FISH ASSEMBLAGES AND HABITAT USE ACROSS A SHOREFACE SAND RIDGE IN SOUTHERN NEW JERSEY

By

JAMES MICHAEL VASSLIDES

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Dr. Kenneth W. Able

and approved by

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ABSTRACT OF THE THESIS

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By JAMES MICHAEL VASSLIDES

Thesis Director:
Dr. Kenneth W. Able

Shoreface sand ridges are prominent components of the inner-continental shelf landscape which may serve as sources for sand material for ongoing beach replenishment projects. In order to determine if these ridges provide unique habitats for fish on the inner continental shelf an analysis of two historic trawl surveys on Beach Haven Ridge (1991-1995 beam trawl and 1997-2006 otter trawl) and a 2006 otter trawl survey from two other sand ridges in the immediate vicinity was conducted to determine if species abundance, richness, and assemblages differed on and away from the ridges. The abundance and food habits of three dominant sciaenid species from Beach Haven Ridge were also examined to ascertain if feeding was influenced by habitat.

Overall species abundance and richness displayed a bimodal distribution across the inlet to offshore transects, with the highest values on either side of the ridges regardless of gear type. Canonical Correspondence Analysis identified three species assemblages; inshore (< 5 meters depth), near-ridge, and offshore (> 14 meters depth), with variation in the species composition between gear types. The beam trawl assemblages differed primarily in the presence or absence of species while the otter trawl assemblages were differentiated based on the relative abundance of shared species. Environmental factors that corresponded with the assemblage changes included depth, temperature, distance from the top of the ridge, and habitat complexity.

The abundance of the three sciaenid species investigated was highest in the habitats in the immediate vicinity of the sand ridge, with all three species absent from samples from the top of the ridge. The mean relative stomach fullness of each species was similar in each habitat, but the diets of all three species varied among the habitats.

In summary, this study documented higher fish abundances associated with sand ridges (but not on top of the ridge) and the presence of a distinct species assemblage when compared to the surrounding inner continental shelf. Furthermore, sand ridges appear to provide enhanced foraging opportunities for a variety of feeding modes. As such, sand ridges may be an important aspect of the inner continental shelf landscape and deserve special management considerations.

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CHAPTER I

Introduction

Ecological considerations are historically lacking in fisheries management (e.g. Link 2002, Beamish et al. 2003) although the use of multispecies models are now receiving increasing attention (Latour et al. 2003, Dame and Christian 2006) in an attempt to address calls for ecosystem-based fisheries management in the United States (NOAA 1999, Rosenberg et al. 2000, Browman and Stergiou 2004). With the Pew Oceans Commission (2003), the U.S. Ocean Commission (2004), and the National Oceanic and Atmospheric Administration (NOAA 2003) all advocating the use of ecosystem-based approaches in fisheries management, integration of biological and physical aspects of a community into management decisions is now a high priority. This is especially true for the coastal zone (Lindeboom 2002) and even more so for the inner continental shelf, which serves as an important migration corridor, feeding, and spawning area for many economically and ecologically important fish species (NRDC 2001).

Within inner continental shelf ecosystems some distinct habitats, including shoreface sand ridges, form dominant components of the seascape. These topographic features consist of unconsolidated fine-to-medium grained sand, have relief up to 10 meters, and are generally oriented obliquely to the adjacent shoreline (Stahl et al. 1974, McBride and Moslow 1991). It appears that ebb-tidal deltas at inlets provided the initial sand source for many of these features, with shelf processes (waves, currents, and other hydraulic features), especially those associated with storm events, reworking the initial deposits (Swift et al. 1978, McBride and Moslow 1991). Over 200 shoreface sand ridges have been identified from Montauk Point, New York to Miami Beach, Florida, with over seventy-one found between Manasquan and Cape May, New Jersey (McBride and Moslow 1991).

These features may be important commercial and recreational fishing areas (Freeman and Walford 1974, Venturo 1995) potentially because they are important as fish habitat, but there is little evidence to refute or accept that possibility. A number of studies have documented the presence of adults, settled juveniles, and larvae on and in the immediate vicinity of sand ridges, indicating that these features are used by most life history stages of fishes (Able and Hagan 1995, Able et al.1995, Duval and Able 1998, McBride et al. 2002, Neuman and Able 2003, Able et al. 2006). While they may provide habitat for important fish species, sand ridges have also gained attention as potential locations from which to extract sand and gravel for ongoing beach nourishment projects and construction materials from Massachusetts to North Carolina (Michel 2004, Hayes and Nairn 2004, Drucker et al. 2004), including off New Jersey (Byrnes et al. 2000, 2004).

Some recent studies began the process of evaluating the effects of mining at sand ridges on physical oceanographic processes (Maa et al. 2004, Kelley et al. 2004, Nairn et al. 2004) while others provided limited evaluation of the biological response to sand mining with a focus on benthic invertebrates and their role in providing trophic support to fishes (Nairn et al. 2004, Diaz et al. 2004). Though Viscido et al. (1997) examined seasonal and spatial patterns for decapod crustaceans on and near sand ridges in New Jersey and Diaz et al.(2003) did the same for juvenile fish in Delaware and Maryland, there are no evaluations of co-varying spatial patterns in the fish community, or their causal relationships with ridges.

If sand ridges are unique components of inner continental shelf ecosystems then some fishes associated with sand ridges could be excellent indicators of the effects of sand and gravel mining or other habitat alterations, such as surf clam dredging. If sand ridges provide ecological "hot spots" or essential fish habitat for economically important species then they may not be the logical choices for sand and gravel mining.

The purpose of this study was to determine how fish use varies between sand ridges and the surrounding inner continental shelf through analysis of abundance and species assemblage patterns (Chapter 2). In addition, the food habits of some of the dominant demersal species were analyzed to gain insight into the possible causes underlying any patterns observed in the abundance and assemblage analysis (Chapter 3). Collectively this information provided a first measure of the importance of sand ridges from a species diversity context as well as for individual species.

CHAPTER II

Patterns in fish abundance and assemblages across sand ridges on the inner continental shelf

Introduction

In the 1970's the fish community of one sand ridge site in southern New Jersey was extensively sampled during the preparation of an environmental impact statement as part of the permitting process for a proposed nuclear generating station (Milstein et al. 1977). Over 90 species, represented by juveniles or adults, were identified on and in the immediate vicinity of the ridge (Milstein et al. 1977, Able and Hagan 1995). The most abundant species were those found throughout the New York Bight, including both year round residents and seasonal migrants. The presence of such a diverse array of both adults and juveniles suggests that fishes may spawn in the vicinity of sand ridges and that ridges have potential value as a site for recently settled nearshore fishes (Able and Hagan 1995, Able and Fahay 1998, Able et al. 2006). Additional studies on and in the vicinity of the same ridge found a number of species that occurred as both pelagic larvae and settled juveniles (Able et al.1995, Duval and Able 1998, McBride et al. 2002, Neuman and Able 2003, Able et al. 2006). Further, this sampling revealed that larval and juvenile fish are most abundant in the vicinity of the ridge during the late summer and early fall.

With increasing pressure to find new sources of sand and gravel for material to be used in ongoing beach nourishment projects and construction (for New Jersey see Byrnes et al. 2000, 2004), the role of sand ridges in supporting any number of economically and ecologically important species needs to be elucidated.

The results of collection efforts from Beach Haven Ridge have previously been reported for individual fish species (e.g. McBride and Able 1994, Able et al.1995, Able and Fahay 1998, McBride et al 1998, Duval and Able 1998, Campbell and Able 1998, Neuman and Able 1998, McBride et al 2002, Neuman and Able 2003) invertebrates (Hales et al. 1995), and multispecies comparisons (e.g. Hales and Able 2001, Martino and Able 2003, Able 2005, Able et al. 2006) but did not include finer spatial scale analysis of the differences between the top of a sand ridge, the flanks of a sand ridge, and the surrounding inner shelf area.

To determine if sand ridges serve as important habitat for any fish species four specific objectives were proposed 1) to ascertain if there is a difference in fish abundance and species richness between the sand ridge and adjacent areas; 2) to determine if there is a pattern in species assemblages across the same locations; 3) to describe any relationships between the species assemblages and environmental factors; and 4) to establish if the findings on one sand ridge system are valid at other ridges in the area.

Taken together this information can provide resource managers a better understanding of the potential impacts to fish species associated with the alteration of sand ridges. In addition, the species assemblage patterns may provide added insight into multispecies interactions in inner continental shelf communities.

Methodology

Study Area

The study area encompasses the inner continental shelf waters between Barnegat Inlet and Brigantine Inlet off southern New Jersey (Fig 2.1). Sampling was conducted along 6.5-km transects across individual shoreface sand ridges off Brigantine Inlet (BRG) and Ship Bottom (SB), Long Beach Island and along a 23-km transect across a shoreface sand ridge (BHR) off Little Egg Inlet. These ridges are typical of the numerous sand ridges found along the east coast of the United States (McBride and Moslow 1991). Beach Haven Ridge extends northeastward from the ebb tidal delta of Little Egg Inlet and is approximately 1 km wide along its central and southern portions, broadening to 1.5 km at the northeastern end (Stahl et al. 1974, Twichell and Able 1993). It has a maximum relief of 8 m between the ridge crest and the trough on the seaward side while the relief on the shoreward side is 4 – 5 m. The substrate on the top of the ridge is composed primarily of coarse sand (Twichell and Able 1993, Craghan 1995). The seaward side of the ridge has two major substrate types, including coarse sand with shells of the surf clam, *Spisula solidissima*, and areas with a mixture of semi-lithified clay and sand. The landward side is characterized as having two major substrate types including both areas of mud and patches of semi-lithified clay/sand mixture (see Twichell and Able 1993, Craghan 1995, Viscido et al. 1997, Able et al. 2003). Bedforms (ripples) are consistently largest on the crest and flanks of the ridge (Able et al. 2003). The crests were often bare but the troughs were filled with varying amounts of shell valves and shell hash, which can be frequently buried and uncovered (Taghon, pers. comm.). While patches/mats of

Diopatra cuprea tubes were found along the flanks and base of the ridge they were never identified on the crest of the ridge.

Brigantine Ridge and Ship Bottom Ridge have similar dimensions and orientation as Beach Haven Ridge but differ in several characteristics (Figs. 2.1 and 2.2). Brigantine Ridge is 5.5 km from shore, while Ship Bottom Ridge is much closer, at 1.6 km from shore. The mouth of Brigantine Inlet is smaller than that of Little Egg Inlet, while Ship Bottom Ridge is not currently associated with an active inlet. Lastly, while the depths at the sampling stations were chosen to be relatively consistent, the relief along transects varies (Fig. 2.2). The "Off-ridge" transect stations have depths consistent with the stations found on either side of the ridge tops but were selected in an area where no ridges are present for comparison with transects over ridges.

Field Sampling

Data from three independent sampling surveys utilizing either 2-m beam trawls or 4.9-m otter trawls conducted from 1991-2006 were analyzed (Table 2.1). While none of the data sets were collected concurrently they do overlap both temporally, in the months in which sampling was conducted, and spatially, over four of the Beach Haven Ridge sampling stations. This overlap between gear types provides the opportunity to observe temporal and spatial variation both within and between gears.

Beam Trawl Sampling

Sampling for recently settled fishes was conducted at eight stations along a transect from Little Egg Inlet across Beach Haven Ridge during July and September from

1991 through 1995 with a 2 meter (3-mm bar mesh) beam trawl (Table 2.1, Figure 2.1). The number of tows conducted at each station varied (BHR-2 n=4, BHR-3 n=8, BHR-4 n=8, BHR-5 n=10, BHR-6 n=22, BHRTOP n=16, BHR-7 n=27, BHR-9 n=2). Tow speed was approximately 1.5 – 2.0 knots, and each tow was one minute in duration in an attempt to sample from discrete habitat types. Tow times, depths, coordinates, and direction of travel were recorded. All fish captured were identified and measured (see Hales et al. [1995] and Neuman [1999] for sorting and preservation procedures). Surface and bottom water samples were obtained using a Nansen bottle. Temperature and salinity were obtained from these samples using a stem thermometer and hand-held refractometer while oxygen concentrations were determined using Winkler titration for samples collected from 1991-1995.

Otter Trawl Sampling

As part of a large, long term sampling program eight stations on and in the vicinity of Beach Haven Ridge were sampled twice a year (July and September, weather permitting) from 1997 to 2006 (Table 2.1, Figure 2.1). Samples were collected with an otter trawl (4.9-m head rope, 19-mm mesh wings, 6-mm mesh cod end) with four replicate tows at the inlet station (BHR-1) using various small boats (4-7 meters) and three replicate tows at each of the other stations using *R/V Arabella* (15 meters), conditions permitting. Sampling at BHR-10 and BHR-11 did not commence until September 2001. Starting coordinates for each tow were recorded along with tow direction. Tow speed varied depending upon the prevailing ocean conditions, but tow times never exceeded two minutes in an attempt to ensure that fish were collected from discrete habitats. For each tow a random selection of up to 20 individuals of each species were measured to fork length (FL) or total length (TL) for species without caudal fins, and the remainder were counted. Beginning in 2001, bottom and surface (upper 1 meter) salinity, temperature, dissolved oxygen, and pH were measured and recorded during the first replicate tow with a YSI model 85. Depth and bottom topography were determined with a Furuno Model 256. Water transparency was measured with a Secchi disk at each station.

In order to make comparisons among sand ridges, sixteen stations were sampled across two additional ridges and one "off-ridge" transect during July and September 2006 (Table 2.1, Figure 2.1). Of these, six stations were on a transect across Brigantine Ridge, six across Ship Bottom Ridge, and four on an east-west transect between Beach Haven Ridge and Ship Bottom Ridge, an area without a sand ridge. The "off-ridge" transect was sampled only in September. Additional sampling across Beach Haven Ridge was also conducted as part of the multiple ridge comparison such that it was sampled on the first and last day of sampling (2006 only). All methodology was identical to the long term sampling protocol.

For both the otter and beam trawl data sets (Fig. 2.1), sampling locations located in Little Egg Inlet (BHR-1 to BHR-4) are hereafter referred to as “inshore”, those found adjacent to and on the flanks of the three ridges (BHR-5 to BHR-7, BRG-5 to BRG-7, SB-5 to SB-7) “near ridge”, and those located seaward of the three ridges (BHR-8 to BHR-11, BRG-8 and BRG-9, SB-8 and SB-9) are “offshore” unless otherwise noted. The sampling stations located on top of the ridges are designated as BHRTOP, BRGTOP, and SBTOP (Fig. 2.1).

Habitat Characteristics

To assess the importance of habitat complexity to fish assemblage structure a qualitative substrate characterization was conducted. Because Beach Haven Ridge and vicinity has been intensively studied in the past it was possible to identify habitat characteristics for the stations along that transect from previous works utilizing SCUBA/submersible/remotely operated vehicle (Able et al. 2003), sidescan sonar (Twichell and Able, 1993) or structural components of the habitat captured during sampling (Hales et al. 1995, Martino and Able 2003, Neuman 1999). Additionally, any benthic material (clay/mud clods, starfish, sand dollars, algae, shell hash, *Diopatra* tubes) retained by the 2006 otter trawl sampling was categorized and quantified to evaluate if any changes in substrate had occurred over time at Beach Haven Ridge and between ridges. Stations were assigned a n index of complexity of 1, 2, or 3 based upon the amount and type of macroalgae or other structural components, with three being the most complex and one being the least complex. Stations with bare sand substrates were given a value of 1; stations with a combination of three or more habitat modifiers (large amounts algae, the presence of polychaete (*Diopatra cuprea)* tubes or *Asabellides occulata* mounds, two different substrate types, shell hash) were assigned a value of 3; and stations with less than three types of habitat modifiers were assigned a value of 2 (Table 2.2).

Data Analyses

A number of univariate and multivariate techniques were utilized to calculate population measures and assemblage structure. For each technique the calculations were repeated under two conditions. The first iteration included all species while the second iteration removed pelagic fish from consideration (*Anchoa hepsetus*, *Anchoa mitchilli*, *Engraulis eurystole*, *Menidia menidia*, and *Peprilus triacanthus*). This was done for two reasons; first, these species are not likely efficiently captured by the sampling gear due to their pelagic nature, and second, when encountered they are in schools and their abundance is orders of magnitude greater than other species. Even with log transformation these species tend to overwhelm any underlying signal.

Mean species richness per unit effort (RPUE), or the number of different species caught in a tow, was calculated for each sampling station. To assess the differences in mean species richness (RPUE) between stations, the data were subjected to an ANOVA and Tukey multiple comparison test. Frequency of occurrence was calculated for each species across tows at each sampling station, as well as each transect. Catch per unit effort (CPUE), or the number of fish captured per tow, was also determined for each species at each station, as well as each transect. ANOVA procedures were used to test for significant differences in patterns of abundance. CPUE data were log transformed prior to analysis to remove heterogeneity of variance (Underwood 1997). All univariate statistics were performed using SAS System v9.1.

To determine the structure of the assemblages in the different habitats various ordination techniques were used. Ordination simplifies large and complex datasets by organizing samples along linear gradients defined by combinations of interrelated variables (McGarigal et al. 2000). Furthermore, ordination techniques can be used as either "exploratory" tools (i.e. how species assemblages differ with different variables) or for hypothesis testing (i.e. statistical tests of how a variable(s) has an effect on species assemblage).

Two related ordination techniques were employed in the exploratory phase of the data analysis. Unconstrained, or indirect gradient analysis, orders species by abundance along latent gradients, and thus explains the maximum variation. Constrained, or direct gradient analysis, orders species by abundance along only a subset of gradients, these being the measured environmental variables. Thus it is the preferred method for relating how the environmental variables shape the community assemblage (Jongman et al. 1995, McGarigal et al. 2000).

Canonical Correspondence Analysis (CCA) is a constrained ordination technique in which the sample scores are constrained to be linear combinations of the explanatory variables (Van den Brink and Ter Braak 1999). This technique is becoming one of the most widely used gradient analysis tools in ecology due to its ability to handle highly skewed species distributions, high noise levels, complex sampling designs, and the fact that it does not create an artificial arch effect (Palmer 1993). The CCA was performed on a subset of the overall data matrix for which environmental information was available for all stations. For the beam trawl data this included the entire dataset while the otter trawl samples were limited to Beach Haven Ridge from 2001 to 2006. The data were arranged in a species-by-sample matrix, where the samples were the combination of all tows for a given location and date and the CPUE represents the value fields. The data were log (CPUE+1) transformed to reduce the influence of abundant species. Any species whose abundance did not exceed five percent at at least one station was removed from the matrix. In the second iteration of the otter trawl data the pelagic species were included as supplementary species for graphical purposes.

Because the constrained ordination orders species only along gradients of the measured environmental variables it may not be representative of the assemblages encountered depending on the environmental variables available. Therefore the constrained gradient analysis was checked for bias using Correspondence Analysis (CA), an unconstrained ordination method. This technique is a dual ordination procedure in which samples and species are ordinated simultaneously on orthogonal axes (Gauch 1982, McGarigal et al. 2000). The species-by-sample matrices were treated in the same manner as in the CCA.

To assess how well the combinations of species assemblages describe the habitats (hypothesis testing) a third ordination technique known as Canonical Variates Analysis (CVA) was used. In this procedure the 1997-2006 otter trawl samples for Beach Haven Ridge were used, with each tow representing an individual sample. The same species utilized in the CA and CCA were included in this analysis, with the number of each species in each sample completing the matrix. Samples that did not contain any fish were removed from the first step of the analysis. A random sub-sample of 70% of the tows at each station was used as a "training", or reference set. The analysis was then run and forward selection was used to create a reduced set of variables by retaining those that were significant for discrimination at alpha= 0.05 in a Monte Carlo permutation test (499 iterations). The remaining 30% of the combined data set and the other ridge transects conducted during 2006 (the "test set") were then projected onto the training set analysis with the reduced set of variables. The assemblage identity assigned by the CVA was then compared to the actual station identification for each of the test samples. This provided an assessment of how well the species assemblages found on Beach Haven Ridge described the assemblages of other sand ridges in the area.

Results

Environmental Gradients

For all cross-ridge transects temperature tended to decrease with increasing distance from the shoreline while depth, salinity, and water transparency generally increased with increasing distance (Figs. 2.2, 2.3, 2.4, 2.6). Habitat complexity was lowest inshore, peaked near the ridge, and was of intermediate value offshore (Table 2.2). The location of the sampling stations along the transects were at similar depths across the three sand ridges, but the bathymetric relief varied between transects (Table 2.2, Fig. 2.2). With the exception of the stations located on the tops of the ridges (BHRTOP, BRGTOP, SBTOP), average station depth increased with distance from the shoreline (range: 2.8-19.9 m) (Table 2.2, Fig. 2.2). Within the Beach Haven Ridge transect there was a change in depth from BHR-4 to BHR-5 of 4.7 m, indicating the transition from the Little Egg Inlet to nearshore coastal waters. Relief varied between the three transects, with water depths changing rapidly on either side of Ship Bottom Ridge, while the Beach Haven Ridge slopes were much more gradual (Fig 2.2).

Temperature samples collected by beam trawl in 1991-1995 decreased with increasing distance from shoreline while salinity generally increased with distance offshore (Fig 2.3). Temperature generally decreased with increasing distance from the shoreline, ranging from a high of 26 °C to a low of 14 °C, with overall mean values between 23 °C at BHR-2 and 18 °C at BHR-7. Salinity ranged from 32 to 29, with overall mean values between 30 (one mid-summer reading at BHR-9) and 30.8. Salinity was generally lower at the stations in and near Little Egg Inlet in both seasons. The exception to this pattern were the late summer measurements at BHRTOP and BHR-9. However, these consisted of one measurement at each station and therefore may not be representative.

