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CHARACTERIZATION OF SANDY BEACH INFAUNA IN THE VICINITY OF UNION BEACH, NEW JERSEY – 1999.

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INTRODUCTION

Sandy beaches along the southern shore of Raritan Bay including that of Union Beach (Aberdeen County, New Jersey) are subject to periodic flooding and storm damage. The U.S. Army Corps of Engineers, New York District, is presently engaged in a study of alternative erosion and storm control methods to preserve residential, commercial, and recreational facilities in this area. 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 waters of Union Beach and an adjacent reference area near Conaskonk Point. This report describes the results of monitoring efforts for infauna conducted in 1999. Results from monitoring of nekton will be reported separately.

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 (Figure 1). The sampling design was repeated at an identically sized reference area located along the western shore of Union Beach starting at Conaskonk Point (Figure 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 (3in.) diameter push corer to a depth of 10cm. A single sample was taken at each reference area station in June 1999 and again in September 1999. Union Beach was sampled only in September. Samples were sieved over a 0.5mm mesh screen to remove 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 Practical Identification Level (LPIL), and counted. Collection and subsequent sample processing was performed by Northern Ecological Associates (NEA). 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 pipette analysis and dry sieving as described by Folk (1968) and Galehouse (1971). In brief, 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).

Community structure was analyzed by calculation of taxa richness, Shannon-Weiner diversity (H’), Pielou’s Evenness (J’), and Simpson’s Dominance (D) indices. 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 design. The main factor was site (Union Beach or Reference Area) and depth was nested within site (intertidal or subtidal). Since there were complete data for only one sample date (Union Beach was not sampled in June), only the September data could be analyzed. After testing for normality and homogeneity of variance, both taxa richness and abundance were 4th-root transformed ($X^{1/4}$). Where the depth within site response was significant ($p<0.05$), linear contrasts were performed between means. The Bonferroni correction ($p = 0.05/n$) was used to adjust p values for multiple comparisons. All analyses were performed using the JMP (SAS Institute) statistical package.

RESULTS

A grand total of 98 taxa was collected including 21 taxa which constituted 1% or more of total abundance (Table 2). There were fewer taxa at Union Beach than the reference area in September. There were also fewer taxa in intertidal than subtidal samples. There were 9 fewer taxa in June reference area intertidal samples than in subtidal samples and 18 fewer in September Union Beach intertidal samples than the corresponding subtidal samples. In September, intertidal samples at the reference area had 5 more taxa than the subtidal samples. Annelids dominated the collections comprising 10 of the 21 most abundant taxa and 52 taxa overall (48 polychaete taxa and 4 oligochaete taxa). Crustaceans were the next most important group represented by 28 taxa, five of which were among the abundance dominants. Crustacean taxa included 17 amphipods and 4 isopods with the remainder being mostly decapods. Molluscs provided 14 taxa (10 bivalves, 3 gastropods, and a nudibranch), four of which were among the abundance dominants. The six most abundant taxa (in order of abundance) were the oligochaete *Tubificoides wasselli*, turbellarians, the amphipod *Ampelisca abdita,* the polychaete *Polydora cornuta*, and the polychaetes *Streptosyllis verrilli* and *Streblospio benedicti*.

Diversity indices varied only slightly among sites and depths (Table 3). Shannon-Weiner's diversity index (H') at the reference area ranged from 2.44 to 2.89 in June 1999 and 2.29 to 2.56 in September. Union Beach values ranged from 2.20 to 2.28. Diversity values appeared to be higher in intertidal than subtidal samples in September at both sites, but were highest in reference area subtidal samples in June. Evenness (Pileou's J') values mirrored those of H' while Simpson's Dominance Index (D) varied in a directly opposite manner. Values for J' were similar, ranging only from 0.59 to 0.73 while D values ranged from 0.10 to 0.25.

Analysis of Variance of infaunal taxa richness (taxa/core) and abundance (number of animals/m^2) data indicated significant differences ($p<0.05$) between depths within sites (Table 4). In both cases, linear contrasts of depth within site means detected significantly ($p<0.025$) greater values in subtidal than intertidal samples at Union Beach, but no significant differences ($p>0.025$) between depths at the reference area (Figures 2 and 3).

