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CHARACTERIZATION OF SANDY BEACH INFAUNA AND NEKTON IN THE VICINITY OF CLIFFWOOD BEACH, NEW JERSEY – 1999.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Cliffwood Beach area of Aberdeen Township, New Jersey is subject to periodic flooding and storm damage. In order to preserve residential, commercial, and recreational facilities the U.S. Army Corps of Engineers, New York District is engaged in a study of alternative erosion and storm control methods. Beach nourishment is one of the leading alternatives to address these issues however, placement of sand during nourishment may have adverse impacts on biological resources at the nourished sites. In order to assess such impacts it is essential to characterize the fauna and sediments of potential nourishment sites to determine if any resources are at risk. To this end, sediments and populations of macroinvertebrates and fish have been sampled in the intertidal and shallow subtidal waters of Cliffwood Beach and an adjacent reference area near Conaskonk Point (Figure 1). This report describes the results of monitoring efforts conducted in 1999.

METHODS

A total of 12 intertidal (Mean Low Water, MLW) and 12 subtidal (MLW-1m) stations were established at intervals along the length of Cliffwood Beach (Fig. 1). The sampling design was repeated at an identically sized reference area located along the western shore of Union Beach starting at Conaskonk Point (Fig. 1). All subtidal station positions are listed in Appendix Table 1. Intertidal stations were established on the same latitude as the corresponding subtidal samples but further inshore.

Samples for infaunal macroinvertebrates were taken with 7.5cm (3 in.) diameter push corer to a depth of 10cm. A single sample was taken at each station in June 1999 and again in September 1999. Samples were sieved over a 0.5mm mesh screen to remove excess fine sediments, placed in cloth bags, and fixed in a 10% formalin solution. After transport to the laboratory, samples were stained with a dilute solution of Rose Bengal, and transferred to 70% ethyl alcohol. Specimens were then separated from the remaining debris by floatation and hand picking, identified by experienced taxonomists to the Lowest Possible Identification Level (LPIL), and counted. Specimen identifications were verified by personnel of the U.S. Army Engineer Waterways Experiment Station (WES).

A sample for sediment grain size analysis was taken at each station with a 2.5cm (1in.) diameter corer and stored in whirl-pac plastic bags. Grain size analysis was performed by both pipette analysis and dry sieving as described by Folk (1968) and Galehouse (1971). Sediments were dispersed in a sodium metaphosphate solution and wet sieved over a 0.062 mm screen. The fine fraction (that passing through the sieve) was analyzed by pipette analysis. The coarse fraction (that collected on the 0.062 mm sieve) was dried, placed in a series of nested screens of 1 phi intervals, and shaken using a Rotap shaker. Samples for sediment total organic content (TOC) were sampled and stored in an identical manner with the exception that the samples were placed on salted ice for transportation and maintained at low temperature until analyzed. TOC was determined by carbon analysis using Method 9600 (USEPA, 1986).

Fish and mobile invertebrates were sampled using a 30.5m (100ft) by 1.8m (6ft), 12.5mm (0.5in) mesh, seine. **Four** to six sites along the beach were sampled on a monthly basis between June and November 1999 (Table 1). Seine hauls were sorted on the beach, and up to 50 individuals of each species were placed in labeled cloth bags, preserved in 10% formalin, and transported to the laboratory. In the lab animals were measured for length and weight and QA/QC identification. If greater than 50 individuals were captured, they were weighed on site using Pesola spring scales to determine overall mass. Total abundance of these species was estimated by dividing total species biomass by the mean weight per fish determined from the 50 animals processed in the laboratory. In the laboratory, fish were fixed in formalin for approximately one week, and then transferred to a 40% isopropyl alcohol and water solution for storage. One individual from other species was sent to WES for identification QA/QC. Collection and subsequent sample processing was performed by Northern Ecological Associates (NEA).

Community structure was analyzed by calculation of as series of indices including taxa richness, Shannon-Weiner diversity (H'), Pielou's Evenness (J'), and Simpson's

Dominance (D). All calculations were made in base e using the Plymouth Routines in Multivariate Ecological Research (PRIMER) statistical package. Assemblage species structure was examined by the ordination technique Nonmetric Dimensional Scaling (NMS) using the PCORD statistical package. NMS runs were using Euclidean distance as the distance measure and log(X+1) transformed abundance of all taxa comprising 1% or more of total abundance. A stress value (a goodness of fit measure) of less than 0.20 was considered to be necessary to reliably interpret the ordination. An r-value of 0.4 or – 0.4 was required for interpretation of species-axis correlations.

Infaunal abundance and taxa richness data were analyzed by Analysis of Variance (ANOVA) employing a nested two-way repeated measures design. Main factors included site (Cliffwood Beach or Reference Area) and date (June or September) with depth nested within site. Date was the repeated measure All data were tested for normality and homogeneity of variance prior to ANOVA. A logarithmic transformation ($\log_{10}$ X+1) was required for abundance and 4th-root transformation ($X^{1/4}$) was required for taxa richness. When the depth(site) by date interaction factor was significant, the main effects and other interactions could not be interpreted (Zar, 1996) and linear contrasts were performed to determine differences between depths among sites over time. The Bonferroni adjustment was used to correct for multiple comparisons ($p = 0.05/n$; n = number of contrasts). If the depth(site) by date interaction was insignificant ($p>0.05$), *a posteriori* statistical power and minimal sample size were calculated. A power value of 0.80 was required to conclude that there was, in fact, no difference present. All analyses were performed using the JMP (SAS Institute) statistical package.

RESULTS

Infauna

A total of 107 taxa was collected including 21 taxa which constituted 1% or more of total abundance (Table 3 and Appendix Table 2). There were generally more taxa at the reference area than Cliffwood Beach and more in June than September. There was no difference in the total number of taxa collected at intertidal or subtidal depths. Annelids dominated the collections comprising 14 of the 21 most abundant taxa and 52 taxa overall. Crustaceans were the next most important group represented by 32 taxa, three of which were among the abundance dominants. Crustacean taxa included 19 amphipods and 5 isopods with the remainder being mostly crabs. Molluscs provided 24 taxa (11 bivalves, 4 gastropods and a nudibranch) three of which were among the abundance dominants. The six most abundant taxa (in order of abundance) were the polychaete *Polydora cornuta*, the oligochaete *Tubificoides wasselli*, turbellarians, the amphipod *Ampelisca abdita*, and the polychaetes *Streptosyllis verrilli* and *Streblospio benedicti*.

Diversity index values varied only slightly among sites and depths (Table 3). Shannon-Weiner's diversity index (H') ranged from 2.73 to 2.93 at Cliffwood Beach and 2.44 to 2.89 at the Reference area in June 1999. In each case diversity was higher at subtidal than intertidal depths. In September 1999, H' values ranged from 2.13 to 2.44 at Cliffwood Beach and 2.29 to 2.56 at the Reference area. Once again values for subtidal samples were higher than intertidal samples. In contrast, at the reference area, September H' values were higher for intertidal than subtidal samples. Values for Pielou's evenness index (J') mirrored those of H' with very slight differences between sites and depths and the same pattern of differences between depths during each collection date (Table 3). Differences among Simpson's dominance index values (D) were also very slight and their pattern of difference between depths was precisely the opposite that of H' and J'. For example, Cliffwood Beach values for H' and J' were higher in subtidal than intertidal samples in June 1999, while D values for this date were higher in intertidal than subtidal samples.

