NOAA Technical Report NMFS 86 February 1990

# Benthic Macrofauna and Habitat Monitoring on the Continental Shelf of the Northeastern United States

## I. Biomass

Frank W. Steimle

U.S. Department of Commerce

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# I. Biomass

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## ABSTRACT

**Information on long-term temporal variability of and trends in benthic community-structure variables, such as biomass, is needed to estimate the range of normal variability in comparison with the effects of environmental change or disturbance. Fishery resource distribution and population growth will be influenced by such variability. This study examines benthic macrofaunal biomass and related data collected annually between 1978 and 1985 at 27 sites on the continental shelf of the northwestern Atlantic, from North Carolina to the southern Gulf of Maine. The study was expanded at several sites with data from other studies collected at the same sites prior to 1978. Results indicate that although there was interannual and seasonal variability, as expected, biomass levels over the study period showed few clear trends. Sites exhibiting trends were either in pollution-stressed coastal areas or influenced by the population dynamics of one or a few species, especially echinoderms.**

## Introduction

In the northeastern United States, the basic definition and spatial distribution of benthic communities and dominant taxa are becoming known (Pratt 1973, Wigley and Theroux 1981, Theroux and Grosslein 1987); however, temporal variability and trends have received less attention. There have been few long-term (>3 years) benthic studies in the northwestern Atlantic and fewer yet that have considered biomass as a variable. Benthic community biomass and production have long been of interest to fishery ecologists, e.g., Peterson (1918), Blegvad (1928, 1951), and McIntyre (1978), particularly as they relate to the quantity of food available to fishery species and as a primary component in ecosystem models. See, for example, Cohen et al. (1982), Lunz and Kendall (1982), and Overholtz and Tyler (1986).

Biomass, as with other benthic community-structure variables, can also be used for environmental monitoring. For example, biomass changes have been related to organic enrichment, resulting from eutrophication or waste discharges (Pearson and Rosenberg 1978, Cedarwall and Elmgren 1980). Biomass estimates are usually less affected than other benthic community-structure variables, e.g., species richness or numbers of individuals, by sorting-efficiency errors. This is because most biomass is from larger, more common species (Coleman 1980, Cedarwall and Elmgren 1980, Glemarec and Menesguen 1980). Biomass estimates can also be influenced by other factors such as the intermittent occurrence of rare, large individuals of certain species. As noted by Coull (1985), long-term data sets may be necessary, in themselves, to propose credible hypotheses. Wolfe et al. (1987) and Lewin (1986) also noted that long-term studies are less likely to miss infrequent, but important, perturbations in the ecosystem.

This report summarizes and provides a preliminary analysis of the range of temporal variability and possible trends in wet weight biomass for 27 sites, well distributed on the northeastern continental shelf of the United States. These were monitored during 1978–85 as part of NOAA's Northeast Monitoring Program (Reid et al. 1987). This report also includes results from earlier studies at some of the same sites. This long-term data set augments the extensive, earlier spatial distribution studies of the area by Wigley and Theroux (1981), Steimle (1985), and Theroux and Grosslein (1987). Analysis of other community-structure variables (numerical abundance, species composition, and richness) is being prepared, with a more rigorous statistical analysis of habitat relationships.

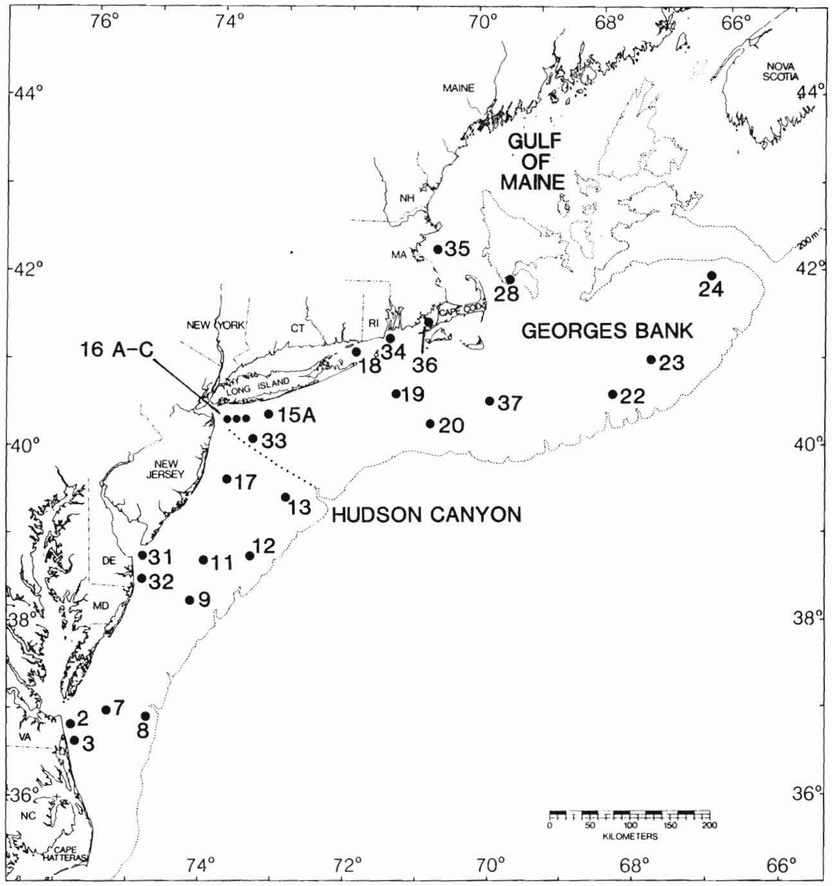


**Figure 1**

**Location of benthic sampling sites on continental shelf, northeastern United States.**

## Methods

The benthic samples used in this analysis were collected during quarterly and annual surveys between 1978 and 1985 (Reid et al. 1987); sampling locations are shown in Figure 1. All samples were collected with a 0.1-$m^2$ Smith-McIntyre grab which provides for a 16-cm maximum hemicylindrical penetration of the sediment. Five grab samples were collected at each site per survey, except as footnoted in figure captions. Gaps in the data sets were the result of samples not being collected or processed. Samples collected before December 1979 were sieved through 1.0-mm mesh screens and thereafter through 0.5-mm screens. After sieving, samples were fixed immediately in a 10% buffered formalin-sea water solution and transferred within 3 days to a 70% ethyl or isopropyl alcohol/5% glycerin preservative. After storage for at least 6 months, samples were sorted, specimens identified to species and enumerated, and each taxon weighed on a electronic balance to 1-mg accuracy, following a 3-minute blot-drying on absorbent paper toweling. No attempt was made to adjust for weight changes (possibly $\pm 15\%$) resulting from fixation and preservation (Mills et al. 1982). It is assumed the 6-month delay in processing would make such change relatively consistent.

Biomass estimates for the standing stock of benthic organisms based on wet weight are subject to other potential errors or biases. Many of these problems are due to the variable contribution to biomass of water and inorganic material (shell and ash), which can vary for each taxonomic group or species. Other changes can be caused by the processing of the samples, i.e., weight changes caused by the preservation media, as noted before, or losses to evaporation during the weighing. Improvements can be made to the estimates by using ash-free dry weight values or energy equivalents for, at the least, dominant species or groups. These conversions can reduce some of the variability in the data because water and inorganic components are mostly eliminated and only the variable of primary importance, that related to the quantity of organic energy in the benthic sample, is presented. This makes the benthic data readily applicable in developing energy-based models or budgets for use in fishery ecology. Because the benthic samples used in this study were to be archived, a nondestructive approach was taken, i.e., use of energy equivalents. The energy equivalency values from Steimle and Terranova (1985) were used, with 1 Kj = 0.239 Kcal.

The occurrence, in samples, of a few larger organisms can obscure basic information or patterns in overall benthic monitoring data (Buchanan et al. 1978). To address this, the biomass of individual organisms weighing more than 1.0 g and occurring in less than 50% of the grab samples in a collection were noted but excluded in the analysis of the data. This also makes the data more relevant to prey-predator considerations since these large, megafaunal organisms are only infrequently used as prey.

To evaluate the possible sources of variability in the data, some factors that can substantially influence results or interpretation are presented: sediment grain size and total organic carbon (TOC), station location precision, population dynamics of dominant species, and general environmental or habitat characteristics for each site, including common benthic predators found at each site. The sediment TOC (total organic carbon) data (mg/g dry weight) were determined for 1978–80 samples by chromate oxidation, for 1981–82 samples by combustion in a furnace, and for 1983 samples by infrared analysis. The sediment PCB (polychlorinated biphenyl) and PAH (polycyclic aromatic hydrocarbon) data were from Boehm (1983), the mean sediment trace-metal data from Reid et al. (1987); these data are dry weight values. The hydrography was from Ingham (1982), and sediment topography (i.e., ridge and swale) was based on Swift (1975). Data on potential benthic predators common at each site were drawn from records of concurrent trawl collections made at the same sites as the benthic samples; these records contained notes on species collected and relative abundance. Stomach contents were examined from a representative sampling of demersal fish species and lobsters in the trawl collections.

During the study, it became readily apparent that biomass levels or trends at several sites appeared to be highly influenced by the population dynamics of one or a few species, especially echinoderms, a factor noted in other benthic studies (Warwick 1980). To evaluate this factor, the echinoderms at several sites, where they dominated the biomass, were measured to provide size-frequency distributions. These distributions can characterize the structure (number of cohorts and approximate ages) and dynamics (frequency of recruitment and approximate growth rates) of populations. In the case of the sand dollar *Echinarachnius parma*, this led to a separate study which included production estimates (Steimle 1990).

An analysis of the significance of the change in December 1979 of sieve mesh size from 1.0 to 0.5 mm was conducted for two surveys, January and July 1982, by sieving each grab sample through both screen sizes.

Many of the sites monitored during the 1978–85 period were originally selected because there was information available from earlier studies, e.g., at stations 15A (R. Swartz and F. Cole, U.S. EPA, Corvallis, OR 97330), 18 (Steimle 1982), 16A and B (Steimle 1985), 28 (Maurer 1982), and three sites from Wigley and Theroux (1981) and Theroux and Grosslein (1987), that were within a kilometer of stations 8, 22, and 32. The biomass data from these studies have been included in the results and any differences in methods or location noted. The biomass data are presented as line graphs instead of histograms, to enhance the definition of possible long-term patterns. It is understood that this makes assumptions about the biomass dynamics of the community between collections, which can be separated by as much as a year. The graphs were interrupted if there were intercollection gaps of more than a year. The results of two studies that collected benthic biomass data bimonthly at stations 31 and 32 (Howe and Leathem 1984) and near stations 16A-C (Steimle 1990) show that biomass levels at a site can be either relatively stable at the bimonthly sampling intensity, disregarding an odd pulse of added biomass, or highly variable. Because the original sampling design was not planned specifically for biomass analysis, and considering the statistical intractability of benthic data from small sample sizes, detailed statistical analysis was considered unwarranted or of dubious value. Linear regressions were calculated, however, for the mean biomass-over-time data for stations with an apparent trend, assuming equal seasonal contributions, and then tested for a significant difference of the slope from zero.

## Results

Analysis of the significance of change in screen size from 1.0 to 0.5 mm in December 1979 (Table 1) indicates the 0.5-mm screen contributed, on average, an additional 4% to total biomass, although this did go as high as 13%. This low contribution is consistent with the results of previous studies on the importance of screen size to biomass, e.g., Reish (1959). Thus, differences in screen size are not considered a major factor in evaluating biomass variability.

A comparison of the mean summer-to-winter biomass values at each site during 1978–83, when seasonal collections were available, shows a majority (20/27) of the sites did have higher mean summer values (Table 2). In general, the mean summer biomass levels averaged about 30% higher than the winter levels (Table 2). Energy equivalents showed about the same average summer increase (28%).

The biomass results for each site (Figs. 2–28) show minor to considerable long-term variability. The results are presented below in regional groups of stations along with available and relevant environmental information. This approach is used because each station can be considered unique, to some degree, due to substantial spatial isolation; thus individual treatment is warranted. The error bars for each mean biomass value on Figures 2–28 represent one standard deviation (SD), as indicated on the vertical axis legend. For economy of space, some wide error bars are broken with the actual SD value given in parentheses at the top of the bar.

**Table 1**

**Significance to total benthic macrofaunal biomass of using 0.5-mm sieve mesh compared with using 1.0-mm mesh for winter (January) and summer (July) 1982 collections. This is based on biomass retained on the 0.5-mm mesh that passed through the 1.0-mm mesh, percent of total biomass this represented, and dominant taxa retained on the 0.5-mm sieve.**

| | Winter | | | Summer | | |
|---|---|---|---|---|---|---|
| Site no. | Biomass ($g/m^2$) | % Total | Dominant taxa | Biomass ($g/m^2$) | % Total | Dominant taxa |
| 2 | 0.70 | 2.36 | P, A | 2.00 | 8.20 | P, B |
| 3 | 0.46 | 1.57 | P | 3.68 | 7.39 | P, B |
| 7 | 3.84 | 4.71 | P | 1.86 | 1.65 | P, A |
| 8 | 1.19 | 3.70 | P | 0.82 | 1.39 | P |
| 9 | 1.94 | 3.43 | P | 1.29 | 2.13 | P |
| 11 | 1.71 | 1.01 | P, A, B | 0.86 | 1.33 | P |
| 12 | 2.79 | 2.58 | P, A | 1.46 | 1.99 | P, A |
| 13 | 2.26 | 1.31 | A, P | 1.40 | 0.04 | P |
| 15A | 1.44 | 0.63 | P, A | 1.90 | 1.11 | A, P |
| 16A | 1.27 | 2.29 | P | 2.58 | 1.68 | P |
| 16B | 0.28 | 2.90 | B | 2.04 | 6.02 | P |
| 16C | 4.91 | 11.88 | P, B | 0.88 | 1.87 | P |
| 17 | 0.41 | 0.10 | P | 0.62 | 0.04 | P |
| 18 | 8.55 | 4.10 | A, B | 10.94 | 2.14 | A, B, P |
| 19 | 2.27 | 3.64 | P, A | 1.17 | 0.37 | P, A |
| 20 | 0.74 | 1.43 | P, O | 5.44 | 10.47 | O |
| 22 | 1.83 | 9.12 | A, P | 1.61 | 4.30 | P, A |
| 23 | 1.17 | 1.52 | A, P | 3.97 | 1.03 | A |
| 24 | 0.13 | 5.40 | P | 0.13 | 4.29 | P, A |
| 28 | 0.70 | 0.97 | P, O | — | — | — |
| 33 | 7.32 | 6.48 | P, A | 4.18 | 7.29 | P |
| 34 | 4.25 | 6.27 | B | 3.18 | 2.03 | B, P |
| 35 | 3.56 | 3.84 | P | 23.22 | 13.07 | P |
| 36 | 3.13 | 5.11 | B | 2.84 | 3.96 | B, P |
| 37 | 2.45 | 6.88 | A, P | 3.87 | 12.26 | P |
| $\bar{x}$ | 2.37 | 3.73 | | 3.41 | 4.00 | |
| SD | 2.12 | 2.81 | | 4.77 | 3.86 | |

**P** polychaete, **A** amphipod, **B** bivalve, **O** ophiuroid

**Table 2**

**Comparison of mean benthic biomass ($g/m^2$) for 1978–83 summer and winter collections at each site, estimated energy values ($Kcal/m^2$), and mean Kcal:B ratios.**

| Site | Biomass | | Energy | | Kcal:B | |
|---|---|---|---|---|---|---|
| no. | Summer | Winter | Summer | Winter | Summer | Winter |
| 2 | 40.5 | 14.0 | 27.5 | 11.7 | 0.68 | 0.84 |
| 3 | 43.3 | 24.3 | 34.0 | 20.0 | 0.78 | 0.82 |
| 7 | 74.7 | 78.0 | 57.3 | 55.7 | 0.77 | 0.71 |
| 8 | 50.0 | 34.3 | 33.0 | 24.7 | 0.66 | 0.72 |
| 9 | 75.7 | 51.1 | 60.0 | 40.0 | 0.79 | 0.86 |
| 11 | 90.0 | 183.3 | 65.7 | 126.7 | 0.73 | 0.69 |
| 12 | 63.3 | 70.3 | 55.0 | 58.0 | 0.87 | 0.83 |
| 13 | 247.7 | 179.7 | 184.7 | 142.7 | 0.75 | 0.79 |
| 15A | 91.0 | 249.3 | 64.3 | 168.7 | 0.71 | 0.68 |
| 16A | 79.7 | 46.0 | 76.3 | 41.0 | 0.96 | 0.89 |
| 16B | 33.0 | 41.0 | 34.3 | 37.3 | 1.04 | 0.91 |
| 16C | 52.7 | 22.7 | 46.7 | 20.0 | 0.89 | 0.88 |
| 17 | 605.7 | 329.0 | 399.0 | 218.3 | 0.66 | 0.66 |
| 18 | 191.0 | 167.3 | 165.0 | 171.3 | 0.86 | 1.02 |
| 19 | 252.0 | 64.0 | 197.3 | 62.0 | 0.78 | 0.97 |
| 20 | 83.0 | 64.0 | 59.7 | 44.3 | 0.72 | 0.69 |
| 22 | 38.4 | 21.5 | 40.6 | 22.8 | 1.06 | 1.06 |
| 23 | 62.0 | 37.8 | 56.6 | 35.3 | 0.91 | 0.93 |
| 24 | 24.6 | 4.5 | 20.0 | 4.3 | 0.81 | 0.94 |
| 28 | 55.0 | 45.3 | 41.0 | 34.7 | 0.75 | 0.77 |
| 31 | 21.5 | 8.0 | 17.5 | 7.0 | 0.81 | 0.88 |
| 32 | 37.0 | 14.0 | 27.0 | 13.0 | 0.73 | 0.93 |
| 33 | 105.0 | 122.7 | 97.7 | 115.7 | 0.93 | 0.94 |
| 34 | 142.7 | 97.7 | 100.7 | 73.0 | 0.71 | 0.75 |
| 35 | 154.7 | 80.0 | 137.7 | 70.7 | 0.89 | 0.88 |
| 36 | 74.7 | 79.0 | 55.0 | 62.5 | 0.74 | 0.79 |
| 37 | 44.3 | 37.0 | 40.7 | 36.5 | 0.92 | 0.99 |
| $\bar{x}$ | 104.9 | 80.2 | 81.3 | 63.6 | 0.81 | 0.84 |

## Chesapeake Bight

The southernmost area, the Chesapeake Bight, contained seven stations: 2, 3, 7, 8, 9, 31, and 32 (Fig. 1). Data at stations 2, 31, and 32 were discontinuous; however, the other stations had biomass levels that ranged mostly between 20 and 120 $g/m^2$, with polychaetes, molluscs, and echinoderms the dominant groups.