For the environmental data collected concurrently with otter trawl surveys from July and September 2001-2006, mean bottom temperature decreased with increasing distance from the shoreline, while mean salinity and mean secchi depth increased (Fig 2.4). Bottom temperature ranged from 28.1 °C to 8.7 °C, with overall mean values decreasing from the shallowest station (21.3 °C at BHR-1) to the deepest station (13.4 °C at BHR-11). Based on data collected by the LEO-15 node located on Beach Haven Ridge, during the mid-summer sampling period temperature in 2002-2004 and 2006 were below the ten-year average, while in 2001 it was above average and in 2005 it approximated the seasonal average (Fig. 2.5). In late summer the inverse was true, with values from 2002, 2004, and 2005 above the average and 2001, 2003, and 2006 below the seasonal average. Salinity across the transect increased with increasing distance from shore, varying from 32.9 to 27.1, with mean values between 29.4 and 31.1. Salinity at all stations decreased markedly in 2004-2005 compared to 2001-2003, partially explaining why the salinity at BHRTOP (2005 and 2006) was slightly lower than the adjacent stations. The pH ranged from 8.2 to 6.9, with mean values between 7.9 and 7.6. Dissolved oxygen varied from 3.9 mg l^{-1} ^{to} 9.9 mg l^{-1}, with means between 6.3 mg l^{-1}

(BHR-9) and 7.4 mg l^{-1} (BHRTOP). As with salinity, the mean dissolved oxygen at BHRTOP was higher than expected due to increased levels in 2005 and 2006 compared to earlier years. Mid-summer readings were generally higher than late summer readings across all stations. Secchi disk readings increased with distance from the shoreline, ranging from 0.7 meters to 20 meters, with means from 1.5 at BHR-1 to 8.9 at BHR-11. For most stations the late summer water transparency was greater than at mid-summer.

While temperature was similar at all transects across the three sand ridges during 2006, the remaining environmental characteristics varied between transects. The 2006 bottom temperature decreased slightly relative to increasing distance from shoreline along all four transects while bottom salinity and water transparency generally increased (Fig. 2.6). Bottom temperature varied from 10.9 °C to 21.2 °C, with mean values between 14.2 °C and 21.2 °C. Bottom salinity increased with distance from shore for all transects, varying from 30.5 to 31.8, with mean values between 30.9 and 31.6. Between-station variability was greatest at the Brigantine Ridge transect, slightly less so at the Beach Haven Ridge transect, and very low at the Ship Bottom and Off-ridge transects. This may be partially explained by the fact that the Beach Haven Ridge and Brigantine Ridge transects are adjacent to inlet mouths which provide for input of lower salinity estuarine waters while the Ship Bottom and Off-ridge transects are not. The pH ranged from 8.1 to 7.7, with mean values between 8.1 and 7.9. The trend in pH varied between transects, but late summer values tended to be greater than mid-summer values for most stations. Dissolved oxygen varied from a high of 9.9 mg l^{-1} to a low of 5.3 mg l^{-1}, with means between 5.3 mg l^{-1} and 8.5 mg l^{-1}. Dissolved oxygen was generally highest in late summer across all transects. Water clarity increased with distance from the shoreline, ranging from 1.0 meters to 6.5 meters, with means from 1.7 to 6.5 meters.

Habitat complexity was lowest inshore, peaked near the ridge (but was low on top of the ridge), and was of intermediate value offshore (Table 2.2). Station BHR-5, with a mix of sand, macroalgae, *Diopatra* tubes and mud was the only one to receive an index of 3. BHRTOP and the inlet stations, all consisting of bare sand substrates, were assigned a 1, with the remaining Beach Haven Ridge stations given a 2. While a number of previous studies incorporating a variety of techniques were used to determine habitat homogeneity, the similarity in descriptions when the same station was included in multiple sources provided confidence in the accuracy of the descriptions as well as the stability of the habitat over time.

Species abundance and diversity

The specific patterns in species abundance and richness varied with sampling gear, habitat, and individual ridges. However, the near-ridge locations typically had the largest number of species and individuals and the inshore, top of ridge, and offshore locations had the least (Figs. 2.7a, 2.8). While abundance and richness values were lower when pelagic species were removed from consideration the patterns showed no significant changes (Figs. 2.7b, 2.9).

In the course of 97 beam trawl tows during 1991-1995, 2,049 individual fish belonging to 34 species represented by demersal and pelagic species were collected (Table 2.3). Fish abundance (CPUE) was lowest inshore, increased slightly towards BHR-5, increased significantly (df=94, alpha=0.05, $p<0.0001$) at the stations on either side of the ridge (BHR-6<BHR-7), and was highest at the offshore station (BHR-9) (Fig. 2.7a). The station on the top of the ridge (BHRTOP) had significantly lower abundances than the stations on either side of the ridge and offshore (df=89, alpha=0.05, p<0.0001) but higher than at the inshore stations.

A total of 389 otter trawl tows from 1997-2006 captured 39,402 individual fish from 52 species (Table 2.3). Fish abundance (CPUE) was highest near-ridge (BHR-5> BHR-7>BHR-6) and significantly lower (df=381, alpha=0.05, p<0.0001) at all other stations (Fig. 2.7a). CPUE at the top of the ridge was not significantly different from the inshore station nor the offshore stations.

In 2006, 36 species totaling 7,023 individual fish were collected across all ridge and non-ridge stations (Beach Haven Ridge 22 species, 3753 individuals, Brigantine Ridge 16 species, 232 individuals, Ship Bottom Ridge 18 species, 2340 individuals, Off-ridge 10 species, 698 individuals) during the course of 156 otter trawl tows (Tables 2.3 and 2.4). CPUE was highest along the Ship Bottom transect and slightly, but not significantly, lower at the Off-ridge and Beach Haven Ridge transects (Fig. 2.7a). CPUE along the Brigantine Ridge transect was significantly lower (df=152, alpha=0.05, p<0.0064) than the Ship Bottom and Beach Haven Ridge transects but not the Off-ridge transect. Given that abundances during mid-summer were lower than late summer the Off-ridge values are most likely overestimates as that station was only sampled in late summer.

Patterns in abundance (CPUE) along the transects varied between the three ridges sampled in 2006 (Fig. 2.7a). Abundance at the stations within the 2006 Beach Haven Ridge transect followed a pattern similar to that of the 1997-2006 data set. Abundance was highest at the near-ridge stations and decreased offshore. Similarly to the 1997-2006 data there was a significant difference (df=65, alpha=0.05, p<0.0001) in CPUE at BHRTOP compared to the near-ridge stations. The pattern at Ship Bottom was similar to that of Beach Haven Ridge with the exception of the first offshore location (SB-8), where CPUE was comparable to that of the near-ridge stations before decreasing significantly (df= 30, alpha=0.05, p=0.0036) farther offshore. The station on the top of the ridge had an intermediate CPUE that was not significantly different from the stations on either side of the ridge. Fish abundance along the Brigantine Ridge transect decreased with increasing distance from shore with the exception of the station on top of the ridge, BRGTOP, which had the lowest abundance in the transect.

The removal of non-demersal species from the analysis of all the datasets caused an overall reduction in the CPUE for all transects except the beam trawl (due to the limited number of pelagic species collected), but had mixed effects in the patterns of abundance across each transect (Fig 2.7b). Removal of non-demersal species from the 1997-2006 otter trawl samples resulted in a non-significant difference in abundance between BHR-9 and BHR-7. In 2006 when mean CPUE for all transects were analyzed, the Beach Haven Ridge transect was highest, with CPUE at the Ship Bottom and Off-ridge transects slightly, but not significantly, lower. CPUE along the Brigantine Ridge transect was significantly lower (df=152, alpha=0.05, p<0.0017) than the Beach Haven Ridge transects but not the Ship Bottom and Off-ridge transects. The pattern of abundance within the 2006 Beach Haven Ridge transect was shifted in that the highest abundances were found on the landward side of the ridge (BHR-5 and BHR-6) such that there was no longer a significant difference in CPUE between the top of the ridge and the seaward flank of the ridge (df=65, alpha=0.05, p<0.0001). There was no difference in abundance between any of the stations across the 2006 Ship Bottom transect. Within the Brigantine Ridge transect CPUE remained relatively constant, with no significant differences between locations.

Both species richness and number of species observed was highest at the near-ridge stations and decreased offshore across all gears and transects for all species (Fig. 2.8). The 1991-1995 beam trawl mean species richness per tow (RPUE) was significantly higher (df=89, alpha=0.05, p<0.0001) at the sides of the ridge and offshore then at the other beam trawl stations. The 1997-2006 otter trawl RPUE was significantly higher (df=312, alpha=0.05, p<0.0001) at the near-ridge stations than at the remaining locations. RPUE at the 2006 Beach Haven Ridge transect was significantly higher (df=65, alpha=0.05, p<0.0001) at the near-ridge sites compared to the remaining stations. Within both the Brigantine and Ship Bottom transects RPUE decreased with distance from shoreline, with the landward most location significantly higher (df=30, alpha=0.05, p<0.0048 and p<0.0010 respectively) than the top of the ridge and seaward most station.

When non-demersal species were removed, RPUE decreased at nearly every location across the transects by varying amounts, with subsequent reductions in the difference between the species rich and species poor stations (Fig 2.9a). This implies that the stations with low RPUE values did not contain as many non-demersal species as the stations with larger RPUE values.

Assemblage Structure Based on Beam Trawl Samples

Canonical Correspondence Analysis revealed two distinct, discrete assemblages within the beam trawl dataset: the inshore and top of ridge locations (BHR-2, BHR-3, BHR-4, BHR-5, BHRTOP) and the near-ridge/offshore stations (BHR-6, BHR-7, BHR-9) (Fig 2.10a.). The two groups separate along both axes (Table 2.6). The near-ridge/offshore stations shared a number of dominant species, while the assemblage of inshore stations varied along both axes, with species composition at each location not only different from the near-ridge/ offshore stations but also from each other (Fig. 2.12a). Of the five most abundant species in each assemblage only *Etropus microstomus* and *Prionotus carolinus* were found in both. Nearly one-third of the species characterizing the inshore/top of ridge group were only collected there. Within the inshore group BHR-3 was characterized by *Ammodytes americanus*, *Dasyatis spp*., and *Gobiosoma spp.* while BHR-5 was differentiated as the only station with *Cynoscion regalis*. The remaining inshore stations were differentiated from other stations, and to some degree each other, by the abundance of *Micropogonias undulatus, Scophthalmus aquosos*, and *Menticirrhus spp*.

When the data set was analyzed by season the pattern of station grouping displayed in the overall beam trawl analysis was not present in mid-summer and was slightly modified in late summer (Fig. 2.11). Within the mid-summer samples there were no similar species assemblages among stations, but there was variability in the species associated with each station between years (Fig. 2.11a). In late summer the top of the ridge shared more species with the near-ridge/offshore group than with the inshore locations (Fig. 2.11b). The relative importance of each species within the assemblages also changed between the overall data set (Fig. 2.12a) and late summer ordination (Fig. 2.12b). *Menticirrhus spp.* and *M. undulatus*, the two most abundant species in the inshore assemblage, appeared in the study area only in late summer, as did *Urophycis chuss*, which was an important component of the near-ridge assemblage. Over 68% of the variance in the species-environment interaction is reflected in both the overall and late summer ordinations (Table 2.6).

The arrangement of the species assemblages in relation to the station assemblages was similar to that of the Correspondence Analysis (CA), providing confidence that constrained ordination gave a satisfactory picture of realized distribution. The main difference between the two results was the ordination of the top of the ridge in the overall analysis; CA placed it in the near-ridge/offshore assemblage while CCA ordered it as part of the inshore assemblage. However, the results were similar at the seasonal level.

Assemblage Structure Based on Otter Trawl Samples

Three station assemblages were apparent in the six year (2001-2006) subset of the otter trawl data during which all of the environmental variables were available for each sampling date and station; inshore, near-ridge, and offshore (Figs. 2.13 and 2.14). In the overall analysis the inshore assemblage was discrete, while the near-ridge and offshore assemblages converged (Fig. 2.13a). The inshore samples grouped together regardless of season, while the near-ridge and offshore samples diverged by season (Fig. 2.13b).

All three assemblages shared a majority of species, with some differences in the abundance of each species (Fig. 2.15a). The inshore assemblage was dominated by *Anchoa mitchilli* and *Syngnathus fuscus*, with *Menidia menidia* only present in this assemblage. *A. mitchilli* was the most abundant species in the near-ridge assemblage, with a mean abundance over an order of magnitude greater than the next most abundant species. Other abundant species in this assemblage included *Peprilus triacanthus*, *Micropogonias undulatus,* and *Cynoscion regalis*. *P. triacanthus* and *A. mitchilli* were the dominant species of the offshore assemblage, with *Prionotus carolinus* and *P. evolans* caught in lesser amounts. *Citharichthys arctifrons* was only found in this assemblage, but infrequently and in low abundance. The percentage of variance of the species-environment interaction reflected in the combination of season and station (64.9%) is comparable to that of the beam trawl (Table 2.7).

Seasonally, the near-ridge and offshore assemblages, based on both pelagic and demersal species, overlapped very little in mid-summer and were discrete in late summer (Fig. 2.14). In mid-summer the near-ridge assemblage was spread along both axes, indicating differences between samples while the offshore assemblage is more compact, suggesting a similarity in samples (Fig. 2.14a). In late summer the situation was reversed (Fig. 2.14b).

This seasonal difference in assemblage resulted from a change in both the number and identity of species present in the study area (Figs. 2.15b and 2.15c). In mid-summer the inshore assemblage was predominately *Syngnathus fuscus* with other species present in negligible numbers (Fig. 2.15b). The near-ridge assemblage in mid-summer was dominated by *Peprilus triacanthus* and *Anchoa mitchilli*, with only the next three most abundant species (*A. hepsetus*, *Urophycis regia*, *Etropus microstomus*) represented by more than a mean of one fish per tow. While *P. triacanthus* was also the dominant species in the offshore assemblage, its abundance there was a third of what was found near-ridge. Additionally no other species in the offshore assemblage had a CPUE greater than one. Of particular interest in the mid-summer analysis is a group of species (*Cynoscion regalis, Pomatomus saltatrix, Sphoeroides maculatus, A. mitchilli, and A. hepsetus*) separated along the primary axis from the rest of the species centroids in the near-ridge assemblage. These species are associated with samples from near-ridge stations taken in 2001 and 2005 (Fig. 2.14a). During late summer the abundance of *A. mitchilli* increased substantially at the inshore assemblage, as did the abundance of *S. fuscus* (Fig. 2.15b). At that time, *A. mitchilli* was the most abundant species in the near-ridge assemblage by nearly two orders of magnitude, with *Micropogonias undulatus*, *C. regalis*, and *Bairdiella chrysoura* all present at CPUEs greater than one. *A. mitchilli* and *P. triacanthus* were the dominant species in the offshore assemblage, and the only species with a mean CPUE greater than 0.5. The preponderance of species found near the ridge compared to offshore was reflected in the ordination by the number of species centroids associated with the near-ridge assemblage. The percentage of variance of the species-environment interaction reflected in the mid-summer (53.6%) and late summer (67.2) ordinations continued to be substantial (Table 2.7).

Removal of pelagic species from the analysis resulted in a loss of differentiation for the mid-summer data set. However, the near-ridge 2001 and 2005 samples and associated species continued to separate from the rest of the samples along the primary axis.

Assemblage-Environment Interactions

A combination of temperature, depth, distance from the top of the ridge, and habitat complexity shaped the beam trawl assemblages and temperature, depth, habitat complexity, dissolved oxygen, and water clarity were the main influences on the otter trawl ordination (Figs 2.10 and 2.13, Tables 2.6 and 2.7). Though all of the variables played a role in shaping the assemblages in the overall beam trawl ordination only temperature and habitat complexity were important in late summer (Table 2.6). While it appeared that depth and distance to the top of the ridge may be covariables, there may also have been a third, unmeasured variable that linked the two. As such the two variables were both included in the analysis as discrete variables.

Temperature, depth, habitat complexity, dissolved oxygen, and water clarity were significant environmental variables in explaining the otter trawl station and species assemblages (Table 2.7). Temperature, depth, and dissolved oxygen continued to play an important role in determining the assemblages in mid-summer, while distance from the ridge and depth were the primary factors in the late summer.

Assemblage Predictive Ability

Although the forward selection of variables in the Canonical Variates Analysis (CVA) on the 1997-2006 otter trawl data set indicated that the abundance of *Syngnathus fuscus*, *Cynoscion regalis*, *Stenotomus chrysops*, *Menidia menidia*, *Urophycis regia*, and *Centropristis striatus* in each sample could be used to differentiate assemblages, there was a high degree of overlap which prevented most samples from being accurately placed (Fig 2.16). When the "unknown" samples from Beach Haven Ridge were projected onto the cenospace, 25% (24 out of 97) of them were located within the correct assemblage envelope while 5% were located outside of the assemblages or in the wrong assemblage (Table 2.8). The remaining 70% were found in the area of overlap. Samples projected into the overlap area may be misidentified and were therefore not considered correct. Of the eight sampling locations along Beach Haven Ridge three did not place any samples correctly and only one had a degree of accuracy of 50% or higher. All of the samples from the Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects projected into the overlap area, preventing any positive identifications of the samples.

Discussion

Species Abundance and Richness

Utilizing all three data sets (1991-1995 Beach Haven Ridge beam trawl, 1997-2006 Beach Haven Ridge otter trawl, 2006 Brigantine Ridge, Ship Bottom Ridge, Off-ridge otter trawl) fifty-nine species were identified within the study area (Tables 2.3 and 2.4). The number of species is likely higher because some taxa may have been polyphyletic (i.e. *Mullus* sp., *Bothus* sp., *Dasyatis* sp., *Sciaenidae, Alosa* sp., *Gobiosoma* sp.). This value is less than that identified by Milstein et al. (1977) probably because they used multiple gear types, including a large (7.6 m semi-balloon) trawl. Given this it appears that the study has captured a representative sample of the fish fauna present in the region.

Overall species abundance (CPUE) and richness (RPUE) displayed a bimodal distribution across the inlet to offshore transects, with the highest values on either side of the ridges regardless of gear type (Figs 2.6 and 2.7). This bimodal pattern has been previously suggested for fish (Martino and Able 2003) and decapod crustaceans (Viscido et al. 1997) at Beach Haven Ridge, but is in contrast to a number of studies of larger scale cross-shelf transects, where abundance linearly decreases with depth (Colvocoresses and Musick 1984, Barber et al. 1997, Colloca et al. 2003, but see Mueter and Norcross 1999).

Previous comparisons between beam and otter trawls of the size used here has shown that otter trawls collect more fish, while the beam trawl caught smaller fish (Able et al. 2002). It would therefore be reasonable to expect to see more recently settled fish and small juveniles in the beam trawl data, as well as flatfish, as the beam trawl tends the bottom better than the otter trawl (Wennhage et al. 1997). This may explain the differences at certain sampling stations in regard to both abundance and richness per unit effort between the two gear types. In the beam trawl both abundance per tow and richness per tow at stations BHRTOP and BHR-9 were of intermediate and high values respectively, while in the otter trawl these stations accounted for the lowest and intermediate values. The environmental variables during the two sampling periods were similar, as were the physical attributes of the sampling sites (depth, habitat complexity). Over 70% of the individuals captured at stations BHRTOP and BHR-9 during the beam trawl were young of the year (YOY) *E. microstomus*, with the majority of those averaging 27 mm and 35 mm TL, respectively. During direct comparisons between beam and otter trawls Able et al. (2002) found that CPUE and frequency of occurrence for this species was greater in beam trawls while mean length was substantially less. As this single species accounts for such a large proportion of the abundance at BHRTOP and BHR-9 when compared to the other stations in the beam trawl it appears that gear selectivity plays a large role in accurately depicting the estimates of their abundance.

The discrepancies in RPUE between gear types at a particular location can be partially explained by limited numbers of tows at those stations. At Station BHR-9 only two tows were collected by the beam trawl. While ten species were collected, five consisted of one individual and two consisted of two individuals. Given this apparent patchiness there is a possibility that additional sampling at this station would yield a RPUE that would more closely reflect the pattern observed in the otter trawl. Even though a limited number of samples were taken with an otter trawl at BHRTOP (n=6), historic opportunistic surveys with the same gear at other locations on the top of Beach Haven Ridge have yielded low numbers of species per tow (K. Able, personal communication). However, the mid-summer sampling in 2006 doubled the number of species caught at this station (but abundance of each new species was five or less). Further, regular observations of a camera mounted on the LEO-15 node on the top of the ridge from April to August 2005 identified three additional species (*Tautoga onitis*, *Tautogolabrus adspersus*, *Centropristis striatus*) that were not captured at this location in the otter trawl (RUMFS, unpublished). It is likely that the total number of species identified at BHRTOP would increase with additional sampling, but unlikely that richness per tow would increase dramatically given the number of empty tows recorded both here and on the other ridges.

Assemblage Structure and Assemblage- Environmental Relationships

The number of assemblages and their constituent members varied by both gear and season, however two general groups were identified in the beam trawl (inshore and near-ridge/offshore) and three in the otter trawl (inshore, near-ridge, and offshore).

