Vol. 89: 237-251, 1992 | MARINE ECOLOGY PROGRESS SERIES Mar. Ecol. Prog. Ser. | Published November 30

Association of benthic macrofauna with habitat types and quality in the New York Bight

Sukwoo Chang, Frank W. Steimle, Robert N. Reid, Steven A. Fromm, Vincent S. Zdanowicz, Robert A. Pikanowski

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory, Highlands, New Jersey 07732, USA

ABSTRACT: Previous qualitative and limited quantitative analyses of benthic data from the New York Bight, USA, have suggested associations among macrofauna and sediment characteristics, including levels of chemical contamination. Benthic data from 3 summers (1980 to 1982) of sampling were used to examine more thoroughly these relationships. Factor and canonical analyses confirmed that a limited group of macrofaunal taxa (*Ceriantheopsis americanus*, *Nephtys incisa*, *Capitella* spp., *Nucula proxima* and *Ampelisca agassizi*), historically considered indicators of habitat quality, were indeed valid indicators. Ordination analyses provided greater detail about the association of, and between, sediment variables and the 80 most frequently occurring species. The results allowed a characterization of the New York Bight benthic habitat, encompassing the range from an undisturbed habitat to the lowest quality habitat. One species group was consistently associated with minimally contaminated sediments and appears to represent a basic natural benthic macrofaunal assemblage for the Bight. This group included taxa such as the sand dollar *Echinarachnius parma* and several species of amphipods (e.g. *Byblis serrata*, *Corophium crassicorne* and *Ampelisca agassizi*) as well as some polychaetes (e.g. *Goniadella gracilis* and *Exogone hebes*). Species that were the most common in the contaminated areas of the Bight were mainly polychaetes (e.g. *Tharyx acutus*, *Nephtys incisa*, *Pherusa affinis* and *Capitella* spp.) as well as the Nemertinea (*Cerebratulus lacteus*), an anemone (*Ceriantheopsis americanus*), a phoronid (*Phoronis architecta*) and the nut clam *Nucula proxima*.

INTRODUCTION

Studies of benthic macrofauna abundance and distribution in the New York Bight, USA, have been used for decades to assess effects of waste disposal (Rowe 1971, Pearce et al. 1976, Reid et al. 1982, Steimle et al. 1982, Caracciolo & Steimle 1983, Steimle 1985, 1990, Reid et al. unpubl.). Associations between macrofauna and habitat defined in these studies were usually based on congruence of sediment types or contamination levels with distribution patterns of certain benthic macrofaunal communities or taxon abundance. Quantitative statistical examinations of these relations in the New York Bight have been limited, however. For example, Saila et al. (1976) investigated optimum sampling strategies to assess effects of waste disposal, using benthic data collected in the early 1970's. Walker et al. (1979), using a subset of the same data, suggested that post-collection stratification, based on environmental gradients, might be a suitable procedure for controlling variability when assessing waste disposal effects. Boesch et al. (unpubl.) used multivariate analysis of the same data to attempt to relate contamination and other environmental factors to observed biological patterns. Reid et al. (1982) presented a correlation analysis of data from the 1980 survey considered here, and Reid et al. (1991) conducted cluster analysis of multi-year (1980 to 1985) data for the same stations.

In this paper we used several parametric and nonparametric statistical procedures to analyze benthic macrofauna and sediment data collected in the New York Bight during the summers of 1980 to 1982. The purpose of this analysis was 2-fold: (1) to examine previously suggested associations between a small group of benthic macrofaunal 'indicator' taxa and sediment variables, such as grain size, organic carbon and trace metal content; and (2) to use a broader proportion of the benthic community to further define associations between assumed 'critical' sediment characteristics and patterns of other benthic macrofaunal species distributions.

METHODS

Benthic macrofauna and sediment data used in our analyses were from samples collected at 45 to 49 fixed stations encompassing a range of sediment types and contamination levels in the New York Bight (Fig. 1).

Sampling procedures and station locations, depths and sediment characteristics were detailed in Reid et al. (1982, 1991). Briefly, one or more 0.1 m^2 Smith-McIntyre grab samples were taken at each station. From each sample, small core subsamples were removed for sediment analysis. The remainder of the sample was washed through a 0.5 mm mesh sieve for macrofauna. The number of grab samples collected was based on a variable monitoring strategy (Reid et al. 1991). In late July-early August of 1980, 45 stations were sampled (Stns 1 to 44 & P13, Fig. 1). This sampling was repeated in August 1981 and September 1982 with 4 stations added (Stns 63, 64, 65 & 158, Fig. 1). Seven of the stations (4, 6, 7, 15, 26, 31 & P13) were sampled as part of the NOAA's Northeast Monitoring Program with 5 replicate grab samples routinely collected for sediment and benthic macrofauna analysis. Usually single samples were taken at remaining stations in 1980 and 1981, with 2 samples per station in 1982. For our analyses, data from replicate samples were averaged.

Sediment core subsamples were analyzed for: mean sediment grain size (MN); percent of finer grain size (GS), i.e. silts and clays; concentrations of 3 trace metals, chromium (Cr), lead (Pb) and zinc (Zn); percent total organic carbon (TOC); and total Kjeldahl nitrogen (TKN). The chemicals measured are not necessarily contaminants, but at elevated levels are considered an indication of anthropogenic contamination.

Earlier studies (Walker et al. 1979, Reid et al. 1982, Boesch et al. unpubl.) suggested that densities of some benthic taxa were strongly associated with certain sediment variables; however, this was based on limited statistical evaluation. Species reported to be useful indicators of different habitat types and conditions included: the tube-dwelling anemone *Ceriantheopsis americanus*, the polychaetes *Nephtys incisa* and *Capitella* spp., the nut clam *Nucula proxima* and the tube-dwelling amphipod *Ampelisca agassizi*. These earlier studies, and Steimle (1985), also suggested that biomass and numbers of species of amphipods, crustaceans and the entire benthic macrofaunal community appear to be sensitive taxa measures. *Capitella* spp. are widely recognized as indicators of organic pollution (Halcrow et al. 1973, Pearson & Rosenberg 1978) or other major habitat disturbances (Eagle & Rees 1973, Pearson & Rosenberg 1978). The *Capitella* spp. population discussed here may not be a single species, but a complex of morphometrically similar species (Grassle & Grassle 1976). Elevated values of TOC in the sediment of the inner New York Bight are thought to enhance the abundance of some species such as

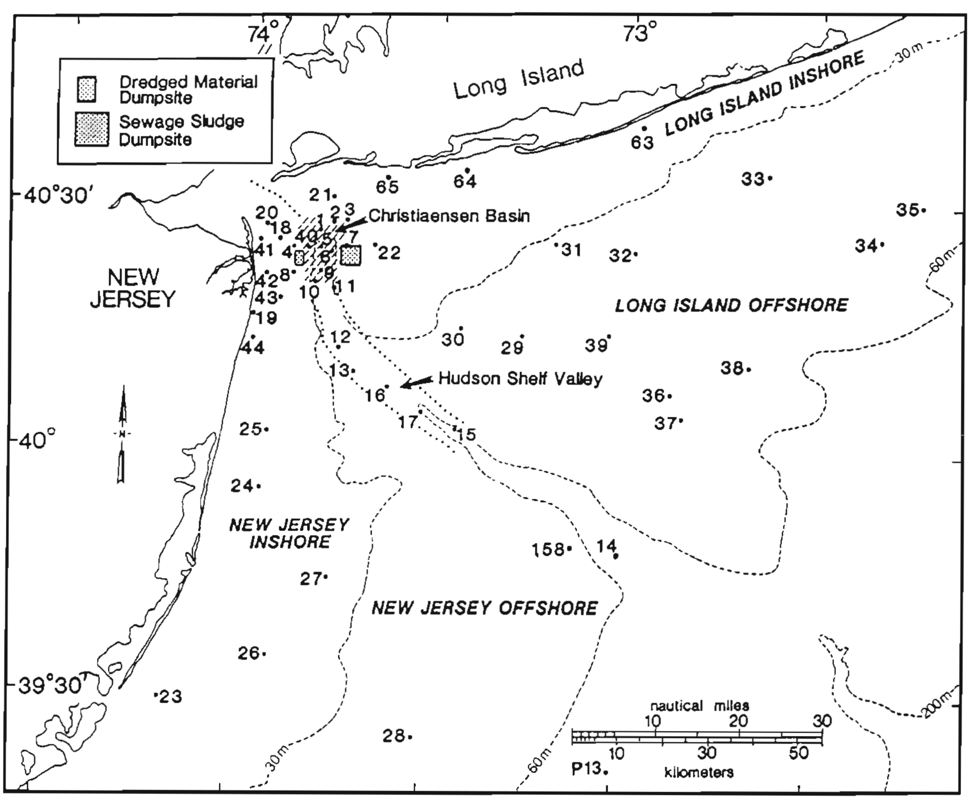

Fig. 1. Station locations in the New York Bight. Five replicate grab samples were taken each summer (1980 through 1982) at 'Northeast Monitoring Program' stations (4, 6, 7, 15, 26, 31 & P13); at remaining stations, 1 to 2 grab samples were taken (Reid et al. 1991)

C. americanus, *N. incisa* and *N. proxima* (Pearson & Rosenberg 1978, Steimle 1985). On the other hand, the amphipod genus *Ampelisca* (Lee et al. 1977, Sanders et al. 1980), amphipods and crustaceans in general (Pearson & Rosenberg 1978), and total number of species in a community (Green & Vascotto 1978) are reported to be negatively affected by even low levels of habitat contamination.

