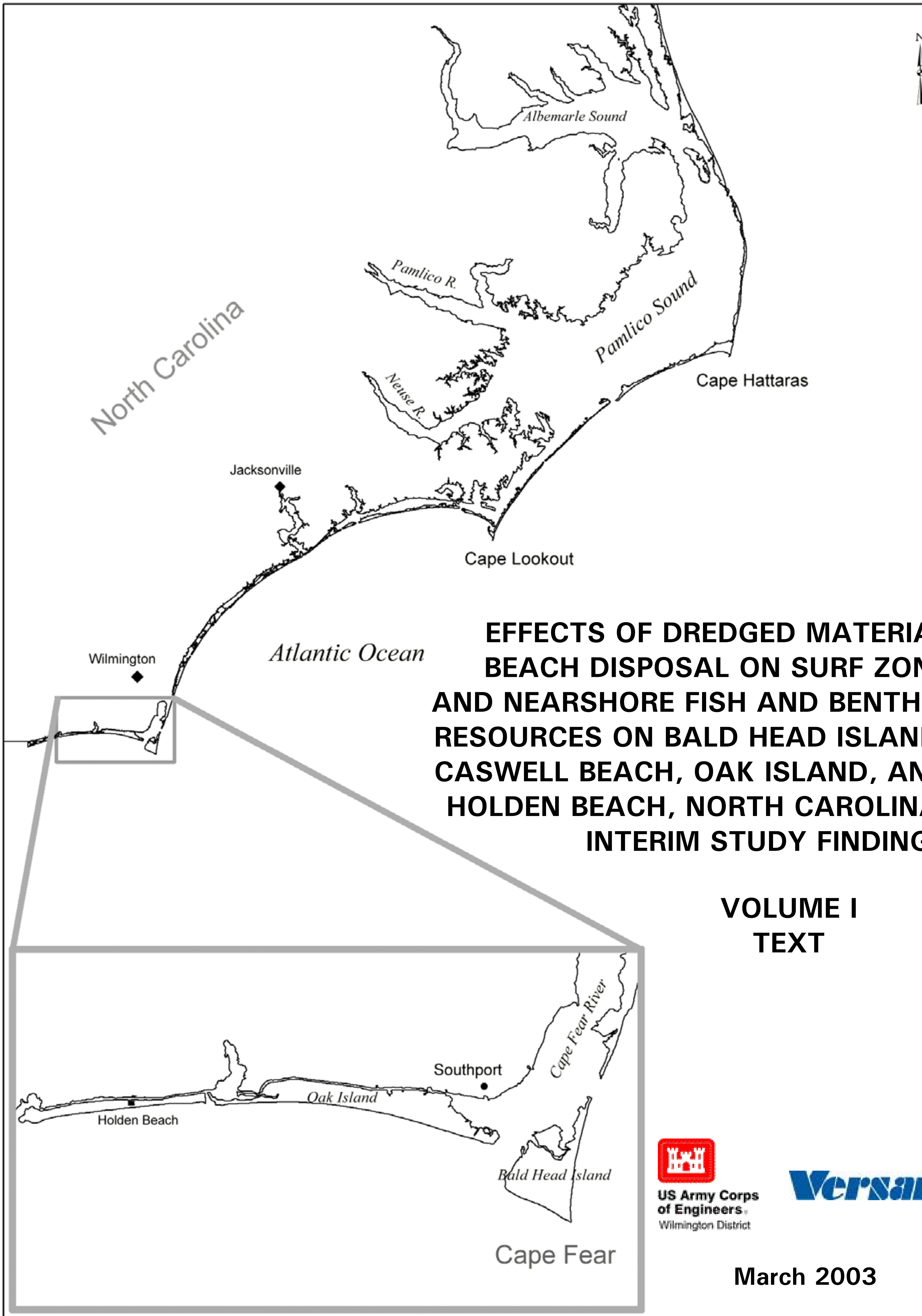

EFFECTS OF DREDGED MATERIAL BEACH DISPOSAL ON SURF ZONE AND NEARSHORE FISH AND BENTHIC RESOURCES ON BALD HEAD ISLAND, CASWELL BEACH, OAK ISLAND, AND HOLDEN BEACH, NORTH CAROLINA: INTERIM STUDY FINDINGS

VOLUME I
TEXT

US Army Corps of Engineers
Wilmington District

Versar INC.

March 2003

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Contract No. DACW54-00-D-0001
Delivery Order No. 2

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March 2003

FOREWORD

This interim report entitled "Effects Of Dredged Material Beach Disposal On Surf Zone And Nearshore Fish And Benthic Resources On Bald Head Island, Oak Island, And Holden Beach, North Carolina" was prepared by Versar, Inc. under the direction of Frank Yelverton from the U.S. Army Corps of Engineers, Wilmington district. Field sample collections, data analysis, and much of the report preparation were accomplished by Philip Wirth, III of Versar, Inc. Other Versar employees who were major contributors to the report include Jon Vølstad (Statistics), Lisa Scott (Benthic), David Wong (Water Quality), Joshua Vanderwagon (Sediment Grain Size). David Wong also assisted with the field collections along with numerous other Versar field technicians. Dr. William Richkus and William Burton conducted in-house editorial reviews and supervised the final production of the report. Dr. Martin Posey from the University of North Carolina at Wilmington (UNCW) assisted in developing the study plan and helped process many of benthic samples collected for the program. Dr. Steve Ross, from North Carolina National Estuarine Research Reserve and Dr. Thomas E. Lankford from UNCW also assisted with the development of the study design.

ABSTRACT

This report summarizes the findings from the first year of a two-year study evaluating the water quality and biological effects of large-scale beach disposal that was conducted as part of the Cape Fear River, North Carolina navigational channel deepening project. Between March 2001 and May 2002 approximately 5.6 million cubic yards of sandy material from the lower portion of the Cape Fear River navigation channel was placed on eroding beaches on Bald Head Island, Caswell Beach, Oak Island, and Holden beach to protect property and to enhance recreation.

To document effects on and potential recovery of the marine biota inhabiting shallow surf-zone habitats, benthic invertebrate collections were taken in the swash zone and shallow and deep subtidal habitats at eight stations at four study sites. At four of the eight stations, replicate beach seining and offshore trawling was also conducted to assess changes in fish communities. Gill net sampling for adult fish and bongo net tows for ichthyoplankton were conducted twice in each season to characterize the pelagic fish communities in the project area and the use of the study beaches as spawning and nursery habitat.

Seasonal sampling followed the progress of the beach reconstruction such that four seasons and beach areas were monitored. The beach areas monitored included Bald Head Island (Spring 2001), Caswell Beach (Summer 2001), Oak Island East (Fall 2001) and Holden Beach East (Winter 2002). During each season four sampling trips were made over a six to eight week period to evaluate short-term effects and recovery. The study design called for sampling the eight stations in the undisturbed condition in the first seasonal trip while subsequent sampling trips were intended to follow impacts and recovery as the dredge pipeline moved through the study site. Each beach/seasonal sampling trip included reference site sampling at four stations on the western end of Holden Beach where no sand placement occurred. Because the beach replenishment operations did not follow the predicted plan, common parametric statistical analyses (i.e., ANOVAs) could not be applied because of the unbalanced dataset that resulted from the unpredictable pipeline movements. Statistical significance among undisturbed, disturbed and the reference site was therefore evaluated using a confidence limit test (Schenker and Gentleman 2001). Water quality (in particular turbidity) was monitored during the entire beach reconstruction project with in-situ data logging meters moored off of two fishing piers (Ocean Crest and Long Beach) on Oak Island. Turbidity plumes created during active sediment pumping were mapped on four separate occasions on Oak Island.

Sand placement impacts on benthic communities were evident at all beach habitats examined but appeared to be more limited in terms of seasonal impacts at some habitats. The benthic communities of the swash habitat appeared to be the most directly impacted by the sand placement, as effects were apparent across all sampling seasons and when all sampling trips were combined. Impacts in the shallow subtidal habitat occurred during the spring and summer sampling periods. Impacts in the deep habitat occurred during the

spring sampling period, the major recruitment period for benthic macroinvertebrates. Impacts detected during the summer sampling period in the shallow habitat most likely were compounded by the additional sand placement that occurred at Caswell Beach the summer 2001. Whether the short-term effects on benthic communities identified in this interim report are sustained for a longer period will be determined from the on-going continuation of the study and will be evaluated in the final project report.

Based on fish sampling with seines and trawls, no consistent significant differences in nekton abundances and diversities among the disturbed, undisturbed, and reference stations were found during any season. The schooling nature of a number of the dominant species (e.g., Bay anchovy) and the highly mobile nature of the nekton community inhabiting the project area constrained our ability to detect differences among the three groups of station effects (i.e., undisturbed, disturbed, and reference). The abilities of the fish community to migrate caused a highly variable community in both a temporal and spatial aspect but also indicated that they could move in and out of the beaches impacted by the replenishment operations. Despite the limitations imposed by the data, there was a trend of fewer gulf kingfish occurring at the disturbed stations relative to the undisturbed stations. This trend could be important because the preferred prey of gulf kingfish was determined to be crustaceans and some benthic organisms did experience a seasonal impact.

Water quality monitoring at the two Oak Island fishing piers revealed that beach replenishment operations did not create large increases in turbidity over background conditions. While turbidity spikes where observed when the pipeline was near both piers, similarly high turbidity values were recorded during periods when the beach replenishment operations were miles from the monitoring sites or when dredging operations where temporarily shut down. These large non-dredged related turbidity events were most likely caused by periodic storm surges and heavy surf conditions. Turbidity plume mapping revealed that the turbidity created by the pipeline discharge hugged the shoreline following the long-shore currents. On-shore wind events contributed to keeping turbidity plume close to shore and in most cases the plumes were not discernable from turbidity created by the breaking waves in the surf zone a few 100 meters away from the end of the pipeline. Elevated suspended sediment loads outside of the surf zone were rarely observed.

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1.0 INTRODUCTION

During 2001-2002 the U.S. Army Corps of Engineers (USACE) Wilmington Harbor Project deepened and realigned the navigational entrance channel to the Cape Fear River located near Wilmington, North Carolina. The work required the removal of about 5.6 million cubic yards of sandy material from the lower portion of the Cape Fear River navigation channel as well as the offshore navigational river entrance channel. The dredged material was to be used beneficially to replenish the sands of four North Carolina Brunswick County beaches (Bald Head Island, Caswell Beach, Oak Island, and Holden Beach), which had eroded over the past years. Erosion of these beaches had reduced the protective, recreational, and economic value of the beaches as a result of the significant reduction in beach width. A total of 14 miles of beach received sands between March 2001 and May 2002.

Environmental monitoring was undertaken as part of this beach disposal project to document effects of the beach disposal operations on fish and benthic invertebrate communities inhabiting the surf zone and adjacent offshore areas. Results from this monitoring will provide useful information about the spatial and temporal variation and trends in benthic and fish communities that can be used to optimize the design and scheduling of future disposal efforts undertaken by the USACE. This report focuses on the short-term impacts on the beach benthic fauna and surf zone fish communities (i.e., those observable within two months after sand placement). Continued quarterly and yearly monitoring currently being conducted will provide a basis for testing if significant long-term adverse impacts resulted from the beach replenishment activities. If such effects can be demonstrated, modifications to future beach disposal programs may need to be considered (e.g., dredging windows to protect resources).

Acute impact on infaunal communities through sand burial is expected and largely unavoidable during beach disposal operations (NRC, 1995). To assess the magnitude of the impact of beach replenishment on the biota within and adjacent to the project area, it was necessary to obtain adequate baseline data on benthic invertebrate and fish communities in the area before it was impacted by the beach disposal operations and to document natural spatial and seasonal variability in abundance, species composition, and diversity. This study was designed to characterize the pre-construction temporal and spatial variability of key population parameters for fish and benthic communities within and near the project area and to provide the data needed to evaluate short-term effects. It was designed to do so by quantitative sampling of benthic and fishery resources before and after beach reconstruction. The indirect effects of temporary losses or changes in the benthic communities on the abundance, distribution, and foraging activities of marine predators were considered in this study. The study also will provide information that can be used to evaluate potential effects on avian predators of fish and benthos. The baseline monitoring of fish and benthos involved sampling at fixed stations distributed along the study beaches. The sampling network includes stations that are adjacent to the areas that were monitored for potential impacts on piping plover, other shorebirds, and colonial waterbirds.

This report presents results of analyses of data collected during the first full year of a 2-year study. The findings presented are thus interim in nature and do not represent a final assessment of potential impacts. Because of the large volume of data collected and presented in this report, it has been compiled into two volumes: Volume I, consisting of report text; and, Volume II, which includes all figures and tables.

2.0 METHODS

The study design included sample collection at eight fixed sites systematically distributed along each of the four study beaches (Bald Head Island, Caswell Beach, Oak Island, and East Holden Beach) and at four sites along the one reference beach (western end of Holden Beach), with stations positioned at the study beaches such that they were expected to be impacted by beach reconstruction within a time span of about 56 days (Figure ME-1). Because the beach disposal work would be conducted over about a one-year period, this design resulted in the four different study beaches each being sampled in a different season of the year. Only the single reference beach was sampled in all seasons.

As the pipeline moved through a section of beach within a particular season, samples were to be collected at time 0 (Trip 1), then at 14 days (Trip 2), 28 days (Trip 3), and 56 days (Trip 4). Sampling was to be coordinated with the progression of beach construction such that the following sampling trips and beach areas would be sampled:

- Spring 2001 - Bald Head Island (Figure ME-2)
- Summer 2001 – Caswell Beach (Figure ME-3)
- Fall 2001 - Oak Island (Figure ME-4)
- Winter 2002 - Eastern Holden Beach (Figure ME-5)

In each sampling season, the eight stations were positioned 800 feet apart at equal distance along the respective beach ahead of the pipeline. The distance was chosen based on prior information provided by the USACE dredging contractor about expected progress of the deposition along the beach and it was anticipated that a hydraulic dredge was going to be used to replenish all the beaches. Sampling stations on Bald Head Island were assigned numbers between 1 and 14. Station 1-4 had to be moved to the east in the impact area on the second trip; these new stations (Figure ME-2) were numbered out of sequence (11, 12, 13, and 14) to distinguish them from the Trip 1 samples. Caswell Beach stations were numbered from 21 to 28 (Figure ME-3, Table ME-7), Oak Island stations were numbered from 41 to 48 (Figure ME-4; Table ME-9), Holden Beach stations were numbered from 61 to 68 (Figure ME-5; Table ME-11), and the reference stations were numbered form 81 to 84 (Figure ME-6). Series numbering was assigned to provide maximum numeric separation between beach areas in the database and does not correspond to beach miles or distance markers used by the dredging company.

The study plan was developed under the assumption that stations would be sequentially impacted over the course of the four sampling trips (Table ME-1), which would be achieved if the sand placement along the beach progressed at a constant speed. Thus, Trip 1 was intended to sample undisturbed beaches (representing pre-construction conditions; Table ME-1). During Trip 2, 14 days later, several or all eight stations along the respective beach would be disturbed or in the recovery phase (depending on the speed of beach replenishment). Subsequent sampling during Trips 3 and 4 would provide data on various stages of recovery. During each sampling event at the four study beaches, parallel samples for benthos were collected at four stations along the reference/control beach, Western Holden Beach, and at one station for fish (ME-6), where no sand deposition occurred. As noted earlier, the study plan calls for follow-up sampling at all stations on a quarterly basis through one year, to evaluate long-term recovery of benthic and fish communities, work that is currently on-going. As will be discussed in further detail below (see section 2.4), this study design was premised on the assumption that sand dredging and deposition would be done using a hydraulic dredge, and that the progression of sand deposition along the four study beaches would be at a relatively constant pace. This assumption proved to be incorrect as a result of numerous operational difficulties encountered during the dredging. The result was that the anticipated impact status of sampling stations was often not achieved, and in many instances (e.g., fall 2001 and winter 2002) a sampling event that was intended to represent a single season instead extended over many months. These deviations from the assumed rate of pipeline progress substantially impacted the types of statistical analyses that could be performed on the data collected, as will be discussed in Section 2.5.

