

## 2-Intertidal and Nearshore Benthos

### Introduction

A major objective of the Biological Monitoring Program (BMP) is the detection of changes in intertidal benthic assemblages as a consequence of fill operations. Inherent limitations in the power of sampling programs to detect less than dramatic changes in fishery resources underscore the general reliance on quantitatively sampling benthos in order to infer impacts on fishery resources. Impacts to beach infauna are expected to include reduced abundance and altered community structure. While there are no standard sampling programs for collecting this type of information, guidelines found in Cochran (1963), Morrissey et al. (1992), and Nelson (1993) have been followed. Likewise, recommendations concerning statistical design found in Saila et al. (1976), Cohen (1988), and Underwood (1992) were applied to the study. Emphasis is placed on detecting both short-term and long-term impacts to abundance, biomass, and assemblage structure along a gradient from intertidal to subtidal depths.

Examination of nourishment impacts to New Jersey beaches is complicated by the relative paucity of quantitative studies of beach infauna along the mid-Atlantic coast. In a review of infaunal zonation on high-energy beaches McLachlan and Jaramillo (1995) reported no studies between North Carolina and southern New England. Fortunately, McDermott (1983) has described the distribution of southern New Jersey beach infauna as part of a study of the surf zone food web. New Jersey beach infauna were dominated by the polychaete *Scolecopsis squamata*, the wedge clam *Donax variabilis*, the mole crab *Emerita talpoida*, the ribbon worm (Rhynchocoela) *Micura leidy*, and a variety of haustoriid amphipods. McDermott has previously reported the distribution of both *S. squamata* (McDermott, 1979) and the nephtyid polychaete *Nephtys bucera* (McDermott, 1987) from the same site. Croker (1970) provides a faunal list of intertidal macrofauna from Long Island that is very similar to that of McDermott (1983). The benthic assemblage described in these reports is essentially identical to these and others reported for U.S Atlantic coast beaches (McLachlan and Jaramillo, 1995).

In addition to the paucity of reports concerning the quantitative distribution of beach infauna, there are virtually no studies of beach nourishment impacts to intertidal infauna north of the Carolinas. Both Nelson (1985 and 1993) and Hackney et al. (1996) have extensively reviewed the literature and neither report studies for this region. The closest study is that of Jaramillo et al. (1987) who followed the recovery of a New England sandy beach after intense erosion. In general, both Nelson (1985 and 1993) and Hackney et al. (1996) categorized nourishment impacts to beach infauna as short-term with recovery times ranging from 2 to 7 months. Subsequent studies by Jutte et al. (1999a and 1999b) in South Carolina arrived at a similar estimate (3 to 6 months). The longest recovery times reported for nourished beaches occur when there is a poor match between fill materials and the original substrate. For instance, Reilly and Bellis (1983) reported that recovery took more than a year for some species on a North Carolina beach where substantial amounts of silts and clays were present in the fill.

Likewise, Rakocinski et al. (1996) found delayed recovery of infaunal assemblages at a nourished beach and shallow inshore habitats in Perdido Key, Florida where there were substantial amounts of silts and clays in the fill material. Peterson et al. (2000) have examined impacts of beach nourishment to large beach infauna (*Emerita*, *Donax* and the ghost crab *Ocypode*) at Bogue Sound, North Carolina. The presence of a substantial amount of silts and clays as well as shell hash in the fill materials resulted in infaunal abundances still being reduced 2.5 months after nourishment.

## Methods

**Monitoring Plan and Overall Execution:** Sampling of intertidal benthos took place in two phases. In the first phase, samples were collected twice a year (spring and fall) at 10 sites within each of three areas and at two depths: 2 seasons x 3 areas/season x 10 sites/area x 2 stations/site x 3 cores/station for a total of 360 samples/year. Target areas were South Area, Middle Area, and North Area (Figure 2-1); and station depths were Mean Low Water (MLW) and MLW-1m (Figures 2-2 to 2-4). Station locations for MLW are provided in Appendix Table 2-1.

Replicate samples were collected at 1-2 m intervals with 7.5 cm PVC coring tubes to a depth of 10-15 cm, and a 0.5 mm sieve was used to separate infauna from the sediment. The monitoring plan also called for 120 sediment samples (one per infauna station per season) taken with a 5 cm, PVC coring tube to a depth of 10-15 cm, which were processed for grain-size distribution. Sampling began in June 1994 and was completed in May 2000. The second phase was initiated only when nourishment operations began. In 1997 the first six stations of both the nourished beach (South Area) and one of the reference areas (Middle Area) were sampled at MLW in June, July, August, October, and November (1997). In 1999-2000, when the Middle Area was nourished, the same stations were sampled, but the South Area acted as reference. As will be discussed later, the South Area had recovered sufficiently to serve as a reliable reference site. Samples were taken on a monthly schedule between June 1999 and April 2000. When combined with data from the May and September collections for the same stations, these samples permit a detailed temporal analysis of potential impacts and recovery ranging over a period of seven (1997) to thirteen (1999-2000) months.

Although sampling of nearshore benthos was not part of the original study design, this component was added in 1995 to extend characterization efforts far enough off the beach to capture potential impacts related to changes in profiles resulting from filling operations. Nearshore stations were located along the pre-construction 5.0-6.5 m depth contour, which generally lies just seaward of the terminal points of the existing groin field (Figures 2-2 to 2-4). Characterization of the nearshore benthos also enhanced interpretation of surf zone fish food habits data. Nearshore samples were collected with a single Smith-McIntyre grab (0.1 m<sup>2</sup>) sample directly seaward of each intertidal site/station set, yielding a total of 30 samples per sampling date (3 areas x 10 sites/area x 1 sample/site). Each site was sampled twice a year (May and September) beginning in

1995 and ending in May 2000. A sample for sediment texture analysis was also taken at each sampling point.

The monitoring plan was executed as planned for all years (1994-2000) except for the loss of a few samples in May 1994, when sediment texture samples were lost in the field from site 25 (MLW of the fifth transect at Middle area), and all samples from September 1995 collections. Infauna and sediment samples from Middle area Stations 23 and 33 were also misplaced in September 1998. While the sample losses were unfortunate, the effect on the monitoring program was minimal. Correlations between sediment type and infauna abundance are either non-significant or weak for the remaining samples. Thus, interpretations of the infauna data are not impaired by the decrease in sediment data. Otherwise, all infaunal and sediment samples were taken on schedule for both phases (biannual and monthly) of the project.

***Field and Laboratory Methods:*** The biannual samples (Phase 1) were collected during daytime, spring low tides during May and September of each year. The time of sampling was standardized to permit the most efficient use of field time and to reduce the influence of tidal migrations on taxa abundances (Jones et al. 1998).