These groups were present whether the data set included all fish captured (pelagic and demersal) or was limited to demersal species only. The species assemblages within these groups varied substantially between gears; within the Beach Haven Ridge beam trawl samples 55% of the fish used in the analysis were found in both species assemblages, leaving nearly half of the species captured to be found in only one assemblage or the other. This is in stark contrast to the 2001-2006 Beach Haven Ridge otter trawl data subset, where 82% of the species were found in at least two of the three assemblages and only 18% of the species (*Bairdiella chrysoura*, *Menidia menidia*, *Menticirrhus saxatilis*, and *Citharichthys arctifrons*,) were present in just one assemblage. The percentages change slightly when only demersal species are considered as most of the species removed were found in at least two of the three assemblages. Thus it appears that there is a definite gradient along the transect, represented by changes in species present in the beam trawl and by the relative abundances of shared species in the otter trawl.

While cross-shelf gradients in demersal fish assemblages have been identified along the northeast U.S. (Steves et al. 2000, Sullivan et al. 2000), northwest U.S. (Mueter and Norcross 1999, Toole et al. 1997, Bailey et al. 2003) southwest U.S. (Johnson et al. 2001), and world wide (Gray and Otway 1994) these were all at substantially larger spatial scales. Few studies, of either juveniles or adults, have been conducted at a resolution similar to this study in inner continental shelf waters. Juvenile fish assemblages of the nearshore (<40 km) coast of Georgia exhibit a cross-shelf gradient in winter and spring, with an innermost station group (8 m) separated from the other station groups (12-18 m) (Walsh et al. 2006). Jaureguizar et al. (2006) found that fish assemblages in northern Argentine in the spring could be identified as either inner, central, and middle regions of the Rio de la Plata estuary or inner, central, and middle regions of the coastal shelf.

Analyses of fish assemblages across continental shelves often point to depth as the primary environmental variable correlated with the changes in the fish assemblages (Gabriel 1992, Mahon et al. 1998, Walsh et al. 2006) while studies focused on shorter distances indicate a combination of environmental and physical variables (Mueter and Norcross 1999, Martino and Able 2003, Jaureguizar et al. 2006). The results of this study point to the latter case. Temperature and distance from the top of the ridge were often as important an explanatory factor as depth, with habitat complexity, dissolved oxygen, and water clarity also correlated with the distribution of fish along the transect (Tables 2.6, 2.7, and 2.9, Figs. 2.9, 2.10, 2.12, 2.13). Temperature plays an important role in regulating fish distribution in temperate waters (Colvocoresses and Musick 1984, Gabriel 1992, Able et al. 2006), and this may explain the variation in the species assemblages between seasons in both the beam and otter trawl. Furthermore, the temperature differences along a transect can also shape the species assemblages within a season, as seen in the significance levels for temperature in the different seasons in the CCA (Table 2.7). In mid-summer, when the CCA identified temperature as a statistically important environmental variable there is a large temperature gradient from BHR-1 to BHR-5 and a slightly smaller change from BHR-7 to BHR-9. These gradients are coincident with the three assemblages identified for the otter trawl mid-summer samples in the CCA (Fig. 2.13a). In contrast, the late summer temperatures were fairly constant across the transect, and this is reflected in the non-significant P-value for temperature in the CCA.

While this study examined seasonal and annual temporal scales, episodic events that affect temperature can also have a dramatic effect on species assemblages. The study area is well known as a region of upwelling during the summer months, with five upwelling events each year lasting at least a week being typical (Glenn et al. 2004). These events bring cooler water generally found at the offshore sampling locations onto the near-ridge stations or even into Little Egg Inlet. An example from the data sets is the difference in mean temperature along Beach Haven Ridge between a year when samples were collected during upwelling (2006; Fig. 2.5) and a time series that was sampled during both temperature conditions (2001-2005; Fig. 2.4). When sampling occurred during an upwelling event, similar species were captured at all stations along the transect (excluding BHR-1). However, in years where the bottom temperatures during sampling were above the study average (1997, 1998, 2001, and 2005), the near ridge species assemblage was dominated by *Cynoscion regalis*, a species more commonly associated with late summer (Fig 2.14b). It is interesting to note that Glenn et al. (2004) recorded the upwelling events of 2001 as some of the most intense during their 9-year study, however when this study's samples were collected the water temperatures had returned to the seasonal norm, thus illustrating the rapidity with which upwelling events break down and fish assemblages may change.

The trend toward less well-defined species assemblages when the environmental gradients were less pronounced lends some support to the idea that cross shelf patterns in species distributions are attributable to environmental gradients (Gray and Otway 1994, Steves et al. 2000, Johnson et al. 2001, Jaureguizar et al. 2006, Walsh et al. 2006). However, the importance of habitat complexity in the analyses of both gear types (Tables

2.6, 2.7) points to the selection of specific habitats by species within a large scale environmental gradient (Stoner and Abookire 2002). This has been shown in many lab and field experiments for flatfishes (Neuman and Able 1998, Stoner and Abookire 2002) and other demersal fishes (Sullivan et al. 2000, Diaz et al. 2003). As suggested by Mueter and Norcross (1999), this difference may be due to differences in how juvenile or small fishes utilize benthic habitat compared to larger adult fishes.

The selection of habitat within the study changed with ontogenetic stage; this is particularly true of the sandy substrate found on the tops of the ridges. The beam trawl, which collected smaller, earlier juveniles, had greater richness and catch per unit effort values on the ridge tops than the otter trawl, which captured larger juveniles and adults. The sandy substrate provided important habitat for *Astroscopus guttatus* and *Trachinocephalus myops*, which were only found on the top of Beach Haven Ridge, although admittedly in small numbers. *Ammodytes* spp., an important forage fish, was also found predominantly in the sandy substrates. In a paired video sled and beam trawl survey on sand ridges off the coast of Maryland and Delaware a substantially larger number of *Ammodytes* spp. were captured in the video surveys than in the trawl (Diaz et al. 2003), indicating that they may be more important to the assemblage here than expected from the trawl results.

Time of day also affects the abundance, richness, and identity of species captured in various habitats. A study of shoals offshore of Maryland and Delaware found that when complex habitats were located in proximity to simple habitats, fish abundance was twice as great in the complex habitats during the day, with the pattern reversed at night (Diaz et al. 2003). This pattern is most likely due to behavior associated with foraging and refuge from predators in juvenile and smaller demersal fish. The fact that all of the trawls in this study were conducted during daytime may explain why the stations located on either side of the top of the ridges, which had more complex habitats, had the highest values for abundance and richness.

While dissolved oxygen appears to be a significant factor in arranging species assemblages along the transect, its importance may be confounded by its relationships with temperature and depth. As expected the highest mean dissolved oxygen levels were found at the stations with the coldest mean temperatures, which also were the deepest stations. However, the lowest mean dissolved oxygen value was found at a station in the same assemblage as the highest value, further clouding the accurate assessment of the variable's value. Water clarity also co-varied with distance from the inlet and depth. A number of estuaries are found within the study area, all of which contribute sediment and other particulates to near-shore water. In addition, the Hudson River plume, which carries sediment and nutrients from one of the world's most industrialized estuaries, can flow by the inshore and near-ridge stations (Frazer et al. 2006). As distance offshore from the estuary increased so did water clarity, and this covariability is seen in the near parallel direction of the distance, depth, and secchi vectors in the CCA figures (Figs. 2.12 and 2.13).

There are a number of other possible explanations for the patterns in species abundance and assemblages identified herein that were not explored as part of this study. Investigations into the abundance and distribution of planktonic larvae around Beach Haven Ridge have identified physical processes as important mechanisms in concentrating larvae on either side of the sand ridge (Weissberger and Grassle 2003, Ma et al. 2006). These same processes may be causing the increased abundance of pelagic species seen on the flanks of the sand ridges. The availability of preferred prey items may also be affecting the abundance and distribution of nearshore species. This is further investigated in the next chapter.

Assemblage Predictive Ability

There is no small set of species that is clearly indicative of a particular assemblage (inshore versus near-ridge versus offshore). The inability of CVA to accurately predict the inshore assemblage along the Beach Haven Ridge transect is surprising given that the other ordination techniques clearly separated that assemblage in each of the iterations. That the samples from the other ridge transects were not associated with the known assemblages may be due to a number of factors. The alternate ridge samples contained fewer than half of those species chosen through forward selection, which the analysis then interpreted to indicate that samples were devoid of fish. This could indicate that the full complement of species found on these ridges may not have been sampled due to the low number of samples compared to Beach Haven Ridge. If the species captured in 2006 were not similar to those captured from 1997-2005 the samples would not score well, falsely indicating that there is a difference in species assemblages between the ridges. However, a low score may also be due to a true difference in the species found at the ridges. To tease out this difference additional sampling over a number of years would be required.

While this study found that the top of a sand ridge may not be as species rich or abundant as the sides of the ridge, this may have been due to the time of sampling (day versus night) and the primary gear used (otter trawl versus beam trawl). However, the top of the ridge did share enough species in common with the sides of the ridge to be considered part of the same assemblage, and prior studies on ridges have shown the importance of having a simple habitat adjacent to more complex habitats (Diaz et al. 2003). Further, the species found at the top of the ridge were typical prey items (*Ammodytes* sp., *Anchoa* spp., *Etropus microstomus*) favored by both resident and transient piscivores in the Mid-Atlantic Bight (Chao and Musick 1977, Eggleston and Bochenek 1990, Chase 2002, Walter et al. 2003, Gartland et al. 2006). As near-ridge habitats have higher species abundances and richness compared to the surrounding inner continental shelf and also possess a distinct species assemblage, including both recreationally and commercially important species, sand ridges are important components of the inner continental shelf and may not be the most suitable area for resource extraction activities.

Table 2.1 Sampling effort over the inner continental shelf (Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, Off-ridge) and the adjacent Little Egg Inlet estuary. See Figure 2.1 for locations of samples.

Location	Gear	Stations	Duration and frequency	Number of samples
Little Egg Inlet to Beach Haven Ridge	2 m beam trawl	BHR-2 to BHR-7, BHR-9	July 1991 - Nov 1992 monthly August - October 1993 monthly September & October 1994 June - Nov 1995 and 1996, monthly	97
Little Egg Inlet to Beach Haven Ridge	4.9 m otter trawl	BHR-1, BHR-5 to BHR-7, BHR-9 to BHR-11; BHR-8 (2006 only)	1997-2006 twice a year (July & September)	389
Brigantine Ridge (BRG) Ship Bottom Ridge (SB) Off-ridge (OFF)	4.9 m otter trawl	BRG-5 to BRG-9 SB-5 to SB-9 OFF-1 to OFF-4	2006 twice a year (July & September)	156

Table 2.2 – Physical attributes of individual sampling stations along the Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects. “Distance to ridge top” is the distance from that station to the station located at the top of the ridge for that transect, + = seaward of the ridge top, - = landward of the ridge top. See Figure 2.1 for station locations.

Station	Distance to ridge top (m)	Distance from shore (m)	Water Depth (m)	Habitat Complexity	Habitat Index
BHR-1	-6000	0	2.8	bare sand	1
BHR-2	-4600	300	3.1	bare sand	1
BHR-3	-3700	752	5.1	bare sand	1
BHR-4	-3200	1252	4.7	bare sand	1
BHR-5	-1400	3052	9.4	sand/macroalgae/ Diopatra tubes; mud	3
BHR-6	-500	3952	11.5	clay/sand/Diopatra tubes; mud	2
BHRTOP	0	4452	10.3	bare sand	1
BHR-7	1100	5552	13.6	sand/shell/Diopatra tubes; clay/sand	2
BHR-8	2700	7152	15.8	shell hash	2
BHR-9	5300	9752	16.3	shell hash	2
BHR-10	10000	14452	18.0	shell hash	2
BHR-11	19000	23452	19.9	shell hash	2
BRG-5	-1340	4133	11.5	N/A	N/A
BRG-6	-600	4873	13.1	N/A	N/A
BRGTOP	0	5473	8.4	N/A	N/A
BRG-7	1100	6573	15.2	N/A	N/A
BRG-8	3000	8473	16.3	N/A	N/A
BRG-9	5200	10673	17.6	N/A	N/A
SB-5	-1200	414	9.5	N/A	N/A
SB-6	-375	1239	13.3	N/A	N/A
SBTOP	0	1614	8.9	N/A	N/A
SB-7	800	2414	14.1	N/A	N/A
SB-8	3200	4814	16.7	N/A	N/A
SB-9	5300	6914	17.6	N/A	N/A
OFF 1	n/a	1067	7.6	N/A	N/A
OFF 2	n/a	2203	10.6	N/A	N/A
OFF 3	n/a	3565	16.1	N/A	N/A
OFF 4	n/a	5335	18.2	N/A	N/A

Table 2.3 – Fish taxa collected by beam trawl (1991-1995) and otter trawl (1997-2006, 2006) along the Beach Haven Ridge transect (see Fig 2.1). Species with a catch per unit effort (CPUE) of at least 5% at any given station were used in the Correspondence Analysis and Canonical Correspondence Analysis and are denoted with an * for the 1991-1995 beam trawl and # for the 1997-2006 otter trawl. Species utilized in the Canonical Variates Analysis (otter trawl only) are denoted with a $.

	1991-1995 Beam Trawl				1997-2006 Otter Trawl				2006 Otter Trawl			
Species	Total Number	Frequency	CPUE	SE	Total Number	Frequency	CPUE	SE	Total Number	Frequency	CPUE	SE
Alosa aestivalis	1	1.03	0.01	0.01	-	-	-	-	-	-	-	-
Ammodytes americanus *	1	1.03	0.01	0.01	2	0.31	0.01	0.01	3	2.78	0.04	0.03
Ammodytes sp. *	2	2.06	0.02	0.01	-	-	-	-	-	-	-	-
Anchoa hepsetus #$	-	-	-	-	304	9.69	0.78	0.25	20	5.56	0.28	0.22
Anchoa mitchilli #$	22	4.12	0.23	0.14	30964	43.44	79.6	23.51	1471	26.39	20.43	10.48
Anchoa sp.	26	5.15	0.27	0.16	15	1.56	0.04	0.02	-	-	-	-
Astroscopus guttatus *	1	1.03	0.01	0.01	-	-	-	-	-	-	-	-
Bairdiella chrysoura #$	1	1.03	0.01	0.01	75	4.06	0.19	0.11	70	11.11	0.97	0.57
Bothus sp. *	1	1.03	0.01	0.01	-	-	-	-	-	-	-	-
Caranx crysos	-	-	-	-	2	0.63	0.01	<.01	2	2.78	0.03	0.02
Centropristis striatus #*$	193	25.77	1.99	0.72	25	5.63	0.07	0.02	-	-	-	-
Chilomycterus schoepfi	-	-	-	-	2	0.63	0.01	<.01	1	1.39	0.01	0.01
Citharichthys arctifrons #	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Clupea harengus	-	-	-	-	2	0.63	0.01	<.01	-	-	-	-
Cynoscion regalis #*$	4	2.06	0.04	0.03	718	29.06	1.85	0.24	128	23.61	1.78	0.47
Dasyatis sp. *	1	1.03	0.01	0.01	-	-	-	-	-	-	-	-
Engraulis eurystole $	-	-	-	-	18	1.88	0.05	0.02	13	5.56	0.18	0.11

Table 2.3 continued

Species	1991-1995 Beam Trawl Total Number	Frequency	CPUE	SE	1997-2006 Otter Trawl Total Number	Frequency	CPUE	SE	2006 Otter Trawl Total Number	Frequency	CPUE	SE
Etropus microstomus #*$	923	71.13	9.52	1.71	188	22.5	0.48	0.08	17	11.11	0.24	0.1
Etrumeus teres	-	-	-	-	2	0.31	0.01	0.01	2	0.64	0.03	0.03
Gobiosoma ginsburgi *	235	28.87	2.42	0.8	2	0.63	0.01	<.01	1	1.39	0.01	0.01
Gobiosoma sp. *	7	2.06	0.07	0.06	1	0.31	<.01	<.01	-	-	-	-
Hippocampus erectus #*	6	6.19	0.06	0.02	3	0.94	0.01	<.01	-	-	-	-
Hippoglossina oblonga	2	1.03	0.02	0.02	2	0.63	0.01	<.01	-	-	-	-
Leiostomus xanthurus	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Lophius americanus	-	-	-	-	2	0.63	0.01	<.01	-	-	-	-
Menidia menidia #$	-	-	-	-	1398	3.75	3.59	2.58	-	-	-	-
Menticirrhus saxatilis $	-	-	-	-	30	5.31	0.08	0.03	-	-	-	-
Menticirrhus sp *	51	9.28	0.53	0.25	-	-	-	-	-	-	-	-
Merluccius bilinearis #	-	-	-	-	4	1.25	0.01	0.01	1	1.39	0.01	0.01
Micropogonias undulatus #*$	54	9.28	0.56	0.26	480	17.5	1.23	0.4	330	18.06	4.58	2.09
Mullus auratus	-	-	-	-	2	0.63	0.01	<.01	-	-	-	-
Mullus sp.	-	-	-	-	2	0.31	0.01	0.01	-	-	-	-
Mustelus canis $	-	-	-	-	19	3.13	0.05	0.02	13	6.94	0.18	0.08
Ophidion marginatum *$	23	6.19	0.12	0.06	27	5.63	0.07	0.02	1	1.39	0.01	0.01
Opisthonema oglinum	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Paralichthys dentatus *$	11	8.25	0.11	0.05	20	6.25	0.05	0.01	1	1.39	0.01	0.01

Table 2.3 continued

Species	1991-1995 Beam Trawl Total Number	Frequency	CPUE	SE	1997-2006 Otter Trawl Total Number	Frequency	CPUE	SE	2006 Otter Trawl Total Number	Frequency	CPUE	SE
Paralichthys oblongus #	-	-	-	-	4	0.94	0.01	0.01	3	2.78	0.04	0.03
Peprilus triacanthus #*$	5	5.15	0.05	0.02	3700	42.19	9.51	2.98	1580	55.56	21.94	13.31
Pomatomus saltatrix #$	-	-	-	-	32	5.94	0.08	0.02	1	1.39	0.01	0.01
Prionotus carolinus #*$	243	47.42	2.51	0.47	535	29.69	1.38	0.49	14	9.72	0.19	0.08
Prionotus evolans #*$	30	12.37	0.31	0.12	82	10.63	0.21	0.05	1	1.39	0.01	0.01
Prionotus sp.	-	-	-	-	6	0.31	0.02	0.02	-	-	-	-
Pseudopleuronectes americanus	-	-	-	-	4	0.94	0.01	0.01	-	-	-	-
Pseudupeneus maculatus	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Raja eglanteria #*$	7	7.22	0.07	0.03	39	9.06	0.1	0.02	9	6.94	0.13	0.07
Raja erinacea #*$	17	10.31	0.18	0.06	65	13.75	0.17	0.03	12	8.33	0.17	0.08
Rhinoptera bonasus	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Sciaenidae sp	-	-	-	-	5	0.94	0.01	0.01	-	-	-	-
Scophthalmus aquosos #*$	35	24.74	0.36	0.08	73	16.56	0.19	0.03	9	11.11	0.13	0.04
Selene setapinnis	-	-	-	-	15	1.56	0.04	0.02	15	6.94	0.21	0.1
Selene vomer	-	-	-	-	4	0.94	0.01	0.01	-	-	-	-
Seriola zonata	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Sphoeroides maculatus #*$	22	16.49	0.23	0.06	90	11.88	0.23	0.06	-	-	-	-
Stenotomus chrysops #*$	3	1.03	0.03	0.03	123	15.94	0.32	0.06	13	9.72	0.18	0.07
Syngnathus fuscus #*$	38	27.84	0.39	0.08	97	11.56	0.25	0.07	5	4.17	0.07	0.04

Table 2.3 continued

Species	1991-1995 Beam Trawl				1997-2006 Otter Trawl				2006 Otter Trawl			
	Total Number	Frequency	CPUE	SE	Total Number	Frequency	CPUE	SE	Total Number	Frequency	CPUE	SE
Synodus foetens	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Tautoga onitis	-	-	-	-	2	0.63	0.01	<.01	-	-	-	-
Tautogolabrus adspersus *	4	3.09	0.04	0.03	-	-	-	-	-	-	-	-
Trachinocephalus myops *	1	1.03	0.01	0.01	-	-	-	-	-	-	-	-
Trachurus lathami	-	-	-	-	1	0.31	<.01	<.01	-	-	-	-
Trichiurus lepturus$	-	-	-	-	6	1.25	0.02	0.01	-	-	-	-
Urophycis chuss #*$	56	17.53	0.58	0.19	6	1.25	0.02	0.01	1	1.39	0.01	0.01
Urophycis regia #*	33	23.71	0.34	0.07	193	19.38	0.5	0.1	15	8.33	0.21	0.1
Urophycis tenuis	-	-	-	-	2	0.31	0.01	0.01	-	-	-	-
Urophycis sp.	1	1.03	0.01	0.01	-	0.31	<.01	<.01	-	-	-	-
Totals	2,049		24.02	2.68	39,402		101.34	23.83	3,753		48.33	15.61

Table 2.4 – Fish taxa collected by otter trawl in 2006 at the Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects off southern New Jersey (see Fig 2.1). Species with a CPUE of at least 5% at any given station and used in the Canonical Variates Analysis are denoted with an $.

