SHORE ZONE HABITAT USE BY FISHES AND CRABS IN DELAWARE BAY:

BEACH VS RIPRAP SHORELINES

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Estuarine habitat loss and fragmentation are among the most serious threats facing coastal fisheries. A major component of habitat loss is coastal development in the form of shoreline hardening, the process of placing hardened structures along soft shorelines to reduce erosion and protect upland property. Shoreline hardening drastically alters morphology of the intertidal zone, and has been shown to disrupt local patterns of habitat usage among shore zone biota. Several types of hardening structures are becoming more common within the Mid-Atlantic, and coastal population growth coupled sea level rise will further increase the demand for shoreline stabilization in the future. In this context, it is crucial to determine the importance of the shore zone as fish habitat, and the effects of anthropogenic modification. This study will assess differences in the usage, value, and function of unhardened shorelines relative to hardened shorelines for estuarine nekton communities within the Delaware Bay.

In the first part of this study, I used quantitative sampling to measure species composition, overall density, and densities of individual species among natural (beach) and hardened (riprap) shorelines to evaluate spatial and temporal changes in the estuarine shore zone assemblage associated with shoreline modification. Fishes and crabs along the western shoreline of Delaware Bay were sampled from June through late September, 2012 and 2013. During 2013, the shore zone assemblage at one site in lower Delaware Bay was also sampled during both day and night hours. Over the two years of this study 14,198 fish and crabs were captured within the shore zone in total, comprised of 51 individual species. Overall nekton density was higher along beach shorelines at 2 of 3 locations. Nekton density was also higher at night along both beach and riprap shorelines.

Habitat preference between hardened and unhardened shorelines existed among several abundant species. Usage of shore zone habitat also changed among several abundant species between day and night hours. Distinct assemblages of fish and crabs were present among beach and riprap shorelines at 2 of 3 locations and among day and night hours. In general, the results demonstrate altered usage of shore zone habitat along hardened shorelines and changes to overall use of shore zone habitat between day and night hours.

Chapter 2 addressed changes in the feeding habits of top piscivorous fish species within the Mid-Atlantic estuarine food web. Diet composition and stomach fullness were measured in weakfish, bluefish, and striped bass captured during shore zone sampling. Striped bass and weakfish diets did not show changes in prey composition or feeding intensity among shoreline types. However, weakfish diet composition shifted among sites, indicating an effect of location on either prey selectivity or availability. Bluefish diet reflected differences in the predation of prey species associated with shoreline type in the month of July, with individuals captured along the beach foraging on fish prey and those captured along the riprap foraging on mysid shrimp. Bluefish captured in August exhibited similar diet composition overall, but different stomach fullness values indicating a difference in feeding intensity. In general, these findings show that shoreline hardening has the potential to alter shore zone habitat use and function for estuarine fishes, and that these effects appear to be inconsistent among species and size-classes.

Chapter 1

INTRODUCTION

Estuaries along the eastern coast of the United States are crucial for many ecologically and economically important fishes during one or more of their life stages (Able & Fahay 1998; 2010). Sandy beach shore zones within estuaries are particularly productive areas that support high densities of small, forage, and juvenile fishes (McLachlan & Brown 2006; Able et al. 2013). However, despite their importance, shore zone areas often exist under substantial anthropogenic influence.

Shore zone habitat is particularly sensitive to urbanization as a result of its close proximity to land (Bilkovic et al. 2006). A major component of urbanization is shoreline armoring, the process of placing hardened structures along soft shorelines to reduce erosion and protect upland property. These structures usually come in the form of rock piles (riprap) or wooden walls (bulkhead) placed within the intertidal zone. Modification of natural shorelines drastically alters the morphology of the land-water interface and has been shown to greatly reduce or completely remove intertidal habitat, a highly productive area for organisms (Bilkovic & Roggero 2008). Additionally, armored shorelines reduce sediment supply from the land and reflect wave energy leading to higher rates of erosion, subsequent deepening of the shore-zone, and a resulting loss of shallow-water habitat. (Davis et al. 2002; Toft et al. 2007).

Changes to shoreline morphology can affect the biological integrity of shore zone ecosystems by impacting a range of fauna, primarily invertebrate and fish communities (Peterson et al. 1999; Toft et al. 2007; Bilkovic & Roggero, 2008; Sobocinski et al. 2010;

Balouskus 2012; Balouskus & Targett 2012). Several studies support the concept that shoreline modification adversely affects adjacent fish communities. These negative effects have been demonstrated across a range of freshwater and marine systems (Toft et al. 2007). Several types of hardening structures are becoming more common within the Mid-Atlantic, and coastal population growth coupled with sea level rise will further increase the demand for shoreline stabilization in the future. In this context, it is crucial to determine the importance of the shore zone as fish habitat, and the effects of anthropogenic modification.

Relatively few studies have specifically focused on riprap shorelines in an estuarine environment (Peterson et al. 1999), possibly because traditional sampling methods are difficult to use in these areas making quantitative comparisons between natural and altered shorelines difficult. The present study is unique in that it will make comparisons in habitat usage between beach and riprap shorelines by fishes and crabs in an exposed, high energy estuarine environment.

The first part of this study uses quantitative sampling to measure species composition, faunal density, and densities of individual species among natural (beach) and hardened (riprap) shorelines to evaluate spatial and temporal differences in the estuarine shore zone assemblage associated with shoreline hardening. The second part of this study addresses the feeding habits of top piscivorous fish species along beach and riprap shorelines. This study will assess differences in the usage, value, and function of unhardened shorelines relative to hardened shorelines for estuarine nekton communities within the Delaware Bay.

Chapter 2

FISH AND CRAB ASSEMBLAGES ALONG BEACH AND RIPRAP SHORELINES OF DELAWARE BAY

Introduction

Estuaries along the eastern coast of the United States are crucial for many ecologically and economically important fishes during one or more of their life stages (Able & Fahay 1998; 2010). Sandy beach shore zones within estuaries are particularly productive areas that support high densities of small, forage, and juvenile fishes (McLachlan & Brown 2006; Able et al. 2013). Utilization of this habitat is likely driven by abundant resources and advantageous physicochemical conditions (Ruiz et al. 1993; Gibson et al. 1996; Able et al. 2013). It is generally accepted that predator refuge is also a major driving force behind this utilization for juvenile and forage fishes (Paterson and Whitfield 2000). These criteria make shore zone areas model nursery habitat and potential migration pathways for a variety of fish species (McLachlan & Brown 2006). However, despite their importance, shore zone areas often exist under substantial anthropogenic influence.

Watershed and shoreline development pose significant threats to estuaries, adversely affecting these ecosystems through increased nutrient inputs, erosion, loss of habitat, and altered hydrology (Bilkovic et al. 2005; Bilkovic & Roggero 2008). Shore zone areas are particularly sensitive to urbanization due to a close proximity to land (Bilkovic et al. 2006). A major component of urbanization is shoreline armoring, the process of placing hardened structures along soft shorelines to reduce erosion and protect upland property. These structures usually come in the form of rock piles (riprap) or wooden walls (bulkhead) placed within the intertidal zone. Modification of natural shorelines drastically alters the morphology of the land-water interface and has been shown to greatly reduce or completely remove intertidal habitat, a highly productive area for organisms (Bilkovic & Roggero 2008). Additionally, armored shorelines reduce sediment supply from the land and reflect wave energy leading to higher rates of erosion, subsequent deepening of the shore-zone, and a resulting loss of shallow-water habitat. (Davis et al. 2002; Toft et al. 2007).

Changes to shoreline morphology can affect the biological integrity of shore zone ecosystems by impacting a range of fauna, primarily invertebrate and fish communities (Peterson et al. 1999; Toft et al. 2007; Bilkovic & Roggero, 2008; Sobocinski et al. 2010; Balouskus 2012; Balouskus & Targett 2012). Several studies support the concept that shoreline modification adversely affects adjacent fish communities. These negative effects have been demonstrated across a range of freshwater and marine systems (Toft et al. 2007). Relatively few studies however, have specifically focused on riprap shorelines in an estuarine environment, possibly because traditional sampling methods are difficult to use in these areas making quantitative comparisons between natural and altered shorelines difficult. However, one such study was carried out along the Gulf of Mexico (Mississippi coast) by Peterson et all (1999) who compared fish abundance between unaltered beach, unaltered marsh habitats, and altered marsh habitats. Altered shorelines included both riprap and bulkhead, and were shown to increase depth profiles at the land-water interface (Peterson et al. 1999). Species richness of fish taxa was very similar between unaltered marsh and beach habitats and markedly lower at altered marsh habitat. Both demersal and nektonic fishes were generally more abundant at unaltered marsh and beach than at altered marsh (Peterson et al. 1999). General patterns in nekton abundance and diversity indicated that altered marsh habitat was less utilized by fishes than was beach or unaltered marsh habitat (Peterson et al. 1999).

The practice of converting natural shorelines to armored structures is prevalent along many coastal areas of the United States, where numerous tributaries and estuaries are already highly modified. This process is continuing to occur at a rapid pace (Able et al. 1999; Davis et al. 2002; Bilkovic et al. 2006; Bilkovic et al. 2007; Bilkovic & Roggero 2008; Bilkovic 2010; Sobocinski et al 2010) and usually corresponds to the rate of population growth within an area (Douglass & Pickel 1999). In the United States the coastal population has doubled within the past 50 years (Cahoon et al. 2010), greatly increasing waterfront development and consequently the demand for shoreline hardening to protect upland property from erosion. Climate change will also intensify the demand for hardened shorelines as predicted sea-level rise will result in increased rates of flooding, higher storm surges, and loss of low-lying coastal land areas (Najjar et al. 2000). In the Mid-Atlantic region the annual rate of sea level rise is almost twice the worldwide value of 1.7±0.5 mm due to localized sinking of land masses, making this area especially vulnerable to these profound effects (Cahoon et al. 2010). Considering the widespread and escalating use of armored shorelines, it is becoming increasingly important to understand how they affect the biology of valuable shore zone ecosystems.

The shore-zone along the Delaware Bay is comprised largely of sandy beach, which accounts for 74% of the total shoreline (Lathrop et al. 2006) and has been historically shown to support high densities of small forage or juvenile fish, as well as spawning and feeding activities of adult fish (Shuster 1959; de Sylva et al. 1962). Shoreline stabilization structures, primarily riprap, currently account for 4% of the total shoreline, making the shoreline of Delaware Bay less armored than many other estuaries along the Mid-Atlantic Coast (Lathrop et al. 2006). However, Delaware is experiencing a period of record population growth and development, especially within already densely inhabited coastal areas (Delaware Sea Grant 2011). This trend, coupled with expected sea level rise for the area, has the potential to greatly increase the demand for stabilization structures in the future. In the context of a continually developing shoreline it is crucial to determine the importance of the shore zone as fish habitat and the effects of anthropogenic modification.

The present study investigated differences in the species composition of the fish and crab assemblage along with densities of individual species between natural (beach) and hardened (riprap) shorelines. Additionally, since fish assemblages are highly temporally variable, night sampling was used to identify differences in shore zone habitat use and relationship among hardened and natural shorelines over a day-night cycle.