Two to three days were required to collect all the samples during each sampling event. The groins were used to guide the distribution of the 10 sites in each sample area, with the goal being to sample the entire area as evenly as practicable. The South Area, which is between Philadelphia Blvd. and Remsen Ave., has 13 groins, which yields 12 inter-groin spaces (Figure 2-2). One sampling site was located near the center of each space, except for the two spaces near the storm-water outlet from Wreck Pond, which were excluded to avoid potential influences from the discharge. This sampling area encompasses 3.7 km of coastline, and the typical distance between transects is 300 m. The Middle Area, which is between Washington Ave. and Seaview Ave., has 12 groins, which yields 11 inter-groin spaces (Figure 2-3). One site was located near the center of each of these 11 spaces, except for the one space near the storm-water outlet from Fletcher Lake, which was excluded to avoid potential influences from the discharge. The sampling area covers 3.3 km of coastline, and the typical distance between sites is 300 m. The North sampling area, which covers 3.4 km between Cedar Ave. and Roosevelt Ave., has 12 groins, which yields 11 inter-groin spaces, but sampling in this area was not as straightforward as in the others (Figure 2-4). The portion near Neptune Ave. (2 inter-groin spaces) could not be sampled because there was no sandy beach during low tide. Furthermore, the groins are not distributed as evenly nor area as uniform in size as in the other areas. As a result, it was necessary to put two sites in two of the inter-groin spaces to provide 10 sites in this area. Distances between sites ranged from 100-220 m. Sampling occurred near the center of each inter-groin space to minimize the influence that groins might have on the immediately adjacent benthic community. In some cases, however, sites were moved away from the center to avoid derelict groins or storm-water outfalls.

Stations were initially located within each area based on standard land survey methods. A base station, usually in the South Area, was established using a transit, Philadelphia rod, and maps of street elevations (height above MLW) prepared by Coastal Planning and Engineering,

Inc. The elevation of the boardwalk above MLW was determined using the transit, rod, and elevation of the street as a reference. The elevation of the beach at the base of the boardwalk was then determined by subtracting the elevation of the boardwalk from the height of the boardwalk above the beach. The transit and rod were then used to locate MLW along the beach face, and the location was marked for that day with a stake. The depth of the water at the stake was used to locate MLW at other locations (i.e., if water depth was 10 cm at the stake at a given time, we assumed other 10 cm deep locations in the study area were also MLW). The sampling crew communicated with an observer at the base station via a cellular phone to obtain information about the depth of water relative to MLW. After several years experience with this method, it was noted that equal levels of accuracy could be obtained basing station locations on beach structure and depth relative to time and tidal height. Specifically, it was found that a small beach step was present at all sites at the Mean Low Water (MLW) mark. Beach steps are common on coarse sandy beaches; the crest of the step is generally associated with the Mean Low Water level (Bauer and Allen, 1995). Using this structure to site the MLW station, the MLW-1m station could be easily determined by depth relative to the depth of water over the MLW station. Thus, if there were 10 cm of water over the MLW station, the MLW-1m station was located at depth of 110 cm. When this procedure was tested against the transect level method in Spring and Fall 1996, no substantive differences could be detected between the two methods.

Infaunal samples were preserved in the field with buffered 10% formalin. In the laboratory at Barry A. Vittor & Associates, Inc. (BVA), Mobile, Alabama, samples were stained with 1% Rose Bengal and transferred to 70% isopropyl alcohol. Organisms were then separated from the remaining debris by flotation and hand picking, identified by experienced taxonomists, and enumerated. Quality assurance and control measures included randomly selecting 10% of the samples and reconstituting with the original debris and repeating the entire separation, identification, and enumeration process. The quality assurance plan used by BVA calls for all samples processed by a particular sorter to be redone if a random audit of 10% of that sorter's work shows any samples to differ by more than 5% from the original results. For this project, all discrepancies were within 5%. The taxonomists previously worked on several projects from the area and verified each other's identifications. When differences of opinion occurred or when significant doubt remained, outside specialists examined the specimens. BVA performed a review of all taxonomic identifications at the request of WES in 1997 and existing discrepancies were rectified. Identifications were made to the lowest practical identification level (LPIL) when not to the species level. Wet-weight biomass was determined to 0.01 mg after grouping the specimens by class within each station and after blotting to remove excess liquid.

Sediment samples were transferred to whirl-pack bags in the field. Between Spring 1994 and Fall 1995, all sediment samples were processed by Tierra Consulting, Inc. of Mobile, Alabama. The samples were thoroughly mixed in a stainless bowl and a 30-50 g subsample was washed with deionized water, dried and weighed. Coarse and fine fractions of the subsample were separated through a 4-phi sieve (0.0625 mm). Sediment texture of the coarse fraction was determined at 1-phi intervals using nested sieves (-2 to 4-phi, 4.00 to 0.0625 mm)

on a Ro-Tap apparatus. The weight of material collected on each sieve was recorded and used to compute mean and median grain size, and percentages by phi interval. No formal analyses of the fine fractions were done. After Fall 1995, all intertidal sediments were analyzed by Wetlands and Coastal Ecology Branch (U.S. Army Engineer Research Development Center). The only change in sample processing was the replacement of physical sieving of the sediments using the Ro-Tap apparatus by a wet-sieving technique. There is no discernable difference in the results produced by the two techniques. Nearshore sediment texture samples were analyzed in a similar manner with the exception that the fine fractions (silts and clays) were explicitly measured using a flotation technique (pipette method).

Water quality data were collected with a HydroLab® sensor during different components of the sampling program. Data reported here were compiled from values obtained during surf zone ichthyoplankton and beach seine sampling as well as nearshore infaunal sampling. Data include water temperature (°C), salinity (ppt), dissolved oxygen (mg/l), and pH. Turbidity (NTU) was also measured but will be reported in Chapters 5 and 7.

***Descriptive and Statistical Analyses:*** Numerical abundance, biomass, and taxa richness data were analyzed using Analysis of Variance (ANOVA) employing a two-way repeated measures design with sampling date as the repeated measure. Prior to testing, all data were converted to a per-m<sup>2</sup> basis, examined for normality and homogeneity of variance, and transformed ( $\log(x+1)$ ) where appropriate. Because multiple analyses were performed on data from each depth, it was necessary to adjust p values for multiple tests using the Bonferroni correction ( $p = 0.5/n$  where  $n =$  number of tests). Since a total of nine tests were analyzed (abundance, biomass, and taxa richness at MLW, MLW-1m, and Nearshore), a p value of 0.006 was necessary to indicate the presence of a statistically significant difference.

If a significant difference ( $p < 0.006$ ) was not detected for an effect, an *a posteriori* statistical power of the test was calculated. A power level of 75-80% was assumed to be necessary to indicate that no statistical difference was present. Where the interaction factor (e.g., Area x Date) was significant ( $p < 0.006$ ), main effects could not be directly interpreted (Zar, 1996). In these cases, linear contrasts were performed on appropriate pairs of means. Because the significance level for interpreting contrasts was also calculated using the Bonferroni correction for multiple tests it was necessary to restrict the number of tests performed to conserve power. Tests were restricted to data from sampling periods during and immediately after nourishment: September 1997, May 1998, September 1999 and May 2000. Since a total of four comparisons were made for each parameter, a p value of  $< 0.0125$  was required for statistical significance. In all but one case, reference area means were compared to that of the nourished area. For instance, the first comparison was between South Area MLW September 1997 and the data for MLW of the remaining two areas. The only exception to this procedure was for taxa richness data from MLW in May 2000. Since, there was no obvious difference between the Middle (Nourished) and one of the reference (North Area) means (Figure 2-11), but there was between these two values and that of the South Area (Reference), the Middle and North Area values were compared to that of the South Area. Where differences were detected

among main or interaction effects, the arithmetic means and standard errors were plotted. Taxonomic distributions of biomass and sediment texture data were examined graphically but not statistically analyzed.