Analysis of Variance (ANOVA) of taxa richness (taxa/sample) data indicated significant differences ($p<0.05$) among depths within sites over time, i.e., the interaction factor was significant (Table 4). Linear contrasts of depth(site) by date means detected significant ($p<0.012$) differences between Reference area samples in June and Cliffwood Beach samples in September. At the Reference area taxa richness was higher in subtidal samples than intertidal samples (Figure 2). The same was true for the Cliffwood Beach samples in September (Figure 2). ANOVA of abundance data resulted in an insignificant depth(site) by time interaction, however, statistical power of the test was too low (~50%) to reliably interpret the results. Calculation of minimal sample size suggests that a total of 104 samples would have been required to achieve the necessary statistical power. This would mean increasing sample size to between 13 and 15 samples per depth and site. Plots of the abundance data suggest that values varied among dates and inconsistently among depths (Figure 3). Abundance values of 3,000-4,000 animals/m^2 were found at Cliffwood Beach in the intertidal area and both Reference area depths in June, but less than 2,000 animals/m^2 were present in the Cliffwood Beach June subtidal samples, all September samples (both sites).

Species composition differed more between depths and sampling dates than between sites (Table 2). For instance, *Polydora cornuta* and Turbellaria (LPIL) comprised greater proportions of intertidal than subtidal abundance at both sites. In contrast, *Tubificoides wasselli*, *Streptosyllis verrilli* and *Streblospio benedicti* consistently made up higher proportions of subtidal than intertidal abundance. Species with distinctive seasonal (sampling date) distributions included the polychaete *Pygospio elegans* and the soft-clam, *Mya arenaria.* Both species were dominant primarily in June. The only species that seemed to differ in its distribution among sites was the amphipod *Corophium tuberculatum*, which was most dominant at the Reference area.

Ordination of the species composition data was successful with a stress value of 0.16 (Table 6). The greatest difference between samples appears to have been between depths rather than sites or collection dates. Most intertidal samples (open symbols) ordinated low on Axis 1 while most subtidal samples (filled symbols) are positioned slightly higher this axis (Figure 4). There is substantial overlap between sites and collection dates within this distribution. Eight species were significantly and positively ($p>0.4$) correlated with Axis 1 including *S. benedicti, M. ambiseta, T. wasselli, I. obsoleta,* and *S. verrilli*. Only Turbellaria (LPIL) was significantly and negatively associated with Axis 1. Species most significantly and positively associated with Axis 2 were *P. cornuta, H. heteropoda, P. elegans,* and *H. filiformis* (Table 6).

Sediments

Sediments at both sites can be classified as gravelly sands with the sand component being predominately medium and fine sands (Table 4). Intertidal sediments tended to be somewhat finer than subtidal sediments although the proportion of gravel was always higher in intertidal than subtidal samples. Silt and clay content (fines) was generally low, less than 8%, with the exception of the reference area samples from September. Fines made up 27-34% of the reference area sediments at this time. The reason for this increase in fines is unclear. Total organic carbon of the sediments was also low, again with the exception of September Reference area samples. Most sediments had less than 1% organic content (10,000mg/kg dry-weight), whereas the September Reference area samples had values of 1.4% and 8.9% for subtidal and intertidal sediments, respectively (Table 4).

Nekton

DISCUSSION

Intertidal sandflats and estuarine beach fauna have been studied for a number of sites in New England and the Mid-Atlantic regions. Sanders et al. (1962) have described infauna of intertidal fine sands in Barnstable Harbor, Massachusetts. Dominant taxa were the clam *Gemma gemma* and variety of polychaetes including *Heteromastus filiformis, Pygospio elegans,* and *Streblospio benedicti*. Abundances of these assemblages ranged from 7,000 to 355,000 animals/m^2. Whitlach (1977) further examined benthic assemblages in this same area and found that *G. gemma* was most abundant on clean sands, while the dominant polychaetes were more abundant on muddy sands. Abundances varied from 2,000 to 52,000 animals/m2 in muddy sands and as high as 197,000 animals/m2 where *G. gemma* was present. Diversity (H') averaged about 2.0 and was highest in spring months (February to March). Most taxa reached peak abundance in summer (May-June) however a few species such as *Mya arenaria* and

Tharyx sp. were most abundant in fall (September –October). Dominant taxa at intertidal sandflats in Nova Scotia were *M. arenaria, Macoma balthica, Nereis diversicolor,* and *Spio setosa* with *G. gemma, Arenicola marina,* and hydrobid snails particularly abundant in protected areas (Emerson and Grant, 1991). Schull (1997) found that Groton, Connecticut sand flats were dominated by fourteen species of polychaetes including *Polydora cornuta, Streptosyllis arenae*, and *Pygospio elegans*. Maurer and Aprill (1979) followed seasonal fluctuations in intertidal invertebrates at a protected site on Cape Henlopen, Delaware. Ranging from 341 to 1333 animals/m2, abundance was high between winter and early summer of the first year of sampling and low until late fall-early winter of the third year. Dominant taxa *included Neohaustorius biarticularis, Scolplos fragilis* (=*Leitoscoloplos*), *H. filiformis, G. gemma, I. obsoleta, Limulus polyphemus*, and *Saccoglossus kowalevskii*.

While the subtidal ecology of the Raritan Bay estuary has been extensively studied (e.g., Dean and Haskin, 1964; Dean, 1975; Kastens et al., 1978; Berg and Levinton, 1985; Cerrato et al., 1989; Steimle and Caracciolo-Ward, 1989;Wilk et al., 1996), surprisingly little attention has been paid to the areas intertidal sediments, benthos and shallow-water nekton. Only two studies of intertidal benthos have been identified as of this date, Simeone (1977) and Ettinger (1996).

Simeone (1977) examined six sites along the western side of Sandy Hook in November 1975. Each site was sampled at high tide, low tide, and an intermediate level using a 12.5cm corer and sieving the samples through 1mm screens. Three of the sites were characterized as “protected” from wave action and the remaining three as “exposed.” Sediments ranged medium sand at the protected sites to coarse sand at the exposed sites. Protected sites generally had far greater abundance and more taxa than exposed sites particularly at high tide and intermediate tide levels (Table 7). There is also evidence for a gradient in abundance and numbers of taxa with tidal level with highest values occurring in the high tide strata. Species composition was very similar for two of the three protected sites (Stations 1 and 2) with *Gemma gemma* the overwhelmingly numerical dominant. *Mya arenaria*, hydrobid snails, *Tharxy acutus*, and oligochaetes were next most abundant taxa. At the third protected site (Station 4) *Haploscoloplos fragilis* (=*Leitoscoloplos*) and *G. gemma* were the most abundant species. Exposed sites (Stations 3, 5, and 6) were dominated by primarily by oligochaetes and nematodes although a number of horseshoe crabs (*Limulus polyphemus*) and insect larvae were encountered at Station 6 in high tide level. Varying widely and inconsistently, diversity (H') and evenness values ranged from 0.14-1.33 and 0.16-1.00 respectively (Table 7).

