

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 96,000 cubic meters (125,000 cubic yards) of clean, sandy dredged material to raise the bottom from -11.6 m MLW to an elevation of -5.5 m MLW. For monitoring purposes a nearby dredged pit served as an un-restored control. Seasonal conditions in both borrow pits were assessed in terms of water quality, fishery resource assemblage composition, and borrow pit utilization patterns. 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 un-restored 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 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 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. Results indicate that placement of dredged material in borrow pits is a viable fishery habitat restoration option.

Keywords: fisheries hydroacoustics, water quality, essential fish habitat, dredged hole

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 (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,

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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 frequently found in dredged holes which may contribute 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 re-establish pre-existing 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 by Tavolaro et al. (1992). 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).

The U.S. Army Corps of Engineers (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. Results of benthic community sampling will be reported elsewhere, whereas this paper concentrates on results related directly to fish habitat. For purposes of comparison a nearby un-restored 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, particularly 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).

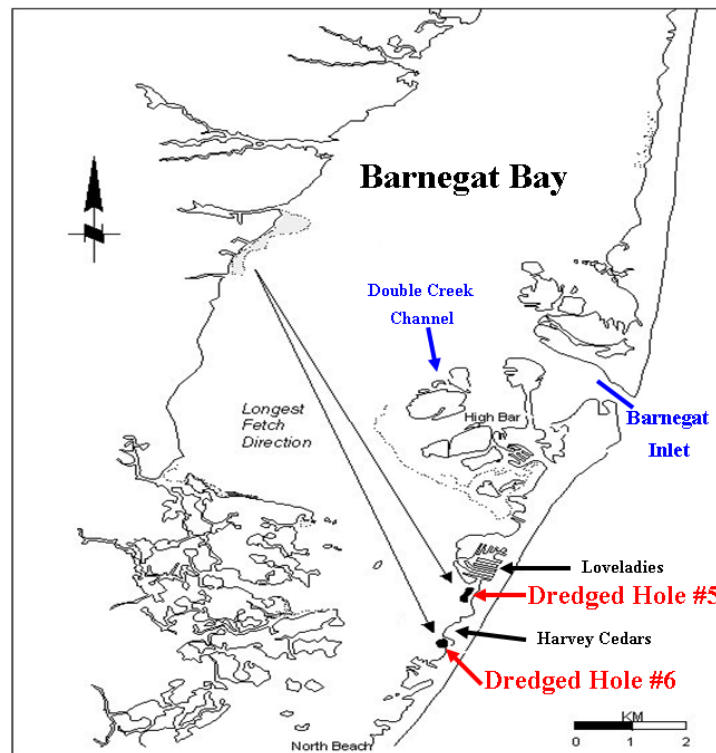


Figure 1. Location of study borrow pits in the Barnegat Bay Estuary.

Water Quality

A calibrated YSI (Model 6920 V2) water quality sonde was used to measure DO concentration (mg/l), temperature (°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 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.

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) were 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 ($1,500 \text{ m s}^{-1}$) 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. Transects extended the full width (shoal to shoal) of each borrow site. Fifteen 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). Volumetric fish densities from surface to bottom were converted to fish/ha by multiplying fish/ m^3 by the volume of water in a 1 hectare area, estimated using the mean water depth of each dredged hole.

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. 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

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 (Dredged Hole #5 or #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.