Patterns in community species composition were examined using the multivariate ordination technique Nonmetric Multidimensional Scaling (NMDS). NMDS utilizes a ranking protocol to remove nonlinear trends in the same way ranking is used to remove non-normality in nonparametric ANOVA's. Since ordination techniques are sensitive to the impact of rare species, only taxa contributing between 0.5% (intertidal) and 1.0% (nearshore) of abundance from any area were incorporated into the analyses. The difference in selection criteria used for samples from the different depths was due to the low number of taxa in intertidal samples. Abundances were logarithmically transformed ( $\log x+1$ ) to reduce the influence of high dominance by one or more taxa. Prior to estimation of the contributions of individual taxa, the list of LPIL taxa was consolidated to remove duplicative listings. For instance, the mole crab was listed both as *Emerita talpoida* and *Emerita* (LPIL). These data were consolidated to form the single taxonomic listing *Emerita talpoida*. In this fashion, the intertidal taxa list was reduced to 80 taxa and the nearshore list to 225 taxa.

Temporal patterns in recovery of abundance, biomass, and taxa richness from monthly samples were examined by linear regression. Individual station data were expressed as a percentage of reference values for each date; after arcsin-square root transformation, data were regressed against time (days) since completion of nourishment. Outliers were identified by visual examination of residual plots and removed.

## Results

***Biannual Infaunal Abundance:*** A total of 132,518 individuals (average density =  $9,388/\text{m}^2$ ) were collected from the intertidal zone and an additional 298,999 animals ( $632/\text{m}^2$ ) from the nearshore subtidal (Table 2-1). The apparent anomaly between total numbers of animals collected and average abundance is due to differences in sample size. In the nearshore, a total of  $3 \text{ m}^2$  were collected during each sampling (3 areas x 10 stations x 1 sample x  $0.1 \text{ m}^2/\text{sample}$ ), whereas only  $0.79 \text{ m}^2$  was collected during each intertidal sampling (3 areas x 10 transects x 2 depths x 3 samples x  $0.0044 \text{ m}^2/\text{sample}$ )

The highest intertidal abundances occurred at MLW of the Middle Area (38,963 individuals, average =  $16,583/\text{m}^2$ ) and the lowest at MLW-1m of the South Area (16,360 individuals, average =  $7,097/\text{m}^2$ ). Nearshore abundances were highest at the North Area (137,503 individuals, average  $883/\text{m}^2$ ) and lowest at the South Area (35,669 individuals, average =  $250/\text{m}^2$ ).

Intertidal abundance was dominated by three taxa: Rhynchocoela (LPIL), the spionid polychaete *Scolelepis squamata*, and Oligochaeta (LPIL). Rhynchocoels were the overall numerical dominant providing 51% of all animals collected, while the other two taxa supplied 35% and 8%, respectively (Table 2-2). Rhynchocoels comprised over 66% of all Middle Area

infauna but only 37% and 44%, respectively, of the North and South Areas. The most abundant taxa also occurred most frequently (Table 2-2). Percent occurrence (% of samples where a taxon was present) was very similar for all three dominants in all areas. Rhynchocoels were present in slightly more than 36% of all samples, while *S. squamata* and Oligochaeta (LPIL) occurred in 30% and 16%, respectively, of all samples. Oligochaetes were particularly important at the North Area where they made up 19% of the assemblage. The blue mussel, *Mytilus edulis*, was also present in 14% of all samples and comprised more than 1% of all animals collected. This taxon, a dominant on the hard substrate rocky groins along the beach, is dislodged by heavy wave action and accumulates on the beach, hence their presence in the intertidal samples. Since these animals are not indigenous to beach sands they were not included in subsequent analyses. The polychaete *Protodriloides* (LPIL) made up almost 1% of all animals collected and was found in 6% of the samples. It was most abundant at the North and South areas. The amphipod *Corophium tuberculatum*, the polychaete *Microphthalmus* (LPIL), *E. talpoida*, and *Microphthalmus* sp. G all contributed approximately 1% of total abundance in the North Area but not to overall intertidal abundance. The remaining taxa made up less than 1% of total abundance but were present in 1% or more of all samples overall or at one of the three area (Table 2-2). Of these taxa, only Spionidae (LPIL) was excluded from further analyses on the assumption that it was comprised mostly of damaged or small specimens of *S. squamata*.

Nearshore samples were overwhelmingly dominated (74%) by the wedge clam, *Donax variabilis* (Table 2-3). The second most abundant taxon, the polychaete *Magelona papillicornis*, comprised almost 6% of total abundance, while the clams *Tellina agilis* and *Spisula solidissima* contributed 3.6% and 2.1% respectively. Other taxa contributing approximately 1% or more to total abundance included the amphipods *Acanthohaustorius millsii* and *Psammonyx nobilis* and the polychaetes *Dispio uncinata* and *Asabellides oculata*. The taxon Ampharetidae (LPIL) was excluded from further analyses because it most likely represents small or damaged specimens of another dominant, *Ampharete americana*, or a mixture of species. *M. edulis* was excluded for reasons previously described. The remaining dominant taxa either contributed 1% or more to the abundance within a specific area or were present in 10% or more of the samples (Table 2-3). It is worth noting that most of the intertidal dominants are present in this list but in lower abundance or frequency of occurrence.

ANOVA of the abundance data revealed a significant ( $p < 0.006$ ) interaction effect (Area x Date) at all three depths and as a result none of the other effects are interpretable (Table 2-4). Linear contrasts of the selected interaction means indicated a significant difference ( $p < 0.0125$ ) between Middle Area MLW values and those of the reference sites in May 1998, however values at this site were higher than the reference areas and are not believed to represent an impact response (Figure 2-5). No significant ( $p > 0.00125$ ) linear contrast was found for MLW-1m abundances in May 2000, although abundance at this time appears to be lower at the nourished area than the reference areas (Figure 2-6). A significant ( $p < 0.00125$ ) linear contrast was found however, for Nearshore abundance in May 2000 (Figure 2-7). Abundance was lower in the nourished area than the reference areas. In the case of both the MLW-1m and Nearshore abundances, the May 2000 values are well within the range of

normal values for unimpacted conditions. For instance, the abundance at MLW-1m in May 2000 was nearly identical to values at the South Area in May 1995, the Middle Area in September 1995 and the North Area in September 1996 (Figure 2-6). Likewise, Middle Area Nearshore abundance in May 2000 was similar to previous May values at this area and actually higher than three of the previous May values for the North Area, the only completely unimpacted site in the study (Figure 2-7).