Ettinger (1996) examined infaunal and sediment distributions at three tide levels from Belford to the western side of Point Comfort and also at Laurence Harbor. Sampling transects were established at 161m intervals and duplicate 7.5cm diameter cores were taken at 30m, 76m, and 183m distances from the shoreline. The first two stations represented intertidal depths while the third was subtidal. Samples were taken in the vicinity of Keansburg and Port Monmouth in September 1994 and at these sites and Laurence Harbor between May and September of 1995.

Sediments were predominately muddy fine and very find sands in 1994 and medium and coarse sands in 1995. Changes in sediment grain size were attributed to a strong storm in 1994. During 1994 there was a tendency for abundance to be lowest at subtidal stations in both the Keansburg and Port Monmouth portions of the study area (Table 8). In 1995 this pattern of distribution was reversed with subtidal stations tending to have the highest abundance values at Keansburg and Port Monmouth. Intermediate stations had the highest abundances at Laurence Harbor in 1995. Total numbers of taxa varied inconsistently among stations throughout the study but values were lower in 1995 than 1994 and lower at Laurence Harbor than Keansburg in 1995 (Table 8). Biomass was measured only in 1995. Its distribution varied inconsistently among stations, but was far higher at intertidal stations in Keansburg samples than either of the other sites. Species composition varied primarily among years. In 1994 the Keansburg and Port Monmouth areas were dominated by *M. arenaria* (47-62%) and *H. filiformis* (10-16%). The gastropod *Ilyanassa obsoleta* (5%) was dominant primarily in Keansburg stations and the polychaetes *Caulleriella killariensis* (8%) and *Leitoscoloplos* sp. (5.7%) were important at Port Monmouth stations. In 1995 the clam *G. gemma* was the primary dominant at both Keansburg (58%) and Port Monmouth (61%). Other dominant taxa at Keansburg included enchytraeid oligochaete worms (15.4%), *Gammarus lawrencianus* (11.7%), and the archiannelid *Protodrilides*. At Port Monmouth the only other dominant taxon was the polychaete *T. acutus* (13.6%). Species composition at Laurence Harbor was similar to Port Monmouth with the only dominants being *G. gemma* (65%) and *T. acutus* (11.3%). Species composition did not appear to differ greatly among stations along the intertidal-subtidal gradient.

While many of the taxa characterizing the Simeone (1977) and Ettinger (1996) study sites were also dominants in samples from the present study, the relative importance of the most abundant species was very different. The previous study areas were dominated primarily by bivalve taxa (*G. gemma* and *M. arenaria*), whereas, Cliffwood Beach and the reference site were dominated by annelid taxa (Table 2). Total numbers of taxa, taxa richness, and diversity values were far greater in the present study sites than either of the previous studies (Table 3 and Figure 2). Abundance of both Cliffwood Beach and the reference area were similar to those reported by Ettinger (1996) and all values reported by Simeone (1977) except for those from protected high water stations (Table 7).

Differences in sediments and benthic assemblages reported in these studies are most likely due to the degree of exposure to wave action of each sampling area and to inter-annual variability. As seen in the results of Simeone (1977), exposed sites had coarser substrates and a less abundant, less diverse benthic assemblage. Since "exposure" to wave action is a function of fetch, the longest uninterrupted distance over which wind passes over water, the degree of exposure of Raritan Bay sites depends on the orientation of the shoreline to prevailing winds. Virtually all of the sites are protected from oceanic swells by Sandy Hook Long Island, therefore, only winds over the immediate bay area should impact the beaches. Prevailing winds are strongest from the northwest in winter and the south and southwest in summer (Lettau et al., 1976). Since the southern shore of the bay is protected by the mass of New Jersey from southerly summer winds, beaches with the greatest fetch to the northwest, i.e., exposed to greatest extent to winter winds, on average, would be most likely to be affected by wave action. Placing the existing study sites in order by this criteria results in the “exposed” Sandy Hook Bay being the most affected followed, in order, by Port Monmouth, Keansburg, Union Beach, Laurence Harbor, reference area (present study), and “protected” Sandy Hook Bay. With the exception of the Laurence Harbor site, this order matches the gradients in diversity and numbers of taxa, as well as the degree of fineness of the sediments from the various study areas. Croker (2977) has reported similar results from intertidal sandflats in New England.

What this arrangement does no account for are periodic atypical strong storms from the northeast (“northeasters”). In this case the exact tract of the storm would determine which sites were most exposed. It seems probable that the order of exposure would be reversed for all sites except the “protected” areas of Sandy Hook Bay. One of these storms was most likely responsible for the detected by Ettinger (1996) in 1994-1995. Recovery after the storm was rapid but altered sediment texture resulted in a change in species composition.

Inter-annual variability in salinity can also have profound effects on intertidal benthos. On average, salinity along the southern shore of the bay ranges above 24ppt (Duedall et al., 1979), however, during periods of exceptionally high runoff, these levels may be reduced. The sites most affected would be those closest to the head of the bay (Laurence Harbor and the Cliffwood Beach) and the areas least affected would be those closest to Sandy Hook. While no reduction was encountered during the described studies, lowered salinity could result in temporary rearrangement of the species list with oligo-mesohaline species (e.g., *S. benedicti, Hypereteone heteropoda, M. ambseta*) being favored over meso-polychaline taxa (e.g., *P. cornuta, T. wasseli, M. arenaria, G. gemma*). Likewise, changes may occur due to inter-annual variation in individual species abundances unrelated (or not immediately attributable) to purely physical or chemical factors. The abundance of most estuarine infauna are highly variable over time reflecting differing reproductive and settlement success which can be related to variations in food supply, competition from other infauna, predation, and other factors. A good example of this is the report of Dorjes et al. (1986). They followed fluctuation in intertidal species abundances on a North Sea tidal flat for ten years. Total infaunal abundance and individual species abundances (e.g. *P. elegans, H. filiformis,* and *Tubificoides* sp.) varied as much as two orders or magnitude over the period of the study. Relative abundances (%) varied less but could still differ by an order of magnitude between years.

Differences among Raritan Bay beach infauna, appear to be within the normal range of variation in abundance, diversity, and species composition found for other New England and Mid-Atlantic sandflat habitats. Infaunal species composition was particularly similar to that of the Groton, Connecticut sandflat studied by Shull (1997). In both studies the polychaetes *Polydora cornuta, Pygospio elegans*, and a species in the syllid polychaete genus *Streptosyllis* were among the most abundant organisms.