The sampling plan involved the collection replicate samples with multiple gears in several different habitats for both benthos and fish during each sampling trip. For benthos, 2 replicate samples were collected at each of the 8 stations of a beach in three different habitats: swash, shallow, and deep For juvenile fish, 2 replicate samples were taken at four of the eight stations using a haul seine, while 2 replicate experimental otter trawl samples were collected just off-shore of the surf zone at four of the eight stations (Figures ME-2, ME-3, ME-4, and ME-5). To characterize species composition and seasonal abundance of larger pelagic fish and fish larvae, gill net sets and plankton tows were conducted twice during each sampling event (Trips 2 and 4), after the pipeline had covered approximately half the beach.

2.1 SURVEY SCHEDULE AND SAMPLING PROTOCOL

2.1.1 Benthos

For each sampling trip in each season similar samples were collected at eight fixed stations at a study beach and four fixed stations at the reference/control beach. Sampling was conducted along one landward to seaward transect at each station, covering four beach zone habitats: (1) wrack zone, (2) swash zone, (3) shallow subtidal and (4) deep subtidal. Sampling procedures employed were selected based on general knowledge of the types of organisms expected to be found in these four zones. In the swash zone of sandy beaches in the southeastern U.S., coquina clams (*Donax*), mole crabs (*Emerita talpoida*) and several polychaete species are typically found (Nelson 1993). Diversity generally increases sharply in the shallow sublittoral, and typically includes a mixture of amphipod groups, bivalves such as *Donax* and *Tellina*, and polychaetes. The benthic sampling procedures employed along each transect were as follows:

Wrack Zone Sampling – Changes in cover of wrack material was estimated by selecting two 15 m long x 1 m wide belt transects parallel to the shore in the wrack zone and recording percent cover. The number of ghost crab burrow holes was recorded in each belt and in the area behind each transect extending to the toe of the dune. In addition, four areas in each belt were sampled by deploying one 0.5 x 0.5 m quadrat and excavating the sediment to a depth of 10 cm. Wrack material and underlying sediment was sieved through a 4.0-mm screen, and the large organisms retained by the sieve were counted and identified in the field.

Swash Zone Sampling – Two replicate Ponar Grab samples was collected at each swash zone station. The samples were sieved through a 1 mm screen. Only two species of benthos were quantified in the swash zone samples: the bivalve species *Donax variabilis* and the mole crab *Emerita talpoida*, and only *Donax* and *Emerita* retained by the screen were counted. A 1 mm sieve size was used for the swash zone to reduce retention of coarser sediment.

Shallow and Deep Subtidal-sampling – Two replicate grab samples was taken at each station in the shallow and deep subtidal zones. Shallow stations were sampled with the Ponar Grab while deep stations collected from a vessel were taken with a Young Grab. Each sample was sieved through a 0.5 mm screen and all organisms were enumerated and identified to lowest practical taxon (species in most cases). The use of a 0.5 mm sieve in the subtidal zones ensured adequate sampling of the smaller macrofaunal species in the subtidal zone (Nelson 1993).

For the subtidal benthic samples (i.e., shallow and deep habitats), after identification and enumeration, organisms were grouped into predetermined taxonomic levels for ash-free dry weight (AFDW) biomass determinations. AFDW biomass was determined by (1) drying and weighing each taxonomic group to a constant weight at 60 °C, and (2) ashing in a muffle furnace at 500 °C for 5 hours, and (3) weighing the remains. The sampling effort for benthic macroinverterbrates is summarized in Table ME-2. Counts of benthic invertebrates collected by the ponar and Young grab samples were expressed in numbers per square meter of bottom area for all subsequent data analyses.

2.1.2 Juvenile Fish

The distribution and abundance of juvenile surf-zone fishes was monitored using a haul seine in the surf zone and otter trawl beyond the breakers. The baseline survey of juvenile fish involved beach seine and trawl sampling at 4 of the 8 fixed stations at each study beach and at one of the four fixed stations at the reference beach during each sampling trip (i.e., every other benthic stations was sampled for fish). Two replicates hauls were made with seine and trawl at each sampling station (Table ME-3).

2.1.2.1 Haul Seines

Surf zone fish communities were sampled with a 150 ft X 6 ft seine with ½ inch square mesh and 6 ft X 6 ft bag, except during the first seasonal sampling (spring) at Bald Head Island when a ¼ mesh net was employed. The switch to a larger mesh net in subsequent sampling was in order to target larger fish and also to reduce haul-back pressure and make sampling more feasible. The net was deployed in a semicircle and pulled to shore by hand during daylight hours at or near low tide. Sampling at or near low tide was intended to control for possible changes in fish abundance that might occur among various tidal stages and to provide a reasonable working area for seine hauling. Fishes and macroinvertebrates (e.g., crabs and shrimps) were identified to species or lowest practical taxonomic level, enumerated, and a random sample of 50 specimens for each species was measured for total length. A subset of the 50 specimens selected for length measurements were preserved for later stomach content analyses for target species. Beach seine collections of nekton are expressed in catch per haul.

2.1.2.2 Otter Trawls

Subtidal juvenile fish sampling was conducted using a 25 ft. semiballoon trawl equipped with two 3 ft X 1½ ft wooden doors. The net had a 2-inch mesh body and 1½-inch stretched mesh cod-end fitted with a 1/8-inch cod liner. Replicate tows were made at each sampling station at or near low tide. Trawls was towed parallel to shore for 10 minutes outside of the breakers in waters considered safe for navigation. Distance covered was estimated from DGPS coordinates recorded at the beginning and end of each trawl. Collected fishes and macroinvertebrates (crabs and shrimps) were identified to species, enumerated, and a random sample of 50 specimens for each species was measured for total length. A subset of the 50 specimens selected for length measurements were preserved for later stomach content analyses of target species. Trawl collections were standardized to numbers per 500 meters of tow length.

2.1.3 Ichthyoplankton

The distribution and abundance of ichthyoplankton was monitored by sampling at four of the eight fixed sites at each study beach and at one of the four fixed sites at the reference beach during two of the four trips comprising each sampling event (Trips 2 and 4). Data acquired in this sampling was intended to provide a general characterization of the timing, species composition, and magnitude of early life stages of larval fish in the project area. At each sampling location, bongo nets (50 cm plankton net, 0.5 mm Nitex mesh) were towed for 5 minutes parallel to shore, targeting the subtidal zone outside of breaking waves that can safely be covered from a boat. Two surface tows were taken at each site (Table ME-3). The bongo nets was equipped with a mechanical flow meter to estimate the volume of water sampled. Ichthyoplankton samples were preserved in the field in 5% formalin. In the laboratory, larvae were removed from the sample, identified to species using appropriate taxonomic keys, and enumerated. Ichthyoplankton densities were expressed in numbers per 100 cubic meters of water filtered by the plankton nets.

2.1.4 Species of Concern and Demersal Fish Diets

To evaluate potential for trophic impacts to occur as a result of the beach disposal, demersal feeding fish that occupied the surf zone were sought for evaluation of stomach content analysis in order to link feeding behavior to any changes that might be observed in benthic communities as a result of sand placement. Three species were initially considered for this element of the program because of the commercial and recreational importance as well as their use of surf zone habitats, including pompano, kingfish, and spot. Concurrent monitoring of benthic invertebrate populations would provide information on the distribution and abundance of macroinvertebrate prey items available to these species. After initiation of the study and its full implementation, it became apparent that sufficient samples of all three species would be unavailable during all four seasons of the study. Spot were taken infrequently, and only small pompano were taken in significant numbers, and then only during the later sampling seasons. As a result, the primary species targeted for stomach content analysis was Gulf kingfish. This species offered the advantage of being present at the study sites during all four seasons and thus being a good indicator of the effects of sand placement at all four of the beaches included in this study.

Stomach contents of the subsamples of target species taken from seine and trawl samples were placed in categories, enumerated, identified to the extent possible, and then quantified based upon the frequency of occurrence (Murphy and Willis 1966). The presence and absence of food items in individual guts was recorded into six groups: bivalves, worms, crustaceans, gastropods, fish, and unidentified other. When all of the guts were examined, the proportion of stomachs that contained one or more of the food items was calculated as the frequency of occurrence of each individual food type. The values were used to determine whether or not there was a shift in prey selection that could be related to any observed changes in benthic community composition or abundance

2.1.5 Large Transient Fish Sampling

A variety of large, transient fish utilize the surf zone and/or adjacent subtidal areas seasonally as foraging habitat and migratory corridors. Many of these species support recreational and/or commercial fisheries along the North Carolina coastline. A general characterization of the distribution and abundance of the pelagic species inhabiting the project area was developed through gillnet sampling.

The monitoring and assessment of adult predators was conducted using gillnet sampling at four of the eight fixed sites at each study beach and at one of the four fixed sites at the reference beach in two of the four trips comprising each sampling event (Trips 2 and 4). The sampling was conducted in the area were the subtidal trawls were conducted using 300 ft X 10 ft experimental gillnets constructed of six 50 ft panels consisting of duplicate panels of 2, 4, and 6 inch stretch mesh. Gillnets were anchored perpendicular to shore and soak times were altered based on the catch rates anticipated by the commercial gill-netter hired to conduct this work. Sampled fishes were identified to species, measured for length, and enumerated. A subset of stomachs from adult fish was examined to relate their diets to those of surf zone fish sampled with the trawls and beach seines. Gill net collections were standardized to catch per 1 hour of soak time

2.2 WATER QUALITY MONITORING METHODS

Water quality parameters were measured and recorded electronically at two piers, Ocean Crest and Long Beach Pier, located in Oak Island, NC. YSI 6600 sondes were deployed to monitor dissolved oxygen, turbidity, water temperature, salinity, and pH at fifteen-minute intervals continuously for the duration of the study. Sensors were calibrated and deployed in accordance with the manufacturers guidelines. Sondes were initially switched out and calibrated once a month by field crews; however, heavy fouling of probes required the deployment period to be shortened to approximately two weeks.

2.2.1 Deployment System

Sondes were initially deployed in four-inch vented PVC pipes. Pipes were attached to the backside of pilings in approximately 5 to 8 ft of water. Sondes were attached using cable, weighted and deployed during low tide to ensure complete submersion during all tidal conditions.

The deployment system had to be modified after the 4 inch PVC pipes failed because of surf conditions. Weights were anchored into the sand with two guide wires attached to the pier. Sondes were suspended between both guide wires with 5 lbs of weight to maintain a constant depth. Periodic maintenance of the anchoring system was required due to a natural shifting of sand beneath the piers.

2.2.2 Filtering Electronic Data

Electronic data for turbidity, temperature, salinity, dissolved oxygen, and pH were examined and filtered for each parameter. The filtering of the data was necessary because of biological fouling that caused sensor degradation over time, failure of probes, or readings out of sensor range. Due to range accuracy limitations on the turbidity probe, all readings above 1000 were assigned a value of 1000. In similar manner, all readings that were below the 0 NTU threshold were assigned a value of 0. The turbidity data were also filtered to remove excessive spikes in the data between successive readings. If the turbidity changed more that 100 NTUs between readings, the data were eliminated. Errant pH readings were obtained due to sensor malfunctions caused by biological fouling which often broke the probes. Data collected over the entire study period showed that salinity and conductivity readings declined over deployment periods of several weeks, most likely as a result of biological fouling of the sensors. Fouling resulted in readings that were well beyond values typical for the study location. For example, salinity readings ranged from lows near10 to highs of 47 ppt during extended sonde deployments. Based on independent grab samples and general knowledge of the area, salinities from 30 ppt to 38 ppt were typical for the local conditions. Thus, salinity data falling outside that range were deleted from the data sets. Observed levels of dissolved oxygen generally were inconsistent between the two stations, another problem associated with biological fouling of sensors. Dissolved oxygen data were deleted from the data set when readings showed sudden drops or increases (2-3 ppt over a 15 minute period) that departed from the data obtained by the other unit. In many cases sensors on units when these aberrant readings were recorded were found to have perforated membranes.

2.2.3 Turbidity Plume Mapping

The discharge of dredged material on the beach created a turbidity plume even though the dredged material averaged 90 percent sand or greater. This plume could adversely impact aquatic resources in the area due to changes in suspended solids. Turbidity plumes resulting from the beach disposal project was assessed by measuring turbidity levels during active dredging and by examining the data from the in-situ water quality meters moored on the Oak Island fishing piers when the beach replenishment operation reached the base on the each pier. During the turbidity plume mapping efforts, measurements were taken from multiple positions from surf zone to the outer seaward edge of the turbidity plume (e.g., 10, 20, 30, 50, 75, and 100 feet). To measure the long shore extent of the plume, shoreward to seaward samples were collected from multiple positions down current of the pipeline. Point measurements of turbidity (NTUs), salinity, DO, and temperature was taken with a calibrated water quality meter. The multiple position measurements perpendicular to and parallel to the shoreline were taken on four separate occasions during the beach replenishment operation to characterize plume size and location during various tidal and meteorological conditions. Plumes 1 and 2 were sampled with a small boat. Because the plumes hugged the shoreline, Plumes 3 and 4 were sampled by wading out from the beach.

2.3 SEDIMENT GRAIN SIZE

2.3.1 Methods

Sediment samplings were collected concurrent with benthic samples. Two composite samples for each of the four habitat zones (wrack, swash, shallow, and deep) were taken each trip. One sample from each of the trips was from the eight stations located at the study beaches and the other sample from the four stations located at the reference beach. The sampling was conducted every trip during each sampling event, except during the first trip at Bald Head Island.

Grain size analysis was completed in accordance with ASTM method D2487. Sediments were sieved and categorized by Wentworth's classifications for use in benthic studies (Table ME-4). The ASTM method states that the smallest sieve to be used is 75-Fm, but the standard division between sand and silt/clay for benthic macroinvertebrate studies is 63-Fm (Buchanan 1984) so this sieve size was used for analysis.

2.4 PIPE LINE MOVEMENT

As noted earlier, the study design was based on the assumption of consistent and predictable progress of hydraulically dredged sand deposition along all of the study beaches over the course of the one-year study. As was also noted, this assumption was not met, due to numerous operational problems encountered by the dredger (e.g., pump breakdowns, pipe breaks, need to use a hopper dredge). The erratic progress of sand placement resulted in the samples collected according to the study design not representing the impact status anticipated in the design.

An initial proposed study design considered for this project called for positioning sampling stations during each sampling trip based on a pre-defined recovery time (i.e., the sampling location would be selected based on the actual observed progress of sand placement on the study beach). However, this initial design was modified to a fixed station design because of concerns that a natural gradient in the benthic community might exist along the beaches scheduled for replenishment that would hinder interpretation of the data (i.e., if the benthic communities were not homogeneous along all of the study beaches, a natural difference due to a gradient could be misinterpreted as an impact of sand placement). Thus, the final study plan called for positioning eight, equally spaced fixed stations numbered sequentially from east to west at each study beach such that the stations sampled during the first trip of each sampling event would all be undisturbed, while the same stations during subsequent sampling trips would have experienced differing periods of impact and recovery. Sample spacing assumed approximately 200 feet of beach would be replenished a day, a figure provided by the dredging company. The anticipated outcome of the sampling station positioning was that most stations would be impacted or in various states of recovery, two weeks after the first samples were taken. Sampling during the third and fourth sampling trips, four and six weeks later, would provide data allowing examination of recovery of the benthic and fish communities within those time frames.

Dredging equipment malfunctions, dredges requires periodic repositioning and maintenance, and other problems were encountered that lead to the estimate of 200 feet of replenished beach per day being atypical throughout the beach replenishment program, with the deviation from that estimate differing by beach and season.

Because the collections for the various habitats and gear types typically took a week to complete and sampling was conducted during active beach replenishment operations, the distribution of disturbed and undisturbed stations for the various habitats included in the study were not always consistent within each sampling trip. The dredging contractor pipeline position logs and the sampling crew field notes were used to determine the date each station was impacted by the beach replenishment operation.