**Biannual Infaunal Biomass:** More than 12 kg of wet-weight biomass was found in the intertidal samples and nearly 33 kg in the nearshore samples (Table 2-1). MLW samples averaged over 150 g/m<sup>2</sup>, MLW-1m samples averaged 97 g/m<sup>2</sup> and nearshore samples averaged 99 g/m<sup>2</sup>. As with abundance, the apparent anomaly between total and average biomass/m<sup>2</sup> in intertidal and nearshore biomass comparisons is the result of differences in sample size. South Area MLW had the highest average biomass with over 220 g/m<sup>2</sup> and North Area Nearshore the lowest with 67 g/m<sup>2</sup>. Annelids composed 72% of total MLW biomass and 78% of MLW-1m biomass. Intertidal mollusc biomass was almost entirely composed of blue mussels (*Mytilus edulis*) washed off of the surrounding jetties rather than true members of the sandy beach infauna. When intertidal biomass is recalculated excluding the mussels, annelids comprised 83% and 78% of MLW and MLW-1m biomass, respectively and crustaceans made up an additional 16%-20%. Nearshore biomass was dominated by the molluscs *Tellina agilis* and *Spisula solidissima* making up 63.5% of the total (Table 2-1). Annelids contributed 10% and crustaceans made up 24% of nearshore biomass.

ANOVA for total wet-weight biomass detected a significant ( $p < 0.006$ ) interaction effect (Area x Date) for all three depths and as a result none of the other effects are interpretable (Table 2-4). Linear contrasts of during and immediately post-nourishment means indicated a significant difference ( $p < 0.0125$ ) between the nourished beach (South Area) and reference beaches in May 1998 for MLW (Figure 2-8) and Middle Area (nourished) and reference areas at all three depths in May 2000 (Figures 2-9 and 2-10). As in the abundance data, the difference between nourished and reference biomass in May 2000 represents an impact, however, the values are no lower than many of those from unimpacted conditions. Specifically, equivalent or lower biomass values were encountered at Middle Area MLW in September 1995 and again in May 1996, at the South Area in May 1994 and September 1996, and at the North Area in May of 1994, 1995, 1997 and 1998 (Figure 2-8). Biomass at MLW-1m of the nourished site was equal to or higher than that reported in the entire period between September 1995 and September 1996 (Figure 2-9). It was also equal to values reported from the South Area during September 1994, 1998, and 1999. In the nearshore, Middle Area biomass in 2000 was equal to or greater than that for the same area in May of all years except 1996 (Figure 2-10). It was also equal to or greater than that of South or North Area values in May 1996.

**Biannual Infaunal Taxa Richness:** Although diversity was not explicitly included as a test parameter in the original study design, this does not preclude its examination. Prior to examination, however, it is important to review the inherent limitations imposed by the study design. First and foremost, Jaramillo et al. (1995) have indicated that at a minimum of 4 m<sup>2</sup> is

required to account for 95% of all taxa present on most beaches. Since this level of effort exceeded the resources available, diversity comparisons will of necessity be relative. Likewise, since the number of taxa collected is a function of sample area, direct comparisons cannot be made between intertidal and nearshore sites due to the difference in gear types used in sampling. Taxa richness (number of taxa/sample) was selected as the test measure since diversity indices such as the Shannon-Weiner Index have been shown to be inadequate in analysis of beach nourishment projects (Nelson, 1985; Wilber and Stern, 1992). Such indices also should not be tested with parametric statistics due to an absence of information on their underlying mathematical distributions (Norris and Georges, 1993).

A grand total of the 80 LPIL taxa were collected at both intertidal depths and 225 in the nearshore zone (Table 2-1). Total numbers of taxa at intertidal depths tended to be higher at MLW-1m than MLW and decrease in value among areas along a gradient from south to north. This pattern was not present in the nearshore data where there was no pattern among areas.

As with abundance and biomass, ANOVA's for taxa richness among intertidal and nearshore data had significant ( $p < 0.006$ ) interaction effects (Table 2-4). Linear contrasts of MLW data indicated a difference among areas during the second fill operation, however the difference does not appear to be directly related to nourishment (Figure 2-11). Taxa richness was found to be higher at the South (reference) Area than either the Middle (nourished) or North (reference) Areas. Linear contrasts of both MLW-1m and Nearshore data indicated taxa richness were significantly ( $p < 0.0125$ ) lower at the Middle Area (nourished) than either reference area in May 2000 (Figures 2-12 and 2-13). Again, the low values were within the range of values encountered during non-impacted periods of time. At MLW-1m, values of taxa richness equal to that of at the nourished site in May 2000 occurred at the South Area in September 1998. In the nearshore, May 2000 values were equal to those occurring at the North Area in May 1995.

***Biannual Biomass Composition:*** Biomass composition (% of total biomass) varied among areas, depths, and sample dates. Annelids dominated biomass at both intertidal depths particularly in the spring (Figures 2-14 to 2-16). Crustacean biomass was generally second most important and was most prevalent in fall collections. Mollusc biomass was only dominant occasionally and then only in fall collections. Since most of this biomass was made up of *M. edulis* it's contribution can be considered to be minimal. Biomass composition appears to have been altered at the South Area during it's nourishment (September 1997) as evidenced by higher than normal proportions of molluscs at MLW and echinoderms at MLW-1m. There was no indication of a change in biomass composition after this time period or at anytime during the nourishment of the Middle Area in 1999 (Figures 2-17 to 2-19). Nearshore biomass was dominated by molluscs followed, in order of importance, by crustaceans and annelids (Figures 2-20 to 2-22). Molluscs were generally most dominant in fall collections while crustaceans and annelids were most dominant in the spring. There is no indication of a change in biomass composition associated with nourishment operations.

**Biannual Species Composition:** Patterns in species composition were explored using the ordination technique Nonmetric Multi-Dimensional Scaling (NMDS). Ordination of data from all three depths was successful (Figure 2-23) with stress, a measure of “goodness of fit”, low at a value of 0.125 (Clarke and Warwick, 1994). A stress value of 0.20 or greater indicates that the data cannot be interpreted (Clarke and Warwick, 1994). Data ordinated almost entirely based on depth; the intertidal samples ordinated high on Axis 1 while the nearshore samples ordinated high on Axis 2 (Figure 2-23). There were no apparent differences between intertidal depths or areas within depths. Taxa positively and significantly ( $r^2 \geq 0.4$ ) correlated with Axis 1 (i.e., those characteristic of the intertidal stations) included Rhynchocoela (LPIL), *Scolepis squamata*, and Oligochaeta (LPIL) (Table 2-5). Taxa positively and significantly ( $r^2 \geq 0.4$ ) correlated with Axis 2 (i.e., those characteristic of the nearshore stations) included *Donax variabilis* and *Magelona papillicornis*.

In order to detect temporal changes in species composition, especially those potentially associated with nourishment, two further analyses were employed. First, NMDS was performed on data for each depth separately, however, none of the results could be interpreted (stress > 0.20). A second strategy was then employed, plotting the original NMDS results but excluding data points from periods of time when no nourishment was occurring. Specifically, only data from September 1997, May 1998, September 1999 and May 2000 were plotted (Figure 2-24). Examination of these data indicated several cases where a change in species composition was associated with nourishment. In September, South Area MLW samples differed from those of the Middle (Reference) Area. This pattern was repeated in September 1999 and May 2000 when samples and both Middle Area (Nourished) MLW and MLW-1m differed from the South Area (Reference). Examination of the individual species data for these time periods (Appendix Tables 2-2) suggests that the generally lower total abundance and taxa richness at these times are responsible for the observed differences rather than a change in the presence, absence, or relative abundance of any given taxon. In the nearshore samples, data from the South Area in September 1997 (during nourishment) and Middle Area in May 2000 (after nourishment) were different from the other samples collected during those time periods (Figure 2-24). Examination of individual species data (Appendix Table 2-3) indicates that abundance of *Donax variabilis* was most responsible for these differences. *Donax* was absent from the South Area samples in September 1997 while in May 2000 there were ten-times fewer clams in the Middle Area than either of the reference areas.

