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Fishery Resource Utilization of a Restored Estuarine Borrow Pit: A Beneficial Use of Dredged Material Case Study

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ABSTRACT: Many open-water habitats that provide Essential Fish Habitat functions are also thought to be particularly susceptible to dredging project impacts. Evidence exists, however, that placement of dredged material in open-water sites can result in viable — even enhanced — habitat attributes and functions for fish and shellfish. For example, offshore disposal sites are often used extensively as recreational fishing areas. Dredged material can also be used to restore degraded fish habitat, such as to fill artificial pits, holes, and depressions that are scattered throughout a majority of estuaries and coastal embayments. Concerns have been voiced that pits periodically or chronically have poor water quality conditions and consequently represent degraded fish habitat. Several borrow pits in estuarine waters of New Jersey have been documented to experience low dissolved oxygen and high hydrogen sulfide concentrations, particularly during summer months. A major contributing factor to potentially poor water quality in dredged holes is hypoxia or anoxia resulting from accumulation of organic material, poor tidal flushing, and water column stratification. In 2005, the Philadelphia District of the U.S. Army Corps of Engineers partially filled a dredged hole in Barnegat Bay, New Jersey with 125,000 cubic yards of clean, sandy dredged material to raise the bottom from -11.6 m Mean Low Water (MLW) to an elevation of -5.5 m MLW. For monitoring purposes a nearby dredged pit served as an unrestored control. Seasonal conditions in both borrow pits were assessed in terms of water quality, benthic invertebrate community structure, fishery resource assemblage composition, and borrow pit utilization patterns. Benthic macroinvertebrates were sampled by Young grab seasonally to evaluate recruitment and community structure. One hundred and fifty-one taxa were collected during the course of the study, including 71 polychaete, 21 amphipods, 17 bivalves, 11 gastropods, 4 isopods, 3 mysid shrimp, 3 cumaceans, and 21 miscellaneous taxa. Benthic data were analyzed using a three-way factorial ANOVA for mean taxa per sample. Significant ($p<0.05$) differences were found for only two factors: habitat (three depth strata) and Before/After restoration. Each of the three habitat depths was found to be significantly different ($p< 0.05$) from one another with the highest average number of taxa occurring in the shallow depth stratum and fewest in the deepest depth stratum. Numbers of taxa per sample increased in the restored pit following placement of dredged material. Fishery hydroacoustic surveys were used to assess temporal and spatial distributions of fish targets by site, time of day, tidal cycle, and season. Fish densities were greater in the unrestored pit during spring and summer sampling events, although the reverse was found during fall sampling. Tidal stage had no statistically significant effect on fish density, whereas significant ($p<0.05$) effects were observed between seasons and day/night sampling events. Conventional otter trawling and gill netting efforts were used to determine the composition of the fishery assemblage at each site by season. Trawl data were analyzed by multivariate statistical methods, which indicated that species composition varied primarily between sampling periods than between sites. Fish assemblages were consistently similar in composition in both pits for all

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individual sampling periods. Pair-wise comparisons by month indicated that August samples differed from those in both May and November, but May and November did not differ. May trawl samples were characterized by anchovies and bluefish, August trawl samples by high abundances of blue crabs, anchovies and spot, and November samples by silversides and Atlantic croaker. While results showed few dramatic changes in fish or invertebrate assemblages directly attributable to partial filling of the restored borrow pit, summer conditions during the monitoring period did not establish a strongly stratified water column in either pit. Benefits of pit filling with respect to fish habitat would be most apparent during periods of high ambient water temperature. Additional monitoring during summer months is warranted to firmly establish that water quality remains above viable fish habitat thresholds. Results indicate that placement of dredged material in borrow pits is a viable fishery habitat restoration option.

INTRODUCTION: In 1995, the U.S. Environmental Protection Agency recognized Barnegat Bay as an estuary of national significance. Soon thereafter, the Barnegat Bay Estuary Program was implemented to promote the environmental health of the estuary (U.S. Army Corps of Engineers (USACE) 2001). One identified concern was the presence of as many as 38 artificial bathymetric depressions (dredged holes) created in New Jersey estuaries as a consequence of historical sand mining to repair storm-damaged beaches. Of these borrow pits or dredged holes, 21 were located within Barnegat Bay. Studies conducted by the New Jersey Department of Environmental Protection (NJDEP) determined that poor water quality conditions contributing to aquatic habitat degradation existed in the deeper portions of these dredged holes (Murawski 1969). The NJDEP study found — at least during summer months — that 21 of the 38 dredged holes had low dissolved oxygen (DO) and high hydrogen sulfide concentrations, and that 20 of the 38 dredged holes were devoid of benthic invertebrates. In 1992, the dredged holes were resurveyed by the NJDEP (cited in USACE 2001) and found to contain water quality conditions that did not differ substantially from those reported by Murawski (1969). As part of restoration planning efforts, environmental monitoring was conducted by Versar Inc. (unpublished data 1999). They reported that benthic invertebrate communities were depressed in comparison with benthos prevalent in adjacent bay habitats shallower than 2 m. This finding was particularly evident in the deep portion of a borrow pit designated as Dredged Hole #6. In contrast to previous studies, severe hypoxic conditions were not observed during summer monitoring events, although occasional readings of DO concentration as low as 3 mg/l were found in the deep basin of Dredged Hole #6. Factors that were frequently found in dredged holes and that may have contributed to hypoxic/anoxic conditions include: accumulation of organic detritus, poor tidal flushing, and water column stratification exacerbated by a lack of wind-induced mixing due to the sheltering effect of nearby shorelines. The NJDEP concluded that habitat conditions could be improved by filling the dredged holes with suitable sediments.

From several perspectives, filling existing borrow pits represent a logistically and ecologically feasible restoration option. Borrow pits are potential placement sites for substantial volumes of dredged material, if navigation channels requiring periodic maintenance dredging lie within reasonable distances. Returning subtidal bottoms in the estuary to their historical depth contours could reestablish preexisting habitat attributes and functions. Detractors opposed to filling dredged holes claim that existing pits provide valuable recreational fishing areas and critical over-wintering habitat for various fishery resources. Potential benefits and detriments of borrow pits are reviewed in Yozzo et al. (2004) and USACE (2001). These include: altered circulation and secondary effects on tidal ranges and wave energies, creation of sinks for deposition of fine sediment, oxygen depletion, altered benthic communities, and recreational fishing use. Previous characterizations of benthic resources in borrow pits in the region include Cerrato and Scheier (1984), and Cerrato et al. (1989). Likewise, regional fishery resource use of borrow pits and surrounding open-water habitats have previously been assessed by Conover et al. (1985) and Woodhead and McCafferty (1986).

USACE and NJDEP considered benefits to fishery resource habitat, available sources of dredged material, the need for restoration, and cost-benefit ratios to evaluate the efficacy of various pit restoration scenarios. An initial scenario considered restoring pit habitat primarily for benthic organisms, whereas a second scenario focused on fish habitat. A third scenario looked at optimizing both benthic and fish habitat functions. Several "depth to fill" alternatives were assessed with regard to impacts on benthic and fish communities. One alternative consisted of a partial filling of Dredged Hole #6 from an elevation of -11.6 m (38 ft) to an elevation of -5.5 m (-18 ft) MLW. A second alternative involved complete filling to an elevation of 1.8 m (-6 ft) MLW, level with the surrounding bottom. These "depth to fill" alternatives were evaluated with respect to impacts to benthic biomass, benthic species diversity, benthic abundance, fish abundance, fish species diversity, water quality and sediment quality. For purposes of comparison, a nearby unrestored borrow pit, designated as Dredged Hole #5, was identified as a reference site. Baseline data were collected in each dredged hole and used to assess the overall "health" of each borrow pit by examining water quality, benthic invertebrate communities, and fishery assemblages. The original environmental assessment concluded that maximum benefit with regard to the benthic community would be obtained from filling both pits to -1.8 m (-6 ft) MLW, the ambient surrounding depth of the bay. However, this alternative was not considered to be advantageous to the fisheries community in that a large number of juvenile weakfish and other species were speculated to use the dredged holes, particularity at intermediate depths. Baseline data showed that fish abundance was generally low in the deep portion of Dredged Hole #6, and a relatively healthy benthic community was found at intermediate depths of the side slopes. Therefore, to increase benefits to the benthic community while improving water quality and avoiding negative impacts to fish habitat, the partial filling alternative was selected.

In 2005, Dredged Hole #6 was filled to a target elevation of -5.5 m (-18 ft) MLW by placing dredged material derived from the Double Creek Channel in Barnegat Bay using a hydraulic pipeline cutterhead dredge. The final design included formation of six mounds in the elevated basin of the hole to add relief and increase the bathymetric complexity of the borrow pit basin. By mounding the sediments during the dredge and fill operation, it was theorized that the tops and sides of the mounds would provide conditions suitable to sustain and support a healthy and diverse benthic invertebrate community. Dredged sediments consisted primarily of sandy material (70 to 90 % coarse fractions). Approximately 96,000 cubic meters (125,000 cubic yards) of dredged material was pumped into Dredge Hole #6. A minimum of one meter (~3 ft) of sand was placed over the underlying fine-grained sediment as a foundation for creation of sand mounds. Dredged Hole #5 was left at its existing depth of -5.5 m (-18 ft) MLW.

Hydroacoustics has been widely used for surveying fishery resources in rivers (Hughes 1998; Lyons 1998), lakes and reservoirs (Gangl and Whaley 2004; Taylor et al. 2005), deep-water systems (Slotte et al. 2004), and shallow water estuarine habitats (Boswell et al. 2007). This technology is particularly suited for assessing fishery usage of borrow pits. Hydroacoustics are an efficient, non-destructive survey technique capable of acquiring high-resolution spatial and temporal data and the capacity to survey large areas in relatively short periods of time (Simmonds and MacLennan 2005). These advantages overcome the limitations of deployment of conventional netting gear within the confines of pits with relatively steep side slopes. One limitation is the inability of hydroacoustic techniques to identify targets to species. For this reason, limited conventional sampling techniques (i.e., otter trawls and gill nets) were used to supplement and "ground truth" the acoustic data.

METHODS

Study Site. Barnegat Bay (39° 43.9' N, 74° 9.1' W) is a 75-square-mile shallow estuary located in Ocean County, New Jersey. Situated behind a barrier spit and Long Beach Island, the estuary's primary connection to the ocean is via Barnegat Inlet (Figure 1). Dredged Holes #5 and #6 are located less than 30.5 m (100 ft) from shore along the western side of Long Beach Island. Dredged Hole #5 is located adjacent to the town of Loveladies, and covers an area of approximately 2.8 hectares (7 acres). Dredged Hole #6 is located in the Borough of Harvey Cedars, approximately 1.6 km (1 mile) south of Dredged Hole #5, and covers an area of approximately 4.9 hectares (12 acres).

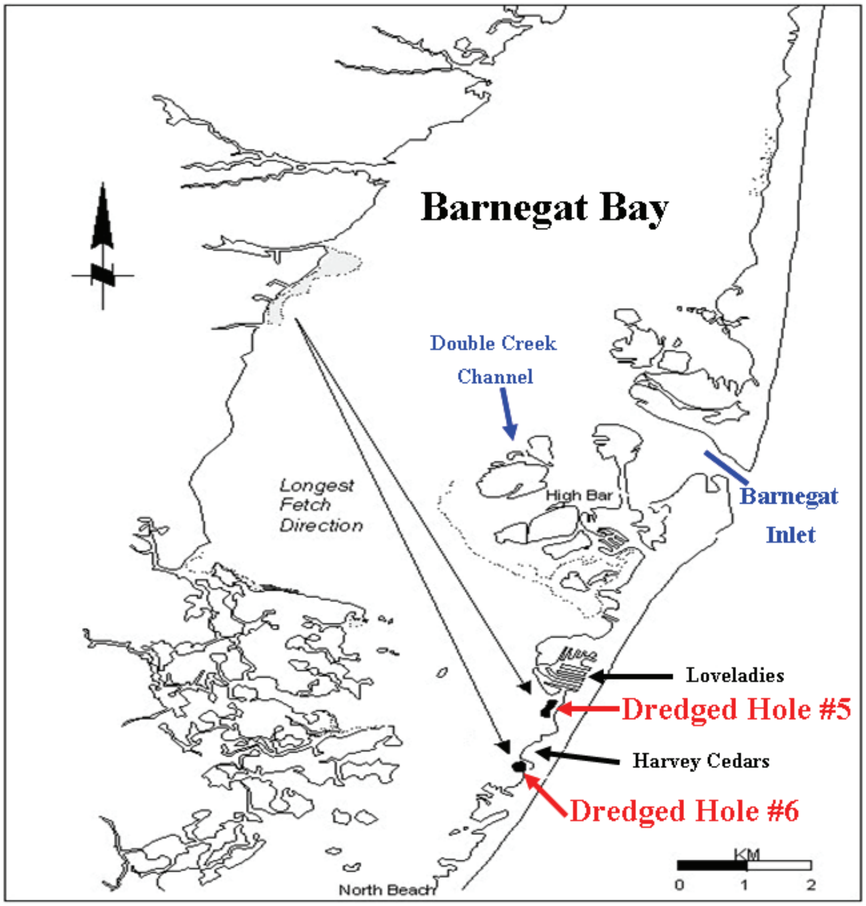


Figure 1. Location of study borrow pits in the Barnegat Bay Estuary.