While intertidal infauna are important as forage for shorebirds and shallow-water nekton, it is assumed that recovery after nourishment will be relatively rapid and these resources will not be significantly affected. The recovery period cannot be precisely estimated at this time, however, Dauer and Simon (1976) have reported recovery of sandflat infauna in Tampa Bay, Florida within 11 months of complete defaunation due to red tide. This is in sharp contrast to results from experiments with defaunated sediments. Grant (1981) used experimentally defaunated sediment plugs to measure colonization rates of crustacean infauna on a South Carolina sandflat and estimated a recovery rate of approximately one month. Smith and Brumsickle (1985) performed a similar type of experiment in a Barnstable Harbor, Massachusetts and determined that ambient abundance and numbers of taxa were reached within 41 days as did Ragnarsson (1995) working in Scotland. Differences in recovery rates between these studies and that of Dauer and Simon (1976) are probably due to the nature and timing of the disturbance. The experimental studies followed recovery after a disturbance (usually freezing of the sediments) which had no long-term effect on recolonization. They were also conducted during peak periods of infaunal reproduction and recruitment. Dauer and Simon (1976) followed recovery after a red tide; the disturbance occurred in late summer, well after the peak of infaunal recruitment (winter-spring) and resulted in organic enrichment (due to an associated fish kill). Both factors would tend to retard normal recovery. Likewise slow recovery rates (1-2 years) after nourishment of high energy beaches have reported by Reilly and Bellis (1983) and Rakocinski et al. (1996). Both involved operations where large amounts of mud were present in the nourishment materials which would also tend to retard recovery. Recovery rates from most high-energy beach nourishment studies range from 2 to 7 months (e.g., Saloman and Naughton, 1984, Van Dolah et al., 1994; Jutte et al., 1999a, 1999b; USACE, 1999).

In conclusion, it appears that no sensitive biological resources are at risk in the project area. Abundance of potential fisheries species such as the soft-clam *Mya arenaria* are low and results from Ettinger (1996) indicate that soft-clam populations in this region are vulnerable to strong storms and therefore their survival naturally variable from year to year. Since the area of beach to be nourished is small, the period of nourishment operations short (2 weeks) and operations are scheduled for late summer–early fall time period, there should be minimal impact to organisms utilizing infauna as forage. There should also be adequate time for recovery by natural recruitment before the next major period of utilization (spring-summer of the following year).

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Figure 1. Cliffwood Beach Area Map.

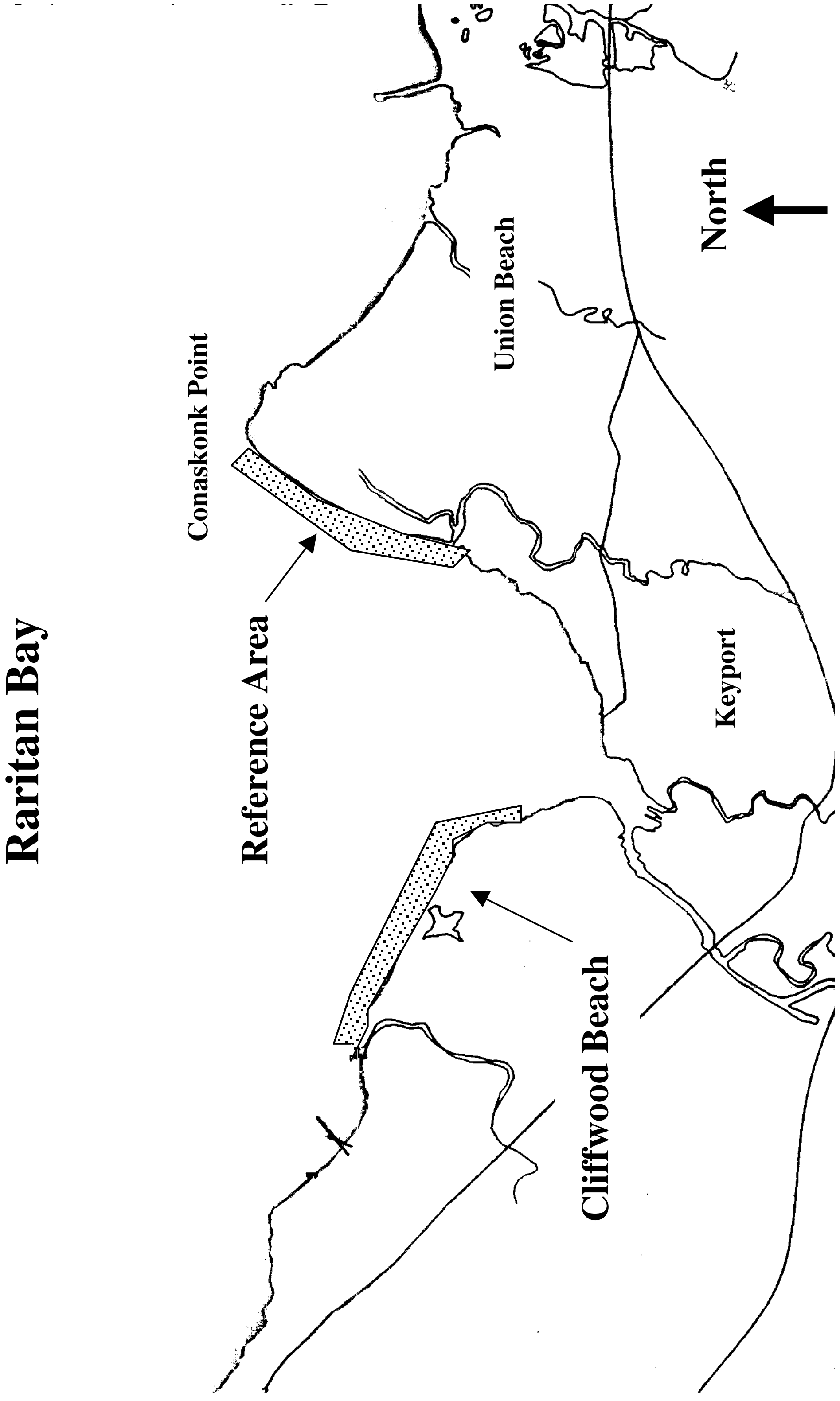
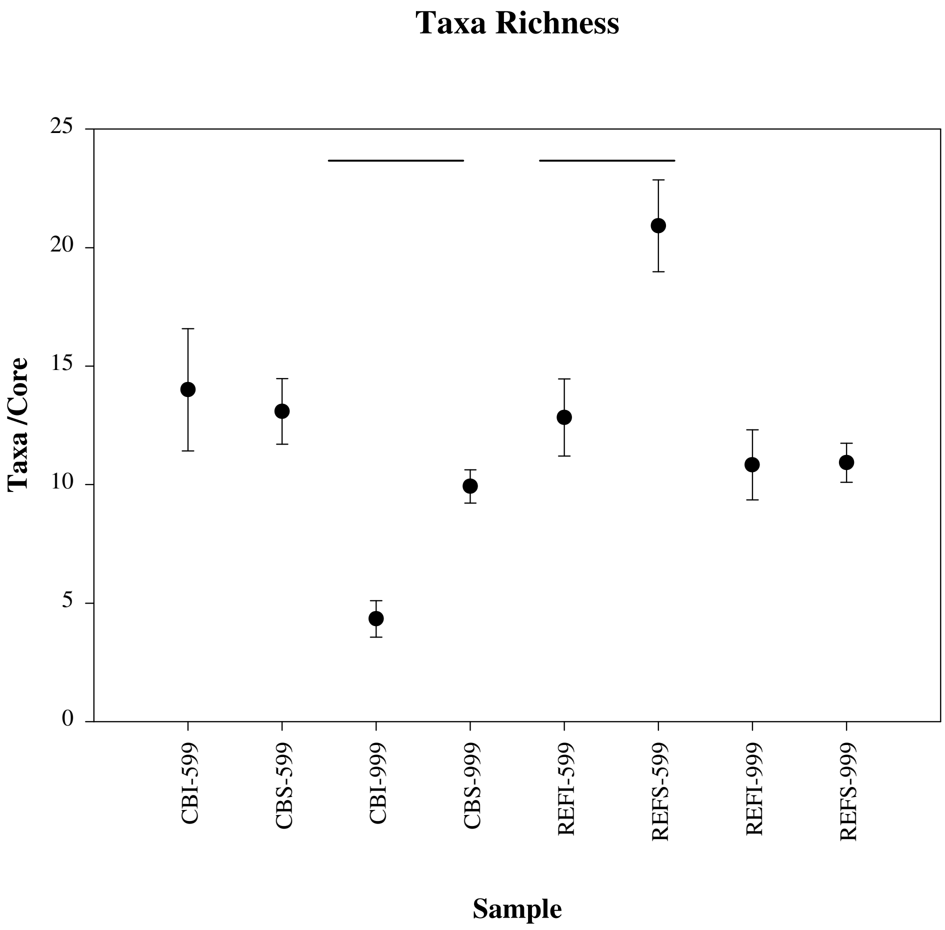