Species	Brigantine Ridge				Ship Bottom Ridge				Off-ridge			
	Total Number	Freq	CPUE	SE	Total Number	Freq	CPUE	SE	Total Number	Freq	CPUE	SE
Alosa mediocris	1	2.78	0.03	0.03		-	-	-		-	-	-
Anchoa hepsetus $		-	-	-	232	11.11	6.44	4.12		-	-	-
Anchoa mitchilli $	108	25	3	1.26	1709	66.67	47.47	16.95	546	41.67	45.5	28.96
Bairdiella chrysoura $		-	-	-	5	2.78	0.14	0.14		-	-	-
Cynoscion regalis $	1	2.78	0.03	0.03	8	8.33	0.67	0.67	8	8.33	0.67	0.67
Engraulis eurystole $	28	5.56	0.78	0.75	87	5.56	2.42	1.76	113	50	9.42	4.99
Etropus microstomus $	3	8.33	0.08	0.05	1	2.78	0.03	0.03		-	-	-
Gobiosoma ginsburgi		-	-	-	4	2.78	0.11	0.11	3	16.67	0.25	0.18
Menidia beryllina $		-	-	-	1	2.78	0.03	0.03		-	-	-
Micropogonias undulatus $		-	-	-	19	5.56	0.53	0.37	14	16.67	1.17	1.08
Mustelus canis $	1	2.78	0.03	0.03	2	2.78	0.06	0.06		-	-	-
Paralichthys oblongus	1	2.78	0.03	0.03		-	-	-		-	-	-
Peprilus triacanthus $	64	50	1.78	0.55	90	33.33	2.5	1.32	6	33.33	0.5	0.26
Pomatomus saltatrix $		-	-	-	3	2.78	0.08	0.08		-	-	-
Prionotus carolinus $	1	2.78	0.03	0.03		-	-	-	1	8.33	0.08	0.08
Prionotus evolans $	3	2.78	0.08	0.08		-	-	-		-	-	-
Raja eglanteria $		-	-	-	7	11.11	0.09	0.12		-	-	-
Scophthalmus aquosos $	8	13.89	0.22	0.1	1	2.78	0.03	0.03		-	-	-
Selene setapinnis	1	2.78	0.03	0.03	157	11.11	4.36	2.76	2	8.33	0.17	0.17
Seriola zonata	1	2.78	0.03	0.03		-	-	-		-	-	-
Sphoeroides maculatus $	1	2.78	0.03	0.03		-	-	-		-	-	-
Stenotomus chrysops $	1	2.78	0.03	0.03	6	16.67	0.17	0.06	1	8.33	0.08	0.08
Syngnathus fuscus $		-	-	-		-	-	-	1	8.33	0.08	0.08
Trichiurus lepturus $		-	-	-	5	11.11	0.14	0.07		-	-	-
Urophycis regia $	9	11.11	0.25	0.13	2	5.56	0.06	0.04		-	-	-
Totals	232		6.44	1.42	2340		65	19.97	698		58.16	29.89

Table 2.5 – Species abbreviations used in the Canonical Correspondence Analysis ordinations for the 1991-1995 beam trawl data and 2001-2006 otter trawl data for the Beach Haven Ridge transect in southern New Jersey.

Ammodytes americanus	*Aa*
Ammodytes sp.	*Asp*
Anchoa hepsetus	*Ah*
Anchoa mitchilli	*Am*
Astroscopus guttatus	*Ag*
Bairdiella chrysoura	*Bc*
Bothus sp.	*Bsp*
Centropristis striatus	*Cs*
Citharichthys arctifrons	*Ca*
Cynoscion regalis	*Cr*
Dasyatis sp.	*Dsp*
Etropus microstomus	*Em*
Gobiosoma ginsburgi	*Gg*
Gobiosoma sp.	*Gsp*
Hippocampus erectus	*He*
Menticirrhus sp.	*Msp*
Merluccius bilinearis	*Mb*
Micropogonias undulatus	*Mu*
Ophidion marginatum	*Om*
Paralichthys dentatus	*Pd*
Paralichthys oblongus	*Po*
Peprilus triacanthus	*Pt*
Pomatomus saltatrix	*Ps*
Prionotus carolinus	*Pc*
Prionotus evolans	*Pe*
Raja eglanteria	*Reg*
Raja erinacea	*Rer*
Scophthalmus aquosos	*Sa*
Sphoeroides maculatus	*Sm*
Stenotomus chrysops	*Sc*
Syngnathus fuscus	*Sf*
Tautogolabrus adspersus	*Ta*
Trachinocephalus myops	*Tm*
Urophycis chuss	*Uc*
Urophycis regia	*Ur*

Table 2.6 - Results of the Canonical Correspondence Analysis (CCA) on the Beach Haven Ridge transect beam trawl (1991-1995) data set utilizing all species.

		CCA Axis			
Data set		1	2	3	4
Overall	Eigenvalue	0.409	0.149	0.144	0.090
	Cumulative percentage variance				
	of species data	14.3	19.5	24.5	27.6
	of species -environment	50.4	68.8	86.5	97.6
Mid-summer	Eigenvalue	0.296	0.176	0.145	0.117
	Cumulative percentage variance				
	of species data	21.3	34.0	44.4	52.8
	of species -environment	39.1	62.3	81.4	96.8
Late summer	Eigenvalue	0.459	0.209	0.153	0.132
	Cumulative percentage variance				
	of species data	17.2	25.0	30.8	35.7
	of species -environment	46.8	68.1	83.8	97.2

The *P* values from a Monte Carlo permutation test on the significance on the environmental variable in each data set. Significant *P* values ($P<0.05$) are in **bold**.

		Data set	
Variable	Overall	Mid-summer	Late Summer
Salinity	0.796	**0.036**	0.874
Temperature	**0.012**	0.212	**0.002**
Depth	**0.002**	0.12	0.266
Distance from ridge	**0.01**	0.062	0.094
Habitat complexity	**0.03**	0.796	**0.028**

Table 2.7 - Results of the Canonical Correspondence Analysis (CCA) on the Beach Haven Ridge transect otter trawl (2001-2006) data set for all species.

Data set		CCA Axis 1	2	3	4
Overall	Eigenvalue	0.492	0.259	0.133	0.097
	Cumulative percentage variance				
	of species data	9.4	14.3	16.9	18.7
	of species -environment	42.5	64.9	76.4	84.8
Mid-summer	Eigenvalue	0.572	0.356	0.277	0.176
	Cumulative percentage variance				
	of species data	10.5	17.0	22.0	25.3
	of species -environment	33.0	53.6	69.6	79.8
Late summer	Eigenvalue	0.343	0.236	0.128	0.067
	Cumulative percentage variance				
	of species data	10.7	18.1	22.1	24.3
	of species -environment	39.8	67.2	82.0	89.9

The *P* values from a Monte Carlo permutation test on the significance on the environmental variable in each data set. Significant *P* values ($P<0.05$) are in **bold**.

Variable	Data set: Overall	Mid-summer	Late Summer
Salinity	0.518	0.200	0.996
Temperature	**0.002**	**0.002**	0.360
Depth	**0.002**	**0.004**	**0.090**
Distance from ridge	0.184	0.406	**0.002**
Habitat complexity	**0.022**	0.132	0.112
Dissolved oxygen	**0.036**	**0.022**	0.654
Water clarity	**0.046**	0.218	0.824
pH	0.148	0.212	0.172

Table 2.8 - Results of the Canonical Variates Analysis on the 1997-2006 otter trawls for Beach Haven Ridge and 2006 otter trawls for Brigantine, Ship Bottom and Off-ridge transects. The number and percent in overlap columns indicate the number of predicted samples that were projected into the area where the assemblage envelopes overlap.

Station	Number of samples	Number correct	Percent correct	Number in overlap	Percent in overlap
BHR-1	12	1	8.3	10	83.3
BHR-5	20	8	40	10	50
BHR-6	19	10	52.6	8	42.1
BHRTOP	4	0	0	4	100
BHR-7	17	4	23.5	13	76.5
BHR-9	17	1	5.8	16	94.2
BHR-10	5	0	0	4	80
BHR-11	3	0	0	3	100
Overall	97	24	**24.7**	68	70.1
BRG-5	6	0	0	6	100
BRG-6	6	0	0	6	100
BRGTOP	6	0	0	6	100
BRG-7	6	0	0	6	100
BRG-8	6	0	0	6	100
BRG-9	6	0	0	6	100
Overall	36	0	**0**	36	100
SB-5	6	0	0	6	100
SB-6	6	0	0	6	100
SBTOP	6	0	0	6	100
SB-7	6	0	0	6	100
SB-8	6	0	0	6	100
SB-9	0				
Overall	30	0	**0**	30	0
OFF-5	0				
OFF-6	3	0	0	3	100
OFF-8	3	0	0	3	100
OFF-9	3	0	0	3	100
Overall	9	0	**0**	9	100

Figure 2.1 - Station locations for the 1991-1995 beam trawls (BHR), 1997-2005 otter trawls (BHR), and the 2006 Ship Bottom transect (SB), Off-ridge transect (OFF), Beach Haven Ridge transect (BHR), and Brigantine Ridge transect (BRG) off Little Egg Inlet in southern New Jersey.

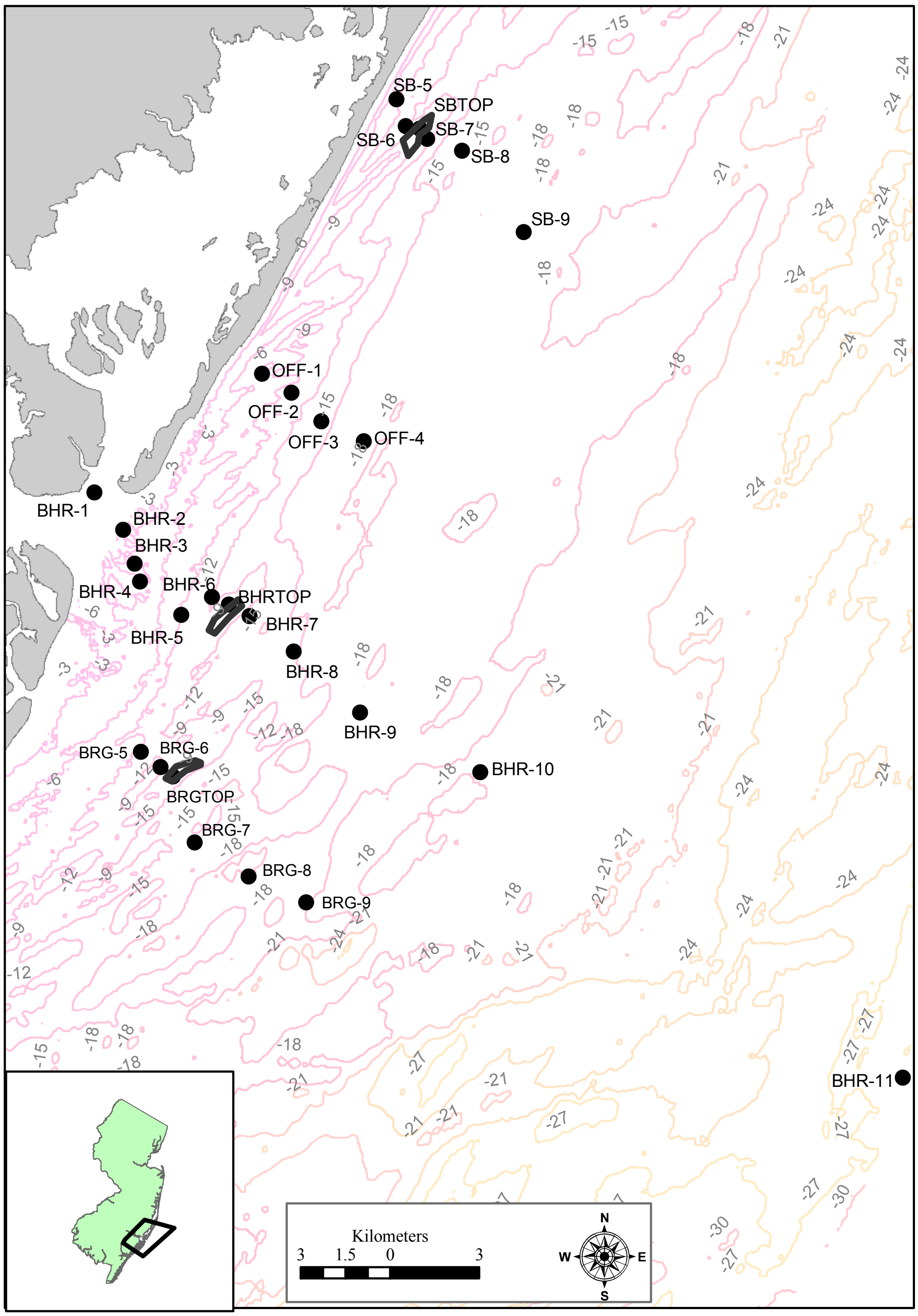


Figure 2.2 - Depth and distance from shoreline for each sampling location on the Beach Haven Ridge transect, Brigantine Ridge transect, Ship Bottom transect, and Off-ridge transect. The top of the ridges are labeled, as are the Off-ridge transect stations. The symbols represent individual stations along each transect. See Figure 2.1 for station locations.

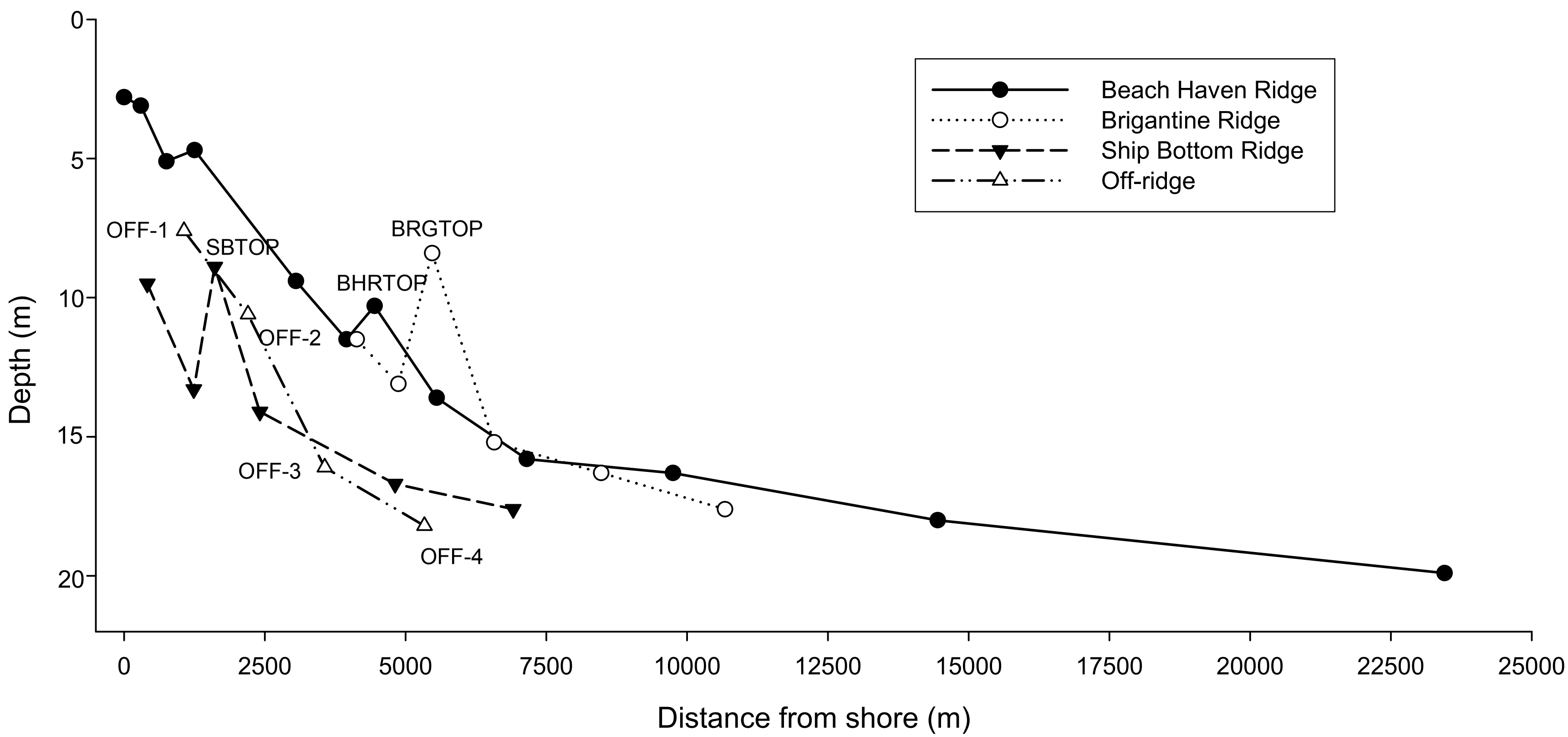


Figure 2.3 - Mean bottom temperature (A) and salinity (B) for the Beach Haven Ridge transect beam trawl samples (1991-1995). BHR-2 was collected in mid-summer 1995 only and BHR-9 was collected in mid-summer 1993 only. See Figure 2.1 for station locations

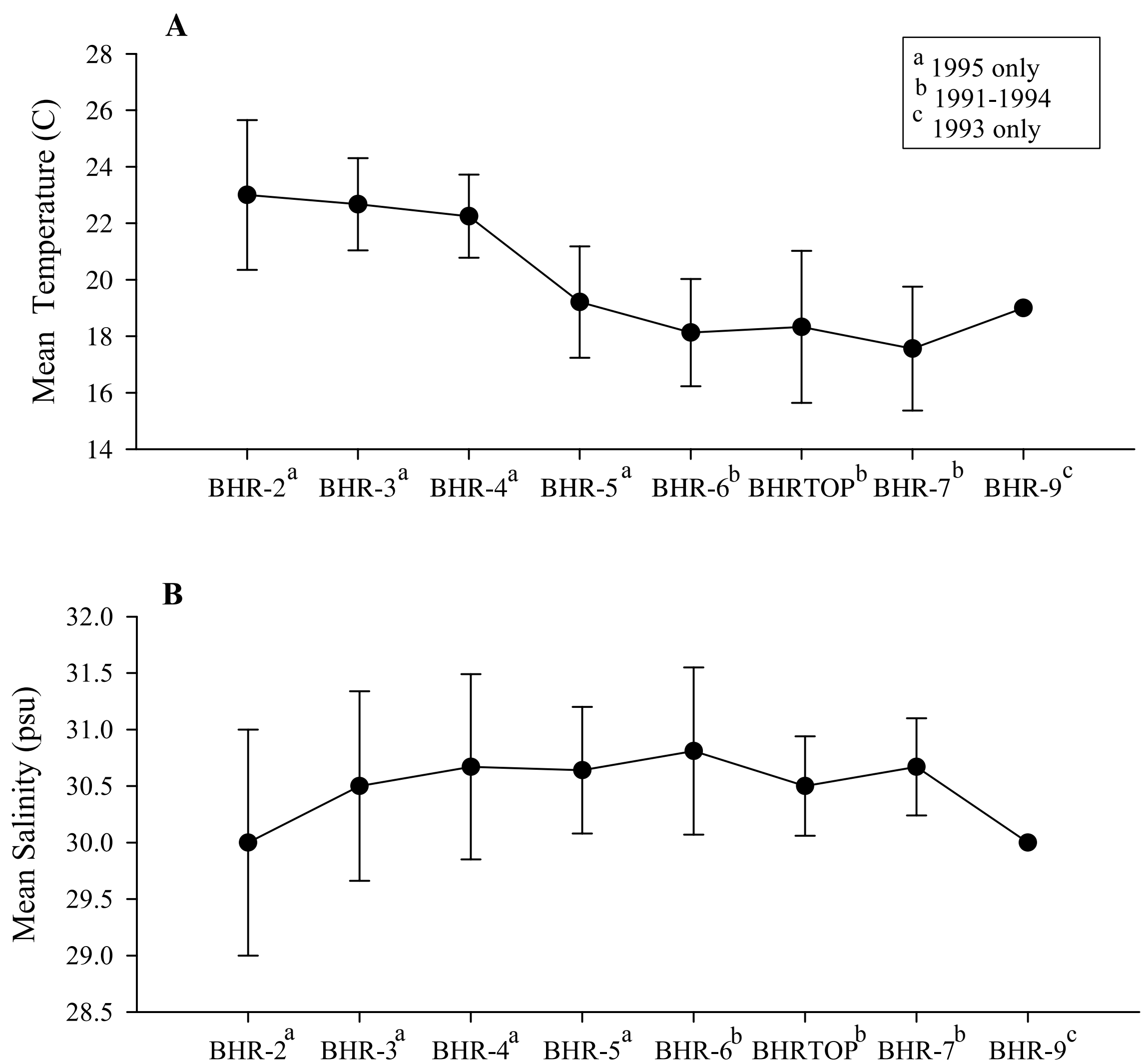


Figure 2.4 - Environmental data (mean bottom values) for the Beach Haven Ridge transect otter trawl samples (2001-2006). BHRTOP data was collected in 2005 and 2006 only. See Figure 2.1 for station locations.