Water Quality. A calibrated YSI (Model 6920 V2) water quality sonde was used to measure DO concentration (mg/l), temperature (^{o}C), and salinity (ppt) at surface, mid- and bottom depths at seven stations in each dredged hole during each sampling event.

Sediments. Representative stations were sampled by Young grab during the May and November 2007 surveys for sediment grain size analysis. Grab samples were processed using a combination of wet sieving and flotation procedures (Folk 1968, Galehouse 1971). Samples were first soaked in a 20% sodium hexametaphosphate solution to disaggregate the silt and clay fractions, then agitated in a sonic bath for several minutes. The disaggregation procedure was repeated prior to pipette analysis to ensure complete separation of the silt and clay fractions. Sediment data analysis was conducted using Gradistat 4.0 (Blott 2000). Sediment analyses were supplemented with visual observations of materials present in the grab samples.

Benthic Sampling. Benthic macroinvertebrates were sampled in the spring, summer and fall months to evaluate recruitment and community structure in each dredged hole and to determine whether benthic conditions were altered by restoration. In Hole #6, samples were collected from each of the tops, sides, and troughs of six mounds using a 0.044-m^2 stainless steel Young Grab Sampler, for a total of eighteen samples. In Hole #5, twelve samples were collected from the bottom and sides of the unaltered pit. Six samples were collected in a nearby reference area at each site in the natural bay bottom. A layout of benthic sampling stations is presented in Figure 2. A successful sample required a minimum penetration depth into the bottom sediment of at least 6 cm. Samples were sieved in the field using 0.5 mm mesh screening, preserved in 10% buffered formalin, and stained with rose bengal for laboratory processing. Changes in number of species, total abundance, and biomass were assessed in relation to water depth as a result of restoration efforts.

Fishery Hydroacoustics. Surveys were conducted in August 2006, and May and November 2007. Acoustic backscatter data were collected with a BioSonics DT 6000 digital echosounder equipped with 200-kHz split-beam transducer (6-degree conical beam angle at -3dB). Targets satisfying single target criteria with target strength (TS) above -52.6 dB (equivalent to a length of 4 cm) was accepted. The acoustic resolution (minimum target separation distance) of single targets was determined to be 0.23 m following $R = c\tau/2$ (Simmonds and MacLennan 2005), where c = speed of sound in water (1,500 m s^{-1}) and τ is pulse length duration (0.3 ms). Water temperature, salinity and depth were measured at stations in each borrow pit for correct calculation of speed of sound and absorption coefficients. Before each sampling period, the hydroacoustic equipment was calibrated using a tungsten carbide sphere (38.1 mm diameter) standard target of known acoustic TS (~39.2 dB in seawater). The calibration was stable over all sampling periods.

The transducer was mounted in a downward, vertical orientation on an adjustable aluminum frame affixed to the gunnels of the survey vessel. Acoustic data were collected and stored on a laptop computer running BioSonics Acquisition Program (version 4.1) software. Post-processing analyses were performed using Hydroacoustic Data Analysis Software (HADAS), developed by the U.S. Army Engineer Research and Development Center (ERDC). Data were collected during mobile surveys with boat speed limited to 5 km h^{-1}. Each site was divided into parallel transects, spaced at 30 m intervals, covering the full north to south footprint of each dredged hole (Figure 2). Transects extended the full width (shoal to shoal) of each borrow site. Fifteen

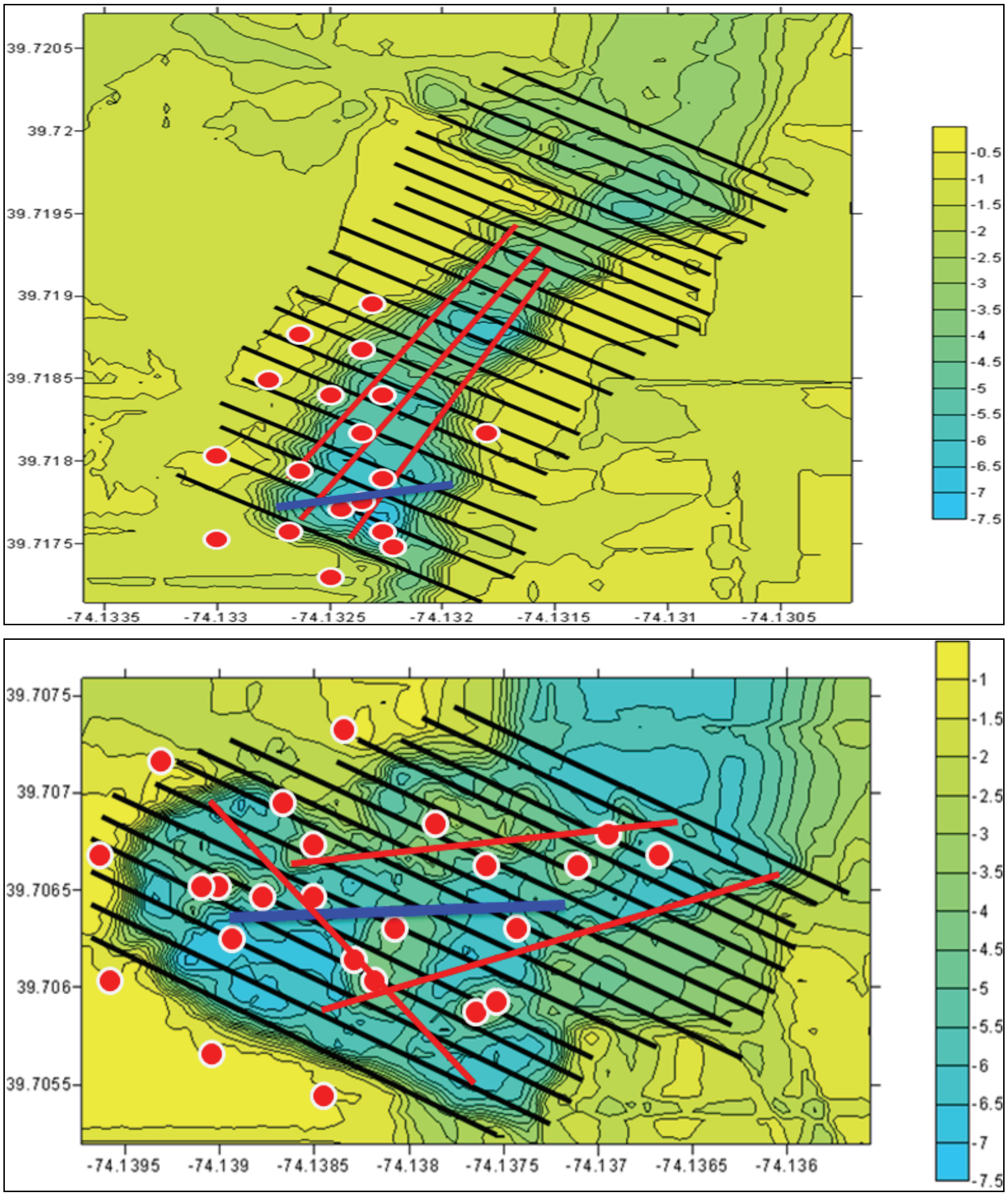


Figure 2. Locations of hydroacoustic transects (black), conventional fisheries (red: otter trawls, and blue: gill nets) and water quality and benthic stations (circles) in Dredged Holes #5 (Top) and #6 (Bottom). Color-coded depths in meters given in legends at right.

transects (mean length = 235 m) were occupied at Hole #6 and 22 transects (mean length = 135 m) at Hole #5 (Figure 2). Total survey distance was 2.5 km (Hole 5) and 3.5 km (Hole 6), respectively. To equalize effort among sampling units, individual transects were divided into 10-meter segments, referred to as elementary sampling distance units (ESDUs). This approach has been widely used in fisheries hydroacoustic studies as a basis for statistical analyses and comparisons (e.g., Gangl and Whaley 2004). During each seasonal survey, all transects were surveyed during both day- and nighttime hours and during flood and ebb tidal stages. Relative fish density was estimated using standard echo-integration techniques, which process the 20logR

Time Varied Gain (TVG) signals. To determine absolute fish density values, the contribution of single fish (average backscattering cross section or σ) was measured. This value (σ) corresponds to the acoustic equivalent of the length of the insonified fish after conversion to target strength (TS). TS values (dB) were converted to fish length using a BioSonics variant of the dorsal-aspect equation developed by Love (1971). Based on the total and the mean echo per fish, the absolute number of fish can be calculated in the area insonified. Thus, every ping transmitted by the sounder provides a measurement of fish density in fish per cubic meter within each ESDU (scaled to fish per 100 m^3).

Conventional Fisheries Gears. Otter trawls and gill nets were used to examine fish assemblage taxonomic composition, and to provide ground truth data for the hydroacoustic surveys (Figure 2). Triplicate fish trawls using a 5-meter otter trawl were conducted seasonally within the deepest portion of each hole. Experimental gill nets equipped with mesh sizes from 5.1 to 22.9 cm (2 to 9 in) were deployed for 5 hours in each hole. All fish collected by both gear types were identified to species, counted, and total length (TL) measured to the nearest mm.

STATISTICAL ANALYSES:

Univariate Methods

Fisheries acoustics: Total fish counts were analyzed by Analysis of Variance (ANOVA) using square-root transformed data. ANOVA was performed using a four-way factorial design: Site (Hole 5 or Hole 6), Sample Date (August 2006, May 2007, and November 2007), Time of Day (Day or Night), and Tide (Ebb or Flood). Initial results suggested that tide was not a significant factor. Therefore, the data were re-analyzed using a three-way factorial design (Site, Date, and Day/Night). The presence of significant Site X Date and Date X Day/Night interaction factors prevented interpretation of the Date or Site factors, thus requiring separate two-way analyses for each sampling event to detect potential differences among sites or day/night collections.

Benthos: Community level variables including taxa per sample, total numerical abundance per sample, Shannon-Weiner diversity index (H'), and Pileou's (J) evenness index were calculated from the infaunal data and subjected to ANOVA. Values for numerical abundance were $\log_{10}(X+1)$ transformed prior to analysis to adjust for non-normality and ensure homogeneity of variance. Due to the fact that shallow depth (Top) samples could only be taken after construction, the ANOVA had to be performed in two steps. First, all data except the shallow depth samples were analyzed using a three-way factorial design (Site (Borrow Area) X Habitat (Depth) X Before/After) to determine whether differences occurred between sites or habitats as a result of the filling operation. A second, one-way ANOVA was performed between all site-habitat combinations (e.g., Hole 5 Bottom, Hole 6 Top) for the after construction samples (May 2006-November 2007) to determine whether the shallow depth samples differed from the bottom, mid, or reference area values. Where significant differences ($p<0.05$) were detected, either a Student's T test or Tukey's Honestly Significant Difference (HSD) test was conducted between pairs of factor means or multiple factor means, respectively.

Multivariate Methods. Fisheries hydroacoustics data were analyzed by a combination of multivariate methods, including hierarchical clustering and Non-Metric Dimensional Scaling (NMDS). Hierarchical clustering is a technique that associates pairs of samples based on the similarity of their species composition and abundances. Samples with the highest degree of similarity are successively combined and the final result presented as a dendrogram in which the degree of similarity of sample is indicated by links in the diagram. The Bray-Curtis Index was used as the similarity index, and samples were combined by group averaging. All data were fourth-root transformed prior to analysis to reduce the influence of extremely abundant species. Similarity Profile (SIMPROF), a bootstrapping technique, was performed on the nodes (sample groups) generated by clustering to determine the likelihood that individual groups were generated purely by chance.