**Biannual Sediment Texture:** Sediment texture data were not contrasted statistically, however, average values are presented in this section. There were three distinct trends associated with the sediment composition results: depth, seasonal, and interannual (Figures 2-25 to 2-36). The most striking and consistent difference occurred between depths with finer sediments being associated with increased depth. The mean grain size (MGS) at MLW ranged between 0.27 mm and 1.78 mm with most values (28 out of 33) being greater than 0.40 mm (Figure 2-25). At MLW-1m MGS ranged from 0.18 mm to 1.16 mm with only 11 of 33 values greater than 0.40 mm (Figure 2-26), while in the Nearshore sediment MGS ranged between 0.05 mm to 0.22 mm (Figure 2-27). These differences are also reflected in the

proportions of individual grain size fractions. For example, in Spring 1996 more than 72% of MLW sediment at the South Area was composed of gravels and coarse to very coarse sands (Figure 2-28). Sediments at MLW-1m for this area contained only 60% of these materials while nearshore sediments contained less than 2% (Figure 2-31 and 2-34).

The next most pronounced difference among sediments was associated with the season of collection; sediments were generally coarser in the spring than in the fall. The coarseness of sediments in the spring reflects the general cycle of beach sediment erosion and deposition; erosion is most common during the winter and spring when strong storms are most frequent (Nordstrom, 1975). Large amounts of fine-grained sediments are removed from the beaches leaving relatively coarse sediments, while during the relatively mild summer months, fine sediments are deposited. This pattern is not absolute since the frequency and intensity of storm activity can change from year-to-year. During mild winters there may be no appreciable change in beach sediments.

The pattern of seasonally alternating coarseness in grain size was most pronounced in the MLW samples from the South Area (Figure 2-25). South Area MGS was far lower in spring than fall of 1994, 1996, and again in 1998. Similar results were found at South MLW-1 in 1996 and 1998 (Figure 2-27) and among North Area Nearshore sediments from 1996 to 1999 (Figure 2-28). These changes are also seen in the distribution of individual grain size fractions. For example, in 1994 the South Area MLW spring samples had a cumulative total of >50% very coarse sands and gravel, while in the fall, the cumulative total was approximately 10% (Figure 2-28). Similar patterns are present during most years for all depths and areas (Figures 2-29 to 2-36).

Interannual variation occurred in both the pattern of seasonal differences and in longer-term changes in sediment texture. The 1997 data are the most striking example of interannual differences in sediment composition. Sediments at both intertidal depths during May 1997 were finer than previous fall samples (September 1996) and as fine or finer than the succeeding September samples (Figures 2-25 to 2-26). A similar anomaly occurred in 1999 when all but Middle Area MLW-1m intertidal sediments were as fine or finer than the previous or succeeding fall. Presumably these results are due to relatively mild winters. The “fining” of the sediments does not appear to be related to beach nourishment activities since neither dredging or sand placement had begun in either case (May 1997 and May 1999). In addition, the effect was detected at all areas and not just the one designated for nourishment. Seasonal variation in sediment texture was present but less consistent in the Nearshore data. Spring sediments were as fine or finer than subsequent fall samples at the South Area in 1996 and 1998 and at the Middle Area in 1998 and 1999 (Figures 2-34 and 2-35). Spring samples were consistently coarser than fall samples in the North Area (Figure 2-36).

Sediment texture also varied between years. Intertidal sediments were particularly coarse in May of 1994, 1996, and 1998 with fine materials (silts, clays and fine and very fine sands) being more prevalent beginning in May 1997 (Figures 2-25 and 2-26). This pattern was

far more pronounced in the nearshore data where fine materials increased in proportion to other sediment fractions from May 1996 to September 1999. This pattern was reversed in May 2000 when silts, clays, and very fine sands declined in proportion to the other sediment fractions (Figures 2-34 to 2-36).

Likewise, a previously noted tendency for nearshore sediments to become progressively coarser along a South to North gradient (USACE, 1999) proved to be ephemeral. Between May 1995 and September 1997, fine sediment fractions, such as the fine and very fine sands, decreased in importance with increasing distance from Manasquan Inlet (Figures 2-34 to 2-36). The degree of difference between areas became progressively less over time, until they were roughly equal in May 1998. Afterwards, all three areas appear to follow similar trends and had nearly equal proportions of fine materials.

**Monthly Infaunal Abundance:** Data from the monthly samples were processed and analyzed in an identical fashion to that described for the biannual samples. Analysis of Variance for the 1997 data detected a significant ( $p < 0.017$ ) area by month interaction (Table 2-6). Linear contrasts of September, October, and November means found a significant ( $p < 0.017$ ) difference only in October, although nourished beach (South Area) abundances were lower than the reference area (Middle Area) in both October and November (Figure 2-37). Regression of monthly abundance (expressed as a percentage of reference values) produced a significant result;  $r^2$ -value = 0.633 and ANOVA  $p = 0.0059$  (Table 2-8). Estimated time for recovery of abundance based on this regression was 49 days.

Monthly abundance data for 1999-2000 yielded relatively high values during the spring and summer months, declining values during the winter, and lowest values in January (Figure 2-38). Analysis of Variance detected a significant ( $p < 0.017$ ) area by month interaction (Table 2-7). Of the three pairs of means tested (January, March and May), only the January data showed a significant difference ( $p < 0.017$ ). Abundance at the South Area (reference) was higher than that of the nourished Middle Area (Figure 2-38). Linear regression of the 1999-2000 abundance data produced a significant regression ( $p = 0.0026$ ), although the  $r^2$  value was only 0.24 (Table 2-8). The estimated time to recovery was 189 days or approximately 6.5 months.

**Monthly Infaunal Biomass:** Monthly biomass for 1997 monthly samples followed the same pattern as abundance with values declining with the onset of fall. ANOVA failed to detect any significant ( $p < 0.017$ ) differences (Table 2-6), however, power values were too low for all three effects (Area, Date, and Area x Date Interaction) to interpret the results. Highest biomass was present at the nourished area in September (Figure 2-39). This high value is attributable to the presence of two unidentified bivalves possibly washed onto the beach during the nourishment process (Appendix Table 2-5). The lowest biomass was found at the reference area in November while nourished area biomass was also low in both October and November. Regression of monthly biomass (expressed as a percentage of reference values) also produced a significant result;  $r^2$ -value = 0.547 and ANOVA  $p = 0.0145$  (Table 2-8). Estimated time for recovery of total biomass based on this regression was 38 days.

Monthly biomass for 1999-2000 also displayed a summer peak and winter low; lowest values occurred in January (Figure 2-40). ANOVA detected a significant ( $p < 0.017$ ) area by month interaction and of the three dates tested only January showed a significant linear contrast ( $p < 0.017$ ) (Table 2-7). Biomass was higher at the reference area than the nourished site at this time (Figure 2-40). Linear regression of the 1999-2000 biomass data produced a significant regression ( $p = 0.0016$ ) although the  $r^2$  value was only 0.24 (Table 2-8). Estimated time for recovery of total biomass based on the regression was 176 days or roughly 6 months.

