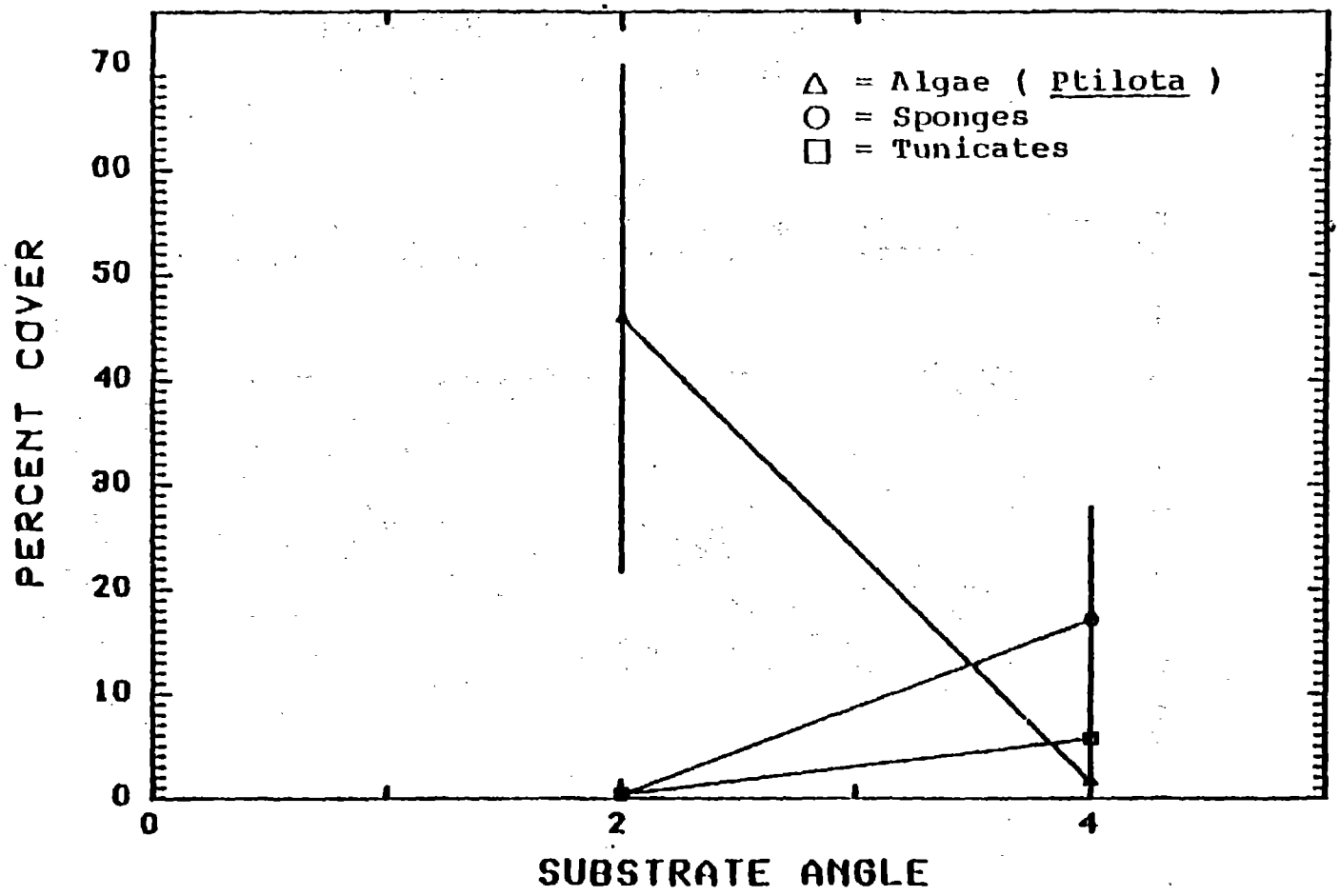
In all Appendix figures, data points are mean values, and error bars, when presented, represent a range of ± 1 standard deviation.