Trawl data were also analyzed by NMDS, an ordination technique that compares species composition between sample pairs and projects the results in two- or three-dimensional space (Clarke and Warwick 2001). NMDS results are interpreted by examining the degree of difference in the spread of data points across axes with the proximity of any two data points being a measure of the degree of similarity between them. Goodness-of-Fit of the plot is measured by a stress value as indicated in the upper right corner of each plot. Stress values of 0.1 or less indicate a high degree of fit (and therefore interpretation with relatively high confidence), while those with stress levels ranging between 0.1 and 0.2 should be interpreted with caution. Plots with stress values of 0.2 or greater should not be interpreted. Simultaneous plotting (biplots) of NMDS and clustering results permits comparison of the results. If the plots are similar, it is assumed that the patterns are robust. Data were also analyzed by Analysis of Similarity (ANOSIM), a nonparametric test analogous to Analysis of Variance, to determine if patterns of sample groupings detected in the clustering-NMDS biplots were statistically significant. Two pairs of ANOSIM tests were performed. The first examined differences between plots by sampling date, while the second reassigned sampling dates to before and after construction to allow a Before/After-Control/Impact (BACI) comparison. In addition, species' contributions to sample similarities were evaluated using the SIMPER technique. All multivariate techniques employed in this study (Clustering, SIMPROF, NMDS, ANOSIM, and SIMPER) were performed using PRIMER (Version 6.0) statistical software following interpretive guidance found in Clarke and Warwick (2001). Infaunal data were analyzed in an identical manner to that of the trawl data.

RESULTS AND DISCUSSION

Water Quality. Water quality measurements taken in August 2006 in Dredged Holes #5 and #6 indicated that DO concentrations were relatively high, ranging from 7.4 to 8.5 mg/l and were generally at or above saturation even in the deepest portions of the pit basins. Average salinity was 29 ppt throughout the water column, indicating an absence of stratification. Water temperatures averaged 24^{o}C in Dredged Hole #6, but were slightly cooler (23.2^{o}C) in Dredged Hole #5.

In May 2007, DO concentrations were again relatively high, ranging from 8 to 9.4 mg/l, and were generally at or above saturation even at bottom depths in both dredged holes. DO measurements obtained in the present study were higher than the 4 to 5 mg/l range observed in a long-term deployment conducted by Versar (unpublished data 1999). No evidence of a halocline or thermocline was found. Salinity averaged 26 ppt throughout the water column, while temperatures averaged 19 ^{o}C in both holes.

In November 2007, DO concentrations (8.4 to 9.4 mg/l) were again relatively high, at saturation throughout the water column. Salinity was approximately 29 ppt throughout the water column, indicating that the water column was not stratified. No thermocline was observed as the water column appeared to be well mixed. Water temperatures were relatively uniform, averaging 9.4°C in both dredged holes.

During February 2000, Versar conducted pre-restoration sampling (unpublished data report to USACE: Philadelphia District) in both Dredged Holes #5 and #6. Versar reported an average water temperature of 3.1°C. In Dredged Hole #6 water temperatures ranged from zero near the bottom to 2.9°C near the surface. Other parameters such as salinity, pH, and conductivity were largely uniform throughout the water column in both dredged holes, with the exception of the water column in the deepest portion of Dredged Hole #6, which had higher salinity and conductivity values, but lower pH. DO concentrations peaked above the theoretical maximum of 16 mg/l due to limitations of the water quality instrumentation under extremely cold conditions.

During the present study, salinity, temperature, and DO concentration measurements in Dredged Holes #5 and #6 fell into ranges of "typical" values for shallow, open-water, estuarine sites. DO concentrations observed in this study (7.4 to 9.4 mg/l) were somewhat higher than those observed in pre-restoration studies. Murawski (1969) recorded DO concentrations during the month of August in Dredged Hole #6 of 4.6 mg/l at 7.3 m, 1.8 mg/l at 8.8 m, and 0.0 mg/l at 10.3 m. In 1992, NJDEP resurveyed Dredged Holes #5 and #6 and found values not substantially different from those reported by Murawski (1969). In August 1999, Versar recorded DO concentrations on an hourly basis at an instrument moored 1-meter off the bottom (unpublished data). During four consecutive days of hourly monitoring in Dredged Hole #5, DO concentrations averaged 5 mg/l. Occasional values as low as 3 mg/l were recorded late in the evening on one day of monitoring. Versar reported that DO concentrations in Dredged Hole #6 were generally slightly lower, averaging 4 mg/l. DO concentrations fell sporadically below 3 mg/l, but not below 2 mg/l. Hypoxia remains a central issue related to the habitat quality of dredged holes. Although anoxic conditions did not occur during any of the sampling events of the present study, it is possible and even probable that such conditions do occasionally occur in the dredged holes. Hypoxic conditions are probably a sporadic phenomenon that occurs primarily during extended periods of calm weather that could induce either density or thermal stratification of the water column. The results of this study support a finding that hypoxia is not a predictable annual occurrence in either Dredged Holes #5 or #6.

Sediment Grain Size Analysis. Sediments in all bottom samples taken from the two borrow pits can be characterized as sandy silt, with percent clay/silt contents ranging from 77 to 83%. Mean grain size for bottom samples averaged 22 microns. Mid-depth stations were characterized as either silty sand to sandy silt. In Dredged Hole #5, the silt/clay percentage ranged from 14.8% for silty sand to 84% for sandy silt. In Dredged Hole #6 the percent clay/silt fraction ranged from 59 to 82.7%. Samples taken from the top of mounds created during construction in Dredged Hole #6 were similar to mid-depth stations both in sediment type and percent clay/silt fractions. Samples from adjacent shoals ranged from sandy silt to sand with clay/silt fractions of less than 24%. The sand fraction tended to be very fine or medium-fine at the silty stations, coarse at the shallow stations, and medium in the remaining silty sand samples.

BENTHIC COMMUNITY

Species Composition. A total of 151 macroinvertebrate taxa were collected during the course of the study, including 71 polychaete taxa, 21 amphipods, 17 bivalves, 11 gastropods, 4 isopods, 3 mysid shrimps, 3 cumaceans, and 21 miscellaneous taxa. The amphipod *Ampelisca* (LPIL or Lowest Practical Identification Level) was the most abundant taxa comprising nearly 43% of all specimens collected (Table 1). These taxa were composed of two species (*A. abdita* and *A. vadorum*) with the preponderance of specimens being too small to accurately identify to the species level. *Ampelisca* (LPIL) was also the most abundant taxon at all sampling sites, with the exception of the bottom samples of both borrow areas prior to construction (where it was second most abundant taxon) and Borrow Area 6 Reference also prior to construction. The second most abundant taxon, the polychaete *Mediomastus ambiseta,* reached maximum abundances during the post-construction time period at middle depth stations of both borrow areas, the shallow (Top) stations of Borrow Area 6 and — to a lesser extent — the reference stations of both sites where it was the third most abundant taxon. The third most abundant taxon overall, the amphipod *Rudilemboides naglei,* was also the most numerous during the post-construction time period and was an important constituent at all stations. Another taxon that warrants special mention is the amphipod *Microdeutopus gryllotalpa,* which was the single most abundant taxon at bottom stations and the second most abundant in middle depth stations and the Borrow Area 6 Reference stations prior to construction. It was present during the post-construction time period but was less abundant.

Community Structure Parameters: Taxa Richness, Abundance, Diversity and Evenness: Standard community structure parameters were measured for each sample, and the averages and standard errors of the means plotted (Figures 3-6). Mean numbers of taxa were highest at reference stations and lowest at bottom stations in both borrow areas and during both time periods (Figure 3). Mid-depth values were intermediate to these, as were samples from the top of the Borrow 6 mounds. Mean numbers of taxa/sample at both bottom and mid-depth stations were also greater after construction than before. Average numbers of animals/sample followed a similar pattern to that of taxa/sample with the exception that post-construction abundances at the reference sites were also higher than pre-construction values (Figure 4). Shannon-Weiner diversity index values followed an identical pattern to that of abundance/sample (Figure 5). Values for Pielou's evenness index were relatively uniform among sites, stations, and over time (Figure 6). The highest index values occurred at mid-depth and reference area stations prior to construction at Borrow Area 6.

Univariate Statistics: The three-way factorial ANOVA for mean taxa per sample was significant ($p<0.05$) for only two factors: Habitat and Before/After. Tukey's HSD test indicated that each of the three habitat depths was significantly different ($p<0.05$) from one another, with the highest average number of taxa occurring in the reference stations, fewer in the mid-depth stations, and the least in the bottom stations. Student's T test results indicated that numbers of taxa per sample were higher after construction than before. Similar results were found in the ANOVA for numerical abundance, with the exception that there was also a significant ($p<0.05$) Habitat x Before/After interaction effect. Both Habitat and Before/After factors were significant ($p<0.05$),

Table 1. Taxa comprising 1% or more of specimens collected.

Taxa Comprising > 1%	**Taxon**	**B5 Bot Before**	**B6 Bot Before**	**B5 Mid Before**	**B6 Mid Before**	**B5 Ref Before**	**B6 Ref Before**	**B5 Bot After**	**B6 Bot After**	**B5 Mid After**	**B6 Mid After**	**B6 Top After**	**B5 Ref After**	**B6 Ref After**	**Total**
Ampelisca (LPIL)	A	26.09	27.27	78.71	53.83	65.66	3.57	70.13	41.60	51.07	56.70	50.14	36.49	26.20	42.878
Mediomastus ambiseta	P	2.17	0.00	1.61	0.82	6.19	3.17	0.22	2.99	20.24	11.07	15.09	11.74	10.83	11.112
Rudilemboides naglei	A	0.00	0.00	0.00	0.00	0.30	4.68	10.74	13.81	4.90	2.51	3.69	15.16	20.44	9.951
Sarsiellidae (LPIL)	O	0.00	0.00	0.00	0.00	0.00	0.00	2.10	6.48	2.08	5.74	2.99	5.32	6.01	3.908
Myocopodina (LPIL)	O	0.00	0.00	0.00	0.00	0.00	0.00	0.83	1.07	4.25	7.28	2.26	0.46	4.42	3.581
Eobrolgus spinosus	A	0.00	0.00	0.66	0.00	0.08	5.75	0.04	2.90	1.25	0.94	1.96	6.28	6.24	3.508
Oligochaeta (LPIL)	O	4.35	0.00	1.56	7.89	2.56	18.67	1.05	0.80	2.94	0.08	0.53	5.34	3.16	3.348
Exogone dispar	P	0.00	0.00	0.18	0.35	0.42	6.62	0.31	1.92	0.75	0.74	0.56	0.90	3.75	1.777
Nematoda (LPIL)	NE	0.00	0.00	0.00	0.00	0.00	0.00	0.09	1.39	1.42	0.62	0.80	1.85	4.10	1.675
Spirorbis (LPIL)	P	0.00	0.00	0.00	0.00	0.00	0.12	0.31	4.83	0.50	1.60	2.71	0.31	0.51	0.993
Heteromastus filiformis	P	2.17	0.00	0.12	1.06	0.62	1.39	0.17	2.23	0.72	0.97	1.07	1.21	0.42	0.876
Elasmopus levis	A	0.00	0.00	0.00	0.00	0.15	7.45	0.39	1.52	0.12	0.53	1.68	0.35	0.98	0.818
Microdeutopus gryllotalpa	A	36.96	36.36	4.01	9.78	0.62	11.61	0.31	1.07	0.10	0.05	0.14	0.05	0.31	0.815
Prionospio heterobranchia	P	0.00	0.00	0.24	0.24	0.42	4.99	0.00	0.71	0.36	0.05	0.05	0.94	1.44	0.803
Spiochaetopterus costarum	P	0.00	0.00	0.00	0.00	0.02	0.24	0.00	0.31	0.40	0.13	0.41	2.36	0.48	0.779
Aricidea catharinae	P	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.04	0.78	0.16	0.19	0.98	1.87	0.768
Glycinde solitaria	P	0.00	0.00	0.96	1.41	1.87	1.51	0.04	0.36	0.59	0.92	0.95	0.54	0.06	0.651
Notomastus (LPIL)	P	0.00	0.00	0.06	1.30	5.40	0.04	0.00	0.13	0.22	0.68	0.63	0.17	0.01	0.601
Listriella barbardi	A	0.00	0.00	0.12	0.12	0.91	0.55	0.00	0.63	0.23	1.09	0.75	0.83	0.27	0.561
Mulinia lateralis	B	0.00	0.00	0.00	0.00	0.06	0.04	1.22	2.50	0.10	0.11	1.62	0.13	0.12	0.515
Capitella (LPIL)	P	10.87	0.00	0.54	3.53	0.02	0.32	6.38	0.67	0.14	0.00	2.13	0.00	0.10	0.497
Oxyurostylis smithi	C	0.00	0.00	0.66	1.41	1.38	1.27	0.04	0.00	0.23	0.05	0.24	0.59	0.36	0.438
Melinna maculata	P	0.00	0.00	0.12	0.24	0.08	0.08	0.00	1.70	0.39	1.09	1.09	0.30	0.13	0.428
Clymenella torquata	P	0.00	0.00	0.30	0.24	4.28	0.83	0.04	0.09	0.05	0.36	0.12	0.07	0.01	0.419
Lysianopis alba	A	4.35	0.00	3.23	1.77	0.27	2.06	0.09	1.56	0.03	0.05	0.10	0.12	0.53	0.392
Hesionidae (LPIL)	P	2.17	9.09	1.67	3.06	0.44	3.41	0.04	0.49	0.04	0.62	0.26	0.05	0.05	0.375
Cyathura burbanki	I	0.00	0.00	0.60	0.00	0.36	1.11	0.00	0.00	0.22	0.09	0.12	0.89	0.23	0.371
Gemma gemma	B	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.47	0.09	0.09	0.22	1.05	0.364
Brania wellfleetensis	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.43	0.53	0.22	0.31	0.363
Nemertea (LPIL)	NR	2.17	0.00	0.06	0.12	0.15	0.32	0.44	0.76	0.23	0.23	0.46	0.30	0.53	0.356