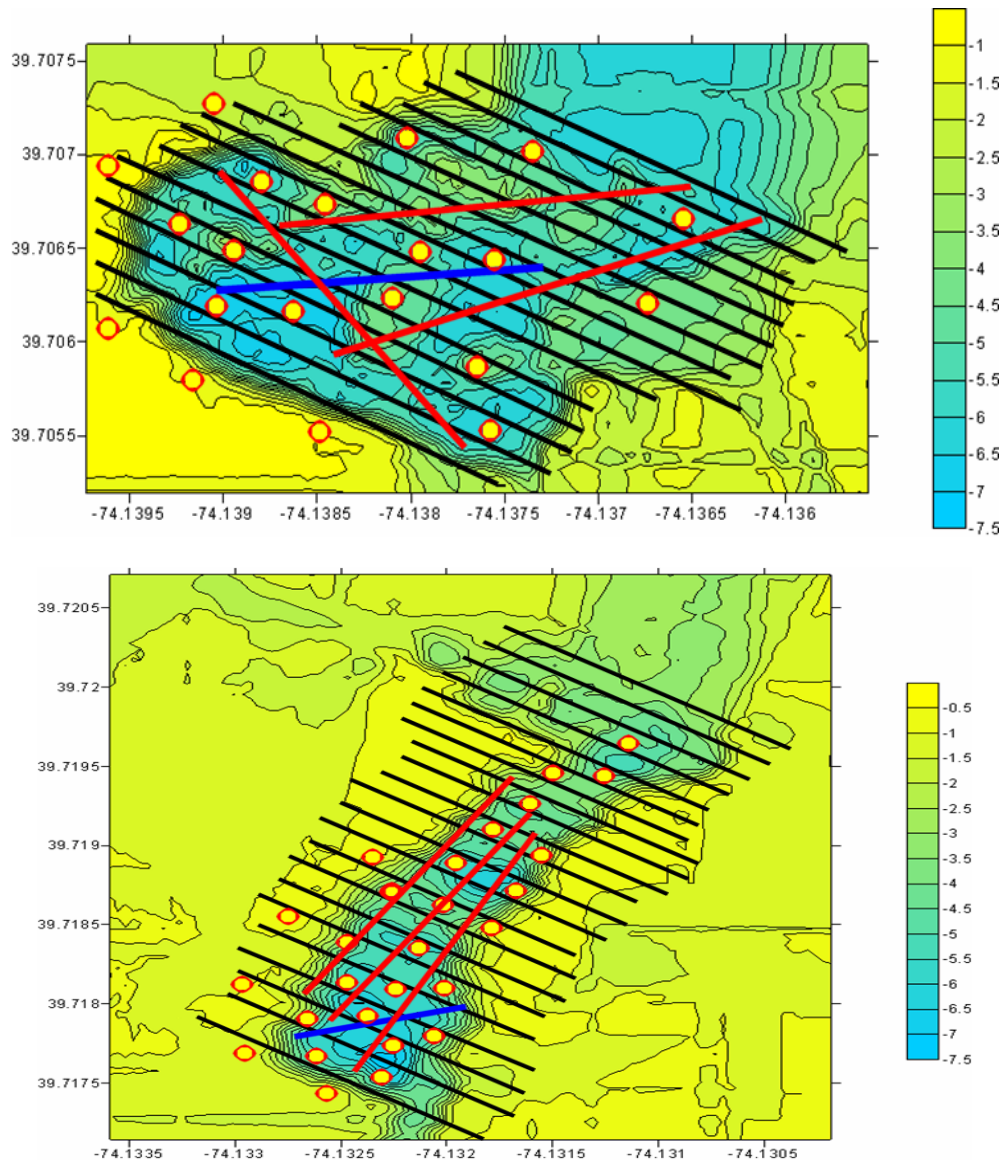


Figure 2. Locations of hydroacoustic transects (black), conventional fisheries (red: otter trawls, and blue: gill nets) and water quality stations (circles) in Dredged Holes #5 (Bottom) and #6 (Top). Color-coded depths in meters given in legends at right.

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 samples 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. SIMPROF (Similarity Profile), 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 among 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 ANOSIM (Analysis of Similarity), 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).

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 °C in Dredged Hole #6, but were slightly cooler (23.2 °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 °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 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 4 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.

Conventional Fisheries Gear Catch

Species Composition

Barneget 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 3 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 3.