Percent cover of Algae, Tunicates, and Sponges on Horizontal Surfaces



PERCENT COVER
ALGAE, TUNICATES AND SPONGES
ON VERTICAL SURFACES

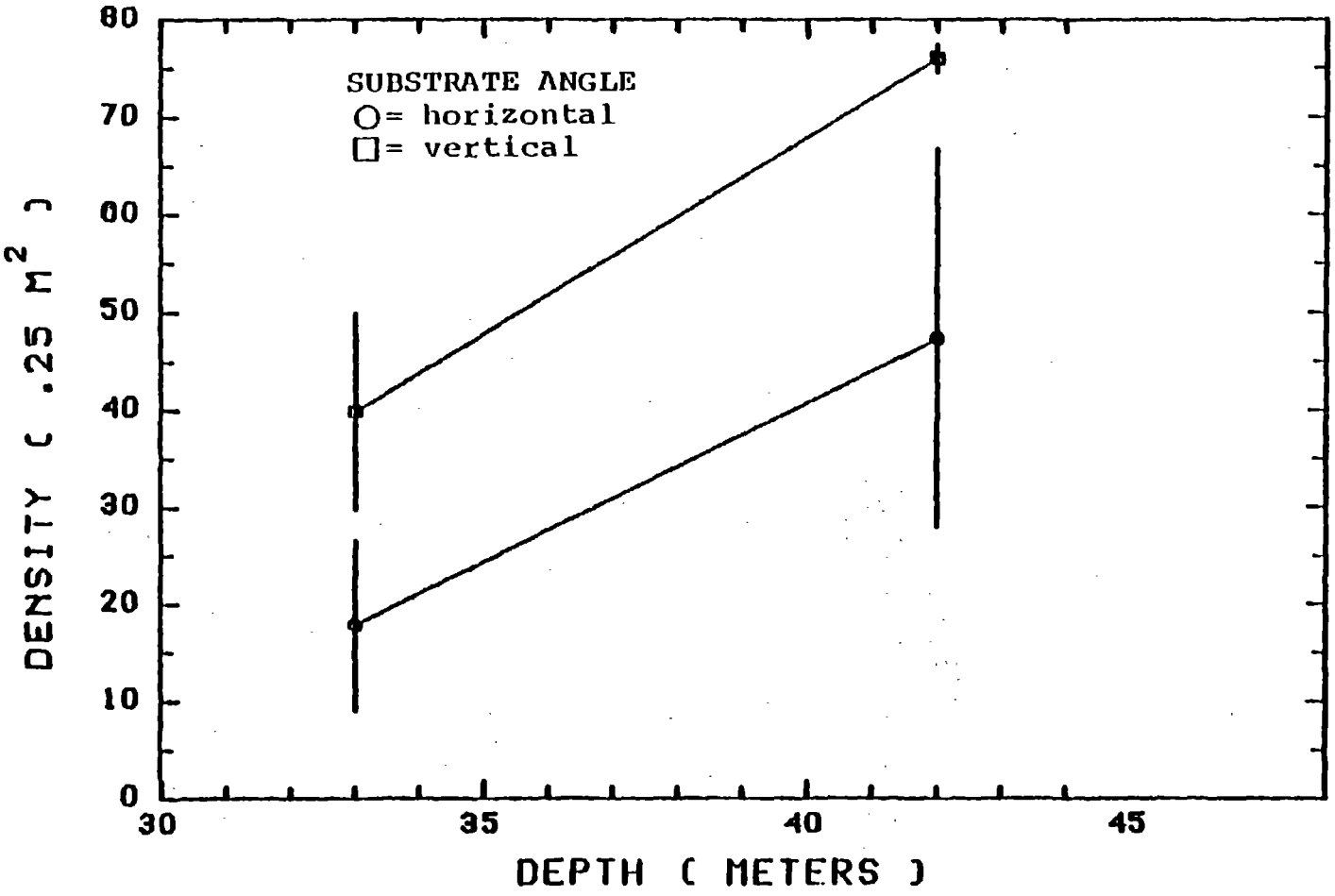


2 = HORIZONTAL SUBSTRATE

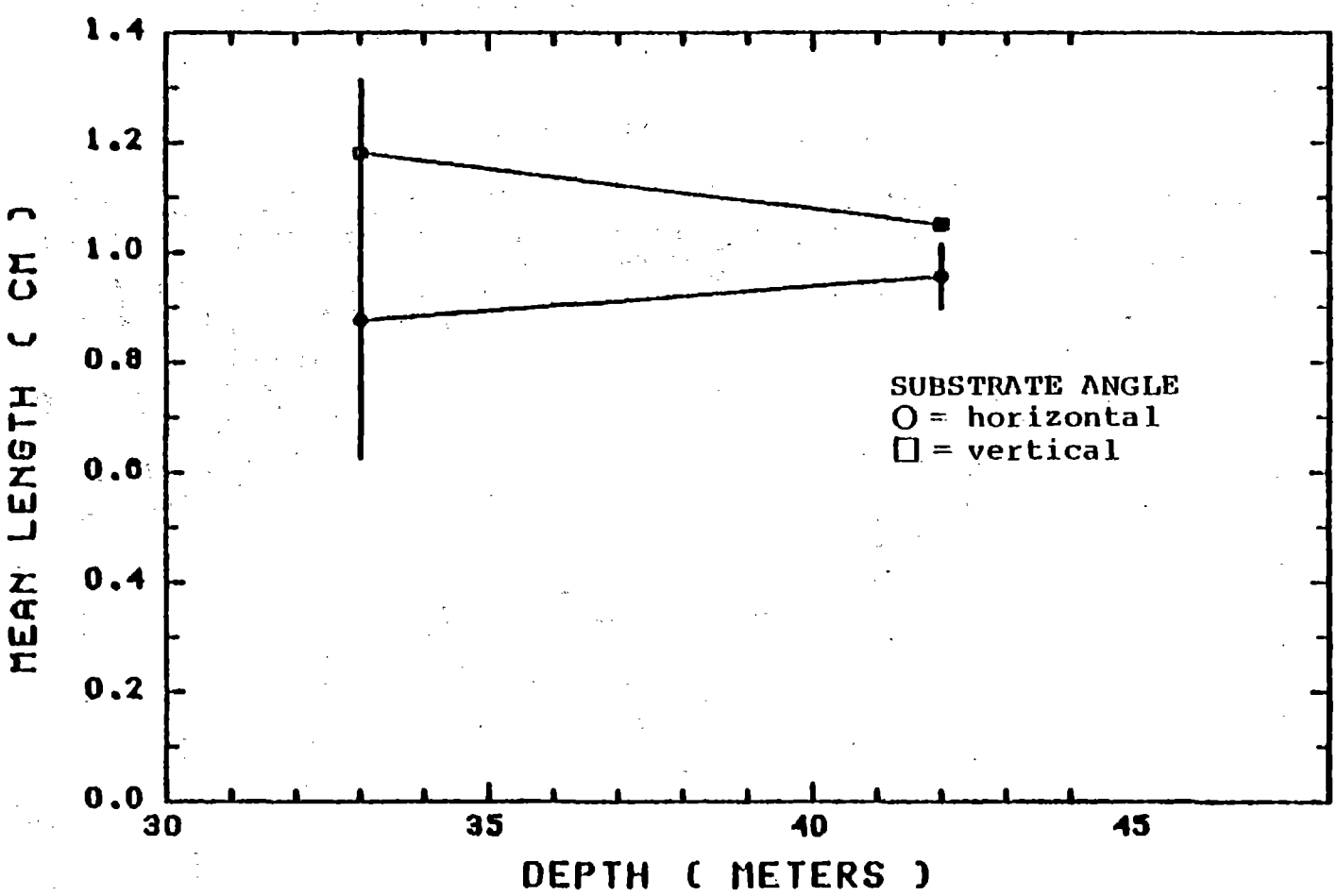
4 = VERTICAL SUBSTRATE

APPENDIX B

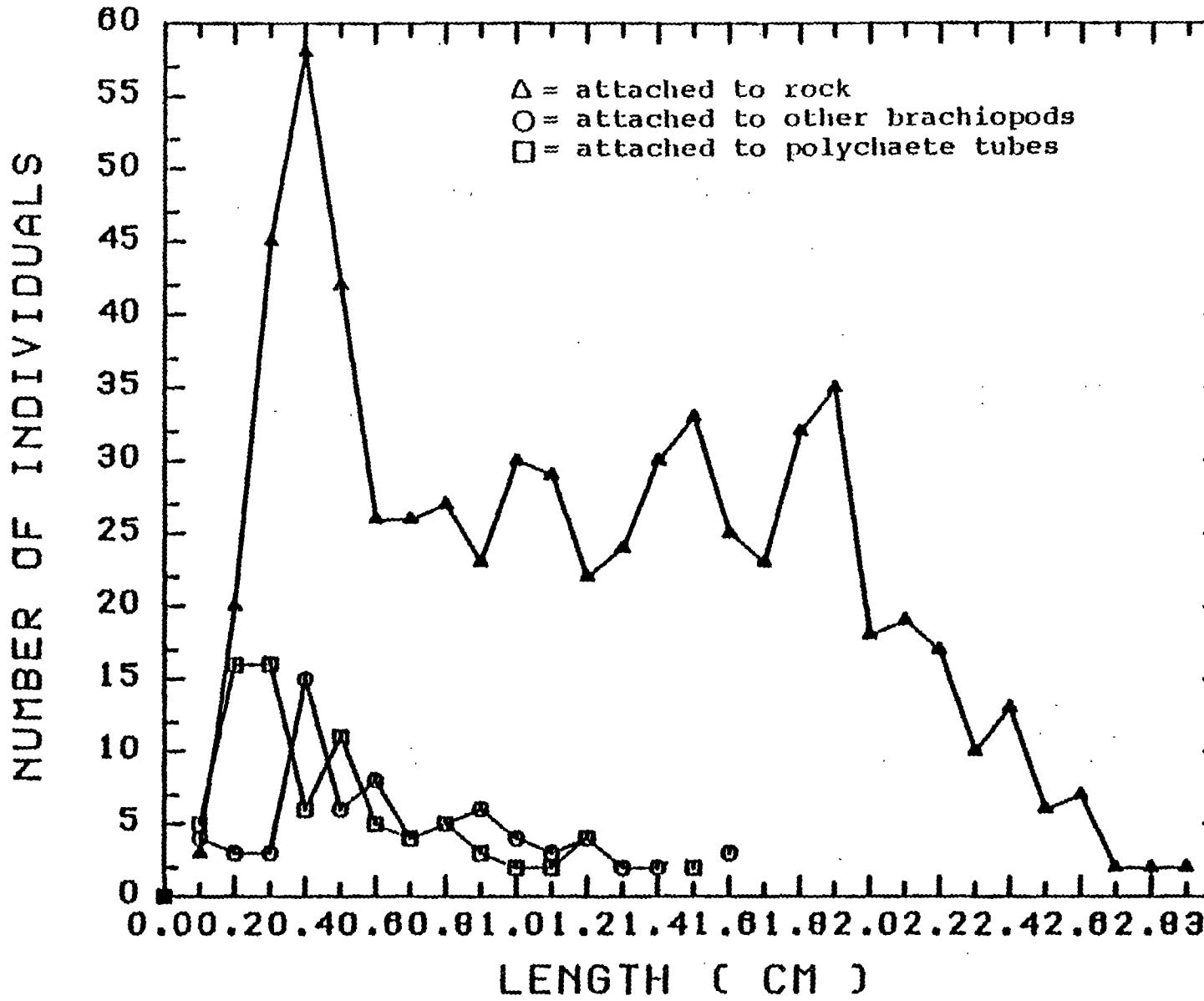
POPULATION STRUCTURE OF TEREBRATULINA SEPTENTRIONALIS

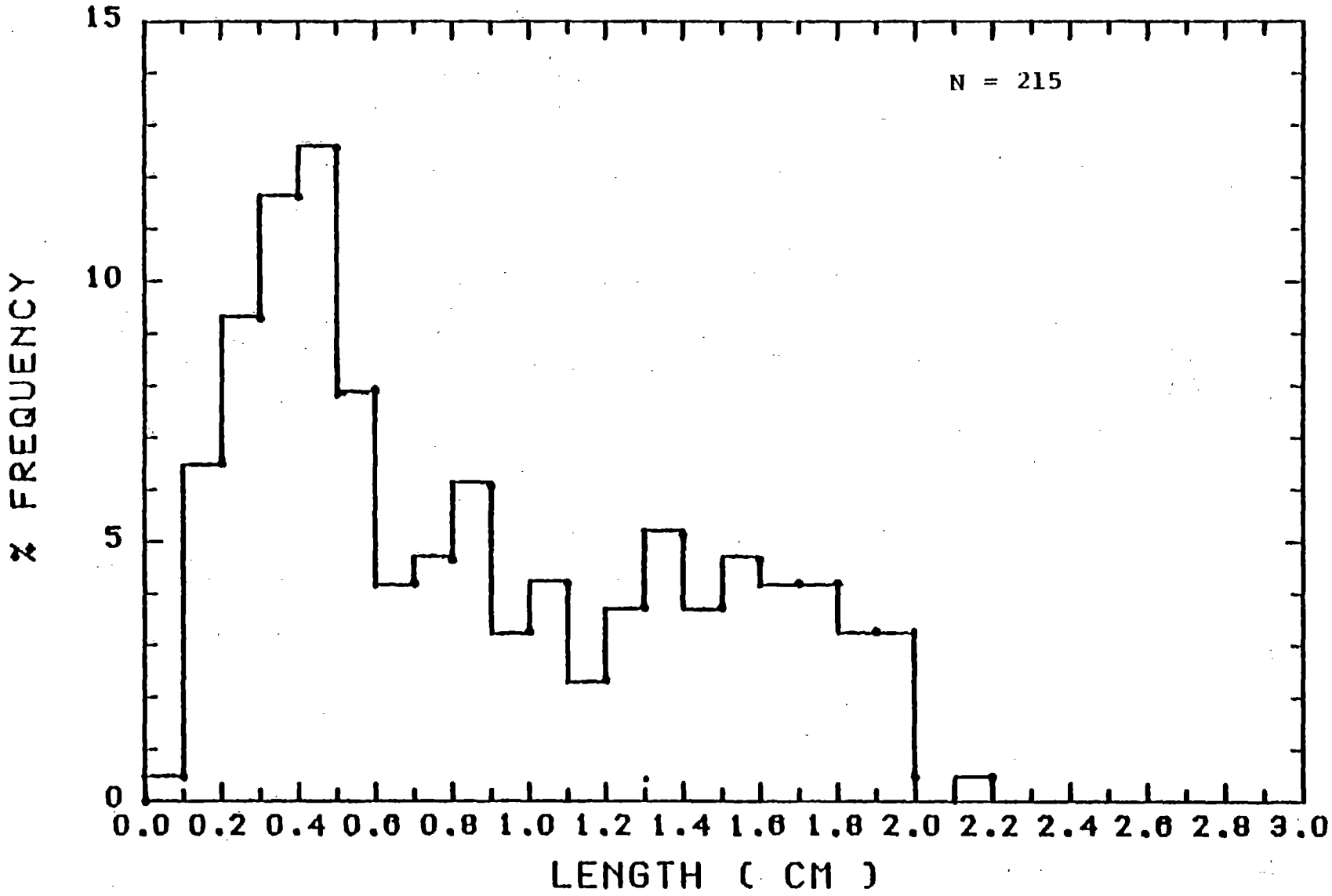


ABUNDANCE OF
TEREBRATULINA SEPTENTRIONALIS

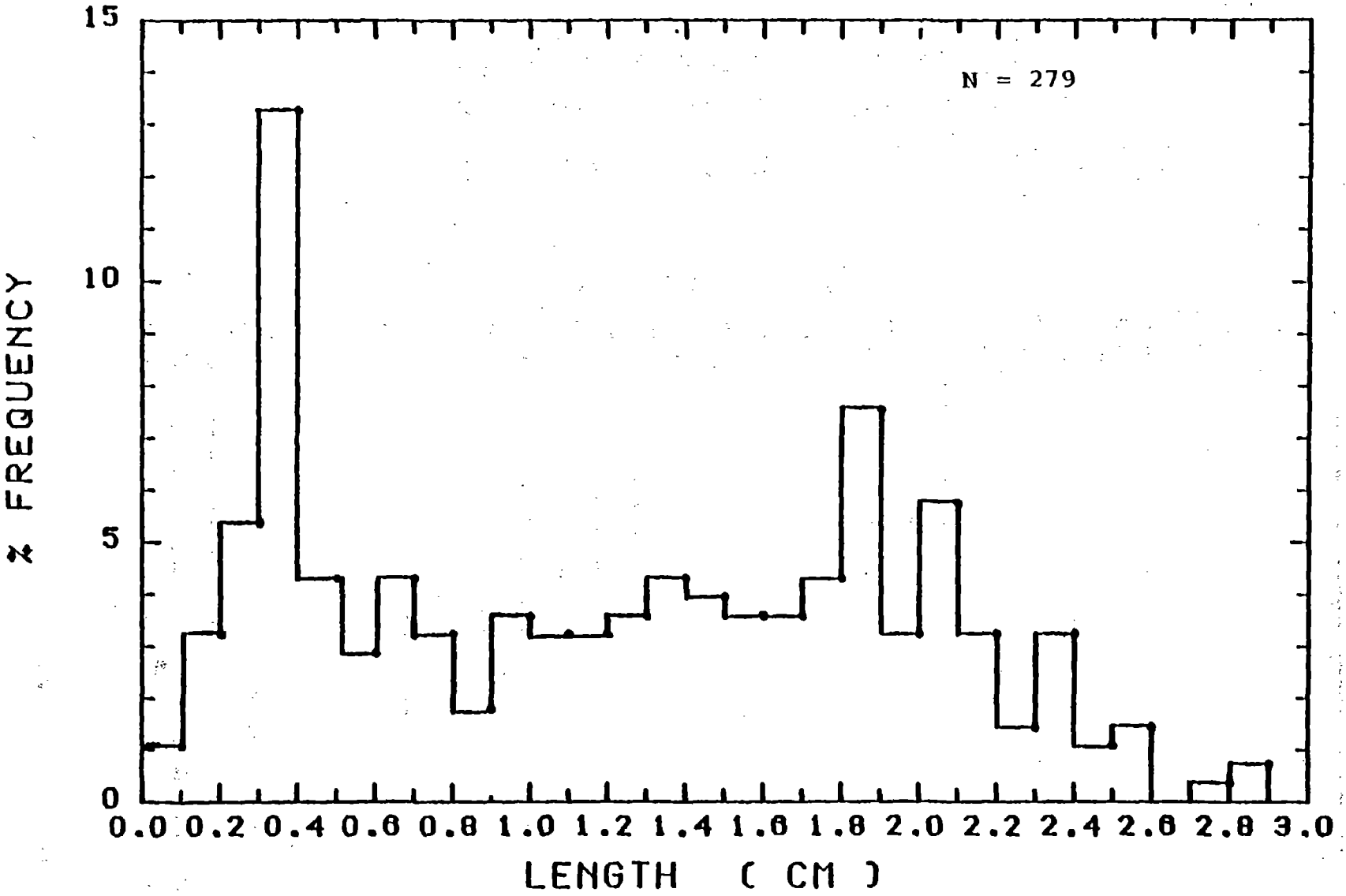


SIZE STRUCTURE OF
TEREBRATULINA SEPTENTRIONALIS

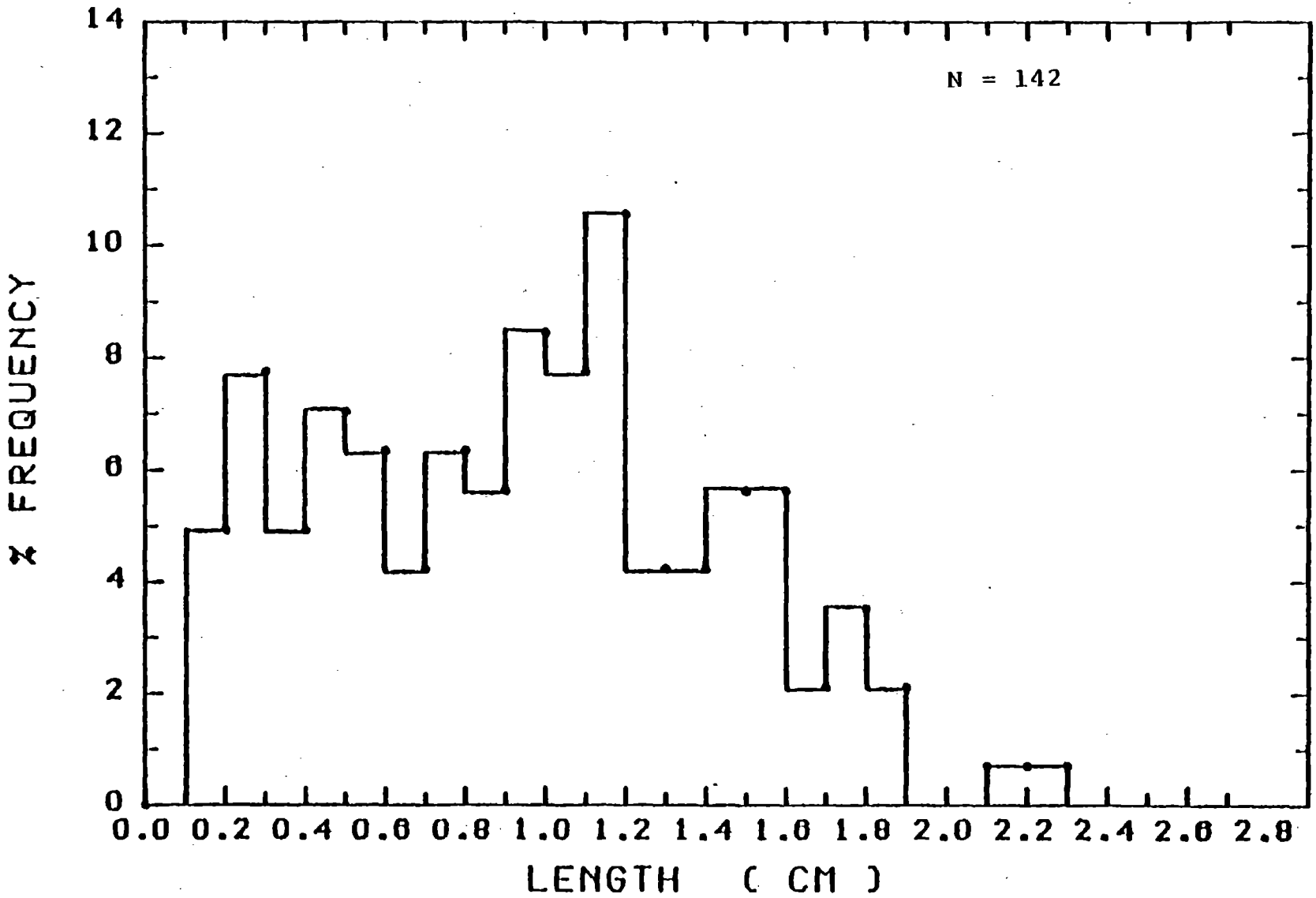

Δ = attached to rock
○ = attached to other brachiopods
□ = attached to polychaete tubes
NUMBER OF INDIVIDUALS
0
5
10
15
20
25
30
35
40
45
50
55
60
0.00.20.40.60.81.01.21.41.61.82.02.22.42.62.83
LENGTH (CM)



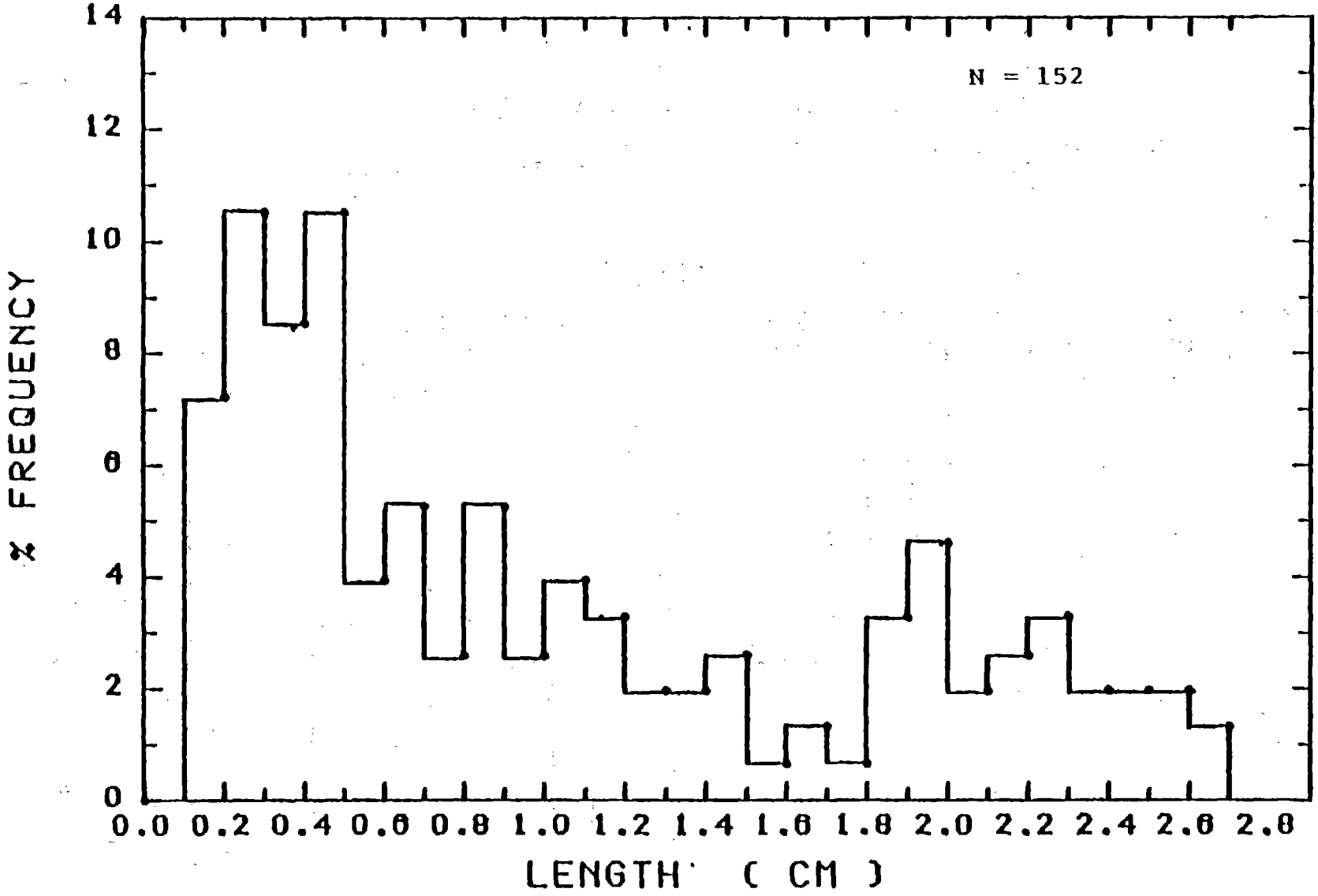
SIZE FREQUENCY DISTRIBUTION OF
TEREBRATULINA SEPTENTRIONALIS
30 M HORIZONTAL SUBSTRATA



SIZE FREQUENCY DISTRIBUTION OF
TEREBRATULINA SEPTENTRIONALIS
30 M VERTICAL SUBSTRATA



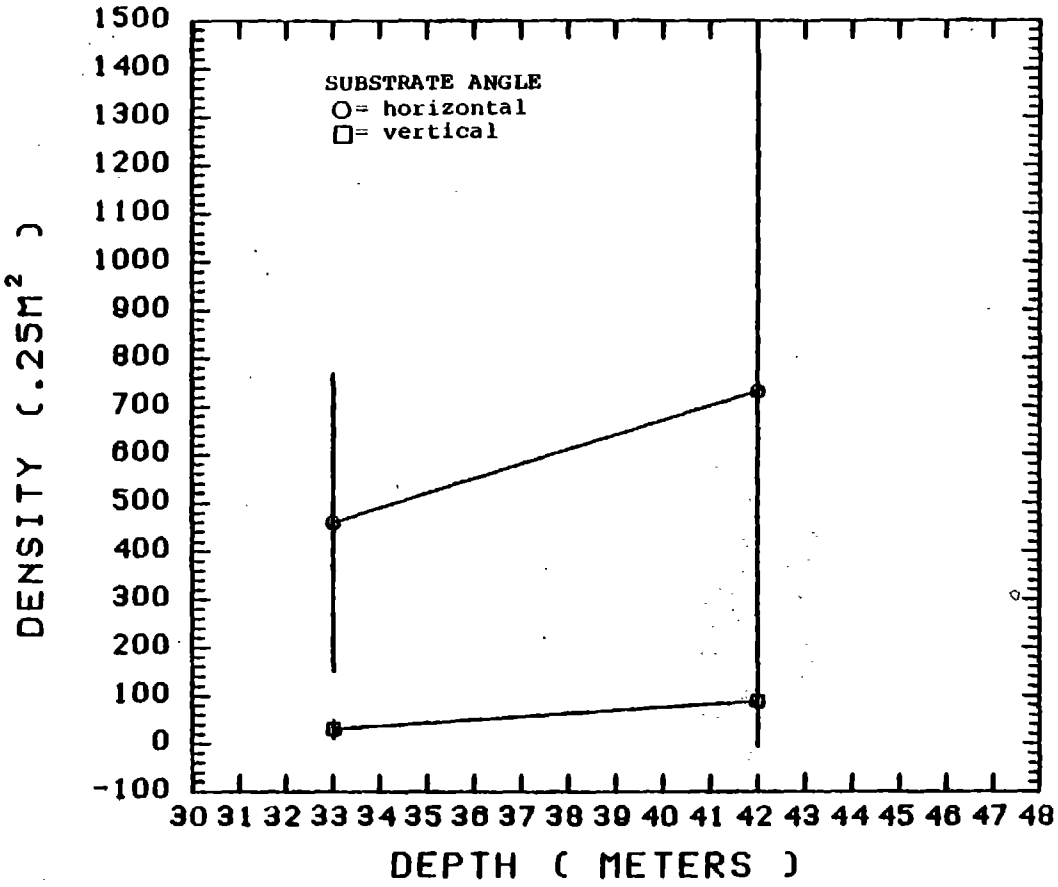
SIZE FREQUENCY DISTRIBUTION OF
TEREBRATULINA SEPTENTRIONALIS
42 M HORIZONTAL SUBSTRATA



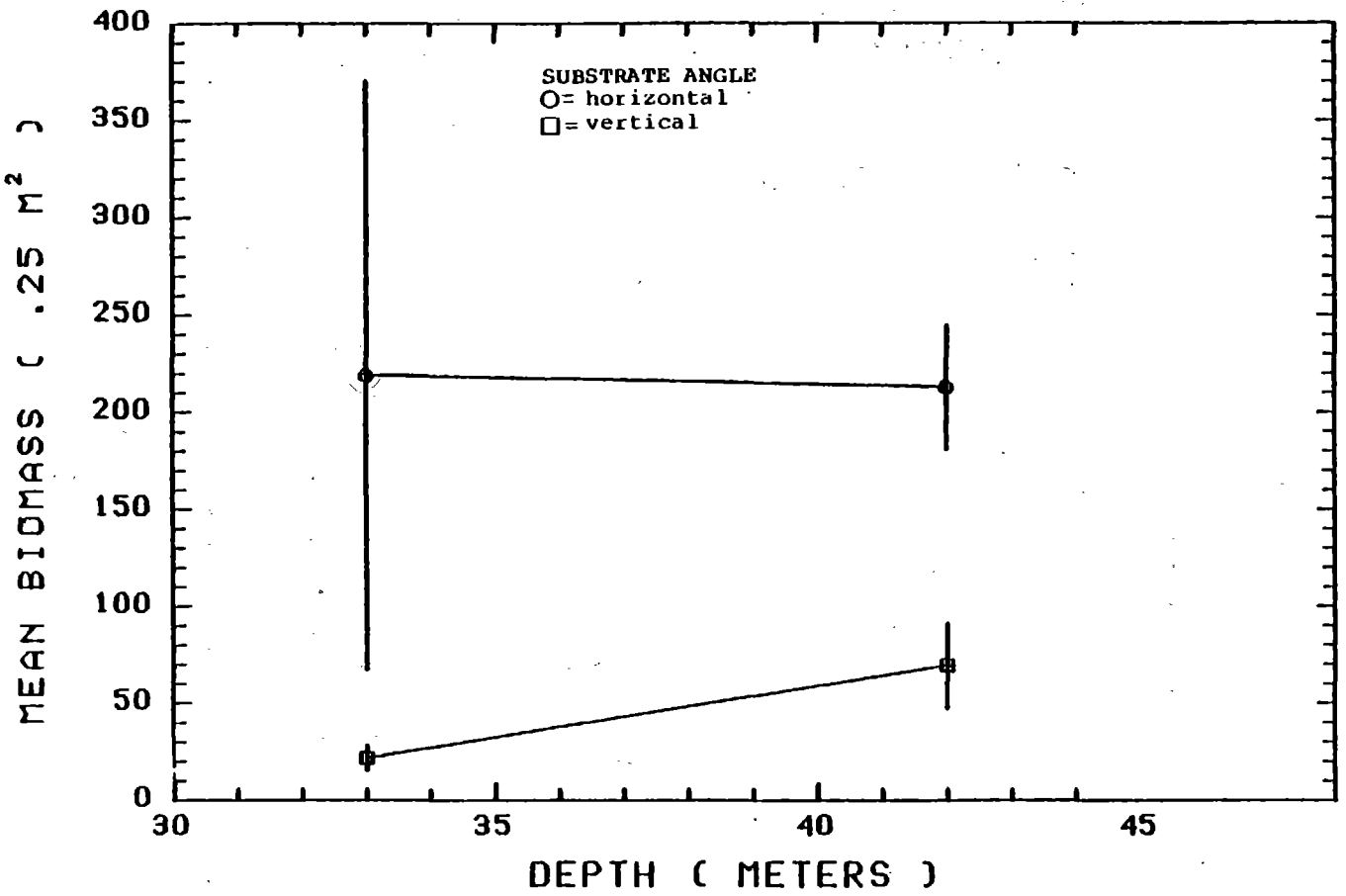
SIZE FREQUENCY DISTRIBUTION OF
TEREBRATULINA SEPTENTRIONALIS
42 M VERTICAL SUBSTRATA