Materials and Methods

Study Area

Delaware Bay is a temperate coastal plain estuary that provides a variety of important habitats for many fishes occurring along the Mid-Atlantic coast (Boutin, 2008) and is one of the largest estuaries on the eastern U.S. coast. The study area comprises three sites along the western shore of Delaware Bay; Lewes Beach, Mispillion, and Port Mahon (Figure 1.1). Lewes and Mispillion are polyhaline, whereas Port Mahon is mesohaline to polyhaline. Un-vegetated shorelines in Delaware Bay are characterized by shallow, gradually sloping sand to slightly muddy beaches which are often subject to wave erosion. Along the western shoreline of Delaware Bay, riprap is the predominant form of erosion control. Each sampling site in this study was selected based on the presence of both natural (beach) and hardened (riprap) shorelines. The shorelines around Lewes and Mispillion are less modified overall then Port Mahon, where a small stretch of beach exists surrounded by riprap (Figure 1.2). One, 200m stretch of each shoreline type was selected at each location (Figure 1.2).

Macrofaunal Sampling

Fishes and crabs were sampled from June through late September 2012 and 2013. Sampling occurred weekly at the Lewes and Mispillion sites in 2012 and bi-weekly at Lewes, Mispillion, and Port Mahon in 2013. Sampling covered the intertidal and shallow subtidal areas < 1.5m in depth. Daytime sampling took place at least one hour after sunrise to one hour before sunset. Each sampling effort consisted of 4 seine-hauls using a 36 meter bag-seine net (4' high; 3.5mm mesh). Two seine-hauls were conducted at randomly chosen locations along a 200 meter stretch of both beach and riprap at each site.

To maximize sampling efficiency and minimize losses of mobile fishes the net was deployed by boat using the following procedure (after Steve Giordano, NOAA Chesapeake Bay Office): 1) One end of the net was deployed onto the shoreline and held in place. 2) The boat was directed along a half circle from the initial deployment point to a second point on the shoreline while the net was fed off the bow to quickly enclose the area of water immediately adjacent to shore. To calculate the volume of water sampled, the distance between both ends of the net was measured along with onshore and offshore water depth at the net apex. 3) Both ends of the net were slowly moved together along the shore. On riprap shorelines fish were actively scared from between the rocks and into the bag of the net by thrusting PVC poles into and around rock crevices. 4) Once the two ends of the net were together, the net was pulled in, forcing all enclosed fish into the bag. 5) The bag contents were pulled out of the water and quickly sorted. Fishes were counted and all individuals were measured (for species with greater than 20 captured individuals a random subsample of 20 was measured; fork length for fishes with forked tails, total length for all other fish species, carapace width for crabs). Weakfish, bluefish, and striped bass were immediately placed on dry ice and later stored in a -80C freezer for diet analysis. All other fishes and crabs were released. Water temperature and salinity also measured during each seine-haul along with onshore and offshore depth.

In this study, sampling was conducted within 3 hours of high tide and every effort was made to standardize water level among shoreline type. To keep seining efficiency similar among beach and riprap shorelines, all sampling locations were positioned along areas where substrate was sand to dense mud, with little to no offshore structure (i.e. woody debris or rock). Sampling technique was as identical as possible along beach and riprap shorelines. Any differences in technique between the two shoreline types were designed to maximize sampling efficiency.

Balouskous (2012) found that two rapidly repeated seine hauls collected >90% of individual fish and >95% of blue crabs along both hardened and unhardened shorelines within the Delaware Coastal Bays. Sampling efficiency found among two rapidly repeated seine hauls was similar between hardened and unhardened shorelines. As a result of these findings, no catchability coefficient was applied to either shoreline type in the present study.

Night sampling within the shore zone at the Lewes site was conducted bi-weekly from June through late September 2013 and took place at least one hour after sunset to one hour before sunrise. Night sampling occurred during the identical tidal phase as the same week's day sampling at the Lewes site. Sampling methodology was identical to that described above.

Data Analysis

Due to differences in sampling frequency, data from 2012 and 2013 was analyzed separately. For both years, a paired t-test (data was paired within each sampling week) was used independently for each site to significant differences between faunal density along beach and riprap shorelines ($\alpha=0.05$). Square root transformations were utilized when necessary to meet the assumption of a parametric t-test. For individual species accounting for > 1% of the total catch, density differences between beach and riprap were compared independently among each site and year using a randomization test of t-scores. Distributions of t-scores were gathered from 5000 repeated t-tests run on random rearrangements of gathered data. This method was used because it was more robust than a standard t-test due to non-normality and frequent occurrences of zero-values within the data (Logan 2010). To reduce variability, data for each species was pooled across sampling weeks.

Differences in faunal density at the Lewes site between shoreline type, day-night, and week were assessed using two-factor ANOVAs ($\alpha=0.05$). Multiple two-factor

ANOVAs were used to test each combination of all 3 factors instead of a full 3-factor model to reduce variability within the data, and to simplify analyses. Square root and log(x+1) transformations were utilized when necessary to meet the assumptions of a parametric ANOVA. To further examine the effect of shoreline type and day-night on overall density, differences between beach and riprap were compared separately for data gathered during both day and night hours and differences between day and night were compared separately for data from beach and riprap shorelines using paired t-tests (data was paired within each sampling week; α=0.05). Density differences of individual species accounting for > 1% of the total catch at site Lewes between shoreline type and day-night were compared using a two-factor ANOVA. If significant effects were found from either factor, a randomization test of t-scores was used independently for each level within each factor to determine where significant effects occurred. Distributions of T-scores were gathered from 5000 repeated sample t-tests run on random rearrangements of gathered data. To reduce variability, data for each species was pooled across sampling weeks.

Differences in the fish and crab assemblage structure between location, shoreline type, and day-night were analyzed for each year using a multivariate approach with PRIMER (version 6). Similarity matrices were constructed using the Bray-Curtis similarity measure from the square root transformed mean density of each species within a day or night sampling effort from each sampling week. Non-metric multidimensional scaling (MDS) based on the similarity matrices was used to generate a two dimensional plot which depicts similarity of faunal assemblages among sampling time and/or location. Group-average hierarchal cluster analysis of the similarity matrices was overlaid upon the

MDS plot to identify biologically significant groupings based on similarity among faunal assemblages.

Results

Water Parameters

In 2012 shore zone water temperatures from June to September ranged from 22.3 to 30.6°C in 2012 and 18.2 to 33.4°C in 2013; salinity ranged from 2.04 to 31.1 in 2012 and 13.2 to 30.4 in 2013 (Table 1.1). No difference in temperature or salinity was observed between shoreline types. During both years temperature increased in the up-bay direction and salinity increased towards the bay mouth (Table 1.1).

Macrofaunal Assemblage

Over the two years, 10,897 fishes and crabs comprising 48 species were captured during daytime sampling. Dominant species in 2012 were Atlantic silverside (*Menidia menidia*; 36.12%) silver perch (*Bairdiella chrysoura*; 12.8%) bay anchovy (*Anchoa mitchilli*; 11.9%), and mummichog (*Fundulus heteroclitus*; 7.2%). Taken together these four species account for 68% of the total shore zone catch in 2012 (Table 1.2). Dominant species in 2013 were Atlantic silverside (36.1%), bay anchovy (11.9%), Atlantic menhaden (*Brevoortia tyrannus*; 9.4%), and weakfish (*Cynoscion regalis*; 9.0) (Table 1.3). Taken together these four species account for 79.9% of the total shore zone catch in 2013.

Data from 2012 showed a significant effect of shoreline type on overall faunal density. Overall faunal density at both Lewes (paired t-test; $P<0.01$) and Mispillion (paired t-test; $P<0.01$) was significantly higher along beach shorelines than riprap (Figure 1.3). Data from 2013 also showed a significant effect of shoreline type on overall faunal density. Overall faunal density at Lewes (paired t-test; $P=0.04$) and Mispillion (paired t-test; $P<0.01$) being significantly higher along beach shorelines than riprap (Figure 1.4). However, overall faunal density was not significantly different between beach and riprap at Port Mahon (paired t-test; $P=0.13$; Table 1.3).

Density of several dominant species (>1% of total catch at location and year of capture) differed between beach and riprap shorelines. During 2012, Atlantic silversides ($P<0.001$), spot ($P<0.001$), northern kingfish ($P<0.001$), lady crab ($P<0.01$), and Florida pompano ($P<0.001$) were significantly more dense along beach shorelines than riprap at Lewes (rand. test, t-score; Table 1.2). At Mispillion Atlantic silversides ($P<0.001$), spot ($P<0.001$), striped killifish ($P<0.001$), striped bass ($P<0.001$), and white perch ($P<0.01$) were more significantly more dense at beach shorelines than riprap (rand. test, t-score; Table 1.2). During 2013 at Lewes, Atlantic silversides ($P<0.01$) were more significantly more dense along beach shorelines (Table 1.3) and at Mispillion Atlantic silverside ($P<0.001$), spot ($P<0.001$), striped killifish ($P<0.01$), and white perch ($P<0.001$) were more significantly more dense along beach and bay anchovy ($P<0.001$) were more abundant along riprap (rand. test, t-score; Table 1.3). No significant differences in the densities of any species were observed between beach and riprap shorelines at Port Mahon during 2013 (rand. test, t-score; Table 1.3).

Average species richness per seine-haul at the two locations in 2012 ranged from 3.5 to 7.7 and was lower along riprap shorelines than beach (Table 1.4). In 2013 average species richness at the three locations ranged from 4.5 to 8.1 and was again lower along riprap shorelines than beach (Table 1.4).

MDS ordination of shore zone density data in 2012 and 2013 revealed distinct beach and riprap assemblages, along with lesser separation between locations (Figures 1.5-1.8). A similarity level of 50-60% produced mostly discrete beach and riprap groupings at each site. While not all samples fit under a single beach or riprap group, an overall separation of data points suggests distinct assemblages. Less apparent distinction was visible between locations. With the inclusion of Port Mahon in 2013 no apparent separation was visible between beach and riprap. The removal of Port Mahon data from the MDS plot revealed distinct separation between beach and riprap assemblages among Lewes and Mispillion samples. A similarity level of 55% produced mostly discrete beach and riprap groupings. Overall structure and separation of shoreline type assemblages is similar in Lewes and Mispillion samples between 2012 and 2013.

<u>Day-Night Differences</u>

A total of 5258 fishes and crabs comprising 34 species were captured at the Lewes site during the comparative day and night sampling in 2013. Dominant species were bay anchovy (39.6%), Atlantic silverside (39.0%), weakfish (6.0%), and blue crab (*Callinectes sapidus*; 3.2%) (Table 1.5). Taken together these four species account for 87.7% of the total shore zone catch in Lewes during 2013. Average species richness per seine-haul between day and night ranged from 5 to 7.6 and was lower during the day than night (Table 1.4).