Infaunal species composition was similar between the two sites but relative abundance differed among depths (Table 2 and Appendix Table 2). Taxa such as *Tubificoides wasselli, Streptosyllis verrilli, Streblospio benedicti, Mediomastus ambiseta, Ilynassa obsoleta,* and *Crepidula fornicata* were present to a greater extent in subtidal than intertidal samples, whereas, Turbellaria (LPIL), *Polydora cornuta*, and *Heteromastus filiformis* were found in the greatest proportion in intertidal samples. Several taxa seemed to vary in their depth distribution between sites (Table 2). These included *Gemma gemma,* Orbiniidae (LPIL), *Corophium tuberculatum*, and *Unciola serrata* which comprised greater proportions of subtidal than intertidal samples at the reference area but were less abundant or showed no difference in abundance between depths at Union Beach. Tubificidae (LPIL) were most abundant at intertidal depths in the June reference area samples but at subtidal depths in all September samples. The soft clam, *Mya arenaria*, was only present in June samples and primarily at intertidal depths.

NMS ordination reflected the importance of depth distribution over site or date distributions (Figure 4). Regardless of date or site of collection, samples taken at the same depth tended to most like one another. In the NMS plot, the position of intertidal samples (open symbols) is almost entirely in the right hand lower corner (high on Axis 1 and low on Axis 2). Subtidal samples (filled symbols) are found predominately from the middle of the plot to the upper left hand corner (lower on Axis 1 and higher on Axis 2). There were no species distributions positively and significantly (r>0.4) correlated with Axis 1, however, 13 of the 21 dominant taxa were significantly and negatively (r <-0.4) correlated with it, including *M. ambiseta, T. wasselli, S. setosa, U. serrata, S. verrilli,* and *S. benedicti* (Table 6). Taxa most significantly and positively correlated with Axis 2 included *H. filiformis, M. arenaria*, *A. abdita, S. benedicti, M. ambiseta,* and *C. tuberculatum*. Only Turbellaria (LPIL) was significantly and negatively correlated with Axis 2.

Sediments at both sites can be classified as gravelly sands with the sand component dominated by coarse and mediums sands at intertidal depths and by medium and fine sands at subtidal depths (Table 6). This pattern was altered to a large extent by the occurrence of relatively large amounts of silts and clays (>30%) in September at the reference area. This represents a tenfold increase from values for June samples or from the corresponding September samples at Union Beach. The percentage of silt and clays (fines) in June reference area samples was close to 30% at only 1 station, whereas, in September there were 11 stations with more than 30% fines (Table 6). The reason for the increase in fines unclear, however, the proximity of the reference area to the marsh on Conaskonk Point makes erosion of marsh sediments a possible source. Sediment total organic carbon (TOC) contents were higher in intertidal than subtidal samples and were particularly high in samples with high silt and clay contents (Table 6).

DISCUSSION

Intertidal sandflats and estuarine beach fauna have been studied for a number of sites in New England and the Mid-Atlantic region. 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) 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/m^2 in muddy sands and as high as 197,000 animals/m^2 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/m^2, 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 area's 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 at the 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 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%), the amphipod *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 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 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 and 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 (1977) has reported similar results from intertidal sandflats in New England.

What this arrangement does not 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 changes 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 expected for 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 among 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 also were 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 been 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) suggest 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. Union Beach Project Area Map.