2.4.1 Pipeline Movement in the Spring at Bald Head Island

Study sampling was initiated on Bald Head Island in the spring of 2001. This beach was replenished in an easterly direction from the mouth of the Cape Fear River initially using a hopper dredge and finishing with the expected hydraulic dredge. Hopper dredges are self-propelled ships that require travel time between dredge and disposal site as the dredged materials are placed onboard for transport to the disposal site. The disposal location only receives dredged materials when the hopper is being emptied. Therefore, the hopper dredge used for replenishing a portion of Bald Head Island averaged much less than 200 feet of replenished beach a day. The slow progress in the replenishment was evident when none of the eight stations sampled in the undisturbed condition during the first week were disturbed when the crew returned two weeks later. The pipe outfall had only moved approximately 1,000 feet in the 14-day period (Tables ME-5 and ME-6). The slow progress necessitated relocating the four eastern stations (Stations 1, 2, 3, and 4) to the west of all eight initial sampling stations (west of Station 8) so that two stations in the second trip would be disturbed and the remaining six stations hopefully would be disturbed by the third trip (Figure ME-2). Beach replenishment on Bald Head Island continued slowly with three of the repositioned stations being impacted by the third trip, and only 6 of the 8 stations impacted by the last seasonal trip.

2.4.2 Pipeline Movement in the Summer at Caswell Beach

Sampling during the summer months took place in Caswell Beach when a hydraulic dredge was in operation. During the first seasonal trip, seven of the eight fixed stations were sampled in the undisturbed condition (Tables ME-7 and ME-8). By the second seasonal trip, all stations had been disturbed and were in various states of recovery. However, between the second and third trips, the dredging company was tasked to pump additional sand on portions of the beach that already had been replenished causing all stations to incur a double impact. Thus, five stations experienced doubled impacts by the start of the third trip and the remaining three stations were re-impacted during the third trip or shortly thereafter. The double impact was not anticipated and as such, the recovery period for affected stations was not as long as that at the other beaches.

2.4.3 Pipeline Movement in the Fall at Oak Island

The first fall sampling trip occurred on October 29, 2001 with all stations being sampled before being impacted (Tables ME-9 and ME-10). However, the pipe did not move between the first trip and scheduled second trip. The dredge company was attempting to pump sand approximately 11 miles and equipment was failing causing the delay in the replenishment. In order to have most samples in a recovery state by the second seasonal sampling trip, the second trip was delayed two weeks. The extension of the sampling period at this beach resulted in sampling being conducted over a period of time when seasonal changes in the benthos and fish communities may have been occurring.

2.4.4 Pipeline Movement in the Winter at Holden Beach

Beach replenishment at Holden Beach was conducted in the winter of 2002 using a hopper dredge similar to the dredge used in the spring construction at Bald Head Island. The offshore pipeline for the disposal operation was positioned in the center of our study beach and was equipped with a "Y" valve. At first the replenishment proceeded in a westerly direction through stations 65 to 68 (Figure ME-5). After that, the Y value was switched and the beach replenishment proceeded in an easterly direction such that stations 64, 63, 62, and 61 were impacted next. All the stations in the first week of sampling were undisturbed while more that half the stations in the second week were disturbed (Tables ME-11 and ME-12). All stations were impacted by the third sampling trip.

2.5 STATISTICAL METHODS

The fixed station study design, with the assumption of consistent progress of sand placement along the study beaches, was intended to be a balanced study design. Each of the four study beaches would be sampled in a different season (spring, summer, fall winter), but the reference beach would be sampled in all four seasons, providing seasonal control data. Samples collected during each of the four trips at each of the study beaches during each sampling event (i.e., season) would provide similar numbers of samples taken prior to disturbance and at the specified intervals after disturbance. If the sand placement process had proceeded as anticipated, data from this study would have been amenable to analysis of variance approaches such as GLM or the BACI approach to test for differences in means among disturbance categories. However, the erratic movement in time of the pipe and hopper dredge along the beach precluded application of such tests of means. Not only was the number of stations in each disturbance category unbalanced and variable among trips, but some sampling trips lacked observations for a particular category entirely. In addition, the extended period of time over which sand placement at some of the beaches occurred resulted in sampling taking place over a period of time that may have included seasonal changes, which complicates data interpretation.

As a consequence of the assumptions of the study design not being met, alternative analysis approaches had to be developed that would allow a statistical assessment to be made of whether significant changes in the benthic and fish communities occurred in response to sand placement. The method employed here is a standard test of differences among data from samples placed in one of three treatment categories: reference, undisturbed and disturbed. The "reference" category includes all samples taken at the reference portion of Holden Beach. The "undisturbed" category includes all samples taken at any of the study beaches prior to the station experiencing sand placement. The "disturbed" category includes all samples taken at stations that experienced sand placement, regardless of the length of time between the time of disturbance and the collection of the sample. The inclusion of all samples from disturbed stations in a single category precludes examination of any very short-term recovery that might have occurred. We have not included in this report a statistical assessment of short-term recovery, since the recovery times among all of the stations sampled varied widely and inconsistently, and also because the continuation of the study for another full year will provide a more sound basis for determining if any effects observed in the first year of the study were sustained into the second year and thus represent lasting impacts.

The analyses we present here consist of tests of differences among means of various attributes (abundance, biomass, and species richness) of each biological community sampled (e.g., benthic macro-invertebrates in the shallow zone) at disturbed, undisturbed, and reference sites.

One initial issue arising in these analyses is how the replicate samples taken at each station should be used. On average, observations from replicate samples within stations were more similar than observations from different stations along the beach. We used the intra-cluster correlation coefficient (Snedechor and Cochran 1980; Pennington and Vølstad 1994a and 1994b) to measure the homogeneity of samples within stations as compared to samples among stations. This coefficient ranges from −1 (poorly correlated) to +1 (highly correlated). Positive values indicate that the samples are more correlated with each other than for negative values. For total abundance, the intra-class correlation was fairly strong for the benthic samples (0.4 for the swash and deep zone, and 0.6 in the shallow). The catches from replicate trawl samples had an intra-cluster correlation of 0.3, while seine samples exhibited a weak intra-cluster correlation (0.1). Positive correlation between samples within stations was also observed for benthic biomass in the shallow and deep zones (0.3). For the measures of diversity in the trawl and seine samples an intra-cluster correlation of 0.4 was observed, while benthic diversity in the shallow and deep zones had intra-correlations of 0.5 and 0.1, respectively. Given the positive correlations found in these analyses, it would not be justified to consider all samples from a respective beach as independent replicates because samples within stations tended to be more similar (correlated) than across stations. Based on these findings, we used the sum of the two replicates to represent the parameter of interest at any given station for all analyses. The effective sample size for testing differences among disturbance categories was thus determined by the number of stations in each category rather than by the number of replicate samples.

A second issue arising in developing the analysis approach was how to utilize data collected in the four individual sampling trips that were made during a single sampling event/season. Within single sampling trips, the number of stations in each treatment category was often insufficient to conduct statistical tests of differences. For example, during the first sampling trip most stations at a beach would typically be undisturbed, while a majority or all stations were disturbed during the final sampling trip in that season. Thus, for each treatment category (reference, undisturbed and disturbed), we estimated the mean for a variable of interest across all sampling trips in a season as

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n}\overline{x}_i \qquad (1.1)$$

where

$$\overline{x}_i = \frac{1}{m_i}\sum_{j=1}^{m_i} x_{ij} \qquad (1.2)$$

is the estimated mean for the m_i stations in that category during sampling trip i.

The seasonal mean (equation (1.1)) is estimated by assigning equal weights to each sampling trip, thus reducing or eliminating bias caused by the unequal sample sizes between
trips.

This is equivalent to treating the study as a two-stage sampling survey, with trips being allocated in the first stage, and stations within trips in the second stage. The ordinary mean of all observations in a category would be driven by observations from trips where more stations fall in that category. In the disturbed category, for example, the last trip would provide more observations than the first trip because the number of disturbed sites typically increased over the season. If a variable of interest exhibited a trend (decline, or increase) over the season, such unbalanced number of sites in each category over time would significantly bias the ordinary sampling mean.

As an approximation for the variance of the mean across sampling trips within a season (equation (1.2)), we used the two-stage sampling estimator (Gilbert 1987)

$$\text{var}(\bar{x}) = \frac{s_1^2}{n} + \frac{s_2^2}{n \times \bar{m}} \quad (1.3)$$

where $\bar{m}$ is the mean number of stations in the disturbance category per trip,

$$s_1^2 = \frac{1}{n-1}\sum_{i=1}^{n}(\bar{x}_i - \bar{x})^2 \quad (1.4)$$

is the estimated variance among the means from the sampling trips, and

$$s_2^2 = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m_i}\frac{(x_{ij} - \bar{x}_i)^2}{(m_i - 1)} \quad (1.5)$$

is the mean variance among stations within sampling trips. The standard error (SE) of $\bar{x}$ is the square root of the variance (equation (1.3)). Note that if any category only is represented by one sampling station (which is the case for beach seine sampling at Holden Beach, for example), then the standard error cannot be calculated using this approach. Multiple samples from only one station on a beach do not provide estimates of the variability along the beach, and is not likely to be an accurate representation of the entire beach.

We tested if the difference between two means (say, means at disturbed versus undisturbed stations) is significant at a 10% level by examining if the 90% confidence interval of their difference contains zero (see Schenker and Gentleman 2001). Suppose that the estimated mean abundance of an organism is Q_1 for disturbed sites, and Q_2 for undisturbed sites, based on equation (1.1), with associated standard errors SE_1 and SE_2. The upper and lower 90% confidence intervals for the difference ($\Delta = Q_1 - Q_2$) is then given by

$$CL_{Upper} = (Q_1 - Q_2) + 1.65\sqrt{SE_1^2 + SE_2^2} \quad (1.6)$$

and

$$CL_{Upper} = (Q_1 - Q_2) - 1.65\sqrt{SE_1^2 + SE_2^2}\,, \quad (1.7)$$

respectively.

A test at α level 0.10 of the null hypothesis that $Q_1 - Q_2 = 0$ was carried out by examining whether the 90% confidence interval defined by equations (1.6) and (1.7) contains 0.

The null hypothesis of equal means was rejected if the interval does not contain 0. This standard method is more powerful (i.e., rejects the null hypothesis more often) than the usual method of examining overlap between the associated confidence intervals for two means (Schenker and Gentleman 2001). The results of the statistical analyses are presented in a summary table for each of the habitats and communities discussed in, Section 3 (Results). In those tables, the upper and lower confidence values (CL_{Upper} and CL_{Lower}) are presented. If both values are positive or both values are negative, zero does not occur within the confidence limits, which means that the differences are significant at the 90% level. Those comparisons that yielded significant differences are highlighted in the tables.

As an additional aid in interpreting the data, ratios of means are presented in results tables in Section 3. Ratios of means were calculated for all three combinations of treatments within a sampling event/season: disturbed and undisturbed, R_{du}; disturbed and reference, R_{dr}; and, undisturbed and reference, R_{ur}. If the reference beach was a good reference location for the beach samples in any given season, R_{ur} would generally be near 1.0. The further the ratio deviates from 1.0, the greater the difference between the means. Thus, for example, if disturbed stations had much lower abundance than undisturbed stations, R_{du} would be very low.

Community diversity for both benthos and fish was assessed using the Shannon Weaver biodiversity index that includes measures of taxa richness and evenness (the higher the number the greater the diversity) (Shannon and Weaver 1949; Krebs 1978).

The formula for the calculation of the Shannon-Wiener Index is:

$$H = -\sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where

H = index of species diversity
S = number of species
p_i = proportion of total sample belonging to *i*th species

3.0 RESULTS

3.1 BENTHIC COMMUNITY

3.1.1 SWASH HABITAT

3.1.1.1 Benthic Community Descriptions

As described in Section 2.1.1, within the swash habitat only two species, the bean clam *Donax variabilis* and mole crab, *Emerita talpoida,* were sampled. Thus, no analyses of number of taxa have been conducted for this habitat. *Donax* and *Emerita* are dominant species within the swash beach habitat and are a major food source for fish and shorebirds.

3.1.1.2 Sand Placement Effects

3.1.1.2.1 Bald Head Island-Spring

While the densities of *Donax* during spring sampling at the reference and undisturbed stations differed substantially during Trips 1, 3 and 4, they were relatively similar during Trip 3 (Figure SW-1). The magnitude of these differences is evident in the widely varying values of R_{ur} in Table SW-1. Most notably, however, was the fact that no *Donax* were collected at disturbed sites during any sampling trip (Figure SW-1). The absence of *Donax* in samples from disturbed stations results in the densities at reference and undisturbed stations being significantly higher than densities at disturbed stations (Table SW-1)

In the case of *Emerita*, densities at reference and undisturbed stations in the spring were relatively similar (Figure SW-5 and R_{ur} values in Table SW-5). But similarly to *Donax*, no *Emerita* were found at the disturbed stations during any of the sampling trips (Figure SW-5). As a result, both the reference and undisturbed stations had significantly more *Donax* and *Emerita* than the disturbed stations during the spring sampling period (Table SW-9).

3.1.1.3 Caswell Beach-Summer

Within the summer sampling period at Caswell Beach, undisturbed stations were only sampled during the first trip as the sand placement equipment moved much faster after switching to the hydraulic system and all the stations were re-impacted halfway through the sampling period (see Section 2.4.2, Methods). As a result, examination of placement effects during this sampling period was mostly limited to reference beach comparisons. During the first sampling trip, however, mean *Donax* clam abundances at the undisturbed and reference stations were very similar (Figure SW-2, Table SW-2). *Donax* clams at the disturbed stations were lower than the reference stations during all summer sampling trips (Figure SW-2 and Table SW-2). The number of *Donax* collected during the first summer sampling trip was also lower but since there was only one disturbed station a variance estimate was not possible. When all trips were combined for the summer sampling period, the disturbed stations had one fifth less clams than the reference stations, (Table SW-2) which were significant (Table SW-9).

Abundances of *Emerita* mole crabs at the disturbed stations at Caswell Beach were lower than the reference stations during the second, third, and fourth summer sampling trips (Figure SW-6, Table SW-6). No crabs were collected from any station during the first summer sampling trip (Figure SW-6). When all trips were combined for the summer sampling period, even though the disturbed sites supported about one third less mole crabs (Table SW-6) no significant differences in mole crab abundance were detected between the disturbed and reference stations (Table SW-9) because of high variability.

3.1.1.4 Oak Island-Fall

As in the spring and summer sampling period, the disturbed stations sampled during the fall period at Oak Island supported lower *Donax* abundances than the reference stations (Figure SW-3, Table SW-3). The second sampling trip was the only trip with both disturbed and undisturbed stations, and clam abundances were similar between these two beach treatments during this trip (Figure SW-3). Mean *Donax* clam abundance at the reference stations during the second fall sampling trip was much higher than at both the disturbed and undisturbed stations, but during the first trip, clam abundances were similar between the reference and undisturbed stations (Figure SW-3). When all the trips were combined for the fall season, the disturbed stations had significantly less clams than the reference stations (Table SW-9). The disturbed versus undisturbed and the reference versus undisturbed comparisons were not significantly different but the number of trips when both were sampled was limited (Table SW-9), thus limiting the power of the statistical test.

Emerita abundances during the fall sampling period were relatively similar between the disturbed, undisturbed, and reference stations during all fall sampling trips (Figure SW-7, Table SW-7) and when all trips for the season were combined there was no significant difference among them (Table SW-9).

3.1.1.5 Holden Beach -Winter

During the second and third winter sampling trips at Holden Beach the disturbed stations supported lower *Donax* clam abundances than the reference stations, but by the fourth sampling trip *Donax* abundances were similar between disturbed and reference stations (Figure SW-4, Table SW-4). Mean clam abundances at the undisturbed stations during the first and second sampling trip were about 50% lower than the reference stations (Table SW-4). When the trips were combined, both the undisturbed and reference stations had significantly more *Donax* clams than the disturbed stations (Table SW-9).