**Station 2** This station was located off Virginia Beach, VA (Fig. 1) and actually included two sites. The initial site was abandoned after a year because of a navigational safety problem; the second site (lat. 36°49.8′N, long. 75°50.3′W) was 5 km south of the original. Both sites were about 15 m deep with medium sand at the initial site and fine to silty-fine sand at the final site. Both also had relatively low levels of trace metals, e.g., <10 ppm dry weight (DW) lead. The sites were also in the coastal-active hydrographic band that can be influenced by the Chesapeake Bay plume and shore-zone upwellings. The few collections made at the initial site (Fig. 2a) are not reliable in any discussion of trends. There was less than an order of magnitude in mean biomass variability at the second site; this appeared to be related to seasonal factors. The species that generally dominated the biomass were the polychaete *Glycera americana*, and the molluscs *Pandora gouldiana*, *Tellina agilis*, *Ensis directus*, and *Ilynassa trivittata*. Trawls made at both sites indicated the benthic predators present were weakfish *Cynoscion regalis*, croaker *Micropogon undulatus*, young summer flounder *Paralichthys dentatus*, northern searobin *Prionotus carolinus*, windowpane *Scophthalmus aquosus*, and spotted hake *Urophycis regia*. Various amphipods, decapods *Cancer* sp., *Ovalipes* sp., *Crangon septemspinosus*), and the razor clam *Ensis directus*, were the benthic prey commonly eaten, although nonbenthic mysid shrimp and small fish were most important to some species.

**Station 3** This station was located south of the previous station, off the Virginia-North Carolina border (lat. 36°34′N, long. 75°48′W, Fig. 1), near a coastal, shoal-retreat massif in 20 m with fine-sand sediments which contained <0.4 ppb PCBs, 12 ppt PAHs, and low levels of trace metals. The

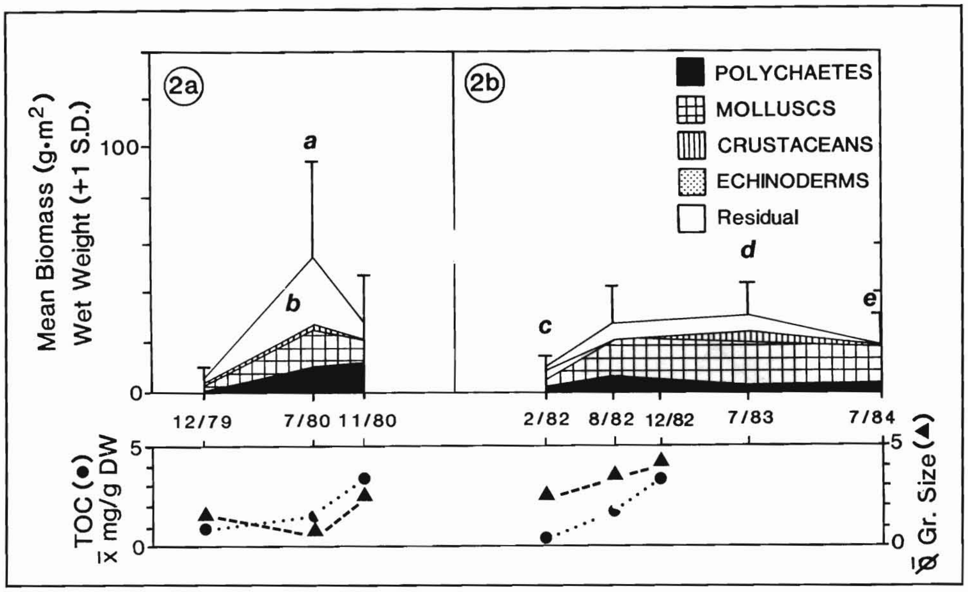


**Figure 2**
**Benthic macrofaunal biomass levels at station 2. (a) Only four grab samples available; (b) residual biomass was mostly tunicates; (c) one 9.9-g *Pagurus* sp. excluded; (d) several *Encope emarginata* (12.0 g) excluded; and (e) one *Mellita quinquiesperforata* (8.4 g) and one *Eupleura caudata* (1.2 g) excluded.**

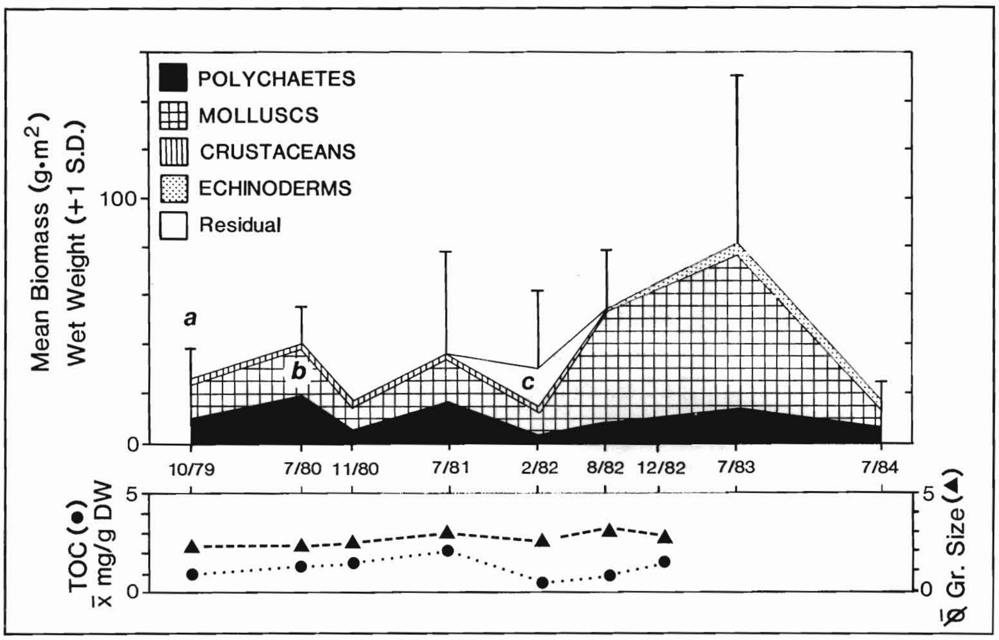


**Figure 3**
**Benthic macrofaunal biomass levels at station 3. (a) Only two grab samples available; (b) one *Neverita duplicata* (6.8 g) excluded; and (c) mostly *E. parma*.**

site was also in a coastal-active band, but only marginally influenced by the Chesapeake plume. The mean macrofaunal biomass levels were relatively stable and ranged from 16.3 to 82.2 g/m$^2$, with seasonal fluctuations apparently responsible for most of the 1978–82 variability (Fig. 3). Biomass was dominated by the polychaetes *Glycera dibranchiata* and *Spiophanes bombyx*, and the molluscs *Ensis directus* and *Ilynassa trivittata*. An expansion of the Atlantic jackknife *E. directus* population was the source of the 1982–83 biomass increase. As with the previous station, potentially important benthic predators were windowpane, summer flounder, and spotted hake. These predators ate predominately *Ovalipes* crabs, *Crangon* shrimp, jackknife clam (*Ensis*), mysids, or small fish.

**Station 7** This station (lat. 36°47.5′N, long. 75°11.7′W) was on the continental shelf off Virginia (Fig. 1) in 33 m of water. Sediments were medium sand in a ridge and swale area, with low levels of trace metals. Hydrography of the site may be influenced by the development of seasonal, coastal fronts. The mean macrofaunal biomass at this site ranged from 19.4 to 114.4 g/m$^2$, without any clear trends but with an increase between 1980 and 1982 caused by increases in several groups (Fig. 4). Species making major contributions to the biomass were the polychaetes *Nephtys picta* and *Spiophanes bombyx*, the molluscs *Ensis directus* and *Tellina agilis*, and the sand dollar *Echinarachnius parma*. The influence of seasonal factors was not evident. Potentially important benthic predators collected here were the northern

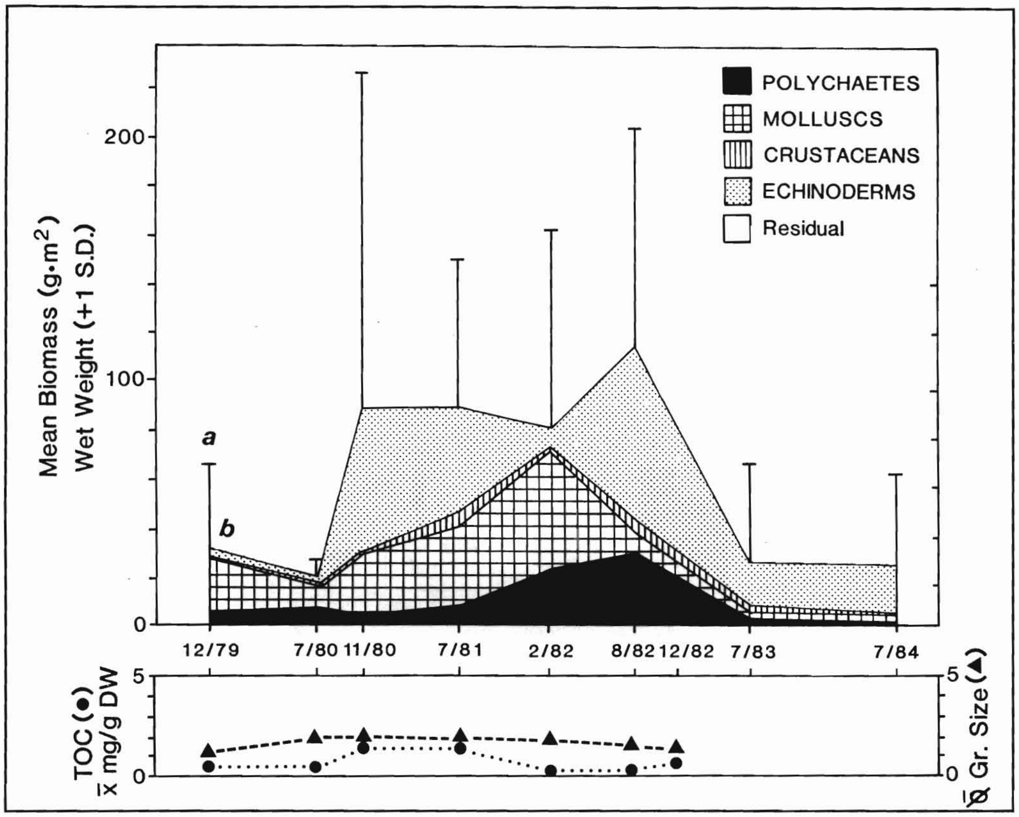


**Figure 4**
**Benthic macrofaunal biomass levels at station 7. (a) Only four grab samples available and one *Asterias forbesi* (12.2 g) excluded.**

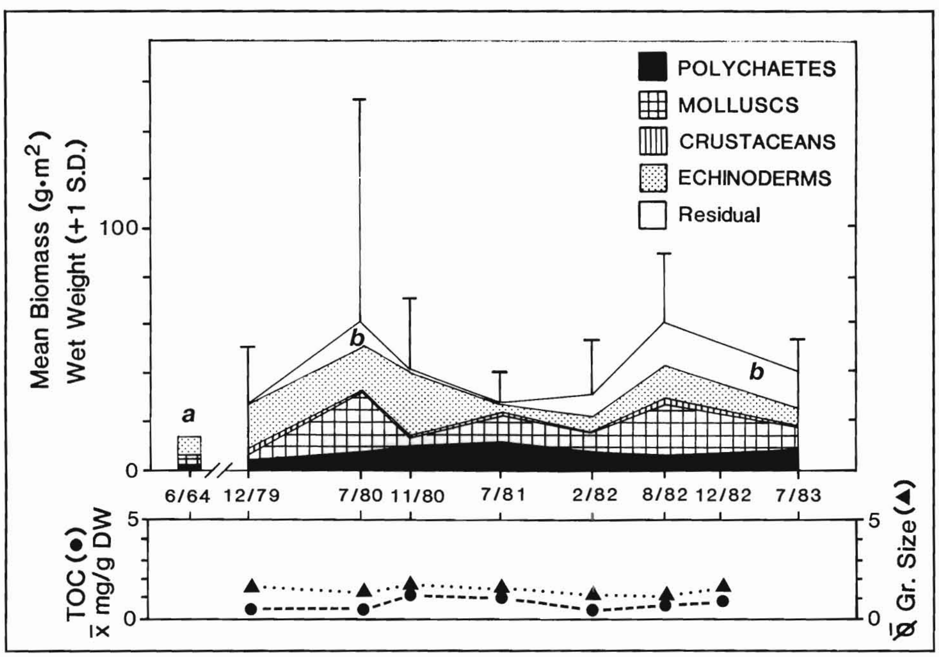


**Figure 5**
**Benthic macrofaunal biomass levels at station 8. (a) Data from a single grab; and (b) residual biomass mostly the anthozoan *Epizoanthus* sp.**

searobin, scup *Stenotomus chrysops*, black sea bass *Centropristis striata*, spotted hake, red hake *Urophysis chuss*, and horseshoe (*Limulus*) and calico (*Ovalipes*) crabs. The rock crab *Cancer irroratus* was a common prey of the fish, along with various polychaetes and amphipods.

**Station 8** This station (lat. 36°40.7′N, long. 74°45.1′W) was on the outer shelf, 80 m in depth, off Virginia (Fig. 1) in a ridge and swale area, with medium sand and low trace metals. The site was possibly influenced by the shelf-slope water-mass front and the "cold pool," as defined by Ingham (1982). Dominant species contributing to the biomass were the bivalves *Astarte* spp., the sea star *Astropecten americana*,

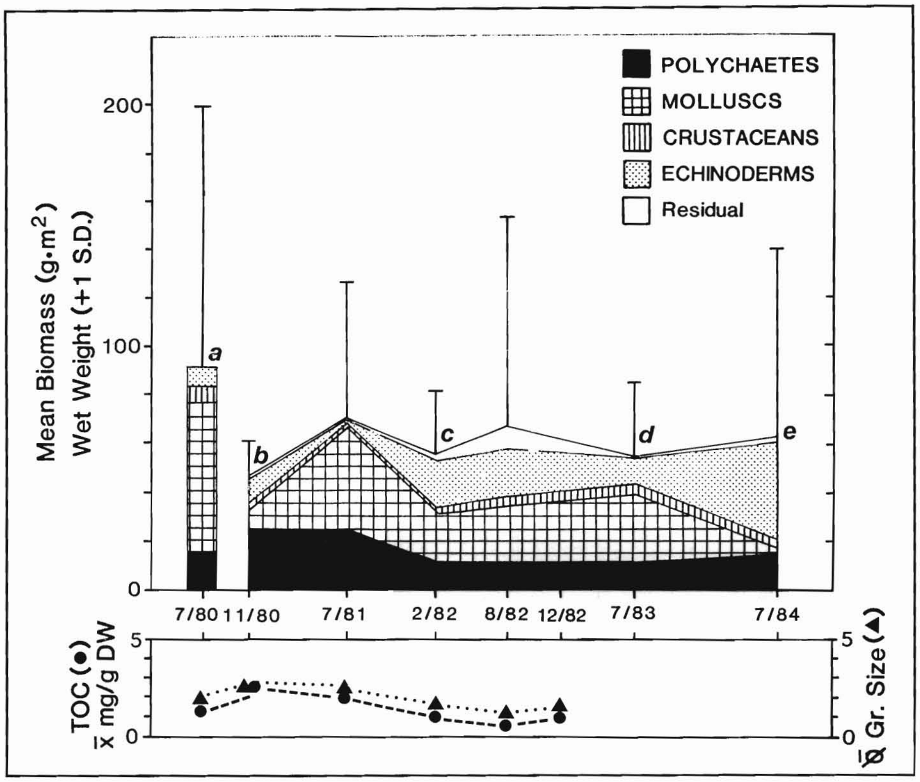


**Figure 6**
**Benthic macrofaunal biomass levels at station 9. (a) This collection might have been off station by 2 km; (b) several *Arctica islandica* (240.5 g) excluded; (c) several *Astarte* sp. (21.4 g), *Buccinium undatum* (49.8 g), *Aphrodite hastata* (10.0 g), and *A. islandica* (11.9 g) excluded; (d) one *A. islandica* (23.0 g) and one *Astarte* sp. (10.3 g) excluded; and (e) one *Astarte castanea* (10.1 g) excluded.**

the polychaete *Onuphis* sp., and the anemone *Epizoanthus* sp. The mean biomass levels were relatively constant over the study period, ranging from 28.0 to 59.8 g/m$^2$, with some suggestion of seasonal fluctuations (Fig. 5). Potentially important predators found at the site were the spotted hake, sea robins, scup, *Cancer* crabs, and others to a lesser extent. Amphipods *Ampelisca agassizi* and *Unciola* sp., polychaetes *Lumbrineris* sp. and *Ophelia denticulata*, and decapods *Cancer* and *Crangon* were the most common prey eaten by the fish.

**Station 9** This station (lat. 38°17.3′N, long. 74°17.7′W) was in a former sewage-sludge disposal area (Fig. 1), used from 1973 to 1980. Sediments were medium sand in a ridge and swale area where <2.1 ppb PCBs, 26 ppt PAHs, and low levels of trace metals were measured. The site was 50 m deep and could have been in the region influenced by the "cold pool." Biomass was primarily dominated by the sand dollar *Echinarachnius parma* and several megafaunal molluscs (*Arctica islandica* and *Astarte* spp.) that were excluded from the data summarized in Figure 6. Mean biomass levels were fairly constant, ranging from 48.5 to 70.9 g/m$^2$, with some seasonal influence evident to 1982. Potentially important predators at the site were the little skate *Raja erinacea*, windowpane, red hake, *Cancer* crabs, and other less frequently occurring species. Polychaetes, as well as *Cancer* and *Crangon*, were important prey.