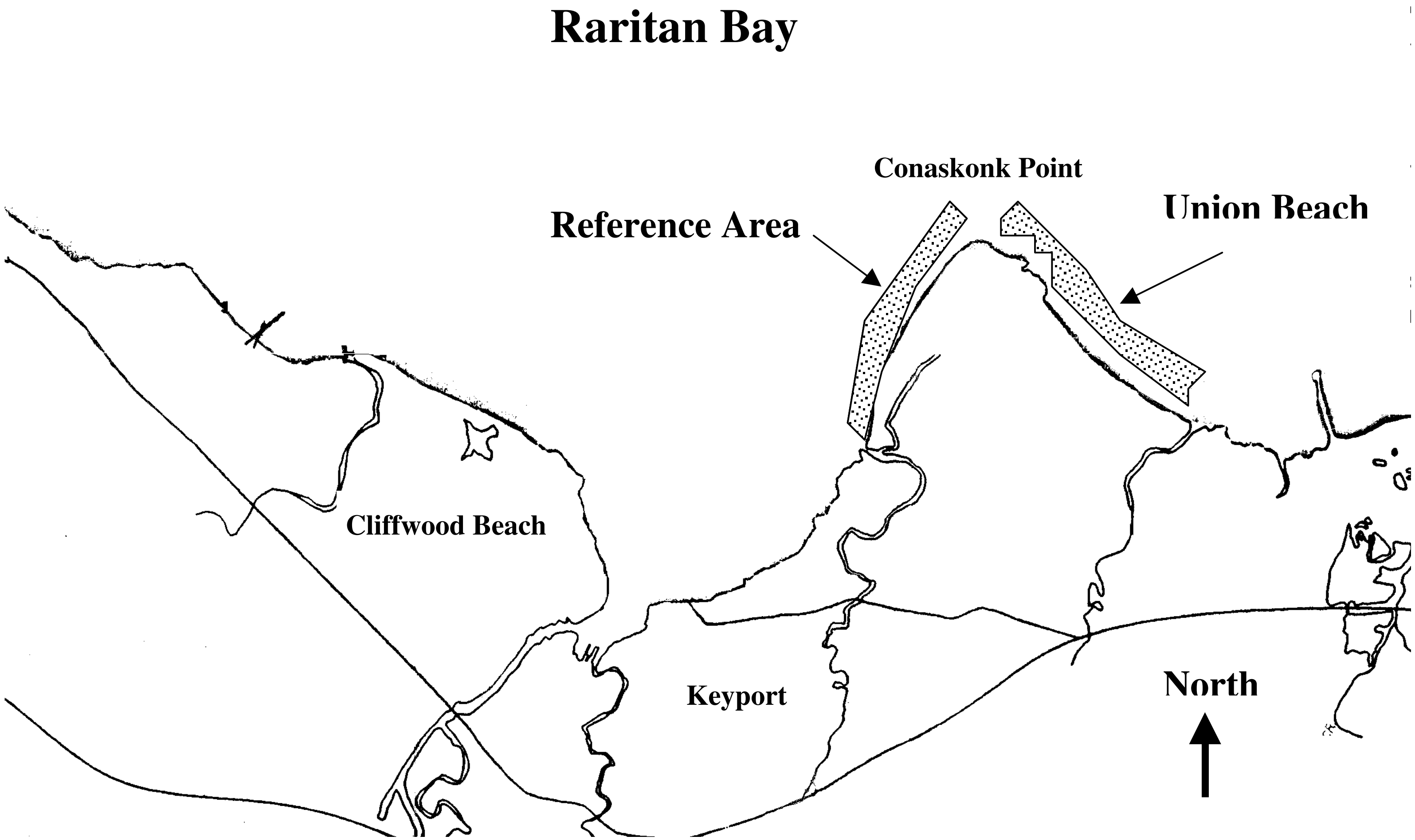
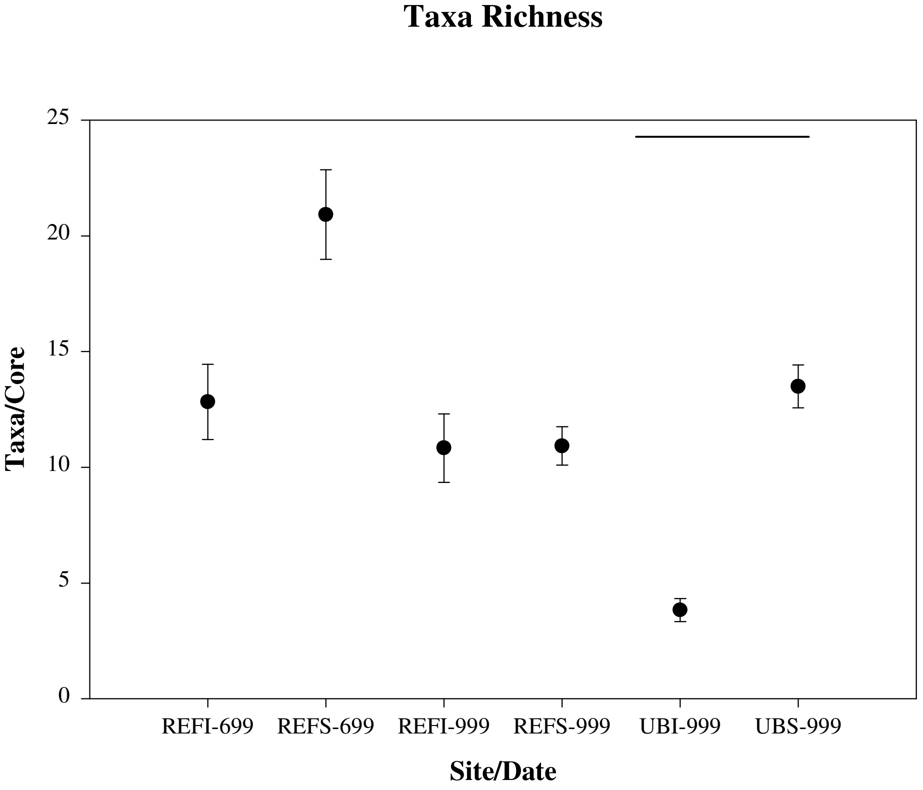