Cymadusa compta	A	2.17	0.00	0.12	0.71	0.08	0.99	0.39	0.04	0.12	0.11	0.12	0.48	0.26	0.265
Leitoscoplos robustus	P	0.00	0.00	0.48	1.88	0.25	0.83	0.00	0.04	0.21	0.09	0.39	0.17	0.06	0.240
Apocorophium acutum	A	0.00	0.00	0.00	0.12	0.00	1.23	0.04	0.13	0.11	0.05	0.15	0.44	0.16	0.213
Streblospio benedicti	P	0.00	0.00	0.42	6.12	0.42	1.78	0.00	0.09	0.10	0.00	0.02	0.00	0.02	0.193
Mytilus edulis	B	0.00	9.09	0.06	0.71	0.00	0.00	2.88	0.13	0.03	0.19	0.44	0.02	0.03	0.174
Pista (LPIL)	P	0.00	0.00	0.06	0.00	0.11	2.06	0.00	0.18	0.02	0.00	0.05	0.02	0.02	0.120
Paracaprella tenuis	A	0.00	0.00	0.00	0.12	0.32	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.096
Sphaerosyllis taylori	P	2.17	0.00	0.12	0.00	0.13	0.12	0.00	0.00	0.17	0.05	0.02	0.09	0.06	0.082
Erichsonella attenuata	I	0.00	0.00	0.00	0.00	0.38	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.064
Arabella iricolor	P	0.00	0.00	0.00	0.00	0.06	0.95	0.00	0.04	0.00	0.01	0.00	0.02	0.09	0.062
Corophiidae (LPIL)	A	0.00	9.09	0.06	0.35	0.51	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.048
Neanthes arenaceodentata	P	2.17	0.00	0.12	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.008
Exogone (LPIL)	P	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.001

* A = amphipod, P = Polychaete, I = isopod, B = bivalve, O = ostracod, NE = nematode, NR = nemertean
** Shading: Yellow = Most abundant species, Turquoise = Second most abundant, Green = Third most abundant
*** LPIL = Lowest Practical Identification Level

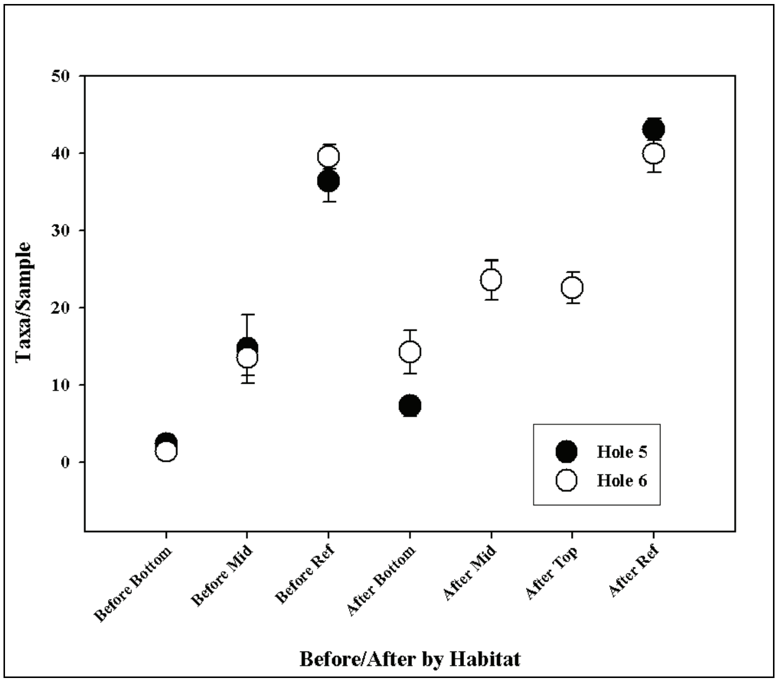


Figure 3. Taxa/Sample (Mean ± Standard Error) by Borrow Area, Habitat and Time Period.

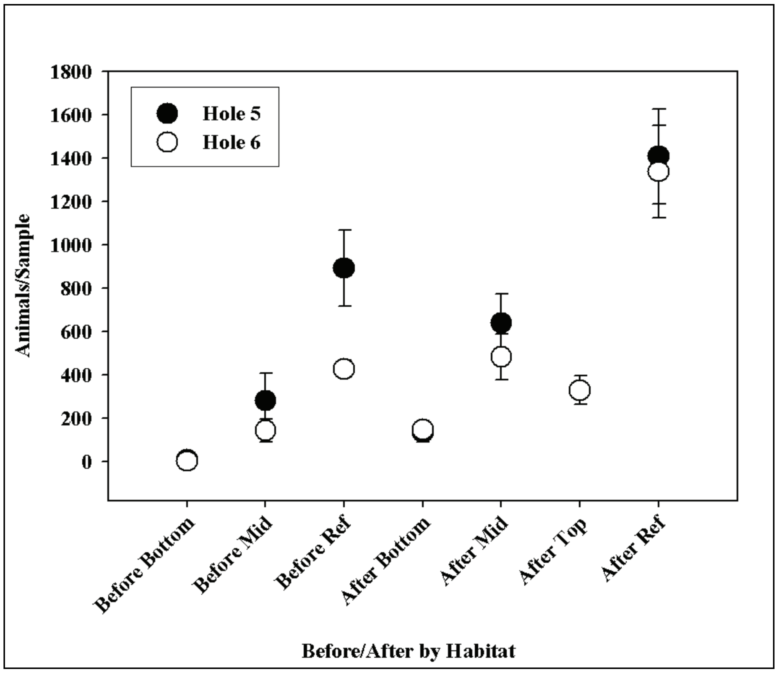


Figure 4. Abundance (# Animals)/Sample (Mean + Standard Error) by Borrow Area, Habitat and Time Period. Clear = Borrow Area 6, Black = Borrow Area 5.

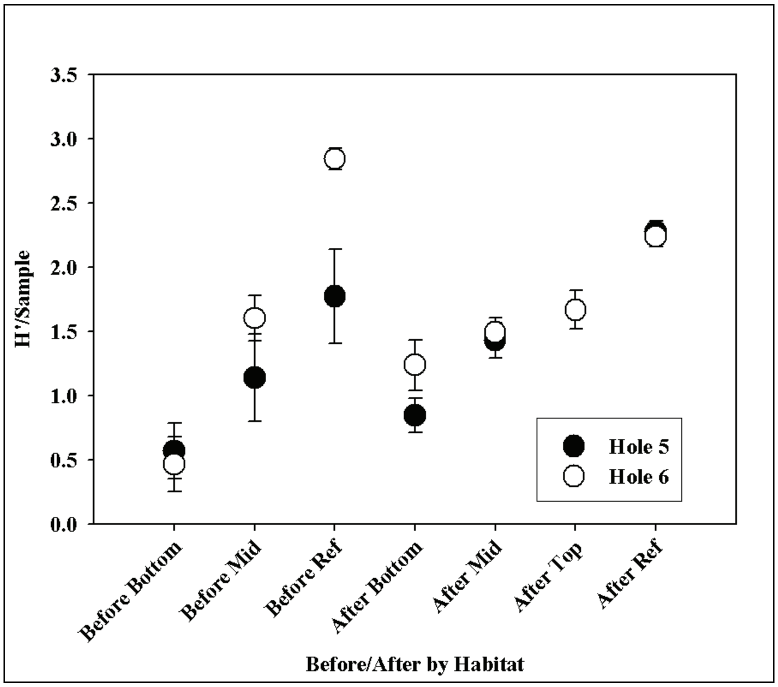


Figure 5. Shannon-Weiner Diversity Index (H')/Sample (Mean + Standard Error) by Borrow Area, Habitat and Time Period. Clear = Borrow Area 6, Black = Borrow Area 5.

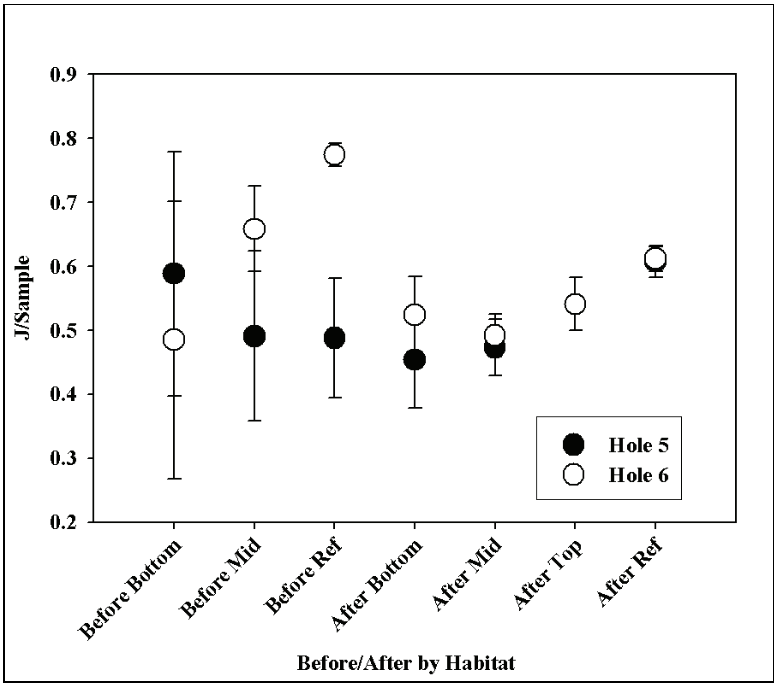


Figure 6. Pielou's Evenness Index (J)/Sample (Mean + Standard Error) by Borrow Area, Habitat and Time Period. Clear = Borrow Area 6, Brown = Borrow Area 5.

and Tukey's HSD and Student's T tests for these factors produced identical results to that of taxa/sample. The Tukey HSD test for the abundance Habitat x Before/After interaction revealed that prior to construction, Bottom station abundances were significantly lower ($p<0.05$) than all other stations. After construction, Bottom station abundances were lower than all other stations except for before construction mid-depth stations (Before Mid) which, in turn — while not different from after construction mid-depth values — were lower than all remaining stations. This pattern continues with the pre-construction Reference station values being intermediate between post-construction mid-depth stations and post-construction reference stations. The three-way ANOVA of Shannon-Weiner Diversity Index ($H'ln_e$) values was significant ($p<0.05$) for sites, habitats, and the Site X Habitat X Before/After interaction effect. Diversity was higher at Borrow Area 6 than Borrow Area 5 (Student's T Test, $t=1.97$, $p<0.05$) and decreased significantly in value with depth (reference > mid > bottom, Tukey's HSD, $Q=3.33$, $p<0.05$). Tukey's HSD test results for the means in the 3-way interaction factor indicated overlapping degrees of difference between reference, mid-depth, and bottom depth index values. The 3-way ANOVA of Pielou's Evenness Index produced no significant difference ($p>0.05$) for the whole model or any of the effect factors.

The one-way ANOVAs for post-construction samples were also significant ($p<0.05$) for taxa/sample, animals/sample, and Shannon-Weiner diversity index, but not for Pielou's evenness index. Tukey's HSD test for taxa/sample indicated the same pattern of decreasing values (reference > middle > bottom) as found in the 3-way test. Shallow depth (Top) samples were intermediate between the middle and bottom depth values. An identical pattern of results was found in Tukey's HSD test for animals/sample. Test results for diversity (H') were significantly different ($p<0.05$) only between reference areas and those of the remaining stations.