There was a significant effect of shoreline type (two-factor ANOVA; DayNight-Shoreline Type $P<0.001$; Week-Shoreline Type $P<0.001$), day-night (two-factor ANOVA; DayNight-Shoreline Type $P<0.001$, Week-DayNight $P<0.001$), and week (two-factor ANOVA; Week-Shoreline Type $P<0.01$; Week-DayNight $P<0.01$) on overall faunal density. A significant interaction (two-factor ANOVA; $P=0.02$) between shoreline type and day-night was detected, suggesting that the effect of shoreline type depends on time of day. Overall faunal density from both day sampling (paired t-test; $P<0.05$) and night sampling (Paired t-test; $P< 0.001$) was higher along beach than riprap (Figure 1.9). Overall faunal density along both beach (Paired t-test; $P< 0.01$; Table 1.5) and riprap (paired t-test; 0.05) shorelines was higher during the night than during the day (Figure 1.9).

A significant effect of day vs night on density was found in bay anchovy, weakfish, blue crab, and bluefish and a significant effect of shoreline type on density was found in Atlantic silverside (two-factor ANOVA). No significant interactions were found between shoreline type and day-night among any individual species. Densities of both bay anchovy and weakfish were significantly higher at night along both beach (bay anchovy: $P<0.001$; weakfish: $P<0.001$) and riprap (bay anchovy: $P<0.001$; weakfish $P<0.01$) shorelines (rand. test, t-score; Table 1.5). Blue crab densities were significantly higher at night along the beach ($P<0.01$) but not riprap ($P=0.13$) (rand. test, t-score; Table 1.5). Densities of bluefish were significantly higher during the day along both beach ($P<0.05$) and riprap ($P<0.001$) shorelines. Densities of Atlantic silverside were higher along the beach during both day ($P<0.01$) and night hours ($P<0.001$) (rand. test, t-score; Table 1.5).

MDS ordination of shore zone density data revealed distinct day-night and beach-riprap fish assemblages within the Lewes shore zone. A similarity level of 60% produced mostly discrete groups between day-night and beach-riprap (Figure 1.10). While not all samples fit into a single group, an overall separation of data points suggests distinct assemblages between the two times of day and shoreline types (Figure 1.10).

Discussion

Macrofauna Assemblage

Overall, fish and crab assemblages in the present study were generally similar to those reported from other studies in estuarine shore zones (de Sylva et al. 1962; Boutin 2008) of the Mid-Atlantic coast of the U.S. The shore zone faunal assemblage over the two year study was dominated by Atlantic silverside, bay anchovy, weakfish, silver perch, menhaden, and blue crab in order of most abundant species to least.

This study shows a large contrast in shore zone habitat usage by fish and blue crabs between hardened and unhardened shorelines, with large differences between hardened and unhardened shorelines apparent at the community level as well as within individual species. Overall faunal density among two out of three sites and the densities of several dominant species were significantly higher along beach shorelines than riprap. Distinct fish and crab assemblages were apparent between beach and riprap shorelines. MDS ordination and cluster analysis of density data revealed generally distinct groupings of beach and riprap samples along the Lewes and Mispillion sites during both years. Most beach and riprap samples taken at Lewes and Mispillion were contained separately within 50-55% similarity groups. Densities were consistently higher along beach than along adjacent riprap shorelines. Differences in assemblages were also present among sites; however this was a weaker pattern than differences between shoreline types. These outcomes are supported by other studies which have shown lower densities of fishes along altered shorelines (Peterson et al. 1999; Toft et al. 2007). In contrast, Balouskus (2012) did not find discrete groupings of the overall fish and blue crab assemblage among shoreline types in tributaries of the Delaware Coastal Bays, although differences among shoreline type were detected among densities of individual species (Balouskus 2012). Greater abundances of all species that showed a singular relationship with shoreline type (mummichog, striped mullet, striped killifish, and silver perch) were collected from *S. alterniflora* marsh and beach shorelines compared with those from altered or hardened shorelines.

No effect of shoreline type on faunal density was observed at the Port Mahon site. It may be that the small stretch of beach sampled at this site was not large enough to support a sufficiently distinct fish and blue crab assemblage. Both the Lewes and Mispillion sampling sites were composed of 18% and 34% riprap, respectively, with the remaining shoreline made up of sandy beach. Port Mahon was made up of 95% riprap with only 5% beach.

Differences in sampling efficiency between beach and riprap shorelines could have influenced density measurements at these areas. The complex structure of riprap has the potential to lower the sampling efficiency of seining; however the sampling methodology used was developed by Steve Giordano, NOAA Chesapeake Bay Office, specifically to minimize this possibility. Dominant fishes captured in this study (Atlantic silverside, bay anchovy, weakfish, silver perch, menhaden) are species that would be unlikely or unable to seek refuge within crevices along a riprap shoreline. Cryptic species, which would be likely to seek refuge within rock crevices, were present in small abundance (<1% of total catch) and thus had a small influence on any comparison made between beach and riprap. Additionally during days of high water clarity, fish which were scared from between rock crevices were visually observed to quickly swim away from structure towards the bag end of the net instead of back into an adjacent crevice. Little to no fish were observed escaping from the bag when pulling the net in.

As a result of these considerations and observations, it is unlikely that observed differences in faunal density were a result of sampling efficiency between beach and riprap shorelines. Lower species richness and density along riprap shorelines, and the rather distinct differences in assemblage structure seen between beach and riprap found in the present study strongly suggest a difference in the habitat quality and function for estuarine nekton.

Several abundant fishes displayed habitat preference between shoreline types in this study. Eight species overall (Atlantic silverside, spot, northern kingfish, lady crab, Florida pompano, juvenile striped bass, white perch, and striped killifish) showed a preference for beach habitat and only one species (bay anchovy) showed a preference for riprap. Atlantic silverside, spot, striped killifish, and white perch were present in significantly higher densities along the beach during multiple years and/or at multiple sites indicating a persistent relationship with shoreline type.

Atlantic silversides dominated shore zone samples along both shoreline types during both years and were present in almost all seine hauls, but were largely more abundant along beach shorelines. This species is known to be pervasive in shallow water habitat and is among the most abundant forage fish in US Mid-Atlantic estuarine food webs (Balouskus & Targett 2012; De Sylva et al. 1962). Atlantic silversides are often the most abundant species encountered in the shore zones of tidal creeks, salt marshes and estuaries (De Sylva et al. 1962) and are known to spawn in the intertidal zone, particularly of *Spartina alterniflora* marsh, between April and July along the Mid-Atlantic coast (Balouskus & Targett 2012). In their comparison of shoreline types, Balouskus & Targett (2012) found that egg deposition was greater along riprap than on beach. Therefore, spawning behavior is unlikely to be a driving factor for the preference of beach habitat by Atlantic silversides in the present study.

Due to greater water depth at the land-water interface, riprap shorelines allow increased access to this area by large piscivores, thereby decreasing shelter from predation, relative to more gently sloping beach habitat. Thus beach habitat likely functions as shallow water refuge for this species and other small fishes in Delaware Bay and other estuaries in the Mid-Atlantic. There has been some argument over whether or not shallow water habitat actually reduces mortality from predators (Baker & Sheaves 2007); however, due to physical constraints (larger body size) as well as disadvantages to foraging in shallow water (risk of avian predation) it is likely that these areas at least have the potential to provide increased refuge from piscivorous fish relative to adjacent deeper water areas.

Striped killifish were most abundant at the Mispillion site and almost entirely absent from the other two sites. Although this species made up a relatively small proportion of the total catch for both years, none were captured along riprap at any site from either year indicating an inability to utilize this habitat type. This preference for sandy substrate has been shown in previous studies (Peterson and Peterson 1979; Balouskus 2012).

White perch were also most abundant at the Mispillion site likely due to lower salinity conditions. Although this species made up a small component of the total catch, white perch were significantly more dense along beach than riprap shoreline during both years. Adults have been previously reported to prefer shallow inshore areas with little or no cover (Rothschild 1990).

Spot made up a substantial component of the shore zone assemblage at all sites. This species was consistently most abundant along beach shorelines during both years. (Balouskus 2012) also found higher densities of spot along unhardened shorelines in tributaries of the Delaware Coastal Bays.

Several other species showed less consistent relationships to shoreline type. Northern kingfish, lady crab, Florida pompano, and juvenile striped bass were denser along beach shorelines in some instances, and bay anchovy were denser along riprap shorelines in some instances. Balouskus (2012) also found striped bass to be more abundant along unhardened shorelines in Delaware Coastal Bay tributaries. Bay anchovy was the only species in the present study to show a preference for riprap over beach habitat.

Day-Night Differences

The fish and crab assemblage in the Lewes shore zone was different during the day than at night. Higher faunal densities along both shoreline types occurred at night. Relationships with shore zone habitat usage varied among several abundant species, with bluefish utilizing the shore zone to a greater extent during the day and weakfish, spot, blue crab, and bay anchovy utilizing the shore zone to a greater extent at night. Distinct fish and crab assemblages were found between day and night samples as well as beach and riprap samples. Several studies have reported diel differences in both fish assemblages and densities in other estuarine habitat types (Stoner 1991; Rountree and Able 1993; Hagan and Able 2008). No other studies have examined different shore zone types over a day-night period, simultaneously. Overall these results suggest that fish usage of shore zone habitat varies between hardened and unhardened shorelines and between day and night hours; however associations of singular species to a particular shoreline type remains consistent between day and night.

Visual gear avoidance during daytime could potentially lower sampling efficiency of mobile fish species (Misund et al 1999; Hagan & Able 2008). However, differences in efficiency between day and night sampling was minimized in this study by seining methods specialized to quickly envelop the intended sampling area, diminishing potential losses of highly mobile fishes. Also, while combined species density was higher during the night, the density of most species was similar between day and night sampling with some highly mobile species being more abundant during the day. It seems unlikely that visual avoidance of sampling gear during the day greatly impacted observed day-night differences.

A variety of behavioral factors could explain diel changes in density observed for several species in the shore zone in this study. Potential drivers for this behavior are foraging movement, predator avoidance, and reproduction (Hagan and Able 2008). Feeding has been hypothesized as to be the main factor responsible for driving individual species into shore zone habitat during either day or night hours (Marin Jarrin & Shanks 2010). Avoidance of avian predators and piscivorous fishes during light hours has been suggested to retain species in deeper water in tightly packed schools (Keenleyside 1955; Furness 1982; Hagan and Able 2008). Although not much is known specifically about the behaviors displayed by dominant species exhibiting strong day night patterns in this study, several prominent behaviors among estuarine fishes can be examined.

Clupeiform fishes typically undergo a well described diel vertical movement responding to light levels (Blaxter and Hunter 1982; Hagan and Able 2008). Bay anchovies have been found to exhibit this behavior, inhabiting deeper water during the day (Vouglitois et. al 1987) and moving upwards or into shallow waters at night (Haroski 1998; Hagan and Able 2008). Bay anchovy was the only species in this study to show a preference for riprap habitat, possibly due to the deeper land-water interface along riprap shorelines, making riprap more suitable for this species during daytime, and increased utilization of shallow beach habitat only at night.

The vast majority of weakfish collected in the shore zone during this study were young of year (YOY) ~25 - 125mm long, and it is likely that increased usage of shore zone habit during night hours was driven by increased feeding opportunities or a reduction in predation risk. YOY weakfish in the present study were feeding almost exclusively on mysid shrimp (*Neomysis americana*) (See pg ##). This mysid has been shown to inhabit deeper areas during daylight and undergo a vertical migration into surface or shallow waters during night in Delaware Bay and the Delaware Coastal Bays (Hulburt 1957; Hopkins 1965). Although Grecay & Targett (1996) found that juvenile weakfish feeding was significantly reduced under dark or turbid conditions in the laboratory, fish compensated during higher prey densities leading to increased feeding rate. Thus, it is possible that increased nocturnal density in shore zone habitat during the present study was a response to higher concentrations of mysid shrimp, and/or a reduction in visual predation by large piscivorous fishes or birds.