APPENDIX C

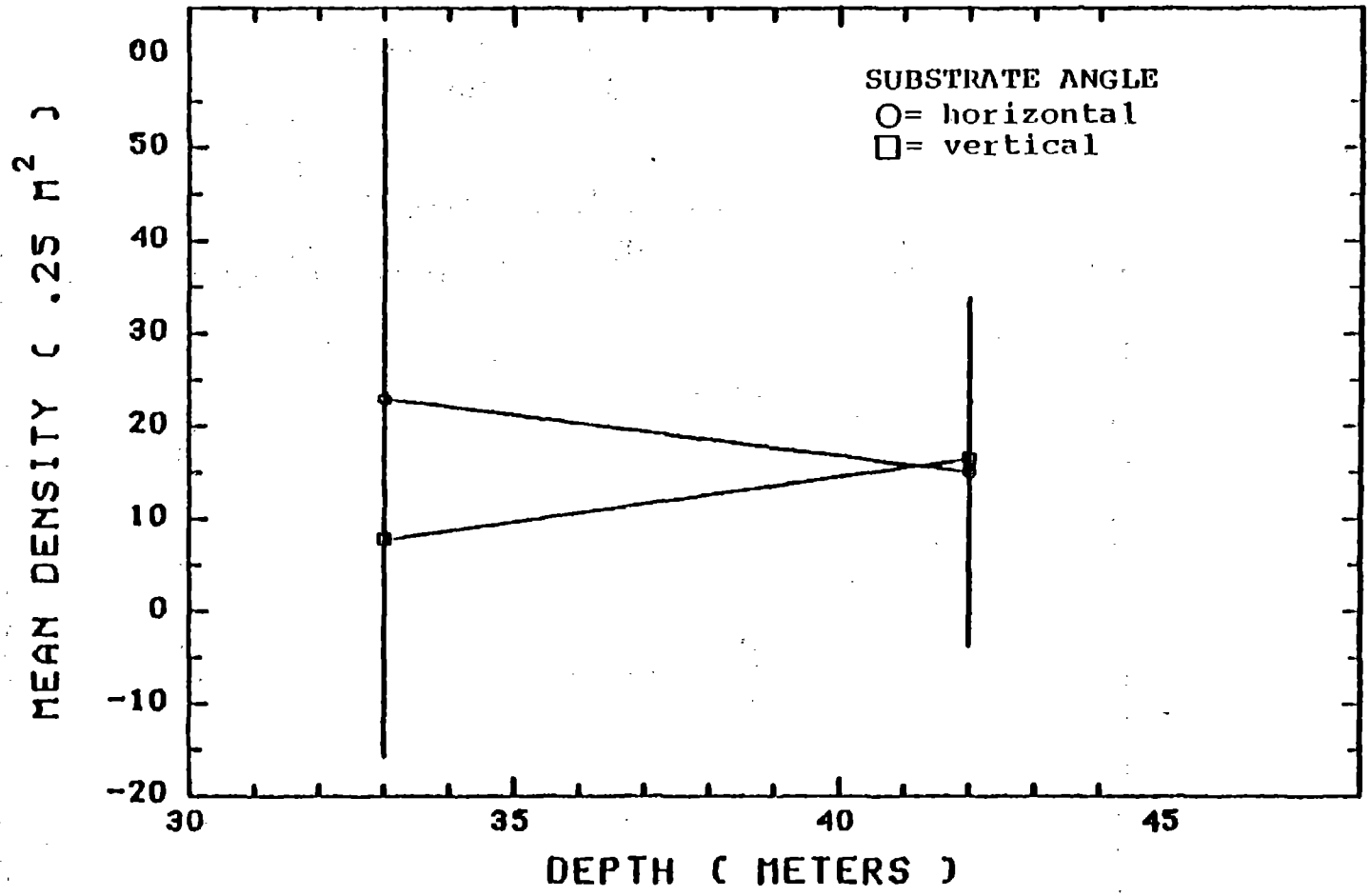
BIOMASS AND ABUNDANCE OF THE DOMINANT POLYCHAETE SPECIES



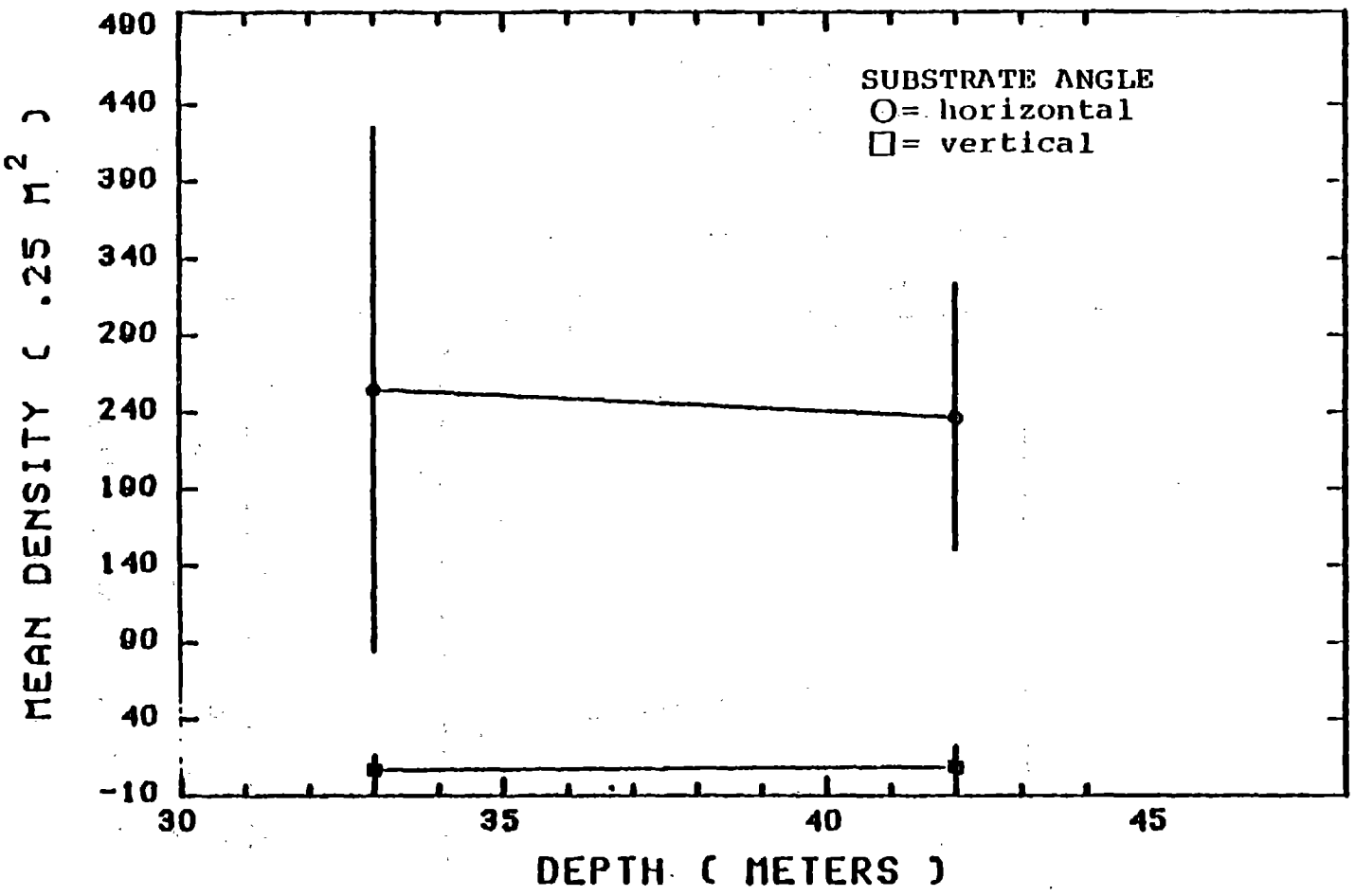
ABUNDANCE
OF ALL POLYCHAETE SPP.



BIOMASS
OF POLYCHAETE SP.

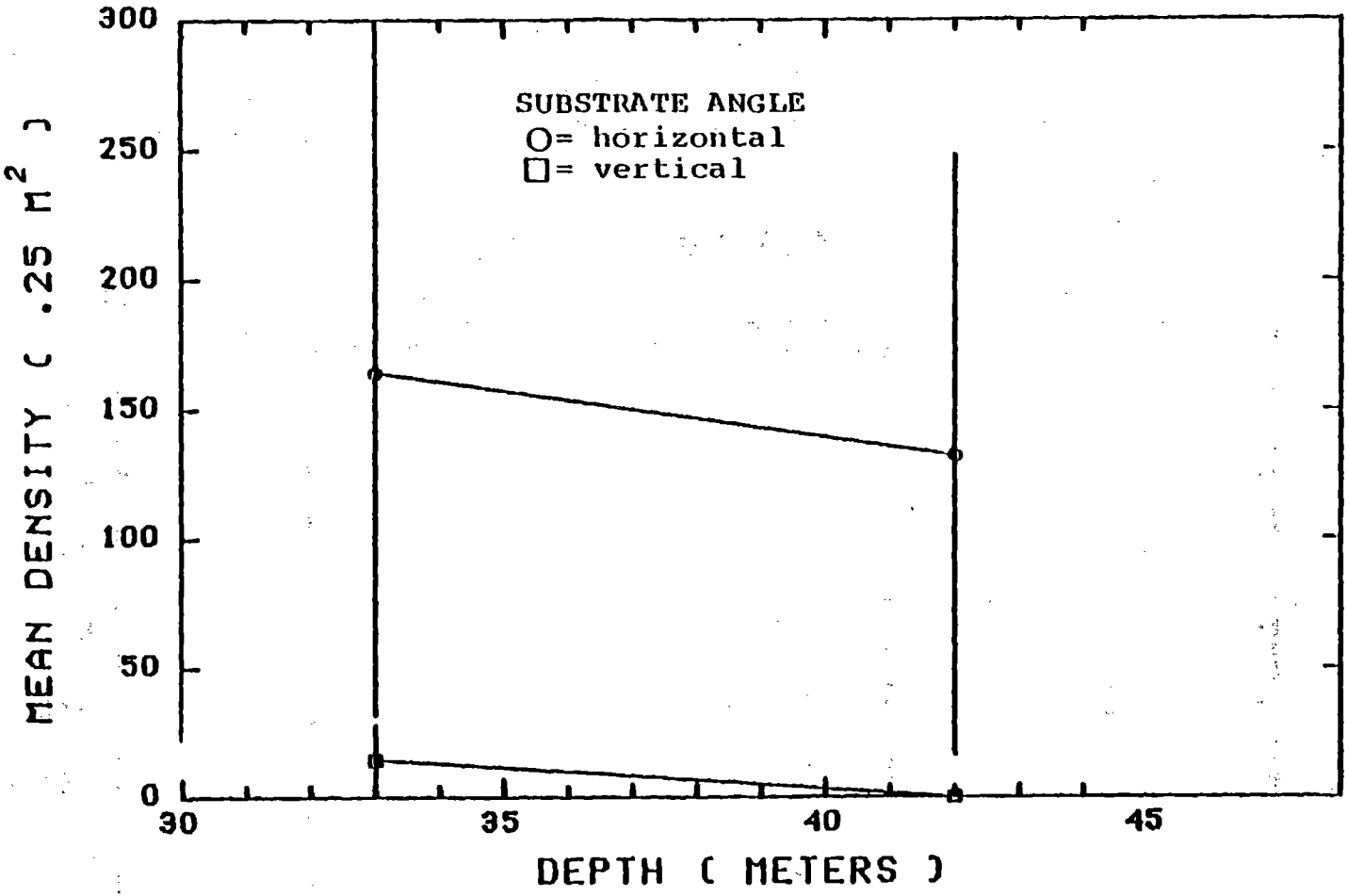


ABUNDANCE
OF NERIES SP.