Multivariate Methods: The results of both hierarchical clustering and NMDS are similar in the sense that there is a high degree of similarity between all stations and time periods (Figure 7). The relatively high-stress value (0.16) for the NMDS analysis indicates that only the largest differences between samples can be reliably interpreted (Clarke and Warwick 2001). In this case, bottom samples, particularly those from the after construction time period, differed the most from the remaining samples. Bottom station samples also were the most variable in species composition as measured by MVDISP (Multivariate Dispersion). Mid- and shallow depth (Top) and reference samples from both borrow areas were relatively similar to one another (Figure 7). Multivariate dispersion was least among reference stations and intermediate among mid- and shallow depth stations. ANOSIM of the species composition data (Habitat X Before/After) was significant (p = 0.1% or 0.001) for the global (overall) test and for all but two of the pairwise tests. The two pairwise tests where insignificant ($p<5.0\%$) results were obtained were between the Top (shallow) station at Borrow Area 6 following construction and either the bottom or mid-depth stations. The highest R values (i.e., the strongest indication of a difference) were between combinations including either Bottom samples before construction or reference samples after construction. SIMPER analysis of the habitat by before and after time periods also indicated the greatest differences in species composition in pairwise comparisons involving preconstruction bottom samples. The lowest degree of difference was encountered among comparisons involving post-construction Reference, Middle or Top (shallow) samples. Examination of the pairwise data for those species contributing the most to dissimilarity indicates that it is not so much the presence or absence of characteristic taxa within a habitat creating the differences, but their relative abundances that is responsible. For instance, the amphipod *Ampelisca* (LPIL) and oligochaetes are found in nearly all habitats and time periods, but their far lower abundances in Bottom stations, particularly during the preconstruction time period, often results in them contributing the most to dissimilarity. Much of the difference between other habitats can be traced to the relative abundances of the amphipods *Microdeutopus gryllotalpa* and *Rudilemboides naglei,* the ostracod Sarsiellidae (LPIL), and the polychaete *Mediomastus ambiseta*.

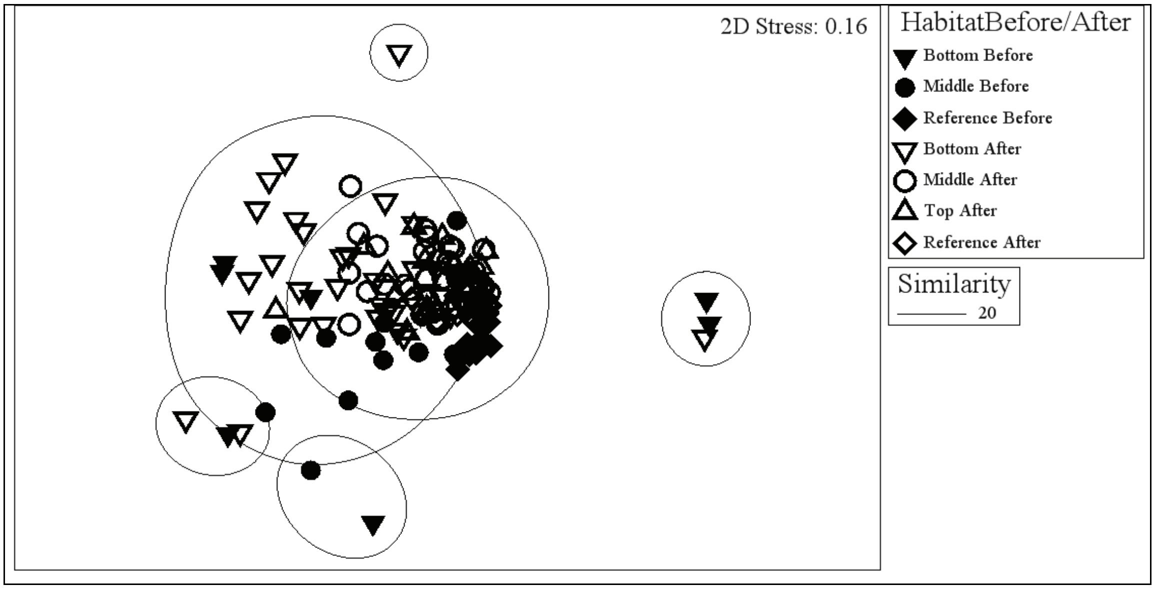


Figure 7. Hierarchical clustering and Non-Metric Dimensional Scaling Results. Inverted triangle = Bottom, Circle= Middle, Diamond = Reference, Upright Triangle = Top, Filled = Before, Unfilled = After

CONVENTIONAL FISHERIES GEAR CATCH

Species Composition. Barnegat Bay serves as an important nursery habitat for bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), Atlantic menhaden (*Brevoortia tyrannus*), and spot (*Leiostomas xanthurus*). Winter spawning fishes such as winter flounder (*Pseudopleuronectes americanus*) and summer spawners such as bay anchovy (*Anchoa mitchilli*), northern pipefish (*Syngnathus fuscus*), gobies (*Gobiosoma* spp.), and tautog (*Tautoga onitis*) are commonly reported in the scientific literature pertaining to the local ichthyofauna. Trawling and gill netting resulted in a total catch of 205 fishes (otter trawls n = 166, gill nets n= 39) during three seasonal surveys. Twenty-six species, representing twenty families, were captured. Catch per unit effort (CPUE) by gear type was determined for each species as either the number of fish per trawl hour or net hour.

Summer Catch (August 2006). Pre-restoration, site-specific data on fisheries resources at Dredged Holes #5 and #6 were described by Versar (unpublished data 1999). Five species of fish were collected in each borrow pit. Species composition between borrow pits was similar, with weakfish and bay anchovies occurring in both pits. Atlantic menhaden and a smooth dogfish (*Mustelus canis*) were taken only in Dredged Hole #6, and blueback herring (*Clupea aestivalis*) and northern puffer (*Sphoeroides maculatus*) only in Dredged Hole #5. Overall CPUE rates were low for all species. Spot (< 0.5 fish/net hour) was the only species captured by gill nets in both holes. Otter trawling produced larger numbers of bay anchovies and weakfish in both dredged holes, although totals were somewhat lower for Dredged Hole #6. Versar caught 161 weakfish during August 1999 pre-restoration sampling in Dredged Hole #5 (CPUE = 966 fish/trawl hr) and 14 in Dredged Hole #6 (CPUE = 84 fish/trawl hr). Weakfish was the most abundant species present in both dredged holes, although few were caught in the deepest portion (11.6 m) of Dredged Hole #6. The deep basin of Dredged Hole #6 contained large amounts of organic detritus, which may be avoided by weakfish. Bay anchovies were present in both borrow pits, averaging 72 fish/ trawl hr in Dredged Hole #6 and 132 fish/trawl hr in Dredged Hole #5. The only shellfish species captured during pre-restoration studies was blue crab (*Callinectes sapidus*). Otter trawling produced 23 blue crabs in Dredged Hole #5 (CPUE = 138 crabs/hr) and 12 in Dredged Hole #6 (CPUE = 72 crabs/hr). A comparison of pre- and post-restoration otter trawl catches is given in Figure 8.

Post-restoration samples (August 2006) indicated that weakfish, bay anchovies, and blue crabs were still the numerically dominant species in both dredged holes. Weakfish numbers were comparable in Dredged Holes #5 (CPUE = 48 fish/trawl hr) and #6 (CPUE = 48 fish/trawl hr) when compared to 1999 results. Although weakfish numerically dominated the catch, particularly in Dredged Hole #5 in 1999, it was not the dominant species in 2006, having been replaced by the bay anchovy (CPUE 148 fish/trawl hr). In Dredged Hole #6, the bay anchovy catch (CPUE = 72 fish/trawl hr) accounted for slightly fewer fish per trawl hour than weakfish. Blue crab totals ranged from 196 in Dredged Hole #5 to 320 in Dredged Hole #6, an increase of 57% and 63%, respectively, over pre-restoration totals. In 2006, the total number of species captured in Dredged Hole #5 increased from 5 to 9 and in Dredged Hole #6 from 5 to 11. Other species in the catch included oyster toadfish (*Opsanus tau*) (CPUE = 20-25 fish trawl/hr) and summer flounder (*Paralichthys dentatus*) (CPUE 8 fish trawl/hr), both of which were absent in 1999 sampling. CPUE rates for these species were nearly identical in both dredged holes. As in 1999, spot was the only fish species captured by gill net in both dredged holes. Other species comprising the gill net catch included bluefish (*Pomatomus saltatrix*) and Atlantic croaker (*Micropogonias undulatus*) in Dredged Hole #5, and smooth dogfish and striped sea robin (*Prionotus evolans*) in Dredged Hole #6. Both bluefish and summer flounder are species for which the Barnegat Bay estuary has been designated as Essential Fish Habitat.

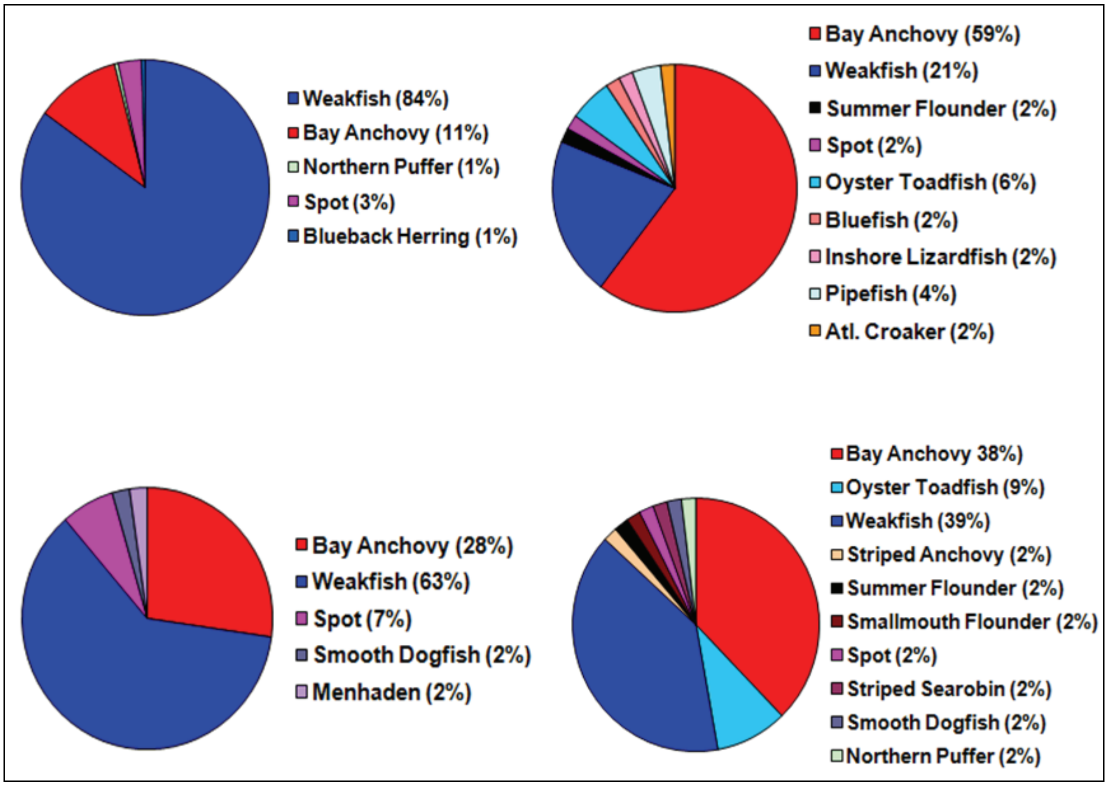


Figure 8. Fishery assemblages based on otter trawls in Dredged Holes #5 (top) and #6 (bottom). Top left: Hole #5-August 1999. Top right: Hole #5-August 2007. Bottom left: Hole #6-August 1999. Bottom right: Hole #6- August 2007.

Spring Catch (May 2007). Relatively low numbers of finfish were present in both borrow pits during the spring survey. Seven species were caught in gill nets, and four species in otter trawls. Bay anchovies were present in both dredged holes, although CPUE (8-20 fish/trawl hr) was somewhat lower than in summer samples. Other species caught by trawl included Atlantic silversides (*Menidia menidia*) in Dredged Hole #5 and spotted hake (*Urophycis regia*), and winter flounder in Dredged Hole #6, all at low catch rates. Atlantic menhaden was the most frequently caught species in gill nets in both borrow pits, and occurred in essentially identical numbers. The distribution of bluefish was similar in that absolute numbers caught in Dredged Hole #6 (CPUE = 0.5 fish/net hr) were comparable to those in Dredged Hole #5 (CPUE = 0.3 fish/net hr). Weakfish were not captured in Dredged Hole #5, but present in the catch (n = 4) in Dredged Hole #6. The remaining portion of the fish assemblage in Dredged Hole #5 consisted of three gill net captures: striped searobin, striped bass (*Morone saxatilis*), and northern kingfish (*Menticirrhus saxatilis*) — all at very low catch rates — and one species captured by otter trawl (Atlantic silversides, CPUE = 4 fish/trawl hr). Additional species collected in Dredged Hole #6 included bluefish, winter flounder, tautog (*Tautoga onitis*), and spotted hake. Of these species only bluefish were captured in

Dredged Hole #5. Two species of crustaceans, blue crab (CPUE = 20 crabs/trawl hr) and black fingered mud crab (*Panopeus herbstii,*) (CPUE = 16 crab/trawl hr) were taken in Dredged Hole #6. Neither species was collected in Dredged Hole #5 in the spring survey. No pre-restoration data are available from spring 1999 for comparison.