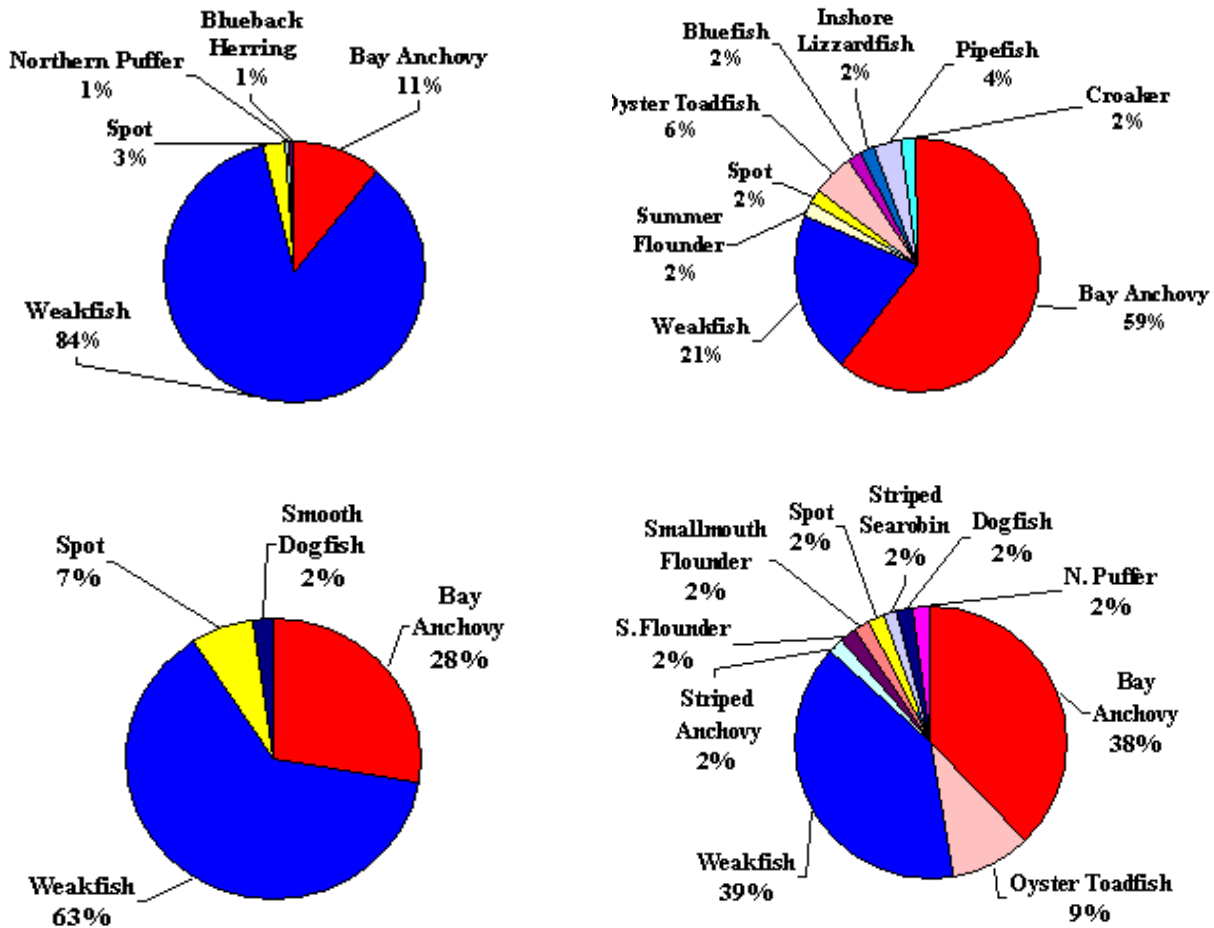


Figure 3. Fishery assemblages based on otter trawls in Dredged Holes #5 (top) and #6 (bottom). Top left: Hole #5-August 1999. Top right: Hole #5-August 2007. Bottom left: Hole #6-August 1999. Bottom right: Hole #6-August 2007.

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.

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*), 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 less than 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*), 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 4.

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 among sampling periods and time of year than between sites (Figure 5). 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