Emerita crab abundances during the winter were generally low, especially at the reference stations where no crabs were collected during the last three sampling trips (Figure SW-8). The only winter sampling trip when both disturbed and undisturbed stations were sampled was the second trip and the disturbed stations had fewer crabs than the undisturbed stations (Figure SW-8 and Table SW-8). When all trips were combined for statistical analysis, the disturbed stations had significantly lower numbers of crabs than the undisturbed stations (Table SW-9). Also the reference stations had significantly lower abundances than the undisturbed and no differences in the reference versus the disturbed were observed (Table SW-9). However, the numbers of *Emerita* were so low that the comparisons may not be meaningful.

3.1.1.6 Summary

Seasonal patterns in the abundance of these species were apparent in the data. For example, *Emerita* abundance was lowest during the spring sampling period at both the study beach and reference beach areas. However, abundances of mole crabs were very patchy within the swash habitat. For instance, at Reference Station 82 during the third summer sampling trip, no moles crabs were collected but at Station 84, during the same sampling trip, mole crab abundance was estimated to be $920/m^2$. Because of the natural patchiness in *Emerita* distribution within the swash habitat, variability in abundance of the mole crab between study and reference area stations was high and affected our ability to detect impacts from sand placement on this species.

Donax abundances were much higher than *Emerita* abundances in the swash habitat reaching numbers as high as $1600/m^2$ at a single sampling station (Reference Station 81, first summer sampling trip). In general, the highest abundances of clams were collected during the summer sampling period and the fewest were collected during the spring sampling period. As with the mole crabs, *Donax* clams were patchily distributed within the swash habitat. In one case, clam abundances at two adjacent stations (Bald Head Island, undisturbed Stations 22 and 23) during the first summer sampling trip were $300/m^2$ to $1420/m^2$, respectively.

Sand placement impacts were apparent during all sampling seasons within the swash habitat. When all seasons were combined, *Donax* clam abundances at the disturbed stations were significantly lower than the reference and undisturbed stations (Table SW-9). The disturbed stations supported significantly less clams than the reference in each individual season as well (Table SW-9). Further, the disturbed stations had significantly fewer clams than the undisturbed stations during the spring and winter sampling periods (Table SW-9). As for the *Emerita* mole crabs, when all seasons were combined, no significant differences were detected between the disturbed, undisturbed, and reference stations (Table SW-9). However, when significant differences were detected in individual sampling seasons, the crab abundances at the disturbed stations generally were lower than the reference and undisturbed areas (Table SW-9).

3.1.2 SHALLOW HABITAT

3.1.2.1 Benthic Community Descriptions

A total of 67 taxa were collected from the shallow beach habitat during the first year of study (Table SH-1). Of these 67 taxa, 20 were polychaete worms and 16 were amphipod crustaceans. Ten of the 67 taxa were collected from all beaches sampled (Table SH-1). By far the most abundant species at all the beaches were the polychaete worm *Scolelepis squamata*, the clam *Donax variabilis*, and several species of haustorid amphipods including the genera *Acanthohaustorius*, *Amphiporeia*, *Parahaustorius*, and *Protohaustorius*. All of these taxa are common to shallow high-energy beach habitats.

The mean number of the dominant taxa fluctuated by season. The polychaete *Scolelepis* peaked in abundance in the spring and decreased to a low during the winter sampling period (Table SH-1). The clam, *Donax* had a peak in abundance during the summer sampling period and decreased to a low during the winter and spring sampling periods. Many of the haustorid amphipods had peak abundances in the spring but maintained a high level of abundance during the other seasons as well.

3.1.3 Sand Placement Effects

3.1.3.1 Bald Head Island-Spring

Because of the sampling design, samples from disturbed stations were only collected during the last three spring sampling trips. Low numbers of organisms were collected from the disturbed stations during the second sampling trip such that the ratios of disturbed mean to reference and undisturbed means was close to 0 (Figure SH-1 and Table SH-2). Total abundance was also lower at the disturbed stations during the third sampling trip but was similar to reference abundances but lower than undisturbed abundances during the fourth sampling trip (Table SH-2). When all the spring trips for Bald Head Island were combined, no statistical differences were detected between the various beach treatments due to the high variance among the means (Table SH-38).

Mean total benthic biomass followed a pattern similar to that observed in total benthic abundance. Mean total biomass at the disturbed stations was lower than the reference and undisturbed stations during each sampling trip (Figure SH-5 and Table SH-6). But unlike total abundance, when all spring sampling trips were combined, the disturbed stations supported significantly lower benthic biomass than the reference stations. No significant difference was detected between the disturbed and undisturbed stations (Table SH-38).

No difference in the Shannon Weiner diversity measure was discernable during any spring sampling trip (Figure SH-9 and Table SH-10) and when all trips were combined, no significant differences were detected between the disturbed, undisturbed and reference stations (Table SH-38). Overall mean diversity was low at all the sampling areas, which is common to these high-energy beach environments that typically contain large numbers of few species.

Crustaceans were one of the dominant taxa in the spring in the shallow habitat and are an important food resource for fish. Very few crustaceans were collected from the disturbed stations during the spring sampling at Bald Head Island (Figures SH-13 and SH-17) and in most cases the abundance and biomass of crustaceans at disturbed stations were lower than values at both the undisturbed and reference stations (Figures SH-13 and SH-17 and Tables SH-14 and SH-18). With all trips combined, the disturbed stations had significantly fewer crustaceans in both numbers and biomass than the reference stations but no significant difference was detected between the disturbed and undisturbed stations (Table SH-38).

Polychaete abundances within the shallow habitat were highly variable between spring sampling trips at Bald Head Island. For example, the mean polychaete abundance at the reference stations went from around 2,800/m^2 during the first sampling trip to over 12,000/m^2 during the second sampling trip, back to about 2,400/m^2 during the third sampling trip (Figure SH-21 and Table SH-22). Mean polychaete abundance and biomass at the disturbed stations were generally lower than at the reference and undisturbed stations during most spring sampling trips but the confidence limits overlapped (Figures SH-21 and SH-25 and Tables SH-22 and SH-26). When all trips were combined, neither abundance nor biomass of polychaetes at the disturbed stations was significantly lower than at the reference and undisturbed stations (Table SH-38), again due to the very high variability observed

Bivalve abundance and biomass were generally low at all stations during the spring sampling at Bald Head Island and Holden Beach reference (Figures SH-29 and SH-33).

Mean abundance of bivalves at the disturbed stations was lower than the undisturbed during all sampling trips and lower than the reference stations during Trips 2 and 4 (Figure SH-29). When all trips were combined, the disturbed stations had significantly lower bivalve abundances than the undisturbed stations but not the references stations (Table SH-38). However, no significant difference was detected in bivalve biomass between the beach treatments (Table SH-38).

3.1.3.2 Caswell Beach-Summer

Because of the sampling design, comparisons between disturbed and undisturbed stations at Caswell during Trips 2, 3 and 4 of the summer sampling period were not possible. At Trip 1, only 7 of the 8 stations were undisturbed. Also the Caswell Beach sites were impacted twice during the summer season when the beach was replenished with more sand after initial construction. Thus, comparisons for this summer sampling event are primarily between disturbed stations and the reference stations. Mean total abundance at the disturbed stations was lower than the reference during all of the summer sampling trips (Figure SH-2, Table SH-3). When all trips were combined, the disturbed stations supported about 40% less organisms than the reference stations and the difference was significant (Table SH-38).

Total biomass at the disturbed summer stations was also lower than biomass at the reference stations during all sampling trips (Figure SH-6; Table SH-7) but when all trips were combined, the difference was not significant (Table SH-38).

Diversity during the summer period was generally higher at the Caswell Beach area relative to the Holden Beach reference area (Figure SH-10 and Table SH-11). Some differences were apparent between the disturbed and reference stations during the individual sampling trips and when all trips for the season were combined, the disturbed stations actually had a significantly higher diversity than the reference stations (Tables SH-11 and SH-38).

Crustaceans do not appear to be the explanation for the decrease in total abundance at the disturbed stations as mean crustacean abundance was mostly higher than at the reference stations during the individual sampling trips (Figure SH-14 and Table SH-15). However, these crustaceans generally weighed less than those collected from the reference area (Figure SH-18 and Table SH-19). When all summer trips were combined, no significant difference was detected between the disturbed and reference stations for both crustacean abundance and biomass (Table SH-38).

In general, polychaetes were less abundant than the other major taxonomic categories within the shallow habitat at the disturbed and reference stations (Figure SH-22). Mean polychaete abundance and biomass at the disturbed stations were lower than at the reference stations during 3 of the 4 sampling trips (Figures SH-22 and SH-26 and Tables SH-23 and SH-27) but when all trips were combined no significant differences were detected (Table SH-38).

Bivalves were the dominant taxa during the summer sampling period in the shallow habitat (Figure SH-30). Bivalve abundance at the disturbed stations was very low during all the sampling trips and was much lower than at the reference stations (Figure SH-30 and Table SH-31). As a result, the disturbed stations had significantly less bivalves than the reference stations (Table SH-38). This significant difference in abundance did not correspond to a significant reduction in the bivalve biomass (Figure SH-34; Table SH-35), however, because no significant difference was detected in bivalve biomass between the disturbed and reference stations (Table SH-38).

3.1.3.3 Oak Island-Fall

During the fall sampling period at Oak Island, sand placement effects on total abundance within the shallow habitat were mixed. During the second and fourth sampling trips the disturbed stations supported a lower total abundance than the reference and undisturbed stations (Figure SH-3 and Table SH-4). However, during the third sampling trip, total abundance at the disturbed stations was higher than the reference stations. As a result, when all stations were combined, no significant difference was detected between the disturbed, undisturbed, and reference stations (Table SH-38).

Total biomass at the disturbed sites was lower over all fall sampling trips (Figure SH-7 and Table SH-8) but no significant difference was detected when all stations were combined for the season (Table SH-38). Total diversity was similar among all the sampling stations and no significant difference was detected (Figure SH-11 and Tables SH-12 and SH-38).

Crustacean, polychaete, and bivalve abundance and biomass also had varying and mixed results among the sampling trips (Figures SH-15, SH-19, SH-23, SH-27, SH-31, and SH-35; Tables SH-16, SH-20, SH-24, SH-28, SH-32, and SH-36). When all trips were combined, no major differences between the disturbed stations and the undisturbed or reference stations were detected within any of the major taxonomic categories (Table SH-38). Two exceptions were polychaete (Table SH-38) and bivalve (Table SH-38) biomass that were lower at the disturbed stations relative to undisturbed stations.

3.1.3.4 Holden Beach-Winter

Differences in mean total abundance during the winter sampling period at Holden Beach were mixed among the disturbed, undisturbed, and reference stations (Figure SH-4). Within each trip, total abundance at the disturbed stations were similar to the other sampling stations except for the fourth sampling trip where mean total abundance at the disturbed stations was much higher than at the reference beach (Figure SH-4, Table SH-5). When all the trips were combined, no significant difference was detected between the disturbed, undisturbed, and reference stations (Table SH-38).

Some differences were detected in total biomass and diversity among the four sampling trips for the winter season (Figures SH-8, SH-12; Tables SH-9 and SH-13) but when the trips were combined, none of the differences were significant (Table SH-38).

Similar mixed results in the mean abundances and biomasses of crustaceans, polychaetes, and bivalves were also detected among the four sampling trips (Figures SH-16, SH-20, SH-24, SH-28, SH-32, and SH-36 and Tables SH-17, SH-21, SH-25, SH-29, SH-33, and SH-37). Again, when all trips were combined, no significant differences were detected among the various beach treatments (Table SH-38).

3.1.3.5 Shallow Habitat Summary

Sand placement effects in the shallow habitat appeared mainly during the spring and summer sampling periods. The impact on bivalve abundance was seen in both the spring and summer sampling period but was not reflected in bivalve biomass (Table SH-38). The only impact detected in total abundance occurred during the summer period between disturbed and reference stations (Table SH-38). Diversity, as measured by the Shannon Weiner Index, was significantly higher at the disturbed stations than at the reference stations during the summer sampling period (Table SH-38). This was not surprising since the Shannon Weiner Diversity Index incorporates measures of both richness and abundance. The reference stations in the summer contained a substantial amount of bivalves (about 70 % of the total abundance) and as a result the Shannon Weiner Index was low. Because of the sampling design and the double impact that occurred at the Caswell Beach study area, comparisons between disturbed and undisturbed stations during this sampling season were not possible. During the spring sampling period at Bald Head Island, total biomass at the disturbed stations was significantly lower than the reference stations (Table SH-38). Additionally, crustacean abundance and biomass were significantly lower at the disturbed stations compared to the reference stations (Table SH-38).

When all sampling seasons were combined for the disturbed, undisturbed, and reference conditions within the shallow habitat, no significant differences were detected in any of the benthic parameters examined with the exception of bivalve abundance (Table SH-38). Bivalve abundance in the disturbed areas was significantly lower than both the reference and undisturbed areas (Table SH-38).

3.2 DEEP HABITAT

3.2.1 Benthic Community Descriptions

One hundred thirty-seven taxa were collected from the deep habitat during the four seasons examined (Table DE-1). Forty-three distinct polychaete taxa were collected, higher than any other taxonomic group. The species that dominated in abundance varied somewhat between sampling seasons. The haustorid amphipod, *Protohaustorius* cf. *deichmannae* was one of the most abundant species during each sampling period (Table DE-1). During the spring sampling period, the polychaete worm *Scolelepis squamata* was also extremely abundant, but no single species of polychaete dominated the abundance during the summer, fall, or winter (Table DE-1). As a group, amphipods and polychaetes contained the most species and individuals during all the sampling trips.

Overall the deep habitat in all seasons supported much higher abundances of benthic organisms than the other two habitats sampled for this study. This was not unexpected since the deep sampling area was located outside the area of breaking waves and the bottom environment is much less harsh for benthic organisms.

3.2.2 Sand Placement Effects

3.2.2.1 Bald Head Island-Spring

Total abundances within the deep habitat were lower at the disturbed stations of Bald Head Island during the three sampling trips with disturbed stations (Figure DE-1 and Table DE-2). Even though total abundances were variable between sampling trips, total abundance at both the undisturbed and reference stations were relatively similar during each sampling trip (Table DE-2). These observations were reflected in the statistical test results. When all trips were combined for the spring season, both the reference stations and the undisturbed stations supported significantly higher total benthic abundances than the disturbed stations (Table DE-38). Overall, the disturbed stations supported a mean total abundance that was about one-tenth the abundances at both the reference and undisturbed stations (Table DE-2). No statistical difference between the reference and undisturbed stations was detected (Table DE-38).

The same response was seen in total benthic biomass. Both the undisturbed and reference stations supported a significantly higher total biomass than the disturbed stations (Figure DE-5, Tables DE-6 and DE-38). The disturbed stations contained between 30 and 50% less mean benthic biomass than the reference and undisturbed stations (Table DE-6). No measurable difference in diversity among the three treatments was detected during the spring sampling period (Figure DE-9, Tables DE-10 and DE-38).

The major taxonomic contributor to the decrease in total abundance after sand placement appears to be crustaceans (Figure DE-13 and Table DE-14). Crustacean abundance at the reference area was significantly higher than both the disturbed and undisturbed stations when all trips for the spring season at Bald Head Island were combined for statistical analysis (Table DE-38). The undisturbed stations also supported a mean number of crustaceans that was significantly higher than the disturbed stations (Table DE-38). Both the reference and undisturbed stations supported a significantly higher mean crustacean biomass during the spring sampling period as well (Figure DE-17, Tables DE-18 and DE-38).

Mean polychaete abundances during each sampling trip were highly variable especially at the undisturbed stations, where densities ranged from a high of 28,532/m^2 during sampling Trip 2 to a low of 546/m^2 during sampling Trip 4 (Figure DE-21 and Table DE-22). Because of this high variability, it is difficult to draw conclusions about any impact due to sand placement at the disturbed stations on this taxonomic group. The disturbed stations had significantly lower densities of polychaetes than the undisturbed stations but no statistical difference between the disturbed and reference stations was detected (Table DE-38). Similar results were observed for the polychaete biomass (Figure DE-25 and Tables DE-26 and DE-38).