ABUNDANCE

OF CHONE INFUNDIBULIFORMIS

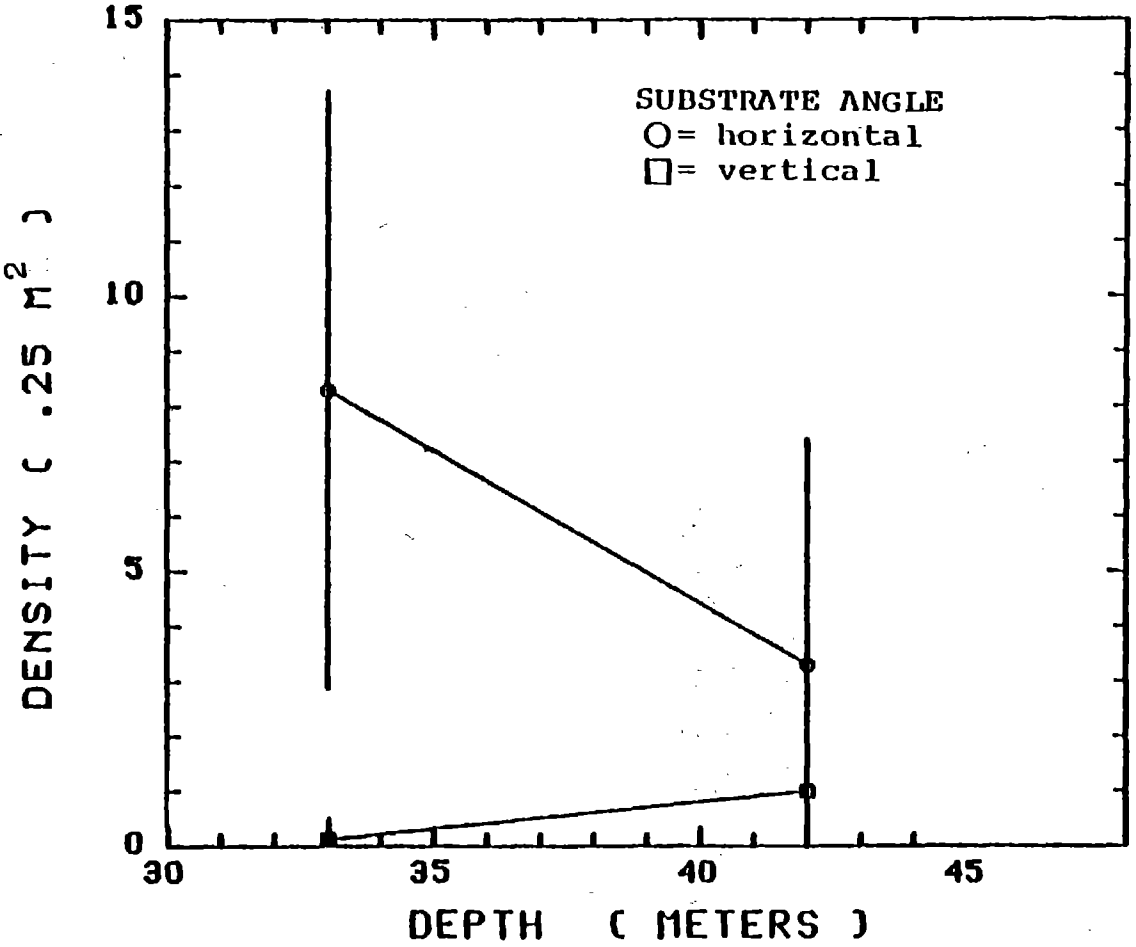


ABUNDANCE

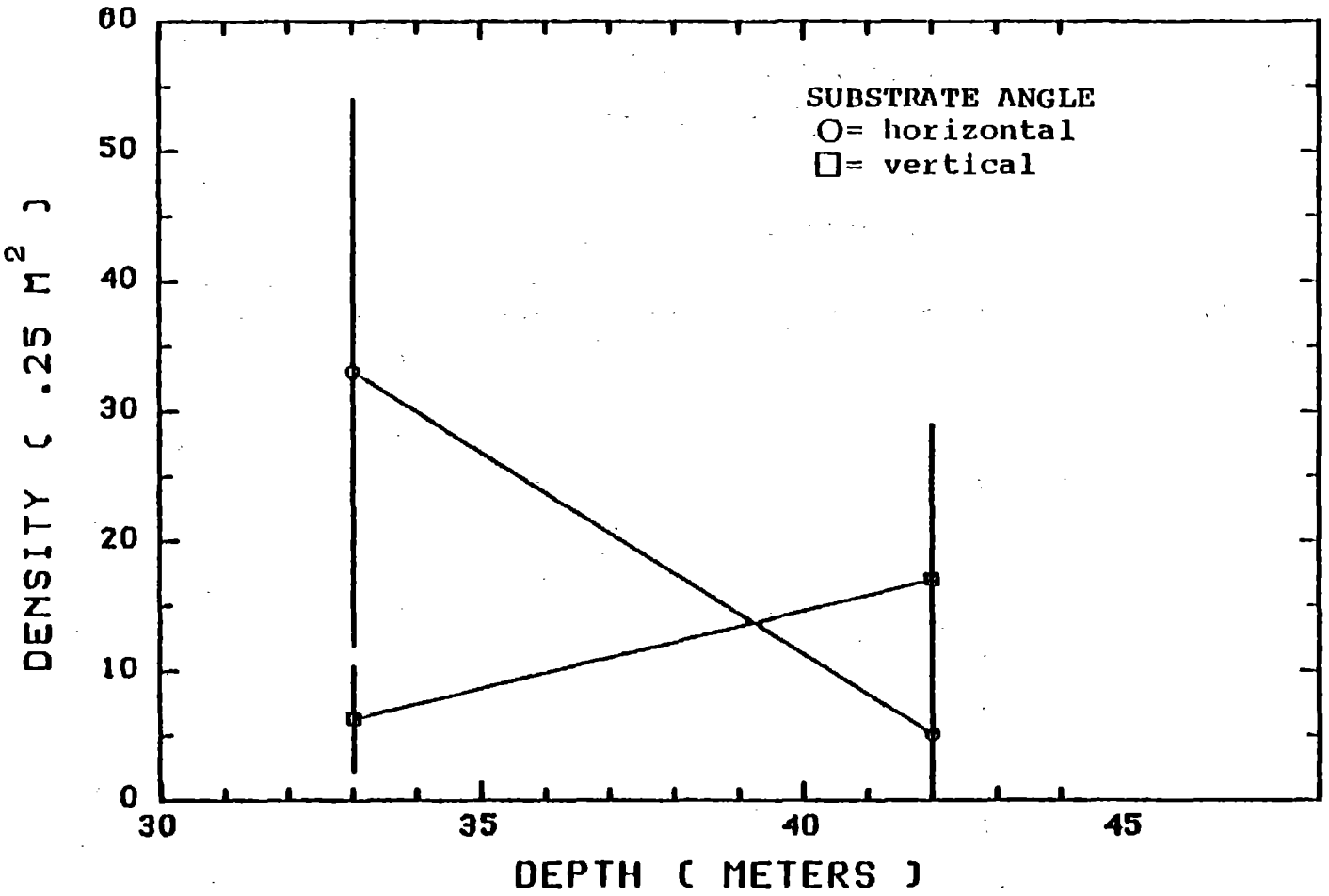
OF THELEPUS CINCINNATUS

APPENDIX D

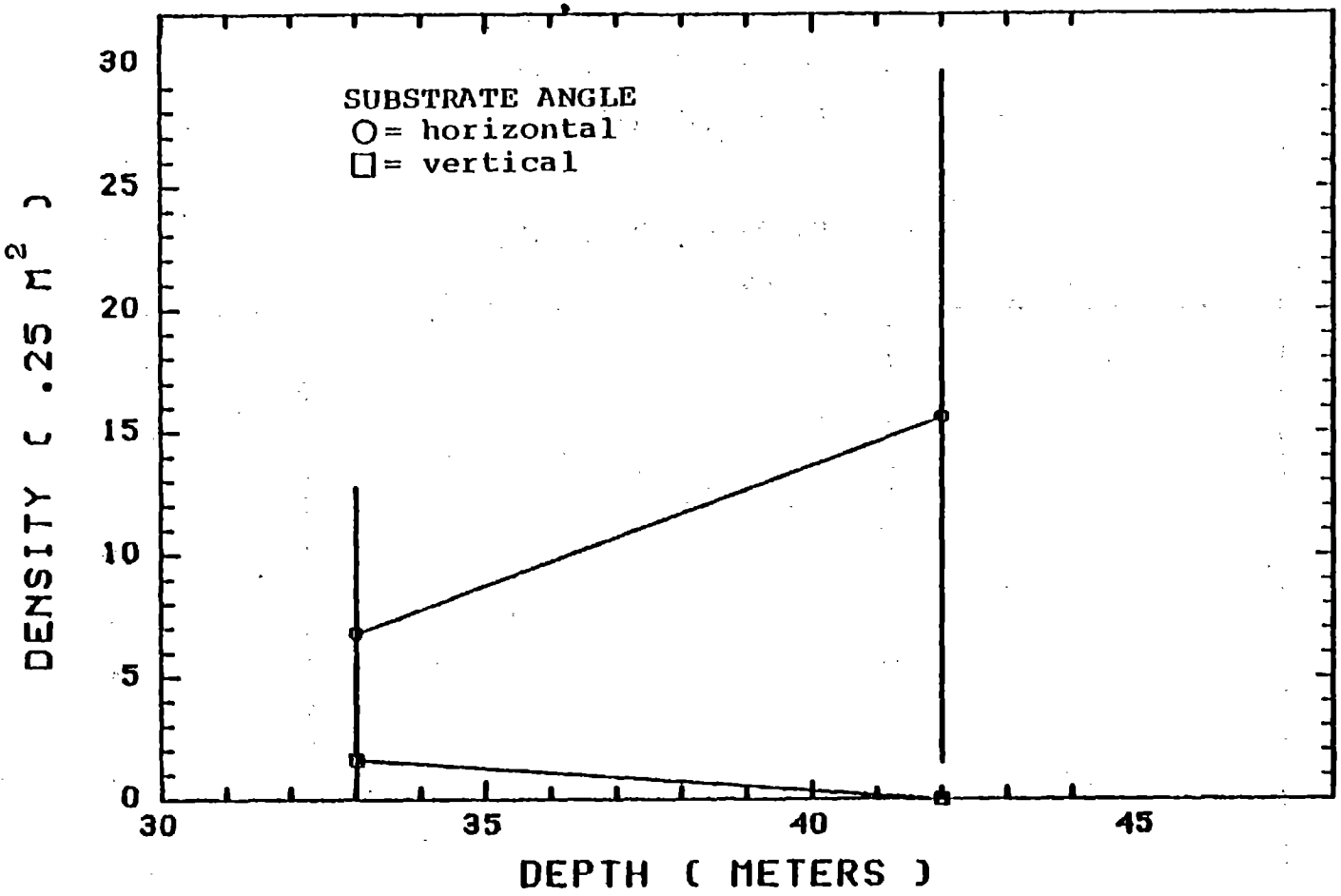
POPULATION STRUCTURE OF THE DOMINANT MOLLUSCAN SPECIES



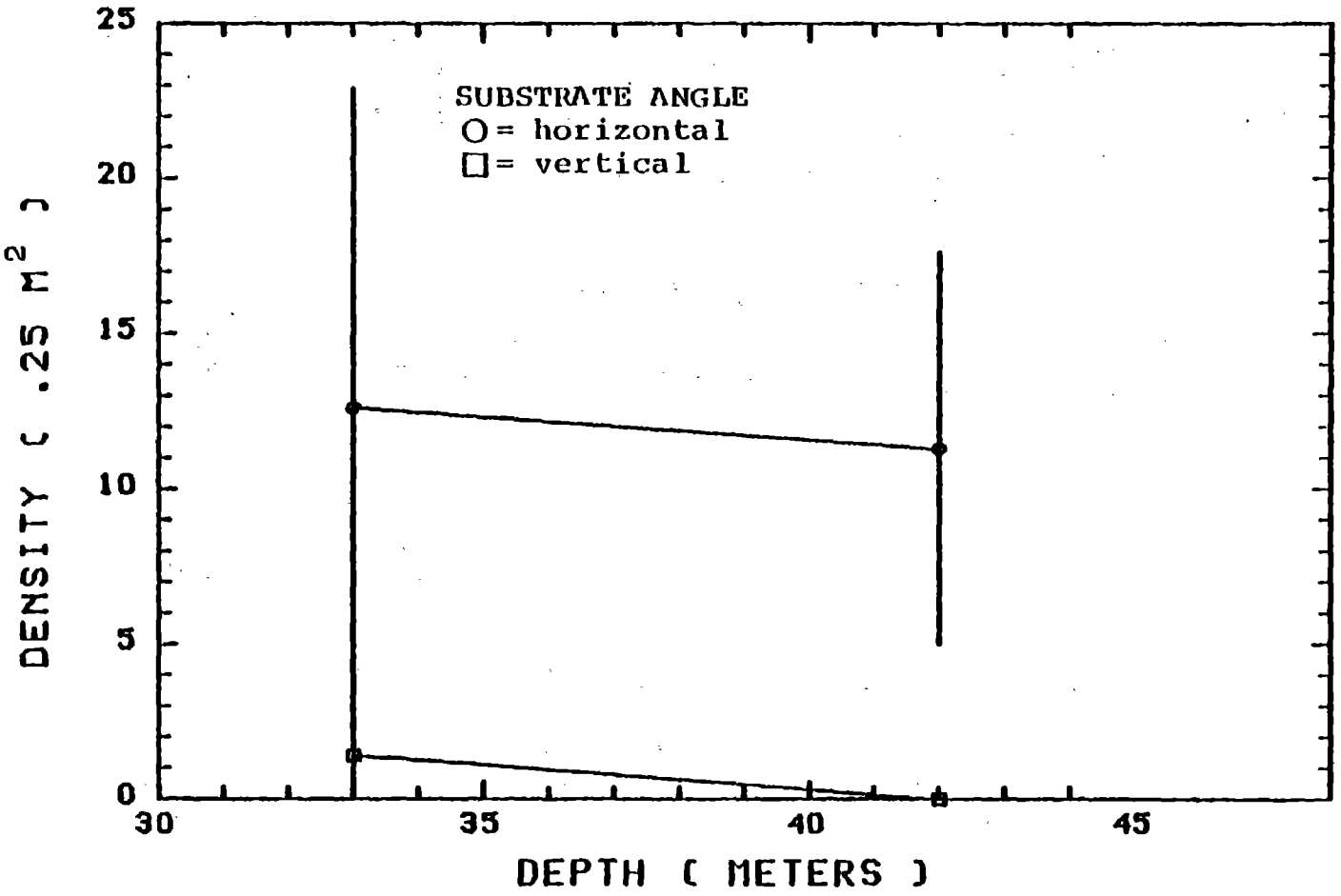
ABUNDANCE OF
MARGARITES COSTALIS



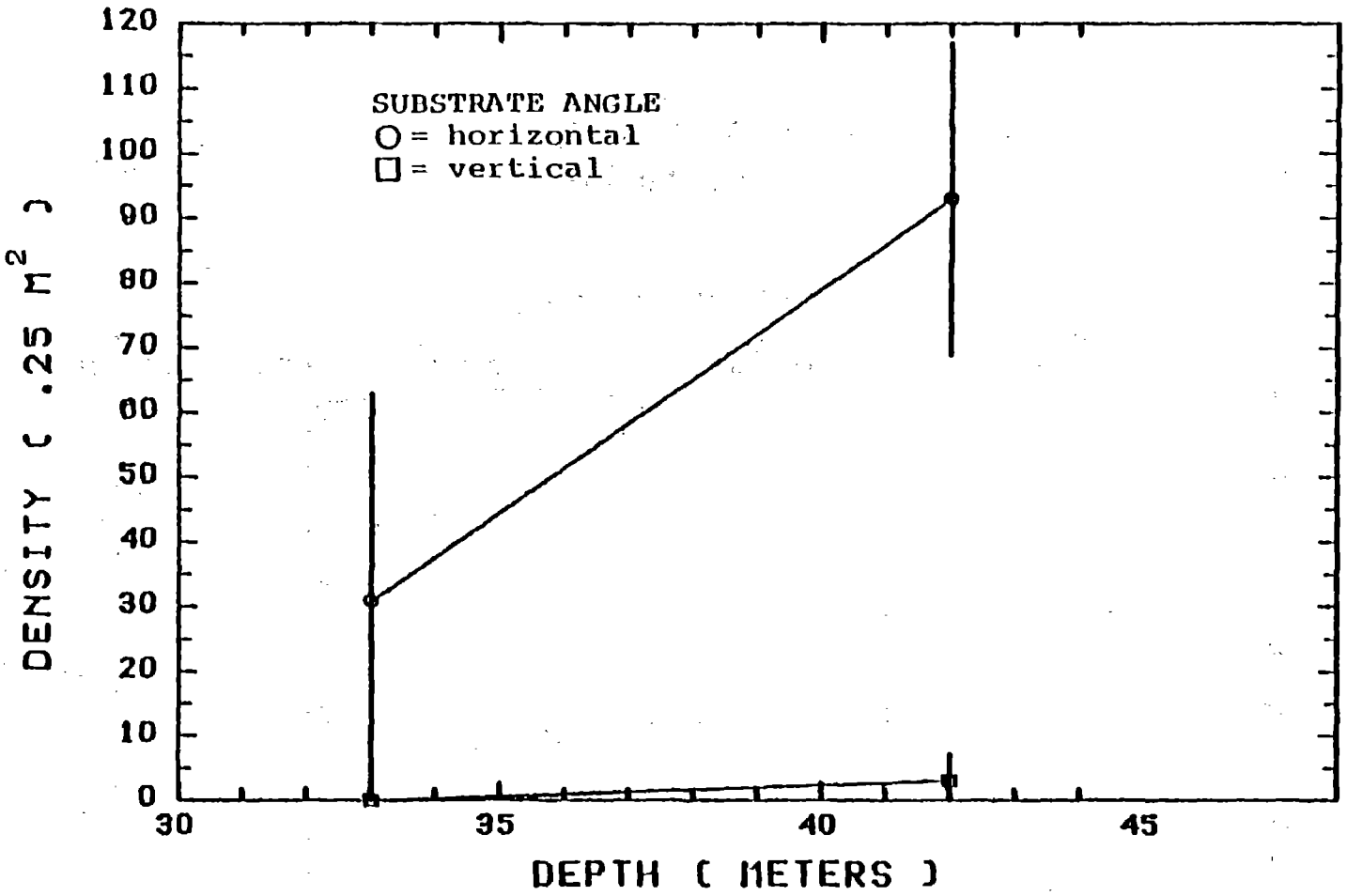
ABUNDANCE OF
ANACHIS LAFRESNAYI



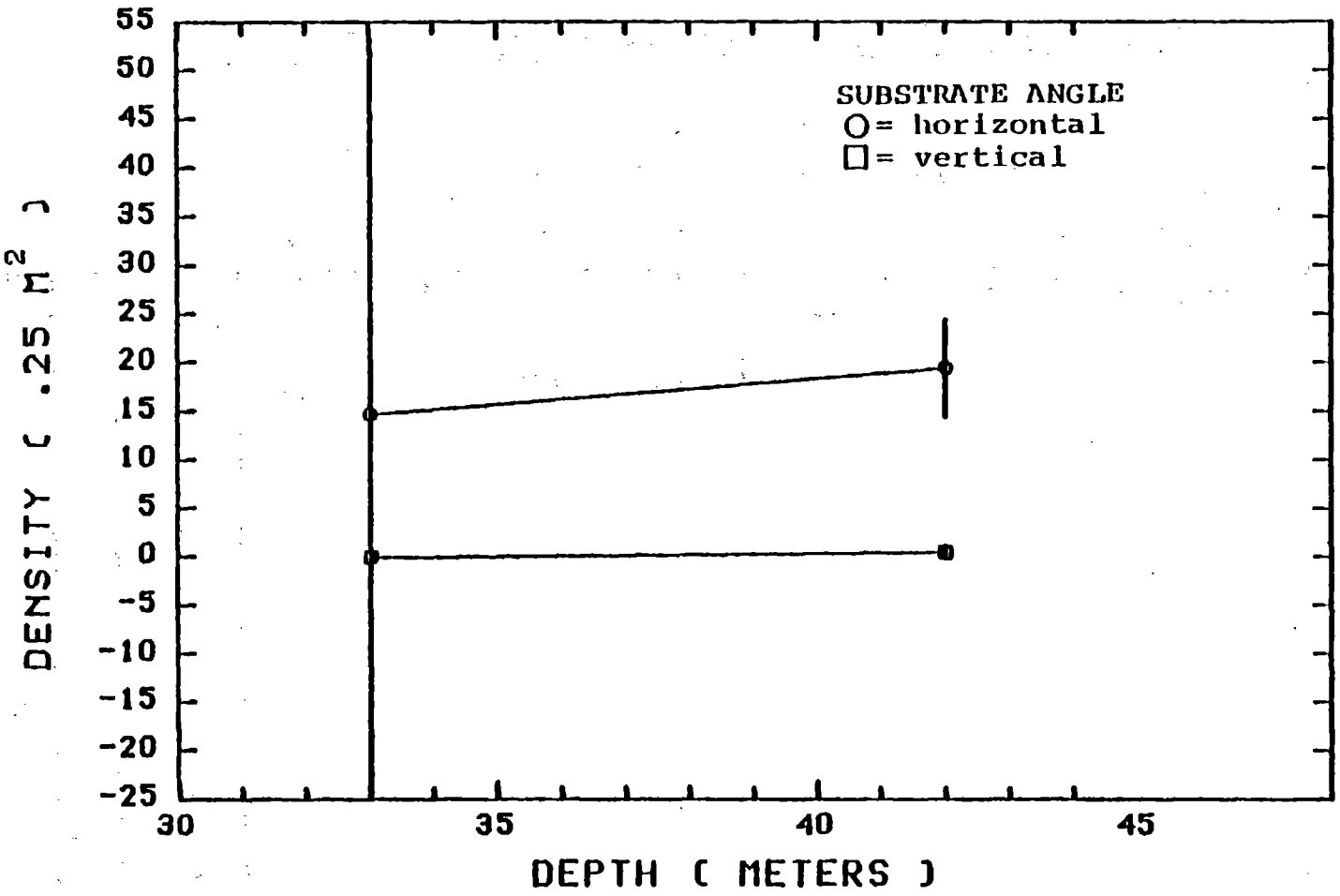
ABUNDANCE OF
COLUS PYGMAEUS



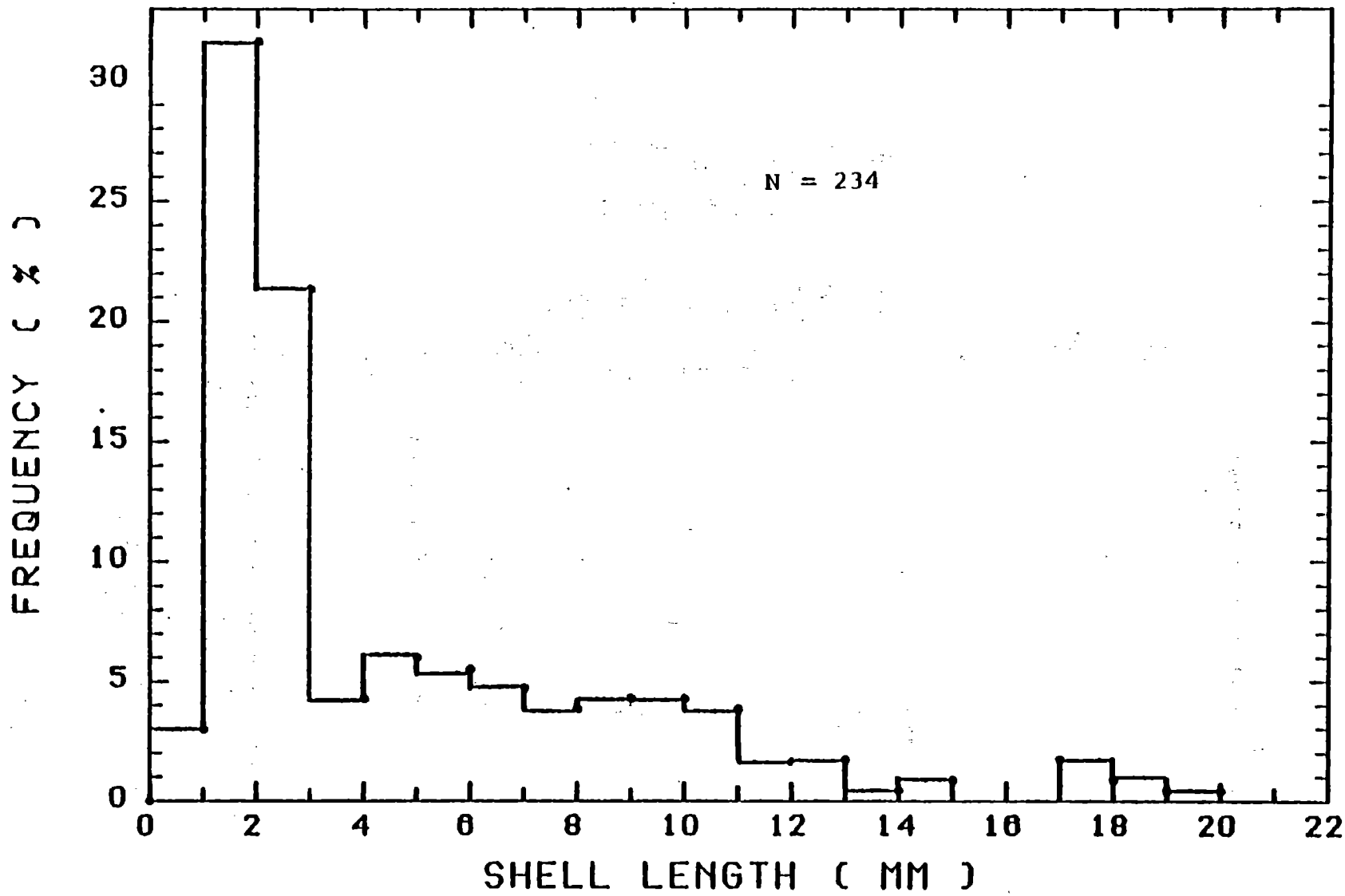
ABUNDANCE OF
HIATELLA ARCTICA