Fall Catch (November 2007). In the fall, forage fishes including Atlantic silversides comprised over half of the total catch in Dredged Hole #6, followed by Atlantic croaker (36% of the total catch, CPUE 60 = fish/trawl hr). Both species were present in Dredged Hole #5, but caught in much smaller numbers, averaging < 5 fish/trawl hour or slightly less than 10% of the total catch. The remaining fish assemblage for Dredged Hole #6 consisted of small numbers of winter flounder, Northern sea robin (*Prionotus carolinus*) and black sea bass (*Centropristis striata*), all of which cumulatively represented less than 10% of the total catch (CPUE 4-8 fish/trawl hr). In Dredged Hole #5, naked gobies (*Gobiosoma bosc*) were the most numerous species caught in 2007, although absolute numbers were very low (n = 4, CPUE 16 fish/trawl hr), followed by northern pipefish (*Syngnathus fuscus*). Atlantic silversides and Atlantic croaker were also caught in Dredged Hole #5, as well as three scup (*Stenotomus chrysops*) that were taken by gill net. In pre-restoration fall sampling (unpublished data, Versar 1999) the only fish species captured in Dredged Hole #6 was Atlantic croaker (n= 17, CPUE = 102 fish/trawl hr), as well as a small number of blue crabs. In Dredged Hole #5, trawling produced 3 fish species (bay anchovies, Atlantic croaker, and Atlantic silversides were taken in small numbers) and 2 crab species (blue crabs, CPUE = 24 crab/trawl hr, and mud crabs, CPUE = 12 crab/trawl/hr). Pre- and post-restoration fishery assemblages are described in Figure 9.

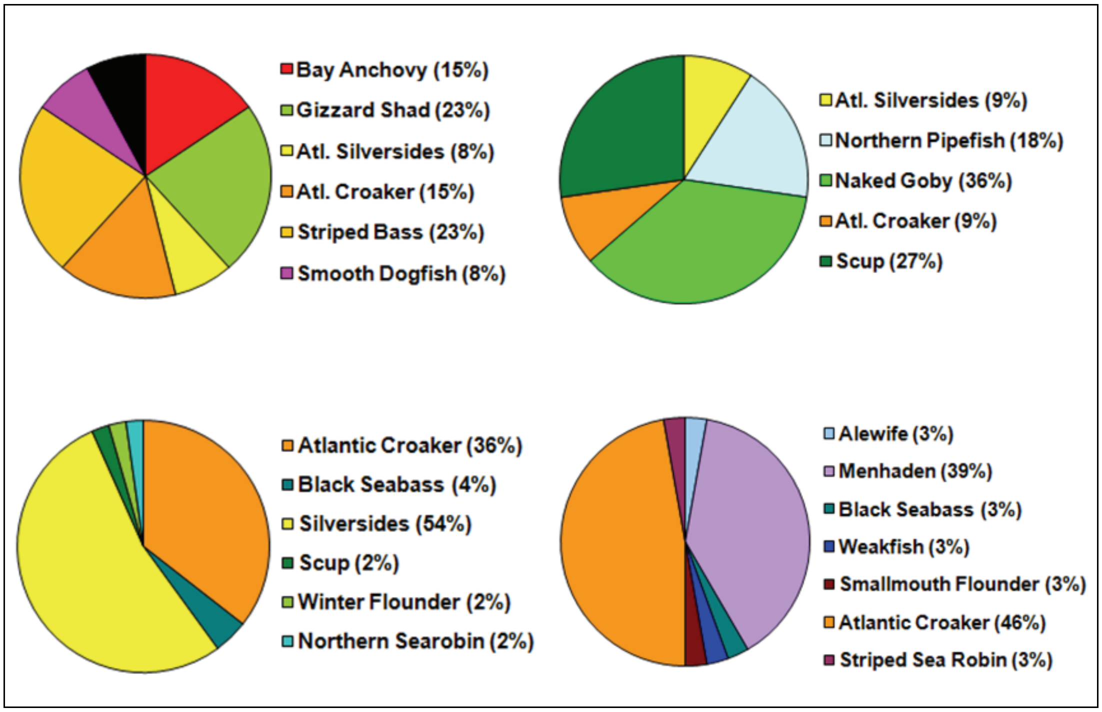


Figure 9. Fishery assemblages based on otter trawls in Dredged Holes #5 (top) and #6 (bottom). Top left: Hole #5-November 1999. Top right: Hole #5-November 2007. Bottom left: Hole #6-November 1999. Bottom right: Hole #6-November 2007.

Winter Catch (February 2000). Winter sampling was conducted in February 2000 by Versar as part of the pre-restoration planning assessment. Based on these unpublished data, the only species captured during otter trawling was the four-spined stickleback (*Apeltes quadracus*). This species is a year-round resident in Barnegat Bay. The only fish species captured by gill net was a single blueback herring, which is likely to have been an early migrant to the bay for spring spawning. Blue crabs, which were numerous during summer sampling events, were absent from catches in both holes during winter sampling. Although the available winter sampling data are sparse, sampling produced no evidence that either dredged hole was used as an over-wintering thermal refuge for fishes or shellfish.

Multivariate Analysis of Trawl Data. Hierarchical clustering of the Barnegat Bay trawl data indicated that species composition varied more between sampling periods and time of year than between sites (Figure 10). For example, all August samples (1999 and 2006) grouped together regardless of site. All but one of the November (1999 and 2007) samples (Dredged Hole #6 November 1999) also occurred in a single cluster group. Samples from May 2007 did not cluster together. NMDS plots were significant (Stress = 0.12) and the results mirrored those of hierarchical clustering (Figure 11) with August and November samples forming relatively compact groups. May samples were found to be intermediate between the August and November groupings. ANOSIM tests failed to produce significant results ($P>0.05$) for either sites or sampling periods, nor were there significant results when the data were reanalyzed using a Before/After-Control/Impact (BACI) design. However, when tests were performed with the data categorized by month (August, May, and November), a significant ($p<0.05$) difference was obtained. Pair-wise tests by month indicated that August samples differed from those in both May and November, but May and November did not differ between themselves. Similarity Percentage (SIMPER) analysis of the month data indicated that August samples were characterized by high abundances of blue crabs, anchovies, and spot, whereas May samples were characterized by anchovies and bluefish. High numbers of Atlantic silversides and Atlantic croakers characterized November samples. Pair-wise comparisons of months using SIMPER indicated that relatively high abundances of blue crabs, weakfish and spot contributed the observed differences between August and May samples, while these three species plus anchovies differentiated August from November samples. There was no significant difference ($p>0.05$) found between May and November samples.

FISH SIZE DISTRIBUTION AND DENSITY

Conventional Gear Catch. Total lengths (TL) of collected fishes ranged from 2 to 53 cm. Of the three numerically dominant species weakfish were largest in terms of mean total length at 17.8 cm). The large majority of weakfish ranged from 10-15 cm. Atlantic silversides ranged from 4.1 to 10.8 cm TL, and bay anchovy from 2.1 to 9.3 cm TL. Both bay anchovies and Atlantic silversides exhibited two size classes of 0-5 and 5-10 cm TL. Although not numerically dominant, bluefish was one of the largest species in the overall catch with a mean TL of 46.1 cm TL. Atlantic menhaden ranged from 33-38.7 cm TL with a mean of 34.8 cm. Scup ranged from 21.7-28 cm TL with a mean of 28.6 cm. Bluefish and scup accounted for approximately 2% each of the total catch, whereas Atlantic menhaden accounted for slightly more than 6%. The largest individual fish taken was a smooth dogfish that measured 53 cm TL.

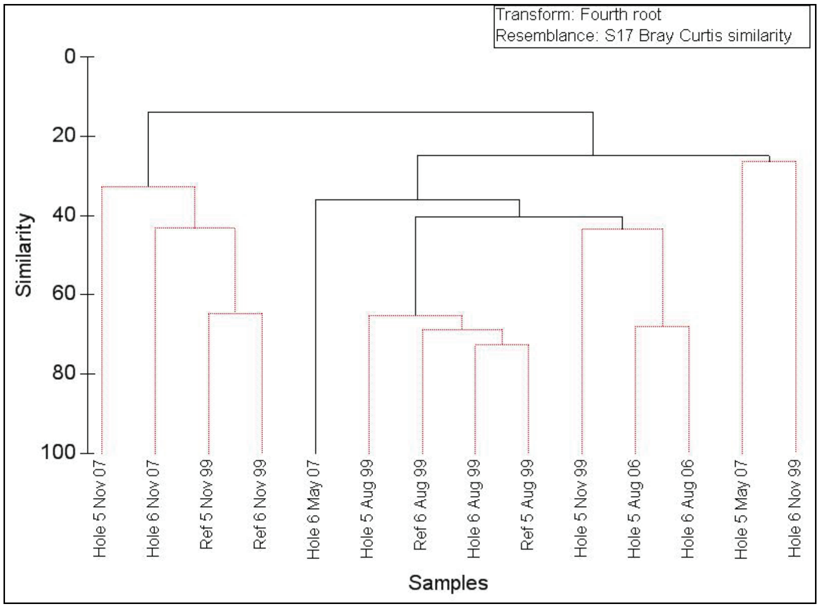


Figure 10. Hierarchical clustering dendrogram of Barnegat Bay trawl data. All data fourth-root transformed and compared using Bray-Curtis similarity index with group averaging.

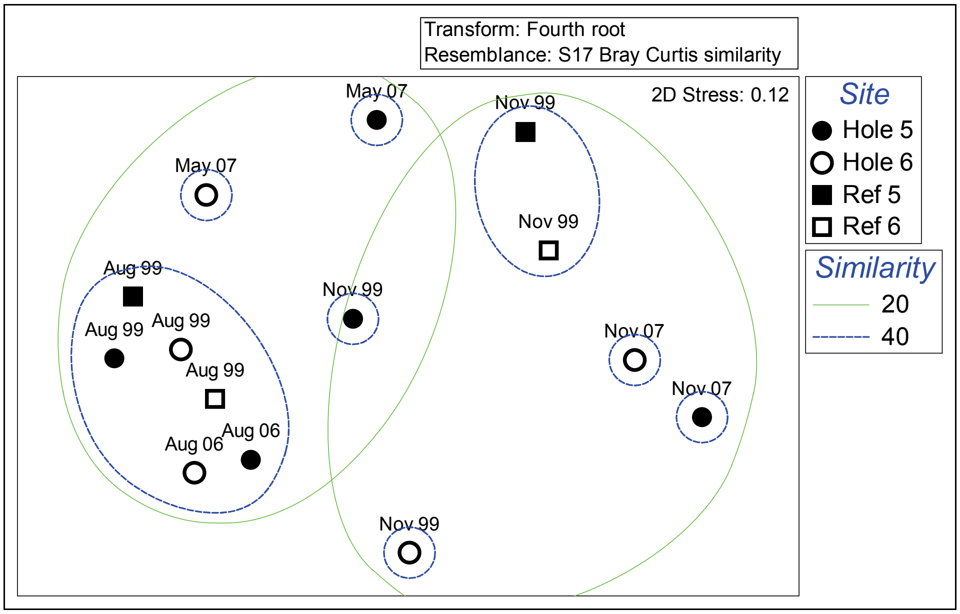


Figure 11. Biplot of MDS and clustering results. All data fourth-root transformed and compared using Bray-Curtis similarity index.

Fisheries Hydroacoustics. Target strength data were used to calculate estimates of fish length for all acoustically detected and accepted fishes. A minimum target strength detection threshold was set at a decibel value of (-52.6 dB) equivalent to an estimated fish length of 4 cm. Estimated lengths of all accepted single targets ranged from 4 to 60 cm, which corresponds relatively well with the conventional catch data. For every sampling event, regardless of tidal cycle, time of day, or season, the majority of acoustically detected fishes (75-90% per survey) were less than 10 cm in length. Results from the conventional gear catch indicated that these targets were predominantly bay anchovies, Atlantic silversides, and Atlantic croaker. Patterns were similar for both dredged holes, with targets in the 10-15 cm category representing 7 to 13% of the total detections. Weakfish was the numerically dominant species captured in this size class. Numbers of targets in the 15-20 cm size class were also similar in both dredged holes at 1.5 to 4% of the total detections. The only exception occurred in the November survey in Dredged Hole #5, where no detections in this size class were made. Additional 5 cm length increment size classes accounted for less than 1% each of the total detections.