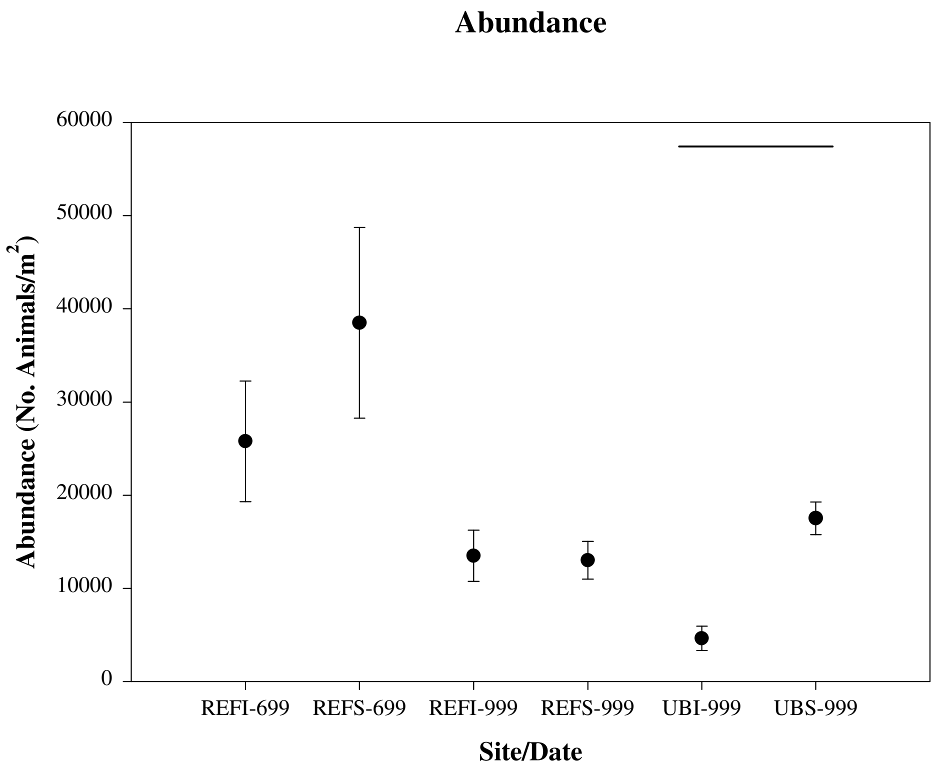