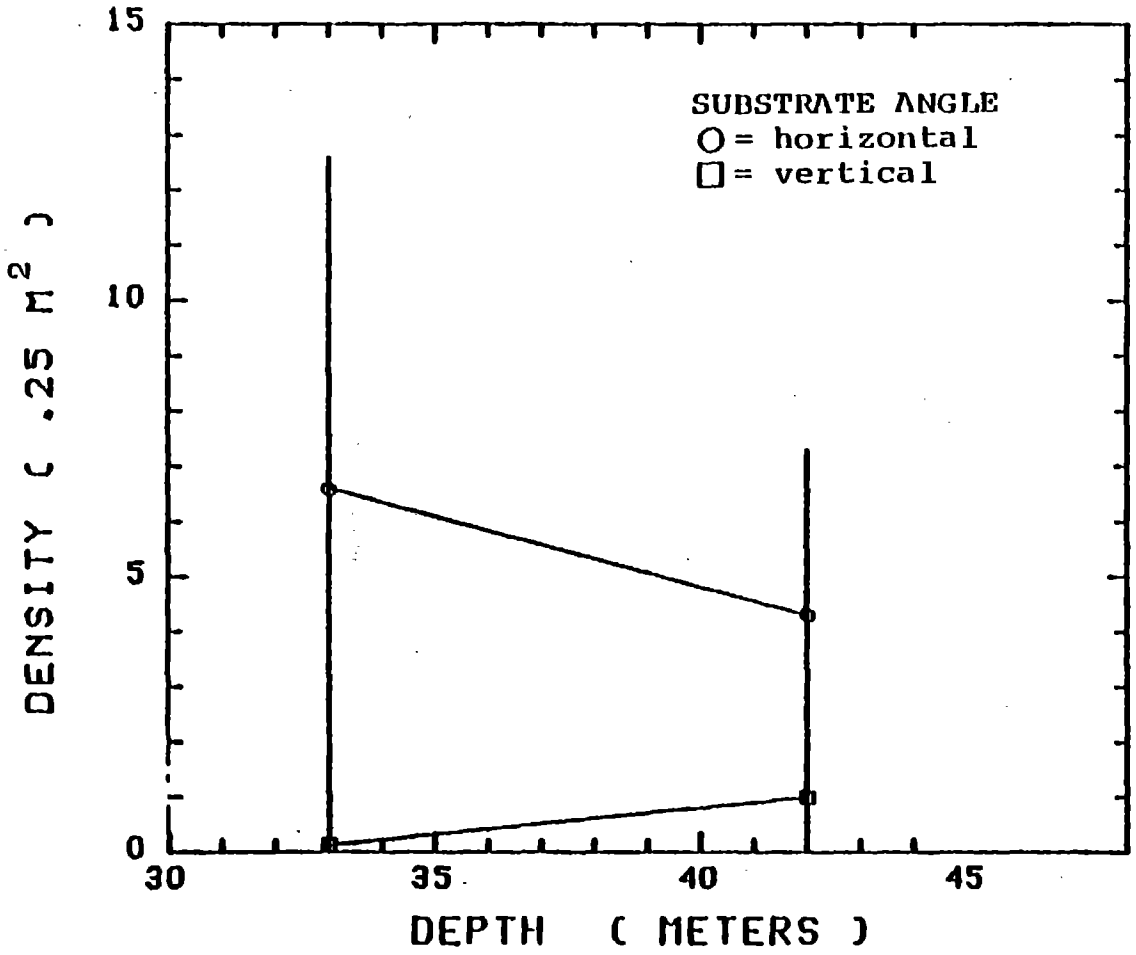
ABUNDANCE OF
CERASTODERMA PINNULATUM



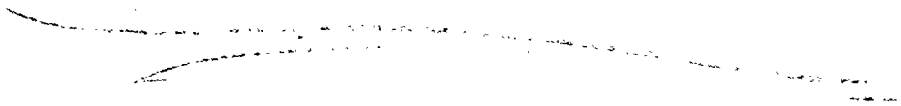
ABUNDANCE OF
MODIOLUS MODIOLUS



SIZE FREQUENCY DISTRIBUTION
OF MODIOLUS MODIOLUS

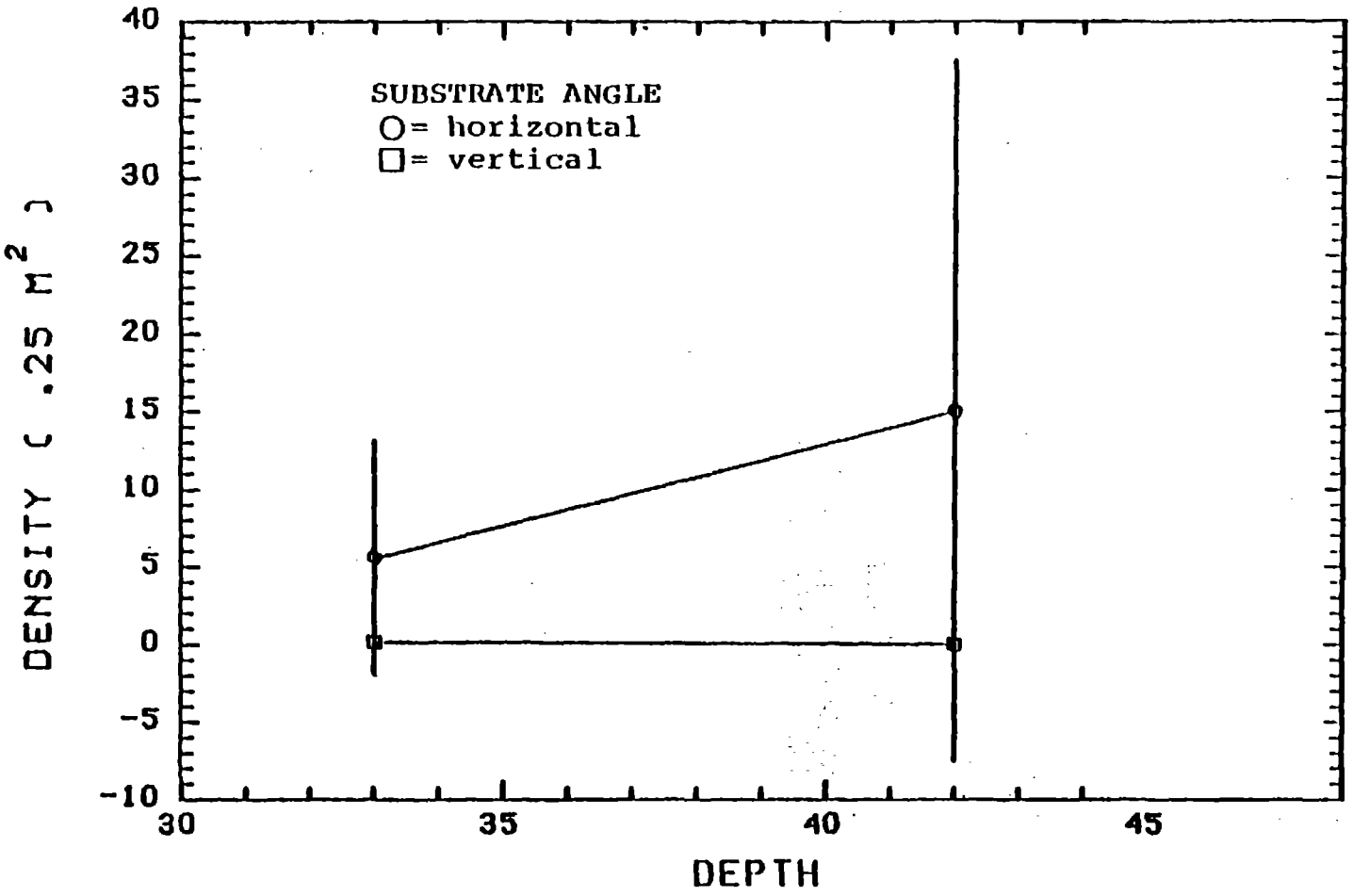


ABUNDANCE OF
MUSCULUS NIGER

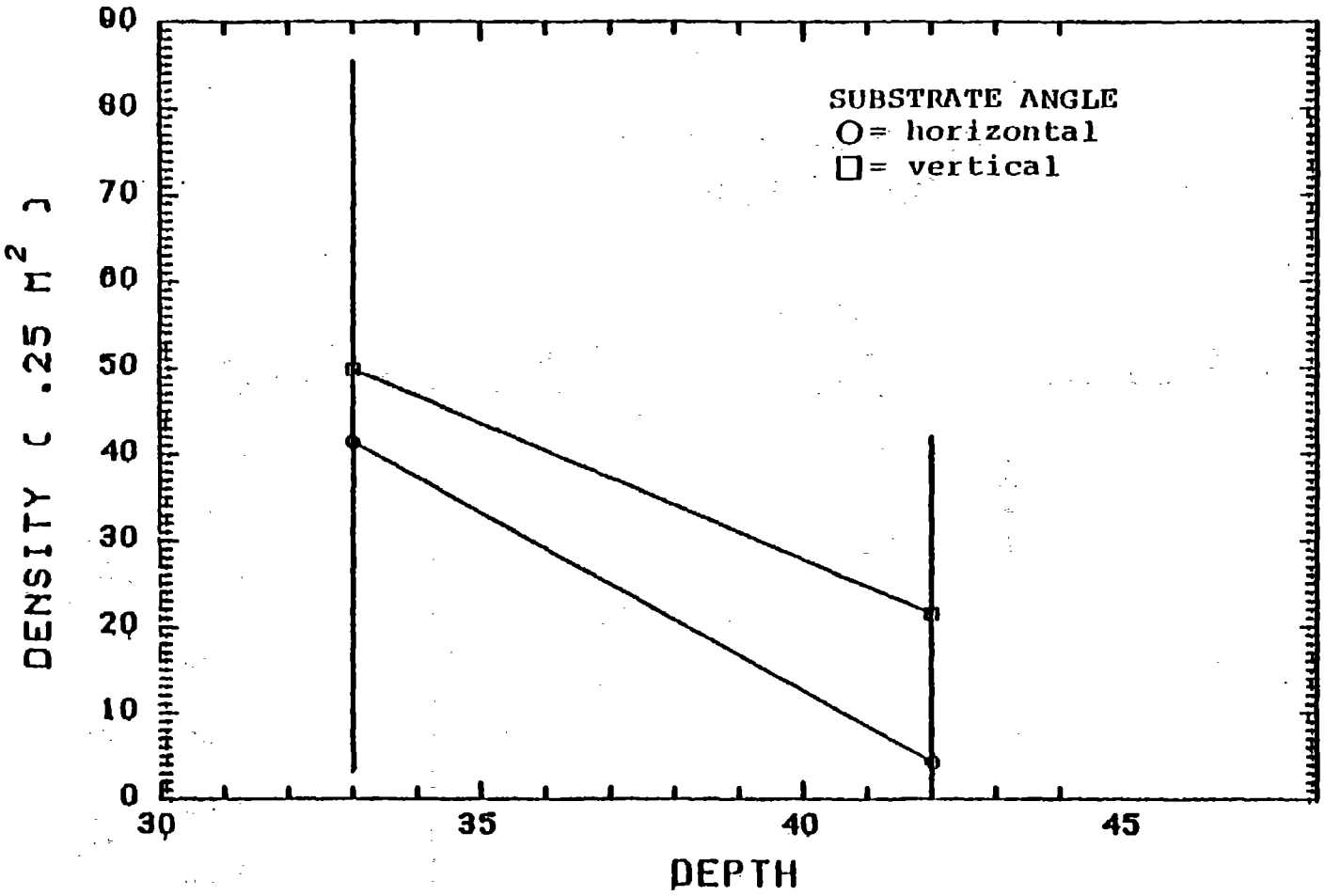


APPENDIX E

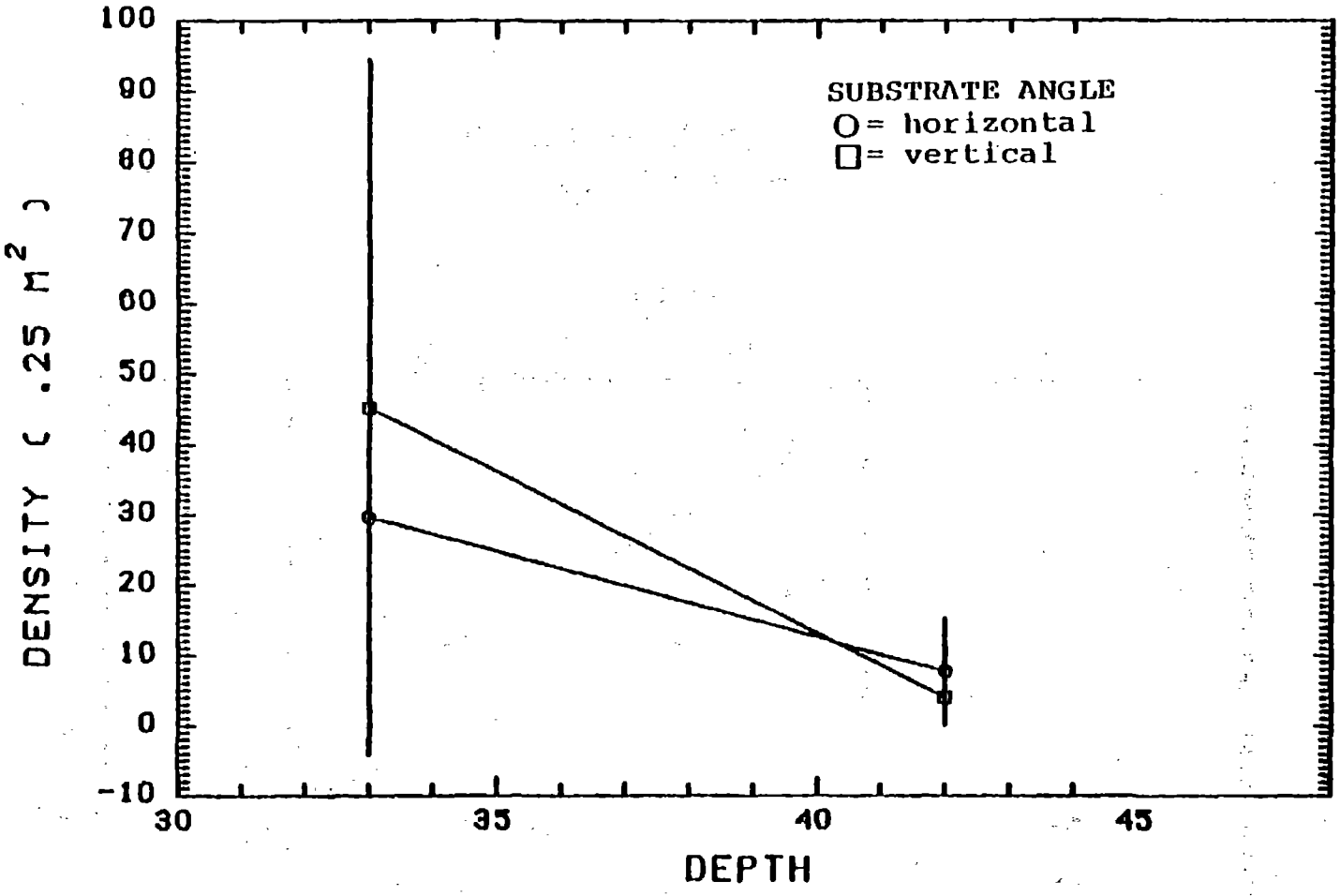
ABUNDANCE OF THE THREE DOMINANT AMPHIPOD SPECIES



ABUNDANCE
OF COROPHIUM SP.



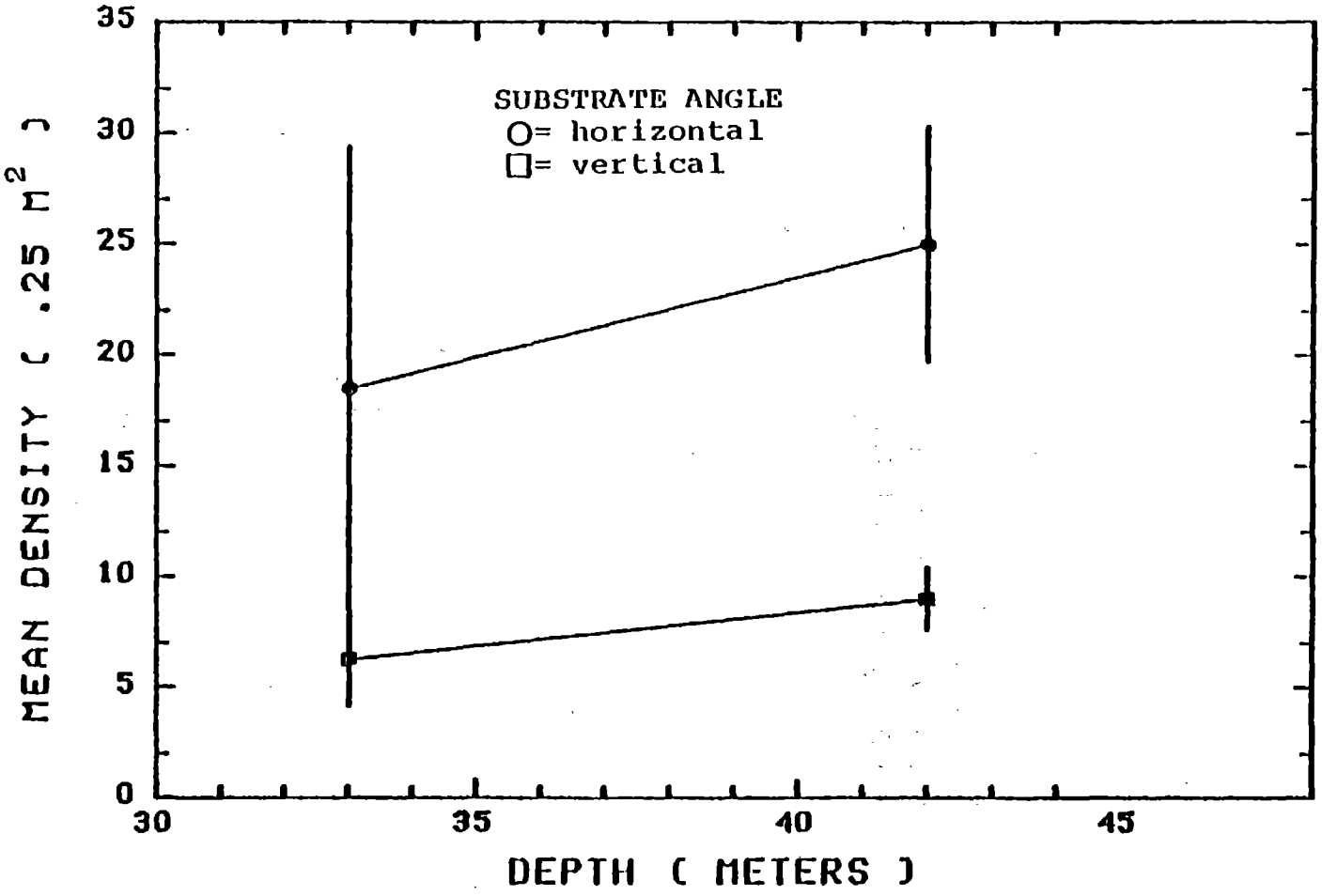
ABUNDANCE
OF PONTOGENEIA SP.



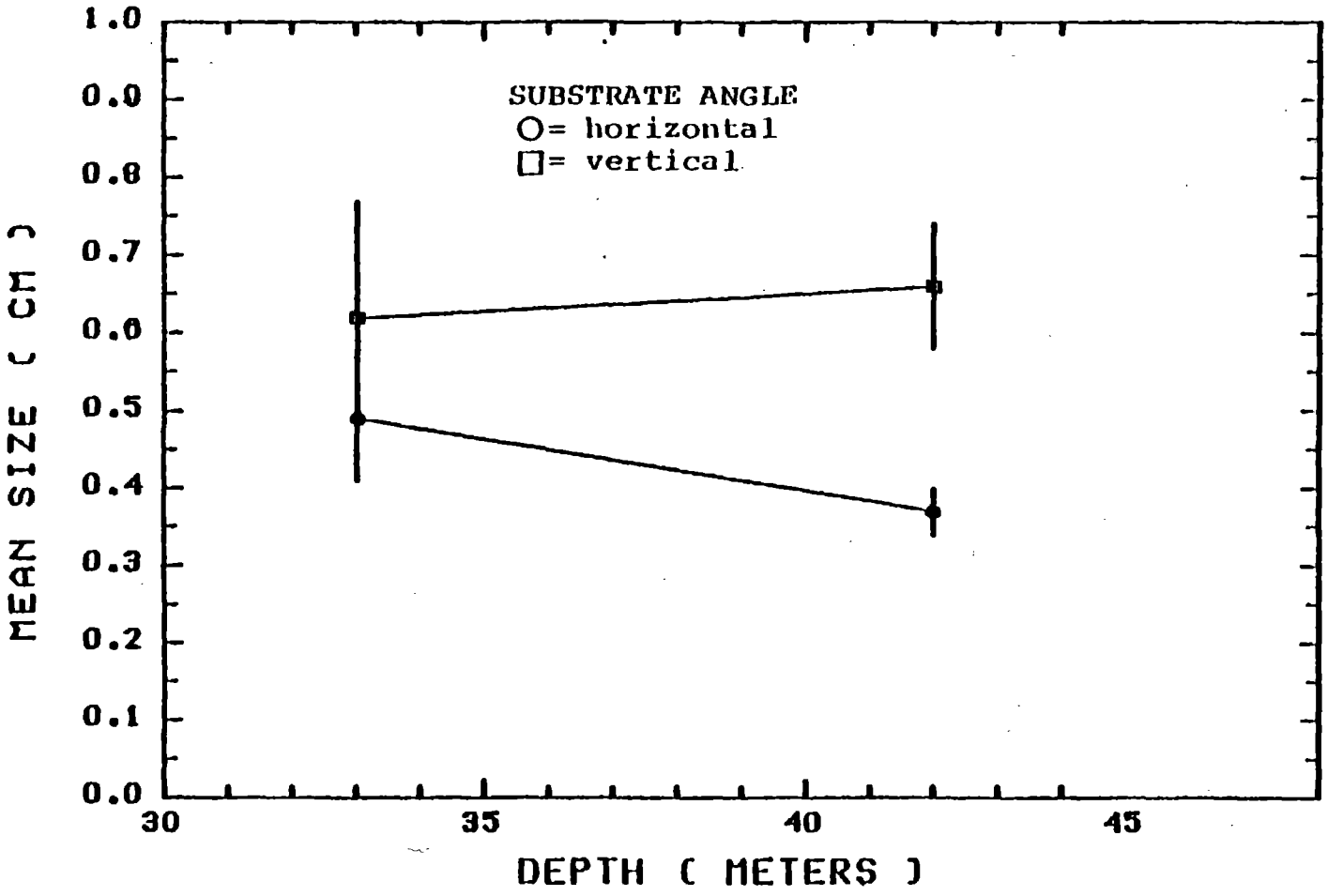
ABUNDANCE
OF PLEUSYNTES SP.