**Station 31** This station (lat. 38°44.8′N, long. 75°01′W) was just below the mouth of Delaware Bay (Fig. 1), 25 m deep, and in the coastal-active band influenced by the Bay plume and coastal upwellings. Some summer hypoxia has been reported in the area. It was in a coastal ridge and swale area and had medium-to-fine sandy sediments with TOC levels more variable than usually found (Fig. 7). There were moderate trace-metal levels, e.g., 6–17 ppm lead, as well. The species that dominated the biomass were mostly molluscs, including *Ensis directus*, *Nucula annulata*, *Tellina agilis*, and *Ilynassa trivittata*, with patches of blue mussel *Mytilus edulis* in 1980. Mean biomass levels for this station were irregular with an order of magnitude change between 1980–81 (7.6–132 g/m$^2$) and 1983–85 (72.9–1535.3 g/m$^2$) collection periods (Fig. 7). This change was primarily because of population dynamics of the small nut clam *Nucula annulata* that often contributed over 1 kilogram of biomass per grab sample. The small predatory mudsnail *I. trivittata* became abundant in 1984, possibly in response to this large forage base and perhaps a reasonable explanation for some of the overall decline in biomass levels of *Nucula* thereafter. Other, larger, potentially important benthic predators collected at the site included windowpane, silver hake *Merluccius bilinearis*, spotted hake, horseshoe crabs, and several less common species. Benthic prey commonly eaten by the fish were *Cancer*, *Crangon*, amphipods (e.g., *Unciola* sp.), and polychaetes such as *Pherusa affinis*.

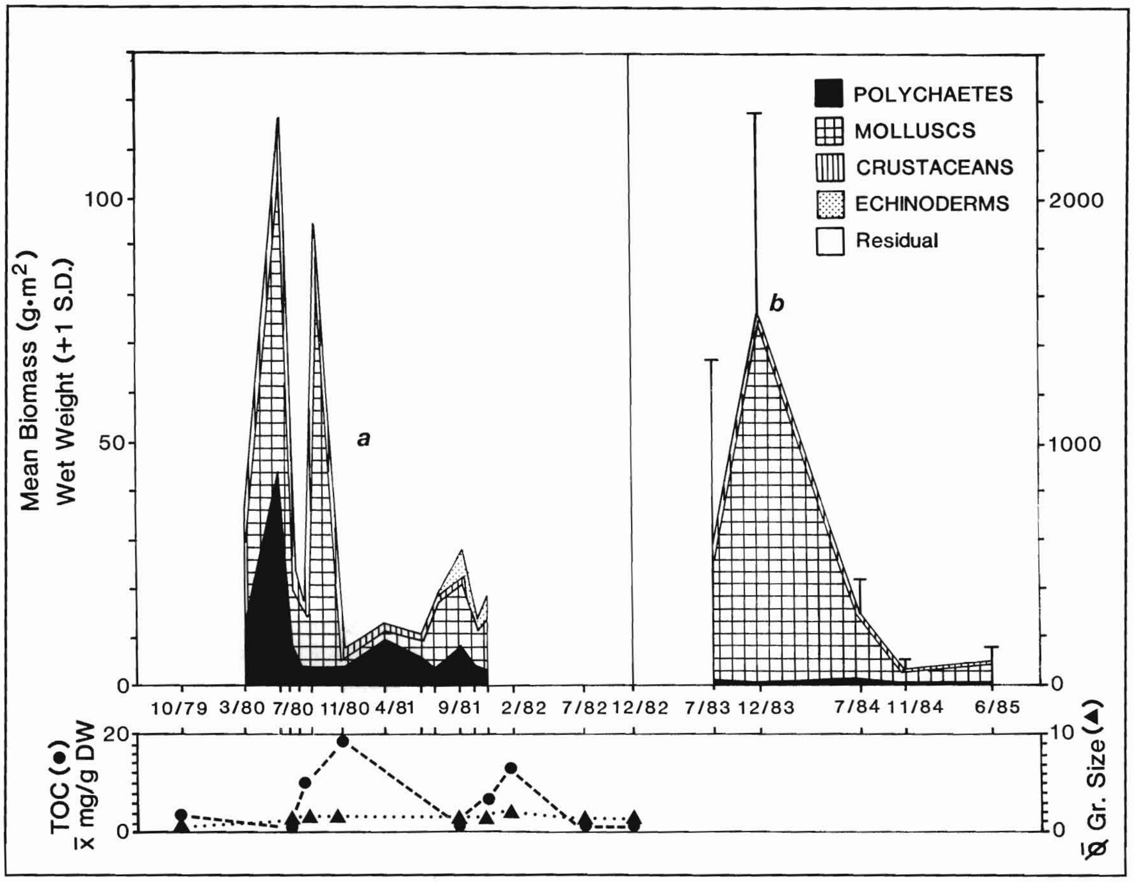


**Figure 7**

**Benthic macrofaunal biomass levels at station 31. (a) 1980–81 data from Howe and Leathem (1984); and (b) one holothurian *Sclerodactyla briarus* (51.8 g) excluded. Note change in scale after 1982.**

**Station 32** This station (lat. 38°31.4′N, long. 74°7.7′W) was farther below the mouth of Delaware Bay than the previous site (Fig. 1) and was shallower, 15 m, but with very similar hydrographic characteristics. It was also in a coastal ridge and swale zone with coarse-to-medium sands and low trace-metal levels. The dominant species of the biomass were the bivalve molluscs *Spisula solidissma* and *Tellina agilis* and a mix of polychaete species. Mean biomass levels were low but fairly stable in the early collections (3.9–15.3 g/m$^2$). This was punctuated by an odd pulse (52.8 g/m$^2$) of *E. parma* in July 1980 (Fig. 8), possibly reflecting some sampling error. The biomass was more variable (9.3–57.7 g/m$^2$) in later collections, but summer increases were clear. Commonly collected benthic predators included the spotted hake, a variety of skates and rays, sea robins, young summer flounder, horseshoe, and other crabs. Decapods, especially *Cancer*, *Crangon*, and *Ovalipes*, were the most common prey found in the fish stomachs examined.

## New York Bight

The next set of nine stations was in the New York Bight with stations 11, 12, and 13 on the shelf, stations 17 and 15A in coastal waters, and stations 33 and 16A-C in the submerged Hudson Shelf Valley (Fig. 1). On the shelf, the mean biomass levels usually ranged between 50 and 200 g/m$^2$, highly variable at the coastal sites (because of sand dollar populations), and about 100 g/m$^2$ in the Hudson Shelf Valley.

**Station 11** This station (lat. 38°44.6′N, long. 74°02.1′W) was midshelf off Delaware (Fig. 1) in 50 m of water, with fine-sand sediments and low trace metals, in an area that can be affected by the "cold pool." During the study period, mean biomass levels of the site were highly affected by population dynamics of *Echinarachnius parma* (Fig. 9), which will be discussed later. The mollusc biomass was due partly to the occurrence, in several collections, of *Cyclocardia borealis* and *Astarte* spp. Potentially important predators occurring at the site included four-spot flounder *Paralichthys oblongus*, little skate, yellowtail flounder *Limanda ferruginea*, windowpane, black sea bass, sea robins, red and spotted hake, *Cancer* crabs, and a variety of less common species. Common fish prey were *Cancer* crabs, *Crangon*, polychaetes, amphipods, e.g., *Ampelisca* sp., and the rhynchocoel *Cerebratulus*.

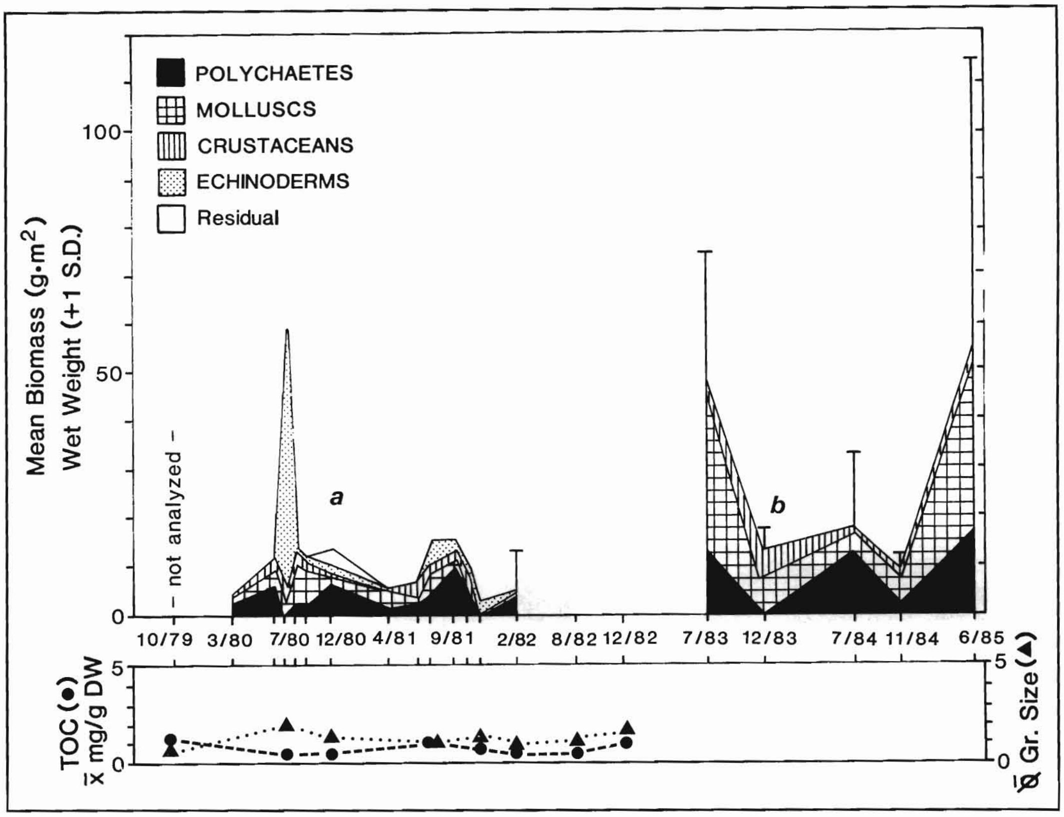


**Figure 8**

**Benthic macrofaunal biomass levels at station 32. (a) 1980–81 data from Howe and Leathem (1984); and (b) one *Neverita duplicata* (28.4 g) excluded.**

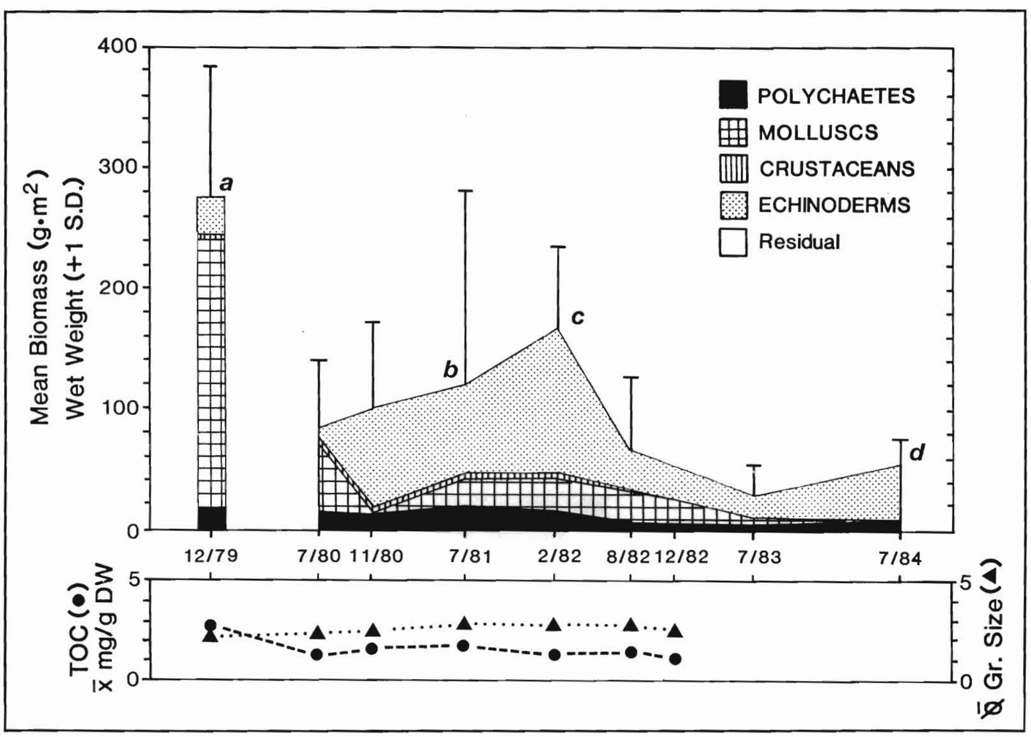


**Figure 9**

**Benthic macrofaunal biomass levels at station 11. (a) This collection might have been off station by 2 km and includes only three grab samples; (b) one *Cancer* sp. (66.0 g) excluded; (c) one *Arctica islandica* (107.0 g) excluded; and (d) one *Aphrodite hastata* (2.1 g) and an unidentified bivalve (4.9 g) excluded.**

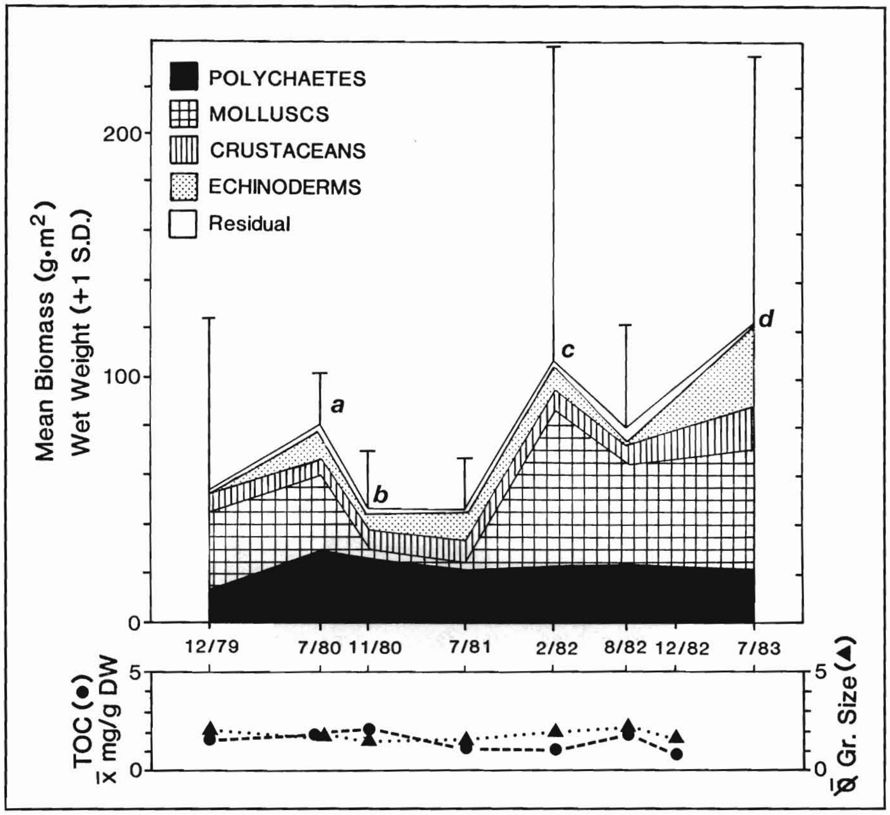


**Figure 10**
**Benthic macrofaunal biomass levels at station 12. (a) One *Cancer irroratus* (3.2 g) excluded; (b) one *Astropecten articulata* (2.9 g) excluded; (c) one *Astarte castanea* (12.2 g) excluded, the high variance due to many small *Cyclocardia borealis* in one sample; and (d) one *Arctica islandica* (11.5 g) excluded, high variance as above.**

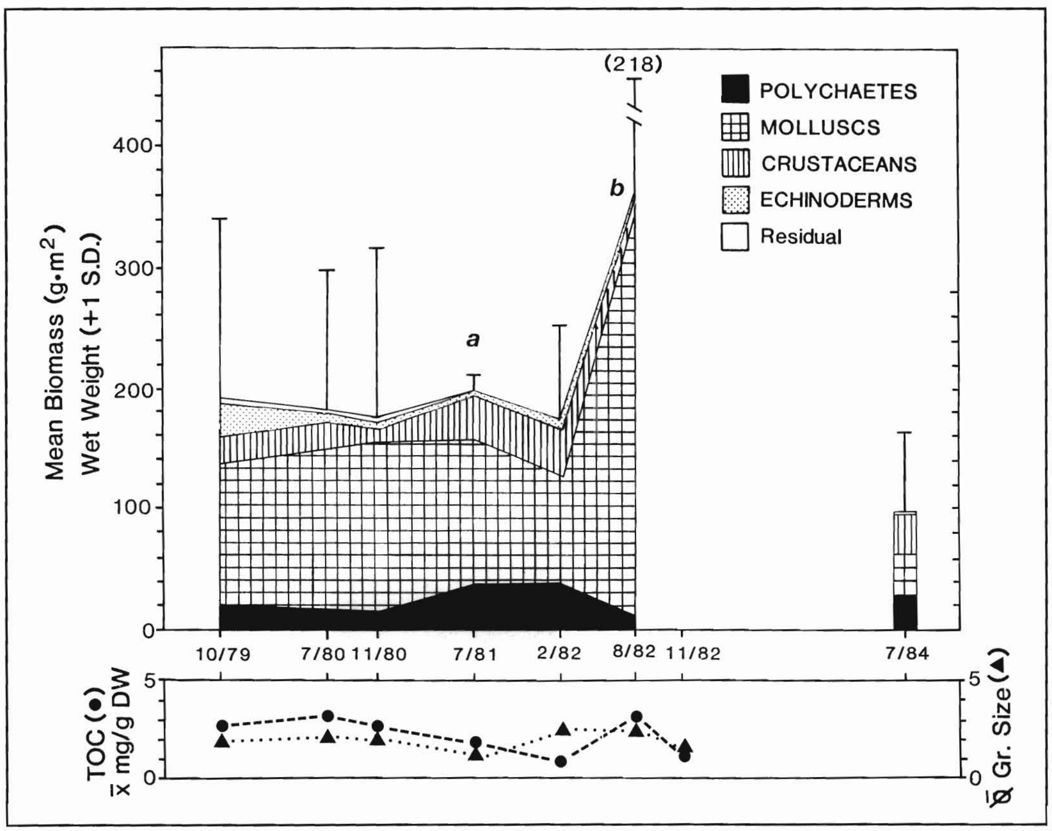


**Figure 11**
**Benthic macrofaunal biomass levels at station 13. (a) Only three grab samples available; and (b) high variance because of several small *Arctica islandica* and *Cyclocardia borealis* in two samples; the mean biomass of the remaining three samples was 210 g·m².**

**Station 12** This station (lat. 38°6.3′N, long. 73°0.7′W) was on the outer shelf off Delaware (Fig. 1) in 70 m, with medium sands containing low levels of trace metals. It could also have been affected by the "cold pool" and the shelf-slope water-mass front. Figure 10 shows polychaetes generally important to the overall mean biomass (with no particular species dominant), as well as molluscs, mainly *Astarte* spp. and *Cyclocardia*. Predators collected here were four-spot flounder, red hake, scup, little skate, sea robins, *Cancer* crabs, and less common species. The fish ate various polychaetes, including *Ninoe* sp., along with ampeliscid amphipods and *Cancer*.