The influence of sediment characteristics on the distribution of benthic organisms is well established (Johnson 1971, Rhoads 1974, Sanders et al. 1980). Large within-station variances in New York Bight benthic data result, in part, from the high local spatial variability of sediment types (Stubblefield et al. 1974) and the patchy or aggregative distribution of some benthic species. To reduce the standard error of the mean (by increasing sample size) we pooled all samples taken over all years per station. To test the validity of this pooling, a non-parametric, multivariate rank sum test was used, with chi-square as the test statistic (Puri & Sen 1971). This test shows whether several independent samples have been drawn from the same population. High chi-square values imply non-homogeneity between the different annual survey data. Only 7 of the 23 variables examined showed significant (α = 0.05) interannual differences (Table 1). We considered this insufficient to prevent using the pooled data for further analyses as the gain in precision should outweigh possible misclassifications caused by averaging.

Table 1. Results of the rank sum test (Puri & Sen 1971) for determining the validity of combining 3 years (1980 to 1982) of New York Bight sediment and benthic macrofaunal data

Variable	Test statistic
Mean sediment grain size (MN)	1.946
Total organic carbon (TOC)	0.984
Total Kjeldahl nitrogen (TKN)	13.621*
Chromium concentration (Cr)	6.929*
Lead concentration (Pb)	1.527
Zinc concentration (Zn)	1.181
Ceriantheopsis americanus (density)	13.561*
C. americanus (biomass)	8.048*
Nephtys incisa (density)	2.321
N. incisa (biomass)	2.289
Capitella spp. (density)	6.121*
Capitella spp. (biomass)	5.712
Nucula proxima (density)	3.416
N. proxima (biomass)	1.866
Ampelisca agassizi (density)	1.642
A. agassizi (biomass)	1.748
All amphipods (biomass)	2.404
All amphipods (no.of species)	3.535
All crustaceans (biomass)	0.239
All crustaceans (no. of species)	6.043*
All species (biomass)	3.840
All species (no. of species)	10.080*

* Significant at 95 % level

To reduce variability further, stations were grouped into strata representing various habitat types. These strata were categorized according to levels of 3 highly correlated sediment variables: mean grain size, total organic carbon and chromium. This is similar to the post-collection stratification approach suggested by Walker et al. (1979). The range of values of each categorizing variable was then subdivided: (1) four levels (coarser, C; medium, M; fine, F; and very fine, V) of mean grain size (MN), a measure of benthic boundary layer hydrodynamics, depositional regime and habitat suitability usually considered a strong determinant of benthic assemblages; (2) two levels (high, H, and low, L) of TOC, a measure of nutrient enrichment; and (3) two levels (high, H, and low, L) of Cr concentration, a representative measure of toxic chemical contamination. The thresholds used to partition the range of sediment variable levels were based on results of previous studies, for example, Walker et al. (1979), Long & Morgan (1990), Boesch et al. (unpubl.) and more recent work (Packer et al. unpubl.). Thus, sixteen (4 $\times$ 2 $\times$ 2) post-collection strata were defined from the sediment data (Table 2). Characteristics of each stratum are coded by stringing the sediment variable level codes for MN, TOC, and Cr respectively. For example, Stratum 15 is represented by VLH, meaning the stratum is characterized by very fine grain size, low total organic carbon, and high Cr concentration (see Table 2). The survey data occupied only 10 of the 16 possible strata. Because of autocorrelation between the stratifying variables, the unoccupied strata may either not occur in the Bight (CHH, for example), or be present in isolated pockets and not sampled. Stations were assigned to strata according to characterizing variables (Table 3).

For each sediment or biological variable, Box & Cox (1964) tests were used to select the best transformation to maximize log-likelihood function; the square-root transformation was the best fit for MN and the logarithmic transformation for other sediment and fauna variables. Normality of the transformed data was assessed with the Kolmogorov-Smirnov test for goodness of fit (Siegel 1956) and found to be acceptable. For the putative indicator species assemblages, an analysis of variance (ANOVA) and Tukey's multiple range test (Steele & Torrie 1960) were used to assess significant differences between strata. A correlation matrix was generated between all sediment variables and all indicator taxa. This matrix became the basis for the factor and canonical correlation analyses (Cooley & Lohnes 1971).

Double ordination was used as a classification procedure to explicitly define strata and species groupings.

Table 2. Benthic habitat stratum (Str.) in the New York Bight Apex based on 4 levels of mean sediment grain sizes and 2 levels each of total organic carbon (TOC, %) and chromium concentration (Cr, ppm dry wt)

Str.[a]	Str. code[b]	Mean grain size (ϕ)	TOC	Cr
1[a]	CLL	MN ≤ 0.0	≤ 5.0	≤ 30.0
2	CHL	MN ≤ 0.0	> 5.0	≤ 30.0
3[a]	MLL	0.0 < MN ≤ 2.0	≤ 5.0	≤ 30.0
4	MHL	0.0 < MN ≤ 2.0	> 5.0	≤ 30.0
5[a]	FLL	2.0 < MN ≤ 5.0	≤ 5.0	≤ 30.0
6[a]	FHL	2.0 < MN ≤ 5.0	> 5.0	≤ 30.0
7	VLL	MN > 5.0	≤ 5.0	≤ 30.0
8[a]	VHL	MN > 5.0	> 5.0	≤ 30.0
9	CLH	MN ≤ 0.0	≤ 5.0	> 30.0
10	CHH	MN ≤ 0.0	> 5.0	> 30.0
11[a]	MLH	0.0 < MN ≤ 2.0	≤ 5.0	> 30.0
12[a]	MHH	0.0 < MN ≤ 2.0	> 5.0	> 30.0
13	FLH	2.0 < MN ≤ 5.0	≤ 5.0	> 30.0
14[a]	FHH	2.0 < MN ≤ 5.0	> 5.0	> 30.0
15[a]	VLH	MN > 5.0	≤ 5.0	> 30.0
16[a]	VHH	MN > 5.0	> 5.0	> 30.00

[a] Strata containing data
[b] Codes for sediment characteristics:

4 levels of MN:	C = Coarse	MN ≤ 0.0 ϕ
	M = Medium	0.0 < MN ≤ 2.0 ϕ
	F = Fine	2.0 < MN ≤ 5.0 ϕ
	V = Very fine	MN > 5.0 ϕ
2 levels of TOC:	L = Low	TOC ≤ 5.0 %
	H = High	TOC > 5.0 %
2 levels of Cr:	L = Low	Cr ≤ 30.0 ppm
	H = High	Cr > 30.0 ppm

This procedure used reciprocal averaging (Hill 1973) of the relative abundances of the 80 most frequently occurring species (of a total of 357 species collected). We assumed these 80 species were most important to benthic community structure and function and thus most appropriate to examine. The first axis of ordination yielded groups of related strata. The second axis grouped related species. The resulting species groups were similar to but not necessarily the same as the division based upon habitat strata. Data in each stratum/species group were successively ordinated, as much as seemed useful (6 rounds) (Hill 1973, 1979, Hill et al. 1975, Gauch 1982).

RESULTS AND DISCUSSION

Post-collection stratification

Our initial attempt to test the validity of the putative indicator taxa, by looking for apparent patterns of significant differences between post-collection stratum means, was inconclusive. The average density and biomass of putative indicator taxa from pooled data from all stations assigned to a habitat stratum, defined in Tables 2 & 3, are shown in Table 4. Some clear groupings are evident in the stratified means (Table 4), e.g. the densities and biomasses of the 5 selected benthic indicator species were closely associated with mean grain size (MN) and contaminant levels (TOC and Cr). Density and biomass of *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima* were relatively high in strata defined by finer grain sizes and higher contaminant levels; i.e. Strata 6 (FHL), 8 (VHL), 14 (FHH), 15 (VLH) and 16 (VHH). *C. americanus* and *N. proxima*, however, were also relatively abundant in the coarser grain size strata, i.e. Strata 1 (CLL), 3 (MLL) and 12 (MHH). These strata contained stations that were either near the sewage sludge or dredged material disposal sites or in the upper Hudson Shelf Valley (Table 3, Fig. 1).

Capitella spp. were found in relatively high densities and biomasses at only 2 stations (6 & 7) in Strata 12 (MHH) and 14 (FHH) characterized by high TOC and Cr (•HH) (• indicates for all levels). This species group showed the expected tolerance to highly contaminated, fine sediments and intermittent hypoxic and reducing conditions (Pearson & Rosenberg 1978) that occur in the Christiaensen Basin. On the other hand, *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima* are thought to have less tolerance for these conditions (Pearson & Rosenberg 1978).