APPENDIX F

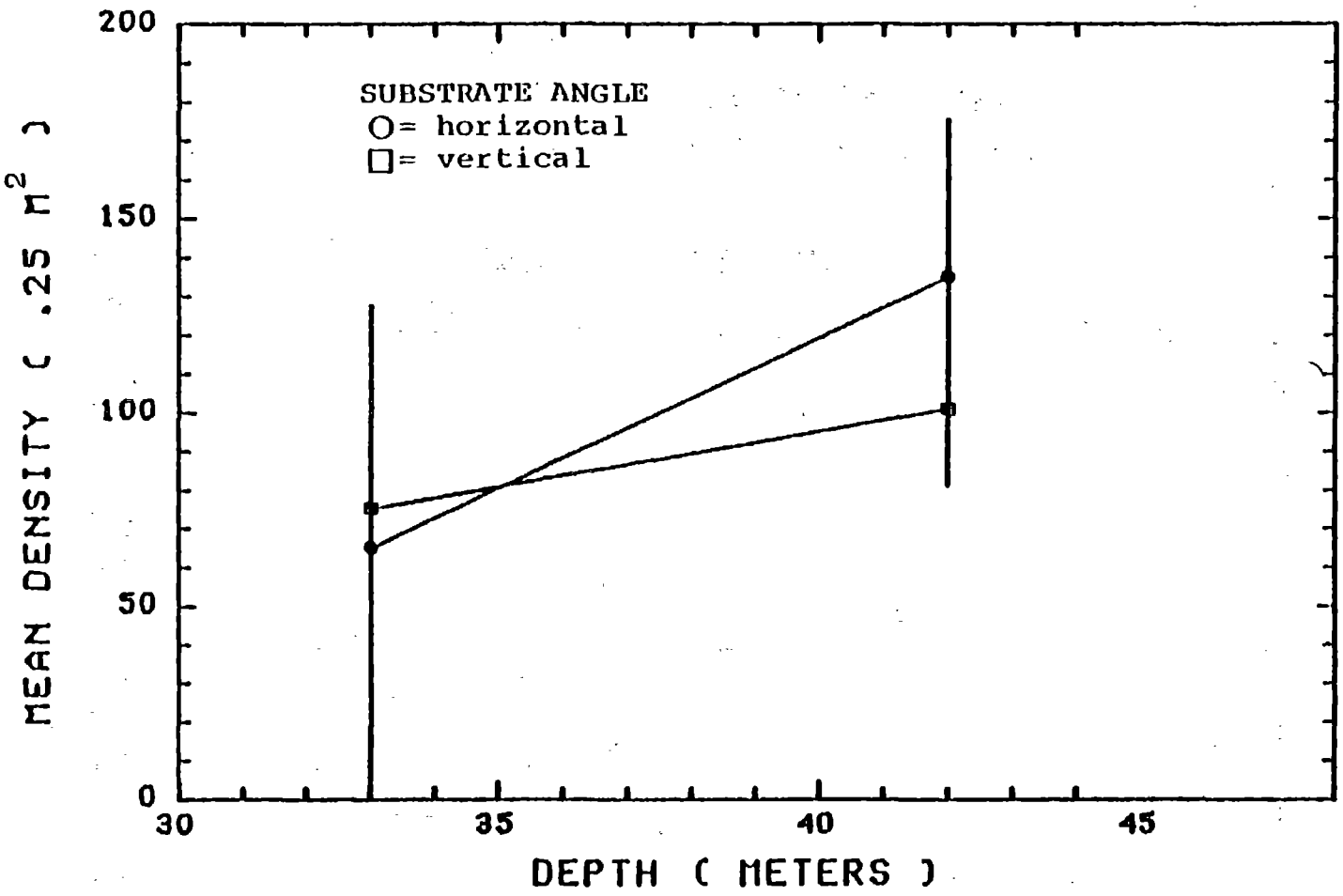
POPULATION STRUCTURE OF THE DOMINANT ECHINODERM SPECIES



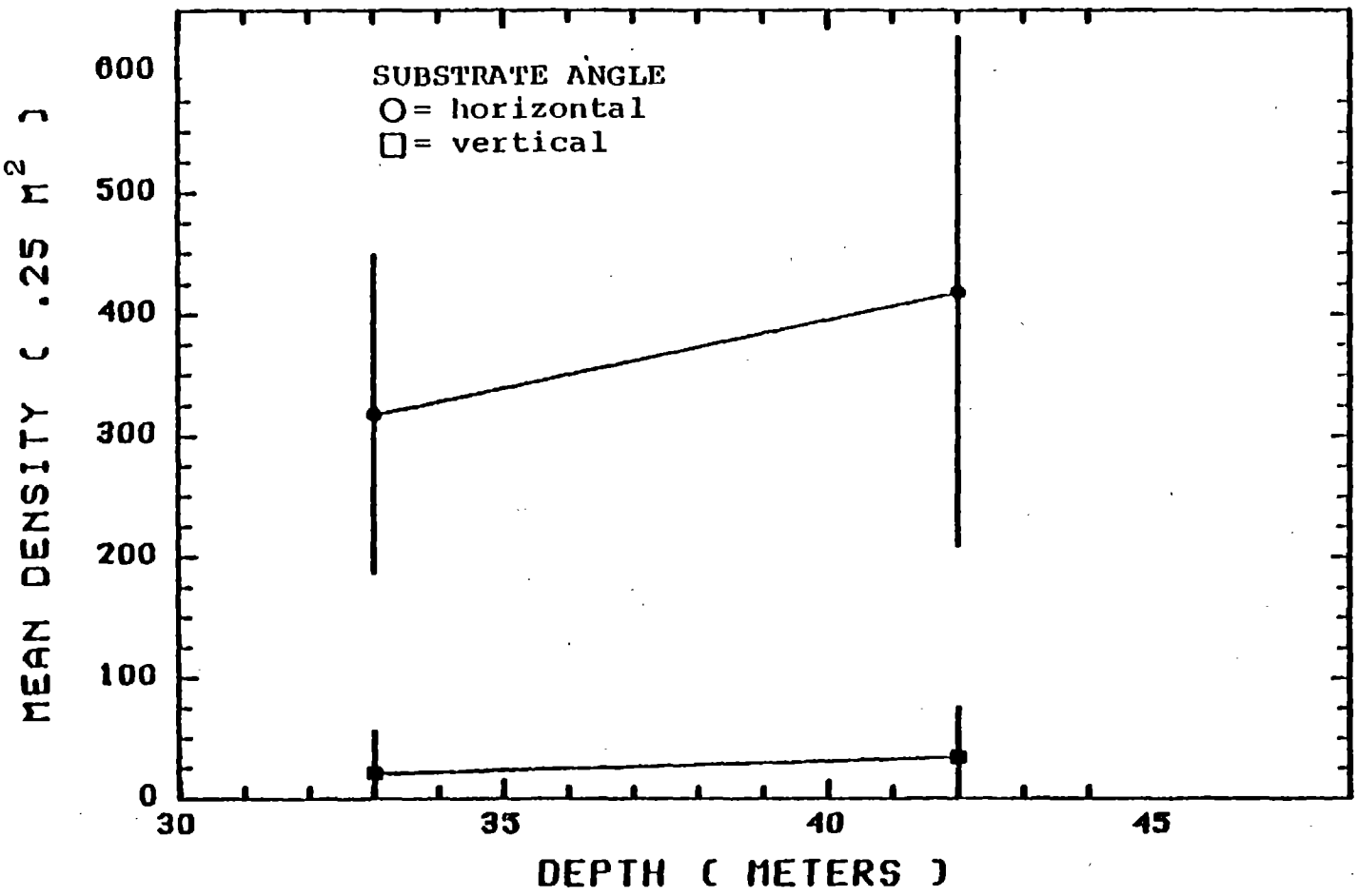
ABUNDANCE OF
STRONGYLOCENTROTUS DROEBACHIENSIS



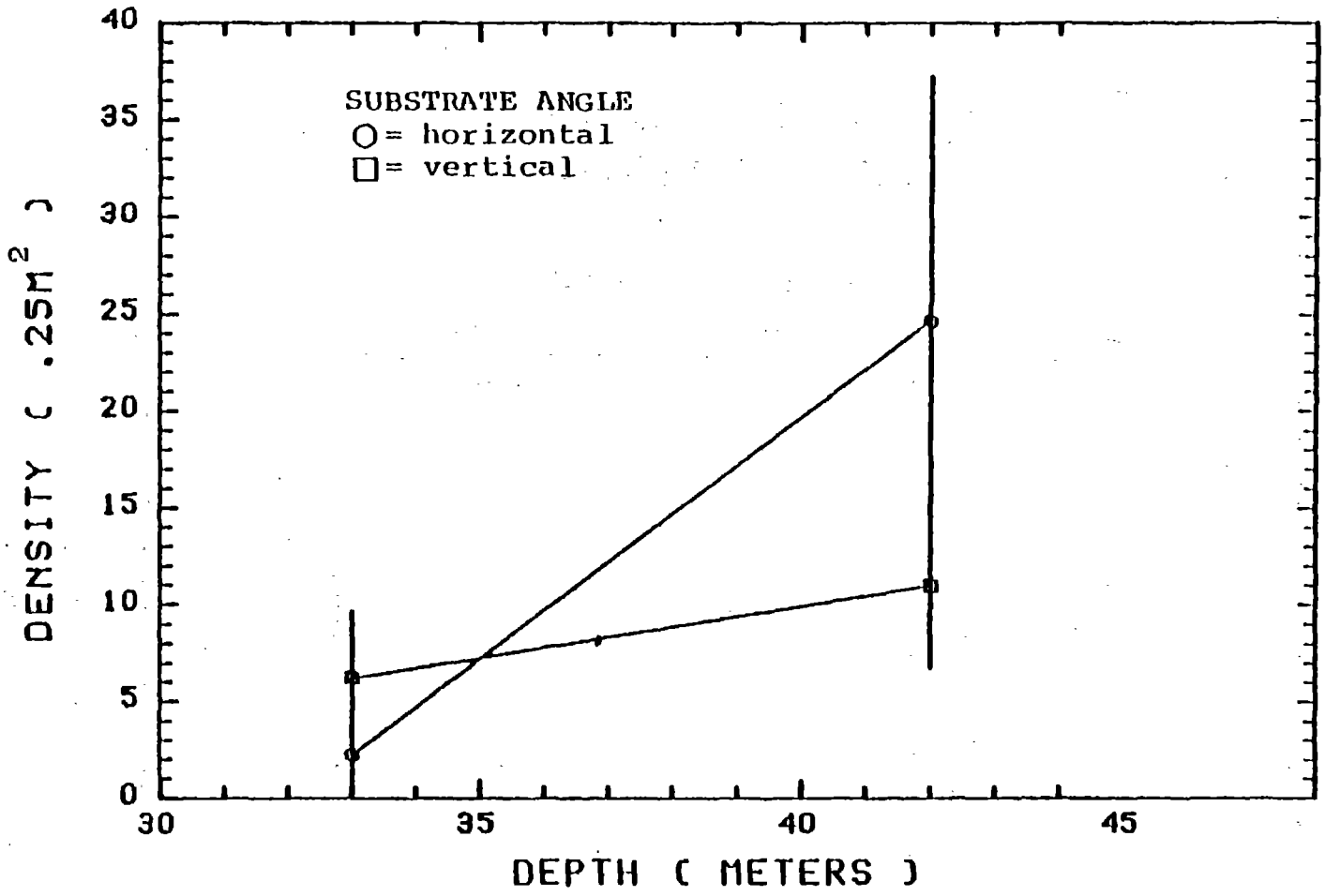
SIZE STRUCTURE OF
STRONGYLOCENTROTUS DROEBACHIENSIS



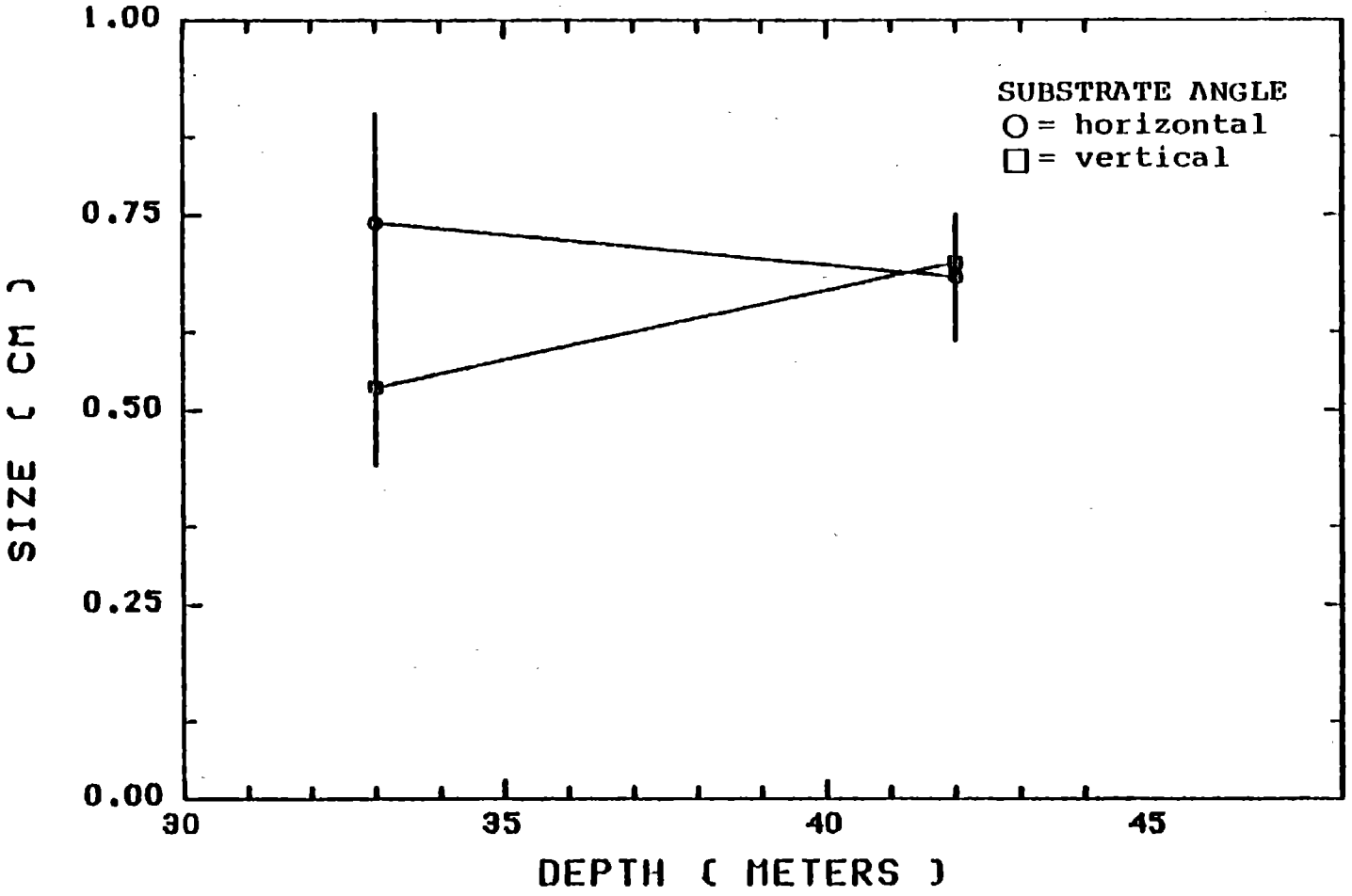
ABUNDANCE
OF OPHIOPHOLIS ACULEATA



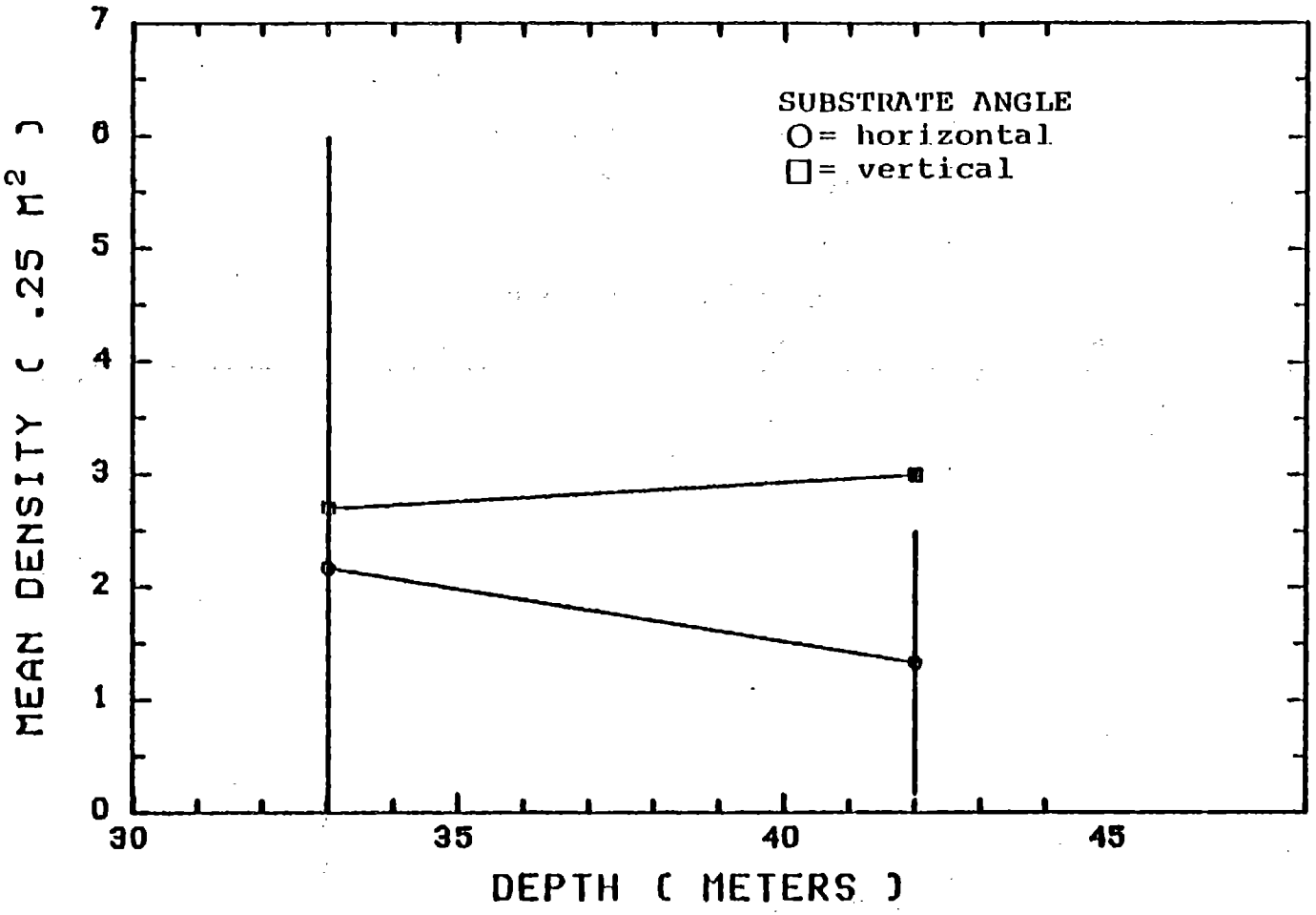
ABUNDANCE OF
OPHIURA ROBUSTA



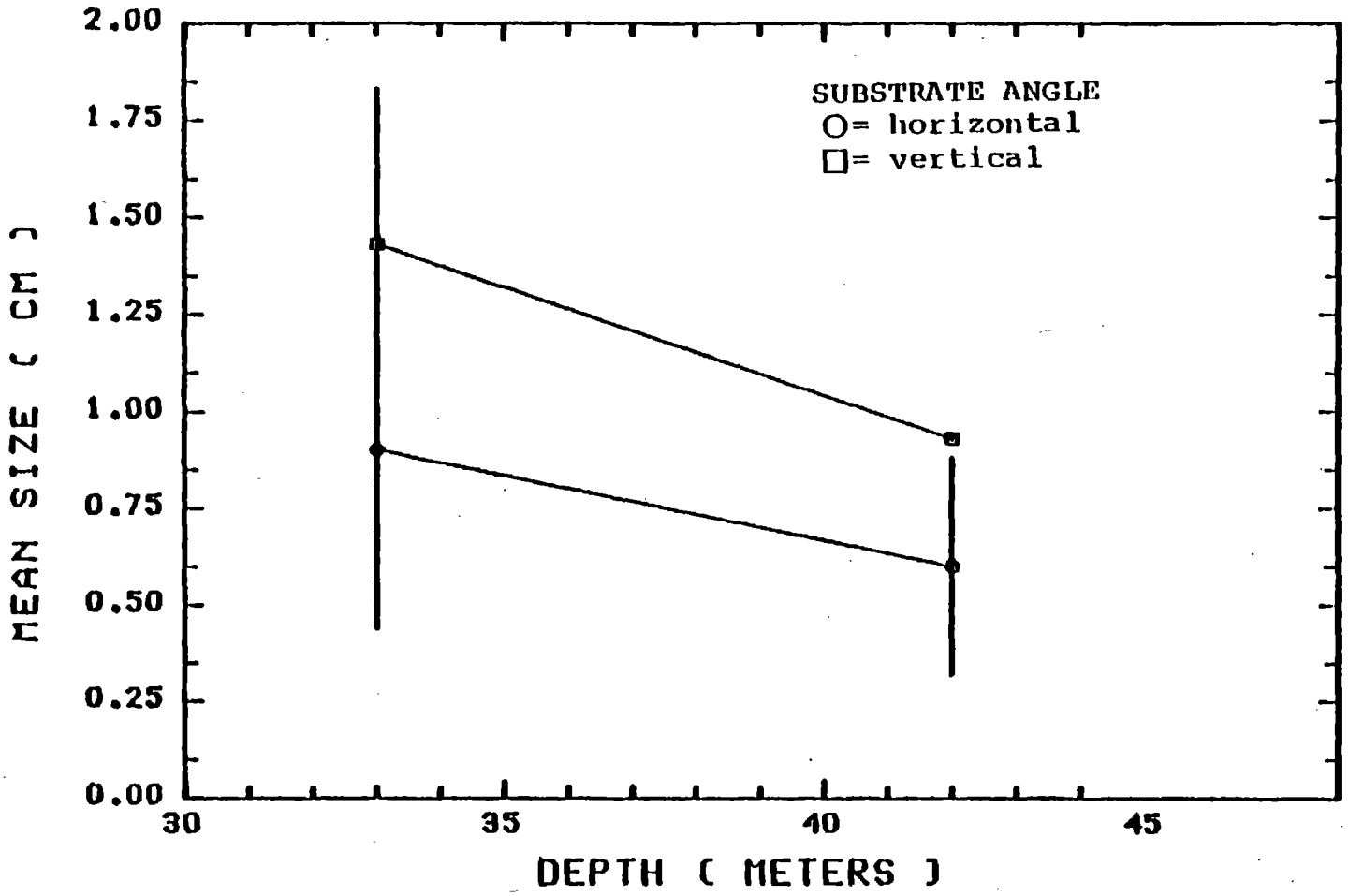
ABUNDANCE
OF STEPHANASTERIAS ALBULA



SIZE STRUCTURE
OF STEPHANASTERIAS ALBULA



ABUNDANCE OF
LEPTASTERIAS SP.



SIZE STRUCTURE OF
LEPTASTERIAS SP.