Figure 2. Taxa Richness (Mean Taxa/Core ± SE)*



*Line over values indicates where significant ($p<0.0125$) linear contrasts were detected.

Figure 3. Abundance (Mean Number of Animals/m2 ± SE)

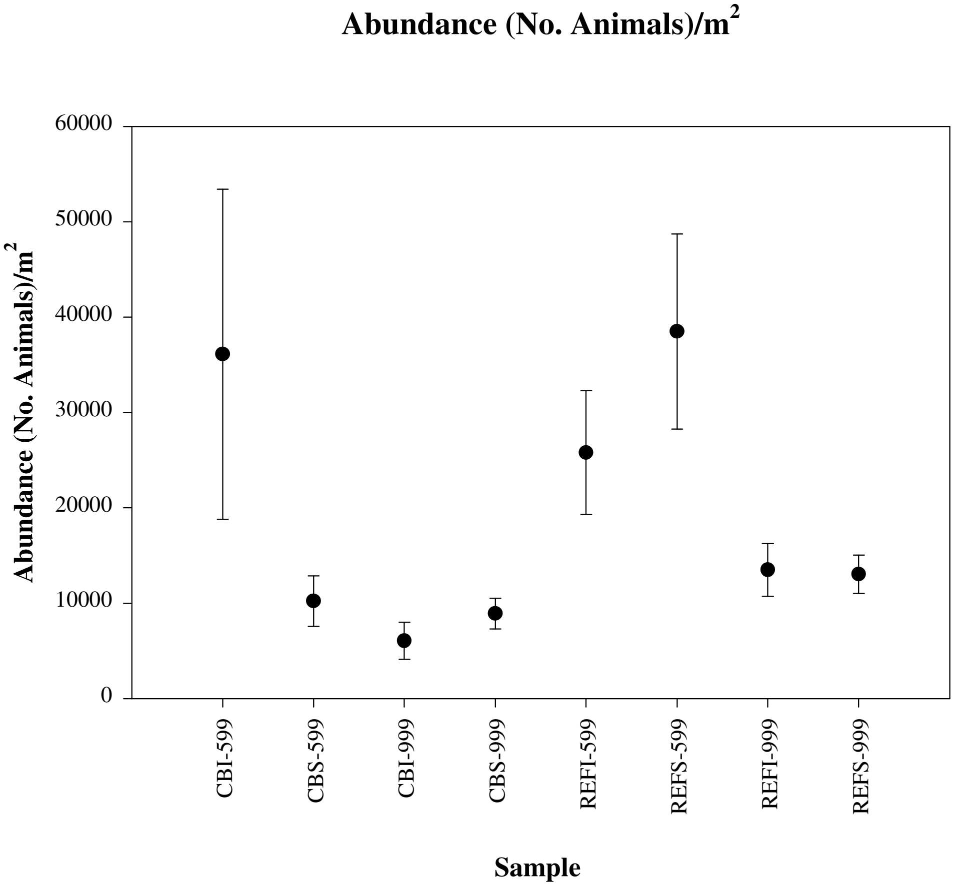


Figure 4. NMS Plot for Infaunal Data

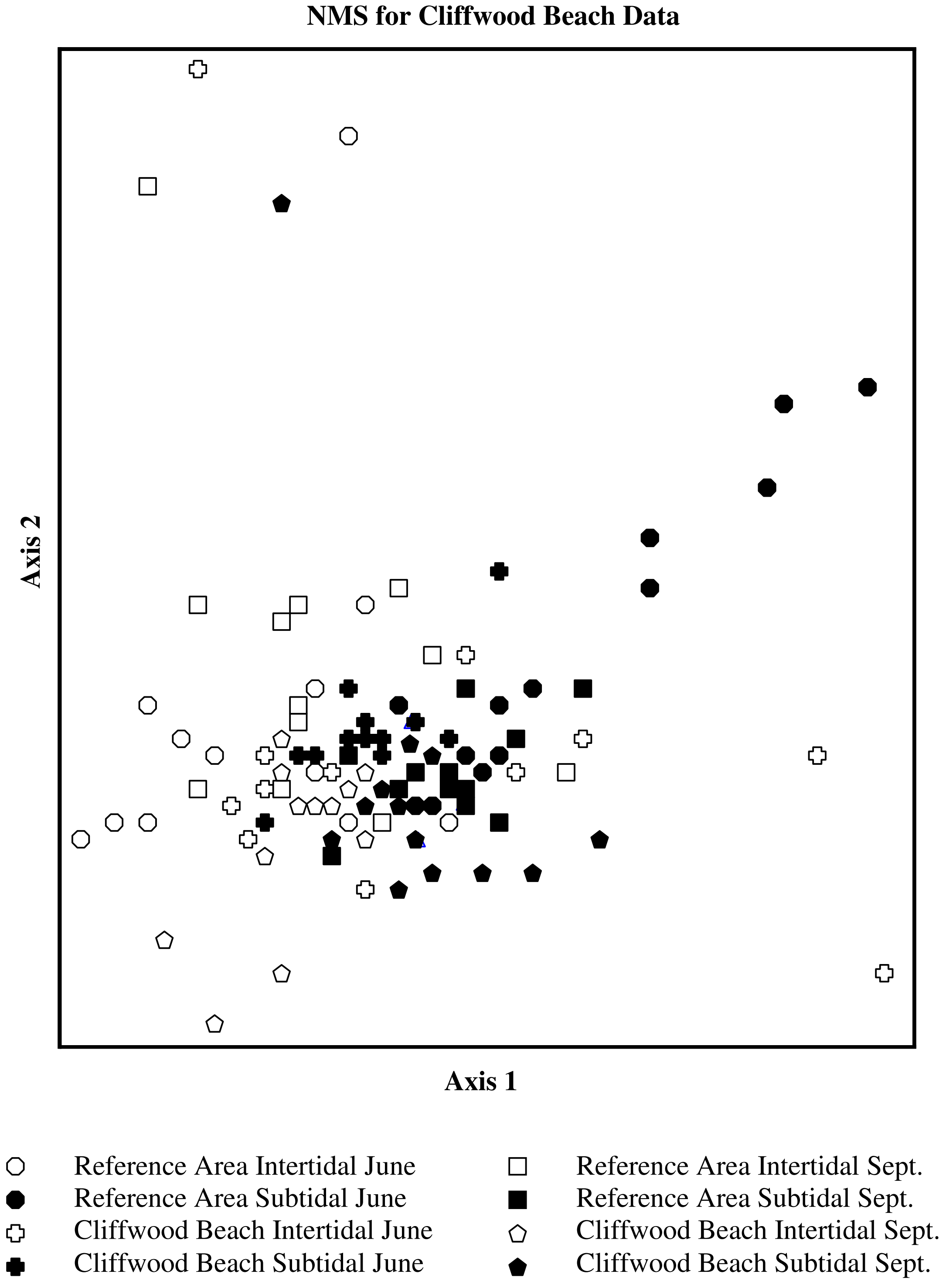


Table 1. Sampling Dates.

Type of Data Collected	Collection Dates
Sediment -- Grain Size	June 1999 (Effort 1)
Sediment -- TOC	June 1999 (Effort 1)
Infauna	June 1999 (Effort 1)
Sediment -- Grain Size	Sept 1999 (Effort 2)
Sediment -- TOC	Sept 1999 (Effort 2)
Infauna	Sept 1999 (Effort 2)
Finfish	June 22-24, 1999 (1)
Finfish	July 22-23, 1999 (2)
Finfish	August 25-26, 1999 (3)
Finfish	Sept. 23-24, 1999 (4)
Finfish	Oct. 21-22, 1999 (5)
Finfish	Nov. 18-19, 1999 (6)
Water Quality	Aug. 30-31, 1999
Water Quality	June 22-24, 1999 (1)
Water Quality	July 22-23, 1999 (2)
Water Quality	August 25-26, 1999 (3)
Water Quality	Sept. 23-24, 1999 (4)
Water Quality	Oct. 21-22, 1999 (5)
Water Quality	Nov. 18-19, 1999 (6)

Table 2. Dominant Infaunal Taxa from Cliffwood Beach and Reference Area- 1999. Values are relative abundance (%).

	Cliffwood Beach		Reference Area		Cliffwood Beach		Reference Area		Total
	June	June	June	June	Sept.	Sept.	Sept.	Sept.	
Taxa	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	Total %
Polydora cornuta	27.02	2.50	12.05	5.13	-----	0.41	29.09	0.42	12.56
Tubificoides wasselli	6.33	7.14	2.27	8.83	15.06	21.52	16.51	32.82	10.74
Turbellaria (LPIL)	0.71	0.18	40.89	0.33	13.25	1.64	1.76	0.14	7.99
Ampelisca abdita	0.86	10.54	0.21	25.82	-----	-----	0.95	0.14	7.58
Streptosyllis verrilli	3.29	13.93	0.99	5.79	3.92	19.06	11.10	14.45	6.85
Streblospio benedicti	2.58	10.54	1.42	9.25	1.20	10.45	3.38	14.31	6.09
Pygospio elegans	18.42	-----	2.69	0.38	-----	-----	0.27	-----	4.95
Tubificidae (LPIL)	3.59	6.25	8.58	3.42	0.60	4.51	0.68	3.65	4.25