Raritan Bay
Reference Area
Conaskonk Point
Union Beach
Cliffwood Beach
Keyport
North

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



Pairs of mean with line over them significantly different ($p<0.025$) as indicated by linear contrasts. (June values not tested)

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



Pairs of mean with line over them significantly different ($p<0.025$) as indicated by linear contrasts. (June values not tested)

Figure 4. NMS Plot for Infaunal Data

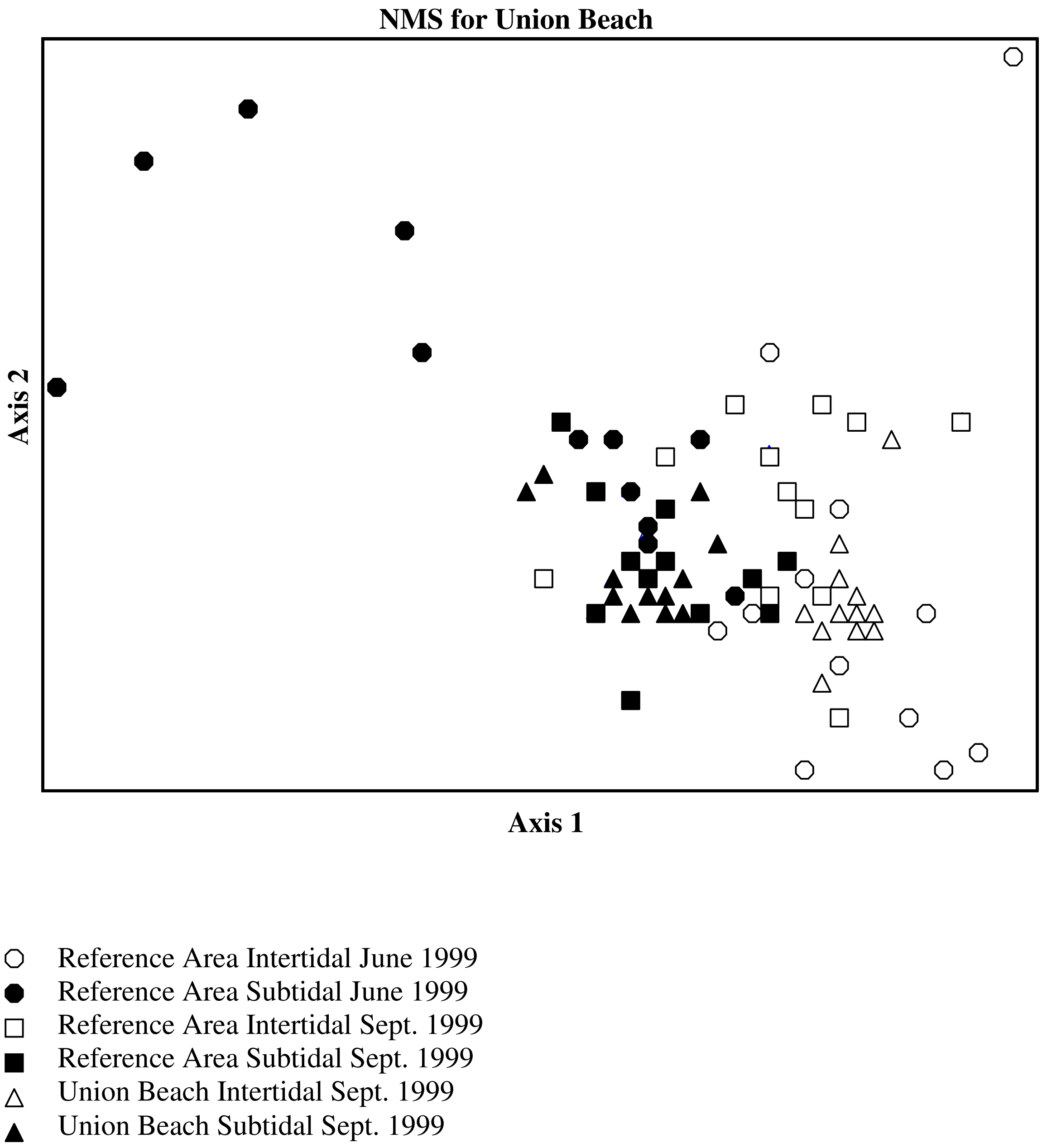


Table 1. Sampling Dates

Type of Data Collected	Site*	Collection Dates
Sediment -- Grain Size	Ref	June 1999
Sediment -- TOC	Ref	June 1999
Infauna	Ref	June 1999
Sediment -- Grain Size	Ref & UB	Sept 1999
Sediment -- TOC	Ref & UB	Sept 1999
Infauna	Ref & UB	Sept 1999
Finfish	Ref	June 22-24, 1999
Finfish	Ref	July 22-23, 1999
Finfish	Ref	Aug. 25-26, 1999
Finfish	Ref	Sept. 23-24, 1999
Finfish	Ref & UB	Oct. 21-22, 1999
Finfish	Ref & UB	Nov. 18-19, 1999
Water Quality	Ref	Aug. 30-31, 1999
Water Quality	Ref	June 22-24, 1999
Water Quality	Ref	July 22-23, 1999
Water Quality	Ref	Aug. 25-26, 1999
Water Quality	Ref	Sept. 23-24, 1999
Water Quality	Ref & UB	Oct. 21-22, 1999
Water Quality	Ref & UB	Nov. 18-19, 1999

* Ref = Reference Area; UB = Union Beach

Table 2. Dominant Infaunal Taxa - 1999. Values are relative abundance (%).

Site	Reference Area		Reference Area		Union Beach		Total
Date	June	June	Sept.	Sept.	Sept.	Sept.	
Depth	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	
Tubificoides wasselli	2.27	8.83	0.79	46.19	16.51	32.82	16.48
Turbellaria (LPIL)	40.89	0.33	12.60	0.31	1.76	0.14	10.24
Ampelisca abdita	0.21	25.82	-----	0.10	0.95	0.14	8.99
Polydora cornuta	12.05	5.13	21.26	0.10	29.09	0.42	8.91
Streptosyllis verrilli	0.99	5.79	8.66	14.81	11.10	14.45	7.84
Streblospio benedicti	1.42	9.25	1.18	5.42	3.38	14.31	6.42
Mediomastus ambiseta	0.14	7.31	-----	5.63	1.08	8.27	4.48
Tubificidae *(LPIL)*	8.58	3.42	0.79	1.77	0.68	3.65	3.93
Heteromastus filiformis	3.19	2.75	2.76	2.61	10.83	1.54	3.66
Gemma gemma	2.34	0.33	5.91	0.42	2.30	9.40	2.31
Orbiniidae (LPIL)	1.13	0.24	26.77	1.36	0.54	0.84	1.81
Elasmopus levis	0.14	3.94	-----	0.94	0.81	0.14	1.63
Corophium tuberculatum	-----	2.61	-----	1.88	2.71	0.56	1.57
Hypereteone heteropoda	3.40	1.38	0.39	0.21	1.62	0.28	1.52
Mya arenaria	5.32	0.33	-----	-----	-----	-----	1.33
Corophium (LPIL)	0.28	3.27	-----	-----	0.41	-----	1.23
Unciola serrata	-----	2.94	-----	1.25	0.14	0.14	1.23
Ilynassa obsoleta	0.35	1.14	0.79	1.25	1.35	3.09	1.21
Spio setosa	0.07	2.09	-----	1.88	-----	-----	1.02
Crepidula fornicata	0.07	1.38	-----	1.67	0.27	1.54	0.95