Ampelisca agassizi was abundant only at deeper stations characterized by medium to fine grained sediments (Stns 14, 15, 34, 35 & P13) in Strata 3 (MLL), 5 (FLL), 6 (FHL) and especially 8 (VHL). *A. agassizi* was never observed in strata with high trace metal levels, i.e. Strata 11 through 16 (••H). There were low densities and biomasses of total amphipods and crustaceans and fewer total species in strata characterized by higher trace metal concentrations. This relation suggests that *A. agassizi* is indeed an indicator of chemical contamination, apparently sensitive to high levels of metals. This and other species may in fact be responding to other covariates that correlate with unmeasured environmental variables, for example, hypoxia or sulfide. Organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs) may also be important in determining community structure. PAH and PCB data were available only for the 1980 survey, however. These organic contaminants data showed a distribution pattern of similar to that found for trace metals (Reid et al. 1982).

The strata means of Table 4 were compared using ANOVA and multiple range tests (Table 5). In most cases, the ANOVA *F*-statistics were significant above the 95 % level; i.e. stratum means of the putative

Table 3. Strata, strata groups (A to D) and appropriate station collections used for stratification and classification analysis of New York Bight sediment and benthic macrofaunal species association. The assigned numbers 0, 1 or 2 for station collection refer to the year collection was defined to be part of a stratum; i.e. 1980, 1981 or 1982 respectively. Str.: stratum

Str. group:	A	B				C		D		
Str. no.:	11	1	3	5	8	6	14	12	15	16
Str. 'code':	MLH	CLL	MLL	FLL	VHL	FHL	FHH	MHH	VLH	VHH
Stn no.										
10	---	0--	---	---	---	---	1--	---	---	--2
44	---	0-2	-1-	---	---	---	---	---	---	---
43	---	01-	--2	---	---	---	---	---	---	---
24	---	01-	--2	---	---	---	---	---	---	---
42	---	-1-	0-2	---	---	---	---	---	---	---
17	---	---	---	---	---	012	---	---	---	---
21	---	---	0--	-1-	---	---	---	---	---	---
32	---	---	012	---	---	---	---	---	---	---
34	---	---	0-2	---	---	---	---	---	---	---
29	---	---	012	---	---	---	---	---	---	---
30	---	---	012	---	---	---	---	---	---	---
7	---	---	01-	---	---	---	---	--2	---	---
20	---	---	0--	-1-	---	---	---	---	---	---
19	--2	---	0--	---	---	---	---	---	---	---
38	---	---	012	---	---	---	---	---	---	---
37	---	---	012	---	---	---	---	---	---	---
23	---	---	012	---	---	---	---	---	---	---
26	---	---	012	---	---	---	---	---	---	---
27	---	---	012	---	---	---	---	---	---	---
25	---	---	0--	-1-	---	---	---	---	---	---
41	---	---	012	---	---	---	---	---	---	---
33	---	---	-12	0--	---	---	---	---	---	---
36	---	---	-12	---	0--	---	---	---	---	---
4	---	---	-12	---	---	0--	---	---	---	---
34	---	---	--2	-1-	0--	---	---	---	---	---
40	---	---	--2	---	---	---	-1-	---	---	---
12	---	---	--2	-1-	---	0--	---	---	---	---
28	---	---	--2	01-	---	---	---	---	---	---
18	---	---	---	---	---	---	---	--2	---	-1-
22	---	---	---	012	---	---	---	---	---	---
14	---	---	---	0-2	---	-1-	---	---	---	---
21	---	---	---	-12	---	---	0--	---	---	---
35	---	---	---	-12	0--	---	---	---	---	---
1	---	---	---	-12	---	0--	---	---	---	---
8	---	---	---	--2	---	---	---	---	---	0--
16	---	---	---	---	---	0--	--2	---	---	---
3	---	---	---	---	---	-12	0--	---	---	---
13	---	---	---	---	0--	-1-	--2	---	---	---
5	---	---	---	---	-1-	---	--2	---	---	0--
9	---	---	---	---	---	---	0-2	---	-1-	---
1	---	---	---	---	---	---	0-2	---	---	---
2	---	---	---	---	---	---	0-2	---	---	---
6	---	---	---	---	---	---	-1-	---	---	---
158	---	---	-1-	---	---	---	---	---	---	---
P13	---	---	-1-	0--	---	---	---	---	---	---
63	---	---	-1-	---	---	---	---	---	---	---
64	---	---	-1-	---	---	---	---	---	---	---

indicator taxa were, in some way, significantly different. Only numbers and biomass of *Ampelisca agassizi* and total species, and biomass of amphipods and crustaceans, were not significantly different between stratum. The multiple range test for *A. agassizi* was performed only for those strata where the species was found (Strata 3, 5, 6 & 8), even though the overall *F*-statistic was non-significant.

The strata analyses confirm the putative strong associations between sediment characteristics and 'indicator' taxa. *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima* appear to be reasonable indicators of fine sediment and high TOC, but are not sensitive to trace metal levels. *Capitella* spp., as expected, were indicators of high TOC and trace metal sediment contamination. Crustaceans, including *Ampelisca agassizi* and other amphipods, and overall species density are indicators of minimally contaminated habitats. These associations were not statistically clear cut in all cases, however.

Associations by correlation analysis

The correlation matrix (Table 6) generated for the 23 transformed, unstratified variables indicated that sediment chemical variables (TOC, TKN and metals) correlated well with physical characteristics (MN and GS). Correlations were strong ($r = 0.94$ to 0.98) between metals (Cr, Pb and Zn) and moderately strong ($r = 0.73$ to 0.75) between TOC and the 3 metals. TOC and TKN were moderately correlated ($r = 0.70$). Sediment grain size variables (MN and GS) were not strongly correlated with density or biomass of some selected taxa, with $|r|$ being typically <0.7. Correlations between sediment contaminants and *Capitella* spp. were weak but positive, while correlations between sediment contaminants and *Ampelisca agassizi*, all amphipods, and all crustaceans were weak and negative. Stronger correlations between all sediment variables and *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima* were found. Correlations were strong among the indicator species *C. americanus*, *N. incisa* and *N. proxima*, but correlations of *A. agassizi* with other indicator species were weak and, as expected, negative, while those for *Capitella* spp. and other species were weak and generally positive.

Using this correlation matrix, unrotated factor analysis reduced the 23 original sediment and biological variables to 6 factors with eigenvalues greater than 1.0 (Table 7). Factor loadings (coefficients of

Table 4. Average density and biomass of selected benthic macrofaunal taxa. Str.: Stratum; *C. amer.*: *Ceriantheopsis americanus*; *N. inci.*. *Nephtys incisa*; *Capit.*: *Capitella* spp.; *N. prox.*. *Nucula proxima*; *A. agas.*. *Ampelisca agassizi*

Str	Sample size	Indicator species					No. of amphipod spp.	No. of crustacean spp.	No. of all spp.
		C. amer.	*N. inci.*	*Capit.*	*N. prox.*	*A. agas.*			
Density (no. per 0.1 m^2)									
1	9	0.3	0.0	4.2	373.3	0.0	1.4	3.4	27.1
3	55	1.7	0.4	2.4	29.8	44.9	7.1	11.2	42.8
5	21	2.1	0.8	4.4	82.1	193.8	6.6	10.5	43.6
6	12	8.8	20.7	3.0	211.4	158.2	4.8	9.3	45.9
8	5	8.2	20.0	0.6	345.0	771.4	9.0	14.0	55.2
11	1	0.0	0.0	1.0	6.0	0.0	2.0	5.0	33.0
12	2	16.0	6.5	341.5	2015.5	0.0	2.5	4.0	42.5
14	19	19.9	83.7	62.6	1453.6	0.0	1.8	4.1	33.2
15	1	32.0	18.0	2.0	547.0	0.0	0.0	0.0	29.0
16	4	32.0	91.0	0.0	2373.3	0.0	0.8	2.3	32.5
Biomass (mg per 0.1 m^2, wet wt)									
1	9	113.3	0.0	4.2	247.3	0.0	13.4	297.6	4560.1
3	55	210.9	5.6	1.6	104.2	60.1	887.7	1106.9	21635.3
5	21	117.2	43.1	4.1	168.2	331.9	1137.3	6301.0	28692.6
6	12	1141.4	2089.1	2.7	401.8	308.5	1220.4	3354.6	27514.7
8	5	292.4	1296.2	1.0	2867.4	1154.4	2027.0	2155.0	65211.8
11	1	0.0	0.0	1.0	5.0	0.0	10.0	20.0	7709.0
12	2	1447.0	145.0	958.0	3807.5	0.0	11.5	302.0	18490.5
14	19	1697.8	2165.1	156.6	7686.4	0.0	22.2	82.5	39780.1
15	1	3430.0	5330.0	1.0	6670.0	0.0	0.0	0.0	23471.0
16	4	2445.8	1986.3	0.0	29769.3	0.0	1.0	83.0	38763.0

correlation between the factors and the original variables) express the relative contributions of the original variables to the derived factors. Using a correlation (loading) of 0.6 or greater to indicate a strong contribution to a factor, it is evident that Factor 1 was mostly influenced by sediment variables as well as density and biomass of *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima*. Factor 1 explained 48 % of the total variance of the original measures. Factor 2 explained another 24 % of the total variance and was influenced mainly by density and biomass of *Ampelisca agassizi*, all amphipods, all crustaceans, and overall number of species. Factor 3 contained an additional 11 % of the total variance and was influenced mainly by *Capitella* spp. abundance. Factors 1 through 3 accounted for 83 % of the total variance explained by these factors. The rotated (varimax) factor analysis (not presented) yielded similar results for both the factor loadings and the associations between the variables comprising each factor, although contributions toward total variance explained were somewhat more evenly spread over the factors.