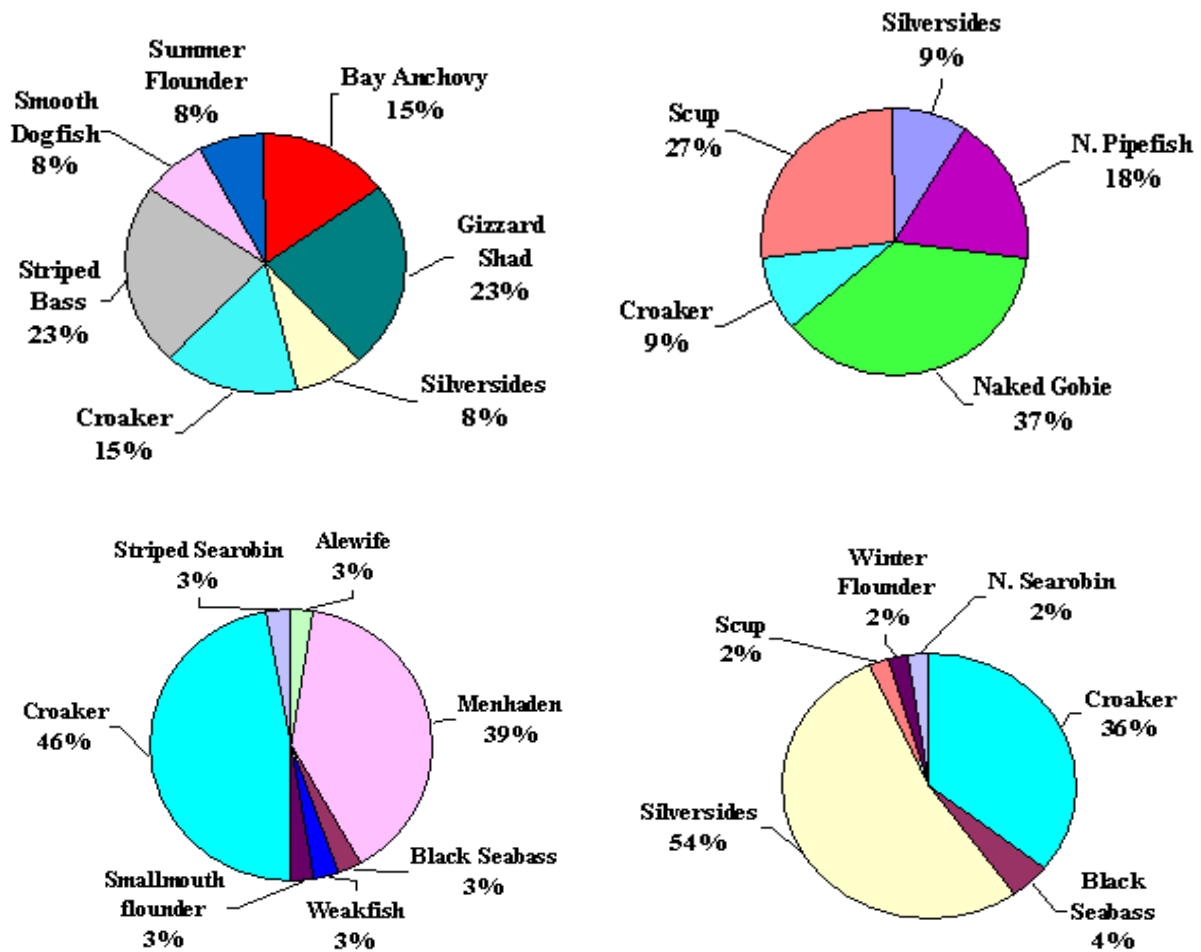


Figure 4. Fishery assemblages based on otter trawls in Dredged Holes #5 (top) and #6 (bottom). Top left: Hole #5-November 1999. Top right: Hole #5-November 2007. Bottom left: Hole #6-November 1999. Bottom right: Hole #6-November 2007.

plots were significant (Stress = 0.12) and the results mirrored those of hierarchical clustering (Figure 6) 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 BACI (Before/After-Control/Impact) 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.

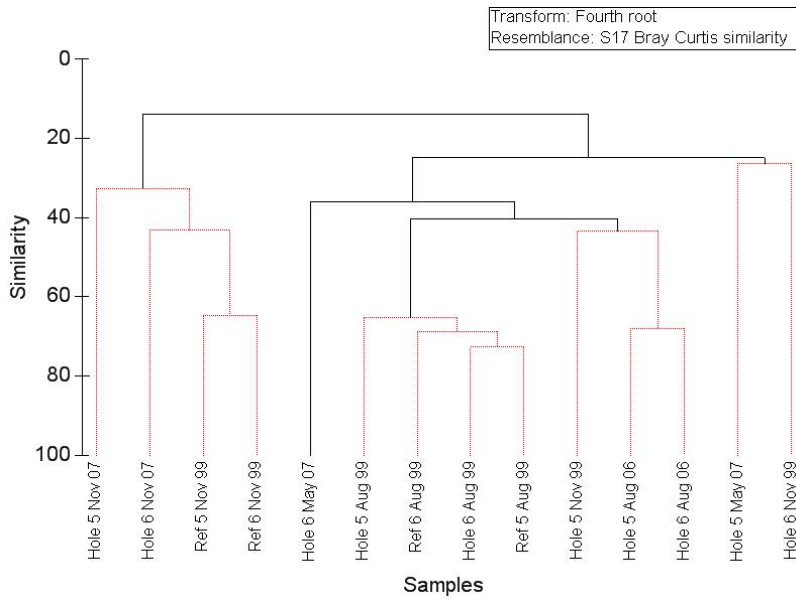


Figure 5. Hierarchical clustering dendrogram of Barnegat Bay trawl data. All data fourth-root transformed and compared using Bray-Curtis similarity index with group averaging.