**Station 13** This station (lat. 39°20.4′N, long. 72°58.9′W) was in an area on the outer shelf (Fig. 1) and was monitored because it lies in the subsurface "Baltimore Canyon Trough", considered to have potential oil or gas reserves. It was 65 m deep with low trace metals, medium sand, in or near the "cold pool" and the shelf-slope water-mass front. Molluscs dominated this site (Fig. 11), again mainly *Astarte* spp. and *Cyclocardia*. Although not an overall major contributor, the amphipod *Ampelisca agassizi* was conspicuous in the samples. With the exception of the last two collections (the first biased by a high biomass cluster of the dominant bivalves in two grabs), the mean biomass was relatively consistent, averaging just under 200 g/m$^2$. Potentially important predators collected here were basically the same as at station 12, but also included yellowtail flounder and silver hake. Decapods (*Cancer*, *Crangon*, and *Dichelopandalus*) were important food for the hakes and four-spot flounder, while polychaetes *Scalibregma* and *Lumbrineris* and amphipods *Ampelisca* and *Unciola* were important to yellowtail and scup.

**Station 17** This station (lat. 39°35.8′N, long. 73°54.2′W) was in the area off New Jersey (Fig. 1) defaunated by an exceptional anoxia event in 1976 (Steimle and Radosh 1979). The depth was 20 m with medium-to-coarse sand and low trace metals, in a coastal ridge and swale area, possibly influenced by upwellings and seasonal fronts. The highly

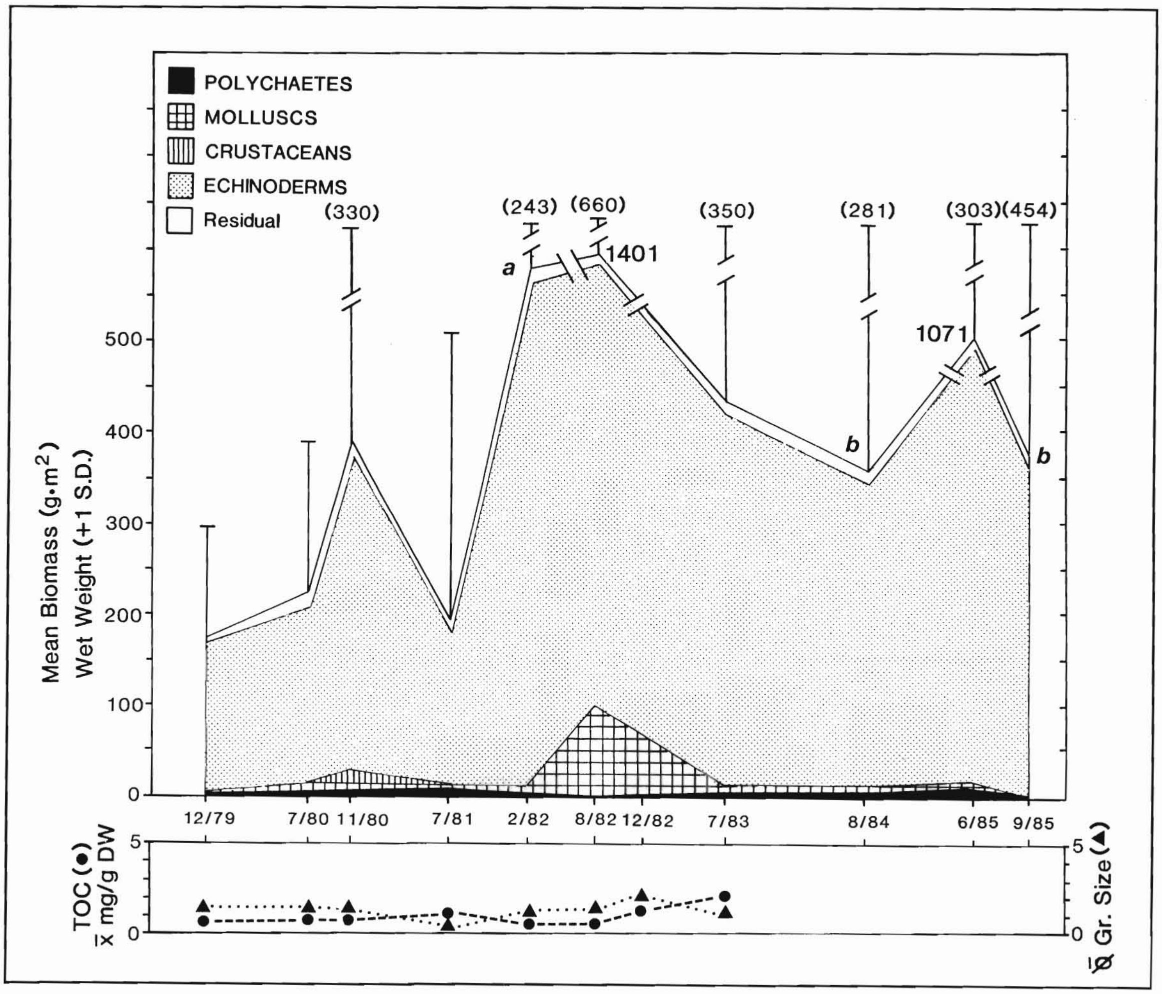


**Figure 12**
**Benthic macrofaunal biomass levels at station 17. (a) Seven *Spisula solidissima* (148.0 g) from one sample excluded; and (b) only two grab samples analyzed.**

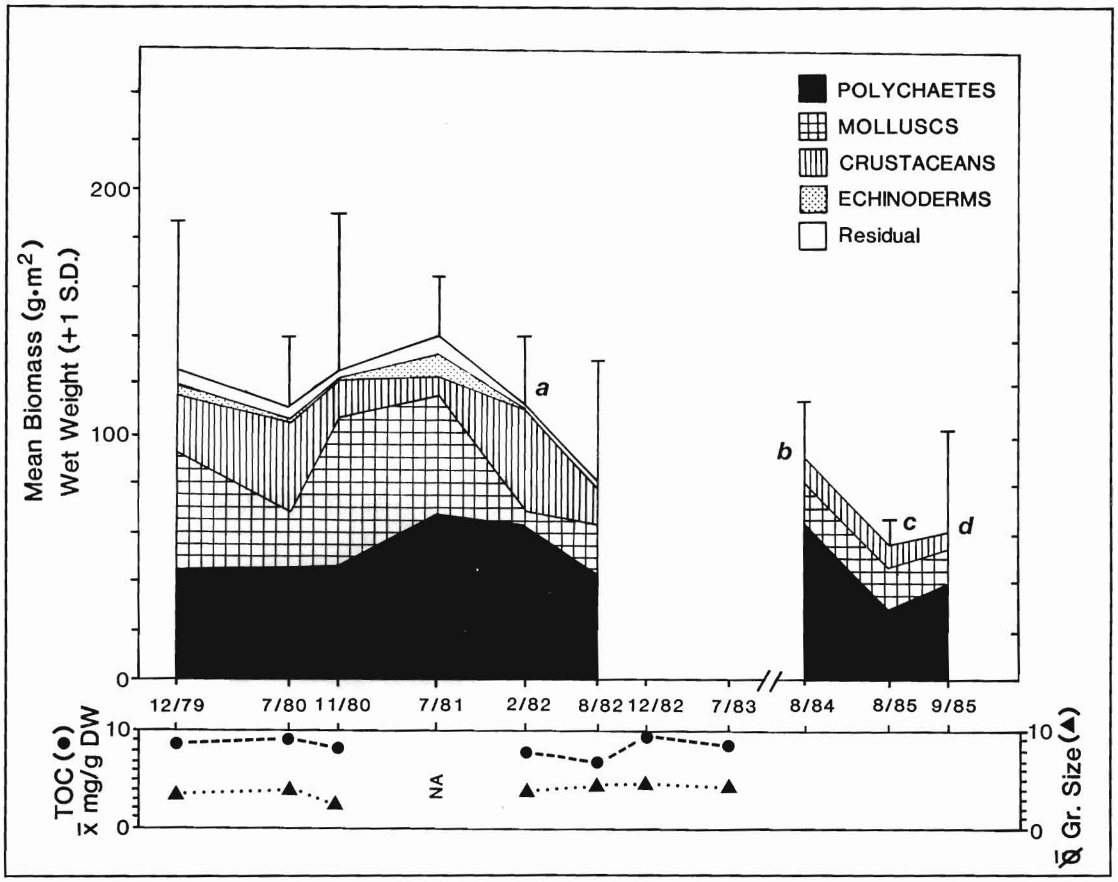


**Figure 13**

**Benthic macrofaunal biomass levels at station 33. (a) Two *Pitar morrhuanus* (28.3 g) and one *Asterias vulgarus* (49 g) excluded; (b) two *Havelockia scabra* (6.4 g) excluded; (c) one *Arctica islandica* (66.5 g) excluded; and (d) only two grab samples analyzed.**

variable biomass at this site was dominated by *Echinarachnius parma* (Fig. 12). Major predators were black sea bass, yellowtail, four-spot flounder, windowpane, sea robins, scup, and spotted hake. Benthic prey found in their stomachs included the tentacular crowns of the burrowing anemone *Ceriantheopsis americanus*, some *Crangon*, *Cancer*, a variety of amphipods, polychaetes, and the ribbon worm *Cerebratulus*, but not *E. parma*.

**Station 33** This station (lat. 40°01.4′N, long. 73°25.6′W) was in the Hudson Shelf Valley (Fig. 1) that traverses the shelf from the mouth of New York Harbor to the Hudson Canyon on the slope. The site was 62 m deep with silty, fine sands possibly reflecting a depositional environment. Boehm (1983) found low levels (6–9 ppb) of PCBs and moderate levels (about 490 ppt) of PAHs in these sediments. This possibly reflects some downvalley transport from the highly contaminated waste-disposal areas just outside the Harbor (Boehm 1983). This site could be influenced by intrusions of outer shelf waters. The mean biomass here (Fig. 13) was dominated by polychaetes, with *Nephtys incisa* conspicuous; the amphipod *Ampelisca agassizi* and several molluscs were also important. The overall biomass levels appear relatively stable (57.9–142.0 g/m$^2$), although there may have been a decline since 1981 (Fig. 13). A variety of predators were commonly found, including little skate; four-spot and yellowtail flounders, and winter flounder *Pseudopleuronectes americanus*; red and silver hake; scup; windowpane; ocean pout *Macrozoarces americanus*; *Cancer* crabs; and American lobster *Homarus americanus*. These predators ate a variety of benthos, particularly *Dichelopandalus* by the hakes and four-spot flounder; the nut clam *Nucula* sp. by lobsters; and polychaetes *Pherusa* and *Lumbrineris*, ampeliscid amphipods, and *Ceriantheopsis* by winter and yellowtail flounders.

**Station 16A** This station (lat. 40°25′N, long. 73°44′W) was at the northwest edge of a sewage-sludge disposal site on a shoulder of the upper Hudson Shelf Valley (Fig. 1). The site contained medium sand in about 25 m of water. PCB values of about 2.2 ppm have been measured in the sediments, as well as relatively high trace-metal levels, e.g., lead above 25 ppm. Besides waste disposal, the site can be influenced by the Hudson-Raritan plume and occasional seasonal hypoxia. Mean biomass was relatively low (<50 g/m$^2$) and consisted mostly of polychaetes (Fig. 14), including a mix

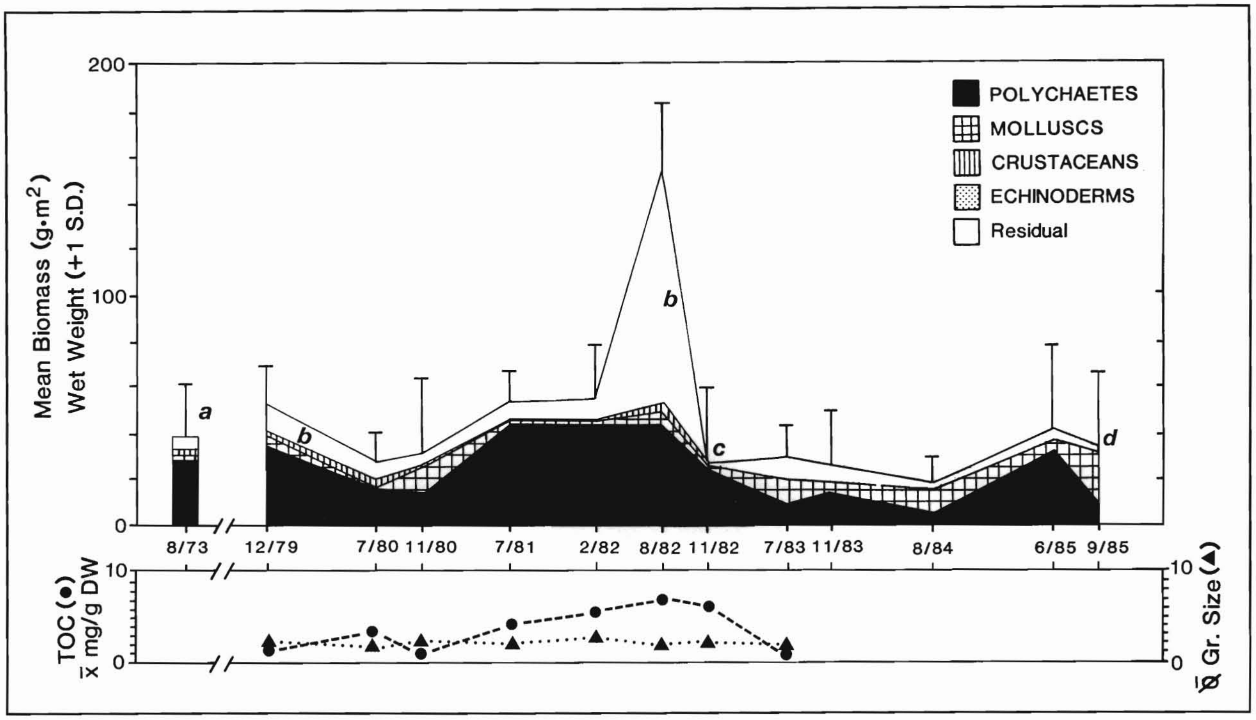


**Figure 14**

**Benthic macrofaunal biomass levels at station 16A. (a) Only four grab samples available; (b) residual biomass was mostly anthozoans and rhynchocoels; (c) one *Pitar morrhuana* (4.6 g) excluded; and (d) only two grab samples analyzed.**

of common sandy-habitat species, e.g., *Nephtys picta*, ubiquitous types such as *Spiophanes bombyx*, and the stress-tolerant *Capitella capitata*. The burrowing anemone *Ceriantheopsis americana* and the rhynchocoel *Cerebratulus* were other major contributors. The aberrant value for August 1982 was mostly that of the easily fragmented, large, predatory rhynchocoel. Other predators found at this site were essentially the same as for station 33 with the major prey consisting of *Pherusa*, *Ceriantheopsis*, and *Dichelopandalus*.

**Station 16B** This station (lat. 40°25′N, long. 73°46′W) was in the Christiaensen Basin of the upper Hudson Shelf Valley (Fig. 1). The site was 27 m deep and in silty-fine sands containing >150 ppb PCBs, >7000 ppt PAHs, and very high levels of trace metals, e.g., up to 175 ppm lead. It was also in the coastal-active band, influenced by the Hudson-Raritan plume and seasonally recurrent hypoxia. Polychaetes were again the dominant taxon (Fig. 15). There appeared to be two basic community groups which dominated the biomass: a *Capitella-Cerebratulus* group and a *Ceriantheopsis-Nephtys incisa-Nucula proxima* group. These two groups could alternately dominate the biomass in separate grabs in a collection. Potentially important predators were the same as at stations 16A and 17, and predation on many benthic species has been previously reported (Steimle 1985). The relatively low recent biomass levels here suggest a declining trend since 1973; however, most of the 1973 biomass was that of the nut clam, *Nucula proxima*. The sediment TOC levels were irregular, but this seems to have had little effect on biomass levels.

**Station 16C** This station (lat. 40°25′N, long. 73°52′W) was located north of the New York Harbor dredge-spoil disposal area (Fig. 1). The site contained mixed sands in 22 m depths of a coastal ridge and swale area possibly influenced by the distribution of dredge spoils during or after disposal. Less than 0.4 ppm PCBs were measured in these sediments, but trace-metal levels were relatively high, similar to station 16A. The site was also in the coastal-active band influenced by the Hudson-Raritan plume, upwellings, and seasonally recurrent hypoxia. The benthos had relatively low, mean biomass (Fig. 16) but with more diversity, e.g., a mix of polychaetes and the northern dwarf tellin *Tellina agilis* being the major contributors. Overall biomass levels suggest a gradual increase during 1980–82, but a decline since. The peak in biomass in 1980 (Fig. 16) appeared to be related to a concurrent peak in sediment TOC, the cause of which is unknown but could be a manifestation of some sampling error. Potential predators were similar to those found at the other stations in the area.