Mediomastus ambiseta	2.88	2.86	0.14	7.31	-----	0.41	1.08	8.27	3.58
Gemma gemma	5.21	1.43	2.34	0.33	2.41	0.00	2.30	9.40	2.92
Heteromastus filiformis	1.16	0.36	3.19	2.75	0.60	2.05	10.83	1.54	2.77
Mya arenaria	6.07	-----	5.32	0.33	-----	-----	-----	-----	2.43
Ilynassa obsoleta	2.28	1.79	0.35	1.14	0.60	6.76	1.35	3.09	1.81
Tharyx acutus	0.91	13.57	0.43	1.38	-----	2.25	0.27	0.56	1.75
Hypereteone heteropoda	1.52	1.25	3.40	1.38	-----	0.20	1.62	0.28	1.55
Leitoscolplos (LPIL)	0.20	3.04	-----	0.28	26.81	1.43	-----	-----	1.48
Micropthamalus sczelkowii	1.72	1.43	0.14	0.14	3.01	6.15	2.84	0.56	1.35
Paranais littoralis	0.30	1.61	0.21	0.24	3.01	12.70	-----	0.70	1.2
Elasmopus levis	-----	0.89	0.14	3.94	-----	-----	0.81	0.14	1.17
Leitoscolplos fragilis	0.10	1.07	-----	0.05	19.58	1.02	-----	0.84	1.02
Corophium tuberculatum	-----	-----	-----	2.61	-----	-----	2.71	0.56	0.95

Table 3. Summary Infaunal Data.

Site	Cliffwood Beach		Reference Area		Cliffwood Beach		Reference Area	
Date	June	June	June	June	Sept.	Sept.	Sept.	Sept.
Depth	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
Total Taxa	52	39	56	67	18	30	44	39
Abundance (No./m^2)	36101	10231	25778	38495	6066	8916	13502	13008
Taxa Richness	4.86	4.12	5.41	6.25	1.95	3.19	4.52	4.01
Shannon-Weiner-H'	2.73	2.93	2.44	2.89	2.13	2.44	2.56	2.29
Pielou-J'	0.69	0.80	0.61	0.69	0.74	0.72	0.68	0.62
Simpson-D	0.12	0.08	0.20	0.10	0.16	0.12	0.14	0.17

Table 4. Infaunal ANOVA Summary

Taxa Richness

Effect Test

Source	DF	Sum of Squares	F Ratio	Prob>F
Site	1	0.6596	12.6278	0.1747
Depth(Site)	2	0.7318	1.4057	0.4157
Date	1	1.4121	27.0335	0.1210
Site*Date	1	0.0522	0.2007	0.6980
Depth(Site)*Date	2	0.5206	5.9489	0.0038
Error	88	3.38506		

Abundance

Effect Test

Source	DF	Sum of Squares	F Ratio	Prob>F
Site	1	2.9946	1805.032	0.0.150
Depth(Site)	2	0.2817	0.2399	0.8065
Date	1	2.2942	1382.84	0.0171
Site*Depth	1	0.0017	0.0028	0.9624
Depth(Site)*Date	2	1.1747	2.8616	0.0625
Error	88	18.0626		