Communality coefficients represent the extent of overlap between the original variables and the principal factors and were high (0.77 to 0.98) for the entire range of variables (Table 7). A communality of 1.0 indicates the variable is completely explained by the principal factors, while a communality of 0.0 indicates all factor loadings are 0.0 and the variable is totally independent of any of the factors. Thus, the original variables are well explained by the principal factors (Table 7).

In the canonical correlation analysis, sediment and biological variables were combined, since solutions for separate factor analyses of sediment and faunal groups (not presented here) were similar to those shown for the combined variables (Table 7). The canonical solution maximizes the correlation between new (reduced) variables (called canonical variates as opposed to factors) generated for the domain of sediment and faunal variables. Variate 1 showed that all sediment variables (with TKN to a lesser degree), all measures of *Nepthys incisa* and *Nucula proxima* and density of *Ceriantheopsis americanus* were strongly and positively associated (Table 8). Variate 2 indicated that all species and amphipod measures and crustacean density were strongly associated. *Ampelisca agassizi* associated with this group to a lesser degree, as did *Capitella* spp., but with opposite signs (Table 8). The first 2 variates accounted for most of the original variables.

Canonical correlations between the first 2 pairs of canonical variates were 0.93 and 0.72 indicating a strong intercorrelation (Table 8). Chi-square values

Table 5. Results of ANOVA and Tukey's multiple range tests for density and biomass of selected benthic macrofaunal taxa; •: significant differences among strata at the 95 % level (ANOVA); the pair of numbers in parentheses show strata that were significantly different at 95 % level in the multiple range tests

Indicator species[a]					No. of amphipod spp.	No. of crustacean spp.	No. of all spp.
C. amer.	*N. inci.*	*Capit.*	*N. prox.*	*A. agas.*			
Density (no. per 0.1 m^2)							
10.88•	19.63•	4.11•	11.72•	1.70	3.14•	3.16•	1.73
(1,14)	(1,14)	(1,12)	(1,16)	(3,8)	(3,14)	(3,14)	
(1,16)	(1,16)	(3,12)	(3,14)				
(3,14)	(3,14)	(5,12)	(3,16)				
(3,16)	(3,16)	(6,12)	(5,14)				
(5,14)	(5,14)	(8,12)	(5,16)				
(5,16)	(5,16)	(11,12)	(6,14)				
(6,16)	(6,14)	(12,14)	(6,16)				
(8,16)	(6,16)	(12,15)	(8,16)				
	(8,14)	(12,16)					
	(8,16)						
	(12,14)						
	(12,16)						
Biomass (mg per 0.1 m^2)							
5.54•	14.72•	3.58•	12.20•	1.78	1.34	0.66	1.27
(1,14)	(1,6)	(1,12)	(1,16)	(3,8)			
(1,16)	(1,14)	(3,12)	(3,14)				
(3,14)	(1,15)	(5,12)	(3,16)				
(3,16)	(1,16)	(6,12)	(5,16)				
(5,14)	(3,6)	(8,12)	(6,16)				
(5,16)	(3,14)	(12,14)	(8,16)				
	(3,15)	(12,16)	(11,16)				
	(3,16)		(12,16)				
	(5,6)		(14,16)				
	(5,14)						
	(5,15)						
	(5,16)						
	(8,15)						
	(11,15)						
	(12,15)						

[a] See species abbreviations in Table 4

from Bartlett's (1947) test confirmed the significance ($\alpha = 0.05$) of the correlations. This suggests that abundances of the 5 putative macrofaunal indicator taxa and the selected sediment variables were highly interdependent.

The results from correlation analysis thus support previously reported ecological associations. For example, *Nephtys incisa*, *Nucula proxima* and *Ampelisca agassizi* are reported to be members of a benthic community commonly found in the silty sands of southern New England estuaries and coastal areas (Pratt 1973, Steimle 1982, Caracciola & Steimle 1983). *Ceriantheopsis americanus* can also be considered part of that community, but is not usually as abundant elsewhere as it is in the New York Bight apex. The analytical groupings suggest that *A. agassizi*, although common in the same southern New England habitats as the other species, may be sensitive to the contaminated sediments of the Bight apex. The analyses also suggest overall crustacean density as being sensitive to chemical contamination as it is relatively low in the apex. Segregation of *Capitella* spp. from the other taxa agrees with reports of its being pollution-tolerant, but a weak competitor, abundant mostly in highly stressed environments that exclude most other species (Pearson & Rosenberg 1978).

Associations by classification analysis

Associations between a large faunal array (the 80 most frequently collected species) and the 10 sediment (habitat) strata defined in Table 2 were examined using a classification with ordination procedure of double reciprocal averaging. For this analysis, the strata were classified into 2, then 4 groups, and the average within-stratum densities of the 80 species were assigned relative abundance codes ranging from 1 to 9 (Table 9). These codes are as such:

Table 6. Correlation matrix for sediment and benthic macrofaunal variables[a] from 1980 through 1982 collections in the New York Bight

	MN	GS	TOC	TKN	Cr	Pb	Zn	CaD	CaB	NiD	NiB	CcD	CcB	NpD	NpB	AaD	AaB	aAB	aAS	aCB	aCS	aSB	aSS
MN	1.00	0.83	0.47	0.74	0.62	0.62	0.59	0.46	0.33	0.56	0.59	0.05	0.05	0.52	0.54	0.13	0.14	−0.13	−0.07	0.20	−0.09	0.34	0.08
GS	0.83	1.00	0.84	0.81	0.70	0.69	0.68	0.53	0.38	0.69	0.74	0.07	0.08	0.43	0.69	0.22	0.22	−0.10	−0.10	−0.15	−0.10	0.40	0.17
TOC	0.47	0.84	1.00	0.70	0.73	0.75	0.75	0.49	0.34	0.70	0.72	0.23	0.23	0.66	0.70	0.16	0.16	−0.21	−0.21	−0.14	−0.20	0.32	0.06
TKN	0.74	0.81	0.70	1.00	0.52	0.53	0.51	0.31	0.23	0.51	0.54	0.12	0.13	0.42	0.48	0.15	0.17	−0.12	−0.12	−0.13	−0.10	0.31	0.06
Cr	0.62	0.70	0.73	0.52	1.00	0.94	0.93	0.61	0.44	0.71	0.72	0.33	0.30	0.75	0.77	0.02	0.01	−0.34	−0.35	−0.32	−0.33	0.26	−0.03
Pb	0.62	0.69	0.75	0.53	0.94	1.00	0.98	0.55	0.39	0.72	0.74	0.35	0.32	0.77	0.80	−0.03	−0.04	−0.43	−0.45	−0.34	−0.42	0.14	−0.15
Zn	0.59	0.68	0.75	0.51	0.93	0.98	1.00	0.54	0.38	0.69	0.71	0.34	0.32	0.75	0.77	0.01	−0.01	−0.42	−0.44	−0.34	−0.42	0.13	−0.15
CaD	0.46	0.53	0.49	0.31	0.61	0.55	0.54	1.00	0.83	0.74	0.70	0.03	0.02	0.49	0.70	−0.16	−0.17	−0.30	−0.25	−0.37	−0.32	0.43	0.03
CaB	0.33	0.38	0.34	0.23	0.44	0.39	0.38	0.83	1.00	0.54	0.55	0.11	0.10	0.52	0.51	−0.17	−0.17	−0.32	−0.26	−0.32	−0.33	0.47	−0.05
NiD	0.56	0.69	0.70	0.51	0.71	0.72	0.69	0.74	0.54	1.00	0.92	−0.01	−0.02	0.83	0.85	−0.17	−0.17	−0.38	−0.37	−0.44	−0.39	0.33	−0.08
NiB	0.59	0.74	0.72	0.54	0.72	0.74	0.71	0.70	0.55	0.92	1.00	0.08	0.05	0.76	0.80	−0.09	−0.08	−0.31	−0.31	−0.38	−0.33	0.29	−0.03
CcD	0.05	0.07	0.23	0.12	0.33	0.35	0.34	0.03	0.11	−0.01	0.08	1.00	0.97	0.01	0.33	−0.04	−0.04	−0.20	−0.23	−0.04	−0.18	−0.04	−0.20
CcB	0.05	0.08	0.23	0.13	0.30	0.32	0.32	0.02	0.10	−0.02	0.05	0.97	1.00	−0.04	0.01	−0.01	−0.01	−0.17	−0.22	−0.02	−0.17	−0.02	−0.21
NpD	0.52	0.43	0.66	0.42	0.75	0.77	0.75	0.49	0.52	0.83	0.76	0.01	−0.04	1.00	0.94	−0.17	−0.18	−0.47	−0.45	−0.47	−0.48	0.22	−0.13
NpB	0.54	0.69	0.70	0.48	0.77	0.80	0.77	0.70	0.51	0.85	0.80	0.33	0.01	0.94	1.00	−0.14	−0.14	−0.42	−0.45	−0.44	−0.47	0.25	−0.11
AaD	0.13	0.22	0.16	0.15	0.02	−0.03	0.01	−0.16	−0.17	−0.17	−0.09	−0.04	−0.01	−0.17	−0.14	1.00	0.99	0.55	0.45	0.49	0.44	0.24	0.52
AaB	0.14	0.22	0.16	0.17	0.01	−0.04	−0.01	−0.17	−0.17	−0.17	−0.08	−0.04	−0.01	−0.18	−0.14	0.99	1.00	0.55	0.43	0.48	0.46	0.25	0.52
aAB	−0.13	−0.10	−0.21	−0.12	−0.34	−0.43	−0.42	−0.30	−0.32	−0.38	−0.31	−0.20	−0.17	−0.47	−0.42	0.55	0.55	1.00	0.91	0.80	0.89	0.15	0.78
aAS	−0.07	−0.10	−0.21	−0.12	−0.35	−0.45	−0.44	−0.25	−0.26	−0.37	−0.31	−0.23	−0.22	−0.45	−0.45	0.45	0.43	0.91	1.00	0.74	0.96	0.13	0.83
aCB	−0.20	−0.15	−0.14	−0.13	−0.32	−0.34	−0.34	−0.37	−0.32	−0.44	−0.38	−0.04	−0.02	−0.47	−0.44	0.49	0.48	0.79	0.74	1.00	0.80	0.11	0.63
aCS	−0.09	−0.10	−0.20	−0.10	−0.33	−0.42	−0.42	−0.32	−0.33	−0.39	−0.33	−0.18	−0.17	−0.48	−0.47	0.44	0.46	0.89	0.96	0.80	1.00	0.09	0.83
aSB	0.34	0.40	0.32	0.31	0.26	0.14	0.13	0.43	0.47	0.33	0.29	−0.04	−0.02	0.22	0.25	0.24	0.25	0.13	0.13	0.11	0.09	1.00	0.39
aSS	0.08	0.17	0.06	0.06	−0.03	−0.15	−0.15	0.03	−0.05	−0.08	−0.03	−0.20	−0.21	−0.13	−0.11	0.52	0.52	0.78	0.83	0.63	0.83	0.39	1.00