**Monthly Infaunal Taxa Richness:** Taxa richness values for both sets of monthly data (1997 and 1999-2000) matched those of the abundance and biomass data with peak values in summer and lowest values in January (Figures 2-41 and 2-42). No significant differences ( $p > 0.017$ ) were found in the ANOVA of the 1997 data, however, statistical power was too low to interpret the results (Table 2-6). Regression of monthly taxa richness produced a significant ANOVA result ( $p = 0.0072$ ), with an  $r^2$  value of 0.616 (Table 2-8). Estimated time for recovery of taxa richness based on this regression was 23 days. ANOVA of the 1999-2000 data produced a significant interaction effect and subsequent linear contrasts found only the January comparison to be significant ( $p < 0.017$ ). As with abundance and biomass, taxa richness was lower at the nourished beach than the reference beach (Figure 2-39). Linear regression of the 1999-2000 data produced a significant regression ( $p = 0.0002$ ), but with a low  $r^2$  value ( $r^2 = 0.36$ ). Estimated time for recovery of total biomass based on this regression was 178 days or roughly 6 months (Table 2-8).

**Monthly Infaunal Biomass Composition:** In 1997, annelids dominated infaunal biomass in both areas during most collection periods. Crustaceans and molluscs dominated a few stations in August and again in November (Appendix Table 2-7). There was no obvious association between nourishment and the numbers of stations dominated by a particular taxonomic group or the extent to which a taxonomic group dominated biomass at a given station. For instance, in October 1997, when disturbance should have been at its peak, annelids comprised more than 95% of biomass at all stations in both areas. At the end of nourishment in November 1997 both areas had two stations dominated by annelids, two or three dominated by crustaceans, and one station with no biomass.

In 1999-2000, most stations in both areas were dominated by annelids between May and November 1999 (Appendix Table 2-8). In December 1999, stations at the reference beach (South Area) continued to be dominated by annelids while at the nourished beach (Middle Area), two stations had no biomass, one was dominated by annelids, one by molluscs, and two by miscellaneous taxa. The following January, four of the six nourished stations had no biomass, one was dominated by annelids and the remaining station was dominated by miscellaneous taxa. Annelids, crustaceans, and molluscs each dominated two reference area stations. During the remainder of the study (February 2000 to May 2000), annelids were dominant at the majority of stations in both areas. These results indicate a nourishment impact lasting from December 1999 to January 2000 with recovery complete by February 2000. While biomass composition results cannot be analyzed in the same fashion (linear regression) as abundance, biomass, and taxa richness data, a conservative estimate can be made by calculating

the time between completion of nourishment at the first station to be disturbed (September 27, 1999) and the February sampling (February 19, 2000) when recovery appears to have been complete. This calculation resulted in a recovery time of 145 days or approximately 4.8 months, a value close to the 176 day recovery estimate for total biomass.

**Monthly Infaunal Species Composition:** Because of the small number of taxa involved, NMDS could not be performed on the monthly infaunal samples. Instead, potential changes in species composition are assessed by directly examining taxa abundances (Appendix Tables 2-5 and 2-6). During 1997, rhynchocoels, *Scolelepis squamata*, and oligochaetes were the most abundant taxa at both sites and in all time periods (Appendix Table 2-5). There was no obvious change in species composition or the abundance of the dominant taxa related to nourishment.

In 1999-2000, rhynchocoels, *S. squamata*, *Protodriloides* (LPIL), oligochaetes and *Emerita talpoida* were the most abundant taxa (Appendix Table 2-8). Changes associated with nourishment included the absence of *Protodriloides* (LPIL) until May 2000 after nourishment and a reduction in the abundance of *S. squamata* relative to the reference area between November and December (Figure 2-43).

**Monthly Infaunal Sediment Composition:** During the 1997 nourishment, sediments at both the nourished beach (South Area) and reference beach (Middle Area) were characterized by mean grain sizes less than 0.5 mm throughout the study period (Figures 2-44 and 2-45). There was no obvious difference in sediment texture after nourishment. The same is true for the 1999-2000 nourishment (Figures 2-46 and 2-47). Mean grain sizes were generally less than 0.5 mm at both the nourished beach (Middle Area) and reference beach (South Area), although higher values were found at Station 1 (South Area) in May and July of 1999 and January of 2000. High values were also found at Station 2 in September 1999 and January 2000. There was no change in sediment texture associated with the 1999 nourishment.

**Water Quality Data:** Water quality parameters varied seasonally and among depths. As might be expected, water temperatures were higher in September than May of all years and generally 1-3 C° higher in the surfzone than in nearshore bottom waters (Figure 2-48). There were no consistent differences among areas and no obvious project-related effects during either dredging operation. Salinity varied among seasons and depths with lowest values occurring during May sampling periods (Figure 2-49). Salinity was usually 2-4 ppt lower in the surfzone than in nearshore bottom waters. Like the temperature results, there were no consistent differences among areas and no obvious changes due to dredging operations. Dissolved oxygen concentrations were similar in both the surfzone and nearshore bottom waters during spring sampling periods, but up to 4 mg/l lower in the nearshore waters during fall collections (Figure 2-50). This was particularly evident in September 1995 and again in September 1997. Comparatively low dissolved oxygen concentrations were also measured in bottom waters at the offshore borrow areas in September 1997 (See Chapter 8). There does not appear to be a relationship between the low values and nourishment since similar values were found in both nourished and unnourished areas and even lower values had been present when no nourishment

was going on (September 1995). Varying over a range of less than one unit, pH was generally higher in September than May sampling periods (Figure 2-51). There were no consistent differences among areas or depths, and no apparent changes related to either dredging operation.

## Discussion

Infaunal assemblages of high-energy sandy beaches are dominated by two different types of organisms: small interstitial forms including rhynchocoels, oligochaetes, and hesionid and protodile polychaetes, and large mobile forms such as the mole crab, *Emerita talpoida*, the wedge clam *Donax variabilis*, and the polychaete *Scolelepis squamata* (McLachlan and Jaramillo, 1995). Interstitial forms tend to dominate numerical abundance while the larger organisms dominate biomass. Infauna are distributed intertidally among three to four zones although it is difficult to precisely assign assemblages to individual zones because of the mobile nature of both the organisms and their environment. Species such as *Emerita talpoida* and *Donax variabilis* undergo diurnal and seasonal migrations (Bowman and Dolan, 1985; Ellers, 1995a,b), while the interstitial taxa are susceptible to being dislodged from the sediment by wave action or moved by bedload transport.

On the U.S. Atlantic coast the uppermost or supralittoral zone is dominated by air-breathing crustaceans such as talpid amphipods (also known as beach-hoppers) and ocypodid (ghost) crabs (McLachlan and Jaramillo, 1995). Between the drift line and midtide level is the littoral or swash zone, an area dominated by isopods, haustoriid amphipods and polychaetes such as *Scolelepis squamata*. Below midtide lies the sublittoral zone where *Emerita*, *Donax*, and a variety of haustoriid amphipods typify the benthic assemblage. On some beaches (macrotidal dissipative), littoral zone benthos may be further subdivided into assemblages associated with the resurgence and saturation zones described by Salvat (1964, 1967) (McLachlan, 1990 and Raffaelli, et al., 1991). Beyond the beach, both McLachlan et al. (1984) and Fleischack and de Freitas (1989) have identified benthic assemblages associated with the area of breaking waves (breaker zone) and a nearshore zone beyond the breakers. Assemblages of these zones are characterized by the decreasing representation of beach fauna and increasing importance of fauna characteristic of offshore waters.