Power Details

Depth(Site)* Date
Power = 0.5474

Least Significant Number = 103.7

Table 5. Cliffwood Beach Infaunal NMS Results

Final Stress for 2-dimensional solution = 0.16

Species – Axis Pearson-Kendall Correlations*

Taxa	Axis 1	Axis 2
Streblospio benedicti	**0.754**	0.320
Mediomastus ambiseta	**0.720**	**0.411**
Tubificoides wasselli	**0.681**	0.115
Ilynassa obsoleta	**0.609**	0.067
Streptosyllis verrilli	**0.607**	0.136
Ampelisca abdita	**0.567**	**0.472**
Tubificoides (LPIL)	**0.465**	0.345
Elasmopus levis	**0.444**	**0.415**
Heteromastus filiformis	0.381	**0.514**
Corophium tuberculatum	0.380	0.354
Tharyx acutus	0.367	0.042
Mya arenaria	0.348	0.393
Microphthamalus sczelkowii	0.238	0.009
Gemma gemma	0.227	-0.231
Pygospio elegans	0.224	**0.536**
Polydora cornuta	0.177	**0.706**
Hypeteone heteropoda	0.166	**0.688**
Paranais littoralis	0.080	-0.311
Leitoscoloplos (LPIL)	-0.062	-0.326
Leitoscoloplos fragilis	-0.222	-0.285
Turbellaria (LPIL)	**-0.422**	-0.176

*Values in **bold** significant ($-0.4 < r > 0.4$)

Table 6. Summary Sediment Data

Data	June CBI	June CBS	June REFI	June REFS	Sept CBI	Sept CBS	Sept REFI	Sept REFS
% Gravel	16.38	4.75	24.32	17.55	14.13	3.38	17.96	7.68
% Very Coarse Sand	2.96	0.82	3.08	2.15	2.22	0.45	7.64	1.91
% Coarse Sand	6.98	1.89	10.40	6.16	8.11	1.74	11.65	3.20
% Medium Sand	35.58	43.52	50.71	53.70	42.87	34.43	17.16	23.29
% Fine Sand	30.57	44.82	7.12	17.60	22.11	51.13	8.31	27.02
% Very Fine Sand	5.15	1.82	0.77	1.32	3.19	5.64	3.28	9.20
% Silt/Clay	1.93	2.34	3.61	1.50	7.38	3.22	34.00	27.70
Median grain size (mm)	1.74	2.00	1.28	1.45	1.56	2.24	2.50	2.66
TOC (mg/kg dw)	3278	1856	8977	2729	1602	1515	89833	14274
TOC (as %)	0.33	0.19	0.89	0.27	0.16	0.15	8.98	1.43

CBI – Cliffwood Beach Intertidal
CBS – Cliffwood Beach Subtidal
REFI – Reference Area Intertidal
REFS – Reference Area Subtidal

Table 7. Summary Data from Simeone (1977)

Parameter	Depth	Protected (1)	Protected (2)	Protected (4)	Exposed (3)	Exposed (5)	Exposed (6)
Abundance No./m^2*	High Water	35,936	368,323	407	489	6,437	14,179
	Intermediate	13,364	10,267	2,770	4,889	3,748	2,934
	Low Water	5,378	245	1,711	81	------	407
Taxa (Total)	High Water	9	17	4	2	3	6
	Intermediate	7	3	3	3	3	4
	Low Water	3	1	1	2	------	3
Diversity (Evenness)	High Water	0.71 (0.32)	0.45 (0.16)	0.67 (0.97)	1.33 (0.96)	0.37 (0.33)	0.77 (0.48)
	Intermediate	1.31 (0.67)	0.89 (0.81)	0.14 (0.20)	0.47 (0.43)	0.58 (0.84)	0.65 (0.47)
	Low Water	0.21 (0.19)	0.58 (0.84)	0.69 (1.00)	------	------	0.95 (0.86)

*Values calculated from raw data
(No.) = Station Number
------ = No Animals
Diversity = H’; Evenness = J

Table 8. Summary Data from USACE (1996)

		Keansburg		Port Monmouth		Laurence Harbor	
Parameter	Depth	1994	1995	1994	1995	1994	1995
Abundance No./m^2	A	6489	4547	5083	256	------	2706
	B	6484	5595	8678	5168	------	4125
	C	3510	8407	3559	11652	------	2786
Taxa (Total)	A	37	21	30	9	------	12
	B	30	26	21	24	------	20
	C	35	24	21	22	------	10
Biomass g/m^2	A	------	229.1	------	2.0	------	19.5
	B	------	334.4	------	56.0	------	21.1
	C	------	12.4	------	17.3	------	17.3

------ = No Data

Table 7. Dominant Nekton Taxa from Cliffwood Beach and Reference Area- 1999. Values are relative abundance (%).

Table 6. Nekton Diversity Index Values.

Table 7A. Nekton Taxa Richness ANOVA Summary

Appendix. Subtidal Station Positions

Station	Latitude	Longitude
CB-S1	40 27.134	74 13.089
CB-S2	40 27.118	74 12.986
CB-S3	40 27.057	74 12.915
CB-S4	40 27.059	74 12.772
CB-S5	40 26.999	74 12.488
CB-S6	40 26.966	74 12.619
CB-S7	40 26.878	74 12.532
CB-S8	40 26.867	74 12.484
CB-S9	40 26.797	74 12.450
CB-S10	40 26.797	74 12.433
CB-S11	40 26.746	74 12.461
CB-S12	40 26.691	74 12.336
REF-S1	40 27.494	74 10.929
REF-S2	40 27.445	74 10.980
REF-S3	40 27.411	74 11.026
REF-S4	40 27.362	74 11.059
REF-S5	40 27.309	74 11.105
REF-S6	40 27.281	74 11.143
REF-S7	40 27.170	74 11.263
REF-S8	40 27.101	74 11.270
REF-S9	40 27.006	74 11.286
REF-S10	40 26.942	74 11.307
REF-S11	40 26.842	74 11.442
REF-S12	40 26.719	74 11.464

Appendix Table 2. Species Abundances (Number of Animals/m^2)