Bluefish in the present study were largely YOY ~50 - 150mm long and were found to be feeding largely on juvenile Atlantic silversides and bay anchovies 10– 20mm long. Bay anchovies and Atlantic silversides of this size were too small to be effectively sampled by the mesh of the seine net, so it was not possible to quantify relative abundance of these fish between day and night; however large numbers of both species within this size range were observed visually within the bag of the seine net during net retrieval during day sampling but not at night (enough artificial light was present during night sampling to observe fish within the seine net bag). YOY bluefish in the Hudson River have been shown to have highest gut-fullness values during the day, indicating a preference for daytime feeding (Buckle and Conover 1997). Therefore, it is possible that increased diurnal shore zone usage exhibited by YOY bluefish in the present study was driven by an increased foraging efficiency, coupled with relatively high concentrations of forage fish during the day.

Blue crabs were also abundant in the shore zone and occurred in greater abundance during nighttime. Fitz et al (1991) captured a greater number of blue crabs during the day than at night in the intertidal zone of a Georgia salt marsh. They also found that blue crabs >100mm carapace width preyed predominantly on fishes, so it is possible that higher overall fish density in the shore zone during night in the present study was driving increased utilization of this habitat by blue crabs during this time.

Differences in the fish and crab assemblage and in densities of several dominant species between beach and riprap shorelines indicate differences in habitat quality and function for estuarine nekton. These differences likely stem from modifications to the shoreline morphology inherent to riprap, which include truncation of intertidal habitat and deepening of the land-water interface. While usage of shore zone habitat changes between day and night hours among dominant fauna, preference for specific shore zone type appears remains constant over a 24 hour period.

Table 2.1 Water parameters within the shore zone of Delaware Bay from June through September 2012 and 2013

2012	**Temperature**		**Salinity**	
Site	**Mean**	**Range**	**Mean**	**Range**
Lewes	25.2	22.7-28.3	19.2	2.04-31.1
Mispillion	27.4	22.3-30.6	17.3	4.79-29.8
2013				
Lewes	22.8	18.3-31.2	24.6	19.5-30.4
Mispillion	26.0	19.0-33.4	22.8	19.3-27.3
Port Mahon	26.4	18.2-30.8	18.3	13.2-21.0

Table 2.2 Mean densities (individuals/m3) of all shore zone fish, crabs and other macroinvertebrates captured a long beach and riprap shorelines among two sites during June to September 2012. Species are listed in descending order of percent contribution to total catch over the four month sampling period. Significant differences in mean density between shoreline type are denoted by asterisks according to the following criteria: P<0.05 = *; P<0.01 = **; P<0.001=***.

		Lewes			Mispillion				
		Beach		**Riprap**	**Beach**		**Riprap**	**Total Abundance**	**% Contribution**
All Species		0.11	***	0.04	0.2	**	0.04	5028	100
Atlantic Silverside	*Menidia menidia*	0.24	***	0.07	0.77	***	0.04	1816	36.12
Silver Perch	*Bairdiella chrysoura*	0.55		0.12	0.06		0.02	643	12.79
Bay Anchovy	*Anchoa mitchilli*	0.12		0.02	0.08		0.07	600	11.93
Mummichog	*Fundulus heteroclitus*	0.02		0.00	2.80		0.00	360	7.16
Atlantic Croaker	*Micropogonias undulatus*	0.20		0.11	0.02		0.00	230	4.57
Spot	*Leiostomus xanthurus*	0.14	***	0.04	0.08	***	0.01	208	4.14
Mullet	*Mugilidae*	0.02		0.05	0.14		0.05	163	3.24
Striped Killifish	*Fundulus majalis*	0.01		0.00	0.08	***	0.00	131	2.61
Menhaden	*Brevoortia tyrannus*	0.09		0.01	0.01		0.33	120	2.39
Halfbeak	*Hyporhamphus unifasciatus*	0.03		0.04	0.00		0.00	110	2.19
Northern Kingfish	*Menticirrhus saxatilis*	0.05	***	0.01	0.03		0.08	93	1.85
Blue Crab	*Callinectes sapidus*	0.01		0.03	0.06		0.03	90	1.79
Striped Bass	*Morone saxatilis*	0.01		0.00	0.06	***	0.02	88	1.75
Weakfish	*Cynoscion regalis*	0.01		0.02	0.02		0.02	71	1.41
Lady Crab	*Ovalipes ocellatus*	0.11	**	0.01	0.00		0.00	49	0.97
Florida Pompano	*Trachinotus carolinus*	0.04	***	0.00	0.03		0.00	45	0.89
Bluefish	*Pomatomus salatrix*	0.01		0.02	0.01		0.00	44	0.88
Atlantic Needlefish	*Strongylura marina*	0.04		0.03	0.07		0.00	32	0.64
White Perch	*Morone americana*	0.00		0.00	0.03		0.00	27	0.54

Table 2.2 Continued.

		Lewes		Mispillion			
		Beach	Riprap	Beach	Riprap	Total Abundance	% Contribution
Black Drum	*Pogonias cromis*	0.01	0.00	0.04	0.00	26	0.52
Sandbar Shark	*Carcharhinus plumbeus*	0.00	0.00	0.03	0.03	19	0.38
Butterfish	*Peprilus triacanthus*	0.05	0.00	0.03	0.00	12	0.24
Northern Puffer	*Sphoeroides maculatus*	0.02	0.00	0.00	0.00	8	0.16
Pinfish	*Lagodon rhomboides*	0.01	0.01	0.00	0.00	7	0.14
Red Drum	*Sciaenops ocellatus*	0.04	0.00	0.00	0.00	5	0.10
Lookdown	*Selene vomer*	0.01	0.00	0.00	0.01	4	0.08
Striped Burrfish	*Chilomycterus schoepfii*	0.01	0.01	0.00	0.00	4	0.08
Summer Flounder	*Paralichthys dentatus*	0.01	0.00	0.00	0.00	4	0.08
Hogchocker	*Trinectes maculatus*	0.01	0.00	0.01	0.00	3	0.06
Northern Pipefish	*Syngnathus fuscus*	0.03	0.01	0.00	0.00	3	0.06
Winter Flounder	*Pseudopleuronectes americanus*	0.03	0.00	0.00	0.00	3	0.06
Smooth Dogfish	*Mustelus canis*	0.00	0.01	0.00	0.00	2	0.04
Squid sp.	*Lolliguncula brevis*	0.00	0.01	0.00	0.00	2	0.04
Atlantic TripleTail	*Lobotes surinamensis*	0.00	0.00	0.00	0.00	1	0.02
Crevalle Jack	*Caranx hippos*	0.00	0.00	0.00	0.00	1	0.02
Northern Sennet	*Sphyraena borealis*	0.00	0.00	0.00	0.00	1	0.02
Sheepshead Minnow	*Cyprinodontidae variegatus*	0.01	0.00	0.00	0.00	1	0.02
Small Mouth Flounder	*Etropus microstomus*	0.02	0.00	0.00	0.00	1	0.02
Stone Crab	*Menippe mercenaria*	0.00	0.00	0.01	0.00	1	0.02

Table 2.3 Mean densities (individuals/m3) of all shore zone fish, crabs and other macroinvertebrates captured a long beach and riprap shorelines among three sites during June to September 2013. Species are listed in descending order of percent contribution to total catch over the four month sampling period. Significant differences in mean density between shoreline type are denoted by asterisks according to the following criteria: P<0.05 = *; P<0.01 = **; P<0.001=***.

		Lewes			**Mispillion**			**Port Mahon**			
Species		**Beach**		**Riprap**	**Beach**		**Riprap**	**Beach**	**Riprap**	**Total Abundance**	**% Contribution**
All Species		1.17	**	0.53	1.44	***	0.50	2.28	1.27	5869	100
Atlantic Silverside	*Menidia menidia*	0.46	**	0.13	0.91	***	0.16	0.31	0.12	2874	48.97
Bay Anchovy	*Anchoa mitchilli*	0.07		0.07	0.03	***	0.08	0.17	0.06	733	12.49
Menhaden	*Brevoortia tyrannus*	0.17		0.01	0.00		0.01	0.80	0.37	552	9.41
Weakfish	*Cynoscion regalis*	0.01		0.02	0.05		0.10	0.20	0.16	530	9.03
Blue Crab	*Callinectes sapidus*	0.02		0.04	0.03		0.02	0.04	0.15	311	5.30
Bluefish	*Pomatomus salatrix*	0.06		0.05	0.02		0.01	0.02	0.01	131	2.23
Silver Perch	*Bairdiella chrysoura*	0.08		0.05	0.02		0.02	0.01	0.06	115	1.96
Spot	*Leiostomus xanthurus*	0.01		0.01	0.05	***	0.01	0.03	0.08	89	1.52
Blueback Herring	*Alosa aestivalis*	0.00		0.00	0.00		0.01	0.38	0.02	75	1.28
Mullet	*Mugilidae*	0.11		0.08	0.03		0.00	0.02	0.01	62	1.06
American Eel	*Anguilla rostrata*	0.00		0.00	0.02		0.01	0.03	0.02	56	0.95
Northern Kingfish	*Menticirrhus saxatilis*	0.02		0.02	0.01		0.01	0.04	0.02	53	0.90
Striped Killifish	*Fundulus majalis*	0.01		0.00	0.08	**	0.00	0.01	0.00	47	0.80
Hogchoker	*Trinectes maculatus*	0.00		0.00	0.00		0.00	0.07	0.08	46	0.78
White Perch	*Morone americana*	0.00		0.00	0.06	***	0.01	0.02	0.01	45	0.77
Striped Bass	*Morone saxatilis*	0.00		0.00	0.01		0.00	0.02	0.01	39	0.66
Black Drum	*Pogonias cromis*	0.01		0.01	0.02		0.01	0.01	0.04	26	0.44
Florida Pompano	*Trachinotus carolinus*	0.03		0.00	0.01		0.00	0.02	0.01	21	0.36
Atlantic Croaker	*Micropogonias undulatus*	0.02		0.01	0.05		0.01	0.00	0.00	17	0.29
Summer Flounder	*Paralichthys dentatus*	0.01		0.01	0.00		0.03	0.01	0.00	11	0.19
Calico Crab	*Ovalipes ocellatus*	0.01		0.01	0.00		0.00	0.00	0.00	7	0.12
Sheepshead Minnow	*Cyprinodontidae variegatus*	0.00		0.00	0.00		0.00	0.04	0.01	7	0.12

Table 2.3 Continued.