Bivalves were a minor contributor to total abundance and biomass during the spring sampling in the deep habitat at Bald Head Island and the reference area at Holden Beach (Figures DE-29 and DE-33; Tables DE-30 and DE-34). When all trips for the season were combined, the reference stations had a significantly higher mean bivalve abundance than the undisturbed stations but no significant differences were detected in the disturbed stations relative to reference stations (Table DE-38). Total bivalve abundance was significantly lower at the undisturbed stations relative to the disturbed stations (Table DE-38). No significant differences were detected among any of the treatments in terms of bivalve biomass (Table DE-38).

3.2.2.2 Caswell Beach-Summer

Substantially fewer benthic macroinvertebrates were collected from the deep area during the summer sampling period at Caswell Beach than the spring sampling period at Bald Head Island. Impacts within the deep area during the summer period were not evident in total benthic abundance, total biomass, and total diversity (Figures DE-2, DE-6, and DE-10, Tables DE-3, DE-7, and DE-11). No significant differences between the reference and disturbed stations were detected when all four sampling trips were combined (Table DE-38). As in the other beach habitats, comparisons between undisturbed and disturbed stations in this season were not possible due to the sampling design and sand placement schedule.

Even though impacts were not detected during the summer sampling period in total abundance, sand placement may have impacted certain taxonomic groups. For example, crustacean abundance at the disturbed stations was very low during all the summer sampling trips at Caswell Beach (Figure DE-14 and Table DE-15). When all trips were combined, the disturbed stations supported a significantly lower mean crustacean abundance than the reference area (DE-38). The lower mean crustacean abundance was not reflected in mean crustacean biomass, as no significant difference was detected (Figure DE-18, Tables DE-19 and DE-38).

Mean polychaete abundance and biomass was actually higher at the disturbed stations than at reference stations during the summer sampling period (Figures DE-22 and DE-26) but the differences were not significant due to the variability among sampling stations (Tables DE-23, DE-27, and DE-38).

Bivalves were again the least abundant of the three major taxonomic categories within the deep habitat during the summer sampling period (Figure DE-30). While the disturbed stations had a higher mean number of bivalves, no significant difference was detected among the various beach treatments (Tables DE-31 and DE-38). Also, no difference in bivalve biomass was detected (Figure DE-34, Tables DE-35 and DE-38).

3.2.2.3 Oak Island-Fall

Mean total abundance at the disturbed stations was significantly lower than at the reference stations during the fall sampling period at Oak Island (Figure DE-3 and Tables DE-4 and DE-38). However, total abundance at the undisturbed stations was also lower than the reference stations and no difference was detected between the disturbed and undisturbed stations (Table DE-38). Because of these confounding results it is difficult to suggest that sand placement had an effect in the deep habitat during the fall sampling period. Also no impact was detected in either total biomass or total diversity (Figures DE-7 and DE-11, Tables DE-8, DE-12, and DE-38).

The major contributors to the higher total abundance at the reference stations were crustaceans, the most abundant taxa during the fall sampling period (Figure DE-15 and Table DE-16). Crustacean abundance was significantly higher at the reference stations compared to the disturbed and undisturbed stations (Table DE-38). As with total abundance, no difference in mean crustacean abundance was detected between the disturbed and undisturbed stations. Again, differences detected in crustacean abundance were not detected in crustacean biomass (Figure DE-19, Tables DE-20 and DE-38).

Polychaete abundance and biomass were variable among trips (Figures DE-23 and DE-27) but overall during the fall sampling period, no significant differences were detected in the deep habitat among beach treatments (Table DE-38).

Bivalves were not an abundant taxonomic group within the deep habitat and no significant differences in abundance or biomass were detected between the disturbed, undisturbed, and reference stations (Figures DE-31 and DE-35 and Tables DE-32, DE-36, and DE-38).

3.2.2.4 Holden Beach-Winter

Figures DE-4, DE-8, and DE-12 and Tables DE-5, DE-9, and DE-13 provide the four trip means and standard errors of the means for total benthic abundance, biomass, and diversity for the deep habitat during the winter sampling period at Holden Beach. No significant differences were detected in total abundance, total biomass and total diversity between the disturbed, undisturbed, and reference stations during the winter sampling period (Table DE-38).

Additionally, no substantial differences in either abundance or biomass of the major taxonomic groups were detected between the Holden Beach disturbed and undisturbed and the Holden Beach reference stations (Figures DE-16, DE-20, DE-24, DE-28, DE-32, and DE-36, Tables DE-17, DE-21, DE-25, DE-29, DE-33, DE-37 and DE-38). Crustaceans were the most abundant taxonomic group during the winter sampling period (Figure DE-16) but no significant differences in crustacean abundance or biomass was detected when all winter sampling trips were combined (Table DE-38). Differences in polychaete and bivalve abundance and biomass were variable between trips but no overall differences were detected between the disturbed, undisturbed, and reference stations (Table DE-38).

3.2.2.5 Deep Habitat Summary

When all seasons in the deep habitat were combined, total benthic abundance at the disturbed stations was significantly lower than at the reference stations (Table DE-38). Among the major taxonomic groups examined for all seasons combined crustacean abudance at the disturbed stations was significantly lower than at both the reference and undisturbed stations (Table DE-38). The majority of the impact from sand placement in the deep habitat occurred during the spring sampling period, the major recruitment period for benthic macroinvertebrates. During this sampling period, total abundance and total biomass at the disturbed stations were significantly lower than at both the undisturbed and reference stations (Table DE-38). The major taxonomic group contributing to the low total abundance and biomass at the disturbed stations in spring were crustaceans (Table DE-38).

Significant differences detected in other seasons between the disturbed, undisturbed, and reference stations may suggest sand placement effects but the results were unclear. During the fall sampling period, mean total abundance at the disturbed stations was significantly lower than the reference stations (Table DE-38). However, this may be due to the high number of organisms collected from the reference area as no significant difference was detected between the disturbed and undisturbed stations during the fall sampling period (Table DE-38). Crustaceans were the major taxonomic contributor to the higher abundance at the reference area during the fall sampling period. Mean crustacean abundance at the reference stations was significantly higher than both the disturbed and undisturbed station means (Table DE-38).

3.3 WRACK RESULTS

The 15-meter by 1 meter wrack line sampling produced very little usable data. No organisms were ever retained in the 0.5 x 0.5 m sieve among the 192 samples taken throughout the study. In addition, only 10 of the 192 wrack line transects inspected for macrocrustaceans in the field produced any organisms, consisting of only a few ants and sand hoppers.

3.3.1 Ghost Crab Hole Results

The number of ghost crab holes observed behind the 15 m wrack line transects were recorded for each station, trip, and season to evaluate the potential impacts of the beach replenishment activity on ghost crab communities that inhabit the upper portion of the beach profile. Because ghost crabs are known to dig more than one hole per borrow the absolute number of crabs in the surveyed area cannot be reliably calculated. However, the comparison does provide a relative measure of beach replenishment effects if we assume that each hole represents at least one ghost crab. The data suggest that the replenishment operations may have significantly reduced the number of ghost crabs in the disturbed beach relative to the reference and undisturbed beach (Figures WR-1 to WR-4; Tables WR-1 to WR-4). In all seasons, mean numbers of ghost crabs holes at the disturbed beaches were less than half the number found at reference and undisturbed beaches despite the fact that the disturbed beaches were wider and presumably had more available habitat (Tables WR-1 to WR-4). However, based on the confidence limit statistical test, these differences were only significant at Bald Head Island in the spring (Table WR-5). When all seasons were combined a significant reduction in ghost crab holes in the disturbed site relative to the undisturbed sites was indicated by the statistical test (Table WR-5).

3.4 FISH SAMPLING RESULTS

3.4.1 Haul Seine Sampling

A total of 63 nekton species were collected in the haul seine sampling effort (Table SE-1). Fish comprised 49 species of which 4 were rays. Decapod crustaceans comprised an additional 11 of the 63 species and the 3 other species were invertebrates. *Sciaenids* (drums) were the dominant fish family, and numerous species of this family were found throughout all seasons and all sampling locations. Generally, the invertebrate species were infrequently encountered in the surf zone (Table SE-1). However, one invertebrate species, the speckled swimming crab, did make up relatively high percentages of the summer and fall samples on Caswell Beach and Oak Island. Higher nekton abundances and diversities generally were encountered during the spring, summer and fall sampling trips than during the winter. However, the beaches sampled in Bald Head Island, Caswell Beach, and Oak Island had higher abundances and more diverse communities than the reference beach located in Holden Beach sampled during the same period.

Note that the numbers of samples in each of the treatment categories (reference, undisturbed, and disturbed) varied by season and beach. Because only one station was sampled at the reference beach during each sampling trip and replicate samples were summed for our analyses, only a single sample mean is available for each sampling trip in the reference category. As a result of the inconsistent progression of sand placement over the course of the study, the number of stations that fall into the undisturbed and disturbed categories vary substantially by season and trip. The result was that there were often insufficient numbers of samples for the calculation of confidence limits on mean values.

3.4.1.1 Spring

Bay anchovy (59%) and rough silverside (32%) dominated the spring nekton community in the surf zone of Bald Head Island (Table SE-1), while bay anchovy (93%) dominated at the reference location, Holden Beach. The highest mean abundances sampled during the spring occurred during the fourth trip to Bald Head Island (Figure SE-1 and Table SE-2) and bay anchovy was the most abundant species collected. However, the abundances in spring samples at all stations and both beaches exhibited extremely high variability, with mean CPUE ranging from 22 fish per haul to 2,644 fish per haul across trips. The ratios of the means between different combinations of the treatment groups (undisturbed/reference, disturbed/reference, disturbed/undisturbed) also varied widely across trips, ranging from a low of 0.07 to a high of 36.61, with no consistent pattern among the treatments (Table SE-2). Also, the means of the treatment categories were not significantly different from each other (Table SE-10). These statistical results arise from the extremely high variability in CPUE, which reflects the schooling nature of the dominant species and the contagious distributions that result from schooling behavior.

The nekton diversity also was not significantly different among the three treatment groups (Table SE-10). Figure SE-5 and Table SE-6 display the mean and standard errors of the nekton diversity for the spring seine samples. The disturbed stations had mean values greater than the undisturbed stations during two of the seasonal trips (Table SE-6), but overall the ratio of the means was close to 1 for the three different combinations of classifications. This result is not unexpected, given the fact that one or two species comprised the majority of catch in all of the seine hauls at a given sampling location, which, a prior, results in extremely and consistently low diversity values.

3.4.1.2 Summer

Of the 63 species collected by seine over all four seasons of seine sampling, 40 species were present in the summer (Table SE-1). However, mean CPUE values for summer nekton were substantially less than the mean CPUE of spring samples (Figures SE-1 and SE-2). The jack family comprised 50% of the summer samples, with Florida pompano the dominant species at the reference beach (78%) and Florida pompano (21%) and Atlantic bumper (32%) dominating at Caswell Beach. Catches at both the beaches also had a large percentage of Gulf kingfish (19% and 13% respectively).

Undisturbed stations were sampled only during Trip 1 as a result of the timing of sand placement. Thus, the primary comparison for assessment of potential effects in summer was between disturbed and reference station. The disturbed stations showed consistently higher nekton abundances than the reference beach stations during all four summer sampling trips (Figure SE-2 and Table SE-3), with the ratio of means ranging from nearly 3 to over 6. The number of samples within each treatment was insufficient to construct confidence intervals to test for differences among means (Table SE-10). Taking into account that the number of samples was very limited, the ratio of means shows that abundance at the undisturbed stations was substantially higher than the abundance at the reference stations (Table SE-3). This suggests the possibility that Holden Beach may not have been a representative reference location for Caswell Beach. However, the data do not permit a more definitive assessment of that issue.

Diversity was consistently higher at disturbed stations than at reference stations during all trips, but similar between disturbed and undisturbed sites for the one trip when undisturbed sites could be samples (Figure SE-6 and Table SE-7). These data suggest a substantial difference in fish communities during summer between Holden and Caswell Beaches, which is evident from the fact that only 7 species were recorded at Holden Beach, while 40 species were taken at Caswell beach (Table SE-1). The observation is also supported by the fact that the ratio of the diversity means was found to be close to one for disturbed and undisturbed stations but much greater than 1 for ratios including the reference category. The number of samples taken was insufficient to construct confidence intervals to test the statistical significance of these differences.

3.4.1.3 Fall

Nekton abundance declined substantially in the fall, with CPUE values being lower than those for the spring and summer sampling trips. Generally less than 50 specimens were collected per station (Figure SE-3; Table SE-4). Gulf kingfish were the dominant species, comprising 75.36 percent of the catch at the reference beach and 47.95% of catch at the study beach, Oak Island (Table SE-1). Florida pompano and the speckled swimming crab were the other major species at Oak Island, making up 11.64% and 13.24% of the catch, respectively. The rations of means among all treatment categories varied widely by trip, ranging from 0.88 (R_{dr} for Trip 3) to 5.93 (R_{dr} for Trip 2). The variability in ratios is driven by variability in abundances, with CPUE at the reference beach ranging from 3.0 to 43. One or no samples were collected in the undisturbed category after the second trip of the season and only one station was sampled at the reference beach. As a result, the number of samples was insufficient to construct confidence interval estimates for the means.

As was seen in the summer sampling event that included Caswell Beach, many fewer species were taken at the reference beach than at Oak Island (5 versus 27) (Table SE-1). However, Figure SE-7 and Table SE-8 show the diversity did not differ substantially between the disturbed and reference stations, a result of few species being dominant at all locations. As was the case for other seasonal sampling events, the number of samples was insufficient for construction of confidence intervals to assess differences among the means.

3.4.1.4 Winter

The average nekton abundance observed during the trips in the winter sampling season declined to very low levels (Figure SE-4 and Table SE-5). Thirteen species were observed at the portion of beach being replenished (Holden Beach) and seven species were observed at the reference portion of Holden Beach (Table SE-1). Gulf kingfish was the most abundant species collected (70.59% of catch at the reference beach and 34.12% of catch at the study beach) with white mullet being the second most abundant (24.71% of catch at the study beach and 7.84% at the reference beach). The reference beach had the highest abundance of nekton for three of the four trips occurring during the winter season (Table SE-5), and disturbed stations had the lowest mean abundance. The test of differences between the undisturbed and disturbed station CPUE means indicated no significant difference (Table SE-10). However, the CPUE numbers are so low that comparisons among treatment categories may not be very meaningful.

The mean ratios over all trips indicated that disturbed stations had lower diversity than both undisturbed and reference stations (Figure SE-8 and Table SE-9). However, no significant difference was detected by the confidence interval test of the difference (Table SE-10).

3.4.1.5 Haul Seine Sampling Summary

The Holden Beach reference station yielded fewer species than all four of the study beaches in all four seasons, with the most dramatic difference occurring in the fall, when only 5 species were found at Holden Beach but 27 species at Oak Island (Table SE-1). One factor that could contribute to this difference is that only two replicate hauls were made at the reference beach, while a total of eight replicates were taken during any given sampling trip at the study beach. However, the consistency of this pattern of lower species numbers over all four seasons suggests Holden Beach may not have represented a good reference location against which to contrast the fish communities at the beaches affected by sand placement. A second clear pattern that emerges from the data is the strong seasonal trend in fish abundance, with a significant decline in abundance from summer through winter. The very high abundances found in the spring are most likely a result of the smaller mesh seine used in that season and are not comparable to abundance data from the other seasons. Subsequent annual sampling at Bald Head Island in the second year will be conducted with this smaller mesh net to provide data consistency.