Table 3. Summary Infaunal Data

Site	Reference Area		Union Beach		Reference Area	
Date	June	June	Sept.	Sept.	Sept.	Sept.
Depth	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
Total Taxa	56	67	23	41	44	39
Abundance (No./m^2)	25778	38495	4641	17521	13502	13008
Taxa Richness	5.41	6.25	2.61	4.09	4.52	4.01
Shannon-Weiner-H'	2.44	2.89	2.28	2.20	2.56	2.29
Pielou-J'	0.61	0.69	0.73	0.59	0.68	0.62
Simpson-D	0.20	0.10	0.15	0.25	0.14	0.17

Table 4. Infaunal ANOVA Summary

Taxa Richness

Effect Test

Source	DF	Sum of Squares	F Ratio	Prob>F
Site	1	0.2843	10.3848	0.0024
Depth[Site]	2	1.7455	31.8806	**<.0001**
Error	44	1.2045		

Abundance

Effect Test

Source	DF	Sum of Squares	F Ratio	Prob>F
Site	1	7.8619	2.7620	0.1036
Depth[Site]	2	84.8968	14.9126	**<.0001**
Error	44	125.2453		

Table 5. Infaunal NMS Results

Final Stress for 2-dimensional solution = 0.14
Species – Axis Pearson-Kendall Correlation's *

Species	Axis 1	Axis 2
Turbellaria (LPIL)	0.310	**-0.487**
Orbiniidae	0.106	-0.276
Gemma gemma	0.074	-0.337
Mya arenaria	0.007	**0.512**
Polydora cornuta	-0.057	**0.620**
Hyperteone heteropoda	-0.153	**0.460**
Tharyx acutus	-0.25	0.125
Heteromastus filiformis	-0.351	**0.708**
Crepidula fornicata	**-0.417**	0.329
Tubificidae (LPIL)	**-0.431**	0.322
Ilynassa obsoleta	**-0.472**	0.377
Corophium (LPIL)	**-0.489**	0.359
Corophium tuberculatum	**-0.500**	**0.532**
Elasmopus levis	**-0.572**	**0.446**
Streblospio benedicti	**-0.654**	**0.574**
Streptosyllis verrilli	**-0.654**	0.136
Ampelisca abdita	**-0.681**	**0.594**
Unciola serratta	**-0.682**	**0.509**
Spio setosa	**-0.736**	**0.526**
Tubificoides wasselli	**-0.737**	0.206
Mediomastus ambiseta	**-0.780**	**0.532**

*Values in **bold** considered to be significant (-0.4 < r > 0.4)

Table 6. Summary Sediment Data

	Reference	Reference	Union Beach	Union Beach	Reference	Reference
	June	June	Sept	Sept	Sept	Sept
Data	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal
% Gravel	24.32	17.55	21.07	9.88	17.96	7.68
% Very Coarse Sand	3.08	2.15	15.39	2.07	7.64	1.91
% Coarse Sand	10.40	6.16	20.99	5.73	11.65	3.20
% Medium Sand	50.71	53.70	21.45	52.59	17.16	23.29
% Fine Sand	7.12	17.60	13.94	26.03	8.31	27.02
% Very Fine Sand	0.77	1.32	2.59	1.58	3.28	9.20
% Silt/Clay	3.61	1.50	3.31	2.11	34.00	27.70
Median grain size (mm)	1.28	1.45	0.87	1.62	2.50	2.66
TOC (mg/kg dw)	8977	2729	15478	4713	89833	14274
TOC (as %)	0.89	0.27	1.55	0.47	8.98	1.43

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 Ettinger (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