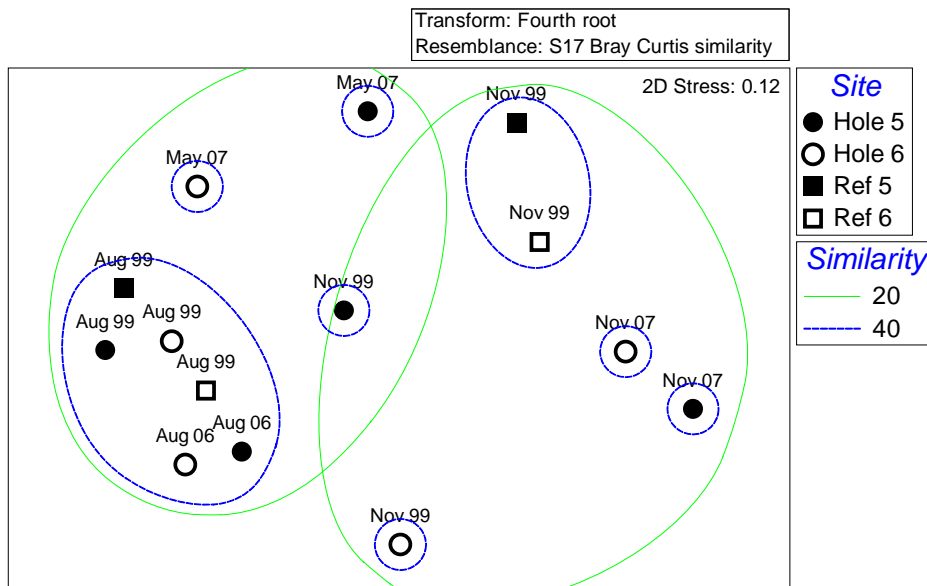


Figure 6. Biplot of MDS and clustering results. All data fourth-root transformed and compared using Bray-Curtis similarity index.

Fish Size Distribution

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.

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 7 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. Because 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.

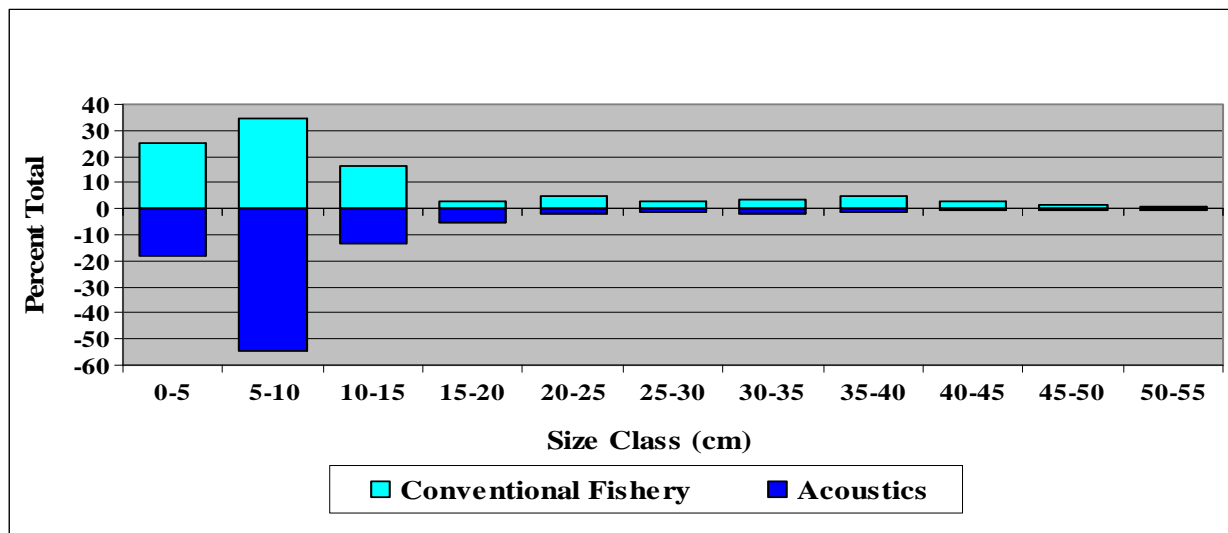


Figure 7. Length frequency distributions of fishes in Dredged Holes #5 and #6, based on conventional fishery gears and hydroacoustic measurements.

Fish Vertical Distribution Patterns

A total of 1,169 single target (non-schooling) fishes was 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 8). 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 between 12 and 16% of fishes, with the exception of the 6-7 m depth stratum in which only a single fish was detected.