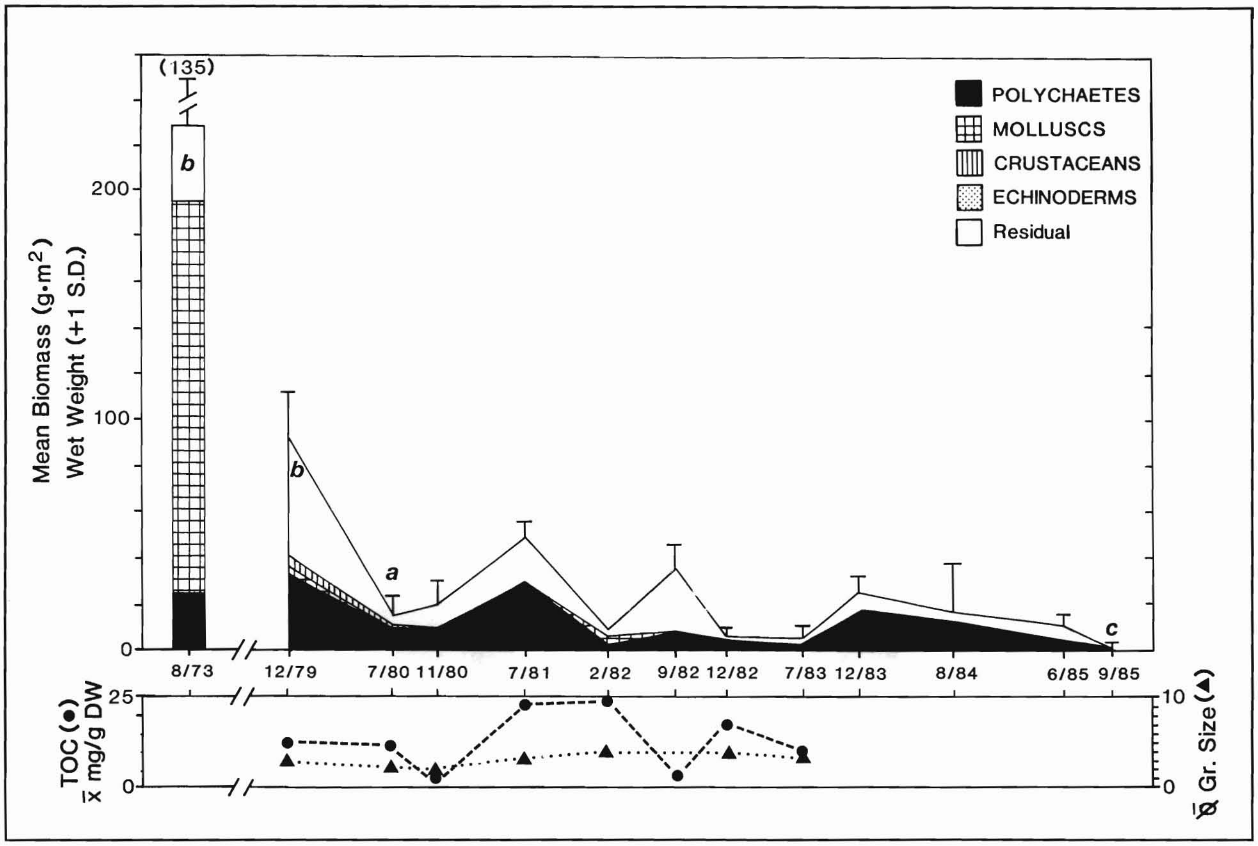


**Figure 15**

**Benthic macrofaunal biomass levels at station 16B. (a) Only four grab samples available; (b) most residual biomass was anthozoans, rhynchocoels, and phoronids; and (c) only two grab samples analyzed.**

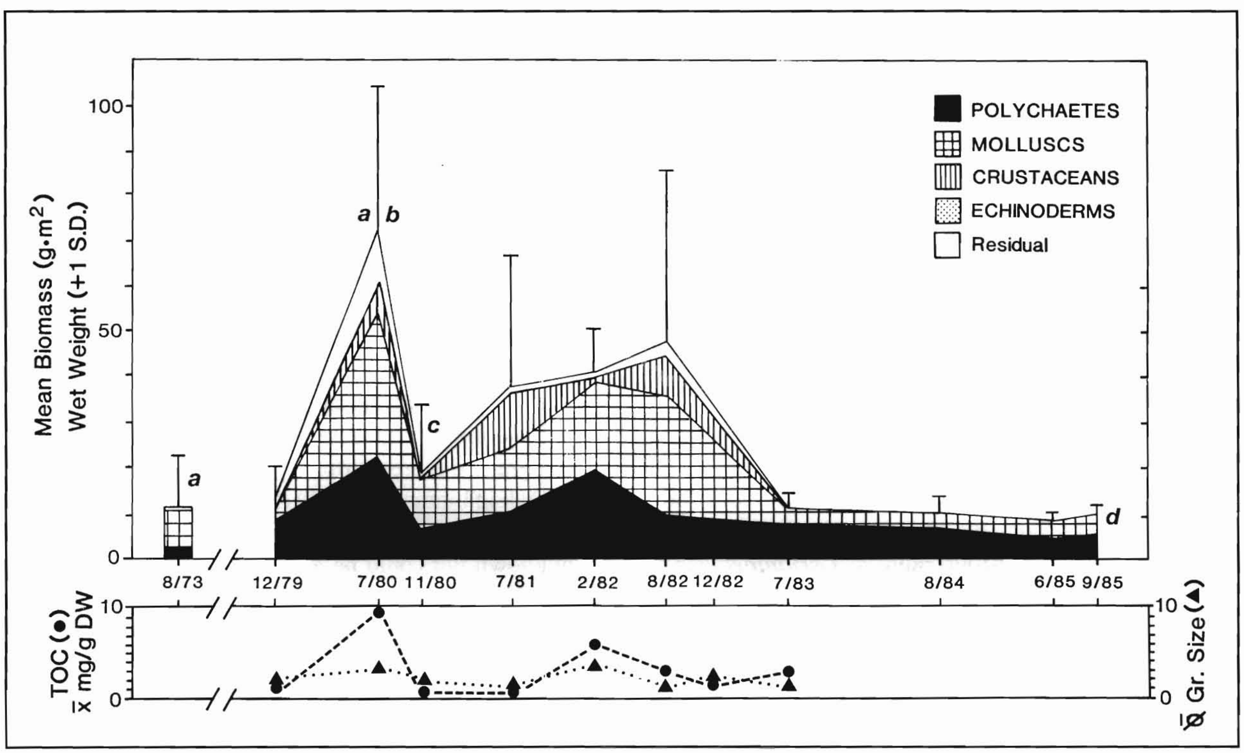


**Figure 16**

**Benthic macrofaunal biomass levels at station 16C. (a) Only four grab samples available; (b) one *Cancer borealis* (91.0 g) excluded; (c) one *Euspira heros* (1.3 g) excluded, and only two grab samples analyzed.**

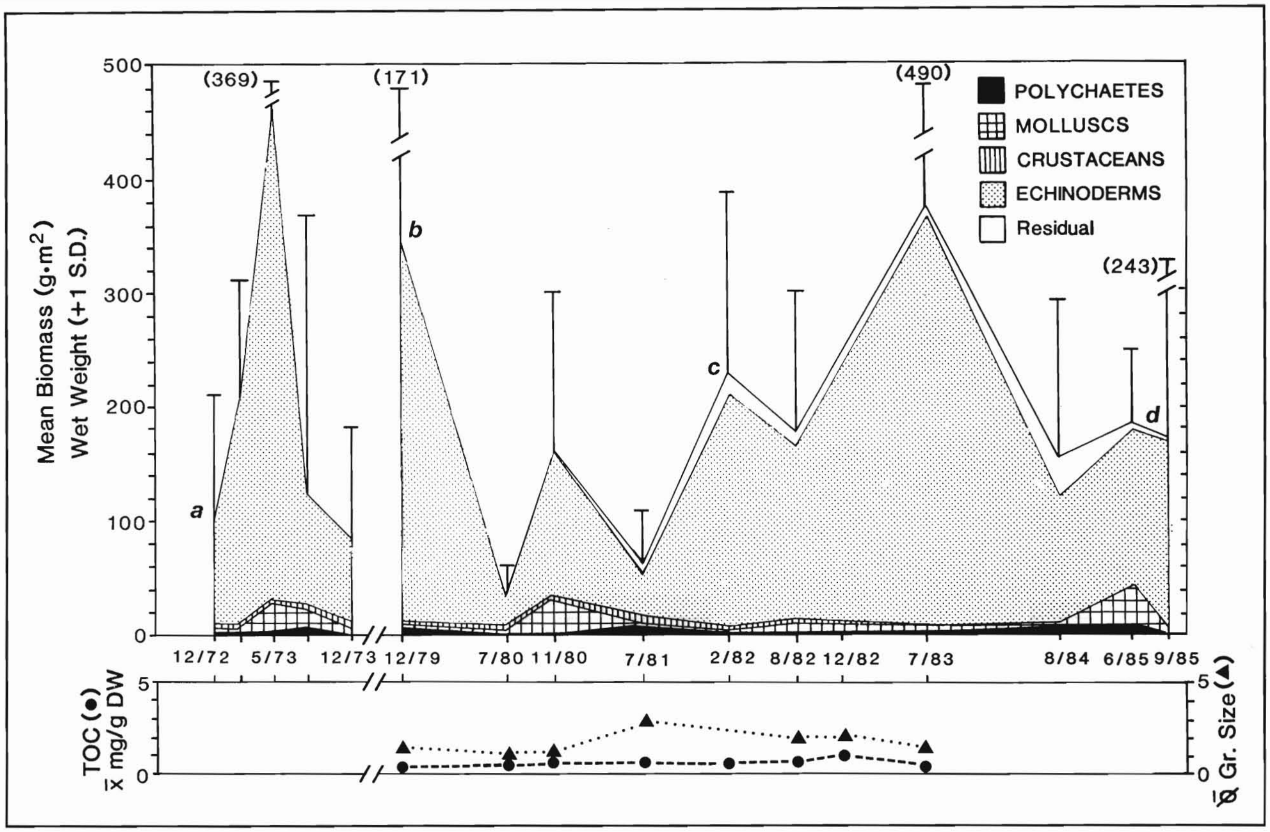


**Figure 17**

**Benthic macrofaunal biomass levels at station 15A. (a) 1972–73 data from R. Swartz and F. Cole (U.S. EPA, Corvallis, OR 97330) with only four grabs collected Dec. 1972 and 14 grabs available for Dec. 1973; (b) only four grabs available; (c) one *Astarte castanea* (11.9 g) excluded; and (d) only two grab samples analyzed.**

**Station 15A** This station (lat. 40°25.6′N, long. 73°11.1′W) was located off Fire Island, New York (Fig. 1) with medium-sand sediments containing low trace-metal levels in a coastal ridge and swale area and 30 m deep. The site was also in the coastal-active band, rarely influenced by the Hudson-Raritan plume, but possibly subject to coastal upwellings and seasonal fronts. This site, like station 17, was also dominated by a large population of the sand dollar *Echinarachnius parma* (Fig. 17). This population appeared to be more persistent than at station 17, being a dominant in 1972–73, with older cohorts in the population collected in 1979. Mean biomass levels (Figure 17) generally show late-fall peaks, in contrast to the summer peak seasonal pattern shown by most other stations in this study. These peaks mostly reflect the population dynamics (recruitment, growth, and mortality) of *E. parma*. A variety of predators were collected here, including windowpane, yellowtail, four-spot, and winter flounders; little skate; scup; and *Cancer* crabs. Mysids were an important prey for many of the fish predators, e.g., yellowtail and windowpane flounders, and scup; however, a variety of polychaetes, (e.g., *Lumbrineris*), amphipods, (e.g., *Ampelisca agassizi* and *Unciola* sp.), and *Ceriantheopsis* were also very important. Only yellowtail ate *E. parma* as a minor diet item.

## Southern New England

The next group of stations were off southern New England and included three sites on the shelf (stations 19, 20, and 37) and three in coastal or estuarine areas (stations 18, 34, and 36) (Fig. 1). The deeper shelf sites, stations 20 and 37, had relatively low mean biomass levels (<100 g/m$^2$) with higher levels, to 250 g/m$^2$, at the inshore sites.

**Station 18** This station (lat. 41°13.5′N, long. 71°51.1′W) was in a 45-m deep bathymetric depression in Block Island Sound (Fig. 1) characterized by silty–very fine sands with moderately high levels of trace metals (10–20 ppm lead), probably a fine sediment depositional area. The site was influenced by the Long Island Sound plume and was in a coastal mixing front area with strong tidal currents. Several taxa contributed to the biomass here (Fig. 18). Dominant species were the polychaete *Clymenella torquata*, the nut clam *Nucula proxima*, and the amphipod *Ampelisca agassizi*. The ocean quahog *Arctica islandica* was also relatively common, but was generally excluded from the analysis because of its large size. Although there was some intercollection variability, overall biomass levels here were relatively stable to 1982 (150–220 g/m$^2$), with sampling error probably being the

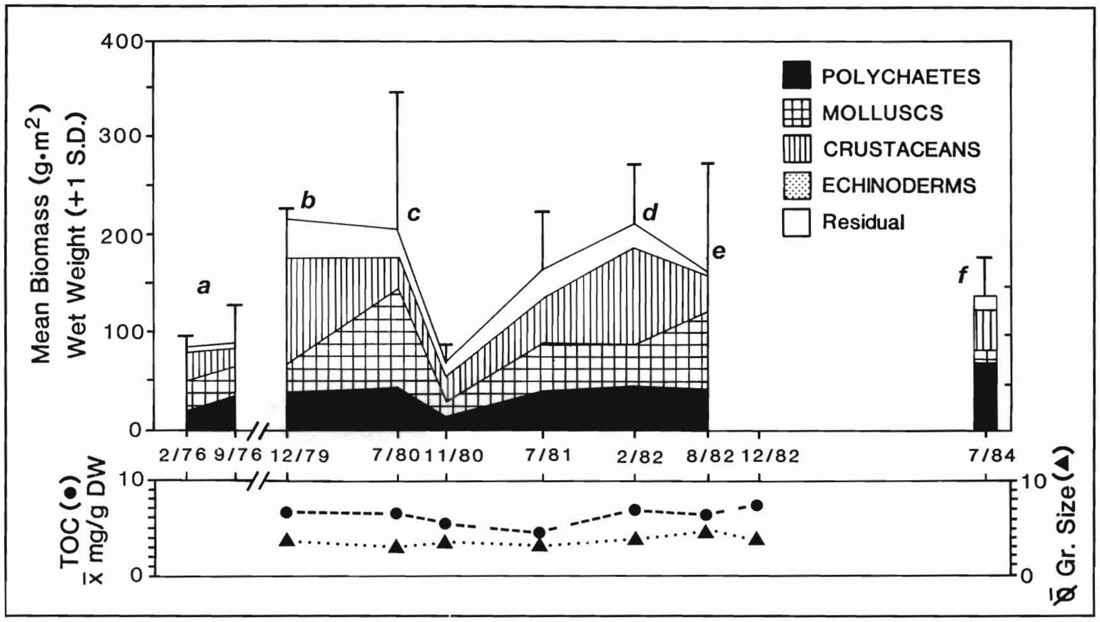


**Figure 18**

**Benthic macrofaunal biomass levels at station 18. (a) Based on three grab samples (Steimle 1982); (b) one *Mercenaria mercenaria* (210.0 g) excluded; (c) one *Arctica islandica* (440.0 g) excluded; (d) one *A. islandica* (53.6 g) excluded; (e) one *A. islandica* (186.1 g) excluded; and (f) one each *Aphrodite hastata* (3.3 g), *A. islandica* (357.1 g), and *Caudina arenata* (4.6 g) excluded.**

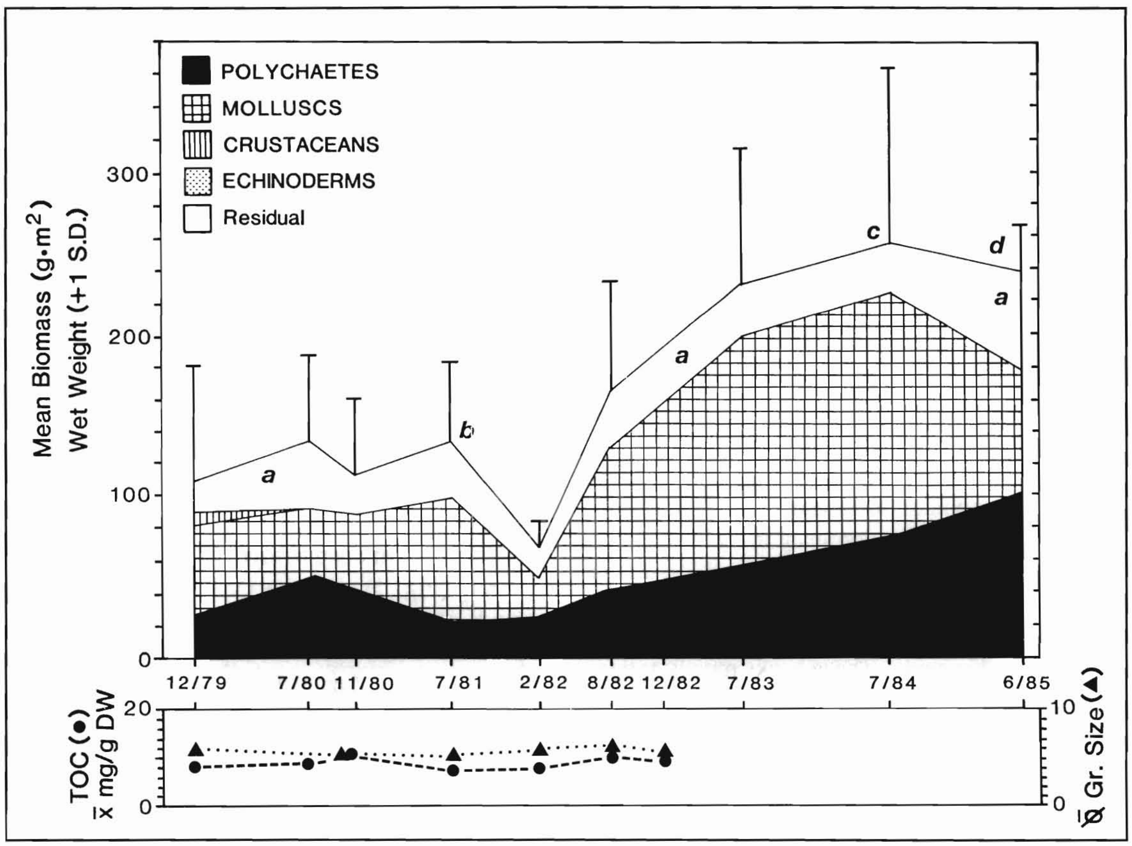


**Figure 19**

**Benthic macrofaunal biomass levels at station 34. (a) Residual biomass was mostly ceriantharian anemones; (b) one *Mercenaria mercenaria* (17.6 g) excluded; (c) one *Havelockia scabra* (2.2 g) and *Caudina arenata* (3.0 g) excluded; and (d) only three grab samples analyzed.**