Contrasts of abundance and diversity among the three treatment categories (reference, undisturbed and disturbed) is strongly impacted in all four seasons by the very high degree of variability in catch, both in abundance and diversity. The high variability results in some cases from the presence of strongly schooling species such as bay anchovy and in other cases by the high degree of mobility of many species that occupy the surf zone. This variability is reflected in the wide range in ratios of means seen in the seasonal data for both abundance and diversity. The small number or absence of samples in the reference and undisturbed categories limited the application of the standard test of means to only 5 of 12 combinations of means over all four seasonal sampling events. None of those tests indicated any significant differences between means for either abundance or diversity (Table SE-10).

3.4.2 Otter Trawl Sampling

Ninety-two species were collected in the trawl in the nearshore environment off the study beaches (Table TR-1). Of the 92 species, 8 species were sharks, skates and rays, 19 were decapod crustaceans, and 7 were other invertebrate species. Bay anchovy and striped anchovy were the dominant species and they were present at all beaches sampled and during all seasons. Eight other species (Atlantic menhaden, spot, windowpane, hogchoker, squids, lady crab, right-handed hermit crabs, and iridescent swimming crab) also were collected during each sampling period. In general, the Holden Beach reference beach had less specimens and species than the other beaches sampled during each of the seasonal sampling periods.

3.4.2.1 Spring

Bay anchovy was the dominant species during the spring sampling season at Bald Head Island and Holden Beach (Table TR-1). Two invertebrates, heart urchins (10%) and coarse hand lady crab (14%), were the next most abundant species collected at Bald Head Island, while butterfish (17%) and striped anchovy (8%) were the second and third most abundant species at Holden Beach. Two species, blue crab (0.1%) and longnose spider crab (2%), were collected only at the reference beach. Fish abundance was consistently highest at undisturbed stations, and disturbed stations tended to have lower abundances than both the reference and undisturbed stations (Figure TR-1 and Table-TR-2), as is confirmed by the ratios comparing the mean abundances among the three different groups. The ratios of means also show that the undisturbed stations tended to have higher abundances than the reference stations. The standard test of means showed that the difference between abundance at disturbed and undisturbed stations was significant (Table TR-10).

While mean nekton abundances differed significantly between disturbed and undisturbed stations, there were no significant differences detected among the diversities of the treatments categories (Table TR-10). Figure TR-5 and Table TR-6 show no pattern in diversity differences among treatments or trips. The ratio comparing the mean diversity among the different treatments is very close to 1 (Table TR-6).

3.4.2.2 Summer

The trawls catches offshore of Caswell Beach were composed primarily of bay anchovy (63%) and star drum (13%). The trawl catches at the reference beach consisted primarily of striped anchovy (49%), bay anchovy (23%), and Atlantic bumper (10%). Six species, bay whiff (0.11%), clearnose skate (0.11%), pinfish (0.09%), striped cusk eel (0.05%), starfish (0.03%), and Atlantic rock crab (0.03%) were collected only at the reference beach.

Disturbed stations had the highest mean abundance during three of the four trips, with the mean over all trips being more than four times the means of the reference and undisturbed sites, as reflected in the ratios of means (Figure-TR-2 and Table TR-3). During the last trip of the season, the disturbed stations had a mean abundance of over 9000 organisms. No confidence intervals could be constructed to confirm any significant differences because of the partitioning of the stations among the three groups (Table TR-10).

The nekton diversity also was the highest at the disturbed stations compared to the other treatments for three of the four summer trips (Figure TR-6 and Table TR-7). However, differences were small for Trips 1 and 2, as indicated by the ratio of the means being close to one. During the last two trips, the disturbed stations had a mean diversity value that was approximately twice the reference station diversity (Table TR-7). Lack of samples in treatment categories precluded construction of confidence intervals of means.

3.4.2.3 Fall

Bay anchovy dominated the trawl samples at Oak Island (65%) and at the reference beach (32%) (Table TR-1). Striped anchovy also was prevalent at both sites (9% at Oak Island and 11% at the reference station). Samples at the reference station also included significant numbers of squids (19%) and pinfish (14%). The northern searobin was the only species found at the reference site and not at the study beach.

The highest nekton abundance was observed during the third and fourth trips, when abundance at the disturbed sites was 2 to 3 times higher than at the reference site (Figure TR-3 and Table TR-4). While the overall mean for disturbed stations was substantially higher than both the reference and undisturbed means, no significant differences could be detected (Table TR-10).

No significant differences could be detected between the mean diversities of the undisturbed and disturbed stations (Table TR-10). Generally, the diversity among the three groups of stations was close to 1 (Figure TR-7 and Table TR-8). The highest diversity during the fall sampling season was detected at the reference station during Trip 3 and the lowest was found at the disturbed stations during Trip 2. The ratios of the means for the fall season were close to 1 for the three different combinations of stations. Furthermore, the ratios comparing the trips also were close to one, indicating little difference between the groups of stations.

3.4.2.4 Winter

The winter sampling season had the lowest abundance of organisms in the trawl samples among the four sampling seasons. Striped anchovy (44%) and bay anchovy (40%) dominated the samples at study beach stations (Table TR-1). The reference station samples were dominated by bay anchovy (42%) and pinfish (20%). Atlantic croaker and blueback herring were both collected in low numbers at the reference station during the winter sampling season and blueback herring were not collected during any other season.

Undisturbed stations had the highest nekton abundance during Trip 1, nearly 6 times the abundance found at the reference site (Figure TR-4 and Table TR-5). No pattern of differences in abundance among treatment groups was evident during the remaining trips. No significant differences among means were found in the standard test of differences (Table TR-10).

Diversity at the reference station was highest for all four trips as well as overall for the season (Figure TR-8 and Table TR-9). The ratios comparing the mean diversities generally were close to 1 indicating little difference among the trips. Overall, the reference station mean diversity was greater than the diversity at the disturbed and undisturbed stations.

3.4.2.5 Otter Trawl Sampling Summary

With the exception of spring abundance being higher in the undisturbed stations relative to disturbed station, few significant differences were detected among the mean abundances or diversity of the nekton communities sampled by trawl at the undisturbed, disturbed, or reference stations during most of the seasons (Table TR-10). In addition, the overall ratio of means for the three different combinations was close to 1 indicating little difference between the groups of stations over the course of a year.

3.4.3 Gillnet Sampling

Thirty-nine species were collected by gillnets set in the nearshore environment (Table GI-1). There were 21 fish species, 12 shark and ray species, and 6 invertebrate species collected in all samples. Generally, Atlantic menhaden, Atlantic thread herring, bluefish, cownose rays, and Atlantic sharpnose sharks dominated the samples. Atlantic sharpnose sharks were collected as both adults and juveniles with juveniles being the most abundant. Also, the total CUPE was much lower at the reference beach compared to the other beaches sampled during each of the seasons. No one species was found in all locations throughout the year. However, Atlantic menhaden, spot, and bluefish were collected during each of the four seasons. Spot was only collected at those beaches that received sand during the replenishment.

Atlantic menhaden (47%) and Atlantic sharpnose shark (21%) were the most abundant species collected during the spring sampling period at Bald Head Island, NC. Cownose rays (40%), bluefish (25%), and Atlantic thread herring (18%) were the most abundant species collected at the reference station located at Holden Beach, NC. Bonnetheads were only collected at the reference beach.

During the spring sampling period, Atlantic menhaden (22%), Atlantic sharpnose shark (22%), bluefish (16%), and cownose rays (12%) were the most abundant species at Caswell Beach. Bluefish (44%) and bonnetheads (27%) were the most abundant species at the reference beach. Only one species (one leatherjack) was found at the reference beach and not at the other beach, Caswell Beach.

Two species, Atlantic menhaden (90%) and spiny dogfish (10%) were collected during the fall sampling period at the reference beach. The collections at beach in Oak

Island, NC also collected these species as well as 11 additional species. Atlantic menhaden (70%) and bluefish (23%) were the most abundant at the beach undergoing sand replenishment.

The winter sampling period samples were dominated by Atlantic menhaden. Thirteen species were encountered at the beach undergoing sand replenishment in Holden Beach, NC while only seven species were taken at the reference beach. Clearnose skate was collected at the reference beach and not at the other beach sampled during the winter sampling period.

A summary of gillnet catches per hour of soak time by season is presented in Table GI-2. The number of gillnet sets was insufficient for conducting statistical analysis of differences among stations in CPUE. However, the only general pattern that emerges from these data is lower species diversity in catches at the reference station, Holden Beach.

3.4.4 Ichthyoplankton Sampling

Twenty-six species were identified in the ichthyoplankton samples (Table IC-1)[1]. Specimens also were identified to their genus for two groups (Anchoa and Menticirrhus), and to the family level for one group (Serranidae). Some specimens collected were unidentifiable, due to sampling damage. The spring and summer samples were dominated by Anchoa spp. Naked gobies (28%) were abundant in the samples collected at Bald Head Island, NC during the spring and hogchokers (17%) were abundant in the samples collected at the reference beach in Holden Beach, NC during the summer. Skilletfish, planehead filefish, windowpane, groupers, and dusky pipefish were found only in samples taken off Bald Head Island, NC during the spring sampling period. Several species, including Blue runner, lined seahorse, feather blenny, and harvestfish, were collected only during the summer sampling period at the reference beach.

Bluefish dominated the samples during the fall sampling period. One other species, butterfish, was collected at the reference beach during the fall sampling period. No larval anchovies were collected, but adult bay anchovies were encountered in the samples taken offshore of Oak Island, NC. During the winter sampling period, pinfish dominated the samples and were not collected during any other seasonal sampling period. Bluefish was the second most dominant species in the samples collected offshore of the reference beach and American eel were the second most dominant species offshore of the beach undergoing sand replenishment. Atlantic menhaden, black seabass, Atlantic silverside were encountered in samples taken at the beaches undergoing sand replenishment during the fall and winter sampling periods and not any other samples.

[1] Species identifications of ichthyoplankton are in the process of verification and validation, so the existing species list should be considered to be preliminary in nature and subject to correction.

A summary of mean ichthyoplankton densities per cubic meter of water per season is presented in Table IC-2. As in the case of gillnet sets, the intensity of ichthyoplankton sampling was insufficient for conducting statistical analysis of differences among stations in density. No general pattern emerges from these data with regard to differences among beaches.

3.5 SPECIES OF CONCERN AND DEMERSAL FISH DIETS

The original intent of the fish diet component of the study was to count, identify, and biomass prey items in at least 200 specimens. However, only 117 useable stomachs were obtained and among those stomachs the majority were empty. When food items were observed in the stomachs, they were so digested that they could not be counted accurately. An alternative means to evaluate the diets was devised where the presence or absence of a particular prey species in each fish stomach was noted. These data were used to calculate the frequency of occurrence among the stomach examined for the target fish species within a sampling trip. Because the sample sizes were so low, we were unable to evaluate diet differences among disturbed and undisturbed beaches.

As was discussed in Section 2.1.4, three species of concern were identified for consideration in this element of the study: spot, pompano, and Gulf kingfish. These species were considered to be of commercial and recreational value, known to be benthic feeders, and were expected to be found in the near-shore area where their feeding might be affected by benthic community changes associated with beach disposal. While stomachs were collected from specimens of all three species over the course of the first year of the study (see data presented in Table ST-1 to ST-10), sufficient samples and data usable for comparison to benthic community data were only obtained from Gulf kingfish. A key determinant of usability was that Gulf kingfish were taken all four sampling periods, and were relatively abundant during three of the four sampling periods. Thus comparisons to benthic data from all study beaches could be made. However, because of the importance of pompano as a resource species, abundance data for pompano are presented and discussed here, although links to benthic community changes could not be assessed for this species.

3.5.1 Florida Pompano

Florida pompano abundance peaked during the summer sampling period with few collected by seine during the other sampling periods (Figure PO-1). Florida pompano were collected only during Trip 4 of the spring sampling with the highest abundance occurring at the reference station (Figure PO-2 and Table PO-1). Summer sampling collections at Caswell Beach for each of the station treatments had numerous Florida pompano (Figure PO-3 and Table PO-2), while during the fall sampling season, pompano were captured only during the first two trips (Figure PO-4 and Table PO-3). Only a few Florida pompano were captured during the winter sampling at Holden Beach (Figure PO-5 and Table PO-4). No significant differences between the means of the different groups of stations could be detected during any of the seasons (Table PO-5). Additionally, no pattern could be discerned from the ratios comparing the means of the different groups of stations (Tables PO-1 through PO-4). While the differences were not determined to be statistically significant, fewer pompano were taken at the disturbed stations for the entire summer sampling event, when pompano were found to be most abundant during the year (Figures PO-1 and PO-3). However this difference was driven by the first trip's data when all the disturbed stations were sampled. All other trips sampled only disturbed stations. The overall mean CPUE at disturbed stations over the entire sampling year was lower than CPUE at undisturbed stations.

3.5.2 Gulf Kingfish

Gulf kingfish abundance peaked during the summer and fall sampling periods, but substantial catches continued in the winter sampling (Figure KI-1). The spring sampling period yielded few gulf kingfish with none being captured during the first trip and only two during the second trip (Figure KI-2 and Table KI-1). Fewer Gulf kingfish were taken at the reference beach than at Caswell Beach in summer, and the undisturbed stations had a greater abundance than the disturbed station during this season (Figure KI-3 and Table KI-2). Gulf kingfish abundances showed a decline as the fall sampling period progressed and no discernable pattern was observed among the groups of stations within that sampling period (Figure KI-4 and Table KI-3). Collections during the winter sampling period had few Gulf kingfish with the reference station always having the greatest abundances during each of the four trips (Figure KI-5 and Table KI-4). Confidence limit testing indicated that the abundances of Gulf kingfish were significantly higher in the disturbed stations at Bald Head Island in the spring. When the data were combined for all seasons, a significant difference between reference and undisturbed stations was indicated (Table KI-5). No significant differences could be detected between the mean abundances of the groups of stations during any of the other sampling seasons (Table KI-5).

Figure KI-6 presents the results of stomach content analysis for Gulf kingfish. These data demonstrate that Gulf kingfish exhibit a preference for crustaceans in their diets during all seasons in which they were captured. Bivalve and polychaete organisms comprised small portions of the gulf kingfish diet during any of the three seasons. Crustaceans were one of the benthic community groups that exhibited a negative response to beach disposal (Section 3.1.2).

3.6 WATER QUALITY RESULTS

3.6.1 Turbidity

The meters were attached to Ocean Crest pier (closest to the Cape fear inlet) and Long Beach pier (approximately 1.5 miles to the west) for approximately one year from June 2001 through May 2002. Many gaps in the continuous record appear in the data set (Figs TU-1 to TU-11) as a result of data filtering process necessitated by probe fouling, mooring failures, meter switch out, and other unavoidable problems, as was discussed in Section 2.2.2, above. The data that are presented in this section were examined to determine if beach replenishment operations created large increases in turbidity over long periods of time that were greater than background conditions. Also to help discern between dredging related turbidity increases and storm related events the wave height from NOAA's National Data Buoy Center Frying Pan Shoals Station (FPSN7) is also included on the plots. Wave height data are provided regardless of wind direction, which can greatly affect surf conditions (e.g., a strong offshore breeze can reduce surf zone wave height but still greatly affect conditions at the offshore NOAA buoy several miles out to sea). This may explain while there are some wave height increases that correspond to increased turbidity (Figures SA-2) while others do not (Figure SA-11). Based on the dredging operation logs the hydraulic pipeline was at or near the Ocean Crest pier at the end of October 2001 (Figure TU-5) and at or near the Long Beach pier at the end of February and the beginning of March 2002 (Figures TU-9 and TU-10). While large turbidity spikes where observed in the data when the pipeline was near both piers and when wave height at the NOAA buoy had not appreciably changed. Similarly high turbidity values were recorded during periods when the beach replenishment operations were miles from the monitoring sites (Figures TU-1, TU-4, TU-6, and TU-11) or when dredging operations where temporarily shut down (i.e., mid-September 2001; Fig TU-4). These large non-dredged related turbidity events were most likely caused by periodic storm surges and the resulting heavy surf conditions. Some, but not all of the wave height data support this.