[a] Key to variables:
- MN: mean grain size
- GS: proportion of silt and clay
- TOC: total organic carbon
- TKN: total Kjeldahl nitrogen
- Cr: chromium concentration
- Pb: lead concentration
- Zn: zinc concentration
- CaD: *Ceriantheopsis americanus*, density
- CaB: *C. americanus*, biomass
- NiD: *Nephtys incisa*, density
- NiB: *N. incisa*, biomass
- CcD: *Capitella* sp., density
- CcB: *Capitella* sp., biomass
- NpD: *Nucula proxima*, density
- NpB: *N. proxima*, biomass
- AaD: *Ampelisca agassizi*, density
- AaB: *A. agassizi*, biomass
- aAB: all amphipods, biomass
- aAS: all amphipods, no. of species
- aCB: all crustaceans, biomass
- aCS: all crustaceans, no. of species
- aSB: all species, biomass
- aSS: all species, no. of species

Table 7. Factor loadings or correlations of factors with original benthic habitat and macrofaunal variables, and communality indices. D., density; B.: biomass; N.: number

Variable	Factor 1	2	3	4	5	6	Communality
Mean grain size	0.671	0.420	0.005	−0.245	−0.036	0.352	0.8119
Silt and clay	0.761	0.510	0.011	−0.204	−0.021	0.219	0.9301
Total organic C	0.784	0.384	0.165	−0.140	−0.048	0.054	0.8149
Total Kjeldahl N	0.500	0.380	0.084	−0.412	−0.027	0.572	0.8972
Chromium	0.869	0.202	0.207	0.033	−0.116	−0.197	0.8912
Lead	0.892	0.111	0.246	−0.066	−0.148	−0.217	0.9416
Zinc	0.877	0.117	0.264	−0.081	−0.114	−0.274	0.9314
Ceriantheopsis americanus, D.	0.743	0.115	−0.313	0.445	0.089	−0.003	0.8687
Ceriantheopsis americanus, B.	0.606	0.025	−0.241	0.582	0.276	0.125	0.8569
Nephtys incisa, D.	0.873	0.111	−0.256	0.058	−0.089	−0.074	0.8558
Nephtys incisa, B.	0.858	0.187	−0.155	0.067	−0.104	−0.067	0.8140
Capitella sp., D.	0.227	−0.123	0.872	0.351	−0.068	0.092	0.9636
Capitella sp., B.	0.207	−0.106	0.882	0.343	−0.027	0.126	0.9673
Nucula proxima, D.	0.885	0.027	−0.226	−0.016	−0.070	−0.222	0.8889
Nucula proxima, B.	0.903	0.071	−0.188	−0.028	−0.069	−0.197	0.8992
Ampelisca agassizi, D.	−0.186	0.738	0.251	−0.217	0.468	−0.268	0.9808
Ampelisca agassizi, B.	−0.188	0.741	0.250	−0.219	0.471	−0.251	0.9801
All amphipods, B.	−0.584	0.772	−0.030	0.111	−0.158	−0.031	0.9016
All amphipods, N.	−0.574	0.714	−0.115	0.159	−0.256	0.042	0.9450
All crustaceans, B.	−0.563	0.614	0.158	0.141	−0.145	−0.076	0.7717
All crustaceans, N.	−0.587	0.711	−0.031	0.129	−0.305	0.023	0.9595
All species, B.	0.288	0.487	−0.181	0.399	0.410	0.273	0.7547
All species, N.	−0.244	0.833	−0.166	0.220	−0.197	−0.080	0.8750
Eigenvalue	9.865	4.827	2.304	1.456	1.029	1.010	
% Variance	48.120	23.550	11.240	7.150	5.020	4.930	

Code # 1 = species occurrence in a stratum, but with an average density of less than 1.0 per 0.1 m^2,
Code # 2 = average densities from 1 to <5,
Code # 3 = average densities from 5 to <10,
Code # 4 = average densities from 10 to <20,
Code # 5 = average densities from 20 to <50,
Code # 6 = average densities from 50 to <100,
Code # 7 = average densities from 100 to <200,
Code # 8 = average densities from 200 to <500, and
Code # 9 = average densities ≥500 individuals.

The density cutoff points are somewhat arbitrary and not truly proportional, but are based roughly on the distribution of mean densities. Both the 'Stratum classification' (columns) and 'Species classification' (rows) must be considered in Table 9 to maximize the information from the analysis.

Species associations with habitat types

For stratum classification, the 10 original sediment strata (Table 3) were reduced by 2-round ordination to 4 strata groups, A to D, as indicated by codes from ordination results with the presence of either a '0' or a '1' in 'Classification for stratum' (Table 9). In the first round of ordination for strata, 2 groups, AB (e.g. as indicated by '0 0000' in 'Classification code for stratum') and CD (e.g. '11 111' in 'Classification code for stratum') were formed. Further, the second round of ordination separated these AB and CD into strata group A (e.g. '0' in 'Classification code for stratum'), strata group B (e.g. '1111' in 'Classification code for stratum'), strata group C (e.g. '00' in 'Classification code for stratum') and strata group D (e.g. '111' in 'Classification code for stratum'). Group A includes only Stratum 11, characterized as MLH. Group B includes 4 strata with low Cr levels (••L): Strata 1 (CLL), 3 (MLL), 5 (FLL) and 8 (VHL). Group C includes 2 strata, Strata 6 (FHL) and 14 (FHH), characterized by fine grain sediments with high TOC levels (FH•). Group D includes 3 strata with high Cr levels (••H): Strata 12 (MHH), 15 (VLH) and 16 (VHH).

Strata group A (Stratum 11) actually represents a collection at a single station (19) sampled in 1982 (Table 3). It includes species associated with coarser sediment, low to moderate TOC levels (less than 5.0 %) and unexpectedly high concentrations of metal contaminants (Cr > 30.0 ppm). Twenty-five of the 80 species occurred in this strata group. None were very

Table 8. Canonical loadings or correlations of canonical variates with original benthic habitat and macrofaunal variables and outcomes of Bartlett's tests with canonical correlations. D.: Density; B.: biomass; N.: number