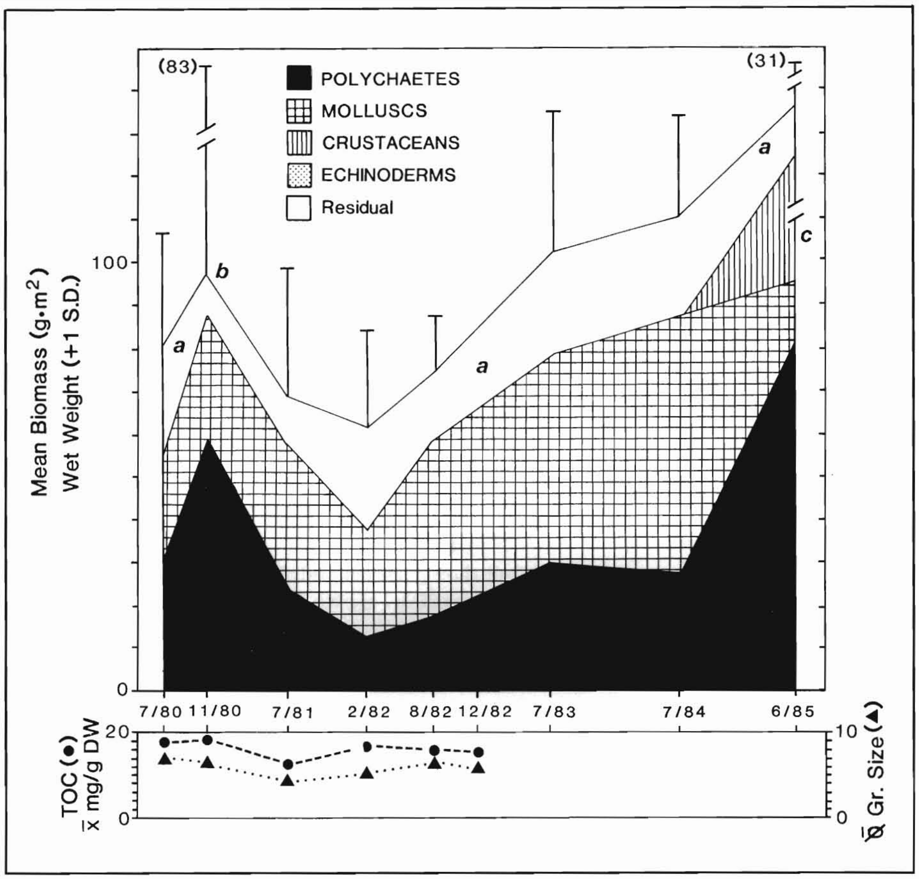


**Figure 20**

**Benthic macrofaunal biomass levels at station 36. (a) Residual biomass mostly ceriantharian anemones; (b) one *Busycon canaliculatum* (16.5 g) and one *Mercenaria mercenaria* (57.2 g) excluded; and (c) an unusually large collection of *Leptocheirus pinguis*.**

cause of the November 1980 aberrant collection (it was extremely difficult to maintain the position of the research vessel in the strong tidal flows). The potentially important predators were the same inshore group found as far south as station 17, i.e., little skate, windowpane, winter flounder, and red and spotted hake, among others. Several amphipods, *Ampelisca* sp., *Leptocheirus pinguis*, and *Unciola* sp., were major prey for most fish species here, but the polychaetes *Nephtys incisa* and *Pherusa*, *Cancer* crabs, and *Crangon* were also important.

**Station 34** This 32-m station (lat. 41°24′N, long. 71°25′W) was at the mouth of Narragansett Bay (Fig. 1) in silty muds with moderate levels of trace metals, similar to the last station. The site was in a coastal-active area influenced by the Bay plume and upwellings. The biomass here was dominated by polychaetes (mainly *Nephtys incisa* early on and *Clymenella torquata* later) and molluscs (mainly *Nucula proxima*). It was relatively stable until 1982 when an overall increase was evident involving the same species. Seasonal fluctuations appeared to be a major source of variability until seasonal collections ceased in 1983 (Fig. 19). Among the typical group of inshore predators, defined previously and found here, there was a more abundant lobster population. A wide variety of prey were found in the fish stomachs examined here, which included several common polychaetes: *Pherusa*, *N. incisa*, and *Lumbrineris*; ampeliscid amphipods, *Cancer*, *Crangon*, *Ceriantheopsis*, and a few small bivalves, e.g., *Nucula*.

**Station 36** This station (lat. 41°29′N, long. 70°53′W), in lower Buzzards Bay (Fig. 1), was 23 m deep and in silty mud with up to 540 ppb PCBs and 560 ppt PAHs, probably from nearby New Bedford Harbor. The mean biomass levels ranged from 61.2 to 173.8 g/m$^2$ (Fig. 20) with the polychaete *Nephtys incisa*, the nut clam *Nucula proxima*, and the anemone *Ceriantheopsis americanus* being the dominant species. The increase in 1985 was due to large contributions

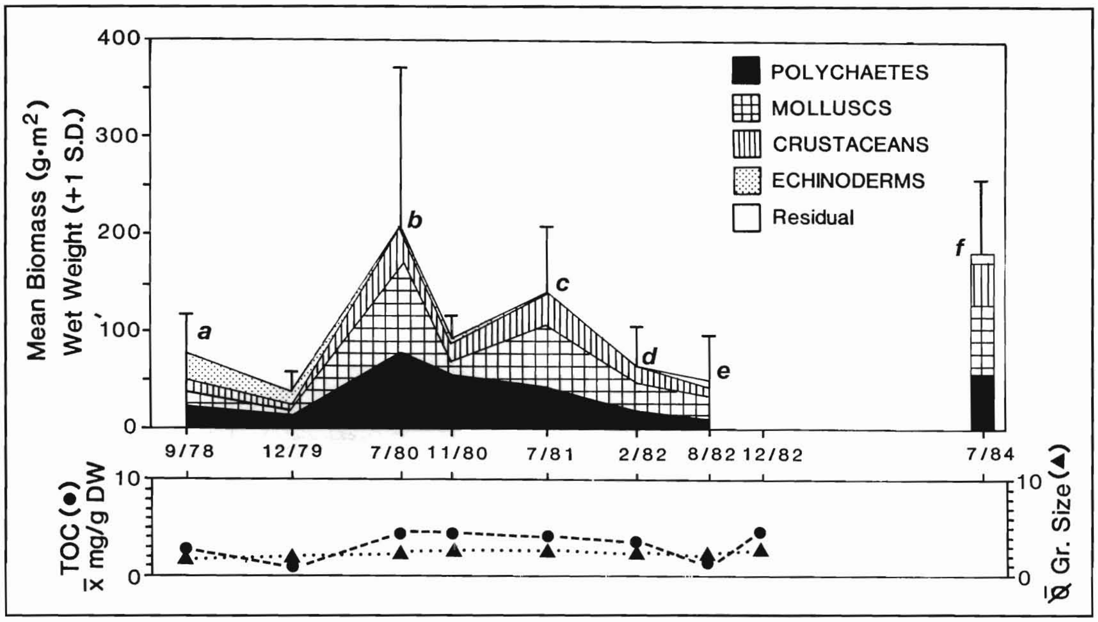


**Figure 21**

**Benthic macrofaunal biomass levels at station 19. (a) Only three grabs sampled; (b) one *Arctica islandica* (300.0 g) excluded; (c) several *Astarte* sp. (180.0 g) excluded; (d) two *A. islandica* (520.7 g) excluded; (e) one *A. islandica* (138.0 g) excluded; and (f) two *A. islandica* (157.7 g) excluded.**

by the amphipod *Leptocheirus pinguis* and the bamboo worm *Asychis elongata*. Spider crabs *Libinia emarginata*, along with scup, winter flounder, and black seabass, were the common predators. Commonly consumed prey were similar to the last two inshore stations (18 and 34).

**Station 19** This station (lat. 40°41.4′N, long. 71°21′W) was on the shelf off Rhode Island (Fig. 1) in 62 m of water with medium-to-fine sand sediments and low trace-metal levels, probably in the "cold pool." The overall biomass levels (Fig. 21) were relatively consistent and ranged from 33.1 to 185.6 g/m$^2$. Seasonal fluctuations appeared to be a major source of variability. The species which dominated this biomass were small ocean quahogs *Arctica islandica* (larger individuals were collected but excluded) and the amphipod *Ampelisca agassizi*. Predators collected included yellowtail flounder, silver and red hakes, among other less-common species. *A. agassizi* was an important diet item for most predators, as well as the commonly co-occurring amphipod species *Leptocheirus* and *Unciola*, the ubiquitous *Cancer* and *Crangon*, and glycerid and lumbrinerid polychaetes.

**Station 20** This station (lat. 40°15.2′N, long. 70°49.1′W) was on the outer shelf south of Rhode Island (Fig. 1) at a depth of 120 m in sandy silt with moderate levels of trace metals, at the edge of the depositional "Mud Patch" to the east. It may be influenced by the "cold pool" and the shelf-slope water mass front. Biomass levels, which ranged between 50 and 100 g/m$^2$, suggest no obvious trends. The brittlestar *Amphioplus abdita* was the dominant species and the source of most of the intercollection variability, with the bivalve *Lucinoma* sp. also occasionally being important (Fig. 22). Potential predators included silver, red, and white hake; four-spot flounder; and *Cancer* crabs, among others. Only a few fish stomachs were examined, and they suggest various polychaetes and *Crangon* may be significant prey.

**Station 37** This station (lat. 40°29.7′N, long. 70°12.2′W) was also midshelf, south of Nantucket Shoals in an area called the "Mud Patch" (Fig. 1), an extensive silty area, 60 m deep, with sandy silt sediments that contained up to 8 ppb PCBs and 150 ppt PAHs. It could have been affected by the "cold pool" and the shelf-slope water mass front. Benthic collections suggested fairly low but stable levels, between 35.4 and 51.5 g/m$^2$ (Fig. 23). Polychaetes were the dominant taxa, especially *Ninoe nigripes*, along with the amphipod *Ampelisca agassizi*. The ocean pout *Macrozoarces americanus* led the list of potential predators, which also included red and silver hakes; *Cancer* crabs; and the four-spot and yellowtail flounders and witch flounder *Glyptocephalus cynoglossus*. Polychaetes, especially *Pherusa*, *Nephtys* sp., *Glycera* sp., and *Lumbrineris*, were important in the diets of many of the fish species common here, but *A. agassizi*, *Cancer*, *Crangon*, and *Dichelopandalus* were also commonly consumed.

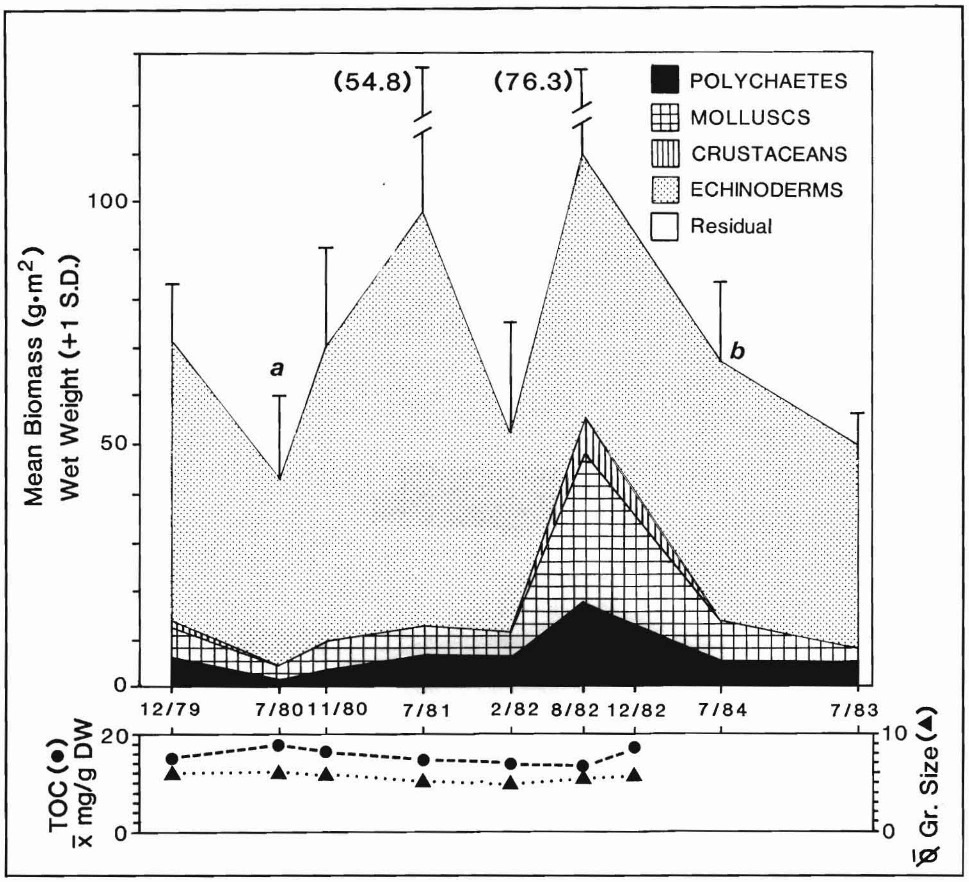


**Figure 22**

**Benthic macrofaunal biomass levels at station 20. (a) This collection might have been off station by 2 km; and (b) one *Cancer* sp. (13.0 g) excluded.**

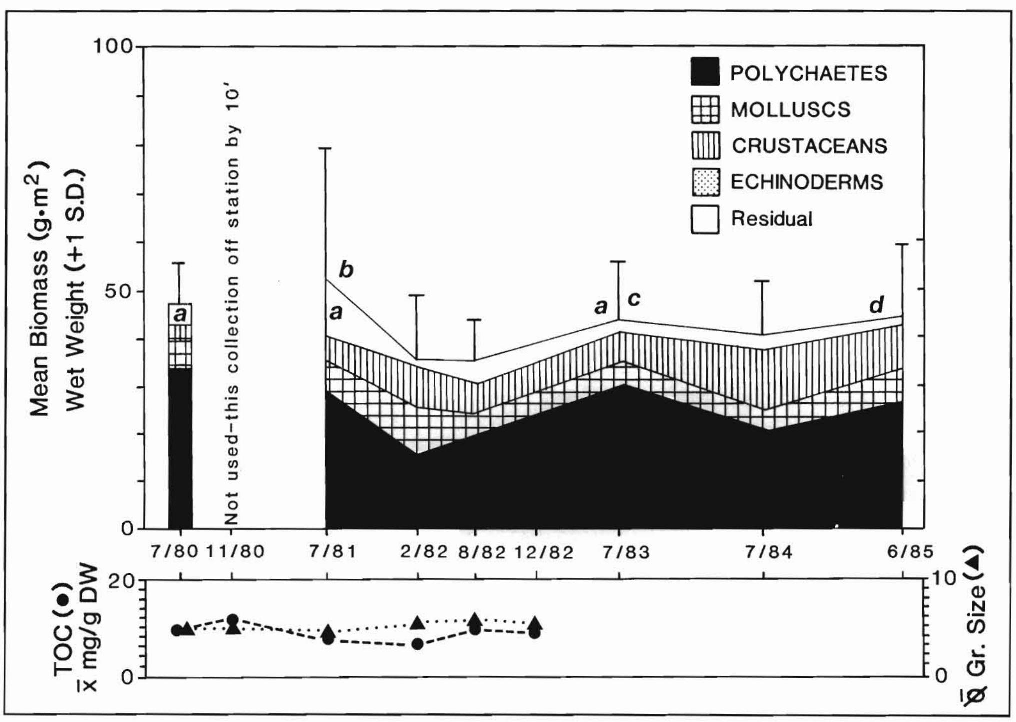


**Figure 23**

**Benthic macrofaunal biomass levels at station 37. (a) Residual biomass mostly rhynchocoels and ceriantharian anemones; (b) one holothurian *Molpadia oolitica* (20.0 g) excluded; (c) another *M. oolitica* (15.8 g) excluded; and (d) one *Caudina arenata* (16.9 g) excluded.**

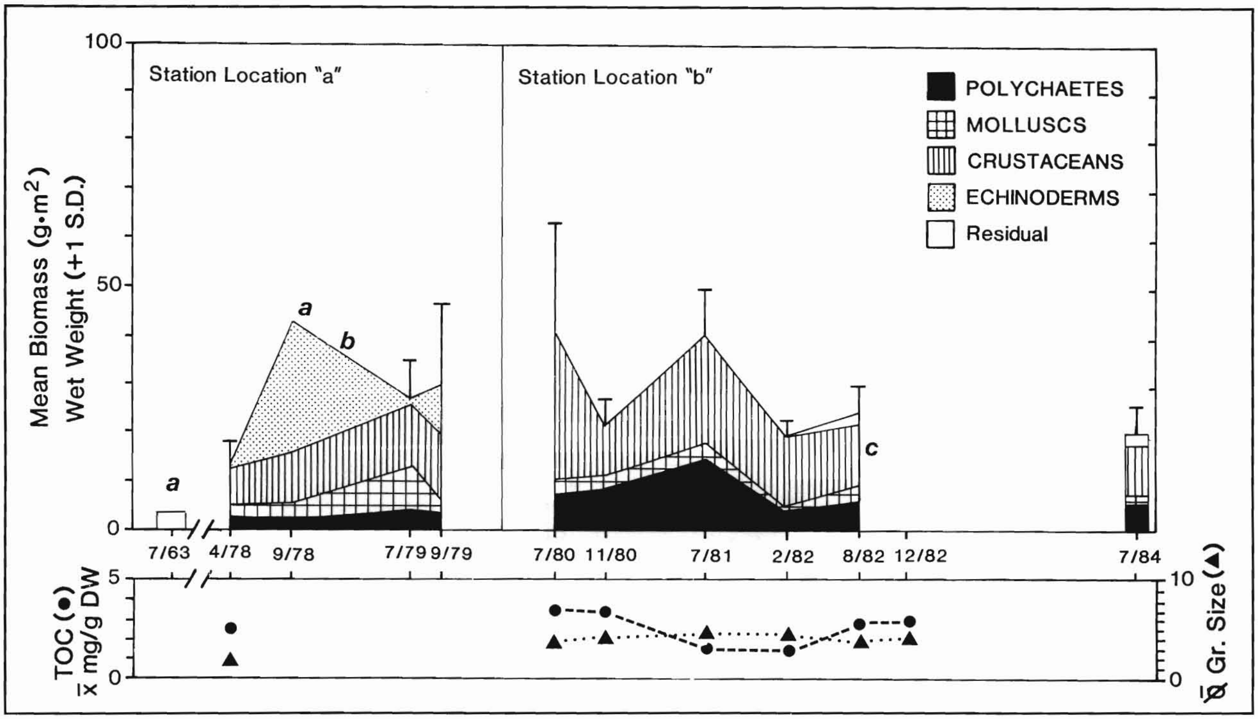


**Figure 24**

**Benthic macrofaunal biomass levels at station 22. (a) One grab sample only; (b) only three grab samples available for 1978–79 collections, except Sept. 1978; and (c) one *Cancer irroratus* (8.4 g) excluded.**

## Georges Bank

The next three stations (22, 23, and 24) were on Georges Bank (Fig. 1) and had relatively low (<50 g/m²) mean biomass levels. The only exception occurred at station 23 because of sand dollar *E. parma* population dynamics.