Length-Frequency Comparison. In Figure 12, the length frequency distributions of fishes in the combined trawl and gill net catches is compared with that of acoustically estimated target lengths derived from the target strength data. Since much larger numbers of fish were acoustically detected when compared to totals from conventional gears, results were converted to a relative frequency percentage by size class. Data were combined for all seasonal surveys and results presented for daytime data collection efforts because all conventional gear surveys were conducted during daylight hours. A close correspondence is seen between size frequencies of fishes caught by the conventional and hydroacoustics gears. Seasonal partitioning of the data indicated strong correspondences among size distributions of fishes collected in August and November. In May, however, acoustic detections were considerably lower than expected in four size classes (30-35, 35-40, 40-45 and 45-50 cm), represented primarily by bluefish and Atlantic menhaden.

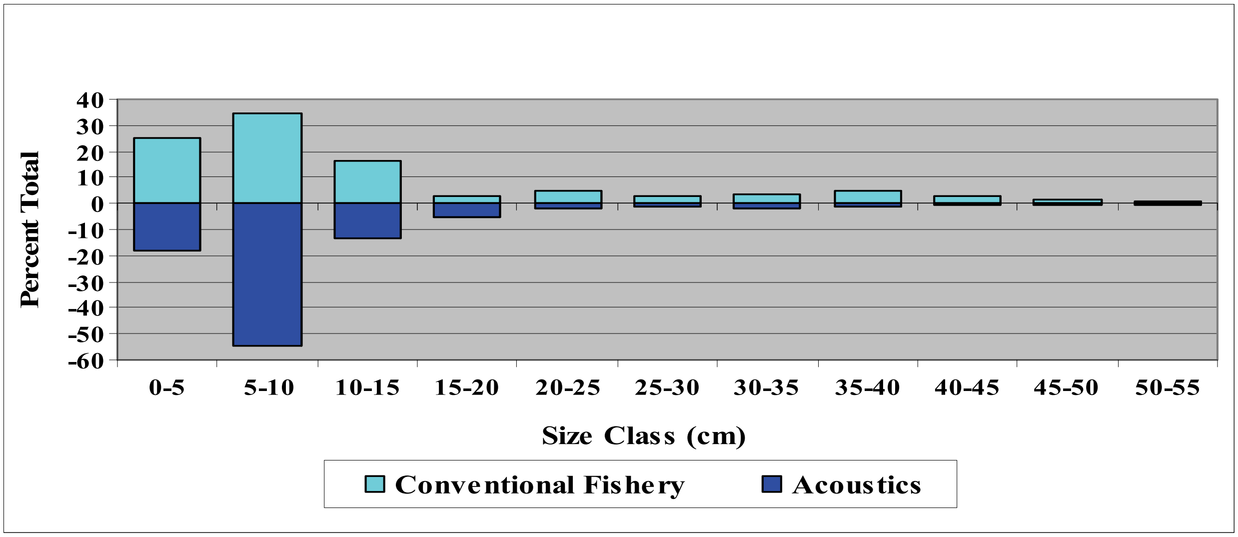
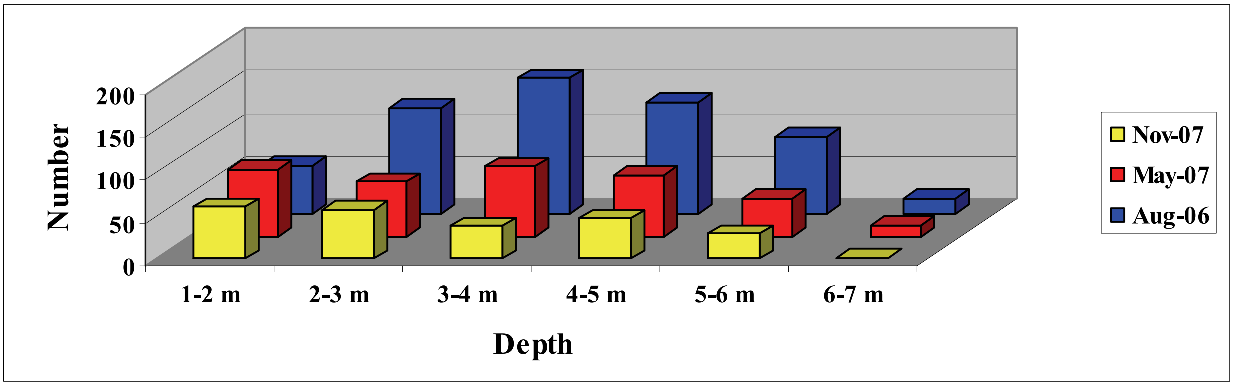


Figure 12. Length frequency distributions of fishes in Dredged Holes #5 and #6 based on conventional fishery gears and hydroacoustic measurements.

Fish Vertical Distribution Patterns. A total of 1,169 single target (non-schooling) fishes were detected during seasonal hydroacoustic surveys of Dredged Hole #5 (581 in August, 355 in May, and 233 in November). To display changes in vertical distribution of fishes, the water column was divided into 1-meter increments from surface to bottom (Figure 13). In August, fishes were concentrated in the 3-4 m depth stratum, which had the highest number of individual fish targets (160), accounting for nearly 28% of the total number of fishes detected. Both adjacent depth strata (2-3 m and 4-5 m) contained slightly more than 20% each of accepted fish targets. Few fishes occurred in the uppermost (1-2 m, n = 56, 9.6%) and lowest (5-6 m n=90, 15.5%) depth strata. Slightly more than 3% of fishes occurred at depths deeper than 6 m, but this represents a smaller volume of pockets in the pit basins. In May 2007, fish targets in Hole #5 were generally evenly distributed throughout the first 5 m of the water column with each depth stratum accounting for 18 to 22% of the total number of fish detections. The deepest two depth strata (5-6 m and 6-7 m) accounted for 12.7% (n = 45) and 4.7% (n =13) of fish targets. In November, 26.2% of fish targets were found in the upper-most depth stratum (1-2 m, n= 61), followed by 24.5% (N=57) at 2-3 m. Forty-seven fishes, slightly more than 20% of the total, were detected at depths of 4-5 m. All other depth strata for the November survey accounted for between 12 and 16% of fishes, with the exception of the 6-7 m depth stratum in which only a single fish was detected.



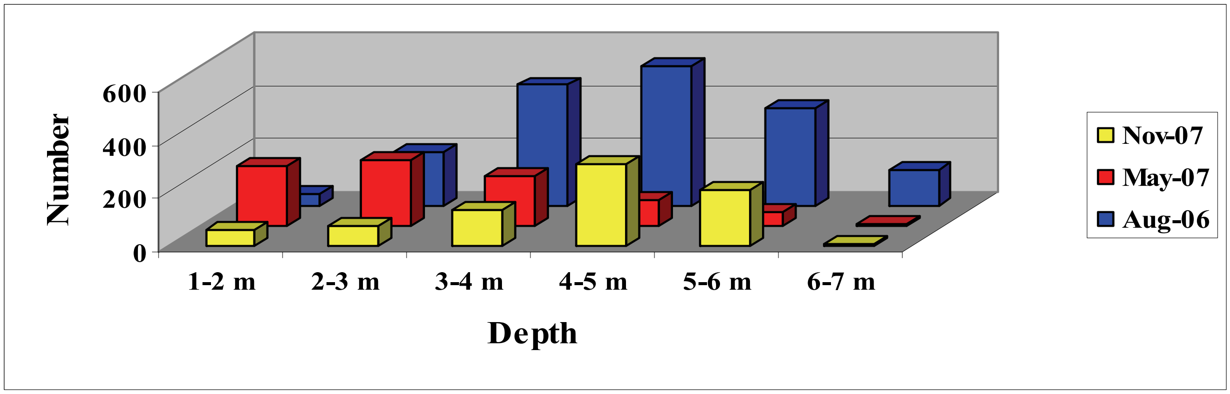


Figure 13. Vertical distribution of fish targets in Dredged Holes # 5 (top) and #6 (bottom).

In Dredged Hole #6, 3,341 fishes were detected during seasonal surveys. Fish counts were higher in August (n = 1,742) than in May (n = 810) or November (n = 789). Fishes were found in highest numbers in the 3-4 m (n = 455, 26%) and 4-5 m (n = 530, 30.4%) depth strata during the summer surveys (Figure 13). Fishes in the adjacent upper and lower depth strata accounted for 14.9% (n = 206, 2-3 m) and 21.3% (n = 371, 5-6 m) of the total number of targets. Fewer fishes were detected (n = 42) in the 1-2 m depth stratum, as well as in the 6-7 m depth stratum (n = 138). During spring sampling, high numbers of fishes (n = 223 and 247) occurred in the upper two meters of the water column, accounting for 58% of the total distribution. Decreasing numbers of fishes were observed with increasing depth: 189 in 3-4 m, 94 in 4-5 m and 52 in 5-6 m. These accounted for slightly more than 40% of total detections. Less than 1% of fishes were detected in 6-7 m depth stratum. In November, the pattern reversed from that observed in spring, with the majority of fish detections in the 4-5 m (n = 309) and 5-6 m (n= 206) depth strata, representing slightly more than 65% of the total distribution. Fewest fish occurred in the 6-7 m depth stratum (n = 9, 10.1%). The upper three depth strata had increasing numbers of fishes: 55 (1-2 m), 75 (2-3 m), and 135 (3-4 m), or approximately 33% of fish detections during the fall sampling.

Fish Densities. Fish densities (fish/100^3) were calculated for each ESDU by dividing the total number of accepted fish targets detected by the volume of water sampled. Fish densities were not uniformly distributed among ESDUs. Highest estimated density approached 850 fish/100 m^3 for a single ESDU in which schooling fishes were present, whereas no fishes were detected in nearby ESDUs along the same transect. Fish density estimates are given for site, season and time of day in Table 2. Changes in density and spatial distribution patterns were compared by factorial ANOVA for significance by site, season, time of day effect, and tidal cycle.

Table 2. Mean fish density per 100 m^3 for all surveys in Dredged Holes #5 and #6. D = day, N = night, E = ebb, F = flood.

Month	Period	Tide	Dredged Hole #5		Dredged Hole #6	
			Density	SE	Density	SE
Aug	D	E	13.2	5.1	8.2	0.95
Aug	D	F	12.1	1.8	4.5	0.66
Aug	N	E	15.2	0.61	11.9	1.5
Aug	N	F	19.0	2.3	13.4	0.46
Aug	D	E,F	13.6	2.6	6.3	0.6
Aug	N	E,F	16.1	1.2	12.6	0.8
Aug	D, N	E	14.2	2.6	10.1	0.9
Aug	D, N	F	15.4	1.5	9.0	0.4
Total August Density			**14.8**	**1.5**	**9.5**	**0.5**
May	D	E	6.4	2.1	1.9	0.46
May	D	F	1.8	0.46	1.1	0.28
May	N	E	3.0	0.29	2.5	0.68
May	N	F	3.9	0.84	2.6	0.54
May	D	E, F	4.1	1.1	1.5	0.27
May	N	E, F	3.4	0.4	2.6	0.43
May	D, N	E	4.7	1.1	2.2	0.41
May	D, N	F	2.8	0.47	1.9	0.3
Total May Density			**3.8**	**0.6**	**2.1**	**0.3**
Nov	D	E	0.6	0.33	1.7	0.77
Nov	D	F	0.5	0.13	1.1	0.31
Nov	N	E	0.6	0.08	1.2	0.26
Nov	N	F	0.8	0.24	1.9	0.13
Nov	D	E, F	0.5	0.18	1.7	0.43
Nov	N	E, F	0.7	0.13	1.6	0.13
Nov	D, N	E	0.6	0.18	1.8	0.41
Nov	D, N	F	0.6	0.13	0.8	0.17
Total November Density			**0.6**	**0.11**	**1.6**	**0.22**

Fish Density by Site and Season. Average fish densities by site were compared between seasons. Fish densities during the summer survey averaged 14.8 fish/100m^3 in Dredged Hole #5, compared to 9.5 fish/100m^3 in Dredged Hole #6. Spring results resembled those of summer surveys in that fish density in Dredged Hole #5 was slightly higher (mean = 3.8 fish/100m^3) than in Dredged Hole #6 (2.1 fish/100m^3). The pattern reversed in fall with higher fish densities in Dredged Hole #6 (1.6 fish/100m^3) than in Dredged Hole #5 (0.6 fish/100m^3). Total densities were found to be significantly different ($p<0.05$) by sampling date (Figure 14). Although no statistical test was possible between sampling sites because of the significant interaction factors in the three-way ANOVA, there were obvious differences in numbers of fish detected during each sampling date. The greatest numbers of fishes were present in August, with considerably fewer in May, and the lowest numbers in November.