Appendix. Table 1 Subtidal Station Positions

Station	Latitude	Longitude
UB-S1	40 27.423	74 10.089
UB-S2	40 27.373	74 10.424
UB-S3	40 27.323	74 10.391
UB-S4	40 27.292	74 10.354
UB-S5	40 27.264	74 10.297
UB-S6	40 27.214	74 10.266
UB-S7	40 27.190	74 10.211
UB-S8	40 27.119	74 10.194
UB-S9	40 27.096	74 10.194
UB-S10	40 27.060	74 10.103
UB-S11	40 27.031	74 10.033
UB-S12	40 26.996	74 10.004
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. Infaunal Species List and Abundances (No. Animals/m^2)

Site	Reference	Reference	Reference	Reference	Union Beach	Union Beach	Total
Depth	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	
Date	June	June	September	September	September	September	
AMPELISCA ABDITA	55	9939	128	18	-----	18	10158
AMPELISCIDAE (LPIL)	-----	37	-----	-----	-----	-----	37
AMPHIPODA (LPIL)	311	256	18	-----	-----	37	621
AMPHIPORUS (LPIL)	91	-----	-----	-----	55	-----	146
AMPITHOE VALIDA	18	55	-----	-----	-----	-----	73
AUTOLYTUS (LPIL)	-----	-----	18	-----	-----	-----	18
AUTOLYTUS FASCIATUS	-----	-----	18	-----	-----	-----	18
BALANUS (LPIL)	128	55	-----	-----	-----	-----	183
BRANIA CLAVATA	384	347	238	-----	-----	55	1023
CAPITELLIDAE (LPIL)	91	18	18	55	-----	-----	182
CAULERIELLA (LPIL)	-----	-----	-----	-----	-----	201	201
CIRRATULIDAE (LPIL)	18	18	-----	18	-----	18	73
PECTINARIA GOULDII	-----	-----	18	-----	-----	-----	18
COROPHIUM (LPIL)	73	1261	55	-----	-----	-----	1389
COROPHIUM TUBERCULATUM	-----	1005	365	73	-----	329	1772
CRANGONYX (LIPL)	-----	18	-----	-----	-----	-----	18
CREPIDULA FORNICATA	18	530	37	201	-----	292	1078
CYATHURA POLITA	-----	365	18	55	-----	73	512
DECAPODA (LPIL)	18	-----	-----	-----	-----	-----	18
DRILONEREIS LONGA	37	128	18	91	-----	256	530
EDOTEA TRILOBA	146	18	55	-----	-----	18	238
ELASMOPUS LEVIS	37	1516	110	18	-----	164	1845
ENCHYTRAEIDAE (LPIL)	18	-----	-----	-----	-----	-----	18
EOBROLGUS SPINOSUS	-----	128	-----	18	-----	128	274
ERICHSONELLA (LPIL)	-----	-----	-----	18	-----	-----	18
ERICHTHONIUS BRASILIENSIS	-----	18	-----	-----	-----	-----	18
ETEONE (LPIL)	91	-----	-----	-----	-----	-----	91
HYPERETEONE HETEROPODA	877	530	219	37	18	37	1717
ETEONE LACTEA	55	18	110	18	-----	18	219
EUBROLGUS SPINOSA	-----	-----	-----	18	-----	-----	18
EUMIDA SANGUINEA	91	110	91	18	-----	91	402
EUPLANA GRACILIS	-----	37	-----	-----	-----	-----	37
EURYPANOPEUS DEPRESSUS	-----	-----	201	18	-----	128	347
EXOSPHAEROMA DIMINUM	91	-----	-----	-----	-----	-----	91
GEMMA GEMMA	603	128	311	1224	274	73	2613
GLYCERA DIBRANCHIATA	-----	-----	37	37	18	18	110
GYPTIS VITTATA	18	37	-----	-----	-----	-----	55
HARMOTHOE IMBRICATA	-----	37	-----	-----	-----	-----	37
HESIONIDAE (LPIL)	-----	18	-----	-----	-----	-----	18
HETEROMASTUS FILIFORMIS	822	1060	1462	201	128	457	4129
HYDROIDES DIANTHUS	-----	-----	-----	18	-----	18	37
ILYNASSA OBSOLETUS	91	438	183	402	37	219	1370
LEITOSCOLOPLOS (LIPL)	-----	110	-----	-----	164	-----	274
LEITOSCOLOPLOS FRAGILIS	-----	18	-----	110	37	-----	164
LEITOSCOLOPLOS ROBUSTUS	-----	-----	0	-----	-----	18	18
LIMULUS POLYPHEMUS	-----	-----	18	-----	-----	-----	18
LYONSIA HYALINA	-----	18	-----	-----	-----	-----	18
MARENZELLERIA VIRIDIS	-----	18	-----	-----	-----	-----	18
MEDIOMASTUS AMBISETA	37	2814	146	1078	-----	987	5061
MELITA NITIDA	-----	55	91	18	18	238	420
MERCENARIA MERCENARIA	55	-----	-----	-----	-----	-----	55
MICRODEUTOPIS GRYLLOTALPA	18	621	-----	-----	-----	-----	639
MICROPHTHALMUS (LPIL)	91	-----	-----	-----	73	-----	164
MICROPHTHALMUS SCZELKOWII	37	55	384	73	37	37	621
MICROPHTHALMUS SP	-----	-----	73	-----	55	-----	128
MICRURA (LPIL)	-----	-----	-----	-----	37	-----	37
AMEROCULODES EDWARDSI	37	-----	-----	-----	-----	-----	37
GAMMARUS MUCRONATUS	767	-----	-----	-----	-----	-----	767
MULINIA LATERALIS	-----	18	-----	-----	-----	-----	18