	June	June	June	June	Sept	Sept	Sept	Sept
Taxa	CBI/m2	CBS/m2	REFI/m2	REFS/m2	CBI/m2	CBS/m2	REFI/m2	REFS/m2
AMPELISCA ABDITA	311	1078	55	9939	0	0	128	18
AMPELISCIDAE (LPIL)	0	0	0	37	0	0	0	0
AMPHIPODA (LPIL)	18	37	311	256	0	0	18	0
AMPHIPORUS (LPIL)	55	0	91	0	0	0	0	0
AMPITHOE VALIDA	840	0	18	55	0	0	0	0
ANTHOZOA (LPIL)	55	0	0	0	0	0	0	0
AUTOLYTUS (LPIL)	0	0	0	0	0	0	18	0
AUTOLYTUS FASCIATUS	0	0	0	0	0	0	18	0
BALANUS (LPIL)	402	73	128	55	0	0	0	0
BALANUS IMPROVISUS	0	0	0	0	18	0	0	0
BOONEA BISUTURALIS	37	0	0	0	0	0	0	0
BRACHIDONTES(LPIL)	55	0	0	0	0	0	0	0
BRANIA CLAVATA	0	91	384	347	0	0	238	0
CAPITELLIDAE (LPIL)	384	128	91	18	0	18	18	55
CAPRELLIDAE (LPIL)	0	0	0	0	0	18	0	0
CAPRELLA (LPIL)	0	73	0	0	0	0	0	0
CHIRODOTEA CAECA	18	0	0	0	0	0	0	0
CIRRATULIDAE (LPIL)	18	0	18	18	0	18	0	18
PECTINARIA GOULDII	0	0	0	0	0	0	18	0
COROPHIUM (LPIL)	0	18	73	1261	0	0	55	0
COROPHIUM TUBERCULATUM	0	0	0	1005	0	0	365	73
CRANGONYX (LIPL)	0	0	0	18	0	0	0	0
CREPIDULA FORNICATA	146	256	18	530	55	91	37	201
CYATHURA POLITA	0	0	0	365	0	0	18	55
DECAPODA (LPIL)	0	0	18	0	0	0	0	0
DRILONEREIS LONGA	0	256	37	128	0	128	18	91
EDOTEA TRILOBA	603	0	146	18	0	18	55	0
ELASMOPUS LEVIS	0	91	37	1516	0	0	110	18
ENCHYTRAEIDAE (LPIL)	0	0	18	0	0	0	0	0
EOBROLGUS SPINOSUS	0	0	0	128	0	0	0	18
ERICHSONELLA (LPIL)	0	0	0	0	0	0	0	18
ERICHTHONIUS BRASILIENSIS	0	0	0	18	0	0	0	0
ETEONE (LPIL)	0	0	91	0	0	0	0	0
HYPERETEONE HETEROPODA	548	128	877	530	0	18	219	37
ETEONE LACTEA	512	37	55	18	0	18	110	18
EUBROLGUS SPINOSA	0	0	0	0	0	0	0	18
EUMIDA SANGUINEA	311	128	91	110	0	0	91	18
EUPLANA GRACILIS	0	0	0	37	0	0	0	0
EURYPANOPEUS DEPRESSUS	0	0	0	0	0	0	201	18
EXOSPHAEROMA DIMINUM	0	0	91	0	0	0	0	0
GEMMA GEMMA	1882	146	603	128	146	0	311	1224
GLYCERA DIBRANCHIATA	18	18	0	0	18	37	37	37
GYPTIS VITTATA	55	0	18	37	0	0	0	0
HARMOTHOE IMBRICATA	0	0	0	37	0	0	0	0
HESIONIDAE (LPIL)	0	0	0	18	0	0	0	0
HETEROMASTUS FILIFORMIS	420	37	822	1060	37	183	1462	201
HYDROIDES DIANTHUS	0	0	0	0	0	0	0	18
ILYNASSA OBSOLETUS	822	183	91	438	37	603	183	402
LEITOSCOLOPLOS (LIPL)	73	311	0	110	1626	128	0	0
LEITOSCOLOPLOS FRAGILIS	37	110	0	18	1188	91	0	110
LIMULUS POLYPHEMUS	37	18	0	0	0	0	18	0
LUMBINEREIDAE (LPIL)	0	0	0	0	0	18	0	0
LYONSIA HYALINA	0	0	0	18	0	0	0	0
MARENZELLERIA VIRIDIS	0	0	0	18	0	0	0	0
MEDIOMASTUS AMBISETA	1041	292	37	2814	0	37	146	1078
MELITA NITIDA	0	18	0	55	0	0	91	18
MERCENARIA MERCENARIA	73	0	55	0	0	0	0	0
MICRODEUTOPIS GRYLLOTALPA	0	0	18	621	0	0	0	0
MICROPHTHALMUS (LPIL)	18	0	91	0	0	0	0	0

Appendix Table 2 (Cont.)

	June	June	June	June	Sept	Sept	Sept	Sept
Taxa	CBI/m2	CBS/m2	REFI/m2	REFS/m2	CBI/m2	CBS/m2	REFI/m2	REFS/m2
MICROPHTHALMUS SCZELKOWII	621	146	37	55	183	548	384	73
MICROPHTHALMUS SP	0	0	0	0	0	0	73	0
AMEROCULODES EDWARDSI	329	55	37	0	0	0	0	0
GAMMARUS MUCRONATUS	18	0	767	0	0	0	0	0
MULINIA LATERALIS	18	0	0	18	0	0	0	0
MYA ARENARIA	2192	0	1370	128	0	0	0	0
MYTILIS EDULIS	73	0	18	0	0	0	0	0
NAIDAE (LPIL)	0	0	37	37	0	0	0	0
NEREIDAE (LPIL)	238	0	0	55	0	0	37	0
NEREIS (LPIL)	0	0	128	0	0	0	0	0
NEREIS SUCCINEA	91	37	128	37	0	0	128	0
NEREIS VIRENS	0	0	37	0	0	0	0	0
NUDIBRANCHIA (LPIL)	0	0	0	55	0	0	0	0
ORBINIIDAE (LPIL)	0	0	292	91	438	18	73	110
OXYURSTYLUS SMITHI	146	0	0	18	0	0	18	18
PAGURIDAE (LPIL)	73	55	55	91	0	0	0	0
PAGURUS ACADIANUS	0	0	0	18	37	18	73	0
PARANAIS LITTORALIS	110	164	55	91	183	1133	0	91
PARAONIDAE (LPIL)	0	0	0	0	0	0	0	18
PARAONIS FULGENS	0	0	238	37	0	0	0	0
PELECYPODA (LPIL)	0	0	0	18	0	0	0	0
PETRICOLA PHOLADIFORMIS	0	0	0	0	0	0	55	0
POLYDORA (LIPL)	0	0	0	18	0	0	0	0
POLYDORA CORNUTA	9756	256	3106	1973	0	37	3928	55
PROTODRILUS (LPIL)	0	0	73	0	0	0	0	0
PYGOSPIO ELEGANS	6650	0	694	146	0	0	37	0
RHYNCHOCOELA (LPIL)	91	55	0	37	37	18	128	0
SABELLA MICROPHTHALMA	18	0	0	0	0	0	0	0
SABELLARIA VULGARIS	402	0	18	457	0	0	0	110
SCOLELEPIS (LPIL)	0	0	91	37	0	0	0	0
SCOLELEPIS TEXANA	37	530	37	146	0	384	0	146
SPIO SETOSA	146	73	18	804	0	0	0	0
SPIONIDAE (LPIL)	0	18	55	0	0	0	18	0
SPIOPHANES BOMBYX	0	0	0	18	0	0	0	0
STREBLOSPIO BENEDICTI	932	1078	365	3563	73	932	457	1864
STREPTOSYLLIS VERRILLI	1188	1425	256	2229	238	1699	1498	1882
SYLLIDAE (LPIL)	0	0	0	18	0	0	0	0
TELLINA (LIPL)	18	0	0	18	0	0	0	0
TELLINA AGILIS	0	37	0	0	0	0	0	0
THARYX ACUTUS	329	1389	110	530	0	201	37	73
THARYX SP(LPIL)	0	0	0	0	0	18	0	0
TUBIFICIDAE (LPIL)	1297	639	2211	1315	37	402	91	475
TUBIFICOIDES WASSELLI	2284	731	585	3398	914	1918	2229	4275
TURBELLARIA (LPIL)	256	18	10542	128	804	146	238	18
UNCIOLA (LPIL)	0	0	37	0	0	0	0	0
UNCIOLA SERRATA	0	0	0	1133	0	18	18	18
XANTHIDAE (LPIL)	0	0	0	0	0	0	0	18

CBI – Cliffwood Beach Intertidal
CBS – Cliffwood Beach Subtidal
REFI – Reference Area Intertidal
REFS – Reference Area Subtidal