Variable	Variate 1	2	3	4	5	6	7
Mean grain size	0.668	-0.367	-0.105	0.424	-0.054	0.072	0.449
Silt and clay	0.845	-0.327	0.274	0.088	-0.016	-0.035	0.304
Total organic C	0.885	-0.084	0.111	0.083	-0.368	-0.228	0.044
Total Kjeldahl N	0.446	-0.187	0.208	-0.007	-0.221	-0.233	0.776
Chromium	0.915	0.043	-0.309	-0.084	0.183	-0.126	0.091
Lead	0.931	0.269	-0.177	0.045	0.103	0.010	0.126
Zinc	0.913	0.260	-0.168	0.091	0.169	-0.160	0.089
Ceriantheopsis americanus, D.	0.666	-0.264	-0.244	-0.057	0.339	0.230	-0.162
Ceriantheopsis americanus, B.	0.483	-0.236	-0.217	-0.079	0.195	0.198	-0.214
Nephtys incisa, D.	0.847	-0.081	0.013	-0.019	-0.068	0.229	0.044
Nephtys incisa, B.	0.880	-0.112	0.101	0.056	0.037	0.223	0.067
Capitella sp., D.	0.293	0.380	-0.388	-0.229	-0.195	-0.230	-0.053
Capitella sp., B.	0.272	0.328	-0.366	-0.198	-0.231	-0.347	-0.051
Nucula proxima, D.	0.853	0.082	-0.133	-0.001	0.125	0.190	0.060
Nucula proxima, B.	0.892	0.082	0.028	-0.044	0.146	0.180	0.147
Ampelisca agassizi, D.	0.091	-0.380	0.395	0.185	0.023	-0.578	-0.150
Ampelisca agassizi, B.	0.086	-0.386	0.385	0.185	-0.024	-0.570	-0.103
All amphipods, B.	-0.322	-0.553	0.302	-0.199	-0.097	0.014	-0.202
All amphipods, N.	-0.330	-0.673	0.162	-0.077	-0.173	0.125	-0.208
All crustaceans, B.	-0.269	-0.252	0.357	-0.161	-0.308	-0.006	-0.464
All crustaceans, N.	-0.315	-0.583	0.179	-0.107	-0.212	0.086	-0.180
All species, B.	0.333	-0.656	-0.025	-0.278	-0.158	-0.117	0.075
All species, N.	0.030	-0.687	0.207	-0.355	-0.001	-0.104	-0.245

Eigenvalue	Canonical correlation	No. of eigenvalues	Bartlett's test for remaining eigenvalues: Chi-square values	df	Significance probability
			411.44	112	0.0000
0.86397	0.92950	1	180.44	90	0.0000
0.51849	0.72006	2	95.67	70	0.0225
0.26132	0.31119	3	60.53	52	0.1951
0.19735	0.44444	4	35.00	36	0.5159
0.12616	0.35519	5	19.36	22	0.6229
0.08347	0.28891	6	9.25	10	0.5085

common (average density less than 20 ind. per 0.1 m^2, Code # ≤ 4) but the group included both contaminant-sensitive and insensitive species. This station collection may represent an unusual or anomalous situation. The station was well inshore and possibly influenced by a local contaminant source, e.g. a sewer outfall or shipwreck, which could explain the unexpectedly high trace metal levels found in such coarse sediment.

Strata group B includes samples from 40 of the 47 stations from 1 or more of the years sampled (see Table 3) and contains all 80 species in at least 1 of the 4 strata in the group (Table 9). Because all 80 species and most of the stations occur in this group, it is likely this strata group defines a basic, major habitat of benthic macrofaunal organisms in the New York Bight. All strata in this group have low levels of sediment chemical contaminants, with the single exception of high TOC in Stratum 8. The stations constituting this group were mostly in areas outside the Hudson Shelf Valley. For example, Stratum 1 includes stations (10, 24 & 42 to 44, Table 3 & Fig. 1) along the New Jersey coast. Strata 3 and 5 include a widely distributed group of stations from areas off both New Jersey and Long Island (Fig. 1, Table 3). Stratum 8 includes offshore Stns 34 to 36, plus Stns 5 and 13 in the Bight apex (Table 3 & Fig. 1). The species that were especially common (≥ 20 per 0.1 m^2; i.e. abundance Code # ≥ 4) would seem to be the basic, dominant infauna of the Bight. Included in this group were the polychaetes: *Goniadella gracilis*, *Exogone hebes*, *Amastigos caperatus*, *Acesta catherinae*, *Scoletoma hebes*, *Tharyx acutus* and *Monticellina dorsobranchialis*; amphipods: *Corophium crassicorne*, *Erichthonius fasciatus*, *Unciola* sp. and *Leptocheirus pinguis*; the sand dollar *Echinarachnius parma*; and the nut clam *Nucula proxima*.

Table 9. Classification analysis for the 80 most common benthic macrofaunal species in the New York Bight. Numbers under the stratum columns (under headings A to D) are relative abundance code (Code # 1 to 9, see text for ranges); (–) species not found in the stratum

	Species[a]	A	B	C	D	Class. code for spp.
	Stratum:	11	1358	6 14	12 15 16	
	Code by ordination – Classification code for stratum:	0 0	0000 1111	11 00	111 111	
I.	**Most contaminant sensitive species**					
15	*Exogone verugera*	–	–242	1–	---	0000
18	*Parapionosyllis longicirrata*	–	14–3	--	---	0000
29	*Hemipodus roseus*	–	421–	–1	---	0000
31	*Goniadella gracilis*	–	5511	--	---	0000
59	*Cirratulidae* spp.	–	5212	--	---	0000
118	*Byblis serrata*	–	–514	1–	---	0000
121	*Corophium crassicorne*	–	1666	1–	---	0000
124	*Unciola inermis*	–	–833	--	---	0000
139	*Rhepoxinius hudsoni*	–	–333	--	---	0000
56	*Caullerilla* cf. *killariensis*	2	1522	--	---	000100
150	*Echinarachnius parma*	2	–545	11	---	000100
110	*Ptilanthura tricarina*	3	2525	--	---	000101
127	*Pseudunciola obliquua*	2	–45–	--	---	000101
42	*Aricidea wassi*	4	–121	--	---	00011
33	*Scoletoma acicularum*	2	5221	11	---	001000
48	*Cirrophorus brevicirratus*	–	42–1	1–	--1	001001
122	*Erichthonius fasciatus*	–	–567	31	---	001001
138	*Phoxocephalus holbolli*	–	2313	1–	1--	001001
70	*Euclymene zonata*	–	–422	21	---	00101
94	*Astarte undata*	–	–232	2–	---	00101
102	*Eualus pusiolus*	–	–244	21	---	00101
117	*Ampelisca agassizi*	–	–579	7–	---	00101
10	*Sthenelais limicola*	2	1121	11	--1	0011
74	*Asabellides oculata*	2	2112	11	---	0011
96	*Spisula solidissima*	4	2222	1–	1--	0011
II.	**Contaminant sensitive species**					
16	*Exogone hebes*	2	–646	1–	5--	010
143	*Crangon septemspinosus*	2	1111	11	2--	010
125	*Unciola irrorata*	–	2456	51	2--	0110
20	*Nereis grayi*	–	1222	11	2--	01110
54	*Spiophanes bombyx*	2	1342	21	5--	01110
7	*Harmothoe extenuata*	–	2223	21	2--	011110
63	*Scalibregma inflatum*	–	1233	31	2--	011110
77	*Terebellides atlantica*	–	–132	21	---	011110
104	*Diastylis quadrispinosa*	–	–134	31	---	011110
119	*Leptocheirus pinguis*	–	1255	52	---	011110
68	*Amastigos caperatus*	3	636–	44	3--	011111
III.	**Contaminant insensitive species**					
14	*Paranaitis speciosa*	–	2111	12	1–1	100010
26	*Glycera dibranchiata*	–	2221	21	2--	100010
43	*Acesta catherinae*	2	7557	76	7–2	100010
53	*Spio setosa*	–	223–	21	2–1	100010
78	*Chone infundibuliformis*	–	–124	21	--2	100010
80	*Euchone elegans*	–	2446	72	2–3	100010
144	*Cancer irroratus*	–	2222	22	2–2	100010
40	*Paraougia caeca*	2	5322	32	6--	100011
23	*Nephtys picta*	4	233–	11	4–5	1001
73	*Anobothrus gracilis*	2	1124	52	--2	1001
34	*Scoletoma hebes*	–	5445	56	523	1010
38	*Drilonereis longa*	–	1122	22	2–1	1010
87	*Mytilus edulis*	–	2414	23	224	1010
5	*Halcampa duodecimcirrata*	–	–1–3	22	--2	101100
12	*Anatides mucosa*	–	2333	42	242	101100
95	*Cerastoderma pinnulatum*	–	1224	23	223	101100
99	*Arctica islandica*	–	–122	23	1–2	101100
57	*Tharyx acutus*	3	5454	78	4–8	101101
58	*Monticellina dorsobranchialis*	2	4548	77	656	101101
6	Rhynchocoela	2	2343	53	332	10111
98	*Tellina agilis*	4	2331	54	524	10111
IV.	**Most contaminant insensitive species**					
113	*Edotea triloba*	2	1222	54	--1	11000
130	*Photis pollex*	–	–128	65	1–2	11001
79	*Euchone incolor*	–	–342	68	227	11100
84	*Nucula delphinodonta*	–	–125	76	--2	11100
4	*Edwardsia elegans*	–	1113	33	123	11101
101	*Periploma papyratium*	–	–121	31	2–2	11101
3	*Ceriantheopsis americanus*	–	1223	35	455	111100
13	*Eteone longa*	–	–111	12	222	111100
22	*Nephtys incisa*	–	–115	56	346	111100
36	*Ninoe nigripes*	–	–245	65	435	111100
46	*Levinsenia gracilis*	–	1227	76	468	111100
52	*Prionospio steenstrupi*	–	4345	76	745	111100
61	*Cossura longocirrata*	–	2228	68	489	111100
62	*Pherusa affinis*	–	2123	24	355	111100
67	*Mediomastus ambiseta*	2	5343	66	765	111100
69	*Clymenella torquata*	–	–12–	2–	121	111100
85	*Yoldia sapotilla*	–	--14	42	124	111100
100	*Pitar morrhuanus*	–	–142	33	3–4	111100
147	*Phoronis architecta*	–	2144	77	198	111100
66	*Capitella* spp.	2	3221	26	82–	111101
2	*Cerianthus borealis*	–	1112	–2	--5	11111
9	*Pholoe minuta*	–	2233	33	533	11111
83	*Nucula proxima*	3	8568	89	999	11111