Appendix Table 2 (Cont.)

Site	Reference	Reference	Reference	Reference	Union Beach	Union Beach	Total
Depth	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	
Date	June	June	September	September	September	September	
MYA ARENARIA	1370	128	-----	-----	-----	-----	1498
MYTILIS EDULIS	18	-----	-----	-----	-----	-----	18
NAIDAE (LPIL)	37	37	-----	-----	-----	-----	73
NEREIDAE (LPIL)	-----	55	37	-----	-----	73	164
NEREIS (LPIL)	128	-----	-----	-----	-----	-----	128
NEREIS SUCCINEA	128	37	128	-----	-----	-----	292
NEREIS VIRENS	37	-----	-----	-----	-----	-----	37
NUDIBRANCHIA (LPIL)	-----	55	-----	-----	-----	-----	55
ORBINIIDAE (LPIL)	292	91	73	110	1242	238	2046
OXYURSTYLUS SMITHI	-----	18	18	18	-----	-----	55
PAGURIDAE (LPIL)	55	91	-----	-----	-----	-----	146
PAGURUS ACADIANUS	-----	18	73	-----	-----	91	183
PARANAIS LITTORALIS	55	91	-----	91	-----	-----	238
PARAONIDAE (LPIL)	-----	-----	-----	18	-----	-----	18
PARAONIS FULGENS	238	37	-----	-----	18	55	347
PELECYPODA (LPIL)	-----	18	-----	-----	-----	-----	18
PETRICOLA PHOLADIFORMIS	-----	-----	55	-----	-----	-----	55
POLYDORA (LIPL)	-----	18	-----	-----	-----	-----	18
POLYDORA CORNUTA	3106	1973	3928	55	987	18	10067
PROTODRILUS (LPIL)	73	-----	-----	-----	-----	-----	73
PYGOSPIO ELEGANS	694	146	37	-----	-----	-----	877
RHYNCHOCOELA (LPIL)	-----	37	128	-----	311	37	512
SABELLARIA VULGARIS	18	457	-----	110	-----	-----	585
SCOLELEPIS (LPIL)	91	37	-----	-----	-----	-----	128
SCOLELEPIS TEXANA	37	146	-----	146	-----	475	804
SPIO SETOSA	18	804	-----	-----	-----	329	1151
SPIONIDAE (LPIL)	55	-----	18	-----	-----	-----	73
SPIOPHANES BOMBYX	-----	18	-----	-----	-----	-----	18
STREBLOSPIO BENEDICTI	365	3563	457	1864	55	950	7253
STREPTOSYLLIS VERRILLI	256	2229	1498	1882	402	2594	8861
SYLLIDAE (LPIL)	-----	18	-----	-----	-----	-----	18
TELLINA (LIPL)	-----	18	-----	-----	-----	-----	18
TELLINA AGILIS	-----	-----	-----	-----	-----	18	18
THARYX ACUTUS	110	530	37	73	18	-----	767
TUBIFICIDAE (LPIL)	2211	1315	91	475	37	311	4440
TUBIFICOIDES WASSELLI	585	3398	2229	4275	37	8094	18617
TURBELLARIA (LPIL)	10542	128	238	18	585	55	11565
UNCIOLA (LPIL)	37	-----	-----	-----	-----	-----	37
UNCIOLA SERRATA	-----	1133	18	18	-----	219	1389
XANTHIDAE (LPIL)	-----	-----	-----	18	-----	37	55