Species		Lewes Beach	Lewes Riprap	Mispillion Beach	Mispillion Riprap	Port Mahon Beach	Port Mahon Riprap	Total Abundance	% Contribution
Lookdown	*Selene vomer*	0.01	0.00	0.00	0.00	0.00	0.00	3	0.05
Northern Puffer	*Sphoeroides maculatus*	0.01	0.01	0.00	0.00	0.00	0.00	3	0.05
Cownose Ray	*Rhinoptera bonasus*	0.00	0.00	0.00	0.01	0.00	0.00	2	0.03
Gizzard Shad	*Dorosoma cepedianum*	0.00	0.00	0.02	0.00	0.00	0.00	2	0.03
Striped Cusk-Eel	*Ophidion marginatum*	0.00	0.00	0.00	0.02	0.00	0.00	2	0.03
Atlantic Needlefish	*Strongylura marina*	0.00	0.00	0.01	0.00	0.00	0.00	1	0.02
Crevalle Jack	*Caranx hippos*	0.00	0.00	0.00	0.00	0.02	0.00	1	0.02
Halfbeak	*Hyporhamphus unifasciatus*	0.02	0.00	0.00	0.00	0.00	0.00	1	0.02
Mummichog	*Fundulus heteroclitus*	0.00	0.00	0.00	0.00	0.02	0.00	1	0.02
Northern Pipefish	*Syngnathus fuscus*	0.01	0.00	0.00	0.00	0.00	0.00	1	0.02
Northern Stargazer	*Astroscopus guttatus*	0.00	0.01	0.00	0.00	0.00	0.00	1	0.02
Pinfish	*Lagodon rhomboides*	0.00	0.01	0.00	0.00	0.00	0.00	1	0.02
Southern Stingray	*Dasyatis americana*	0.00	0.01	0.00	0.00	0.00	0.00	1	0.02
Striped Burrfish	*Chilomycterus schoepfii*	0.00	0.00	0.00	0.00	0.00	0.01	1	0.02
Winter Flounder	*Pseudopleuronectes americanus*	0.01	0.00	0.00	0.00	0.00	0.00	1	0.02

Table 2.4 Mean species richness ± standard error per seine-haul within the shore of Delaware Bay from June through September 2012 and 2013

2013	Night	Day		
Shoreline Type	**Lewes**	**Lewes**	**Mispillion**	**Port Mahon**
Beach	7.6±2.7	5.2±2.4	6.1±1.3	8.1±2.5
Riprap	7.1±2.9	5±1.9	4.5±1.6	7.1±2.1
2012				
Beach		7.2±2.4	7.7±1.9	
Riprap		5±2.3	3.5±1.8	

Table 2.5 Mean densities (individuals/m3) of all shore zone fish, crabs and other macroinvertebrates captured a long beach and riprap shorelines during day and night hours in Lewes during June to September 2013. Species are listed in descending order of percent contribution to total catch over the four month sampling period.

		Day		Night			
Species		**Beach**	**Riprap**	**Beach**	**Riprap**	**Total Abundance**	**% Contribution**
All Species		1.17	0.53	2.15	0.76	5258	100
Bay Anchovy	*Anchoa mitchilli*	0.07	0.07	0.63	0.33	2081	39.58
Atlantic Silverside	*Menidia menidia*	0.46	0.13	0.73	0.07	2048	38.95
Weakfish	*Cynoscion regalis*	0.01	0.02	0.28	0.08	316	6.01
Blue Crab	*Callinectes sapidus*	0.02	0.04	0.05	0.06	170	3.23
Bluefish	*Pomatomus salatrix*	0.06	0.05	0.02	0.01	124	2.36
Silver Perch	*Bairdiella chrysoura*	0.08	0.05	0.01	0.01	86	1.64
Mullet	*Mugilidae*	0.11	0.08	0.03	0.01	72	1.37
Spot	*Leiostomus xanthurus*	0.01	0.01	0.09	0.01	57	1.08
Menhaden	*Brevoortia tyrannus*	0.17	0.01	0.03	0.00	53	1.01
Atlantic Croaker	*Micropogonias undulatus*	0.02	0.01	0.05	0.01	49	0.93
Atlantic Needlefish	*Strongylura marina*	0.00	0.00	0.03	0.03	40	0.76
Northern Kingfish	*Menticirrhus saxatilis*	0.02	0.02	0.02	0.01	35	0.67
Florida Pompano	*Trachinotus carolinus*	0.03	0.00	0.04	0.00	27	0.51
Summer Flounder	*Paralichthys dentatus*	0.01	0.01	0.02	0.01	24	0.46
Calico Crab	*Ovalipes ocellatus*	0.01	0.01	0.02	0.01	16	0.30
Atlantic Breif Squid	*Lolliguncula brevis*	0.00	0.00	0.01	0.02	11	0.21
Northern Puffer	*Sphoeroides maculatus*	0.01	0.01	0.00	0.01	7	0.13
Lookdown	*Selene vomer*	0.01	0.00	0.01	0.01	6	0.11
American Eel	*Anguilla rostrata*	0.00	0.00	0.00	0.01	5	0.10

Table 2.5 Continued.

Species		Day Beach	Day Riprap	Night Beach	Night Riprap	Total Abundance	% Contribution
Winter Flounder	*Pseudopleuronectes americanus*	0.01	0.00	0.01	0.01	4	0.08
Black Drum	*Pogonias cromis*	0.01	0.01	0.00	0.00	3	0.06
Northern Stargazer	*Astroscopus guttatus*	0.00	0.01	0.02	0.00	3	0.06
Striped Burrfish	*Chilomycterus schoepfii*	0.00	0.00	0.01	0.00	3	0.06
Mummichog	*Fundulus heteroclitus*	0.00	0.00	0.03	0.00	2	0.04
Oyster Toadfish	*Opsanus tau*	0.00	0.00	0.00	0.01	2	0.04
Striped Killifish	*Fundulus majalis*	0.01	0.00	0.01	0.00	2	0.04
Halfbeak	*Hyporhamphus unifasciatus*	0.02	0.00	0.00	0.00	1	0.02
Northern Pipefish	*Syngnathus fuscus*	0.01	0.00	0.00	0.00	1	0.02
Pinfish	*Lagodon rhomboides*	0.00	0.01	0.00	0.00	1	0.02
Smooth Dogfish	*Mustelus canis*	0.00	0.00	0.00	0.01	1	0.02
Southern Stingray	*Dasyatis americana*	0.00	0.01	0.00	0.00	1	0.02
Striped Bass	*Morone saxatilis*	0.00	0.00	0.00	0.01	1	0.02
Striped Cusk-Eel	*Ophidion marginatum*	0.00	0.00	0.00	0.01	1	0.02

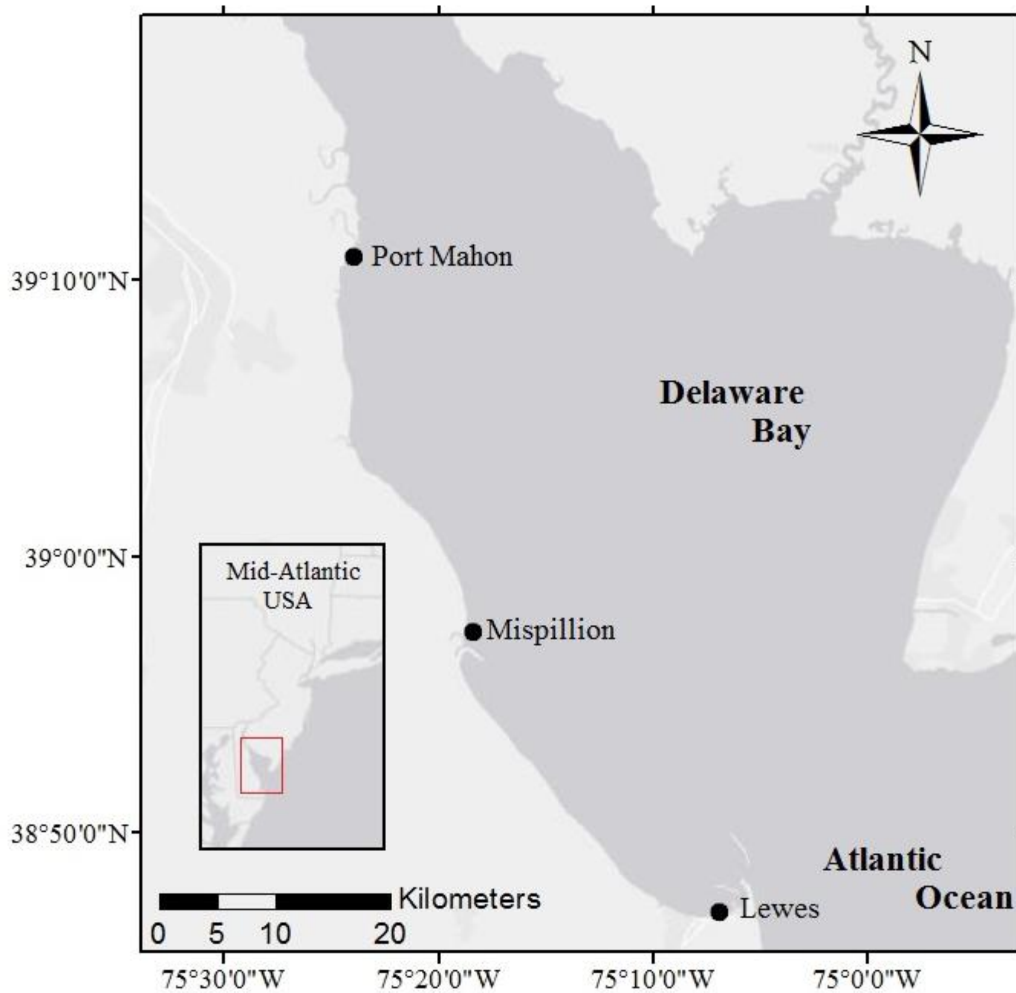

Figure 2.1 Shore zone sites along the western shore of lower Delaware Bay sampled from June through September 2013. Each site contained a stretch of beach adjacent to a stretch of riprap.

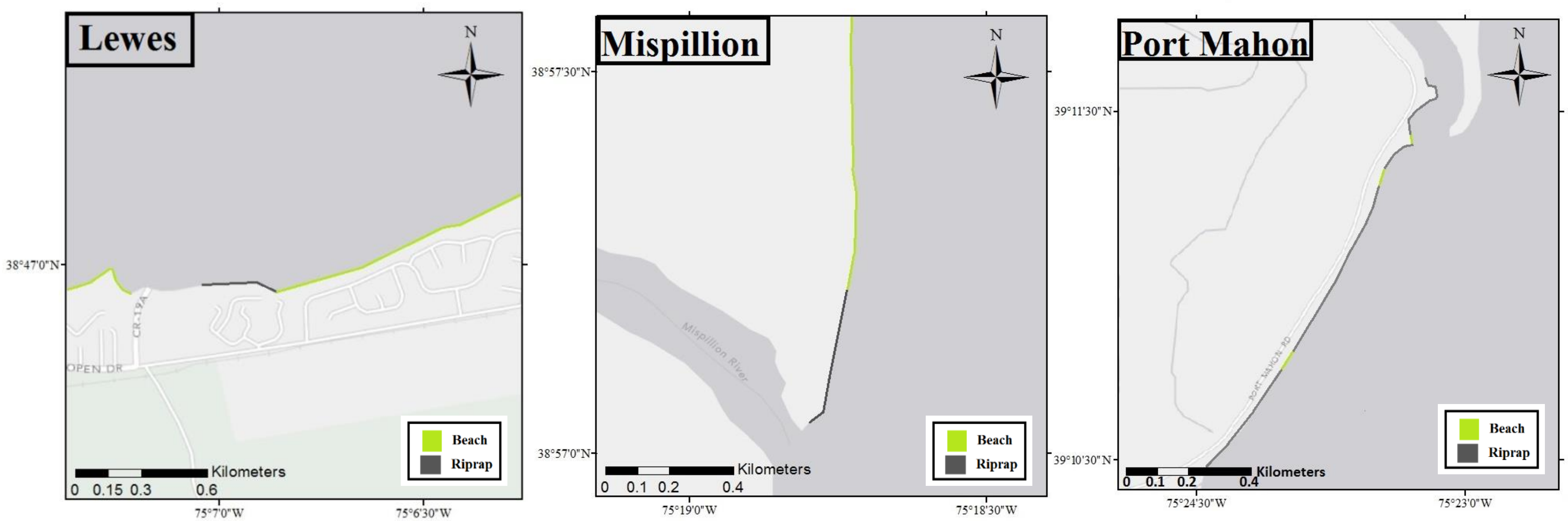

Figure 2.2 Composition of shoreline at each sampling site along the western shore of lower Delaware Bay sampled from June through September 2013. A single stretch of beach and riprap was sampled at each site.