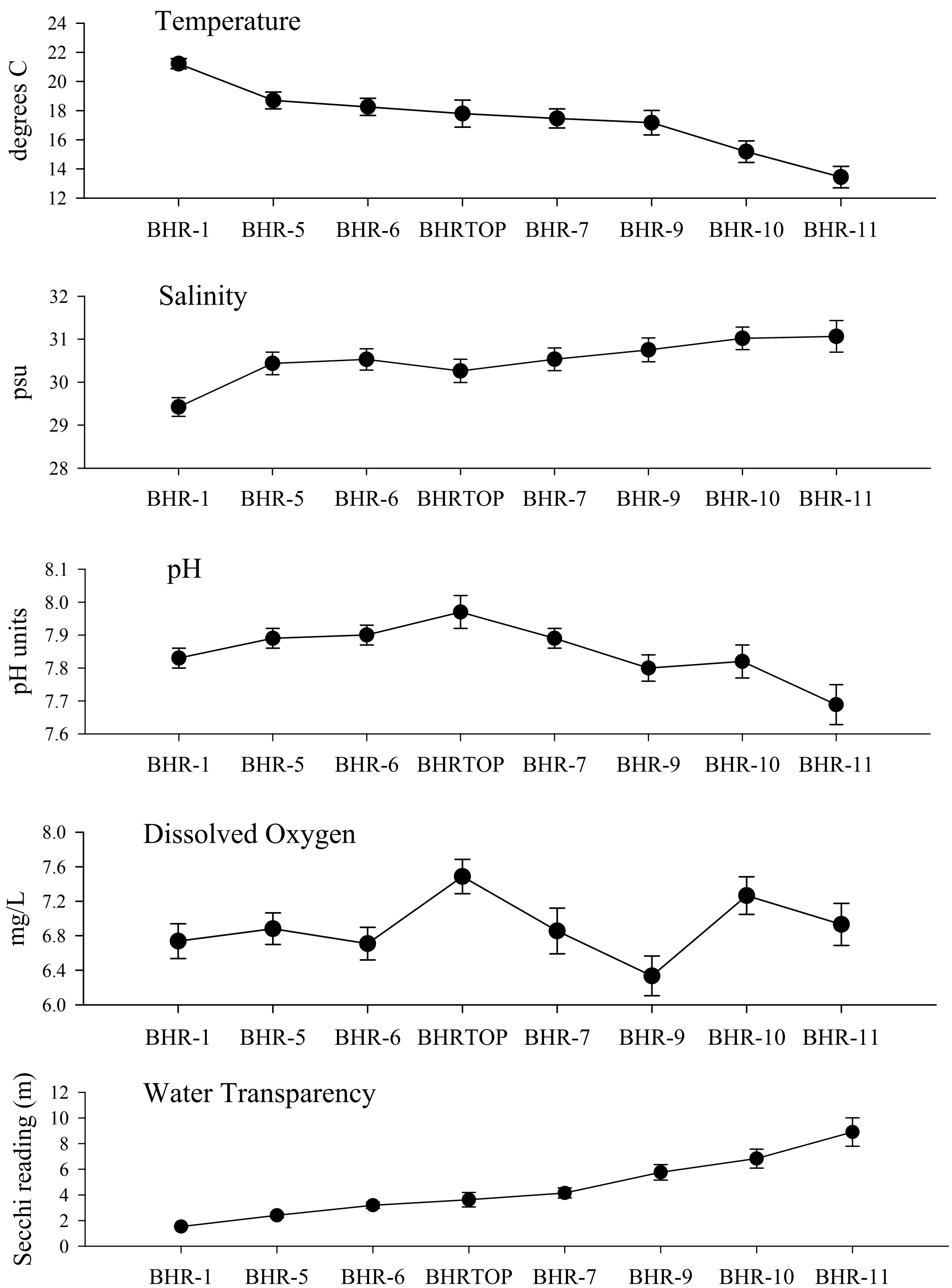


Figure 2.5 - Yearly bottom temperatures for the top of Beach Haven Ridge compared to the 10-year average based on LEO-15 node data for the sampling dates (1997-2004) and otter trawl sampling (2005 and 2006).

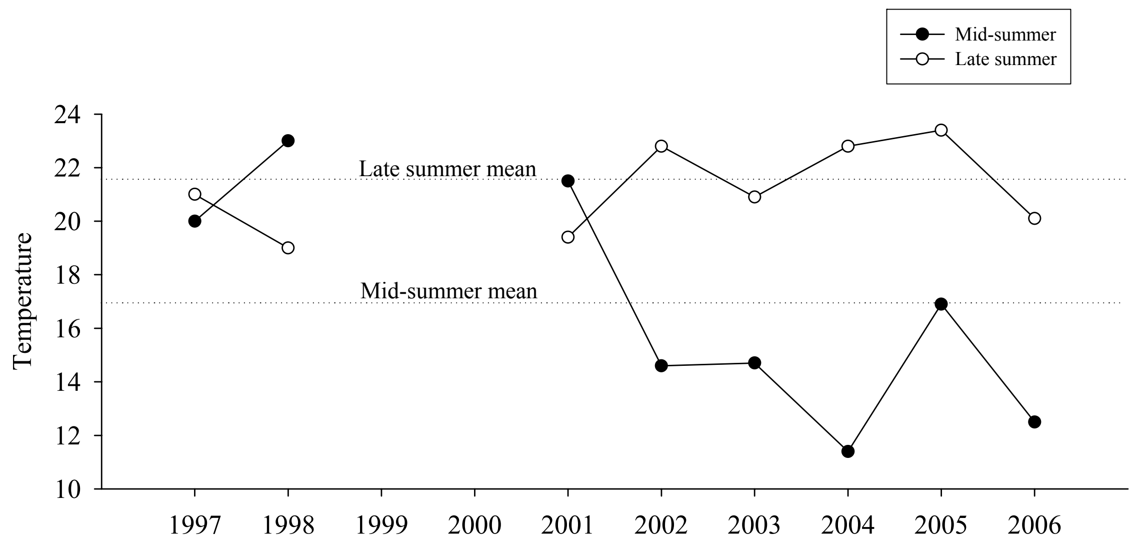


Figure 2.6 - Environmental data (mean bottom values) for the otter trawl samples collected at the Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects off southern New Jersey in 2006. Off-ridge readings are late summer only. Stations are grouped based on similar depth and distance from top of ridge. See Figure 2.1 for station locations.

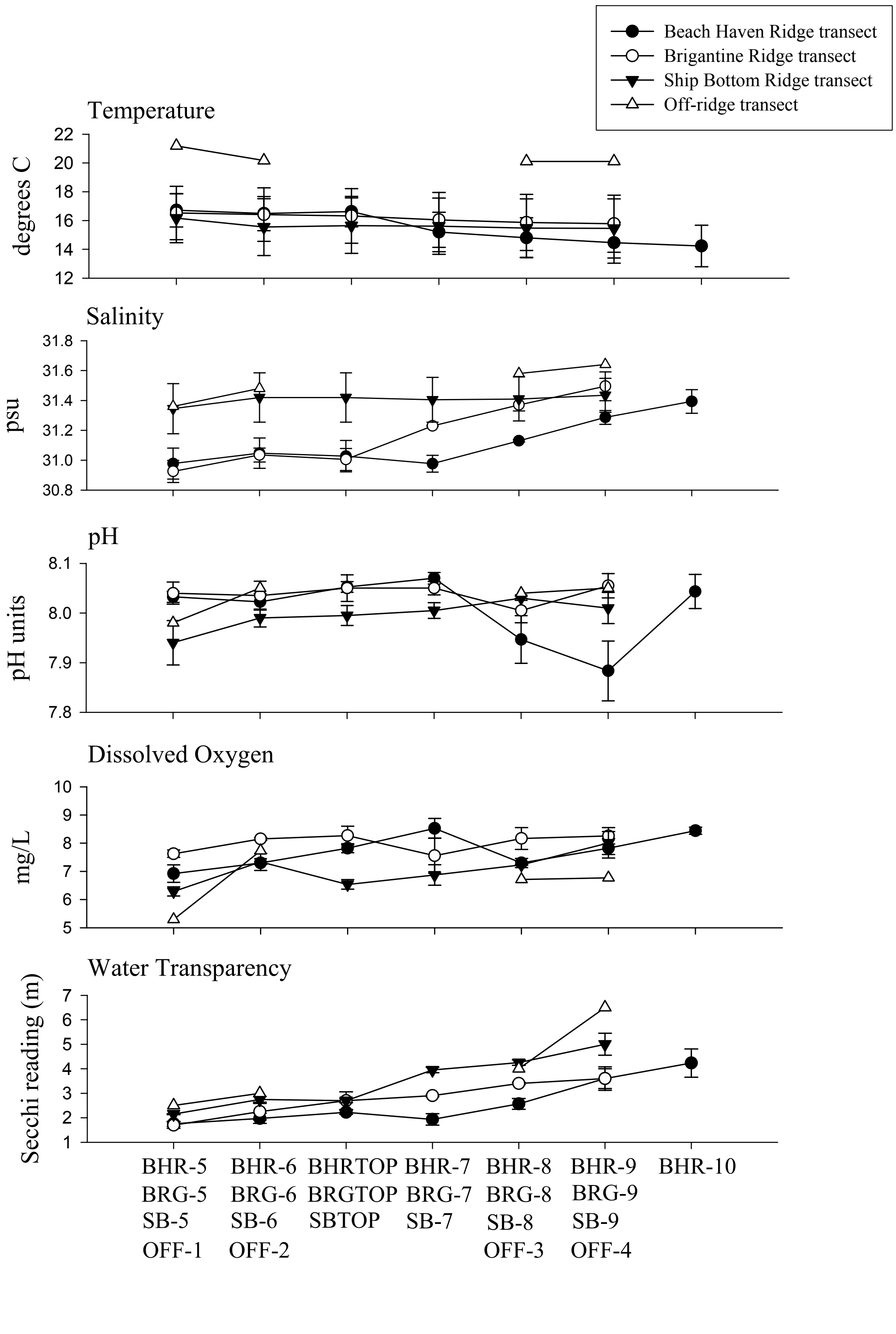


Figure 2.7 - Catch-per-unit-effort (CPUE, number per tow) by sampling location for all fish species (pelagic and demersal) (A) and with only demersal species (B) for the 1991-1995 Beach Haven Ridge beam trawl, the 1997-2006 Beach Haven Ridge otter trawl, and the 2006 Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects otter trawls from southern New Jersey. The Off-ridge samples are from late summer only. Stations are grouped based on similar depth and distance from top of ridge. See Figure 2.1 for station locations.

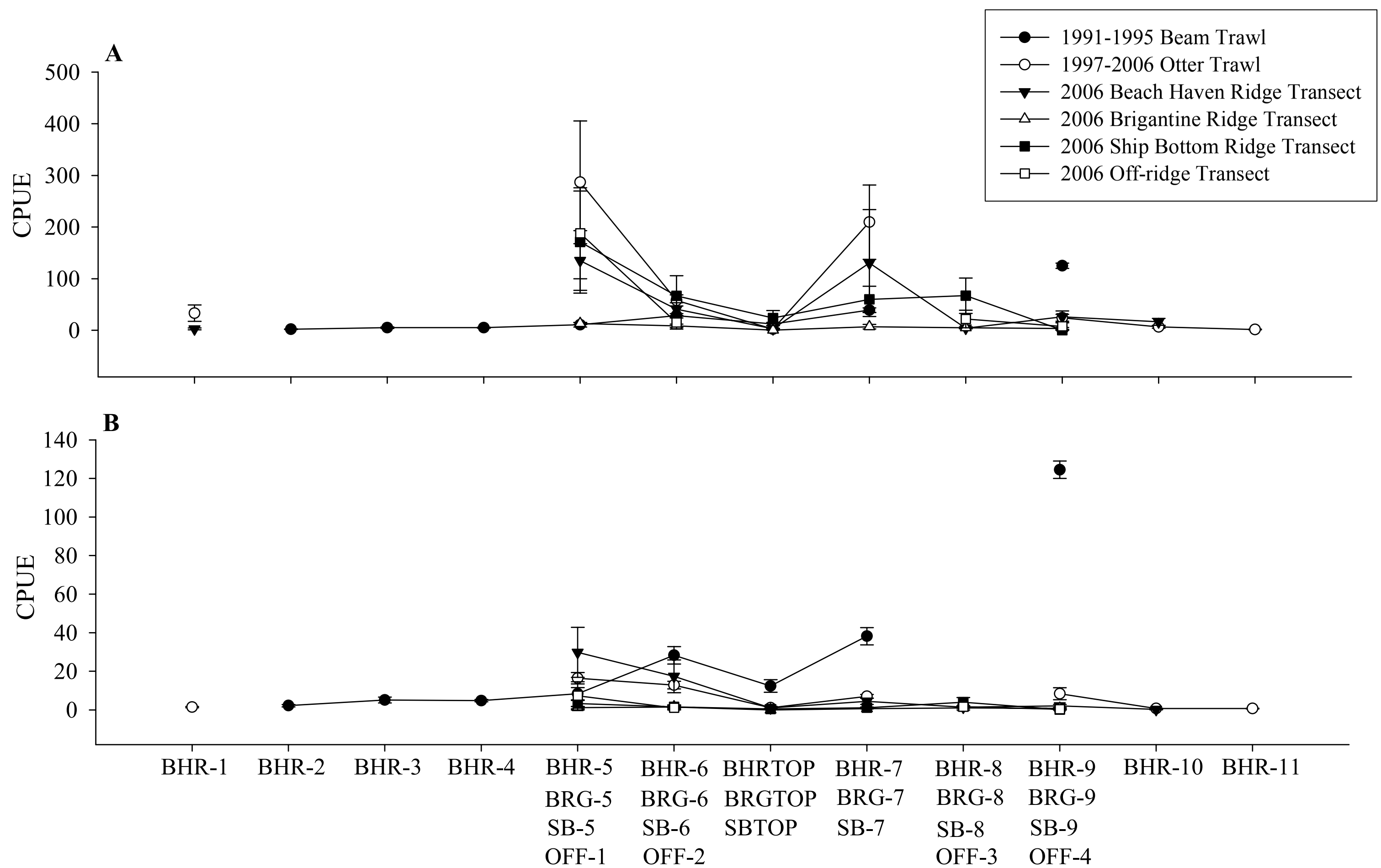


Figure 2.8 - Species richness parameters for all fish species (pelagic and demersal) from the 1991-1995 Beach Haven Ridge beam trawl, the 1997-2006 Beach Haven Ridge otter trawl, and the 2006 Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects otter trawls from southern New Jersey including richness per unit effort (RPUE, A) and observed number of species (B). The Off-ridge samples are from late summer only. Stations are grouped based on similar depth and distance from top of ridge. See Figure 2.1 for station locations.

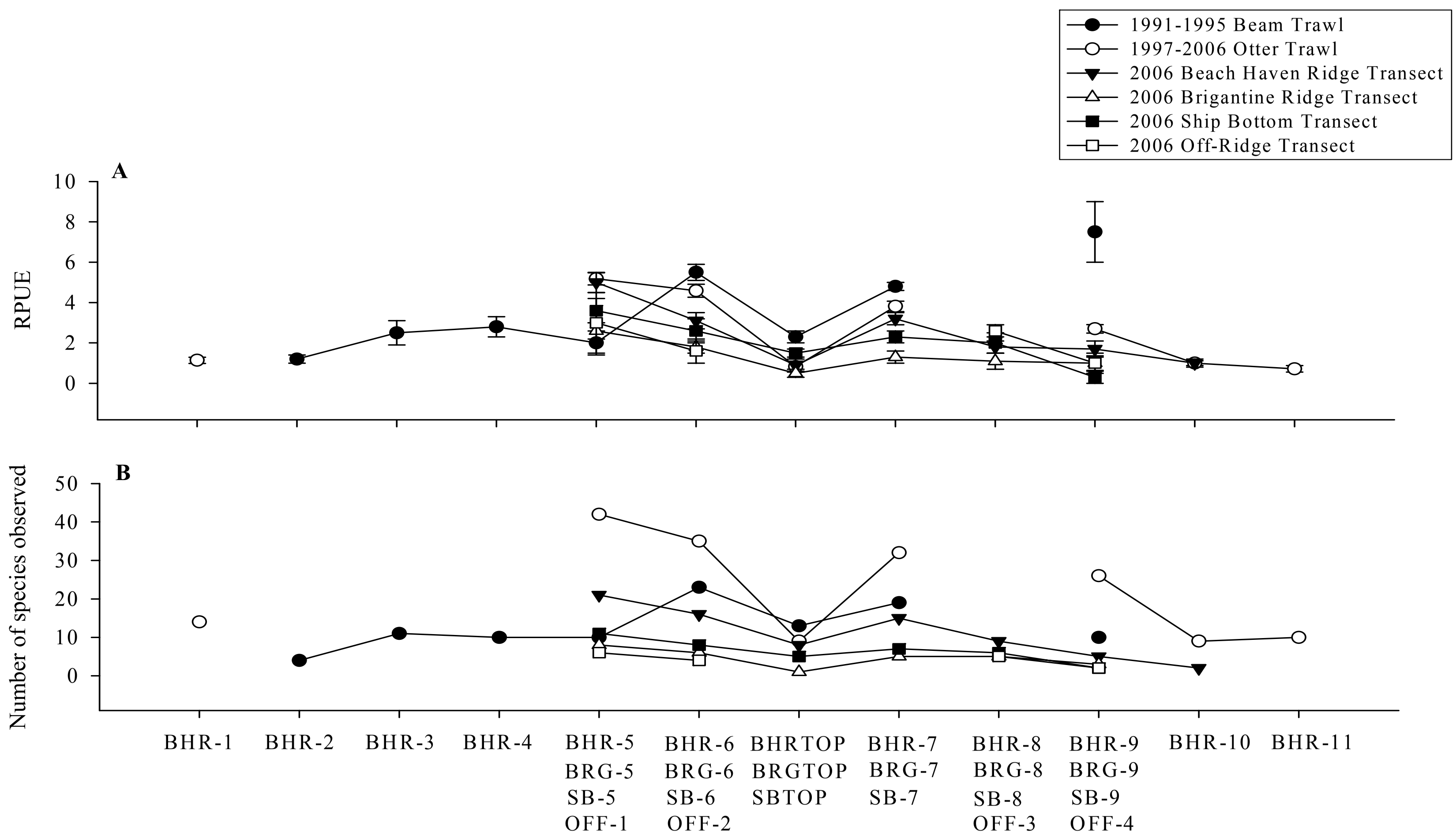


Figure 2.9 - Species richness parameters for demersal species from the 1991-1995 Beach Haven Ridge beam trawl, the 1997-2006 Beach Haven Ridge otter trawl, and the 2006 Beach Haven Ridge, Brigantine Ridge, Ship Bottom Ridge, and Off-ridge transects otter trawls from southern New Jersey including richness per unit effort (RPUE, A) and observed number of species (B). The Off-ridge samples are from late summer only. Stations are grouped based on similar depth and distance from top of ridge. See Figure 2.1 for station locations.