[a] Species code numbers:

2–5 = anthozoans
6 = Nemertea
7–80 = polychaetes
81–101 = molluscs
102–145 = crustaceans
146 = sipunculid
147 = phoronid
148–150 = echinoderm

Strata group C includes stations within Strata 6 and 14. Stratum 6 stations (4 & 11 to 17, see Table 3 & Fig. 1) were generally in the mid Hudson Shelf Valley and adjacent to the disposal sites in the apex, but not in the Christiaensen Basin. Stratum 14 stations, however, were generally in the Christiaensen Basin area (Stns 1 to 3, 5, 6, 9 & 10) and the upper Hudson Shelf Valley (Stns 13, 16 & 21, Table 3 & Fig. 1). The dominant species in this group (≥ 20 per 0.1 m^2; i.e. abundance Code # ≥ 4) were those that are considered typical of silty habitats, e.g. the nut clams *Nucula* spp. and northern dwarf tellin *Tellina agilis*; the polychaetes *Nephtys incisa*, *Tharyx acutus*, *Monticellina dorsobranchialis*, *Acesta catherinae*, *Scoletoma hebes*, *Ninoe nigripes*, *Levinsenia gracilis*, *Prionospio steenstrupi*, *Cossura longocirrata*, and *Mediomastus ambiseta*; the phoronid *Phoronis architecta*; the isopod *Edotea triloba*; and amphipods *Photis pollex* and *Ampelisca agassizi* (Stn 6, Table 9). Many of these species appear well adapted to a wide range of sediment types, although they are most common in silty sand and mud, while some species (but *not* the most abundant species in this group) belonging to this stratum group may be dependent on sediment type.

Strata group D, including Strata 12 (MHH), 15 (VLH) and 16 (VHH) (Table 3), is characterized by high concentrations of both TOC and metals. The lone exception is Stratum 15, with low TOC levels; Stratum 15 includes only 1 station collection (Table 3) and is possibly another anomaly. The 6 stations comprising this group (Stns 5, 7 to 10 & 18, Table 3 & Fig. 1) were tightly clustered within the Christiaensen Basin and dredge spoil disposal area. Most dominant species in this group (≥ 20 per 0.1 m^2; i.e. abundance Code # ≥ 4) were the same as those in strata group C, and few additional species occurred frequently in strata group D; *Ceriantheopsis americanus*, *Pholoe minuta*, *Pherusa affinis* and *Nephtys picta*.

Strata groups C and D, which appear closely related, represent the most contaminated habitat conditions in the area, considering strata group A as an anomaly. The most abundant species found in these groups presumably have high tolerance levels for the contaminants examined (Table 9). The main differences in habitat conditions between these 2 groups were consistently high Cr levels for group D and uniformly fine mean grain sizes for group C. Species with high occurrence in group C appear to be more sensitive to sediment grain size than species that are common in group D. Strata group D, as a separate group, is tentative because it consists of data from only 7 collections.

Species that prefer coarser sediments, but can also tolerate contaminants, are abundant in strata group A, although this group is probably an anomaly, as discussed previously. Strata group B appears to be the basic habitat/benthic macrofaunal community for most of the New York Bight outside the Christiaensen Basin/Hudson Shelf Valley (a depositional sink for fine sediments and anthropogenic contaminants). Some species in this group appear tolerant of higher levels of contaminants (trace metals and/or TOC), occurring in relatively high abundance (≥ 20 per 0.1 m^2; i.e. abundance Code # ≥ 4) in contaminated strata groups A, C and/or D, e.g. *Acesta catherinae*, *Euchone elegans*, *Scoletoma hebes*, *Tharyx acutus*, *Photis pollex*, *Nucula delphinodonta* and *N. proxima* (Table 9). Only species that can tolerate higher levels of sediment contamination, such as *Nephtys incisa*, *Edotea triloba*, *Ceriantheopsis americanus*, *Pherusa affinis* and others are found in strata groups C and D.

Species associations with habitat quality

Species classifications, based on 6 rounds of ordination for the 80 most common species, resulted in the first round of ordination defining 2 primary species groups, that appear to be either mostly 'Contaminant sensitive' (e.g. as indicated by '0' in the first column of classification code for species in Table 9) or 'Contaminant insensitive' (e.g. '1' in the first column of classification code for species in Table 9). In the second round of ordination, these 2 groups were further separated into 2 subgroups; refer to the second column of classification code for species assigned according to the presence of either a '0' or '1' in Table 9. Thus, 4 species assemblages I to IV were formed by the codes '00', '01', '10' and '11' respectively, for each species in the first 2 columns of classification code for species (Table 9). Four additional rounds of ordination provided the refined species groupings evident in classification code for each species (Table 9).

Species group I contains species that appear to be the 'most contaminant sensitive' (as indicated by '00' in the first 2 species ordination code columns). This group's species were most common in strata group B, with some contribution from strata group A, e.g. *Aricidea wassi* and *Spisula solidissima* (Table 9). The species common in this subgroup are rare in contaminated strata groups C and D (≤5 per 0.1 m^2; i.e. abundance Code # being generally ≤3).

Species group II (e.g. '01' in the first 2 species ordination codes), containing the remaining first ordination (00) group species, *Exogone hebes* through *Amastigos caperatus* (Table 9), were common in strata group B, but could also be found in relatively high abundance (≥10 per 0.1 m^2; abundance Code # ≥4) in strata groups C and D, e.g. *E. hebes*, *Unciola irrorata*, *Spiophanes bombyx*, *Leptocheirus pinguis* and *Amastigos caperatus* (Table 9). This suggests more contaminant tolerance than the species in group I.

Species group III (e.g. '10' in the first 2 species ordination codes), included species that appear to be moderately tolerant of sediment contamination (Table 9). The species in this group, although classified as contaminant tolerant in the primary ordination, may differ only in degree from the last subgroup II, i.e. subgroup III species were most common in strata groups B and C, with some contribution to the other groups, A and D, e.g. for group A: *Nephtys picta* and *Tellina agilis*, and for group D: species included in this habitat strata with abundance Code # ≥4 (Table 9). The 2 middle groups, II and III, including species with '01' or '10' in the first 2 species ordination code columns (Table 9), may include either moderately contaminant tolerant or sensitive species.

Species group IV (e.g. '11' in the first 2 species ordination codes), including the remaining species, *Edotea triloba* and below (Table 9), are also common in strata group B but are most common in strata groups C and D. A few species from the previous subgroup, i.e. *Tharyx acutus*, *Monticellina dorsobranchialis*, rhynchocoels, and *Tellina agilis*, appear to belong to this subgroup because of their relative abundance in strata groups C and D, despite the ordination classification results. This last subgroup appears to include the most contaminant insensitive species, e.g. *Nucula proxima*, *Capitella* spp., *Mediomastus ambiseta* and *Prionospio steenstrupi*.

The species subgrouping revealed by the third through sixth ordination results, as indicated by the 0 or 1 coding sequences in classification code columns 3 to 6 (Table 9), could suggest closer species associations. For example, the first 9 species (codes '0000') are indicated as a group of species with the highest contaminant sensitivity. It is worth noting that *Capitella* spp. forms a distinct subgroup, '111101', in the ordination results, which supports the results of the correlation analysis (Table 7). For the most part these ordination-defined primary strata groups are ecologically realistic, i.e. defining species habitat associations that are consistent with those reported in previous qualitative studies or reviews, e.g. Pratt (1973), Pearson & Rosenberg (1978), Caracciolo & Steimle (1983) and Steimle (1990). For example, most of the species in the contaminant sensitive group are reported to be typical of silty fine sand habitats in the Middle Atlantic Bight: *Unciola* sp., *Euclymene zonata*, *Astarte* sp., *Ampelisca agassizi*, *Scalibregma inflatum* and *Leptocheirus pinguis* (Pratt 1973). Some contaminant tolerant species are also reported to be included in this 'community' as well, e.g. *Arctica islandica*, *Nephtys incisa*, and *Pherusa affinis* (Pratt 1973). *Nucula proxima* is also found associated with these species (Steimle 1982).

Although only 80 most common species, of the 357 found in the surveys, were summarized in this analysis, another classification analysis was run with a larger number of species. This expanded analysis (not presented) contributed a few species to the contaminant insensitive group (IV), but most of the additional species were rarer and were classified into the first, most contaminant sensitive group (I) with a moderate number to the intermediate second and third classification groups (II and III). This is not unexpected as it reflects the use of a greater diversity of species found in the relatively unstressed but variable benthic habitats in the entire New York Bight. The 80-species analysis seems adequate to define important indicator species assemblages relative to habitat type and quality.