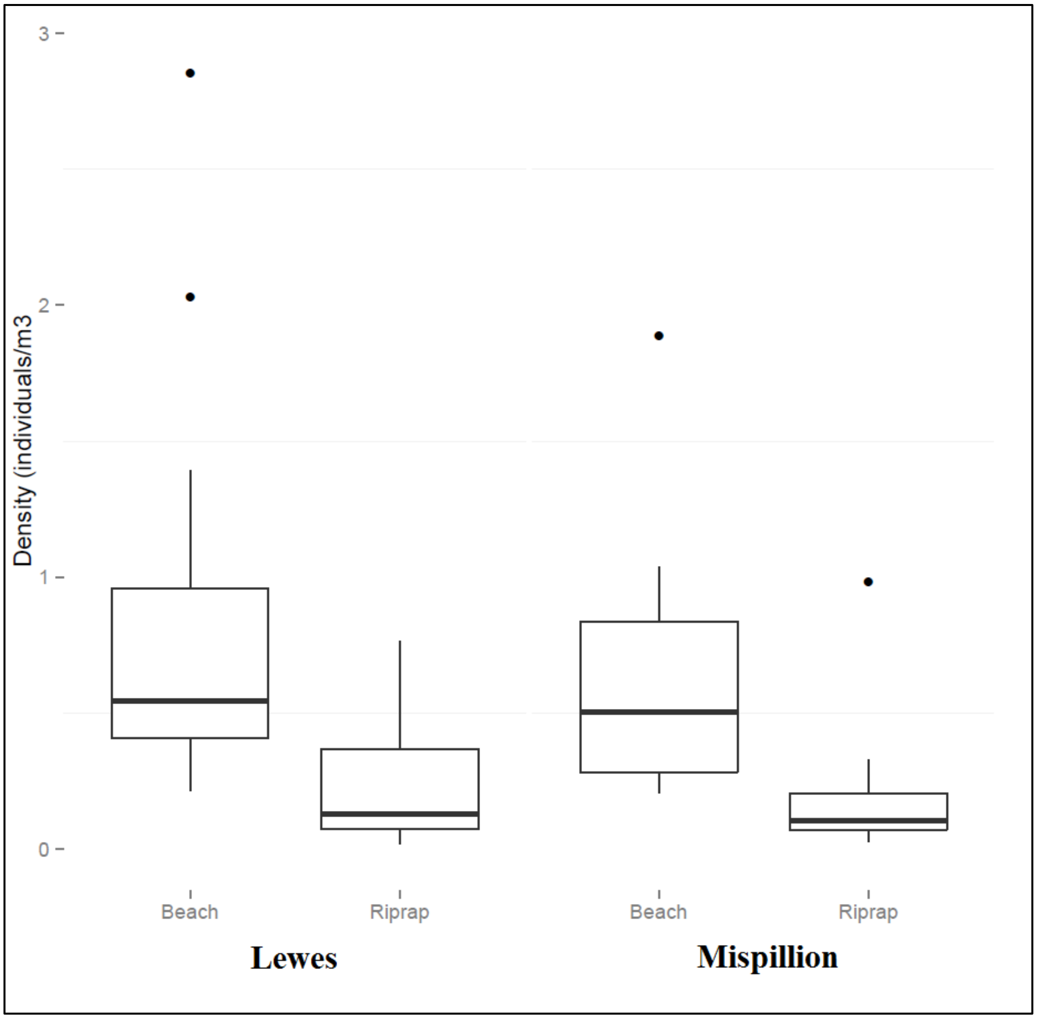

Figure 2.3 Mean densities (individuals/m3) of all combined species captured a long beach and riprap shorelines among two sites during June to September 2012.

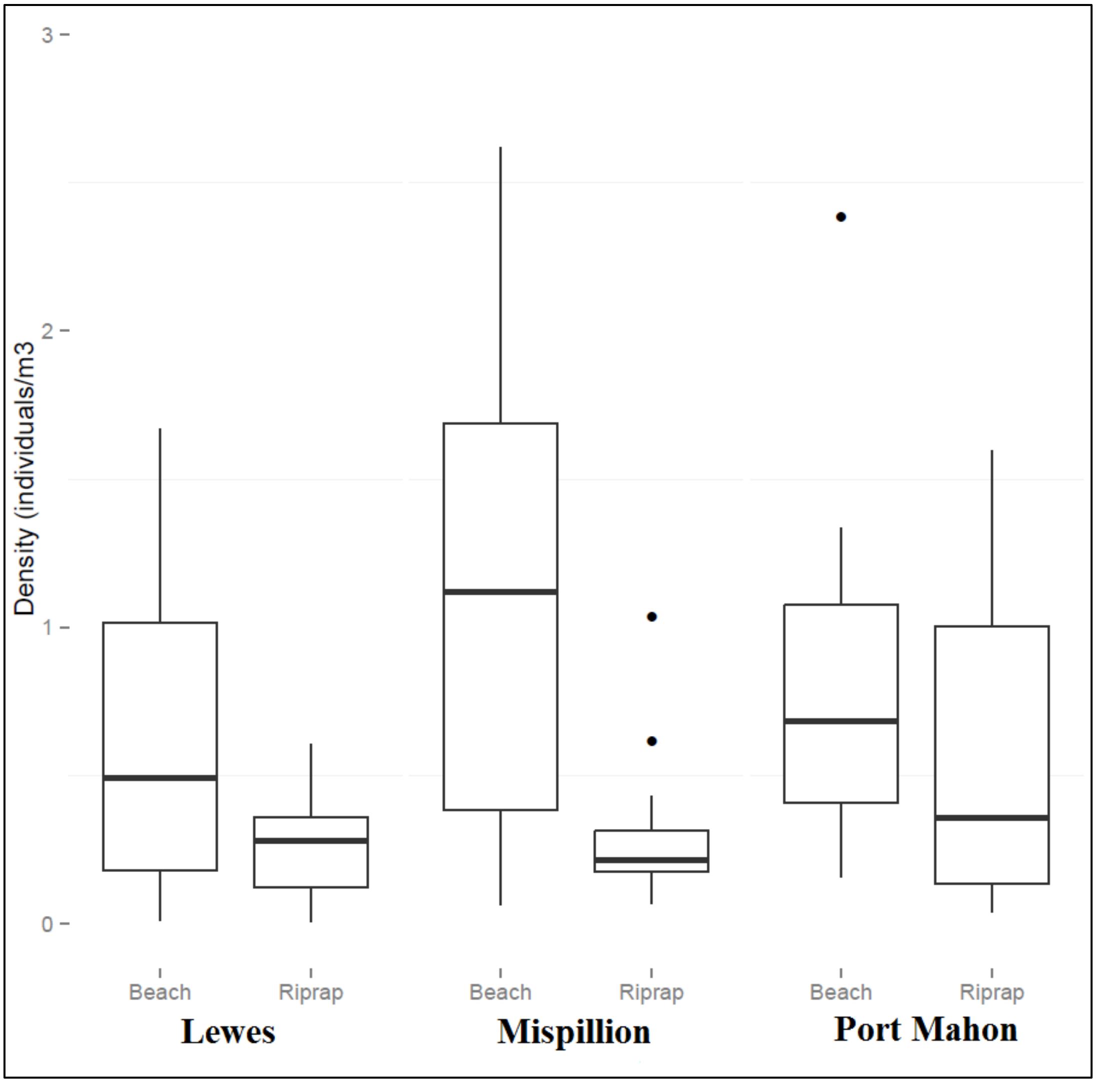

Figure 2.4 Mean densities (individuals/m3) of all combined species captured a long beach and riprap shorelines among three sites during June to September 2013.