The graphed data illustrates periods of high turbidity intertwined with periods of low turbidity. Graphed turbidity levels during baseline monitoring in June 2001 (Figure TU-1) showed high NTUs values at Long Beach Pier. Isolated point-spikes can be observed in the Ocean Crest data during this same period. July and August data (Figures TU-2 and TU-3) showed similar point-spikes during baseline monitoring conditions.

In September 2001 turbidity levels at Ocean Crest increased during the middle of the month and were sustained until the end of the month when they tapered off (Figure TU-4). During the same time period, Long Beach Pier experienced three distinct increases in turbidity that also tapered off at the end of the month.

With the exception of isolated incidents, turbidity readings in October 2001 (Figure TU-5) at both piers remained below 150 NTUs. Around the 16^{th} of October, turbidity levels at Ocean Crest Pier increased and were sustained above 1000 NTUs into November. Long Beach data during the same period showed jumps in turbidity levels but no sustained increase until the beginning of November (TU-6).

By the end of the first week in November turbidity levels at Ocean Crest Pier returned to levels below 100 NTUs (Figure TU-6). At the end of the first week, the monitoring station at Long Beach Pier marked a sudden increase in turbidity readings above 800 NTUs. This was sustained until approximately mid-November. From mid-November until the end of the month, readings for both stations generally stayed below 100 NTUs with intermittent increases in the turbidity.

Long Beach Pier showed a marked increase in the turbidity levels in December 2001 while the readings from Ocean Crest Pier remained relatively low in comparison (Figure TU-7). A slight increase in turbidity levels can be observed around the December 12th at Ocean Crest Pier.

No data was obtained for either pier between December 14, 2001 and January 28, 2002 (Figure TU-8).

Recorded turbidity levels from between January 29, 2002 and February 28, 2002 at Long Beach Pier were higher than those seen at Ocean Crest (Figure TU-8; Figure TU-9). There was no data for Long Beach Pier between February 14th and February 25th for comparison to Ocean Crest. Recorded turbidity readings for Long Beach Pier were high at the end of the February and continued on into the first week of March (Figure TU-10) when they dropped to readings of 0 NTUs. A short spike in turbidity was observed at Ocean Crest but returned to levels below 100 NTUs.

Observed turbidity levels in April 2002 showed high NTUs values at Long Beach Pier while the respective values at Ocean Crest Pier were much lower (Figure TU-11). During the last week in April, there was a simultaneous increase in turbidity levels for both piers.

3.6.2 Temperature

Temperature readings from both sites showed very little variation with a few exceptions. During the entire monitoring period, stations observed a maximum temperature of 31°C and minimum temperature of 9°C.

June 2001 temperature data showed very little variation in temperatures with the exception of about a four-day period in the middle of the month (Figure TE-1). During this period, recorded temperatures at Long Beach Pier were notably higher than those at Ocean Crest. Subsequent data between July 2001 and October 2001 (Figures TE-2 to TE-5) showed no discernable differences in temperatures. In late November, into early

December, temperatures at both stations averaged about 18 °C (Figures TE-6 and TE-7). Both stations observed the lowest recorded temperatures of 9 °C in February 2002 (Figure TE-9). Recorded temperatures continued to show similar values from in March (Figure TE-10). Temperature readings in mid-April for Long Beach Pier did appear to be slightly cooler then those temperatures observed at Ocean Crest for about a one-week period (Figure TE-11).

3.6.3 Salinity

Salinity levels in all deployments showed a consistent tapering off to lower values with a periodic increase and decrease in salinity values greater than 2 ppt. Several gaps in the long-term data set exist due eliminating data where the conductivity probe was fouled with marine organisms. Initial deployment of sondes in June 2001 (Figure SA-1) yielded initial readings at both Long Beach and Ocean Crest Pier of 34 ppt. With a decline to below 30 ppt in less than a 2-week period, subsequent deployments between July 2001 and October 2001 (Figures SA-2 to SA-5) showed similar patterns. Salinity readings began to stabilize for longer periods beginning in the fall and continued through the early winter (Figures SA-6 to SA-7); however tapering off of values after deployment was still evident. Although the data were screened for obvious errors, the gradual reductions in salinities recorded by the units were probably a result of the gradual build up of fouling organisms on the conductivity probe. Because Ocean Crest pier was closer to the inlet salinities would be expected to be lower (due to the freshwater discharges from the inlet) than those recorded at the Long Beach pier. While this was generally the case (e.g., Figure SA-5) there were other occasions when the opposite occurred (e.g. Figure SA-7). Because of these potential equipment malfunctions, these data should be viewed with caution. Recorded salinity values in late January 2002 (Figure SA-8), February 2002 (Figure SA-9), and March 2002 (Figure SA-10) had high variability between readings but showed similar patterns in salinity level changes. During this period, the Ocean Crest station typically exhibiting higher readings than the Long Beach Station. Recorded levels in April 2002 (Figure SA-11) at Ocean Crest Pier started off high and then tapered off to reading between 33 and 35 ppt. These readings were then observed to jump to 36 ppt on April 16th, and then increase to 38 ppt before tapering off to levels below 30 ppt. Long Beach data showed high variability during this same period with values fluctuating below 30 ppt and reaching maximum values close to 36 ppt.

3.6.4 Dissolved Oxygen

Dissolved Oxygen (DO) during the monitoring period typically ranged in values between 6 mg/L to 12 mg/L. On two separate occasions, August 2001 (Figure DO-3) and September 2001 (Figure DO-4) both stations recorded dissolved oxygen levels below 4 mg/L. While low ocean DO's are fairly unusual (particularly near the surf zone) these data passed the data screening procedure. Higher dissolved oxygen levels were typically seen in the winter months (Figure DO-8 and Figure DO-9) while the lower readings of 6-8 mg/L were seen in the warmer months. With the exception of August 2001 (Figure DO-3) DO readings were typically found to be higher at Ocean Crest Pier when compared to the readings at Long Beach Pier.

3.6.5 pH

Recorded pH levels remained constant over the monitoring period falling between 7.0 and 8.5 units. At the beginning of the monitoring period readings at Ocean Crest Pier were typically lower than those observed at Long Beach Pier. In September 2001 (Figure pH-4), there was a shift in the pH levels. Readings at Long Beach Pier started higher than those observed at Ocean Crest but shifted to lower levels at the middle of the month. Levels at Long Beach were again higher in October 2001 (Figure pH-5) but then shifted again to lower levels in November 2001 (Figure pH-6). After November 2001, pH readings at Long Beach Pier typically stayed below the levels recorded at Ocean Crest. In March 2002 (Figure pH-10) pH readings at Long Beach Pier had a sudden shift to levels below 8 units.

3.7 PLUME MAPPING RESULTS

Field crews mobilized to map turbidity plumes created by active sand placement on the beach on six occasions on Oak Island. Because of unscheduled shutdowns and intermittent sediment pumping by the dredger only four plumes were successfully mapped (Figures PL-1 to PL-4). The first plume was mapped in November 2001 while the second and third mapping was conducted in mid-March 2002. The four and final mapping was successfully completed in mid-April 2002. Table PL-1 provides a summary of measured turbidities for each sampling location. During a typical beach disposal operation sand and water was pumped into a small basin created by bulldozers around the discharge pipe. Excess water within the temporary basin was channeled away such that turbid water entered the surf zone a few 100 meters in front of the pipeline. In each case, the turbidity created by the discharge hugged the shoreline following the long-shore currents that were generally for east to west. On-shore wind events also contributed to keeping turbidity plume close to shore and in most cases the plumes were not discernable from turbidity created by the breaking waves in the surf zone a few 100 meters away from the end of the pipeline. During each mapping event, elevated suspended sediment loads outside of the surf zone were rarely observed. Although turbidity measurements were conducted over 5000 meters down current from the discharge during the first plume mapping, elevated levels were only observed within the first few 1000 meters (Figure PL-1). Mapping activities in subsequent events were thus reduced in spatial scope. During the second successful plume mapping event turbidities between 100 and 200 NTUs were observed at the point of discharge, dropped to below 100 NTUs a few meters away, and was below 30 NTUs beyond that (Figure PL-2). Ambient conditions were typically below

30 NTUs. Plume mapping during the third and fourth surveys resulted in turbidities over 1000 NTUs near the discharge point but levels generally returned to near ambient levels within 500 meters (Figures PL-3 and PL-4).

3.8 SEDIMENT GRAIN SIZE ANALYSIS

The results of the grain size analysis indicate that both the Holden Beach Reference and replenished beach study sites consisted of primarily medium and fine grained sand with a few exceptions (Figures GR-1 to GR-8). In general, the shallow, swash, and wrack habitat grain size composition had similar percentages of fine and medium sands relative to the deep habitats which typically had a higher percentage of fine sands. Some exceptions to the above observations include the spring samples at the Holden Beach Reference site (Figure GR-1) where a very low percent of very fine sand was found in the composite sample. In the spring at Bald Head Island (Figure GR-5) the composite sample for Trip 4 contained a large percentage of silt/clay in the deep habitat. During the fourth round of Bald Head Island collections, the field crew noted that the dredging operation was pumping high amounts of silt on the beach which was reflected in the grain size analyses where over 35% of the Trip 4 sample was comprised of silt/clay (Figure GR-5).

4.0 DISCUSSION

4.1 BENTHIC INVERTEBRATES

The benthic fauna inhabiting the 3 beach habitats examined in this study are typical of beach fauna along the east coast and South Atlantic Bight. The dominant benthic taxa inhabiting the swash zone, defined for this study as the beach area wetted only during high tide, included the bean clam, *Donax variabilis*, the mole crab, *Emerita talpoida*, the polychaete worm *Scolelepis squamata*, and amphipods in the Haustoridae family. For this study we only examined the abundance and biomass of *Donax* clams and *Emerita* mole crabs. Since both of these species are dominant in the swash area some investigators consider them important biological indictors of anthropogenic impacts on beach communities (Hackney et al. 1996).

The shallow subtidal habitat, defined as the area located within the wave breakers during low tide, contained a benthic community dominated by *Donax variabilis* clams, *Scolelepis squamata* worms and haustorid amphipods. These are common species to this beach habitat as documented by previous researchers in North Carolina (Daiz and DeAlteris 1982, Hackney et al. 1996, Jutte et al. 1999a and 1999b) and along the Atlantic coast (USACE 2001). The polychaete worm *Scolelepis squamata* had a peak abundance in the spring and declined in numbers to a low in winter. *Donax variabilis* had a peak in abundance during the summer and declined in numbers to a low in spring, whereas the haustorid amphipods as a group had a peak in abundance during the fall and declined in numbers to a low in the summer. Similar patterns of abundance with peaks in late spring and summer and lows in winter have been documented by other researchers in the North and South Carolina region (Van Dolah et al. 1994, Hackney et al. 1996) and along the Atlantic coast (USACE 2001).

Sand placement impacts on benthic communities were evident at all beach habitats examined but appeared to be more limited in terms of seasonal impacts at some habitats. The swash habitat appeared to be the most directly impacted by the sand placement, as effects were apparent across all sampling seasons and when all sampling trips were combined. For example, when all seasons were combined for the swash habitat, *Donax* clam abundances at the disturbed stations were significantly lower than the reference and undisturbed stations (Table SW-9). Within seasons, the disturbed stations supported significantly fewer clams than the reference in each individual season as well (Table SW-9). The ratio of clams at disturbed versus reference within each season ranged from a high of 0.3 (meaning that the disturbed site contained 70% less clams) during the summer sampling period to a low of 0 (meaning no clams were collected at the disturbed stations) in the spring (Tables SW-1 to SW-4). Further, the disturbed stations supported significantly less clams than the undisturbed stations during the spring and winter sampling periods (no significance test for disturbed versus undisturbed was possible in the summer due to the sand placement schedule, Table SW-9).

Sand placement effects on *Emerita* mole crabs in the swash habitat were less apparent. No significant differences were detected in *Emerita* mole crab abundance between the disturbed, undisturbed, and reference stations, when all seasons were combined, (Table SW-9). However, significant differences were detected in some individual sampling seasons. The disturbed stations had significantly less crab abundances during the spring than either the reference and undisturbed areas (Table SW-9). The disturbed stations also had significantly less crabs during the winter sampling period than the undisturbed stations (Table SW-9). The more limited impact detected in crab abundance and is more likely due to the patchy crab distribution than the crab's ability to escape sand placement effects. Patchily distributed crab populations lead to a high variance around the means within a sampling treatment, thereby reducing the ability to detect a significant impact. For example during the summer, the overall mean abundance of crabs at the disturbed stations was about one third less than the reference stations, but because of the large differences in abundance of crabs collected within each trip at both of these treatments (i.e., from 0 to 630/m2 at the reference stations), the variance around the mean was large (Table SW-6).

Impacts in the shallow subtidal habitat were more limited seasonally, with the greatest impact occurring during the spring and summer sampling periods. When all sampling seasons were combined for the disturbed, undisturbed, and reference conditions within the shallow habitat, no significant differences were detected in any of the benthic parameters examined with the exception of bivalve abundance (Table SH-38), which was significantly lower at the disturbed stations than at both the reference and undisturbed areas (Table SH-38). On a seasonal basis of all the benthic parameters tested in the shallow habitat, a total of four means in the spring, two in the summer, two in the fall, and none in the winter, were significantly lower at the disturbed stations than at the reference and undisturbed stations (Table SH-38). In no instance was the mean of any abundance or biomass parameter significantly higher at the disturbed stations compared to the reference or undisturbed areas.

In the shallow habitat, impacts on bivalve abundance were apparent during the spring and summer sampling period (Table SH-38). In the spring, the disturbed stations contained significantly fewer clams than both the reference and undisturbed areas (Table SH-38). In the summer, the reference area supported significantly more clams than the disturbed stations. Because of the sampling design and the double impact that occurred at the Caswell Beach study area during the summer sampling period, statistical comparisons between disturbed and undisturbed areas were not possible. Visually, however, the number of clams collected from the disturbed stations was about 90% less than those collected from the undisturbed area (Table SH-31).

The impact on bivalves in the summer at Caswell Beach in the shallow habitat was considerable since bivalves comprised about 70% of the total abundance at the reference stations (Table SH-38). When all trips were combined, the ratio between the disturbed and reference area was 0.09 indicating that the disturbed stations contained about 10 times fewer clams than the reference stations (Table SH-31). Since bivalves made up such a large percentage of the total benthic abundance at the reference area, total abundance during the summer period at the disturbed stations was also negatively impacted (Table SH-38). Diversity, as measured by the Shannon Weiner Index, was significantly higher at the disturbed stations than the undisturbed stations during the summer sampling period (Table SH-38). This is not surprising since this diversity index incorporates measures of richness and abundance. The reference stations in the summer contained a substantial amount of bivalves resulting in a low Shannon Weiner Index whereas the disturbed stations contained much fewer bivalves as a percentage of the total resulting in a higher Shannon Weiner Index. The impact on bivalve abundance seen in the summer was not reflected in bivalve biomass indicating that clams collected from the reference beach area were small in size (Table SH-38).

In the deep habitat, when all seasons were combined, total benthic abundance and mean abundance of crustaceans were significantly lower at the disturbed stations than at the reference and undisturbed stations (Table DE-38). Sand placement impacts in the deep habitat were concentrated during the spring sampling period, the major recruitment period for benthic macroinvertebrates. A total of 10 means in the spring, one in the summer, two in the fall, and none in the winter, were significantly lower at the disturbed stations compared to the reference and undisturbed stations (Table DE-38). The only instance where the disturbed stations contained a significantly higher mean abundance or biomass than the reference or undisturbed stations was during the spring sampling season (i.e., bivalve abundance, Table DE-38). In this instance, the abundance of bivalves was extremely low at all treatments (Table DE-30).

During the spring sampling period, the disturbed stations in the deep habitat contained significantly less total abundance and total biomass than the undisturbed and reference stations (Table DE-38). The mean total abundance at the disturbed stations in spring was about 90% less than at both the undisturbed and reference stations (Table DE-2). Total biomass was about 30 to 50% lower at the disturbed stations during the same season (Table DE-6).