There were a few species that seemed to be misclassified by this statistical analysis, possibly because of one of the potential errors or biases mentioned previously. The strong statistical association of the tube-dwelling, opportunistic polychaete, *Asabellides oculata*, usually found in silty sediments, with the Atlantic surf clam *Spisula solidissima*, and the polychaete *Sthenelais limicola* (Table 9), both typical of coarser, sandy sediments, is a possible spurious classification. The strong association of the blue mussel *Mytilus edulis* with 2 burrowing polychaetes in the same group is questionable because the mussel is typically found attached to hard substrates at or above the sediment surface. The group consisting of the burrowing, predatory rhynchocoel (undoubtedly *Cerebratulus lacteus*), typical of silty sediments, with the small clam *Tellina agilis* (Table 9), usually associated with medium to fine sands (Pratt 1973), is doubtful as well. Some of these questionable associations could also represent ephemeral recruitment to atypical habitats. Alternatively, the actual substrate upon which the species was found may not have been properly classified, e.g. *Mytilus* sp. spat on a rock or shell fragment not noted in the sediment analysis data. Other inconsistencies may be due to chance, considering the large number of comparisons that were made.

The station collections within each classification analysis stratum often exhibited year to year variability in their habitat characteristics, explaining their assignment to more than 1 stratum (i.e. Table 3). For example, in 1980 Stn 4 was classified in Stratum 6 (group C), while in 1981 and 1982 the station was assigned to Stratum 3 (group B). This could suggest a number of things, including sampling error, high habitat heterogeneity at the station, or a changing environment.

SUMMARY

For the study's first purpose, both the association and correlation analyses found strong relations between sediment characteristics and putative 'indicator' species or taxa. The association analyses suggested that 3 species, *Ceriantheopsis americanus*, *Nephtys incisa* and *Nucula proxima*, are reasonable indicators of a fine sediment habitat with high TOC levels, and that these species were tolerant of high levels of trace metals. *Capitella* spp., as expected from the results of other studies, were indicators of high TOC and metal contamination. Crustaceans, including *Ampelisca agassizi* and other amphipods, as well as overall macrofaunal species density, proved to be indicators of minimally contaminated habitats. These relations were reasonably clear-cut in the analysis, but included several exceptions to these generalizations.

The classification analysis, using a broader range of benthic species (the 80 most abundant) with no further pre-selection, addresses the second purpose of this study and suggests that there are commonly co-occurring species in relatively high abundances which are reliably associated with specific habitat types, defined by sediment characteristics and quality. There appear to be 2 primary species groups, one consisting of sediment contamination-sensitive species and the other containing basically tolerant species, but there is overlap among the groups, with some species occurring in both. Strata group B appears to contain species that are representative of the basic benthic habitat community in the New York Bight. This group includes all contaminant insensitive species and many tolerant ones, as well. Strata groups C and D contain more contaminant tolerant species that are common in the upper Hudson Shelf Valley and areas adjacent to waste disposal sites. Strata-group A appears to be a unique exception and could represent either sampling or analytical error or special habitat conditions.

Our analyses generally support the use of certain species or taxa for indicating habitat quality. They also suggest other potentially useful species or species-groups that are strongly associated with certain habitat types and levels of quality. A major assemblage of species was defined that appears to represent a basic, dominant, natural benthic community in the New York Bight. The associations and definitions suggested by the statistical approaches used here were mostly ecologically realistic, based on comparison with other studies, but there were occasional exceptions.

Acknowledgements. We thank Joseph Vitaliano and Ann Frame for their assistance with taxonomic nomenclature, and Michael Fahay, Anne Studholme and Stuart Wilk of Sandy Hook Laboratory, Robert Murchelano and John B. Pearce of Woods Hole Laboratory, and anonymous reviewers for their critical comments and valuable suggestions.

LITERATURE CITED

Bartlett, M. S. (1947). Multivariate analysis. J. R. statist. Soc. Ser. B: 176-197

Box, G. E. P., Cox, D. R. (1964). An analysis of transformations. J. R. statist. Soc. Ser. B: 211-252

Caracciolo, J., Steimle, F. W. (1983). An atlas of the distribution and abundance of dominant benthic invertebrates in the New York Bight apex, with reviews of their life histories. NOAA Tech. Rept. NMFS SSRF-776

Cooley, W. W., Lohnes, P. R. (1971). Multivariate data analysis. John Wiley and Sons, New York

Eagle, R. A., Rees, E. I. S. (1973). Indicator species - a case for caution. Mar. Pollut. Bull. 4(2): 25

Gauch, H. G. (1982). Multivariate analysis in community ecology. Cambridge Univ. Press, Cambridge

Grassle, J. P., Grassle, J. F. (1976). Sibling species in the marine pollution indicator *Capitella* (Polychaeta). Science 192: 567-569

Green, R H., Vascotto, G. L. (1978). A method for the analysis of environmental factors controlling patterns of species composition in aquatic communities. Mar. Res. 12: 583-593

Halcrow, W., Mackay, D. W., Thomson, I. (1973). The distribution of trace metals and fauna in the Firth of Clyde in relation to the disposal of sewage sludge. J. mar. biol. Ass. U.K. 53: 721-739

Hill, M. O. (1973). Reciprocal averaging: an eigenvector method of ordination. J. Ecol. 61: 237-249

Hill, M. O. (1979). TWINSPAN - A Fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Section of Ecology and Systematics. Cornell Univ., Ithaca

Hill, M. O., Bunce, R. G. H., Shaw, M. W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. J. Ecol. 63: 597-613

Johnson, R. G. (1971). Animal-sediment relationships in shallow water benthic communities. Mar. Geol. 11. 93-104

Lee, W. Y., Welch, M. F., Nicol, J. A. (1977). Survival of two species of amphipods in aqueous extracts of petroleum oils. Mar. Pollut. Bull. 8: 92-94

Long, E. R., Morgan, L. G. (1990). The potential for biological effects of sediment-seabed contaminants tested in the National Status and Trends Program. NOAA Tech. Memo. NOSOMS-52

Pearce, J. B., Thomas, J., Caracciolo, J., Halsey, M., Rogers, L. (1976). Distribution and abundance of benthic organisms in the New York Bight apex, 2-6 August 1973. NOAA TR ERL MESA-8

Pearson, T. H., Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr mar. Biol. Ann. Rev. 16: 229-311

Pratt, S. (1973). Benthic fauna. In: Coastal and offshore environmental inventory, Cape Hatteras to Nantucket Shoals, Chap. 5. Univ. Rhode Island, Kingston

Puri, M. L., Sen, P. K. (1971). Nonparametric methods in multivariate analysis. Wiley and Sons Publ. Co., New York

Reid, R. N., O'Reilly, J. E., Zdanowicz, V. S. (eds.) (1982). Contaminants in New York Bight and Long Island Sound sediments and demersal species, and contaminant effects on benthos, summer 1980. NOAA Tech. Mem. NMFS-F/NEC-16

Reid, R. N., Radosh, D. J., Frame, A. B., Fromm, S A. (1991). Benthic macrofauna of the New York Bight, 1979-89. NOAA Tech. Report NMFS 103

Rhoads, D. C. (1974). Organic-sediment relations on the muddy sea floor. Oceanogr. mar. Biol. Ann. Rev. 12: 263-300

Rowe, G. T (1971). The effects of pollution on the dynamics of the benthos of the New York Bight. Thalassia jugosl. 7(1): 353-359

Saila, S. B., Pikanowski, R. A., Vaughan, D. S. (1976). Optimum allocation strategies for sampling benthos in the New York Bight. Estuar. coast. mar. Sci. 4: 119-128

Sanders, H. L., Grassle, J. F., Hampson, G., Morse, L. Garner-Price, S., Jones, C. (1980). Anatomy of an oil spill: long-term effects from grounding of the *Florida* off West Falmouth, MA. J. mar. Res. 38: 265–380

Siegel, S. (1956). Nonparametric statistics for the behavioral science. McGraw-Hill Book Co., New York

Steele, R., Torrie, T (1960). Principles and procedures of statistics. McGraw-Hill Book Co., New York

Steimle, F. W. (1982). The benthic macroinvertebrates of the Block Island Sound. Estuar. coast. shelf Sci. 15: 1–16

Steimle, F. W. (1985). Biomass and estimated productivity of the benthic macrofauna in the New York Bight: a stressed coastal area. Estuar. coast. Shelf Sci. 21: 539–554

Steimle, F. W. (1990). Benthic macrofauna and habitat monitoring on the continental shelf of the northeastern United States I. Biomass. NOAA Tech. Report NMFS 86

Steimle, F. W., Caracciolo J., Pearce, J. B. (1982). Impacts of dumping on New York Bight apex benthos. In: Mayer, G. (ed.) Ecological stress and the New York Bight: science and management. Estuarine Research Federation, Columbia, SC, p. 213–224

Stubblefield, W. L., Dicken, M., Swift, D. L. (1974). Reconnaissance of bottom sediments on the inner and central New Jersey shelf (MESA Report No. 1). Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

Walker, H. A., Saila, S. B., Anderson, E. L. (1979). Exploring data structure of New York Bight benthic data using post-collection stratification of samples, and linear discriminant analysis for species composition comparisons. Estuar. coast. mar. Sci. 9: 101–120

This article was presented by K. Sherman, Narragansett, Rhode Island, USA

Manuscript first received: May 4, 1992
Revised version accepted: September 28, 1992