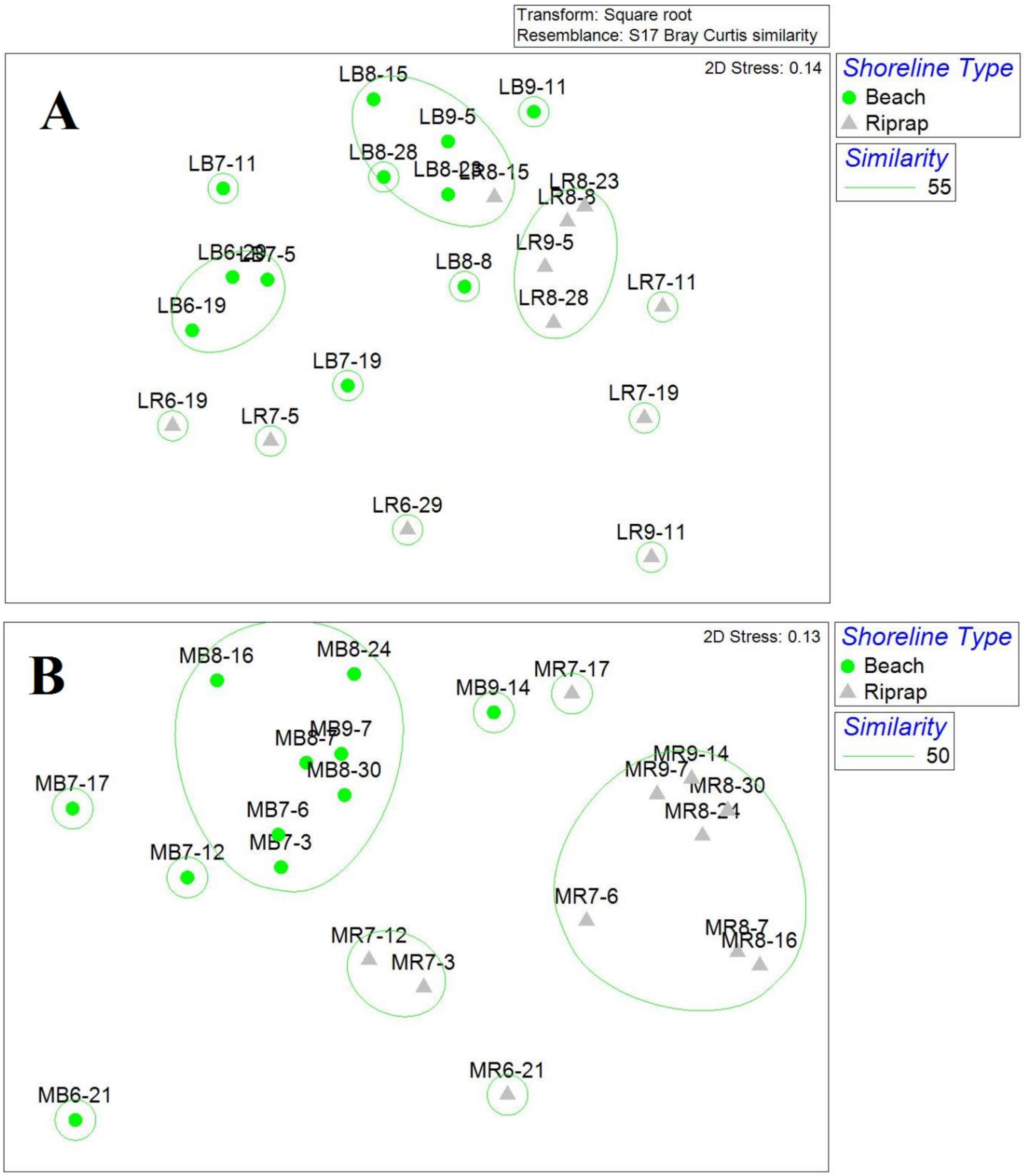

Figure 2.5 Non-metric multidimensional scaling (MDS) based on overall fish and crab density within the shore zone of the A-Lewes, and B-Mispillion sites sampled from June through September 2012.

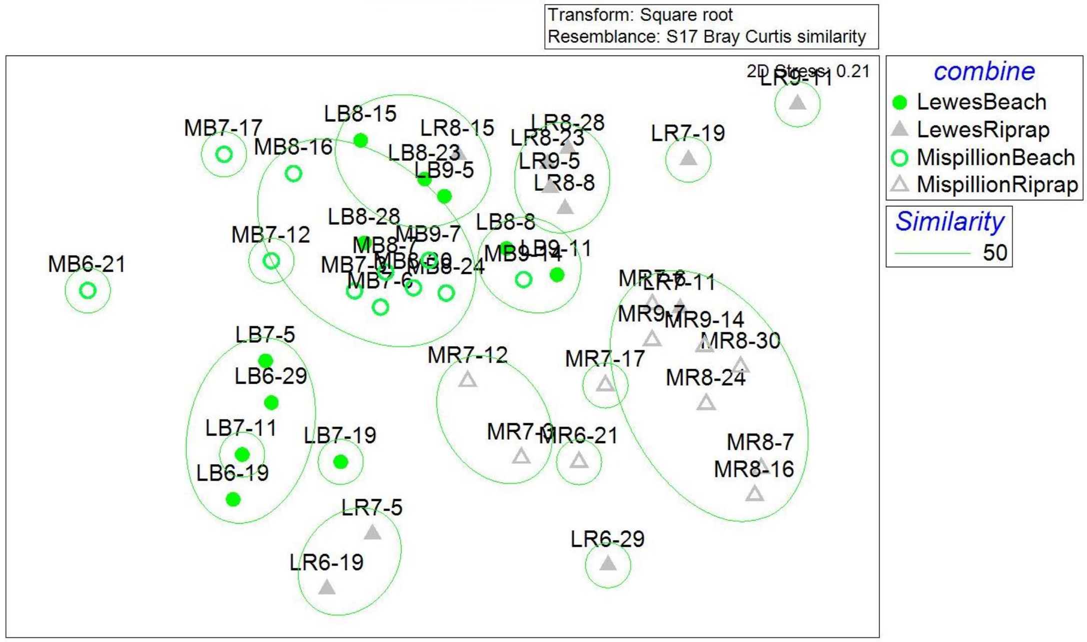

Figure 2.6 Non-metric multidimensional scaling (MDS) based on overall fish and crab density within the shore zone of all combined sites (Lewes and Mispillion) sampled from June through September 2012.

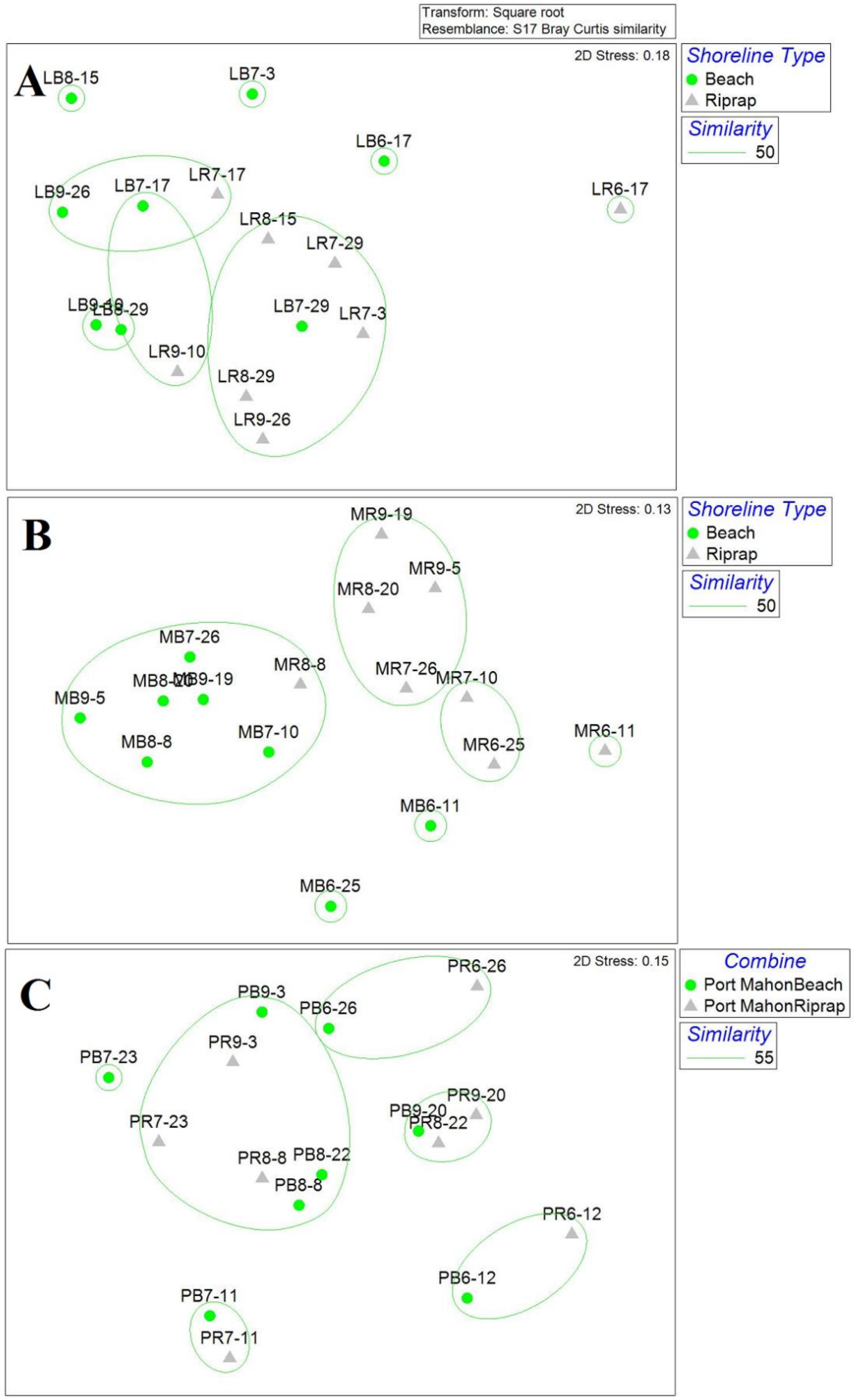

Figure 2.7 Non-metric multidimensional scaling (MDS) based on overall fish and crab density within the shore zone of the A- Lewes, B-Mispillion, and C-Port Mahon sites sampled from June through September 2013.

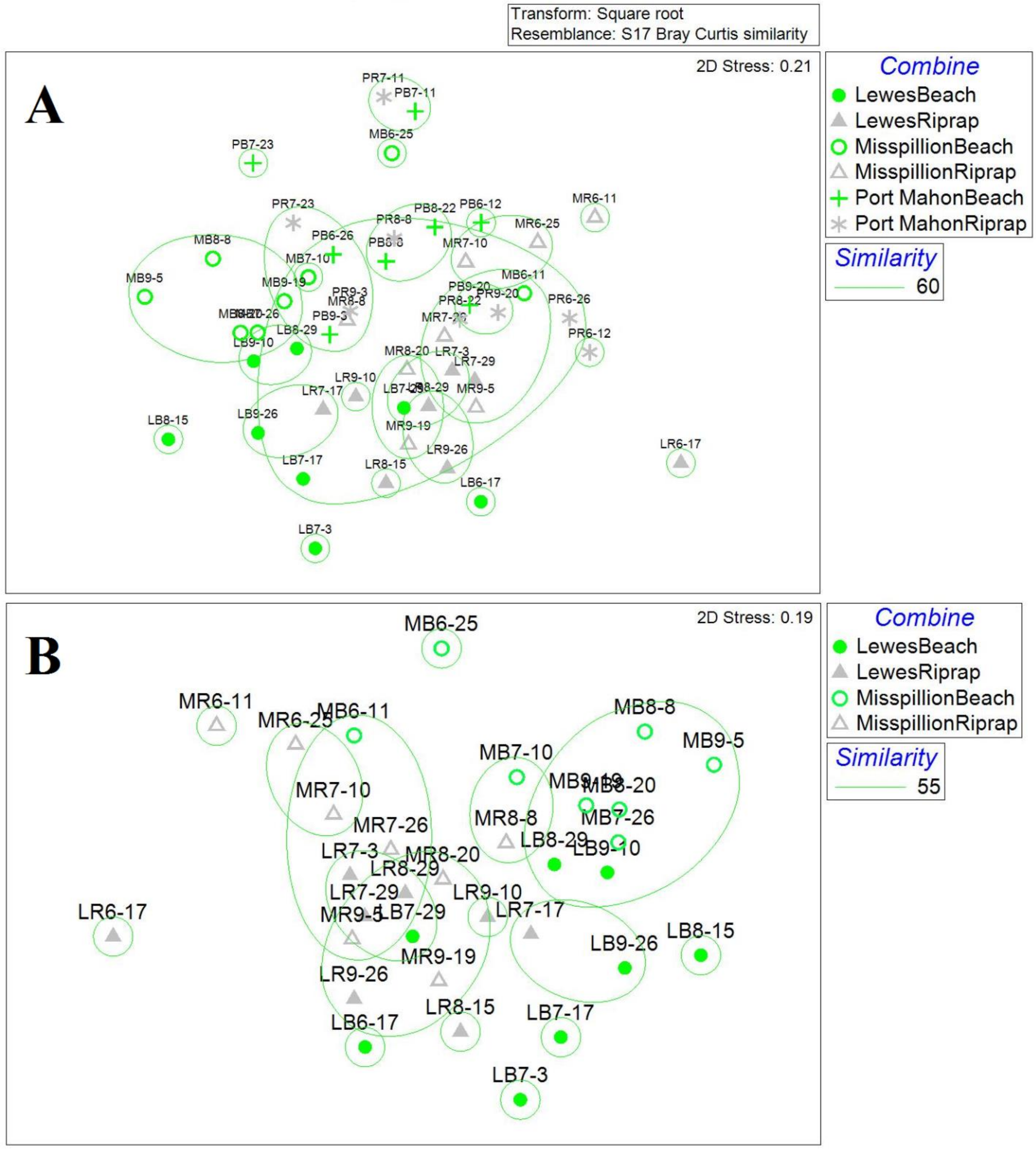

Figure 2.8 Non-metric multidimensional scaling (MDS) based on overall fish and crab density within the shore zone of all combined sites A- Lewes, Mispillion, Port Mahon and B-Lewes, Mispillion (Port Mahon removed) sampled from June through September 2013.