The distribution of beach infauna is controlled by physical factors, particularly wave energy and tidal range (McLachlan, 1990), as manifested in beach morphology (Wright and Short, 1984; Short, 1991). Different combinations of wave energy and tidal range produce characteristic beach types which can be classified by their slope and the average height of incoming waves (Masselink and Short (1993). Beach slope and wave height, in turn, have been identified as the two factors associated the most with different beach assemblages (McLachlan 1990; McArdle and McLachlan 1991, 1992). Wave height is important because it is a measure of wave energy: the higher the wave energy, the more stressed and therefore less diverse and abundant the infaunal assemblage (McLachlan, 1983). Beach slope is important because beaches with steep slopes have a relatively small swash zone and species such as *Emerita* and *Donax* which “ride” the tides in the swash zone (Bowman and Dolan, 1985;

Ellers, 1995ab) may not have sufficient scope for feeding and thus be unable to establish large populations (Leber, 1982b). Lateral features of beach morphology also influence assemblage structure. McLachlan and Hesp (1984) have shown that meiofauna, macrofauna, and nekton were distributed in different manners along the cusps and horns of a cusped beach. Meiofauna were concentrated along the sides of the rip current, macrofauna in the cusp center, and nekton near the head of the rip currents.

Sediment texture, which is largely determined by the wave environment, can be a factor, although it is more difficult to detect unless the change in grain size is relatively large. Dexter (1969) and Leber (1982b) sampled beaches in the vicinity of Morehead City, North Carolina, but found relatively different assemblages. Dexter sampled a fine and medium sand beach dominated by haustoriid amphipods, while Leber found a medium sand beach to be dominated by *Emerita* and *Donax*. McLachlan (1996) has found that placement of coarse sands associated with mine tailings on a sandy beach in South Africa altered both beach morphology and the intertidal fauna. Species associated with the naturally occurring fine sands were replaced by larger, more robust fauna. In Uruguay, Defeo et al. (1997) have noted that the distribution of fine and coarse sands have substantial impacts on the distribution of species of the isopod genus *Exocirolana*.

Species composition in the study area was similar to that of other New Jersey and Atlantic coast beaches, although the relative dominance of individual taxa differed (Table 2-9). In an examination of sandy beach infauna in Maine, Larsen and Doggett (1990) found three different assemblages. Corresponding closely to temperature discontinuities, two assemblages were found north of Mount Desert; the northernmost was characterized by opheliid and paraoniid polychaetes and the other by oligochaetes and nephyid and orbiniid polychaetes. The third and southernmost assemblage was dominated by *Scolecipis squamata* and the amphipods *Amphiporeia virginica* and *Haustorius canadensis*. This southernmost assemblage was the only one representing exposed (high-energy) beaches while the more northerly assemblages represent protected or low-energy beaches. Croker et al. (1975) and Croker (1977) described a similar distribution in southwestern Maine and New Hampshire. Amphipods dominated the more exposed sites, while polychaetes tended to be most abundant in areas with less direct exposure to wave action. In a study of sandy beach infauna near Avalon, New Jersey, McDermott (1983) reported *Scolecipis squamata* as the overall dominant followed by *Donax variabilis*, *Emerita talpoida*, *Amphiporeia virginica*, *Micrura leidy* (a rhyngocoel), and the haustoriid amphipod *Haustorius canadensis*. Five other haustoriids were also present at the site. Croker (1970) has reported the same assemblage from sandy beaches of Long Island, New York. As previously noted, Dexter (1969) has described a North Carolina beach community dominated (in order) by haustoriids, *Donax*, and *Scolecipis*, while Leber (1982b), working in the same general area, found *Emerita*, two species of *Donax*, and haustoriids to be most abundant. Diaz and DeAlteris (1982) reported similar distributions for a beach at Duck, North Carolina. In a study of a South Carolina beach Knott et al. (1983) found *Scolecipis* and haustoriid amphipods accounted for 63% of all animals present with *Donax* abundant in two of three sampling transects.

Intertidal infauna in the project reach of the present study were dominated by interstitial rhynchocoels, oligochaetes, hesionid and protodile polychaetes, and larger forms such as *Emerita talpoida*, *Scolelepis squamata* and *Nephtys buccera* (Table 2-2). The interstitial forms dominated abundance while the large forms dominated biomass. *Scolelepis* was unique in that it was dominant in both abundance and biomass. As previously mentioned, large numbers of the blue mussel, *Mytilus edulis*, were also present in the samples but were excluded from consideration since they were not true beach infauna. Nearshore fauna were dominated by the larger forms with *Donax variabilis* being especially abundant (Table 2-3). The tendency for *Donax* to be most abundant in the nearshore rather than intertidally may be a function of beach slope.

As noted in a previous report (USACE, 1999), the distribution of intertidal infauna in the study area was patchy with "hot-spots" of high abundance and/or biomass occurring unpredictably. High numerical abundances were generally associated with interstitial infauna such as rhynchocoels, enchytraeid oligochaetes, and archiannelids. These small animals live on and between sand grains and are routinely redistributed by wave action. Concentrations of suspended meiofauna can be considerable with up to a third of the total consisting of interstitial forms (e.g., Bell and Sherman 1980; Hagerman and Rieger 1981). Between 1994 and 1996 total assemblage numerical abundance was generally highest at MLW of the Middle Area in spring, however this pattern dissipated after 1996 (Figure 2-5). Peaks in abundance coincided with high rhynchocoel densities. There was no predictable difference in abundance among areas or seasons at the other depths. "Hot-spots" of biomass seemed to correspond to high densities of the mole crab *Emerita* and occasionally to abundance of *Scolelepis* in the intertidal and *Donax* in the nearshore. Both *Emerita* and *Donax* migrate up and down the swash zone during a tide so how many animals are encountered may vary with the time of sampling. Highest abundances of *Emerita* are associated with low wave energy and low tides (Bowman and Dolan 1985). Seasonally both abundance and biomass displayed peak values in the summer and fall and lowest values in mid-winter. This pattern has also been noted in Florida (Salomon and Naughton, 1984), South Carolina (Van Dolah et al., 1994; Jutte et al., 1999b), and North Carolina (Leber, 1982b; Reilly and Bellis, 1983).

While abundance values are low compared to those of McDermott (1983) at Avalon Beach, NJ, they are similar to densities reported from other Atlantic coast beaches (Table 2-9). It should also be noted that the present study encompasses a much larger stretch of beach and longer time period than that of McDermott (1983) and as a result incorporates a higher degree of spatial and temporal variability.