APPENDIX G

PIGEON HILL SPECIES LIST

Pigeon Hill Species List [Updated 11/81]

Species	NODC Code
Phylum Porifera	
Class Calcispongiae	
Leucosolenia sp.	*360701
Class Demospongiae	
Apoysilla gracialis	*
Halichondria panicea	3665020202
Haliclona oculata	*36630201
Haliclona palmata	*36630201
Haliclona urceola	3663020101
Hymedesmia sp.	36641108
Iophon nigricans	3664111002
Iophon pattersoni	3664111001
Myxilla fimbriata	3664111502
Plocamionida ambigua	*
Polymastia infrapilosa	*366604
Polymastia sp.	366604
Suberitechnius hispidus	*
Phylum Cnidaria	
Class Hydrozoa	
Abietinaria sp.	37040504
Campanularia verticillata	*37040101
Clytia hemisphaerica	3704010503
Clauvlaria modesta	*374502
Eudendrium raeum	3703080102
Eudendrium sp.	370401
Grammaria abientina	*37040204
Obelia sp.	370401
Sertularella polyzonias	*37040502
Thuiaria cupressina	*37040505
Tubularia indivisa	3703030203
Class Anthozoa	
Gersemia rubiformis	*
Goniactinia prolifera	*
Metridrim senile	3760060101
Tealia felina	376001

Pigeon Hill Species List [Updated 11/81]
(cont'd)

Species	NODC Code
Phylum Nemertea	
Class Enopla	
Amphiporus sp.	43060501
Phylum Ectoprocta	
Class Gymnolaemata	
Dendrobenia murrayana	7815250201
Crisia eburnea	7809010101
Scruparia ambigua	7815020301
Eucratea loricata	7815020101
Cribrilina punctata	7815300102
Hippothoa hyalina	7816020101
Porella minuta	7816130101
Phylum Brachiopoda	
Class Articulata	
Terebratulina septentrionalis	8005070103
Phylum Annelida	
Class Polychaeta	
Chone infundibuliformis	5001700102
Eunice pennata	5001300105
Euphorsine borealis	5001110106
Filograna implexa	*50017310
Glycera capitata	5001270101
Harmothoe sp.	50010208
Lepidonotus sublevis	5001021104
Myxicola infundibulun	5001700502
Nereis pelagica	5001240403
Pherusa affivis	5001540304
Phyllodocae maculata	*5001130108
Protula tubularia	5001731101
Spirorbis borealis	5001730509
Thelepus cincinnatus	5001681003

Pigeon Hill Species List [Updated 11/81]
(cont'd)

Species	NODC Code
Phylum Sipuncula	
Golfingia sp.	72000201
Phylum Mollusca	
Class Polyplacophora	
Hanleya hanleyi	5302020101
Ischnochiton ruber	5303020308
Tonicella rubra	5303020604
Class Gastropoda	
Subclass Prosobranchia	
Acmaea testudinalis	5102050108
Alvania areolata	5103200115
Alvania mighelsii	*
Buccinum undatun	5105040145
Caliostoma occidentale	*51021001
Colus pygmaeus	5105050328
Epitonium sp.	51035001
Margarites costalis	*51021003
Margarites groenlandica	*51021003
Margarites helicina	*51021003
Mitrella rosacea	5105030201
Natica clausa	5103760201
Natica pusilla	5103760204
Odostomia eburnea	5108010134
Propobela pingelii	*
Ptychatractus ligatus	*51050901
Puncturella noachina	5102040202
Trichotropis borealis	5103620203
Velutina laevigata	5103660409
Subclass Opisthobranchia	
Aeolidia papillosa	5142030101
Cadlina laevis	*51300201
Coryphella nobilis	*51410401
Coryphella verrucosa	*51410401
Dendronotus frondosus	5134060103
Dendronotus robustus	*51340601
Eubranchus pallidus	*51410101
Tergipes despectus	*

Pigeon Hill Species List [Updated 11/81]
(cont'd)

Species	NODC Code
Class Bivalvia	
Aequipecten glyptus	*55090508
Anomia aculeata	5509090201
Anomia simplex	5509090202
Astarte borealis	5515190101
Astarte elliptica	5515190114
Cerastoderma pinnulatun	5515220601
Hiatella arctica	5517060201
Modiolus modiolus	5507010601
Musculus niger	5507010401
Phylum Arthropoda	
Class Pantopoda	
Phoxichilidium femoratun	6001060102
Class Crustacea	
Order Decapoda	
Cancer borealis	6188030107
Geryonidae sp.	618904
Homarus americanus	6181010201
Hyas coarctatus	6187010202
Pagurus arcuatus	6183060233
Sclerocrangon boreas	6179220201
Spirontocaris groenlandica	*61791602
Order Amphipoda	
Acanthonotozoma inflatum	6169010101
Amphilochus manudens	*61690302
Amphithopsis longicaudata	*
Anonyx sarsi	6169340314
Corophium crassicorne	6169150203
Dyopedos porrecta	*
Ericthonius rubricornis	6169150306
Gammaropsis maculata	*61692604
Haploops tubicola	6169020301
Ischyrocerus anguipes	6169270202
Leuchochoe spinicarpa	*
Melita dentata	6169211003

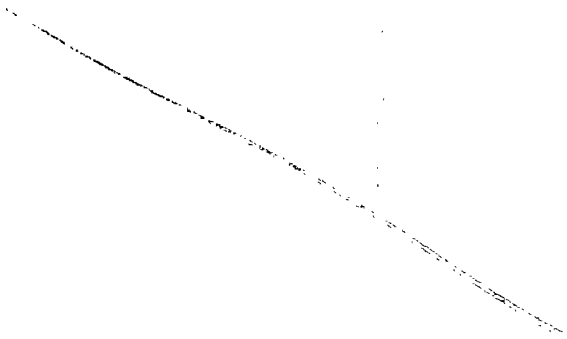
Pigeon Hill Species List [Updated 11/81]
(cont'd)

Species	NODC Code
Monocuclodes intermedius	6169370817
Orchomene groenlandica	6169342909
Orchomene minuta	6169342901
Orchomene serrata	6169342908
Phoxocephalus halbolli	6169420702
Pleustes panoplus	6169430406
Pleusymtes glaber	6169430503
Pontogenia inermis	6169201203
Proboloides holmesi	6169480801
Stenopleustes gracilis	6169430609
Stenothoe minuta	6169481002
Syrrhoe crenulata	6169500301
Thetonyx cicoda	*
Thryphosa groenlandica	*
Suborder Caprellidea	
Aegina longicuris	*37120101
Caprella linearis	6171010703
Phylum Echinodermata	
Class Holothuroidea	
Cucmaria frondosa	8172060104
Psolus fabricii	8172030202
Class Echinoidea	
Strongylocentrotus droebachiensis	8149030201
Class Asteroidea	
Asterias vulgaris	8117030204
Crossaster papposus	8113010103
Henricia sanguinolenta	8114040111
Hippasteria phrygiana	8111040404
Leptasterias sp.	81170304
Porania insignis	8114030301
Solaster endeca	8113010302
Stephanasterias albula	*

Pigeon Hill Species List [Updated 11/81]
(cont'd)

Species	NODC Code
Class Ophiuroidea	
Ophiopholis aculeata	8129020101
Ophiura robusta	8127010611
Axiognathus squamata	*
Phylum Chordata	
Class Ascidacea	
Aplydium constellatum	*84030206
Ascidia callosa	8404050102
Boltenia echinata	8406020201
Boltenia ovifera	8406020202
Botrylloides sp.	84060101
Didennun albidum	8403030101
Halocynthia pyriformis	*84060204

*Indicates correct species code not found in NODC Code Manual



APPENDIX H

HEAVY METAL CONTENTS OF PIGEON HILL INDICATOR SPECIES

1980

[Seastars (*Leptasterias* sp.), algae (*Ptilota serrata*) and tunicates (*Ascidia callosa*) cited in the report are from Pigeon Hill; the remaining samples are from George's Bank and are part of another study.]

FORMAL REPORT OF ANALYSIS

1980

Prepared for:

National Marine Fisheries
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Woods Hole, Massachusetts 02543
Attention: Kenneth Pecci

Customer Order Number:

NA-80-FA-C-00044

Prepared by:

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Watertown, Massachusetts 02172
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Senior Scientist, Cambridge Analytical Associates

Approved by:

Martin H. Wolf
Analytical Services Manager, Cambridge Analytical Associates

Report Number:

ASD-80-127

SUMMARY OF RESULTS -- 1980
CAMBRIDGE ANALYTICAL ASSOCIATES

TRACE METALS (listed in parts per million, ug/g)								
C.A.A. #	Description	Ba	Cd	Cu	Cr	Hg	Pb	Zn
A	Sea stars	48.1	1.04	1.84	0.9	0.034	0.46	11.1
B	Algae	46.4	0.04	1.77	2.3	0.027	1.31	16.2
C	Tunicate	29.1	0.06	0.76	0.7	0.009	0.18	34.2
D	STA 1 10/17 Crab muscle	0.14	0.14	9.8	0.98	0.034	0.55	95.9
E	STA 2 10/16 Crab muscle	0.11	0.49	11.8	0.18	0.063	0.94	102.6
F	STA 2 7/7 Scallop visc.	0.59	77.0	2.22	0.6	0.019	0.38	12.9
G	STA 2 7/7 Scallop edible	0.17	1.92	0.25	0.55	0.022	0.04	11.3
H	STA 2 Sediment	40.3	0.02	1.03	3.1	0.003	0.40	40.5
I	STA 3 Crab muscle	0.13	0.50	10.9	0.22	0.050	0.08	84.8
J	STA 3 Scallop visc.	0.16	41.7	2.52	0.24	0.013	0.27	24.2
K	STA 3 7/7 Scallop edible	0.12	0.50	1.30	0.39	0.014	1.74	13.7
L	STA 3 Surf. sediment	39.4	0.01	0.25	3.8	ND[1]	0.38	1.6
M	STA 6 10/20 Lobster claw	0.07	0.18	7.38	0.05	0.218	0.05	37.0
N	STA 6 10/20 Lobster hepato-pancreas	0.04	19.5	18.3	0.07	0.087	0.62	37.3

[1] ND = none detected; less than 0.005 ppm (ug/g)

SUMMARY OF RESULTS -- 1980
CAMBRIDGE ANALYTICAL ASSOCIATES

TRACE METALS, CON'T. (listed in parts per million, ug/g)								
C.A.A. #	Description	Ba	Cd	Cu	Cr	Hg	Pb	Zn
O	STA 6 Lobster tail	0.12	0.12	10.6	0.06	0.270	0.07	25.9
P	STA 6 Crab muscle	0.06	1.18	9.70	0.07	0.006	0.78	87.1
R	STA 6 Crab hepato-pancreas	0.50	17.3	40.8	0.92	0.064	0.23	56.5
S	STA 5 Sediment	58.9	0.07	2.15	11.3	ND[2]	0.52	13.6
T	STA 5 Crab muscle	0.08	0.33	7.7	0.47	0.011	0.06	77.0
U	Tile fish STA 6 Hk/Ln	0.21	0.002	1.79	0.09	0.019	0.90	3.7
V	Lobster eggs	0.23	0.13	62.0	0.24	0.035	0.07	39.8

SUMMARY OF RESULTS BY SAMPLE TYPE
CAMBRIDGE ANALYTICAL ASSOCIATES

TRACE METALS (by sample type)								
C.A.A. #	Description	Ba	Cd	Cu	Cr	Hg	Pb	Zn
A	Sea stars	48.1	1.04	1.84	0.9	0.034	0.46	11.1
B	Algae	46.4	0.04	1.77	2.3	0.027	1.31	16.2
C	Tunicate	29.1	0.06	0.76	0.7	0.009	0.18	34.2
D	STA 1 10/17 Crab muscle	0.14	0.14	9.8	0.98	0.034	0.55	95.9
E	STA 2 10/16 Crab muscle	0.11	0.49	11.8	0.18	0.063	0.94	102.6
I	STA 3 Crab muscle	0.13	0.50	10.9	0.22	0.050	0.08	84.8
P	STA 6 Crab muscle	0.06	1.18	9.70	0.07	0.006	0.78	87.1
T	STA 5 Crab muscle	0.08	0.33	7.70	0.47	0.011	0.06	77.0
R	STA 6 Crab hepato-pancreas	0.50	17.3	40.8	0.92	0.064	0.23	56.5
N	STA Lobster hepato-pancreas	0.04	19.5	18.3	0.07	0.087	0.62	37.3
F	STA 2 7/7 Scallop visc.	0.59	77.0	2.22	0.6	0.019	0.38	12.9
J	STA 3 Scallop visc.	0.16	41.7	2.52	0.24	0.013	0.27	24.2
G	STA 2 7/7 Scallop edible	0.17	1.92	0.25	0.55	0.022	0.04	11.3
K	STA 3 Scallop edible	0.12	0.50	1.30	0.39	0.014	1.74	13.7

SUMMARY OF RESULTS BY SAMPLE TYPE
CAMBRIDGE ANALYTICAL ASSOCIATES

TRACE METALS, CON'T. (by sample type)								
C.A.A. #	Description	Ba	Cd	Cu	Cr	Hg	Pb	Zn
M	STA 6 Lobster claw	0.07	0.18	7.38	0.05	0.218	0.05	37.0
O	STA 6 Lobster tail	0.12	0.12	10.6	0.06	0.270	0.07	25.9
V	Lobster eggs	0.23	0.13	62.0	0.24	0.035	0.07	39.8
U	Tile fish	0.21	0.002	1.79	0.09	0.019	0.90	3.7
H	STA 2 Sediment	40.3	0.02	0.77	3.1	0.003	0.40	40.5
L	STA 3 Sediment	39.4	0.01	0.25	3.8	ND	0.38	1.6
S	STA 5 Sediment	58.9	0.07	2.15	11.3	ND	0.52	13.6

SAMPLE PREPARATION
CAMBRIDGE ANALYTICAL ASSOCIATES

Sample Preparation -- Trace Metals Analysis

Determination of Ba, Cd, Cu, Cr, Pb, and Zn

Sea Stars, algae, tunicate, crab, lobster, scallop and tile fish tissues:

The samples were chopped into one inch chunks if necessary. Approximately 75 grams of each sample material was placed in a glass jar blender and pulverized. Sample material was weighed into Erlenmyer flasks precleaned for ultra-trace metal analysis by soaking in 1:1 nitric acid followed by a rinse with Type I reagent grade water just prior to use.

The samples were then digested using concentrated nitric acid and heating. Nitric acid was added as necessary to completely oxidize the organic material present. After a clear solution was obtained, the sample was boiled to near dryness and reconstituted to its final volume with 5% nitric acid solution. The digests were then stored in polyethylene flip-top vials. A blank was prepared and analyzed with the samples.

Sediments:

The water was decanted from the top of the sediment sample. A portion of the sediment was placed in a two liter beaker and mixed thoroughly. Sediment was weighed wet into cleaned Erlenmyer flasks. Sediment samples were treated with 50 ml of concentrated nitric acid and boiled until the sample liquid volume was less than 25 ml. The sediment acid extract was then filtered through a membrane filter to remove particulates and analyzed.

Determination of Hg

Sea Stars, algae, tunicate, crab, lobster, scallop and tile fish tissues:

Approximately 5 grams of the pulverized fish tissue was accurately weighed into 125 ml Erlenmyer flasks. 40 ml of concentrated sulfuric acid was slowly added, and the samples were placed in a shaking water bath and incubated at 50° C until a clear solution was obtained. The sample was then removed from the bath and was placed in an ice water bath. 30 ml of 5% $KMnO_4$ was added slowly with swirling. The samples were then stored at 3° C overnight after being capped with parafilm. Just prior to analysis the sample volume was adjusted to 100 ml by the addition of deionized Type I reagent grade water.

Sediments:

Wet sediment samples were weighed into 125 ml Erlenmyer flasks. 30 ml of aqua regia was added and the samples were placed in a 95° C water bath for two minutes. 15 ml 5% potassium permanganate was added and the sample was diluted to a final volume of 100 ml.

Analytical Methodology

Analysis for the trace metals was performed by atomic absorption spectroscopy. Protocols were taken from the EPA document Methods for the Chemical Analysis of Water and Wastes (EPA 600 4-79-020). The use of these protocols is suggested in the EPA document Interim Methods for the Sampling and Analysis of Priority Pollutants in Sediments and Fish Tissue. (EPA, Cincinnati.)

The following specific protocols were used:

Ba	Method #208.1	Direct Aspiration AA and #208.2 Furnace AA
Cd	Method #213.1	Direct Aspiration AA and #213.2 Furnace AA
Cu	Method #220.1	Direct Aspiration AA
Cr	Method #218.1	Direct Aspiration AA and #218.2 Furnace AA
Hg	Method #245.1	Manual Cold Vapor
Pb	Method #239.2	Furnace AA
Zn	Method #289.1	Direct Aspiration AA

Analysis for barium, cadmium, copper, chromium, and zinc was first performed using flame atomic absorption. If not detected using flame AA the sample was reanalyzed by furnace atomic absorption.

Samples analyzed by flame atomic absorption were quantitated by calibration of the instrument against standards prepared in acid concentration similar to that of the samples.

Samples analyzed by flameless (furnace) atomic absorption were quantitated by the method of standard additions. All flameless determinations were made using background correction. A strip chart trace was made of the results. Samples analyzed for mercury were quantitated by the method of standard additions.

For all standard additions analyses, a calibration curve was prepared to demonstrated linearity in the concentration range of concern. As a general practice samples with peak absorbances greater than 0.3 A.U. were diluted to insure linear instrument response.

For all analyses data was recorded on sample analysis worksheets. The worksheets detail the method of standard preparation, instrument conditions, and contain a complete record of the raw data. Sample analysis worksheets are included with this report.

SAMPLE WEIGHTS
CAMBRIDGE ANALYTICAL ASSOCIATES

SAMPLE WEIGHTS (trace metal analysis for Ba, Cd, Cu, Cr, Pb, Zn)

C.A.A. Sample ID	NMF ID	Sample weight	Final volume (after wet ash)
A	Sea Stars	127.63 g -102.68 g tare 24.95 g net	50 ml
B	Algae	120.15 g - 95.35 g tare 24.80 g net	50 ml
C	Tunicate	122.24 g - 97.88 g tare 24.36 g net	50 ml
D	STA 1 10/17 Crab muscle	104.20 g - 91.50 g tare 12.70 g net	25 ml
E	STA 2 10/16 Crab muscle	120.95 g -107.65 g tare 13.30 g net	25 ml
F	STA 2 7/7	107.35 g - 94.76 g tare 12.59 g net	25 ml
G	STA 2 7/7 Scallop edible	121.50 g -108.50 g tare 13.00 g net	25 ml
H	STA 2 Sediment	118.99 g -105.03 g tare 12.96 g net	25 ml
I	STA 3 Crab muscle	109.72 g - 96.60 g tare 13.12 g net	25 ml
J	STA 3 Scallop visc.	112.00 g - 99.42 g tare 12.58 g net	25 ml
K	STA 3 7/7	114.40 g -101.55 g tare 12.85 g net	25 ml

SAMPLE WEIGHTS
CAMBRIDGE ANALYTICAL ASSOCIATES

SAMPLE WEIGHTS, CON'T. (trace metal analysis for Ba, Cd, Cu, Cr, Pb, Zn)

C.A.A. Sample ID	NMF ID	Sample weight	Final volume (after wet ash)
L	STA 3 Surf. sediment	122.56 g -109.20 g tare 13.11 g net	25 ml
M	STA 6 10/20 Lobster claw	119.65 g -106.40 g tare 13.25 g net	25 ml
N	STA 6 10/20 Lobster hepato- pancreas	120.90 g -108.10 g tare 12.80 g net	25 ml
O	STA 6 Lobster tail	109.13 g - 96.39 g tare 12.74 g net	25 ml
P	STA 6 Crab muscle	116.80 g -104.15 g tare 12.65 g net	25 ml
R	STA 6 Crab hepatopancreas	103.10 g - 90.10 g tare 13.00 g net	25 ml
S	STA 5 Sediment	121.75 g -109.20 g tare 12.55 g net	25 ml
T	STA 5 Crab muscle	112.35 g - 99.79 g tare 12.55 g net	25 ml
U	Tile fish STA 5 Hk/Ln	111.40 g - 98.42 g tare 12.98 g net	25 ml
V	Lobster eggs	108.57 g - 95.37 g tare 13.20 g net	25 ml

SAMPLE WEIGHTS
CAMBRIDGE ANALYTICAL ASSOCIATES

SAMPLE WEIGHTS (mercury analysis)

C.A.A. Sample ID	NMF ID	Sample weight	Final Volume (after digestion)
A	Sea stars	83.22 g - 78.41 g tare 4.81 g net	100 ml
B	Algae	80.36 g - 77.83 g tare 2.53 g net	100 ml
C	Tunicate	78.96 g - 74.82 g tare 4.14 g net	100 ml
D	Crab muscle	83.10 g - 78.00 g tare 5.10 g net	100 ml
E	Crab muscle	83.38 g - 78.02 g tare 5.36 g net	100 ml
F	Scallop viscera	102.01 g - 96.92 g tare 5.09 g net	100 ml
G	Scallop edible	102.05 g - 97.05 g tare 5.00 g net	100 ml
H	STA 2 Sediment	102.32 g - 97.30 g tare 5.02 g net	100 ml
I	Crab muscle	78.50 g - 73.40 g tare 5.10 g net	100 ml
J	Scallop viscera	85.70 g - 80.50 g tare 5.20 g net	100 ml
K	Scallop edible	82.99 g - 78.05 g tare 4.94 g net	100 ml

SAMPLE WEIGHTS
CAMBRIDGE ANALYTICAL ASSOCIATES

SAMPLE WEIGHTS, CON'T. (mercury analysis)

C.A.A. Sample ID	NMF ID	Sample weight	Final volume (after digestion)
L	STA 3 Sediment	102.35 g - 96.20 g tare 6.15 g net	100 ml
M	Lobster claw	101.90 g - 96.70 g tare 5.20 g net	100 ml
N	Lobster h-pancreas	84.45 g - 79.10 g tare 5.35 g net	100 ml
O	Lobster tail	100.20 g - 94.95 g tare 5.25 g net	100 ml
P	Crab muscle	86.10 g - 80.35 g tare 5.75 g net	100 ml
R	Crab h-pancreas	84.80 g - 79.10 g tare 5.70 g net	100 ml
S	STA 5 Sediment	104.05 g - 98.25 g tare 6.79 g net	100 ml
T	Crab muscle	100.45 g - 95.05 g tare 5.40 g net	100 ml
U	Tile fish	83.10 g - 77.45 g tare 5.65 g net	100 ml
V	Lobster eggs	98.95 g - 93.95 g tare 5.00 g net	100 ml

APPENDIX I

HYDROCARBON AND PCB CONTENTS OF PIGEON HILL INDICATOR SPECIES

1980

[Seastars (*Leptasterias* sp.), algae (*Ptilota serrata*) and tunicates (*Ascidia callosa*) cited in the report are from Pigeon Hill; the remaining samples are from George's Bank and are part of another study.]