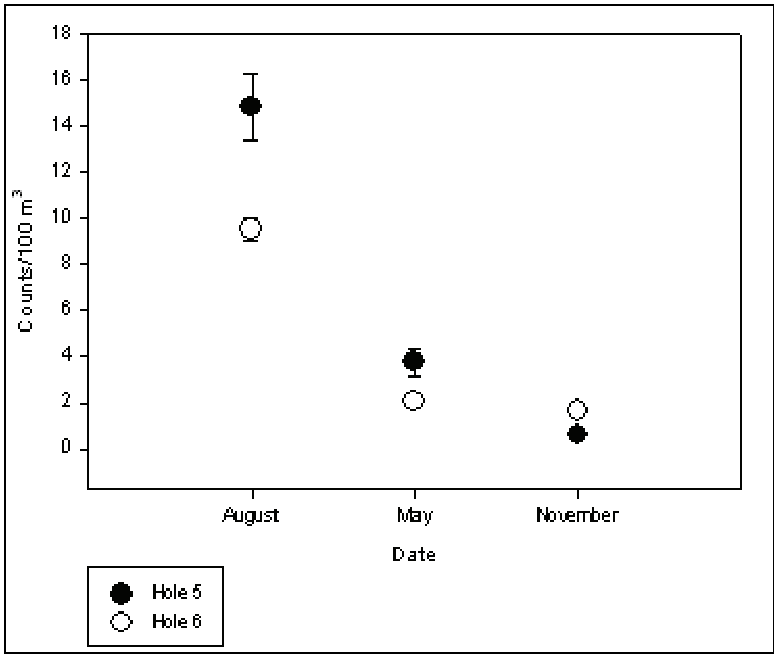


Figure 14. Total numbers of fish/100 m^3 ±SE by sampling date in Dredged Holes #5 (solid circles) and #6 (open circles). All values are significantly different ($p<0.05$) within sampling date.

Influence of Tide on Fish Distribution. Normal tidal amplitude in Barnegat Bay is 0.95 m (3 ft). However, near the study area dampening effects reduce the amplitude to approximately 0.15 m. Mean tidal current velocities at the nearby inlet are 1.1 m/sec during flood and 1.3 m/sec during ebb tidal stages. Although there was minimal evidence of strong tidal flows, fishes were consistently observed to move into and out of the dredged holes on a tidally-based cycle. At Dredged Hole #6, fish densities were highest during the ebb tidal cycle in all seasons surveyed (Table 2). Differences in fish density between tidal cycles were lowest in May (mean = 0.4 fish/100 m^3) and highest in summer (mean = 1.1 fish/100 m^3). Across all seasons, fish density averaged 4.7 fish/100 m^3 for surveys completed during an ebbing tide and 3.9 fish/100 m^3 during a flooding tide.

The pattern of greater fish density during ebb tidal cycles observed at Dredged Hole #6 was not seen as consistently as at Dredged Hole #5. Summer survey densities were slightly higher during the flood tide (15.4 fish/100m^3) than during the ebb tide (14.2 fish/100m^3). At Dredged Hole #5, the largest difference in mean density (ebb = 4.7 fish/100m^3, flood = 2.8 fish/100m^3) occurred during the spring sampling event. In fall surveys, nearly equal densities (0.6 fish/100m^3) occurred during both ebb and flood tides in Dredged Hole #5. Across all seasonal surveys, fish density averaged 6.5 fish/100 m^3 during an ebbing tide and 6.3 fish/1000 m^3 during a flooding tide.

Fish densities were higher in Dredged Hole #5 (control) during ebb and flood tides for both spring and summer surveys. During fall surveys, higher densities were found in the restored borrow pit (Dredged Hole #6) during both ebb and flood tidal cycles. Across all surveys, approximately 12% fewer fish were found in Dredged Hole #6 than in Dredged Hole #5 during ebb tide surveys, and nearly 24% fewer fish during flood tide surveys. Despite these differences, tidal effects on fish density examined by ANOVA were not found to be significant ($P > 0.05$).

Influence of Time of Day on Fish Distribution. During summer surveys, nighttime fish densities were higher in both Dredged Holes #5 and #6 than during daytime surveys. Nighttime estimates of fish density (12.6 fish/100 m^3) were approximately double the daytime estimates (6.3 fish/100 m^3) in Dredged Hole #6 (Table 2). Day-night differences at Dredged Hole #5 were not as large. Higher nighttime densities resulted from an influx of small fishes (< 10 cm), probably consisting primarily of bay anchovies. The highest overall density (19 fish/100m^3) occurred in Dredged Hole #5 during a summer nighttime, flood tide survey. In contrast, the lowest fish density (4.5 fish/100m^3) obtained during summer surveys occurred in Dredged Hole #6 during daytime hours. In spring, higher nighttime (2.6 fish/100m^3) than daytime (1.5 fish/100m^3) fish densities occurred only in Dredged Hole #6. At the control site (Hole #5), fish densities were greater during daytime surveys. Combined (ebb/flood) daytime surveys produced a higher overall mean density (4.1 fish/100m^3) than did nighttime surveys (3.4 fish/100m^3). This pattern was strongly affected by the presence of four large schools of fishes detected during the daytime survey, whereas the majority of ESDUs had much lower daytime density than the corresponding nighttime values. Little difference was observed between day/night fish densities during fall surveys. At both the restored and control borrow pits, day-night densities averaged less than 0.2 fish/100m^3. A slightly higher nighttime estimate occurred in Dredged Hole #5. Across seasons, fish densities were more consistent between day-night results at Dredged Hole #5. At the restored site, day-night differences in fish density varied widely across seasons, with summer results contributing the greatest difference, followed by spring results. The smallest difference between day and night surveys occurred during the fall at both borrow pits. Results from two-way ANOVA (Site X Day/Night) for each of the three sampling events were identical in the sense that there were statistically significant differences ($p < 0.05$) for Site and Day/Night, but not for the Site X Day/Night interaction (Figure 15). This indicates that differences detected between sites or day/night surveys were a consistent pattern.

Results from the infaunal sampling suggest that there is little difference in the distribution or structure of the benthic community between borrow areas, between depths, or over time. The same pattern of decreasing taxa richness (taxa/sample), abundance, and diversity with increasing depth are found in both borrow areas and both time periods (before and after). Likewise, the species composition of reference areas and middle and shallow (Top) depth samples are quite similar to one another in both borrow areas and both time periods. Only bottom depth samples appear to be different as evidenced by the lowest values for taxa richness, abundance, diversity, and the highest degree of variation in species composition. The results from bottom depth samples are most likely due to differential survival as a result of periodic exposure to low oxygen conditions.

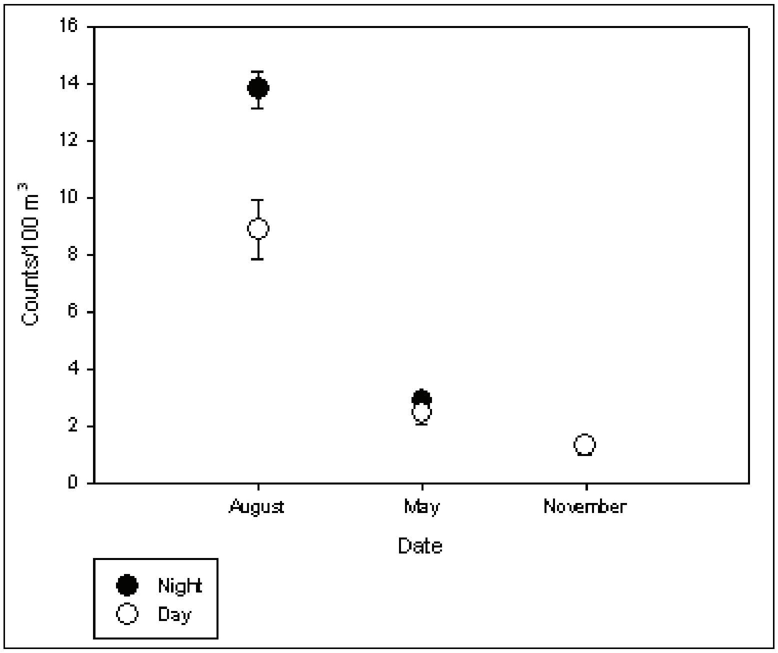


Figure 15. Total numbers of fish/100 m3 +SE collected in day (open circles) versus night (filled circles) by sampling date. All night values are significantly greater ($p<0.05$) than day values within all sampling dates.

CONCLUSIONS

The results of conventional netting and acoustic fisheries indicated that both borrow pits were seasonally occupied by fishery resource assemblages typical of greater Barnegat Bay. During the course of surveys undertaken in the present study, no evidence was seen of water column stratification that would induce hypoxic or anoxic water quality conditions, even during the summer surveys. This may simply reflect more benign meteorological and hydrographic conditions prevailing during these surveys than had been the case during earlier studies. Clearly, additional monitoring is advisable during periods likely to experience water column stratification. Composition of the fishery assemblages did not change dramatically between pre- and post-construction surveys. Conventional gear catches were typically low, reflecting inherent difficulties in sampling deep pits at intensities sufficient to yield quantitative comparisons. Fisheries hydroacoustics, in tandem with limited convention netting efforts, was demonstrated to be an effective means to examine fish distributions within deep borrow pits.

Some limitations in assessing the fishery habitat functions of the borrow pits are inherent in the study design, which are acknowledged herein. For example, fish densities were not simultaneously surveyed in other open-water habitats in Barnegat Bay, so comparisons to shallow, barren or vegetated bottoms are not possible. Likewise, because the final selected alternative resulted in a partial rather than complete filling of Dredged Hole #6, a direct comparison between an unrestored borrow pit and a pit returned to historical contours cannot be made. Indeed, the “restored” condition of Dredged Hole #6 created a borrow pit of similar depth profiles to Dredged Hole #5. Thus, the restoration as conducted effectively reproduced an existing borrow pit configuration, and not a distinctly different fishery habitat. It is therefore not surprising that in terms of absolute numbers and densities of fishes, the differences between the borrow pits appear to be relatively minor. Partial filling of Dredged Hole #6 does not appear to have detrimentally affected fishery resource occupation. The project has in fact satisfied the objectives of creating habitat less susceptible to degraded water quality conditions, while retaining sufficient vertical relief to maintain associations with juvenile weakfish and other potential forage fishes. Density or thermal stratification was not pronounced in either dredged hole during any seasonal survey. DO concentrations were relatively high, even during summer, and well above prerestoration surveys dating back to 1969. Although not seen in this study, periodic hypoxic conditions may still occur within the borrow pits under certain conditions. To verify the outcome of improved water quality, further monitoring will be necessary during appropriate seasons and time periods. Likewise, neither borrow site was found to be a thermal refuge during winter, although more extensive monitoring would be required to verify this finding.

Fishes were observed to move freely within and outside of both borrow pits. Given the location of both dredged holes — in close proximity to shorelines — the lack of s trong tidal flows may affect the “flux” of fishes between pits and adjacent shallow habitats. Inspection of individual echograms of transects across the dredged holes yielded some evidence of associations between fish targets and bathymetric features such as the sand mounds formed in the basin of Dredged Hole #6 and the toes or upper rims of the side slopes of the borrow pits, suggesting further analyses of the fine spatial scale interactions between fishes and borrow pits are needed. The efficacy of created mounds to provide long-term habitat benefits can only be evaluated by longer-term monitoring. The mounds may or may not be attractive to certain fish species. It should also be noted that fisheries hydroacoustics techniques provide data on fishes in the water column only and not in contact with the substrate. Therefore, fish densities recorded herein do not include flatfishes, gobies, and other bottom-oriented species.

There was no evidence of fish avoiding any portion of the water column within the borrow pits, although depth distributions of fishes were shown to change subtly between seasons and between dredged holes. The latter observation may simply reflect differences in geometries of the dredged holes and orientation to prevailing water currents. Some variation in depth preferences of fishes on given dates was observed between sites. For example, during the fall sampling, some affinity for the upper depth strata was observed in Dredged Hole #5, whereas deeper depths were occupied in Dredged Hole #6. Fishes were more evenly distributed throughout the water column in both borrow pits in the spring surveys, but congregated at mid-water depths during summer surveys at both sites.

In conclusion, there appears to be little to lose and much knowledge to be gained by additional projects demonstrating different borrow pit restoration alternatives. Surprisingly, few borrow pit restoration projects have been conducted. In certain open-water situations it is likely that complete filling to historical contours would be very beneficial, particularly if the restored bottom results in establishment of submerged aquatic vegetation, oyster reef, or benthic habitats that support fishery resources.

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> Reine, K. J., D. G. Clarke, G. L. Ray, and C. Dickerson. 2011. *Fishery resource utilization of a restored estuarine borrow pit: A beneficial use of dredged material case study*. Technical Note ERDC TN-DOER-E33. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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