**Station 22** This station on southern Georges Bank (Fig. 1), was moved in 1980 from lat. 40°21.5′N, long. 68°29′W (station 22a), to lat. 40°30′N, long. 68°00′W (station 22b). Both sites were 110 m deep with medium sand at the initial site and very fine sand, with near undetectable PCB and PAH levels, at the second site. The shelf-slope front and "cold pool" could have affected both sites. Biomass levels at both sites were about equal, 16 to 49 g/m², with the second site showing seasonal variability (Fig. 24). The dominant species were the tube-dwelling amphipod *Ampelisca agassizi* and the polychaete *Ninoe gayheadi*. The predator guild was similar to that found at the last two sites, with at least the ubiquitous *Cancer* and *Pagurus* commonly eaten.

**Station 23** This central Georges Bank (Fig. 1) station was located (lat. 40°58′N, long. 67°33′W) in 70 m with medium-to-fine sand and low trace metals, in a ridge and swale area. Ridges were typically 5–15 m in amplitude and 150–175 m apart. The site could have been in the central Bank mixing area with strong tidal currents. Biomass levels here were unusual in that they showed a notable increasing trend after 1980, from <40 to >70 g/m² (Fig. 25). The increased levels in July 1981 were partly the result of a large quantity of epifaunal hydrozoans being collected; however, some of the increase can be attributed to the amphipod *Byblis serrata* and the sand dollar *Echinarachnius parma*, with the razor clam *Siliqua squama* adding to levels in July 1982. Yellowtail flounder was a common predator collected at the site, along with little skate, red and silver hake, ocean pout, haddock *Melanogrammus aeglefinus*, winter flounder, and others. The most common prey found in the stomachs examined were, again, the *Ampelisca-Leptocheirus-Unciola* group of amphipods, the *Nephtys incisa-Pherusa* polychaete group, and the decapod group, *Cancer-Crangon-Pagurus-Dichelopandalus*. Winter flounder was the only species to use the hydroids as food, possibly ingesting them secondarily while feeding on other species hiding within the colonies.

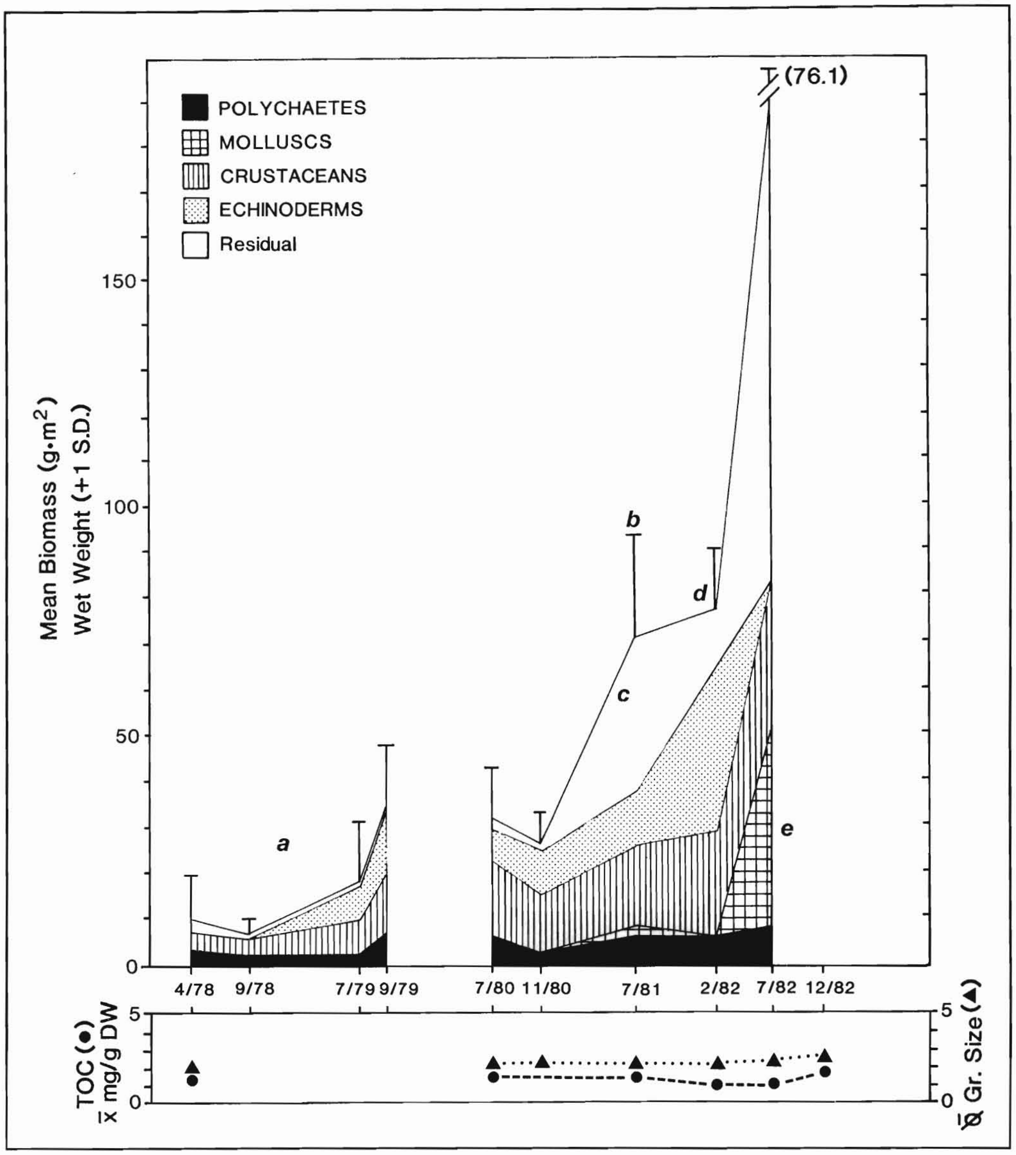


**Figure 25**

**Benthic macrofaunal biomass levels at station 23. (a) Only three grab samples available for 1978–79; (b) this collection might have been off station by 2 km; (c) unusual contribution by hydrozoa; (d) one *Arctica islandica* (613.2 g) excluded; and (e) another *A. islandica* (107.0 g) excluded.**

**Station 24** This station on the northeast "peak" of Georges Bank (Fig. 1) also consisted of two sites; the first, station 24a (lat. 41°50′N, long. 67°51′W) was moved to be consistent with other sampling. Most of the data are from the second site, station 24b (lat. 42°00′N, long. 67°00′W), which was 65 m in depth with coarse, gravelly sand containing low trace metals. It was in a dynamic ridge and swale area influenced by upwellings and strong currents. Biomass levels at this hydrographically active site were very low, <20 g/m$^2$ (Fig. 26). The overall biomass levels at the site were very stable, with only one polychaete, *Nepthys bucera*, possibly qualified to be considered as a dominant. The predator guild at this site included all those mentioned at the last station but with a stronger contribution by the longhorned sculpin *Myoxocephalus octodecemspinosus* and the cod *Gadus morhua*. Basically the same prey were important here as at the last station.

## Gulf of Maine

The final two stations (28 and 35) were in the Gulf of Maine (Fig. 1) with several species of echinoderms dominating the biomass. Mean biomass levels varied, but were generally between 50 and 200 g/m$^2$.

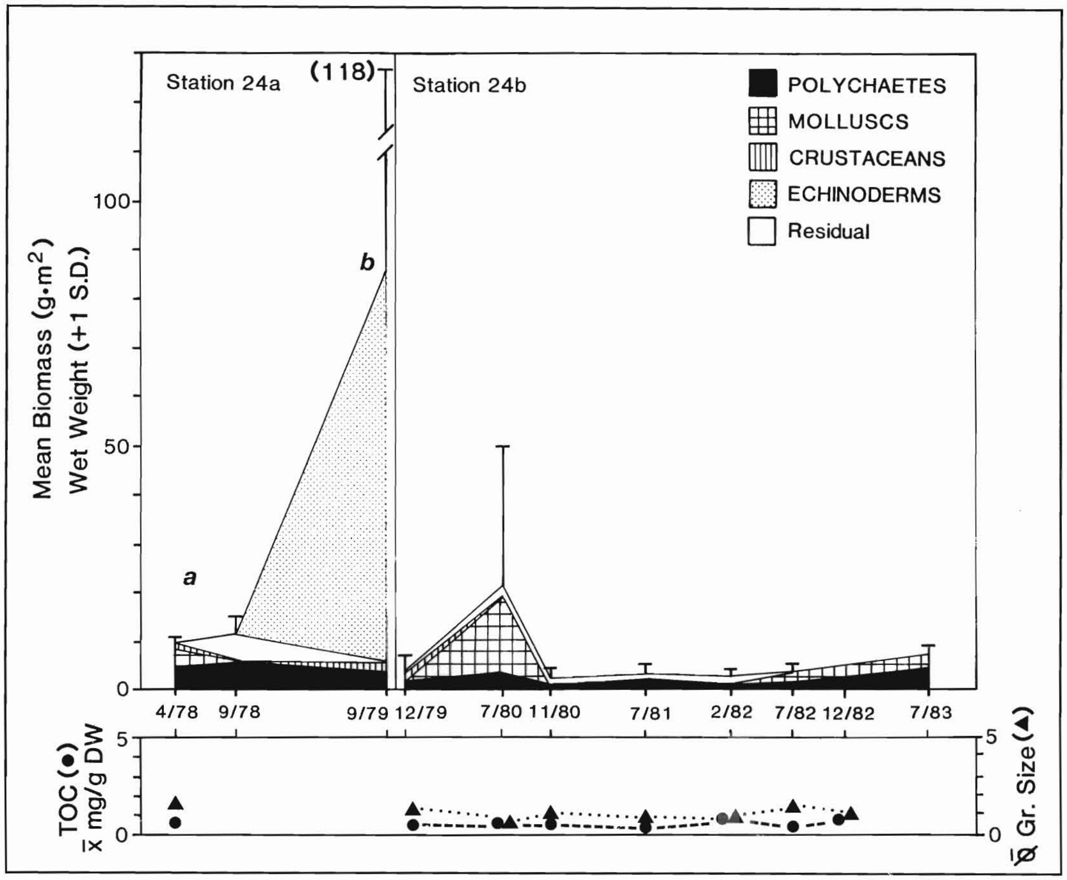


**Figure 26**
**Benthic macrofaunal biomass levels at station 24. (a) Only two grab samples available Apr. 1978–Sept. 1979; and (b) mean biomass of this collection was 5.8 g·m² if the unusual sample of *Echinarachnius parma* were excluded.**

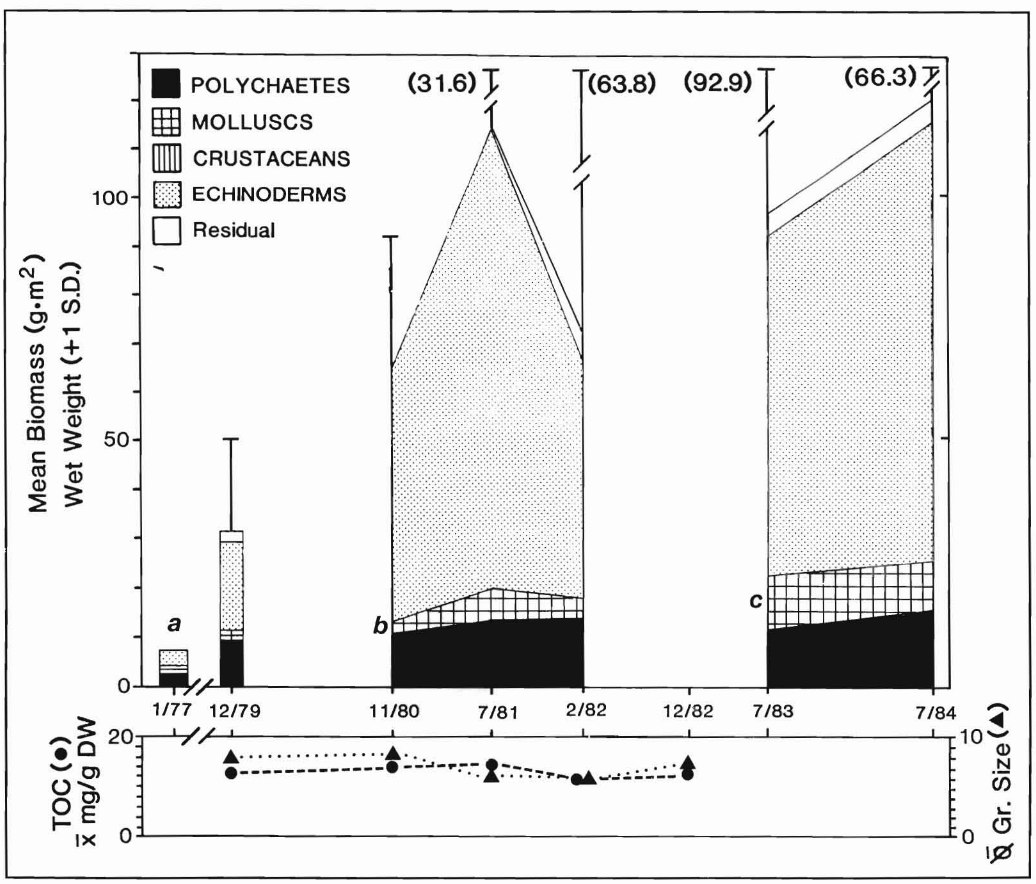


**Figure 27**
**Benthic macrofaunal biomass levels at station 28. (a) Data from a single grab sample (D. Maurer 1982) at the same location; (b) one *Arctica islandica* (10.7 g) excluded; and (c) one *Astarte borealis* (12.0 g) excluded.**

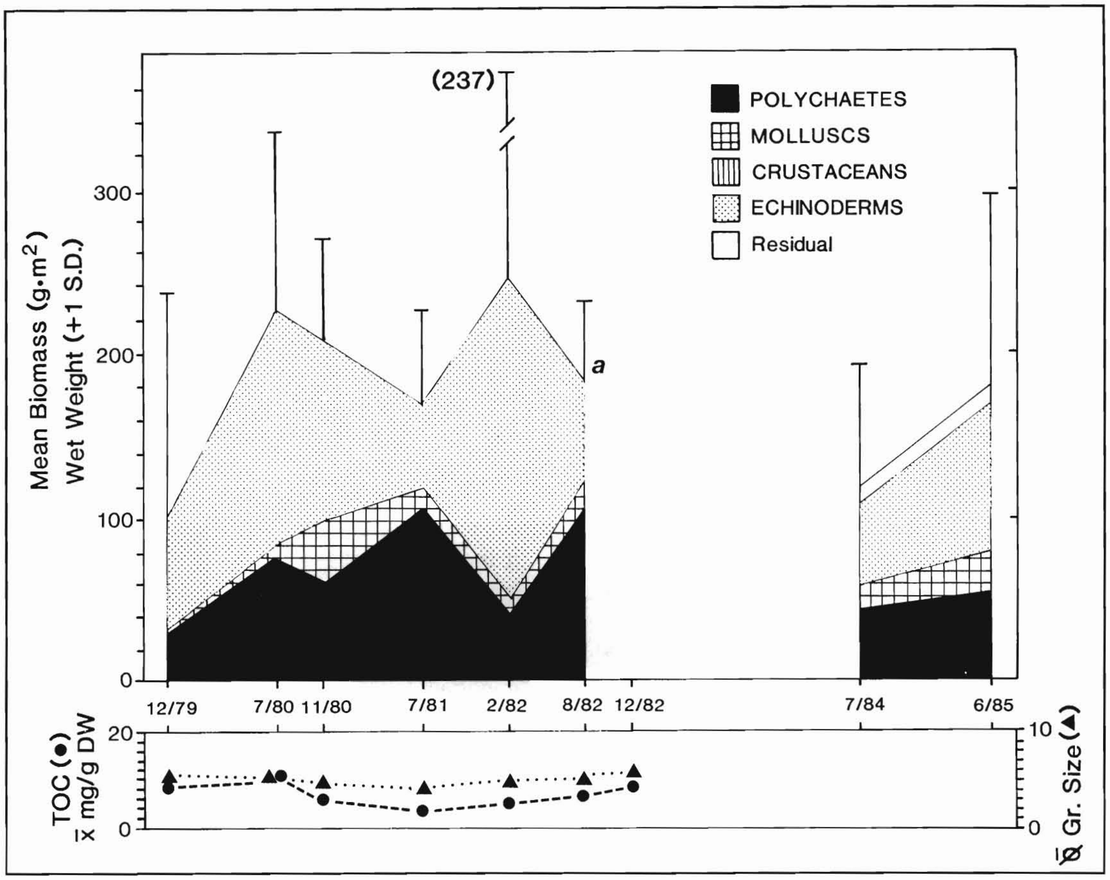


**Figure 28**
**Benthic macrofaunal biomass levels at station 35. (a) One *Molpadia oolitica* (16.2 g) excluded.**

**Station 28** This 60-m deep station (lat. 41°50.6′N, long. 69°30′W) was in the southwest Gulf of Maine (Fig. 1) with silty-clay sediments and moderately high trace-metal levels. The collection sequence here was incomplete (Fig. 27) but suggests a general increase between 1977 (<10 g/m$^2$) and 1980–83 (67–122 g/m$^2$). It is obvious that most of this increase was due to echinoderms, primarily two species: the urchin *Brisaster fragilis* and a brittlestar *Ophiura* sp. Based on a cursory size-frequency distribution analysis, the major biomass contribution of each of these species was from older cohorts, although there was evidence of new *Ophiura* recruitment almost every year. These recruitments either did not survive to the next collection or had limited growth, as size-frequency modal progressions were not evident. Predators collected at this site included the American plaice *Hippoglossoides platessoides*, cod, silver hake, and little skate. Predation data were not available from this station.