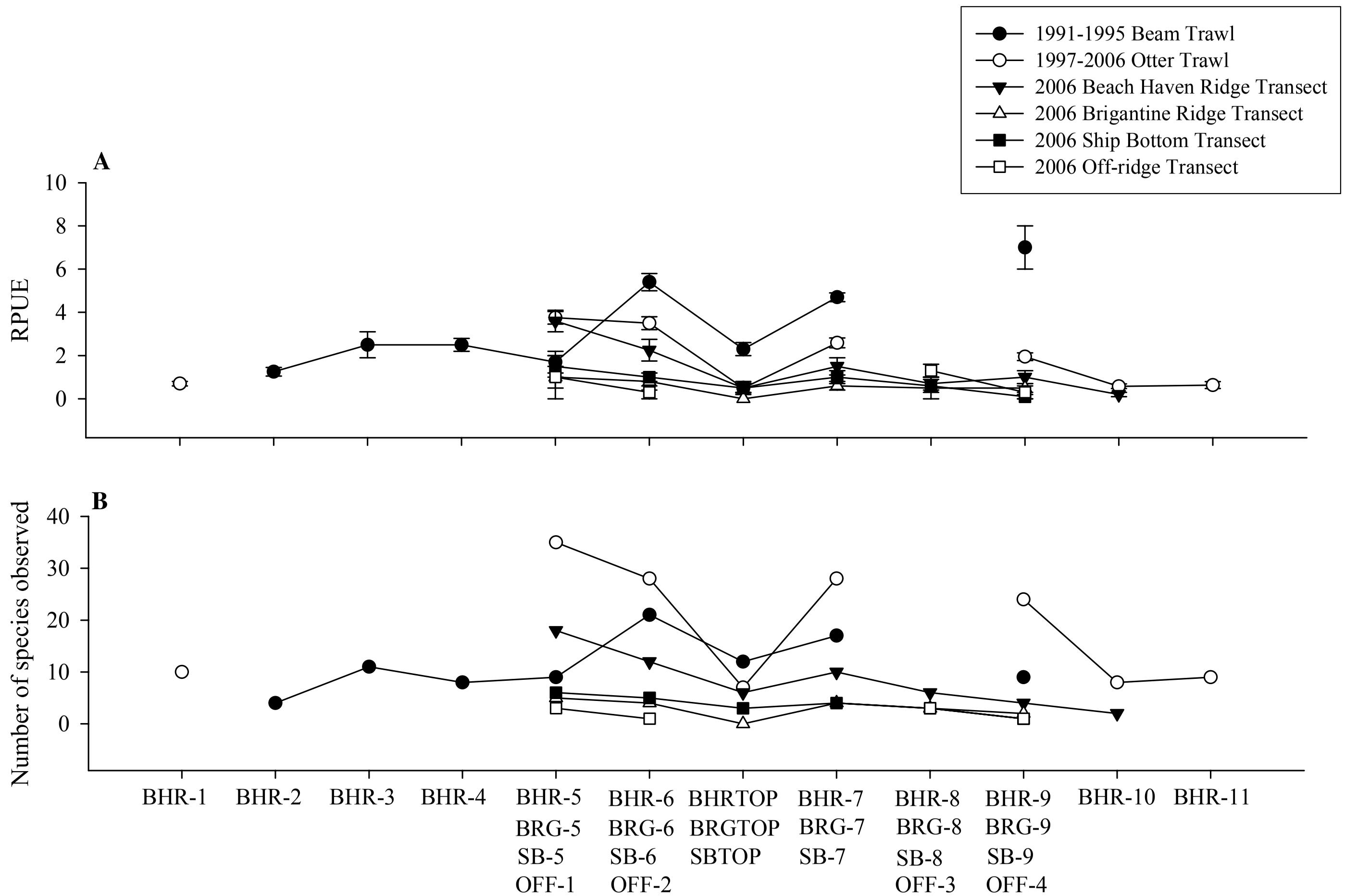
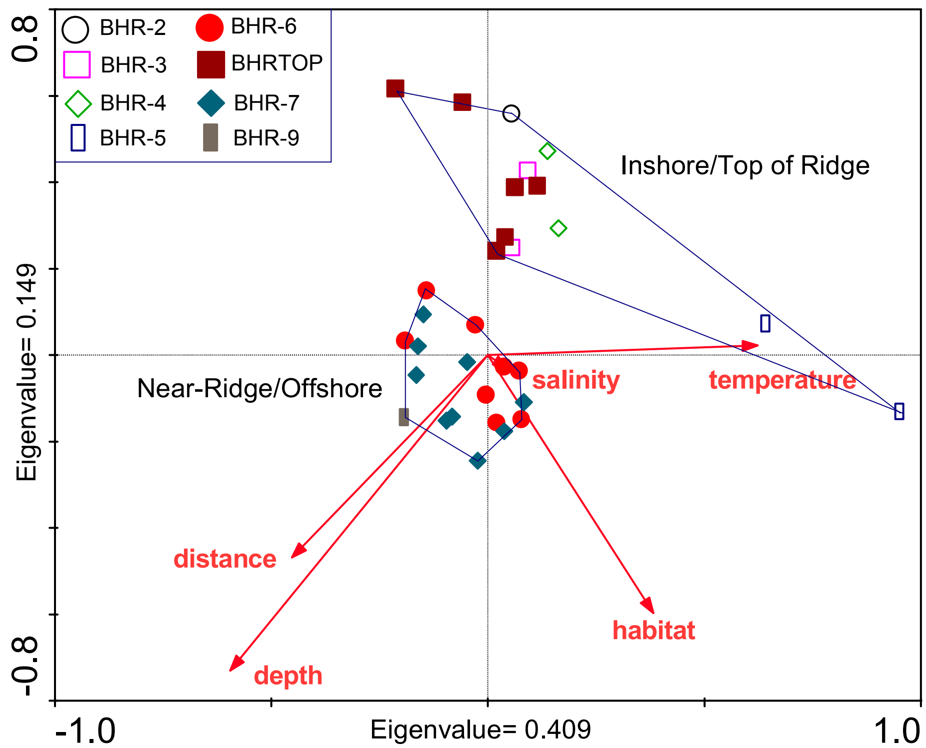


Figure 2.10 – Canonical Correspondence Analysis (CCA) ordinations of the Beach Haven Ridge 1991-1995 beam trawl data set for all species. Samples are represented as stations in (A) and seasons in (B). See Figure 2.1 for station locations.

A.



B.

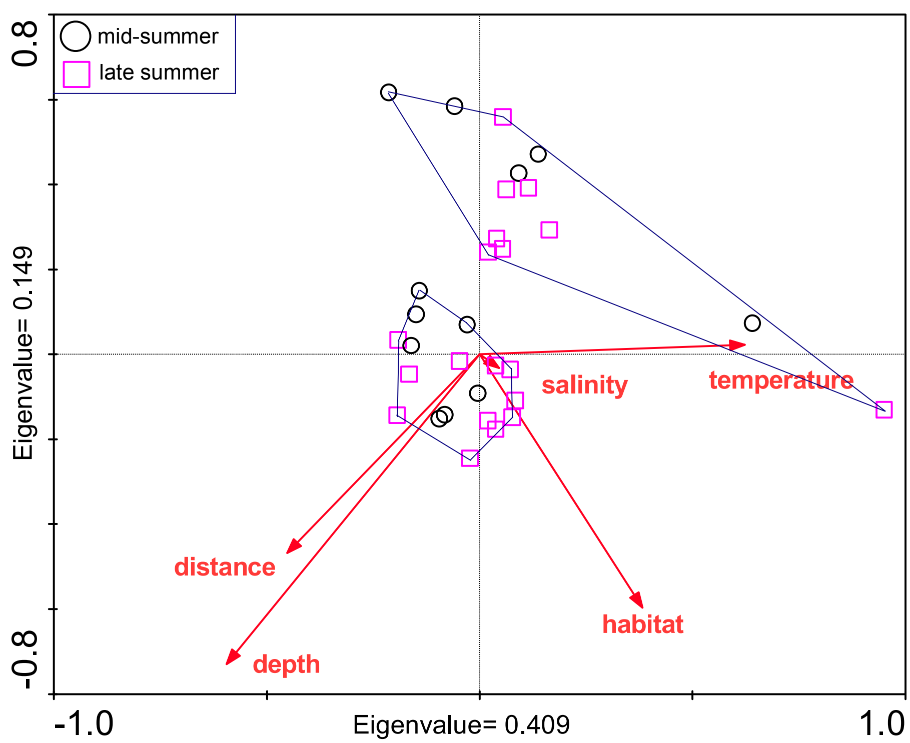
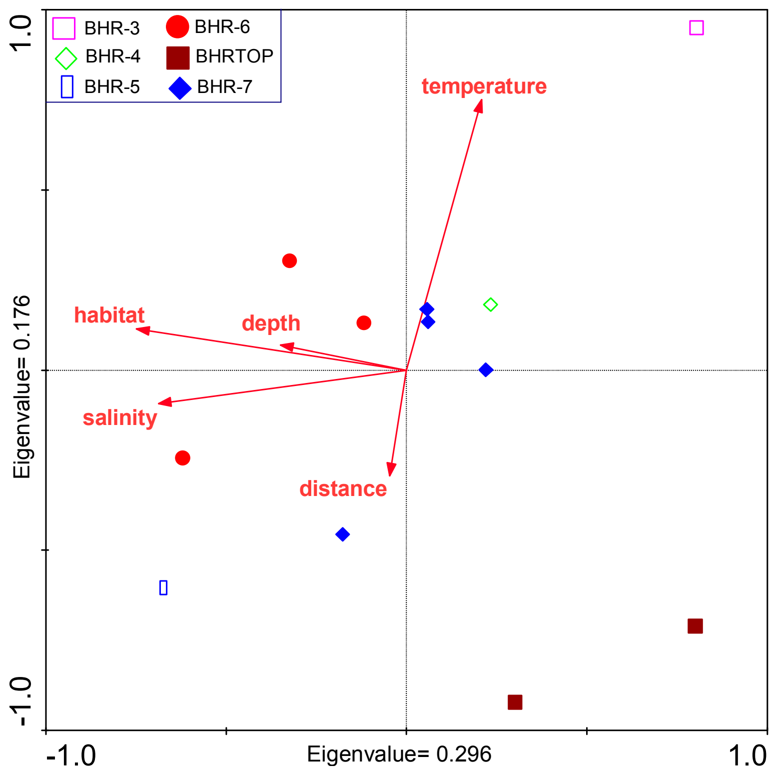


Figure 2.11 – Canonical Correspondence Analysis (CCA) ordinations of the Beach Haven Ridge 1991-1995 beam trawl data set (all species) for mid-summer only (A) and late summer only (B). See Figure 2.1 for station locations.

A.



B.

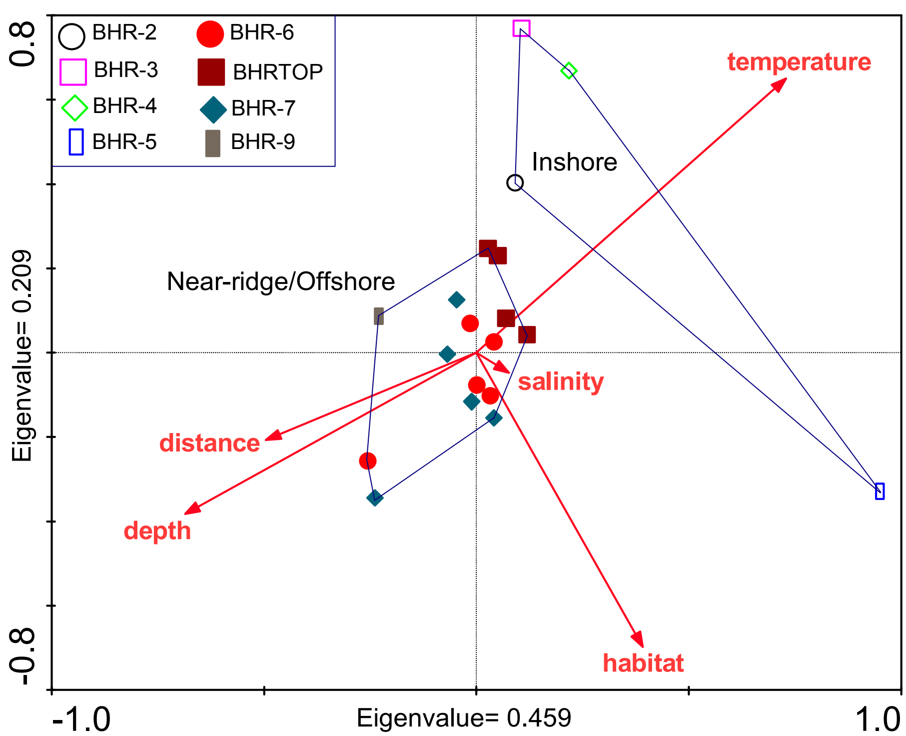


Figure 2.12 – Species assemblages identified from Canonical Correspondence Analysis of the Beach Haven Ridge 1991-1995 beam trawl data set including all species for mid and late summer (A) and late summer only (B). There were no clear assemblages for the mid-summer only data. Hatched circles enclose stations that grouped together each season. Taxa are listed in order of abundance for each assemblage. Asterisks indicate species that were found in multiple assemblages. Station locations are indicated in Figure 2.1.

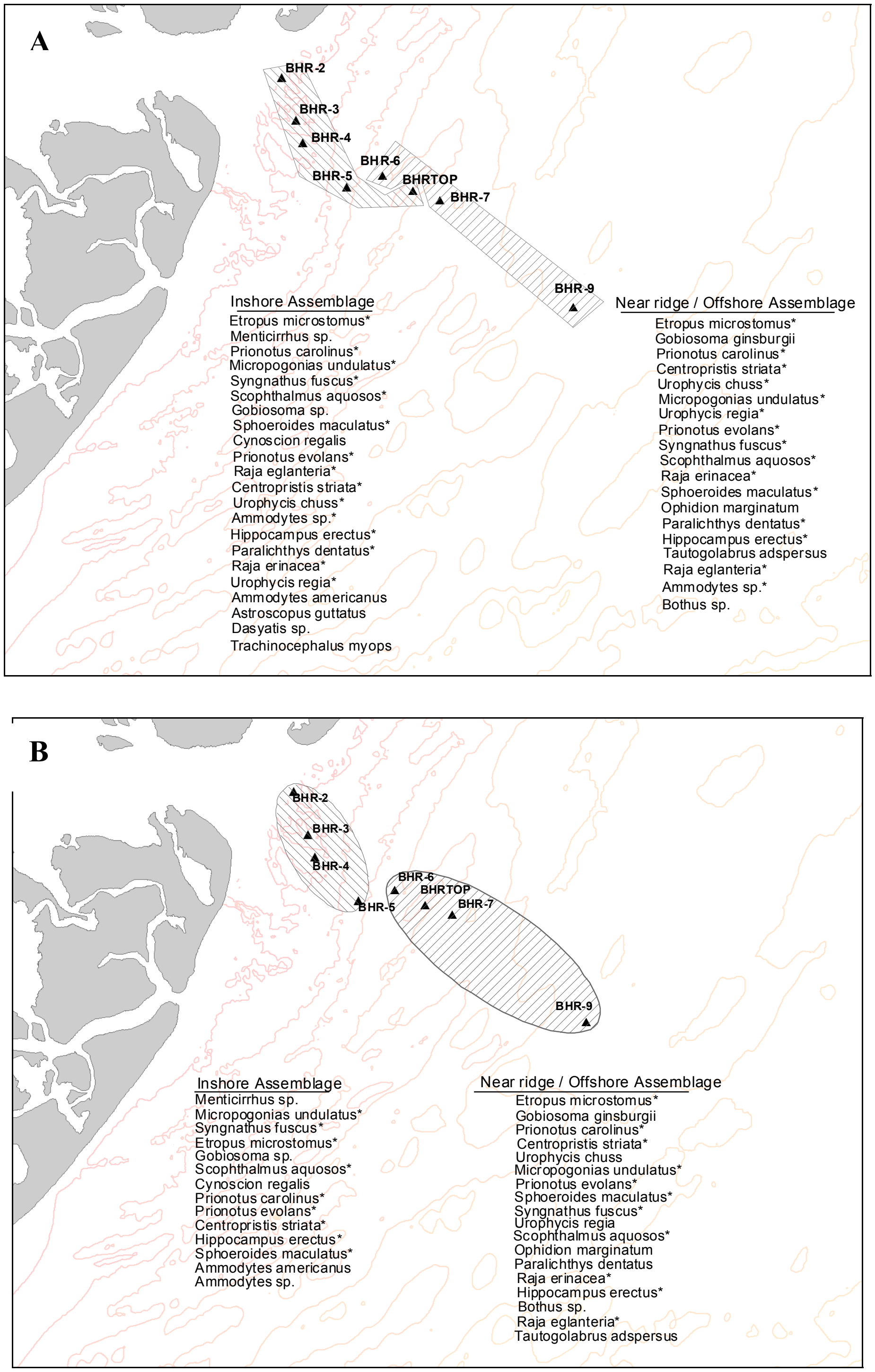
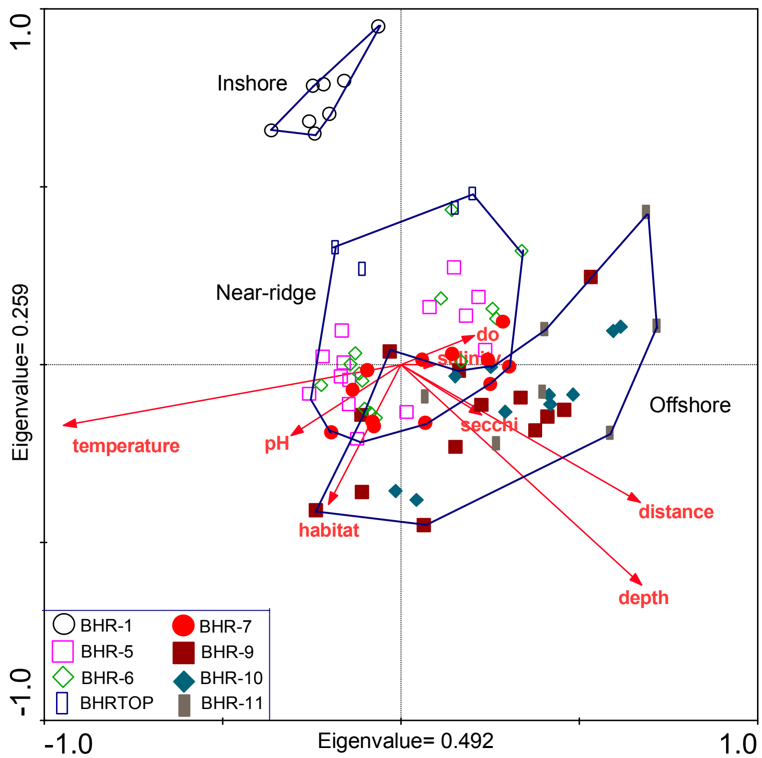


Figure 2.13 – Canonical correspondence analysis (CCA) ordinations of the Beach Haven Ridge 2001-2006 otter trawl data subset for all species displaying the samples represented as stations (A) and seasons (B). See Figure 2.1 for station locations.

A



B

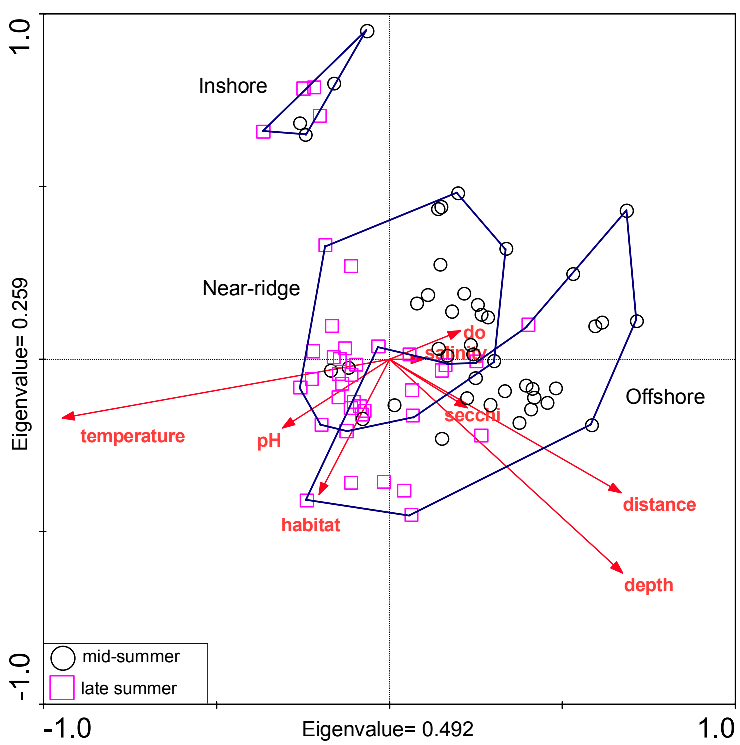
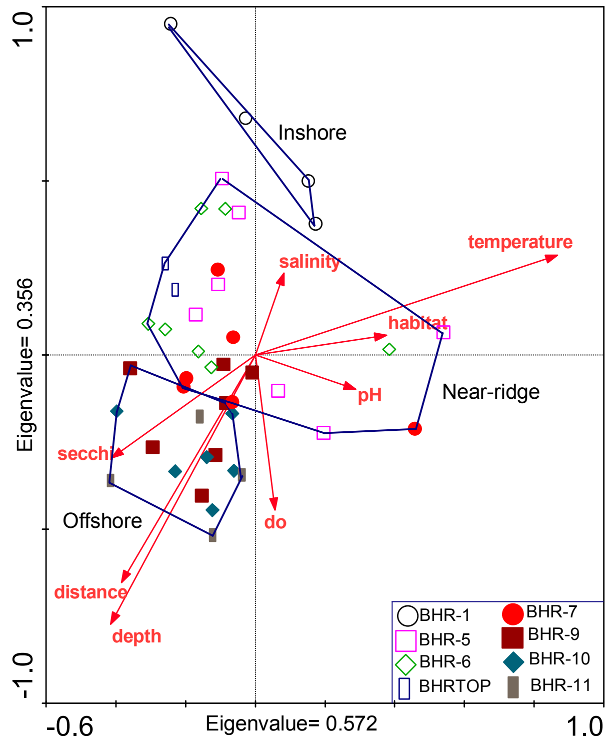


Figure 2.14 – Canonical correspondence analysis (CCA) ordinations of the Beach Haven Ridge 2001-2006 otter trawl data subset for all species displaying mid-summer samples only (A) and late summer samples only (B). See Figure 2.1 for station locations.

A



B

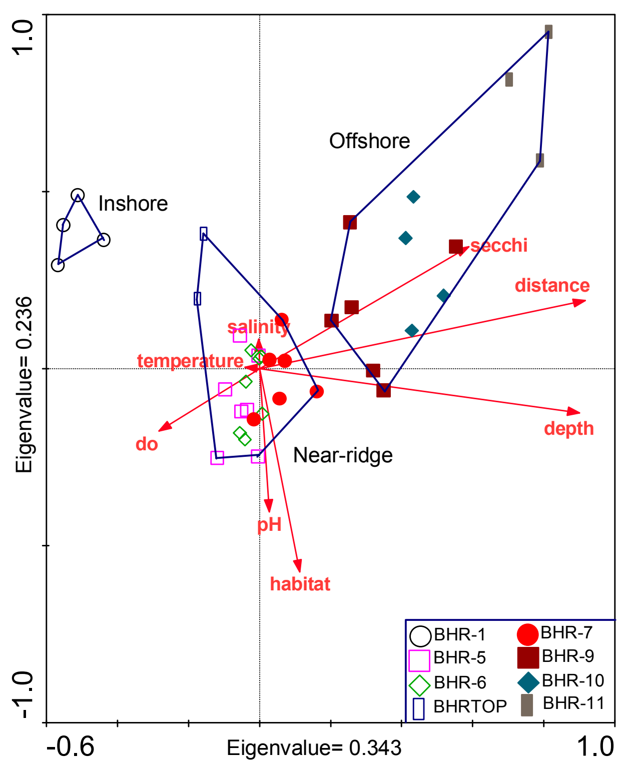


Figure 2.15 – Species assemblages based on Canonical Correspondence Analysis (CCA) of the Beach Haven Ridge 2001-2006 otter trawl data subset set for all species. The overall analysis is shown in (A), the mid-summer analysis in (B), and the late summer analysis in (C). See Table 2.5 for species abbreviations.