During the 1997 nourishment operation, no deleterious impacts to the intertidal assemblages were detected. The biannual (long-term) samples showed no indication of a difference in abundance between the nourished beach (South Area) and either of the reference areas (Figures 2-5 to 2-6). Biomass results were very similar with little predictable pattern in seasonal or geographic distribution from the biannual samples (Figures 2-8 to 2-9). Monthly data indicated very high biomass in September but low values afterwards (Figure 2-39). Diversity, as measured by taxa richness, did not appear to differ among areas or seasons and no

impact was detected associated with nourishment (Figures 2-11 to 2-12). Likewise, no dramatic differences could be detected in either biomass composition or species composition. Biomass was dominated either by annelids (mostly *Scolelepis*) or crustaceans (mostly *Emerita*) but without a distinct pattern of spatial or temporal distribution (Figures 2-14; 2-17; 2-20). The only changes in biomass composition associated with nourishment appeared to be the stranding of a few large bivalves on the nourished site immediately after nourishment. Likewise, there were no consistent differences in species composition among areas, depths or dates and no apparent change in assemblage structure following nourishment (Appendix Tables 2-2 and 2-5). The only discernable change in the nearshore assemblage was the temporary disappearance of *Donax variabilis* (Appendix Table 2-3).

During the 1999 nourishment operation, there were clear but short-lived impacts to abundance, biomass, and taxa richness at all three depths. Abundance and biomass, in particular, were still lower at the placement area than the reference sites as late as May 2000. Short-term (monthly) sampling at MLW indicated that the most severe impacts occurred in the period November 1999 to January 2000. Values began to reach reference site values only between February and April 2000 (Figures 2-38; 2-40; 2-42). The same pattern was evidenced in the abundance of *Scolelepis squamata* (Figure 2-43). Biomass composition did not change in respect to nourishment during this period. Changes in species composition in the intertidal zone were related to declines in abundance and taxa richness rather than an altered assemblage structure. In the nearshore there was no difference in species composition during nourishment, but afterwards abundances of *Donax* and *Asabellides oculata* were lower in the nourished area than the reference sites. Despite the continuing lower abundance and biomass in May 2000 and the occasional differences in the abundance of individual species, these results were within the range of values reported during unimpacted conditions. Based on the 6.5 month estimate for recovery time, approximately 80% of the nourishment area had already recovered and only the portion nourished after mid-November (Stations 21-23) was still impacted.

Results of both the long-term (biannual) and short-term (monthly) sampling are consistent with previous studies of beach nourishment impacts. Impacts tend to be most severe to small relatively immobile species, those unable to burrow through the overburden of new sand (e.g., Maurer et al. 1978). Impacts during the present study were most apparent to densities of rhynchozoels, oligochaetes, and the polychaete *Scolelepis squamata* (e.g., Figure 2-40). Fortunately, these taxa generally have high reproductive rates, wide dispersal capabilities, and can recover in short periods of time. Larger, more mobile taxa which can burrow through the new sediment or avoid the disturbance by migrating out of the area are generally less impacted by sediment deposition. Hayden and Dolan (1974) examined the impact of beach nourishment on the mole crab, *Emerita talpoida*, and found that while crab abundance declined in the immediate proximity of the nourishment there was no evidence of mortality; crab abundance recovered within a few weeks. The authors hypothesized that the crabs migrated out of the immediate area during the disturbance but rapidly colonized the site after the disturbance was over. Schoeman et al. (2000) have conducted manipulative experiments on beach infauna and reported that defaunated sediments were colonized within two weeks.

Literature reviews of beach nourishment impacts to beach infauna (Nelson, 1985, 1993 and Hackney et al., 1996) categorize impacts as short-term with recovery times ranging from 2 to 7 months. For instance, Saloman and Naughton (1984) reported infaunal recovery within 5-6 weeks of nourishment at Panama City, Florida. Studies by Van Dolah et al. (1994) and Jutte et al. (1999a,b) report recovery periods of 3 to 6 months for nourished beaches in South Carolina. The longest estimated recovery times for beach nourishment monitoring studies occurred when the silt/clay content of fill materials was higher than that of the natural beach. Reilly and Bellis (1983) reported that recovery took more than a year for some species on a North Carolina beach. Recovery was not complete until the silts and clays had been dissipated by wave action. Rakocinski et al. (1996) also found delayed recovery of infaunal assemblages due to the presence of substantial amounts of silts and clays in fill material used for a nourished beach and shallow inshore habitats in Perdido Key, Florida. Jaramillo et al. (1987) followed the natural recovery of a New England sandy beach after intense erosion and found that it took nearly three years for sand to accrete to pre-disturbance levels. During this time, polychaetes dominated the infauna; amphipod abundances did not reach pre-disturbance levels until a year later. Likewise, Peterson et al. (2000) found that the presence of finer than normal sediments and large amounts of shell hash in fill materials resulted in delayed recovery of large fauna such as *Emerita*, *Donax* and the ghost crab *Ocypode*. This study was further complicated by the fact that placement occurred during the late spring-early summer when filling could be expected to interfere with recruitment.

Estimates of recovery time in the present study, 2 months for the 1997 nourishment and 6.5 months for the 1999 operations, are precisely in the range of values found where there was a good match between fill materials and natural beach sediments (Table 2-10). The difference in recovery rates between the two nourishment operations seems most likely due to when placement was finished. The 1997 operation was completed by early October, whereas the 1999 nourishment was not completed until mid-December. Infaunal populations decline precipitously between November and January (e.g., Figure 2-40), suggesting that in 1997 there was enough time for colonization to be completed before the onset of the decline. In 1999, nourishment was not completed until a decline was well underway with the repercussion that there were insufficient animals available to fully colonize the disturbed sediments. The similarity between the results of this program and those of previous studies indicate that the findings will be applicable to subsequent renourishment operations at these sites and to similar projects in the New York-New Jersey area.

The principal conclusions from this portion of the study are as follows:

- 1) The intertidal infaunal assemblage was dominated by rynchocoels, the polychaetes *Scolelepis squamata*, *Protodriloides* (LPIL), and *Microphthalmus* spp., oligochaetes, the mole crab *Emerita talpoida*, as well as a number of haustoriid amphipods.

- 2) The nearshore infaunal assemblage included many of the same taxa, but was dominated by the wedge clam, *Donax variabilis*, the polychaete *Magelona papillicornis*, the clams *Spisula solidissima* and *Tellina agilis*, and the amphipods *Acanthohaustorius millsii* and *Psammonyx nobilis*, and the polychaete *Asabellides oculata*.
- 3) Infaunal assemblages of intertidal and nearshore beach environments were similar in species composition and abundance to those reported elsewhere on the Atlantic Coast. Abundance was somewhat lower than that reported for beaches in Southern New Jersey.
- 4) Intertidal abundances were highest in the summer and lowest in mid-winter.
- 5) Intertidal sediments varied between depths, seasons, and years. Mean grain size declined with depth and was generally highest in the spring.
- 6) Beach nourishment resulted in short-term declines in abundance, biomass, and taxa richness.
- 7) Recovery of intertidal assemblages was complete within 2-6.5 months of the conclusion of filling. Differences in the rate of recovery were most likely due to differences in when nourishment was complete. Sites where filling did not conclude until the low point in the seasonal cycle of infaunal abundance took the longest to recover.
- 8) Recovery rates are similar to those reported from other studies, particularly where the grain size of the fill material matched that of the beaches to be nourished.
- 9) There is no evidence of long-term impacts of beach nourishment operations on intertidal or nearshore infaunal assemblages.

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