**Station 35** This station (lat. 42°19′N, long. 70°36′W) was in Massachusetts Bay (Fig. 1) at 60 m in a postglacial depositional area near a mixed waste-disposal site, the "Foul Grounds;" sediments were silt with up to 30 ppb PCBs and 1200 ppt PAHs. The site was in, or near, an area where seasonal fronts develop; a general warming trend has been noted in the Gulf of Maine for the last decade. Biomass levels, 100–250 g/m$^2$, did not suggest any pattern or trend, except polychaete seasonality (Fig. 28). Most of the biomass came from polychaetes, with *Spio filicornis* prominent, and the echinoderms *Ctenodiscus crispatus* and *Molpadia oolitica*. Predators trawled at this site included American plaice, cod, red and silver hakes, and witch, winter, and yellowtail flounders. Ophuroids (brittlestars) were important prey to cod and plaice, pandalid shrimp to the hakes, and polychaetes, e.g., sabellids and nereids, to the other flounder.

## Discussion

These results suggest several general conclusions: (1) there was considerable interannual variability in the biomass data at most sites, as might be expected, but within ranges previously reported for each area; (2) the range of variability differed at each site and seasonal patterns of fluctuation were often evident; (3) with only a few exceptions, the general tendency of the mean biomass, within the time frame and sampling scale involved, did not usually suggest any clear increasing or decreasing trends; (4) the population dynamics of one or a few species were found to be important in the explanation of some of the variability and apparent trends; and (5) the relationship of the biomass levels to other environmental factors, e.g., sediment type or quality, could not be fully evaluated with the available data. These conclusions or general observations and several others are expanded upon below and, although the relationships may be tentative at this time, they are noted to suggest hypotheses that could be explored in the future.

Seasonal cycles of benthic community biomass levels are a common, if not normal, pattern described frequently (see Beukema 1974, Buchanan et al. 1978, Glemarec and Menesguen 1980). Seasonal fluctuations were evident at many of the sites, e.g. stations 3, 9, 32, 19, and 22 (Figs. 3, 6, 8, 21, and 24) with biomass peaks generally occurring in the summer. Some sites that did not show higher mean summer values were dominated by sand dollar *Echinarachnius parma* populations, whose relatively long life-span, 7+ yrs (Steimle 1990), can mask much of the seasonal fluctuations of other species with generally shorter or annual life cycles.

Review of Figures 2–28 also suggests that biomass levels at most of the sites appeared to be either relatively constant (considering normal seasonal fluctuations and disregarding a few unusual collections), demonstrated no clear increasing or decreasing trends, or the data were too irregular. Some dispersed sites, e.g., stations 12, 23, 34, 36, and 28 (Figs. 10, 19, 20, 25, and 27), had biomass levels that did suggest overall long-term increasing trends. This was supported by $t$-tests indicating the slopes were significantly different at $p<0.05$. These trends were frequently related to the population dynamics or growth of one or a few dominant species, e.g., sand dollars at station 23, or possibly to nearby eutrophic estuarine enrichment, e.g., stations 34 and 36. A decreasing trend was suggested at stations 16B, 16C, and 33 (Figs. 13, 15, and 16), and to a lesser degree at stations 11, 24b, and 26 (Figs. 9, 24, and 26). The $t$-tests indicated that the trends at stations 16B and 33 were significant at $p<0.05$. Stations 16B and possibly 33 were in an area considered to be variably affected by pollution from various sources. No strong reason can be suggested for the decline at the other sites, although the population dynamics of *E. parma* are involved at station 11. The remaining sites, 31 and 32 (Figs. 7 and 8), had collection periods that were either too brief in duration, discontinuous, or too variable to suggest trends.

Although mean sediment grain size and TOC are only two of many sediment variables, they can be important to benthic community structure. The sediment data, summarized also in Figures 2–28, despite being incomplete or discontinuous, suggest these two variables were relatively stable at most sites. When a sedimentary change was evident, possibly because of sampling error, there was seldom a significant, consistent, concomitant response in biomass. The proximity of many sites, e.g., stations 7, 8, 17, and 15A, near or in ridge and swale areas suggest a source of some of the variability in the data at these sites. Schaffner and Boesch (1982) have demonstrated how benthic community structure can vary significantly relative to location on sand ridges, slopes, or swales. It is possible that these submerged sand dunes might move, thus besides the possible variability caused by minor shifts in sample location in a ridge and swale environment, future monitoring at these sites needs to take into account the potential natural changes that may occur at precise, fixed locations to accurately interpret any later community changes. Generally, the dominant species found at any site were consistent with the major habitat-related community types defined by Pratt (1973), considering these communities are usually not discrete but occur in a variable continuum (Mills 1969).

Hydrographic conditions at a site can potentially influence benthic communities, but information on the significance of this factor in the study area is mostly lacking. These factors are most likely to be important in coastal areas rather than offshore. For example, although it is not well documented, it is very probable that estuarine plumes influence coastal benthic communities and these plumes can vary in volume, particulate load, or distribution over time. Chronic seasonal hypoxia is one possibly plume-related problem that can be important to benthic communities in some coastal areas, e.g., along the New Jersey and Delaware coast (Reid et al. 1987). Benthic community changes at plume-influenced sites should be evaluated against any major changes in the plumes, e.g., excessive freshwater runoff and particulate load due to major storm events in the drainage area. The influence of the variable, coastal-active band is also not well studied, although a variety of physical and chemical stresses are features of this band. The potential occurrence and influence of shifting water mass fronts at several sites cannot be truly assessed in the data presented here. These fronts have been shown to be important to the shelf benthic community in at least one study (Magnuson et al. 1981). Likewise, the influence of the variably configured, semipermanent "cold pool" cannot be assessed at the sites likely to be affected, although low temperatures are known to be important to benthic communities (Buchanan et al. 1978). Tidal velocity gradients also can be important (Creutzberg 1984), but the significance of this and other hydrographic factors to the benthic community have not yet been evaluated in the study area.

The influence of anthropogenic activities on benthic biomass levels are reported frequently (Pearson and Rosenberg 1978, Cedarwall and Elmgren 1980, Steimle 1985, Pearson and Barnett 1987). The sediments at several stations were moderately to highly contaminated by trace metals or toxic organic chemicals, e.g., stations 31, 33, 18, 34, 20, 28, 36, 37, 16A-C, and 35. There may be a suggestion of an effect from this contamination in some of the data examined in this study, i.e., at stations 33 and 16B. The declining trends at these two New York Bight apex stations are possibly a response to the increase in sewage sludge disposal after 1979, although the actual increase in sewage sludge solids is reported to be only 5% (Reid et al. 1987). The biomass data at other contaminated stations, even those near other dumpsites, e.g., station 35 in Massachusetts Bay and station 9 at the former dumpsite off Delaware, do not show any clear response. However, this may be because there is inadequate information about these sites, e.g., pre-impact data, or suitable control areas. Alteration of other benthic community structure variables was reported for the former Delaware dumpsite (Lear and O'Malley 1983).

Several studies have demonstrated the influence of predators on benthic fauna (McIntyre 1978, Berge 1980, Persson 1981, Choat 1982, Arntz and Rumohr 1986). The predator-occurrence summaries presented for each site are only gross indicators of the potential predation pressures at any site. Although the predator groups were typical of what would be expected at any site and vary with season and population dynamics of the species involved (Grosslein and Azarovitz 1982), the limited data on diets at the sites is inadequate to discuss any more than crude linkages between predators and the benthic community. However, the data are consistent with several more comprehensive studies in the region (Langton and Bowman 1980, 1981; Sedberry 1983). Overall, the dietary data discussed here, and generally supported by other studies mentioned above, suggest that despite the diversity in most benthic communities, much of the diet consists quantitatively of a limited number of benthic prey species. These are generally characterized as being common at the sediment surface and relatively large or conspicuous, e.g., the tube-dwelling amphipods *Ampelisca*, *Leptocheirus*, *Unciola*, the polychaetes *Nephtys*, *Pherusa*, *Lumbrineris*, the tube-dwelling anemone *Ceriantheopsis*, and especially the smaller decapods such as small *Cancer*, *Crangon*, *Pagurus*, and *Dichelopandalus*. These motile decapods are most likely not well-sampled in either grab or trawl collections and their overall abundance and biomass underestimated. Molluscs and echinoderms are not generally consumed, despite their availability, although some predators do eat them as a relatively common or predominant prey. This suggests that fish-predation influences to the benthic community, although variable, are relatively selective. There also is an intermediate trophic level involved, i.e., many of the "prime" prey listed above (especially the decapod crustaceans) are themselves predators of smaller organisms, at least being omnivores (Commito and Ambrose 1984). What this would mean to benthic biomass levels and trends can only be speculation. For example, the low predation pressure on echinoderms and subsurface dwellers, such as most molluscs and many polychaetes, may explain why trends can be relatively stable since these species tend to be the dominant biomass components. However, in terms of value to fishery resources, the prime prey types listed above must be either very productive or more abundant than their apparent low occurrence in grab or trawl collections would suggest.

Energy equivalents of the benthic biomass are not presented since they closely parallel the biomass-level patterns at each site, differing proportionally by the variable mean Kcal/g ratios defined for each site (Table 2). It had been anticipated that the energy in the benthic pool would be more conservative, with less variability, since it should reflect the basic primary production and distribution characteristics of an area; it should also remove some of the variability caused by the water or shell content of the biomass. However, this was not evident; some sites had higher winter energy equivalents that moderated seasonal differences, but other sites had higher summer equivalents. The minor overall seasonal difference in energy equivalents, 0.81 to 0.84, is probably not significant. Because the energy equivalents vary between benthic groups (Steimle and Terranova 1985), the proportional contribution of the groups to mean estimated energy levels of each site changed from that defined by the original biomass data. Higher energy-equivalent polychaetes (1.09 Kcal/g wet wt) and crustaceans (1.29 Kcal/g wet wt) increased their share of the total, while lower-equivalent molluscs (0.37 Kcal/g wet wt) and echinoderms (0.48 Kcal/g wet wt) declined. The overall means, 0.81–0.84 Kcal/g, with a median of 0.82 Kcal/g, were consistent with an earlier 0.8 Kcal/g estimate (Steimle and Terranova 1985), based on Wigley and Theroux's (1981) summer data. This suggests, if only wet-weight benthic macrofauna biomass data are available for the northeast continental shelf, the use of the 0.8 Kcal/g conversion will provide a reasonable ($\pm 25\%$) estimate of the energy pool. If specific areas or communities are to be considered, then the site-specific data of Table 2 could be used to refine the estimate.

It is apparent that the biomass, at almost all sites, was dominated by three groups: molluscs, polychaetes, and echinoderms, with cerianthiid anemones and crustaceans occasionally being important. This dominance is similar to the results of Wigley and Theroux (1981) for the Middle Atlantic Bight, although they show a higher proportion of molluscs than generally found in this study. This difference is probably because many of the megafaunal species excluded in the present analysis were molluscs. Molluscs and polychaetes were notable contributors to the biomass at almost all sites, with polychaetes being particularly abundant in siltier sites, e.g., stations 16A-C, 33, 34, 35, 36, and 37. These sites are all near estuaries or in coastal areas, except station 37 (the "Mud Patch" off Nantucket). In some cases, this dominance may reflect some anthropogenic influence as suggested for other areas (Reise 1982). The echinoderms were dominated by a few species, e.g., *Echinarachnius parma* on Georges Bank and at several Middle Atlantic Bight sites, and brittlestars or holothurians on deeper areas of Georges Bank and in the Gulf of Maine basins. The dominant taxa were generally stable in their proportional contribution to the overall biomass at each site. Exceptions occurred when a community was influenced by the population dynamics of a particularly dominant species, such as the brittlestar *Amphioplus* at station 20 or *E. parma* at several sites.

The separate study of the population dynamics of *Echinarachnius parma* (Steimle 1990), focusing on four stations (11, 17, 15A, and 23), provided insight on how the recruitment, survival, and growth of this species can greatly influence biomass trends. For example, at station 11 there were substantial annual recruitments in 1980–82. This is evident in the station's biomass (Fig. 9) as the expansion of the echinoderm biomass component (almost entirely the recruitment and growth of these *E. parma* cohorts) after July 1980, with a peak in early 1982. The subsequent decline occurred as recruitment was reduced or ceased in 1983–84 and mortality outpaced growth. At station 17, there were only two recruitments, one in 1976 after the anoxia event defaunated the area, and the second in 1978 (Fig. 12). These two recruitments constitute the entire echinoderm population in Figure 12. This sand dollar population was not growing any faster than at the other stations. It also could have been subject to a lower mortality because most nonfish predators or competitors were also removed from the area by the anoxic conditions. The average life span of this species appears to be about 8 years in this area (Steimle 1990), and it can be anticipated that unless there is new recruitment the role of this species at the site will diminish and other taxa should increase, as they may be inhibited by the dense *E. parma* population. At station 15A, *E. parma* has been a persistent part of the community since at least the early 1970s (Fig. 17). There have been annual recruitments between 1978 and 1982 (Steimle 1990) evident as winter/spring peaks to 1982 (Fig. 17). The growth of a dominant 1978 cohort is responsible for the 1983 biomass peak, and mortality in this cohort is the cause of the subsequent decline. At station 23 a situation similar to station 17 was evident with no sand dollar population evident in the community studied until recruitments occurred between 1978 and 1982, the last collection there. The cohorts at this Georges Bank station appeared to have a lower survival than at the other three sites studied, since the population did not expand via these frequent recruitments and their expected growth, as they did elsewhere. This may be related to Collie's (1987) observation of preferential feeding by yellowtail flounder on <12 mm *E. parma* on Georges Bank. Much of the gradual increase in community biomass after 1978 (Fig. 25) was the result of these recruitments and their growth.

In the discussion of biomass variability at each site, the influence on the biomass from population dynamics of only a few echinoderm species was considered. There are other species that need to be considered, e.g., molluscs, as suggested by *Nucula* and *Ilyanassa* at station 31. They would be expected to produce results similar to that of the echinoderms. Several bivalve molluscs are commercially harvested which also affects their abundance and population dynamics. Population dynamics of dominant species should be examined as part of any interpretive monitoring program (Pearson and Barnett 1987). Life-history summaries (Caracciolo and Steimle 1983) and studies of some dominant species (Steimle 1990) are becoming available and should be used or considered in evaluating the relative status or trending of a community. The importance of biological interactions to long-term community stability is well known (Gray 1977). Some community change can be expected, because of these interactions and natural environmental factors, including a change to significantly different or alternate communities. The definition and understanding of these natural fluctuations or changes are extremely important in detecting and understanding anthropogenic effects.

The mean biomass ranges found at the sites from the 1970s and 1980s were generally consistent with the values reported for nearby stations or areas by Wigley and Theroux (1981) and Theroux and Grosslein (1987), based on extensive collections in the late 1950s and early 1960s. The only notable exception was the recent data for Buzzards Bay, MA (station 34, Fig. 19), which was generally above 100 g/m$^2$, compared with the Wigley and Theroux (1981) value of <25 g/m$^2$ for this area. The number of sites monitored in the present survey were a small fraction (about 3%) of the earlier 1950s–60s studies; there were small differences in the methods involved. Other comparisons between the conclusions of these two earlier surveys and the recent series suggest little difference in overall shelf faunal composition (bivalves, polychaetes, and echinoderms as biomass dominants), bathymetric trends (general inverse relationship), and other relationships.

There have been relatively few subtidal benthic macrofaunal studies that have included long-term biomass data, and these were mostly for European waters as reviewed by Pearson and Barnett (1987). There also have been other studies, again in the same areas, that have examined relatively limited data sets separated by several decades (Pearson and Barnett 1987). These studies were often for the purpose of attempting to define changes in the benthic community that could be related to pollution, especially organic enrichment. In some cases, changes were found that appeared to support that relationship (Cedarwall and Elmgren 1980, Pearson et al. 1985). But these studies are not without the possibility of alternate interpretation because of a number of confounding factors. These can include differences in methods or other environmental variables other than pollution, including changes in the demersal fish populations in the area over the period being compared (Persson 1981). In other cases, a clear benthic biomass response to pollution was evident (Pearson and Rosenberg 1978). In general, these other long-term studies show results or conclusions similar to those described in this paper: (1) Seasonal biomass fluctuations were usually evident as late summer-early fall peaks, with late winter-early spring lows (Buchanan et al. 1978); (2) biomass levels and trends can be significantly influenced by the population dynamics of a few larger, long-lived species, frequently echinoderms and molluscs (Pearson et al. 1985); (3) there can be substantial interannual variability in the amplitude of the biomass ranges (Blegvad 1951); and (4) cause-and-effect relationships of any changes or trends are usually difficult to determine with reasonable confidence because of the usually large variety of additional factors that can be involved and need to be monitored (Buchanan et al. 1978). In interpreting causal relationships, the types and levels of change which are significant for resource management purposes need to be defined (Green 1984, Duinker and Beanlands 1986). The changes of significance are likely to be, as McIntyre (1978) states, either a major qualitative alteration in the biomass or a shift to a new population structure which has significance to predators. Experiments or studies are needed to define the term "major" and determine what benthic population structures are of importance to fishery resources.

Because the sites examined were not in rocky habitats, the communities associated with these habitats are not discussed here or in Wigley and Theroux (1981). These habitats and their epifauna are important to fisheries, but almost nothing has been done in the Northeast to quantify the potential forage value of the community or its natural variability or production for comparison with non-rocky bottom areas. This is especially important because of the recent interest and increased use of artificial reef habitats as fishery-enhancement or habitat-loss mitigation tools.

In summary, long-term benthic macrofaunal biomass data from a number of sites on the continental shelf of the northeastern United States showed little evidence of clear temporal trends. It appears that most sites had relatively stable biomass levels, although there were seasonal and annual variability. The population dynamics of a few species, such as the sand dollar *Echinarachnius parma*, were a major factor in variability at several sites. Preliminary examinations of other potential causes of variability were inconclusive because of inadequate data but suggested a number of information deficiencies that should be explored in the future. This study demonstrates the need for caution in using limited benthic biomass data to characterize a station or area, since this variable is dynamic.

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