The major taxonomic group in the deep habitat contributing to the low total abundance and biomass at the disturbed stations during the spring sampling seasons were crustaceans and polychaetes (Table DE-38). As with total abundance, the mean number of crustaceans at the disturbed stations was about 90% less than the mean at both the reference and undisturbed stations (Table DE-14). Total crustacean biomass at the disturbed stations was also significantly lower than at both the reference and undisturbed stations (Table DE-38). Polychaetes were also a dominant taxonomic group in terms of abundance during the spring sampling season. The abundance of polychaetes at the disturbed stations was about 90% less than the undisturbed stations (Table DE-22) and was significantly lower (Table DE-38). However, no significant difference in polychaete abundance was detected between the disturbed and reference stations (Table DE-38).

The reduction of crustaceans and polychaetes detected in the spring in the deep habitat may be related to the increased silt/clay content of the fill material. At the time of sampling field crew noticed that a substantial amount of silty material was being pumped on the Bald Head Island (Figure GR-5). Other researchers (Peterson et al. 2000, Rakocinski et al. 1996, Van Dolah et al. 1994, Reilly and Bellis 1983) have shown that impacts on benthic communities from sand disposal activities are greater and recovery is slower if changes in sediment characteristics occur.

Significant differences detected in other seasons between the disturbed, undisturbed, and reference stations in the deep habitat may suggest possible additional sand placement effects, but the results are not definitive. During the summer sampling period, crustaceans were significantly lower at the disturbed stations compared to the reference (Table DE-38). But, as previously stated, differences between the disturbed and undisturbed stations could not be tested. Total abundance during the fall sampling period was significantly lower at the disturbed stations than the reference stations (Table DE-38). However, this may be due more to the high number of organisms collected from the reference area than sand placement impacts since both the disturbed and undisturbed stations were not significantly different during the fall sampling period (Table DE-38). Crustaceans were the major taxonomic contributor to the higher abundance at the reference area during the fall sampling period. Mean crustacean abundance at the reference stations was significantly higher than both the disturbed and undisturbed station means, and no significant difference between the disturbed and undisturbed stations was detected (Table DE-38).

This report presents preliminary findings that relate to relatively short-term effects of the beach disposal program. The most significant short-term impact on benthic communities observed was in the swash habitat of the beach. This effect is not unexpected, since the swash habitat is the location in which the dredged sand was placed on the beach, and was thus the most severely perturbed. Effects in the swash habitat were seen in all seasons.

Most impacts in the shallow and deep habitats appeared to be limited to the spring and summer. Because spring and summer are the major seasons for recruitment of most of the major components of the benthic community in this region, these effects may suggest that the beach disposal activities altered recruitment patterns in some way. The major impacts detected during the spring sampling season occurred in taxonomic categories such as crustaceans and polychaetes, both major food resources for fish populations. These short-term changes in the benthic community had the potential for having some effect on organisms that forage from that community, such as fish and mobile invertebrates.

Impacts detected during the summer sampling period in the shallow habitat are difficult to interpret, since the responses observed were compounded by the additional sand placement that occurred at Caswell Beach. Mean numbers of clams collected from the disturbed area of Caswell Beach were 10 times less than those collected from the reference area and undisturbed area (SH-31). Since Donax clams were the most dominant taxa (Table SH-1), this 10-fold reduction in clam abundance, led to a significant impact to total abundance. What is unclear due to the double sand placement is whether such a substantial reduction in clam abundance would have occurred with just a single disposal event.

This initial phase of the study documents the immediate and short-term decline of benthic communities within days to weeks of sand placement. By sampling within such a short time frame of the actual sand placement, we are able to quantify the decline caused by sand placement. For example in the swash habitat, *Donax* clam abundance at the disturbed sites showed a 100% reduction in the spring (the period of lowest abundance for this species, Table SW-1). In the summer, *Donax* clam abundance at the disturbed sites was reduced by about 70 to 80% (the period of highest clam abundance, Table SW-2) after sand placement. In the shallow habitat, bivalves displayed a significant reduction in abundance during the summer sampling period of about 90% (Table SH-31). In the deep habitat during the spring sampling period (the season displaying the majority of impact in this habitat), crustaceans had a 50 to 70% reduction at the disturbed stations (Table DE14) and polychaetes declined by about 70 to 90% (Table DE-22).

This report provides results of impacts on benthic communities immediately after sand placement. An additional year of sampling at the same disturbed and reference stations is ongoing at all four beaches that received sand disposal. Studies conducted at nourished beaches along South Carolina recorded benthic recovery within 3 to 6 months after sand placement (Van Dolah et al. 1994, Jutte et al. 1999a and 1999b). A large scale nourishment project along the New Jersey coast near Asbury Park recorded benthic recovery rates within 2 to 6.5 months of sand placement (USACE 2001). Whether the short-term effects noted by these historical studies are sustained at the Cape Fear River beaches will be determined from the results of the final year of sampling and will be addressed in the final project report.

4.2 FISH

The surf zone fish community documented in sampling at all five beaches samples was found to be similar to that reported for surf zone fishes in the South Atlantic Bight (Hackney et al. 1996). However, when catches at the five beaches are contrasted, it appears that abundance and diversity were higher at the four study beaches than at the portion of Holden Beach designated as the reference beach. This difference may be attributable to the fact that the study beaches were all closer to the mouth of the Cape Fear River, a large estuary, than was the Holden Beach reference area, which was located approximately 10 miles away from the estuary. The consequence of this finding is that catches at Holden Beach did not represent good references for catches at the study beaches. With the exception of spring trawl abundance being higher in the undisturbed stations relative to disturbed station, fish catches with seines and trawls revealed no significant difference in nekton abundances and diversities among the disturbed, undisturbed, and reference stations during any of the four sampling periods (Tables SE-10 and TR-10). In addition, the overall ratio of means for the three different beach treatment combinations (i.e., disturbed, undisturbed, and reference) were generally close to 1, indicating little difference between the groups of stations over the course of a year.

The statistical analyses of the fish data were constrained by the relatively small numbers of samples collected and the extremely high variability in the catch data, which reflects the schooling behavior of many of the major species (e.g., Bay anchovy) and also the high degree of mobility of the fish present in the surf zone and near-shore habitats. The high degree of mobility of the most common species in the study area suggests that they could readily move in and out of areas where habitat and water quality conditions were being affected by the replenishment operations. As was seen in the plume mapping, however, the affected areas were restricted in size, with further limits the extent to which effects on fish might occur. The one observation from the fish data that may reflect a response to beach disposal activity was a trend of fewer gulf kingfish occurring at the disturbed stations then the undisturbed stations. This trend could be related to the fact that the preferred prey of gulf kingfish was determined to be crustaceans and crustaceans were one of the benthic community components that did show a seasonal impact.

The results of the fish studies for the current Wilmington North Carolina study was similar to studies conducted by the New York District of the Corps of Engineers for the Asbury Park to Manasquan beach replenish environmental monitoring (USACE 2001). The Asbury Park to Manasquan study included pre-construction baseline monitoring between1994 and 1996, a year of during construction testing (1997), and three years of post construction monitoring conducted between 1998 and 2000. Beach seine sampling indicated that the silversides, *Menidia* and *Membras* spp numerically dominated the surf zone. Among the subject beaches, fish community composition and abundance was relatively homogeneous and post-disposal monitoring did not reveal any long-term impacts to surf zone finfish distribution and abundance. The only beach disposal related effect noted by the study was that the surf zone finfish community changed from an assemblage dominated by silversides to bluefish (*Pomatomus saltatrix*) during the construction phase of the project. However, this change was attributed to natural change in fish community composition that was observed throughout the study area. The study concluded that there were no biological indicators within the fisheries data that distinguished nourished beaches from non-nourished beaches.

The gill net and ichthyoplankton data collected provide a means of characterizing the large mobile species that move through the study area and the species that utilize the near-shore habitats as spawning or nursery areas. While these data provide a good characterization of species that would be exposed to the effects of beach disposal, they are not amenable to analysis of short-term sand placement effects. Thus, the data documented in this report will be of greatest value for comparison to similar data collected during the second year of the study.

The design of this study does not allow for assessments of potential impacts on fish communities at the population level, since the species occupying the habitats sampled are very mobile and common along major regions of the East Coast. Also, the fish stomach content data was too weak to provide any meaningful assessment of potential shifts in diet. Thus, the findings from the second year of the study will only provide a means of assessing whether fish communities present at study beaches a year after beach disposal are similar to those that were present prior to and during sand placement, as a basis for determining if any sustained impacts to fish communities may have occurred.

4.3 SEDIMENT AND WATER QUALITY

Several elements of this study were implemented in order to document the magnitude and temporal/spatial extent of water quality and substrate changes that may have been caused by beach disposal activities. Such information is useful for assessing the types and magnitudes of environmental perturbations to which both the benthic and fish communities may have been exposed, thus allowing for possible interpretation of any biological responses observed. Sediment analyses documented that, with the single exception of spring samples at Bald Head Island, the sand being placed on the study beaches did not significantly alter the sediment characteristics of the beaches. This finding is of biological significance because the benthic community composition is strongly influenced by sediment characteristics. This was confirmed by the fact that the unusually high silt content of samples taken at Bald Head Island were accompanied by a distinct and significant change in the benthic community present. The sediment data from this first year of study suggests that any sustained change in benthic communities that might be observed later in the study will not be attributable to changes in sediment characteristics.

Within the water quality parameters monitored, no changes of biological significance were observed in temperature and pH. In the case of oxygen, only a single excursion to a low of 4 ppt was found, and that was short-lived. Thus, it does not appear that beach disposal was responsible for any changes in these water quality parameters that would have consequences to biota. The single major water quality parameter that was clearly influenced by the sand placement activities was turbidity, which was measured at the fixed, continuous monitoring stations, and also through grab samples during plume mapping. Observed spikes in turbidity at the fixed stations did occur when sand placement was occurring in close proximity to the monitoring stations, but also occurred during other periods, most likely in response to off-shore storms, winds, and tidal cycles. The high turbidity observed at Long Beach pier in June 2001 (Figure TU-1) may have been the result of a local storm as Ocean Crest pier observed the same event but on a lower scale. In September 2001 (Figure TU-4), pipes were located well to the east of Ocean Crest pier and progressively moving west towards the monitoring stations. During this period, it is possible that increased turbidity values at both piers were caused by beach disposal activities. However, because the field crews were not present during these periods of periodic pumping followed by long periods of no pumping, no specific increases can be solely attributed to pumping activities. The monitoring station at Ocean Crest pier recorded a similar event in October 2001 (Figure TU-5) while concurrent readings at Long Beach Pier were much lower. Beach disposal pipes approached Ocean Crest pier in mid-October 2001 and by October 31st, the pipes were at the base of Ocean Crest pier. The observed turbidity values at Ocean Crest Pier were high and sustained at levels above 1000 NTU. During this period, field crews did observe that the monitoring station was in the plume of dredge materials. High turbidity values continued to be observed into November 2001 (Figure TU-6) as the pipe moved past Ocean Crest and progressed westward towards Long Beach Pier. Once the pipes were past Ocean Crest pier, turbidity levels dropped. This may have been an indication that the plume was no longer affecting the Ocean Crest station. Increased turbidity levels at Long Beach Pier were observed and may have been an indicator of continued pumping activities through December 2001 (Figure TU-7). Between February 2002 (Figure TU-9) and April 2002 (Figure TU-11) graphs shows scattered periods of high turbidity at Long Beach Pier while the readings at Ocean Crest remained relatively low. In a few cases (Figure TU-9) both units recorded simultaneous increases in turbidity that may have been a storm event as there were multiple occasions when turbidity readings were higher at Long Beach during this period. In late April 2002, high turbidity was recorded by both piers that must have been a result of a non-dredging event because the pipe was located west of the Ocean Crest monitoring station at this time (Figure TU-11). Plume mapping confirmed that the turbidity plume associated with sand placement tended to remain close to shore, with its direction of displacement being associated with tide stage and currents.

5.0 REFERENCES

Buchanan, J.B. 1984. Sediment analysis. Pages 41-65. In: N.A. Holme and A.D. McIntyre, eds. *Methods for study of Marine Benthos*. IBP Handbook No. 16 2nd Edition. Blackwell Scientific Publications. Oxford, England.

Diaz, R.J. and J.T. DeAlteris. 1982. Long-term changes in beach fauna at Duck, North Carolina. U.S. Army Corps of Engineers Coastal Engineering Research Center Miscellaneous Report 82-12. November 1982, 48 pp.

Gilbert, R. O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold. New York.

Hackney, C.T., M.H. Posey, S.W. Ross, and A.R. Norris. 1996. A review and synthesis of data on surf zone fishes and invertebrates in the South Atlantic Bight and the potential impacts from beach nourishment. Prepared by the University of North Carolina at Wilmington and the North Carolina National Estuarine Research Reserve for the U.S. Army Corps of Engineers, Wilmington, NC.

Jutte, P.C., R.F. Van Dolah, and M.V. Levisen. 1999a. An environmental monitoring study of the Myrtle Beach Renourishment Project: Intertidal benthic community assessment of Phase I. – Cherry Grove to North Myrtle Beach. Final Report. Prepared by the Marine Resources Division, South Carolina Department of Natural Resources for U.S. Army Corps of Engineers, Charleston, SC.

Jutte, P.C., R.F. Van Dolah, and M.V. Levisen. 1999b. An environmental monitoring study of the Myrtle Beach Renourishment Project: Intertidal benthic community assessment of Phase II. – Myrtle Beach. Supplemental Report. Prepared by the Marine Resources Division, South Carolina Department of Natural Resources for U.S. Army Corps of Engineers, Charleston, SC.

Krebs, C.J. 1978. *Ecology: The Experimental Analysis of Distribution and Abundance.* New York: Harper & Row.

Murphy, B.R. and D.W. Willis. 1996. *Fisheries Techniques*, 2^{nd} edition. American Fisheries Society, Bethesda, MD

National Research Council. 1995. *Beach Nourishment and Protection*. National Academy Press. Washington DC. 334 pp.

Nelson, W. G. 1993. Beach restoration in the southeastern US: Environmental effects and biological monitoring. Ocean & Coastal Management 19: 157-182.

Pennington, M. and J. H. Vølstad. 1994a. The effect of intra-haul correlation and variable density on estimates of population characteristics from trawl surveys. Biometrics 50: 725-732.

Pennington, M. and J. H. Vølstad. 1994b. Local homogeneity of marine populations and its implications for the design of sampling surveys. Invited paper for the Biometrics Society Conference on Sampling Issues in Ecology, Cleveland, April 1994.

Peterson, C.H., D.H.M. Hickerson, and G.G. Johnson. 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. Journal of Coastal Research 16: 368-378.

Rakocinski, C.F., R.W. Heard, S.E. LeCroy, J.A. McLelland, and T. Simons. 1996. Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, U.S.A. Journal of Coastal Research 12: 326-353.

Reilly, F.J. and V.J. Bellis. 1983. The ecological impact of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina. Miscellaneous Report 83-3. U.S. Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA.

Schenker, N. and J.F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. Am. Stat. 55(3): 182-186.

Shannon, C.E. and W. Weaver. 1949. *The Mathematical Theory of Communication.* Urbana: University of Illinois Press.

Snedecor, G.W. and W.G. Cochran. 1980. *Statistical Methods*, 7th edition. The Iowa State University Press, Ames, IA.

USACE. 2001. The New York District's Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project, Final Report. Prepared by U. S. Army Corps of Engineers, Waterways Experiment Station Vicksburg, MS 39180.

Van Dolah, R.F., R.M. Martore, A.E. Lynch, P.A. Wendt, M.V. Levisen, D.J. Whitaker, and W.D. Anderson. 1994. Final Report. Environmental Evaluation of the Folly Beach Nourishment Project. Prepared by the Marine Resources Division, South Carolina Department of Natural Resources for U.S. Army Corps of Engineers, Charleston, SC. 101 p.p. & appendices.