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 8). 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/100³) 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 m³ for a single ESDU in which schooling fishes were present, whereas no fishes were detected in nearby ESDUs along the same transect. Fish density was converted to fish per hectare by multiplying density per meter by the area of 1 hectare (10,000 m²) by the average water depth at each site (Table 1). This approach was used to compare fish densities among repeated hydroacoustic surveys in two Wyoming reservoirs by Gangl and Whaley (2004). Changes in density and spatial distribution patterns were compared by factorial ANOVA for significance by site, season, time of day effect, and tidal cycle.

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/100m³ in Dredged Hole #5, compared to 9.5 fish/100m³ 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/100m³) than in Dredged Hole #6 (2.1 fish/100m³). The pattern reversed in fall with higher fish densities in Dredged Hole #6 (1.6 fish/100m³) than in Dredged Hole #5 (0.6 fish/100m³). Total densities were found to be significantly different ($P < 0.05$) by sampling date (Figure 9). 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. Greatest numbers of fishes were present in August, considerably fewer in May, and fewest in November.

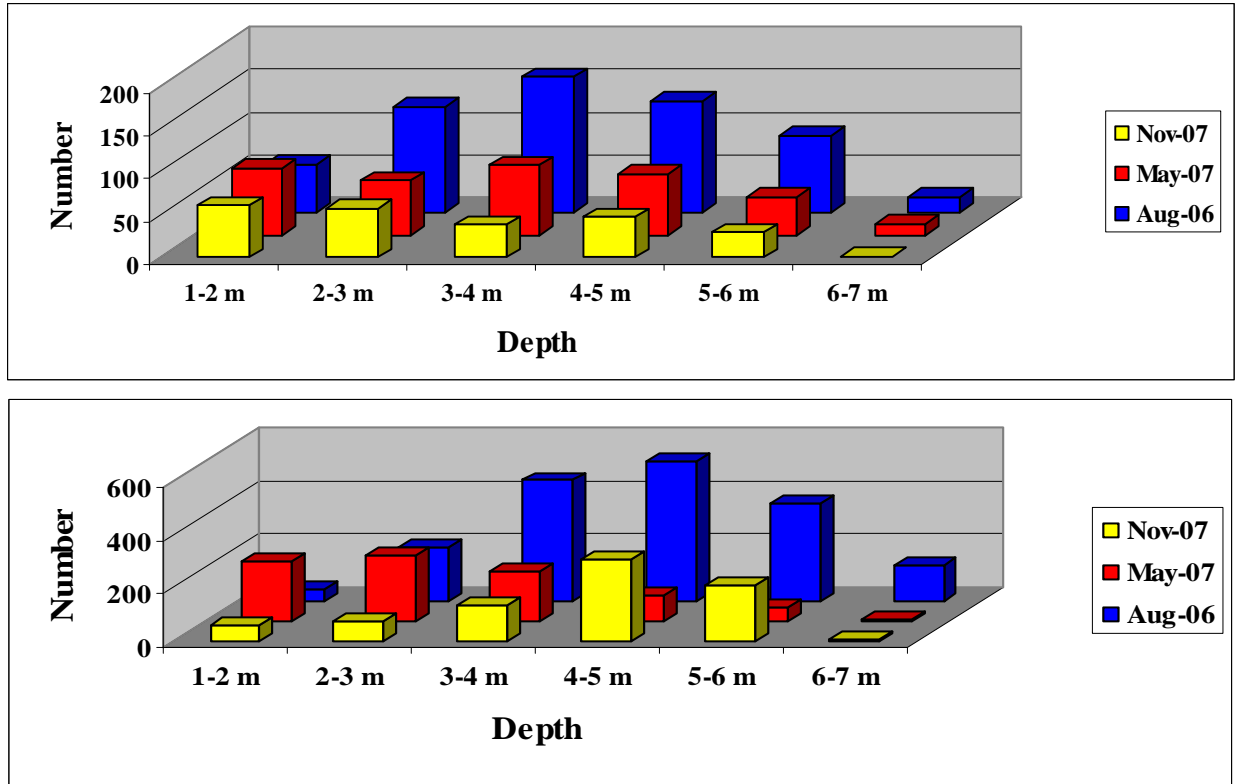


Figure 8. Vertical distribution of fish targets in Dredged Holes # 5 (top) and #6 (bottom).

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 1). In terms of fish per hectare, densities reached nearly 5,600 fish/ha in Hole #6 on ebbing tides during the summer, in comparison to 4,950 fish/ha on a flooding tide. Similar results were obtained for the spring surveys, in which 1,210 fish/ha were present during an ebbing tide as compared to 1,045 fish/ha on a flooding tide. Fish/ha decreased from 990 (ebb tide) to 440 (flood tide) during the fall sampling event, a difference of slightly more than 55%. Across all seasons, numbers of fish/ha averaged 17% fewer during surveys completed during a flooding tide.