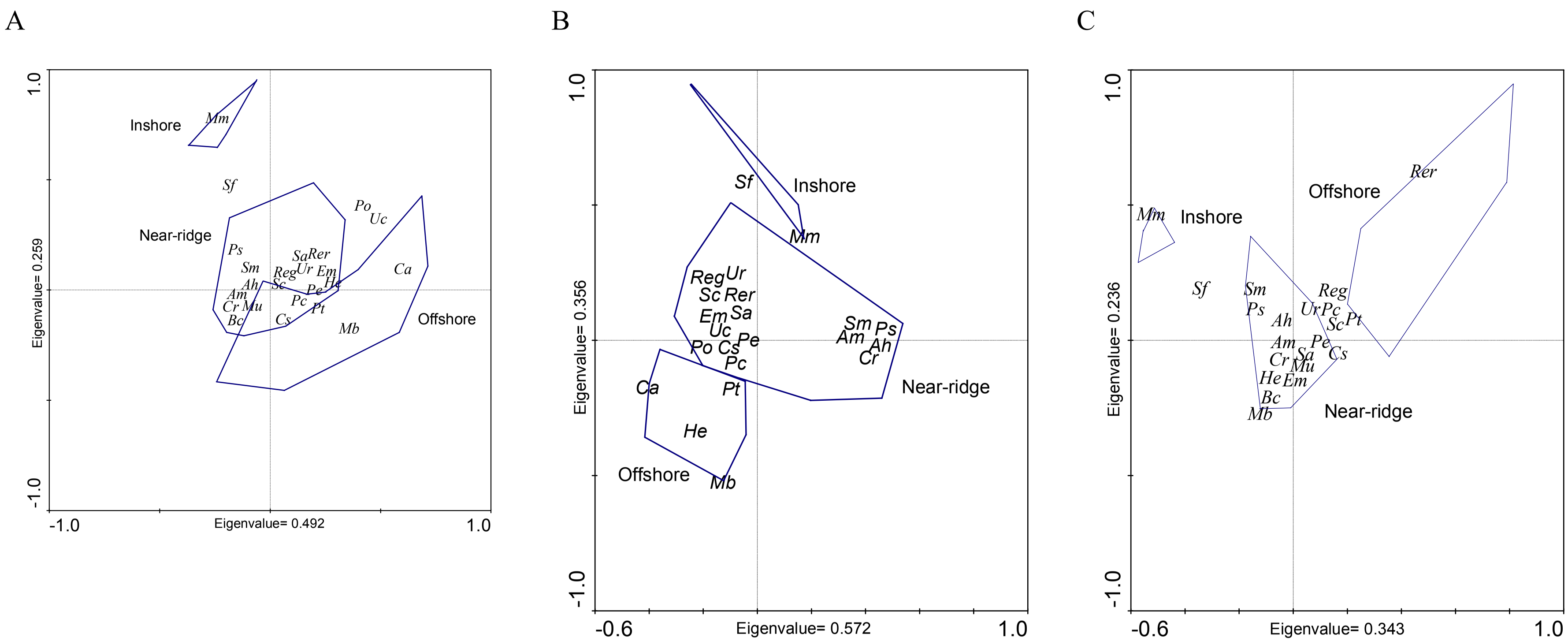
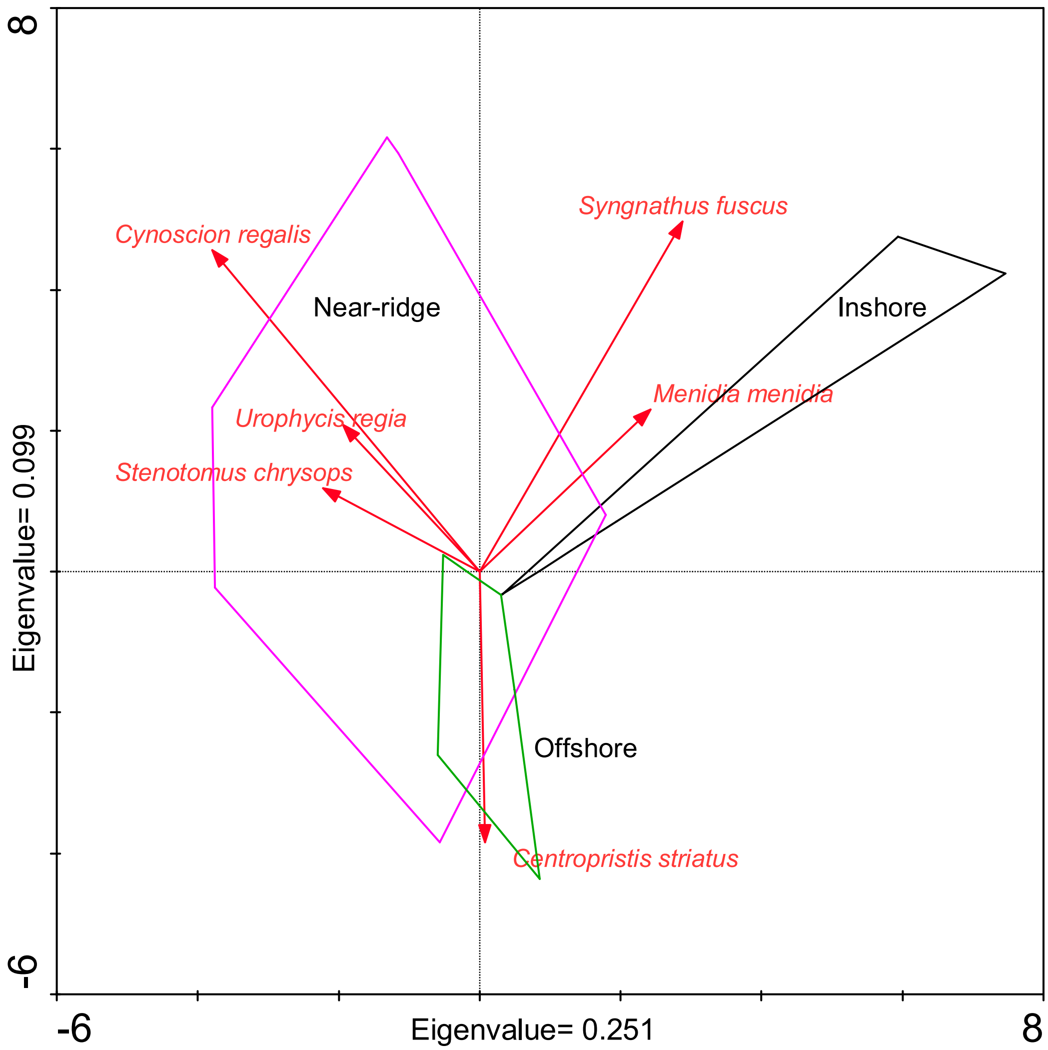


Figure 2.16- Ordination of the Canonical Variates Analysis (CVA) on the Beach Haven Ridge 1997-2006 otter trawl "training" set showing the reduced set of variables selected through a Monte Carlo permutation test. See Table 2.5 for species abbreviations.



CHAPTER III

Abundance and diet of three sciaenid fishes in the vicinity of shoreface sand ridges in southern New Jersey

Introduction

Shoreface sand ridges are topographic features with relief up to 10 meters consisting of unconsolidated sand which are generally oriented obliquely to the adjacent shoreline. They are common geophysical components of the inner continental shelf (Stahl et al. 1974, McBride and Moslow 1991). Beach Haven Ridge, one sand ridge site in southern New Jersey, was extensively sampled in the 1970's with over 90 species of fish consisting of both juveniles and adults identified on and in the immediate vicinity of the ridge (Milstein et al. 1977, Able and Hagan 1995). The most abundant species were those found throughout the New York Bight, including both year round residents and species that migrate along the coast. Subsequent sampling has found that species abundance and richness tended to be higher in the vicinity of the sand ridge when compared to more estuarine and shelf waters (Martino and Able 2003), and that there were differences in abundance and richness between locations on either flank of the ridge and the top of the ridge (Chapter 2).

One potential factor underlying this pattern of abundance and richness may be enhanced feeding opportunities at sand ridges. The presence of multiple fish life history stages in the vicinity of sand ridges suggests that ridges may provide for a variety of prey items with prey abundance higher than the surrounding area. Higher abundances in the immediate vicinity of sand ridges has been documented for some prey fish (Chapter 2) as well as benthic infauna (Hales et al. 1995, Viscido et al. 1997, Diaz et al. 2004). The diet preferences of many of the dominant New York Bight species are well known from studies in estuaries (Merriner 1975, Stickney et al. 1975, Kobylinski and Sheridan 1979, Hartman and Brandt 1995, Nemerson and Able 2004) but little study of food habits has occurred in inner continental shelf waters. Further, no studies have assessed the feeding condition of dominant species around sand ridges, nor identified if the preferred prey items at the ridges vary from those found for other locations.

In order to ascertain if the patterns in abundance and richness identified around the sand ridge (Chapter 2) may be influenced by feeding, three dominant benthic species were compared for differences in mean stomach fullness and prey item composition and abundance along a transect across Beach Haven Ridge. These measures of foraging success, when combined with abundance, provide an assessment of the value of the sites to these species (Gilliam and Fraser 1987). If abundances are highest where feeding success is high it can be inferred that resource availability is a major factor in habitat selection on and near sand ridges.

Methodology

Study Area

The project study area encompasses the inner continental shelf waters off Little Egg Inlet on the coast of southern New Jersey (Fig 3.1). The area sampled consisted of a 23-km transect across a shore faced sand ridge off Little Egg Inlet, known as Beach Haven Ridge. This sand ridge has been extensively studied as it was the site of a proposed nuclear power plant (Milstein et al. 1977, Able and Hagan 1995) and lies within the Jacques Cousteau National Estuarine Research Reserve. Eight sampling stations were selected along the transect based on a combination of habitat characteristics and position relative to Beach Haven Ridge , beginning in Little Egg Inlet and extending onto the inner continental shelf (Fig. 3.1). For a physical description of Beach Haven Ridge and the individual stations see Chapter 2 (Table 2.2).

Field Sampling

The eight stations were each sampled two times during July and September of 2006, with sampling in each month conducted three days apart. Samples were collected with an otter trawl (4.9-m head rope, 19-mm mesh wings, 6-mm mesh cod end) with three replicate tows at each of the stations. The latitude and longitude of the starting point for each tow was recorded, as was the direction of the tow. Tow speed varied depending upon the prevailing ocean conditions, but tow times never exceeded two minutes in an attempt to ensure that fish were collected from discrete habitats. The dominant demersal species at each station were retained for stomach content analysis. All fish held for stomach content analysis were either placed in jars containing buffered 10% formalin or injected with buffered 10% formalin and then frozen immediately after capture to preserve the stomach contents. Bottom and surface (upper 1 meter) salinity, temperature, dissolved oxygen, and pH were measured and recorded during the second replicate tow with a YSI model 85. Depth and bottom topography were determined with a Furuno Model 256. Secchi disk readings were also taken at each station.

Laboratory Methods

The fish retained for stomach content analyses were sorted by station and species, measured, and pooled into 10-mm size classes for individuals up to 140-mm TL, 30-mm classes for individuals between 140 and 200 mm, and 100-mm classes for individuals larger than 200 mm. Wet weight, eviscerated wet weight, and eviscerated dry weight was obtained for all intact individuals. The stomach contents of up to twenty individuals per size class (per species) were pooled into a common vial filled with a solution of rose bengal and 95% ethyl alcohol. The sieve fractionation method described by Carr and Adams (1972) was then used to determine the weight of each prey category.

Prey Categories

All prey items were identified to the lowest taxonomic level practicable. For diet comparisons prey were grouped into 16 general categories (Table 3.1). The groups were chosen to emphasize major constituents of the diet and are not necessarily taxonomically consistent. Any small crustacean parts that could not be identified to one of the specific categories (crab, shrimp, mysid) were included in the Crustacean Part category. Further, pieces of bivalve shell were included in the bivalve category rather than the sediment category based on the small size of the shell hash and the presence of intact bivalves in a number of stomachs.

Data Analysis

In order to compare differences in diet between habitat types along the transect and maintain a statistically viable sample size for each species, three dominant species found during the 2006 sampling season were selected; *Bairdiella chrysoura*, *Cynoscion regalis*, and *Micropogonias undulatus*. Fish abundance at each station was calculated as catch per unit effort (CPUE), or the number of fish captured per tow, averaged across all tows at a given station. When stomachs were removed in the laboratory the relative stomach fullness was assessed on a scale of 0 to 4, with zero being empty, 2 being half full, and 4 completely full. In an effort to remove bias due to examining individuals of different sizes, all of one size category of one species was examined before viewing subsequent size classes. ANOVA procedures were used to test for significant differences in patterns of fish abundance and stomach fullness. All univariate statistics were performed using SAS System v9.1. Fish diets were compared by calculating the weight of each prey category as a proportion of the total weight of prey consumed (Carr and Adams 1972).

Results

Abundance and Size Structure

Off all the demersal fish captured (Chapter 2) only the sciaenids were consistently collected at multiple stations in appreciable numbers (n>5), and only in September. *B. chrysoura*, *M. undulatus*, and *C. regalis* were all found at both BHR-5 and BHR-6, while *M. undulatus* and *C. regalis* were also found at BHR-7. BHR-5, the nearshore station, has a substrate composed of patches of sand/macroalgae/Diopatra tubes and mud. BHR-6, located on the landward flank of the ridge, has a similar substrate of clay/sand/Diopatra tubes and mud. BHR-7 is found on the seaward flank of the ridge and has patches of sand/shell/Diopatra tubes and clay/sand.

Catch per unit effort (CPUE) for *B. chrysoura* and *M. undulatus* was highest at the nearshore compared to the other stations, but not significantly so, while CPUE for *C. regalis* was nearly equal across all three stations (Fig. 3.2b). Further, mean total length for *B. chrysoura* was similar between the two stations at which it was found but *C. regalis* and *M. undulatus* showed significant differences in mean length between the stations, with the larger individuals (> 220 mm) found on the seaward side of the ridge (Fig. 3.3a). The *B. chrysoura* were predominately young-of-the-year, while the *M. undulatus* were all age 1 or older based on comparisons with Able and Fahay (1998). The *C. regalis* were a combination of larger young of the year and age-1 individuals found at BHR-5 and age-1 and older fish at the other stations.

Stomach Fullness

A total of 312 stomachs from *Bairdiella chrysoura*, *Cynoscion regalis,* and *Micropogonias undulatus* were examined for their fullness and contents (Table 3.2). There was no difference in mean relative stomach fullness between the three habitats, and mean fullness for all species was at least 2.4 (Fig. 3.3b). While stomach fullness for each species was similar between habitats, *C. regalis* showed a significantly greater stomach fullness seaward of the ridge compared to landward (df= 107, alpha=.05, p= 0.0489). *M. undulatus* had a significantly greater stomach fullness than the remaining species at all stations except for *C. regalis* seaward of the ridge (df=308, alpha=.05, p<0.0001).

Diet Composition

The diet of *Bairdiella chrysoura* was dominated by mysids, decapod shrimp, and fish, with slight differences between habitats (Table 3.3). The rates of piscivory at the two habitats were similar (7.5% and 8.3%) and mysid consumption was slightly more prevalent nearshore than on the landward flank of the ridge (64.2% to 48.1%). Based on scale identification the major fish prey were atherinids and engraulids, most likely *Menidia* sp. and *Anchoa* spp. Shrimp consumption on the landward side (20.3%) was twice that of nearshore (10.2%), while the presence of decapod megalopae was nearly an order of magnitude greater on the landward side of the ridge (5.0%) compared to nearshore (0.6%). Detritus comprised less than 5% of stomach content at either station, and no sediment was found in the stomachs.

Fish, mysids, and decapod shrimp formed a majority of the diet of *Cynoscion regalis*, with a substantial amount of variability between habitats (Table 3.3). Piscivory decreased slightly from nearshore (47.2%) to the landward side of the ridge (39.3%), and then decreased significantly on the seaward side of the ridge (20.3%). Prey fish consisting of engraulids (including *Anchoa mitchilli and Anchoa* sp.), sciaenids, and *Scophthalmus aquosos* were identified from whole fish, scales, and otoliths. Consumption of mysids displayed an opposite trend, with rates relatively stable at the stations landward of the ridge top (38.4% to 35.7%) and then increasing dramatically on the seaward side of the ridge (63%). Shrimp were found at highest levels on the landward flank of the ridge, with substantial reductions nearshore (0.9%) and on the seaward flank (0.1%). Detritus comprised less than 5% of stomach content at either station, and no sediment was found in the stomachs.

Of the three species investigated, the diet of *Micropogonias undulatus* was the broadest and showed the most variation between habitats (Table 3.3). Polychaetes, primarily from the Family Ampharetidae, comprised a large proportion of the overall prey, decreasing in importance from 43.7% nearshore to 30.3% on the landward side of the ridge to 19.5% on the seaward side of the ridge. The consumption of mysids was greatly reduced, ranging from 12.1% on the landward flank of the ridge to 2.9% on the seaward flank. The same was true of piscivory, which accounted for 2.9% on the seaward side of the ridge, 1.6% nearshore, and was totally absent from the landward side of the ridge. In addition to polychaetes, other prey items generally considered epibenthic fauna were present in varying amounts. With this benthic foraging the expected increases in the amount of detritus (> 20%) and sediment (1.7% - 15.5%) consumed were also observed.

Based on an analysis of stomach contents from all three species, it appears that mysid shrimp are distributed across the three habitats in relatively high abundances and that decapod shrimp and polychaete worms are present in the three habitats in varying abundance. Potential prey fish abundances during the same sampling period were highest in the nearshore habitat and substantially lower on the sides of the ridge. The number of different prey items is highest in the nearshore habitat (16 categories), slightly less on the landward side of the ridge (14 categories), and lowest on the seaward side of the ridge (12 categories).

Discussion

Distribution, abundance, and stomach fullness

The abundance of the three sciaenid species investigated was highest in the immediate vicinity and on either side of the sand ridge, with none of the species discussed captured on the top of the ridge. This is consistent with prior sampling at Beach Haven Ridge (Chapter 2). While physio-chemical conditions (temperature, salinity, pH, dissolved oxygen, water clarity) were similar at the top of the ridge compared to the flanks of the ridge and nearshore waters, there were no life stages of *B. chrysoura*, *M. undulatus*, or *C. regalis* present on the top of the ridge. The absence of these species under similar water quality characteristics across the sand ridge habitats rules out physiological tolerances as a reason for the pattern in distribution observed. The mean relative stomach fullness for each species and the similarity in fullness at the nearshore and side of the ridge habitats suggests that these habitats provide important prey resources.

There is a possibility that the species in question may move between habitats on a diel or tidal cycle and that the stomach fullness and diet composition observed are not reflective of the habitat in which they were captured. While this may be the case, prior studies of young-of-the-year *M. undulatus* in estuarine habitats have shown a high degree of habitat fidelity (Miller and Able 2002). This increases the likelihood that the species were actively using the habitat in which they were captured. In addition, gastric evacuation times for larval and juvenile sciaenids have been found to range from two to five hours, with rates slowing as fish size increases (Wuenschel and Werner 2004). Combined with the slightly digested condition of most of the prey items it is likely that feeding occurred immediately before if not at the time of capture and thus the diet data reflects the location/habitat of capture.

Diet Composition

The diets of all three species displayed variability across the habitats, with *Micropogonias undulatus* showing the greatest variability and *Bairdiella chrysoura* the least. This variation in diet may be due to changes in the availability of the preferred prey item of each species in each habitat. *Cynoscion regalis* consumed similar quantities of fish landward of the ridge top (47.2% and 39.3%), with a substantial reduction in fish consumption seaward of the ridge (20.3%). This pattern did not appear to be related to a change in predator size as the mean length of the fish found nearshore was less than those found on either flank of the ridge, which were of similar size. The pattern of piscivory was mirrored in the abundance of the prey fish favored by *C. regalis* (*Anchoa mitchilli*) at those stations during the same sampling effort (unpublished data). The reduction in fish consumption seaward of the ridge by *C. regalis* was compensated for by a comparable increase in consumption of mysids. The higher consumption of prey fish where they were readily available and a partial switch to mysids when prey fish abundance was low suggests that fish are the preferred prey of *C. regalis* larger than 180 mm TL in inner shelf waters. This is supported by prior estuarine studies showing the diets of *C. regalis* greater than 160 mm SL to be dominated by fish (Stickney et al. 1975, Chao and Musick 1977).

The diet of *Bairdiella chrysoura* showed the least amount of variation across habitat, with mysid shrimp comprising nearly half the diet in both habitats. Prior estuarine studies have found that mysids are the most common prey item for *B. chrysoura* of 120-140 mm TL (Chao and Musick 1977), and the findings of the present study are similar. One potential explanation for the relatively small variation in diet between habitats is that the abundance of mysids nearshore was sufficient to meet the energetic requirements of the species and that few additional prey items were needed. On the landward flank of the ridge, a slight reduction in the abundance of mysids may have required the consumption of supplementary prey such as decapod shrimp and amphipods. Conversely, the abundance of alternative prey items may be lower in the nearshore habitat, thus causing *B. chrysoura* to consume more mysids there. Without an assessment of prey item availability in the two habitats no conclusion can be reached.

The diet of *Micropogonias undulatus* also showed variation across habitats based on the availability of prey resources. Polychaete worms in the Family Ampharetidae comprised the largest prey item, but declined in consumption across the transect. These worms are present nearshore and on either ridge flank, and can form large mounds nearshore which have been known to develop and disappear within a matter of five to six months (Rose Petrecca and Joseph Dobarro, pers. comm.). Side-scan sonar images taken two months prior to sampling in 2006 show a number of these mounds nearshore and provide a plausible explanation for the large proportion of ampharetids present in stomachs in this habitat compared to other habitats.