TABLE OF CONTENTS

INTRODUCTION

This work, performed under the direction of the Manned Undersea Research and Technology Program at the Northeast Marine Fisheries Center, is a chemical assessment of the environmental state of two sites off the Massachusetts coast. The data generated will be integrated into the Ocean Pulse Program, a system of continuous, long-term assessment of the well-being of United States coastal waters, to determine the extent to which human activities produce environmental change.

Samples were collected at Jeffreys Ledge, (off Rockport, Massachusetts), and at Lydonia Canyon on the outer continental shelf.

Species collected included sea stars, algae, tunicate, crab, scallop, lobster, and tile fish. Sediment samples were also collected.

The samples were analyzed for polychlorinated biphenyls, petroleum hydrocarbons (aliphatic and aromatic fractions) and trace metals. The samples were received during August and September, 1980, and initial analyses were completed mid-December. A report on the trace metals and most polychlorinated biphenyls was issued in December. However, it was clear that the hydrocarbon analysis was not sufficiently selective to differentiate petroleum hydrocarbons from hydrocarbons, fatty acids, and other materials naturally present in the species studied. Therefore, additional sample preparation steps were developed to chemically remove interfering biological materials, and advanced pattern-recognition techniques were developed to aid interpretation of results. This extra work delayed completion of the project until March, 1981.

Generally, no polychlorinated biphenyls were detected in the sediment samples. However, in crab muscle, lobster tail, and tile fish the presence of trace levels (<20 ppb) could not be ruled-out due to the presence of interfering compounds of biological origin.

Similarly, no hydrocarbon contamination was present in the sediment samples, but trace levels of f_1 hydrocarbons could not be ruled out in algae, crab muscle, scallop viscera, scallop muscle, lobster, or tile fish.

Results of trace metal determinations were reported earlier.

The remainder of this report describes the analytical methods used and detail results for each sample. The original data is also included.

Experimental

Polychlorinated Biphenyl and Hydrocarbon Ananlysis

Fish & Algae Samples

25-50 grams of sample was weighed and thoroughly mixed with 100 grams of anhydrous sodium sulfate in a high speed Waring blender. 150 milliliters of hexane was added and ground for 2 minutes with the sample and sodium sulfate. The sides of the blender were scraped down and the hexane was poured through a Buchner funnel fitted with 2 sharkskin filter papers into a 500 milliliter suction flask. The sample was re-extracted with 2 x 100 milliliters of hexane and this was combined with the first extract. The residue from the blender was transferred to the Buchner funnel, rinsed with 3 x 50 milliliters of hexane, and pressed to force out the remaining hexane. Combined extracts were poured through a 10 centimeter column of anhydrous sodium sulfate and collected in a 1000 milliliter round bottom flask. Suction flask and column were rinsed with 3 x 10 milliliters of hexane and this was collected in the round bottom flask.

Sediment Samples

10.0g of sediment was passed through a 2 millimeter sieve and mixed thoroughly in a 250 milliliter erlenmeyer flask. 7 milliliters of 0.2 M NH_4Cl solution was added and allowed to stand for 15 minutes. 100 milliliters of hexane-acetone (1 + 1) was added. The flask was covered and shaken overnight on a reciprocal shaker at 180 rpm. The supernatant was poured through a 3 centimeter column of Florisil and the eluate was collected in a 1 liter separatory funnel. 200 milliliters of distilled water was added to the funnel, and the funnel

shaken for 30 seconds. The aqueous phase was drained into a second separatory funnel and extracted with 50 milliliters of hexane. The hexane layers were combined in the first separatory funnel and washed with 100 milliliters of distilled water. The water was discarded, the hexane was poured through a 5 centimeter column of anhydrous sodium sulfate and collected in a 1 liter round bottom flask.

Fish and Sediment Samples-Clean-up Procedures

Hexane extracts in round bottom flasks were evaporated, under vacuum, to approximately 10 milliliters and put into a 125 milliliter separatory funnel. The flasks were rinsed with 3 x 5 milliliters of hexane and this was added to the separatory funnel. 30 milliliters of acetonitrile saturated with hexane was added, shaken for 1 minute, and the layers were allowed to separate. The acetonitrile layer was drained into a second 125 milliliter separatory funnel containing 15 milliliters of hexane, shaken for 1 minute, allowed to separate and drained into a 1 liter separatory funnel containing 650 milliliters distilled water, 40 milliliters saturated sodium chloride, and 100 milliliters hexane. The hexane layer in the first separatory funnel was extracted with an additional 2 x 30 milliliters of acetonitrile and passed through the same 15 milliliters of hexane in the second 125 milliliter separatory funnel. All acetonitrile extracts were combined in the 1 liter funnel. The hexane layers, which contained the hydrocarbons, were combined and put aside. The acetonitrile extract, which contains the PCB's was shaken thoroughly for 45 seconds, the layers allowed to separate, and the aqueous layer was drained into a second 1 liter separator. 100 ml hexane was added to the second separator, shaken vigorously 15 seconds and allowed to separate. The aqueous layer was discarded, the hexane layers were combined in original separator and washed with 2 x 100 milliliters of water. The washings were discarded, the hexane layers, (PCB and hydrocarbon) were passed through a 10cm. column of anhydrous sodium sulfate and collected in a 500 milliliter round bottom flask. Extracts were concentrated to approximately

10 milliliters on a rotary evaporator and poured over a 10 cm column of activated Florisil topped with 1 cm of anhydrous sodium sulfate, prewet with 50 milliliters of hexane. Round bottom flasks were rinsed with 3 x 10 milliliters of hexane and this was poured over the column. Columns containing hydrocarbon portions were then rinsed with 200 milliliters of hexane, and this was collected in a 500 milliliter Kuderna Danish concentrator. PCB extracts were rinsed through columns with 200 milliliters of 6% ethyl ether in hexane and collected in a 500 milliliter Kuderna Danish concentrator. PCB extracts were concentrated to approximately 8 milliliters and injected on a gas chromatograph with electron capture detector. Hydrocarbon extracts were concentrated to approximately 5 milliliters, transferred to culture tubes, further concentrated to 1 milliliter under a gentle stream of nitrogen and fractionated.

Hydrocarbon Fractionation

Sample preparation:

The concentrated sample extract was transferred to a 0.9 x 25 cm column packed with 10.0g activated silica gel. The extract was allowed to move down the column, then the walls of the column were rinsed with approximately 2 ml hexane. The column was then eluted with 25 ml hexane and the eluate was collected in a 250 ml round bottom flask. This is Fraction 1. The column was then eluted with 50 ml of 20% dichloromethane in hexane (v/v), and the eluate, Fraction 2, was collected as above. The fractions were concentrated to 5 ml on a rotary evaporator, transferred to culture tubes, further concentrated to 0.5 ml under a gentle stream of nitrogen and injected on a gas chromatograph with flame ionization detector.

Results and Discussion

Hydrocarbons

Table I lists the samples and the concentration of hydrocarbons fractions f_1 and f_2.

Many of the fish samples contained F1 hydrocarbons, but the presence of interfering biogenic hydrocarbons (fatty acids etc.) made it impossibe to identify petroleum contamination at such low levels. The flame ionization detector detects not only hydrocarbons but also the fatty acid make-up of the fish.

Fraction 1 samples typically showed a series of dominant peaks at retention times between 25 and 38 minutes (see table II). This series of peaks accounted for 40-80 percent of the total peak areas in the samples, whereas, in the Crude Oil Standard it accounted for only 9 percent of the total peak area. There were no F1 hydrocarbons detected in any of the sediment samples, nor was the 25-38 minutes series of peaks detected. (This would seem to indicate that these compounds are of biogenic origin and not from a petroleum input)

Fraction 2 samples did not show a crude oil pattern. The lobster egg sample does appear to contain f_2 hydrocarbons, but biogenic olefins, which also appear in Fraction 2, make the determination of trace amounts of f_2 hydrocarbons very difficult.

Fraction 2 samples were dominated by a group of three peaks at retention times between 20 and 24 minutes. These peaks accounted for 3-90 percent of the total peak area for different samples. There was also a predominant peak at a retention time of 29-30 minutes with an area percent between 3 and 82. These peaks were not present in Fraction 2 of the Crude Oil Standard, Therefore they are not from a petroleum input.

HYDROCARBONS

Analytical Efficiency:

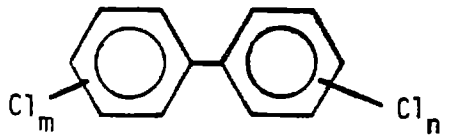
Samples were spiked with 50 µg/g Louisiana crude oil (approximately 3 milliliters of 0.86 mg/ml crude oil standard) prior to grinding.

Chromatographic Conditions:

Instrument:	Perkin Elmer Sigma I
Column:	6' x 1/8" stainless steel
Packing:	OV 17
Method:	Attached
Carrier Gas:	Nitrogen @ 30 ml/min
Detector:	Flame Ionization
Range:	100
Injection volume:	2 µl

RESULTS AND DISCUSSION - POLYCHLORINATED BIPHENYLS

Polychlorinated biphenyls (PCBs or Arochlors) are mixtures of compounds with the general structure:



These compounds can be separated and individually identified by gas chromatography. The pattern of compounds displayed by the gas chromatograph is characteristic of each Arochlor mixture. A summary of characteristic peaks for different Arochlors is given in Table III. The individual compounds in Arcolor mixtures are identified by their retention time relative to 1,1-dichloro-2,2,-bis(p-chlorophenyl) ethene (p,p'-DDE). The Arochlor mixture is identified by the individual compounds present.

In the present case, identification was made by examining the chromatograms of standard solutions of Arochlors to determine which peaks in the chromatograms were characteristically present for each Arochlor. If any of these characteristic peaks were absent from the sample, the Arochlor was considered not present. If the sample chromatogram contained all the characteristic peaks, the Arochlor was considered possibly present.

When the presence of Arochlors in the sample was a possibility, the sample was injected onto one or two other columns to try to obtain a more definitive separation. If, when this was done, all of the characteristic peaks were still present, the probability that the Arochlor was present was increased, but not confirmed. In the present case, most of the samples contained a considerable number of interfering peaks, which covered many of the Arochlor peaks and distorted the characteristic patterns, making identification tentative at best. Even so, it was possible to determine that most of the Arochlors were not present in most of the samples.

In those samples where the presence of Arochlors could not be ruled out, a concentration representing the maximum amount of polychlorinated biphenyls which could be present in the sample was calculated. When more than one Arochlor was possibly present in the sample, the concentration values calculated represent the concentration of each Arochlor as if it were the only one present in the sample. Thus, for a sample with more than one Arochlor concentration listed, the results should be interpreted as an either/or situation, as opposed to both/and situation. Of course,

if more than one of the Arochlors were in fact present, the actual concentration of each would be less than the values listed in the Summary of Results.

An example of this follows. In run no.47, Tile Fish, peaks were observed with the following retention indices:

72,78,99,131,141,164,180 and 225.

An examination of Table III indicated Arochlor 1254 contains similar peak distributions. Only peaks 66 and 107 do not show up in the sample. Examination of the chromatogram shows a large negative deflection at retention 66, which could have obscured the peak even if it were present. Also the large peak at 99 could have been overlapping 107 (there is a shoulder on the back side of the peak). Thus, even though the pattern is distorted by interfering peaks, all of the necessary peaks can be accounted for, so Arochlor 1254 might be present. Table IV summarizes these findings.

ANALYTICAL EFFICIENCY - Polychlorinated Biphenyls

A sample of each main type (except Tunicates) was fortified with one or more of the Arochlors to determine recovery. The results are listed below.

	AROCHLOR						
Sample	1016	1221	1232	1242	1248	1254	1260
Sea Stars					1.33		.67
Algae		.04					
Sediment			.26				
Crab				.52		.52	
Scallop	.50						
Lobster		.48	.45	.51			
Tile Fish						.66	
Male Tile Fish						.32	

GC METHODS FOR POLYCHLORINATED BIPHENYLS

OV-101

Instrument:	Perkin-Elmer Sigma 1 Gas Chromatograph
Column:	6 ft. x 1/4" o.d. glass tube 2 mm i.d.
Packing:	3% OV-101 on Chromosorb W-HP 100/120
Injection temperature:	225°C
Detector temperature:	300°C
Column temperature:	Arochlors 1016,1221,1232,1242,1248 - 170°C
	Arochlors 1254,1260 - 200°C
Carrier Gas:	5% Methane in Argon at 40 ml/min
Detector:	Electron capture, Range 2

OV-17/QF-1

Instrument:	Perkin-Elmer 3920B Gas Chromatograph
Column:	6 ft. x 1/4" o.d. glass tube 2 mm i.d.
Packing:	1.5% SP-2250/1.95% SP-2401 on 100/120 Supelcoport
Injection temperature:	250°C
Detector temperature:	275°C
Column temperature:	Arochlors 1016,1221,1232,1242,1248 - 160°C
	Arochlors 1254,1260 - 190°C
Carrier Gas:	5% Methane in Argon at 30 ml/min
Detector:	Electron capture, Range 1

GC METHODS FOR POLYCHLORINATED BIPHENYLS (continued)

OV-210

Instrument:	Perkin-Elmer Sigma 1 Gas Chromatograph
:	Perkin-Elmer 3920B Gas Chromatograph
Column:	6 ft. x 1/4" o.d. glass tube 2 mm i.d.
Packing:	3% OV-210 on 80/100 Chromosorb W-HP
Injector Temperature:	Sigma 1 - 225°C
	3920B - 250°C
Detector temperature:	Sigma 1 - 300°C
	3920B - 275°C
Column temperature:	Sigma 1 - 175°C
	3920B - 135°C
Carrier Gas:	5% Methane in Argon
Detector:	Electron Capture, Range 1

Table I - f_1 and f_2 hydrocarbons in various organisms

Sample	F1	F2
Sea Stars #1	N.D.	N.D
spike	38%	86%
Algae #3	40µg/g	N.D.
spike	150%	
Tunicate #5	approx. 7.0µg/g	N.D.
spike	12%	
Sta. 1 Crab Muscle	200µg/g	N.D.
Sta. 2 Crab Muscle	25 µg/g	N.D.
Sta. 2 Scallop Viscera	3.0µg/g	N.D.
Sta. 2 Scallop Muscle	1.5µg/g	<1µg/g
Sta. 2 Sediment	ND	N.D.
spike	115%	
Sta. 3 Crab Muscle	approx 4.0µg/g	N.D.
spike	58%	25%
Sta. 3 Scallop Viscera	N.D.	N.D
spike	58%	22%
Sta. 3 Scallop Muscle	6.0µg/g	N.D.
Sta. 3 Sediment	N.D.	N.D.
Sta. 5 Sediment	N.D.	N.D
Sta. 5 Crab	1.5µg/g	N.D.

Table I (continued)

Sample	F1	F2
Sta. 6 Lobster Claw	2.0µg/g	N.D.
Sta. 6 Lobster H. Pan	N.D.	N.D.
Sta. 6 Lobster Tail	6.0µg/g	N.D.
spike	23%	
Sta. 6 Crab Muscle	15µg/g	N.D.
Sta. 6 Crab H. Pan	20µg/g	N.D.
Sta. 6 Tile Fish	2.0µg/g	N.D.
Lobster Eggs	N.D.	50µg/g
spike		106%
Lobster Tail #2	N.D.	N.D.
Lobster Tail #5	N.D.	N.D.
Lobster Tail #8	6.0µg/g	N.D.
spike	16%	
Female Tile Fish	2.0µg/g	N.D.
Male Tile Fish	10µg/g	N.D.

1) N.D.; Hydrocarbon pattern not detected, although some peaks may be present (see table II). Lower limit of detection 1 µg/g

Table II - Characteristic Chromatographic Peaks in Marine Organisms

F1 Fraction

Sample Type	Predominant Peaks-Area Percent Retention Times					
	0-14	15	16-20	21-25	31	26-38
Sea Stars		5%				88%
Algae		3%				50%
Tunicate						97%
Crab Muscle						45%
H. Pan		3%			22%	50%
Scallop Viscera						92%
muscle						91%
Sediment						
Lobster Claw						81%
Tail						91%
H. Pan		3%			60%	
Tile Fish Male						80%
Female		4%				86%
Lobster Eggs						80%
Crude Oil Standard	50%	11%	16%	14%		9%

Table II (continued)

F2 Fraction

Sample Type	Predominant Peaks - Area Percent Retention Times						
	0-14	15	16-19	20-24	25-28	29	30-38
Sea Stars				90%			
Algae		1%		20%			
Tunicate				84%			
Crab Muscle		4%		50%		2%	
H. Pan				4%		25%	
Scallop Viscera				75%			
Muscle							
Sediment							
Lobster Claw		2%		30%			17%
Tail				62%			4%
H. Pan							
Tile Fish Male						82%	
Female						42%	
Lobster Eggs	2%			3%	10%	26%	50%
Crude Oil Standard	16%	13%	40%	21%	7%		3%

TABLE III

Relative Retention Times[1] of Arochlor Peaks on Various Columns

1. Relative to p,p'-DDE

OV -101

170°C					200°C	
1016	1221	1232	1242	1248	1254	1260
16	15	15	15			
21	17	17	17		70	115
25	23	23	23	23	84	122
31	26	26	26	26	98	146
33	32	32	32	32	103	155
35	34	34	34	34	124	171
	36	36	36	36	145	196
41	43	43	43	43	170	228
47	48	48	48	48		277
51	51	51	51	52		328
	65			65		

OV -17/QF-1

160°C					190°C	
1016	1221	1232	1242	1248	1254	1260
12	12	12	12	12	68	71
14	14	14	14		80	79
19	19	20	20	19	102	114
	21	23	23			
24	27	27	27	27	110	127
27	30	31	30		127	145
30	33	33	33	38	144	165
33			37	48	164	189
38		37				205
	37	46	46	62	188	254
				75		307

TABLE III (continued)

OV-210

135°C					175°C	
1016	1221	1232	1242	1248	1254	1260
	9	9				
	10	10		10		
	11	11			66	102
14	14	14	14	14	72	115
18	18	18	18	18	79	142
22		22	22		98	156
28	28	28	28	28	107	180
31	32	31	31	31	131	223
36	36	36	36	36	142	288
44					164	361
					178	
					225	

TABLE IV

SUMMARY OF RESULTS
POLYCHLORINATED BIPHENYLS

	AROCHLORS[1]						
Samples	1016	1221	1232	1242	1248	1254	1260
Sea Stars #1	2.5	ND[2]	ND	ND	ND	ND	ND
Algae # 3	ND	ND	ND	ND	ND	ND	ND
Tunicates # 5	ND	ND	ND	ND	ND	ND	ND
Crab Muscle Sta 1	17	17	ND	ND	ND	ND	ND
Crab Muscle Sta 2	ND	ND	ND	ND	17	ND	ND
Scallop Viscera Sta 2	ND	ND	ND	ND	ND	ND	ND
Scallop Edible Flesh Sta 2	ND	ND	ND	ND	ND	ND	ND
Sediment Sta 2	ND	ND	ND	ND	ND	ND	ND
Crab Muscle Sta 3	ND	ND	ND	ND	ND	ND	ND
Scallop Viscera Sta 3	ND	ND	ND	ND	ND	ND	ND
Scallop Edible Flesh Sta 3	ND	2.3	ND	ND	ND	ND	ND
Sediment Sta 3	ND	2.3	ND	ND	ND	ND	ND
Lobster Claw Sta 6	18	ND	ND	18	18	ND	ND
Lobster Hepatopancreas Sta 6	ND	ND	ND	ND	ND	ND	ND
Lobster Tail Sta 6	2.8	ND	ND	2.8	ND	ND	ND
Lobster Tail # 2	2.7	2.7	2.7	2.7	2.7	ND	ND
Lobster Tail # 5	2.7	2.7	ND	ND	ND	ND	ND
Lobster Tail # 8	9.2	6.1	ND	ND	3.7	ND	ND
Crab Muscle Sta 6	14	ND	ND	14	14	ND	ND
Crab Hepatopancreas Sta 6	ND	ND	ND	ND	ND	ND	ND
Sediment Sta 5	ND	ND	ND	ND	ND	ND	ND
Crab Sta 5	7.6	7.6	ND	ND	ND	ND	ND
Tile Fish Sta 6	ND	ND	ND	ND	ND	7.2	ND
Male Tile Fish	2.3	ND	ND	4.4	4.4	ND	ND
Female Tile Fish	3.0	ND	ND	3.0	30	300	3.0
Lobster Eggs	ND	ND	ND	ND	ND	ND	ND

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SUMMARY OF RESULTS
POLYCHLORINATED BIPHENYLS (page 2)

1. Concentrations given in ng/g. The value given assumes the presence of only one Arochlor.

2. ND - None detected. Lower Limit of detection is 2 ng/g except as follows:

Lobster Hepatopancreas	-	LLD = 160 ng/g
Lobster eggs	-	LLD = 32 ng/g
Crab Hepatopancreas	-	LLD = 14 ng/g
Sediments	-	LLD = 10 ng/g