The pattern of greater fish density during ebb tidal cycles observed at Dredged Hole #6 was not seen as consistently at Dredged Hole #5. Summer survey densities were slightly higher during the flood tide (6,930 fish/ha, or 15.4 fish/100m³) than during the ebb tide (6,390 fish/ha, or 14.2 fish/100m³). At Dredged Hole #5 the largest difference in mean density (ebb = 4.7 fish/100m³, flood = 2.8 fish/100m³) occurred during the spring sampling event. During spring, nearly 40% more fish per hectare were detected during the ebb tidal cycle. In fall surveys nearly equal densities (0.6 fish/100m³, 270 fish/ha) occurred during both ebb and flood tides in Dredged Hole #5. Across all seasonal surveys, numbers of fish/ha averaged 3.6% more during ebb tides than during flood tides.

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/ha were found in Dredged Hole #6 than in Dredged Hole #5 during ebb tide surveys, and nearly 24% fewer fish/ha during flood tide surveys. Despite these differences, tidal effects on fish density examined by ANOVA were not found to be significant (P> 0.05).

**Table 1. Mean fish density per 100 m³ and fish per hectare for all surveys in Dredged Holes #5 and #6.
D = day, N = night, E = ebb, F = flood.**

Month	Period	Tide	Hole #	Density	Fish/ha	Hole #	Density	Fish/ha
Aug	D	E	5	13.2	5940	6	8.2	4510
Aug	D	F	5	12.1	5445	6	4.5	2475
Aug	N	E	5	15.2	6840	6	11.9	6545
Aug	N	F	5	19.0	8550	6	13.4	7370
Aug	D	E,F	5	13.6	6120	6	6.3	3465
Aug	N	E,F	5	16.1	7245	6	12.6	6930
Aug	D, N	E	5	14.2	6390	6	10.1	5555
Aug	D, N	F	5	15.4	6930	6	9.0	4950
Total August Density			5	14.8	6660	6	9.5	5225
May	D	E	5	6.4	2880	6	1.9	1045
May	D	F	5	1.8	810	6	1.1	605
May	N	E	5	3.0	1350	6	2.5	1375
May	N	F	5	3.9	1755	6	2.6	1430
May	D	E, F	5	4.1	1845	6	1.5	825
May	N	E, F	5	3.4	1530	6	2.6	1430
May	D, N	E	5	4.7	2115	6	2.2	1210
May	D, N	F	5	2.8	1260	6	1.9	1045
Total May Density			5	3.8	1710	6	2.1	1155
Nov	D	E	5	0.6	270	6	1.7	935
Nov	D	F	5	0.5	225	6	1.1	605
Nov	N	E	5	0.6	270	6	1.2	660
Nov	N	F	5	0.8	360	6	1.9	1045
Nov	D	E, F	5	0.5	225	6	1.7	935
Nov	N	E, F	5	0.7	315	6	1.6	880
Nov	D, N	E	5	0.6	270	6	1.8	990
Nov	D, N	F	5	0.6	270	6	0.8	440
Total November Density			5	0.6	270	6	1.6	880

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/ha (6,930 fish/ha) were approximately double the daytime estimates (3,465 fish/ha) in Dredged Hole #6 (Table 1). 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/100m³) occurred in Dredged Hole #5 during a summer nighttime, flood tide survey, a density corresponding to nearly 8,600 fish/ha. In contrast, the lowest fish density (4.5 fish/100m³) obtained during summer surveys occurred in Dredged Hole #6 during daytime hours. In spring, higher nighttime (2.6 fish/100m³) than daytime (1.5 fish/100m³) fish densities occurred only in Dredged Hole #6, in which numbers of fish/ha increased by 73% (daytime = 825 fish/ha, nighttime = 1,430 fish/ha). At the control site, fish densities were greater during daytime surveys. Combined (ebb/flood) daytime surveys produced a higher overall mean density (4.1 fish/100m³) than did nighttime surveys (3.4 fish/100m³). 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/100m³. A slightly higher nighttime estimate occurred in Dredged Hole #5. Across seasons, numbers of fish/ha were more consistent between day-night results at Dredged Hole #5. At the restored site, day-night differences in numbers of fish/ha 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 10). This indicates that differences detected between sites or day/night surveys were a consistent pattern.