The three sciaenids investigated here represent a range of feeding modes found in coastal near-shore waters; piscivory (both benthic and pelagic), predation on small crustaceans (i.e. mysids), and predation on larger epibenthic prey (i.e. polychaete worms, mollusks). The abundances of the three fish species were highest on the flanks of Beach

Haven Ridge and in a nearshore habitat, with none of the species found on top of the ridge. While the physical characteristics of the habitats varied, those on the top of the ridge were not favored by the polychaete worms preferred by *M. undulatus*, and few of the prey fish found in the stomachs of *C. regalis* were captured on top of the ridge in previous sampling (Chapter 2). Although the sampling duration of this study was brief (two days in September 2006) the similarity in water quality between the top of ridge and ridge flank habitats coupled with the differences in the abundance of both predator and preferred prey items in these habitats support the conclusion that prey availability affects fish habitat selection. For species that depend on these feeding strategies, this sand ridge provides a mosaic of habitat types that provide enhanced feeding opportunities and are an important aspect of the coastal seascape.

Table 3.1 - Names, categories, and descriptions of aggregated prey categories included in the stomach content analysis of *Bairdiella chrysoura*, *Cynoscion regalis*, and *Micropogonias undulatus* collected during September 2006 in the vicinity of Beach Haven Ridge, southern New Jersey (see Fig. 3.1 for locations).

Amphipods	Amphipods, primarily gammarids
Crabs	Crabs
Decapod shrimp	Decapod shrimp
Mysid shrimp	All mysid shrimp
Decapod Megalopae	
Crustacean parts	Parts of crustaceans too small to identify
Isopods	Valviferean isopods
Polychaetes	Amphoretidae, Phyllododaciae, polychaete tubes, and unidentified polychaetes
Nematodes	All nematode worms
Nemertines	All nemertine worms
Bivalves	Bivalve mollusks and shell fragments
Gastropods	Gastropods
Fish	Fish and fish remains including scales and eggs
Detritus	
Sediment	Sediment, including sand
UID	Unidentifiable material

Table 3.2 – Number of stomachs, size range, and average stomach fullness for *Bairdiella chrysoura, Cynoscion regalis, and Micropogonias undulatus* collected during September 2006 in the vicinity of Beach Haven Ridge in southern New Jersey (see Fig. 3.1 for sampling locations). Fish size ranges are total length in millimeters.

	Number of stomachs	Size range (TL mm)	Avg Stomach Fullness
B. chrysoura			
BHR-5 (nearshore)	61	97-149	2.6 range: 1-4
BHR-6 (landward flank)	19	110-197	2.4 range: 0-3
BHR-7 (seaward flank)	NA	NA	NA
C. regalis			
BHR-5 (nearshore)	46	88-262	2.8 range: 1-4
BHR-6 (landward flank)	40	100-278	2.5 range: 0-4
BHR-7 (seaward flank)	24	166-301	3.1 range: 2-4
M. undulatus			
BHR-5 (nearshore)	73	114-290	3.4 range: 1-4
BHR-6 (landward flank)	45	144-216	3.4 range: 2-4
BHR-7 (seaward flank)	4	222-314	3.5 range: 2-4

Table 3.3 – Percentage consumption of prey type for three demersal fish species (*Cynoscion regalis*, *Bairdiella chrysoura*, and *Micropogonias undulatus*) captured in the vicinity of Beach Haven Ridge, southern New Jersey in September 2006 (see Fig. 3.1 for sampling station locations and Table 3.1 for prey categories).

	BHR-5	BHR-6	BHR-7
Bairdiella chrysoura			
Amphipods	2.0	7.9	NA
Crabs	0.2	0	NA
Shrimp	10.2	20.3	NA
Mysid	64.2	48.1	NA
Decapod Megalopae	0.6	5.9	NA
Crustacean parts	4.0	4.0	NA
Isopods	0.5	0.2	NA
Polychaetes	0.4	0.2	NA
Nematodes	0	0	NA
Nemerteans	0	0	NA
Bivalves	0	0	NA
Gastropods	0	0	NA
Fish	7.5	8.3	NA
Detritus	4.1	0.3	NA
Sediment	0	0	NA
UID	6.3	4.8	NA
Cynoscion regalis			
Amphipods	0	0	0
Crabs	0	0.1	0
Shrimp	0.9	5.9	0.1
Mysid	38.4	35.7	63.0
Decapod Megalopae	0.3	0.3	0.4
Crustacean parts	6.5	9.5	7.9
Isopods	0	0	0
Polychaetes	0.2	0.2	0.2
Nematodes	0	0	0
Nemerteans	0	0	0
Bivalves	0	0	0
Gastropods	0	0	0
Fish	47.2	39.3	20.3
Detritus	3.1	4.7	3.7
Sediment	0	0	0
UID	3.5	4.3	4.4
Micropogonias undulatus			
Amphipods	0.4	0.4	0
Crabs	1.4	0.30	9.2
Shrimp	0.1	0.5	5.5
Mysid	10.0	12.1	2.9
Decapod Megalopae	1.3	8.4	0
Crustacean parts	1.7	1.5	1.8
Isopods	1.0	0	0.4
Polychaetes	43.7	30.3	19.5
Nematodes	0.2	0.6	0
Nemerteans	3.1	7.0	1.0
Bivalves	4.2	0.3	8.1
Gastropods	0.1	0	0
Fish	1.6	0	2.9
Detritus	21.8	29.5	28.3
Sediment	6.2	1.7	15.5
UID	3.2	7.4	4.9

Figure 3.1 - Station locations for otter trawl collections across Beach Haven Ridge conducted in July and September 2006. Bathymetric data from NJ Geological Survey.

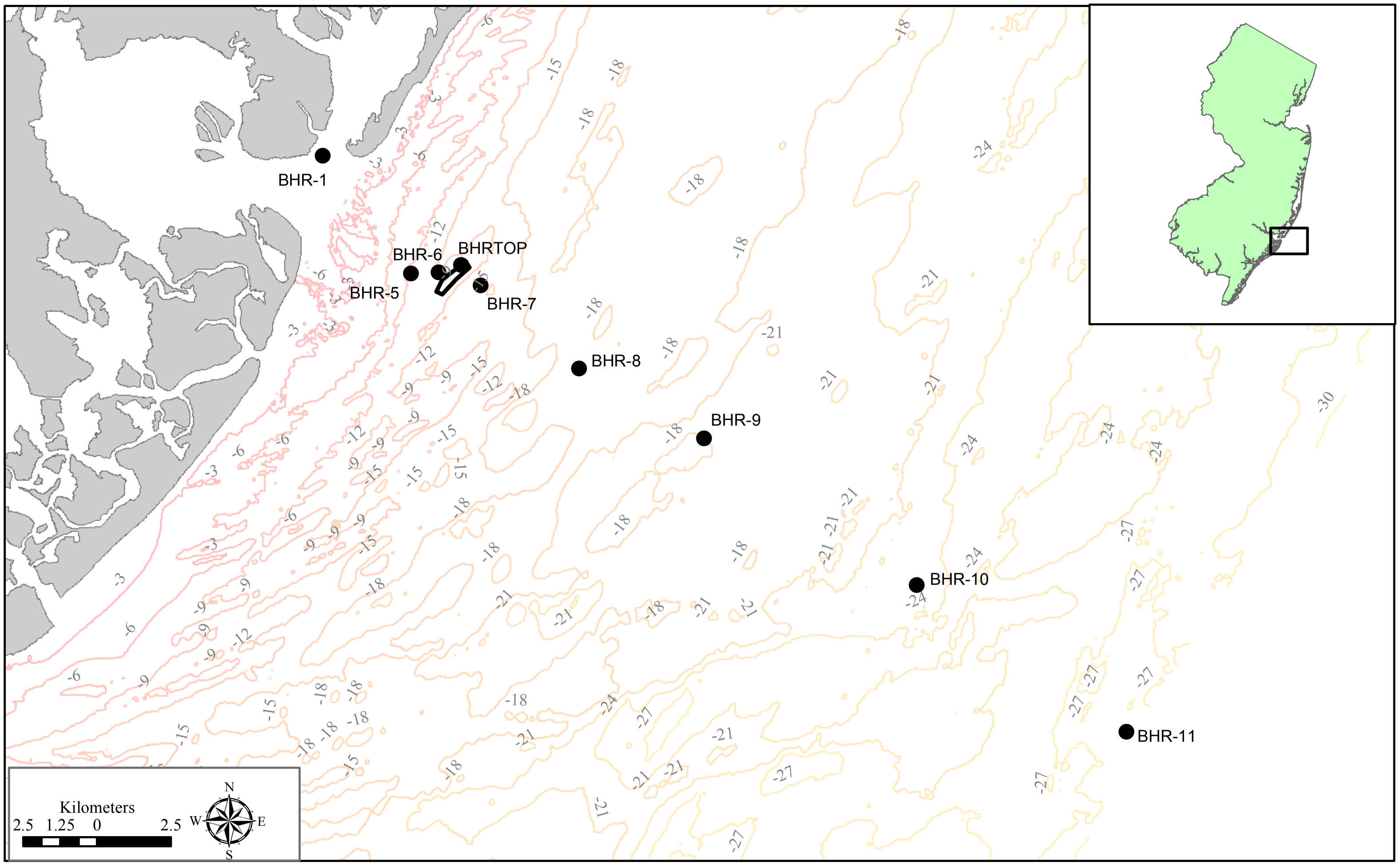


Figure 3.2 - Catch-per-unit-effort (CPUE) for all species (A) and for *Bairdiella chrysoura*, *Cynoscion regalis*, and *Micropogonias undulatus* (B) collected in September 2006 in the vicinity of Beach Haven Ridge in southern New Jersey. See Figure 3.1 for station locations.

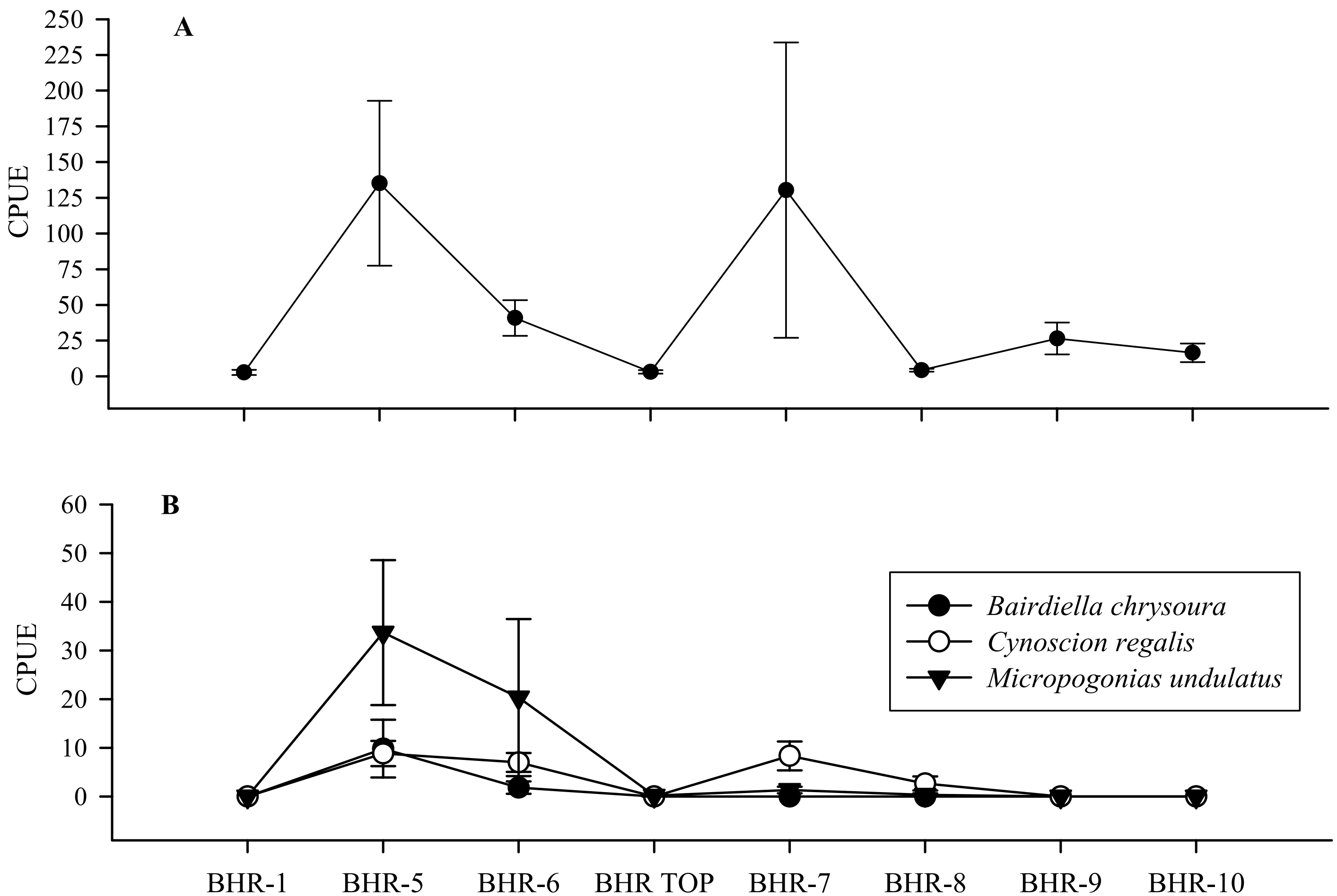
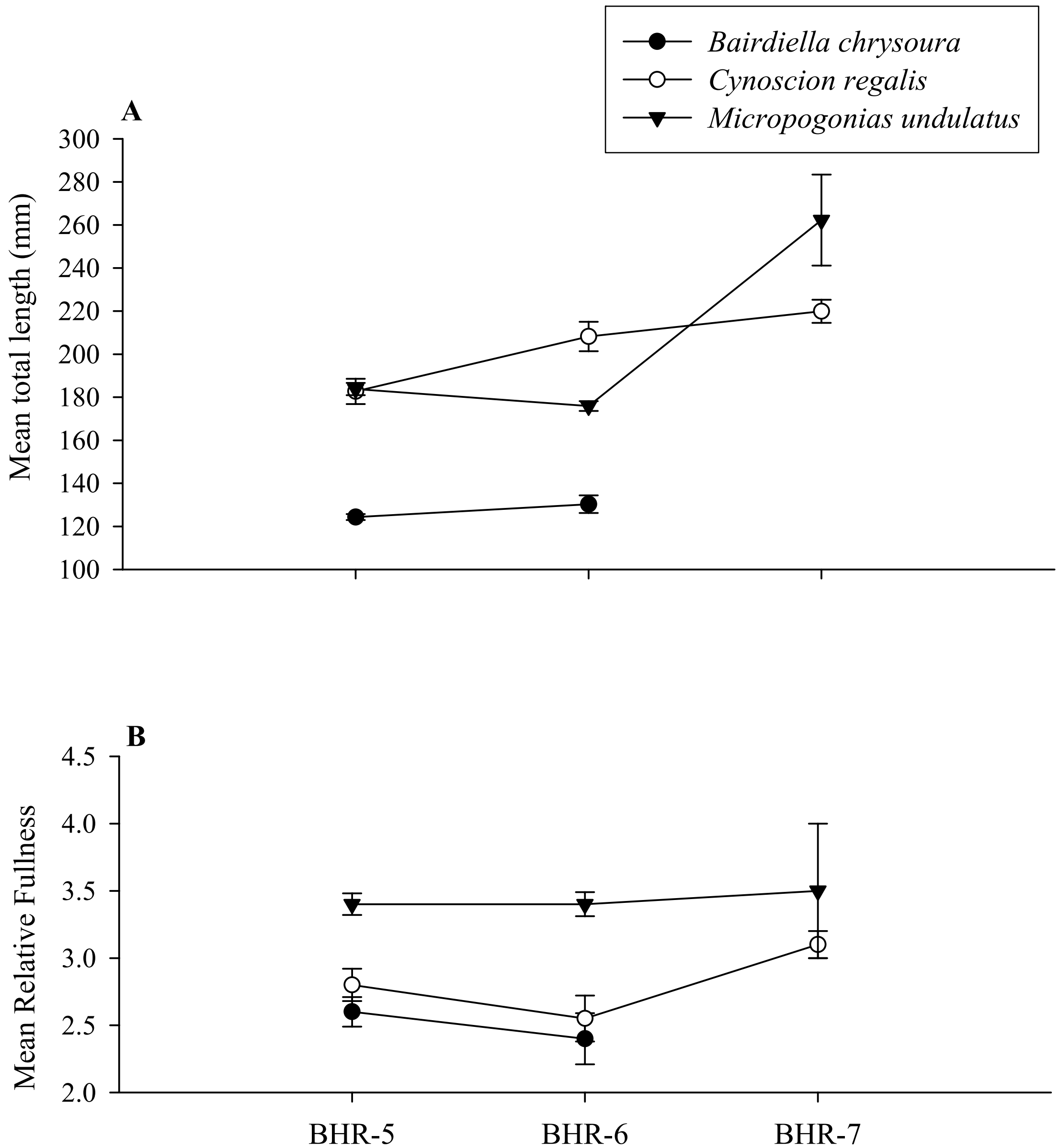


Figure 3.3 - Mean total length (A) and mean relative stomach fullness (B) for *Bairdiella chrysoura*, *Cynoscion regalis*, and *Micropogonias undulatus* collected in September 2006 in the vicinity of Beach Haven Ridge. See Figure 3.1 for station locations.



CHAPTER IV

Summary and Implications

The goal of this study was to determine if fish use differs between shoreface sand ridges and the surrounding inner continental shelf in order to understand the importance of sand ridges to individual species or species assemblages. Further, food habits of the dominant demersal species were assessed to determine if aspects of feeding (stomach fullness, diet composition) were related to patterns observed in the abundance and assemblage analysis. Through the use of historic multi-gear trawl datasets and new collections, patterns in species abundance and assemblages were identified, as were environmental factors associated with those assemblages. While studies at larger spatial scales have identified cross-shelf changes in species assemblages this is the first study to address how the presence of a sand ridge affects species abundances and assemblages in nearshore waters. The results of the stomach content analysis lend support to the idea that prey availability affects small scale habitat selection within a larger hydrographic framework.

Species Abundance and Assemblage- Environmental Relationships

Analysis of beam and otter trawl datasets revealed that species abundance and richness displayed a bimodal distribution across the inlet to offshore transects, with the highest values on either side of the ridges regardless of gear type. Ordination techniques identified three species assemblages; inshore, near-ridge, and offshore. These assemblages were present whether the data set included all fish captured (pelagic and demersal) or was limited to demersal species only. The species within these groups varied substantially between gears, and to some degree between mid-summer and late summer seasons. Differences in the beam trawl assemblages were due to the presence or absence of species while the otter trawl assemblages primarily differed from each other in the relative abundance of shared species. Environmental factors influencing the assemblages consisted of depth, temperature, distance from the top of the ridge, and habitat complexity.

This study provides information on multispecies communities and their interactions with the environment, a prerequisite for the ecosystem-based management approaches that are being advocated by a number of prominent commissions (Pew Oceans Commission 2003, U.S. Ocean Commission 2004). The presence of a distinct species assemblage and the higher abundances associated with sand ridges suggests that the structure of sand ridges and their associated assemblages should be taken into consideration when evaluating these features for mineral extraction. Habitat complexity was an important factor in determining species assemblage and abundances were lowest in simple habitats on top of the ridges and in the vicinity of the ridges. Alteration of the ridges through mining may have adverse impacts on habitat complexity and could consequently lead to reduced abundances and changes in species assemblages in nearshore waters.

Food habits

The abundance of the three sciaenid species investigated was highest in the habitats in the immediate vicinity and on either side of Beach Haven Ridge, with none of the three species captured on top of the ridge. The mean relative stomach fullness of each species was similar in each habitat, but the diets of all three species varied across the habitats. The variation in diet is likely due to changes in the availabilities of the preferred prey items in each habitat, which may also be habitat associated.

The importance of sand ridges is reinforced by the high abundances of the three sciaenid species only in the vicinity of the ridge during the study and the high mean relative stomach fullness for each species. While alteration of the habitats around the ridge may directly affect those species that rely on benthic and epibenthic prey, the results of this study suggest that the effects may also be felt by the piscivorous fish found primarily in the near-ridge assemblage.

Future work

As part of this study other shore faced sand ridges in the vicinity of Beach Haven Ridge were sampled to determine if the assemblages at Beach Haven Ridge were local phenomenon or were more broadly applicable. Due to the small sample size that question could not be adequately addressed. Additional sampling at these ridges, and in inner shelf waters without ridges, using the same protocol described here should continue. Identification of the habitat complexity at each sampling location through definitive means (i.e. camera sled, SCUBA, etc.) should also be conducted as it provides important insights into assemblage structure. If the assemblages are localized to a particular ridge then management considerations would need to be tailored to each ridge, or groups of ridges with enhanced abundance, richness, and assemblage structure.

Additionally, sampling should also be conducted at night to identify species and potential assemblages not collected during daytime sampling. A study at a shoal system in Maryland and Delaware found evening assemblages that were distinct from their daytime counterparts within similar habitats (Diaz et al. 2003). Given the nocturnal feeding habits of some species there is the possibility that species richness of near-ridge habitats will increase, lending further support to the importance of sand ridges.

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