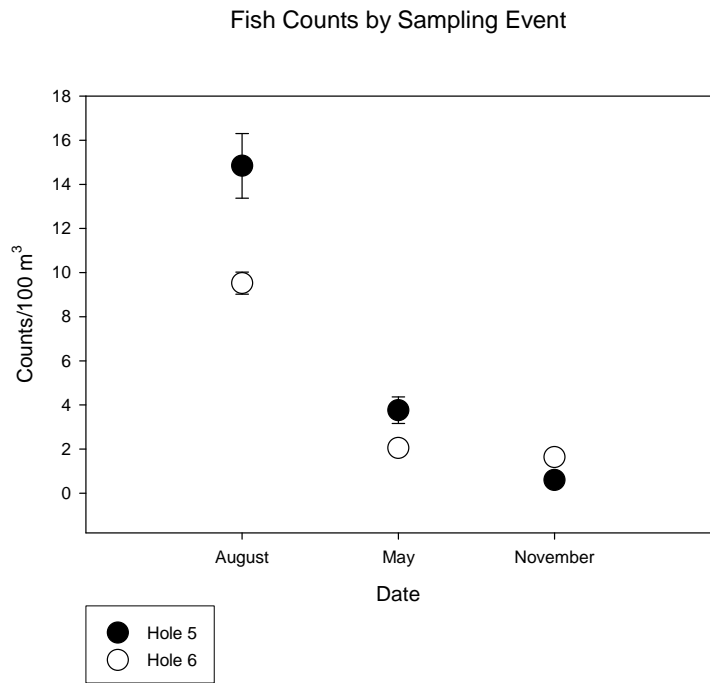


Figure 9. Total numbers of fish/100 m³ ±SE by sampling date in Dredged Holes #5 (solid circles) and #6 (open circles). All values are significantly different (p<0.05) within sampling date.

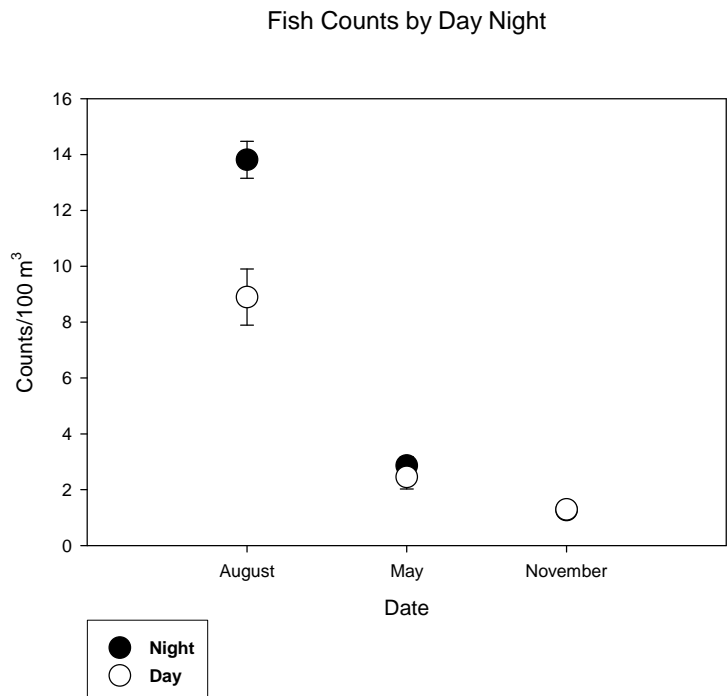


Figure 10. Total numbers of fish/100 m³ ±SE collected in day (open circles) versus night (filled circles) by sampling date. All night values are significantly greater (p<0.05) than day values within all sampling dates.

CONCLUSIONS

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 our 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 conventional 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 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 of an un-restored borrow pit with 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. Therefore it is 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. To that end, the project has 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 pre-restoration 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 strong tidal flows may affect “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, further analyses of the fine spatial scale interactions between fishes and borrow pits are recommended. The efficacy of created mounds in providing long-term habitat benefits can only be evaluated by longer-term monitoring. They may or may not act as attractive to certain fish species. It should 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.

ACKNOWLEDGMENTS

We thank Joan Clarke for providing guidance in statistical analysis of the fisheries hydroacoustics data. We also thank Willy Burton and staff at Versar, who ably served as captain and crew of the survey vessel. Sincere appreciation is also extended to Terry Fowler, Mark Eberle, and Beth Brandreth of the USACE Philadelphia District for technical and logistical support.

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