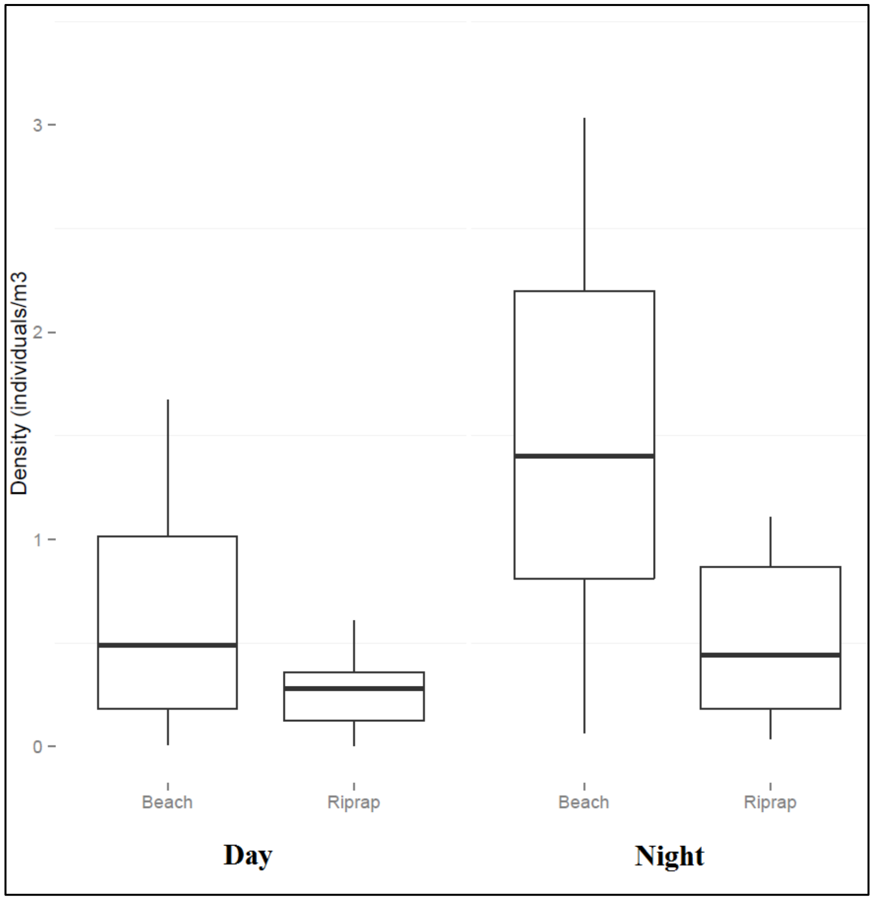

Figure 2.9 Mean densities (individuals/m3) of all combined species captured a long beach and riprap shorelines during day and night hours at site Lewes, June to September 2013.

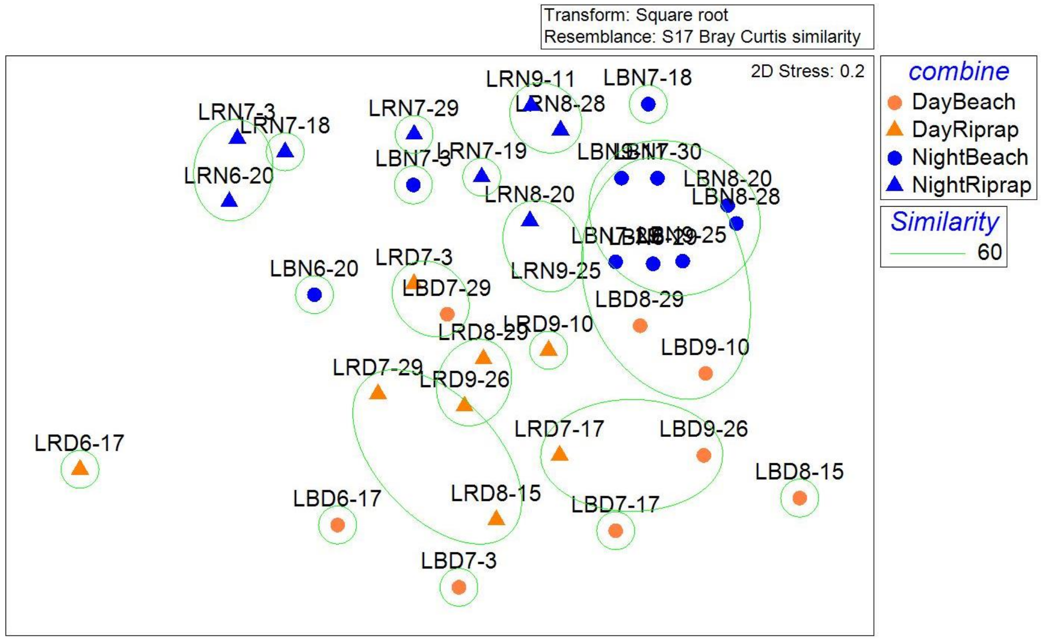

Figure 2.10 Non-metric multidimensional scaling (MDS) based on overall fish and crab density within the shore zone of the Lewes site sampled during day and night hours from June through September 2013.

Chapter 3

FEEDING BY WEAKFISH (*CYNOSCION REGALIS*), BLUEFISH (*POMATOMUS SALATRIX*), AND STRIPED BASS (*MORONE SAXATALIS*) IN THE SHORE-ZONE OF DELAWARE BAY: COMPARISON BETWEEN BEACH AND RIPRAP SHORELINES

Introduction

Estuarine shore zones are valuable habitat, supporting high nekton densities, and providing accelerated growth and lower mortality rates for early life stages (Able et al. 2013, Felix et al. 2007). Although vegetated areas are often highlighted as critical habitat; non-vegetated shore zones dominate the shorelines of many estuaries (Ruiz et al. 1993, Clark et al. 2003, Felix et al. 2007). Sandy beach shore zones are productive habitats that serve important functions as nursery areas and migration pathways (McLachlan & Brown 2006). Utilization of this habitat is often attributed to abundant resources, advantageous physicochemical conditions, and shallow water predator refuge (Ruiz et al. 1993; Gibson et al. 1996).

Much of the work on fishes in estuarine shore zones has focused on larval, juvenile, or forage species due to their dominance in these habitats (Able et al. 2009, 2013). Whereas the nursery function for early life stages is relatively well documented, these habitats also support predatory fishes which have been less frequently studied, in part because getting an accurate assessment of highly mobile piscivores is difficult in these areas and requires specialized sampling techniques. Another reason may be the low piscivore abundance often reported in these shallow waters (Sheaves 2001). There is increasing understanding that piscivorous fishes are ecologically important components of estuarine fish assemblages, play a pivotal role in shaping shore zone communities, and may influence energy flow into other systems (Birkeland & Dayton 2005; Able et al. 2009; Hartman & Brant 1995).

Small forage and juvenile fishes frequently concentrate within shallow water habitat and it is generally accepted that predator refuge is a major driving force behind this utilization (Paterson and Whitfield 2000). There has been some argument over whether or not shallow water habitat actually provides refuge from predators, thereby reducing mortality for small fishes (Paterson and Whitfield 2000; Baker & Sheaves 2007); however, due to physical constraints (larger body size) as well as disadvantages associated with foraging in shallow water (mobility and risk of avian predation) it is likely that these areas at least have the potential to provide increased refuge from piscivorous fish relative to adjacent deeper water areas. Despite the potential refuge offered to small fishes, high concentrations of prey can drive predators to focus foraging efforts in these areas during certain times (Baker & Sheaves 2007).

Shoreline hardening (e.g. placement of riprap) has the potential to affect ecologically and economically important fish species that constitute shore zone assemblages. Riprap embankments transform intertidal habitat from wide, gently sloped beaches to steep rock structures, which reduces sediment supply from the land and reflects wave energy leading to higher rates of erosion, coarsening of sediments, and can lead to deepening at the land-water interface (Davis et al. 2002; Toft et al. 2007). The results are a loss of shallow-water habitat (Gibson et al. 1996; 2002) which may influence fish assemblage structure and fish density (reference Chapter 1) and also shore zone predator-prey interactions.

Weakfish (*Cynoscion regalis*), striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*) are three dominant piscivorous fishes in the shore zone of Delaware Bay (see Chapter 1). All are ecologically and economically important estuary-dependent fishes occupying upper trophic levels in the estuarine food web and all are piscivorous during later stages in life history (Hartman and Brant 1995; Nemerson and Able 2003, Scharf et al 2009,), with bluefish undergoing an ontogenetic diet shift relatively early within their life cycle (Scharf et al 2009). The overall objective of this study was to compare feeding of potential piscivores along beach and adjacent riprap shorelines to determine the effect that shoreline hardening has on predator-prey interactions within the shore zone. Specific objectives were to measure diet composition and stomach fullness to assess shore zone predation on small fishes and examine potential differences between natural beach and hardened shoreline habitats.

Materials and Methods

Food Habits

Weakfish, bluefish, and striped bass were captured during shore zone sampling along the western shoreline of Delaware Bay (Figure 2.1) from June to August 2013. Fishes were sampled from June through late September 2013. Sampling occurred bi-weekly at Lewes, Mispillion, and Port Mahon. Sampling covered the intertidal and shallow subtidal areas < 1.5m in depth. Daytime sampling took place at least one hour after sunrise to one hour before sunset. Each sampling effort consisted of 4 seine-hauls using a 36 meter bag-seine net (4’ high; 3.5mm mesh). Two seine-hauls were conducted at randomly chosen locations along a 200 meter stretch of both beach and riprap at each site.

Fish were frozen in the field for subsequent diet analysis. In the laboratory, fish were examined immediately after thawing from a -80°C freezer. They were weighed (nearest 0.01g) and measured (fork length for fish with forked tails, total length for other species) before dissection. Stomach were removed and weighed, and the mass of stomach contents and stomach wall were measured for stomach fullness calculations. Prey items in each stomach were identified, grouped into 8 general categories, counted, and weighed (wet weight for whole category). Prey categories (Table 2.1) were chosen to reveal major constituents of the diet and feeding strategy. To minimize prey items consumed in areas distant from the habitat where collected, only recently consumed prey items (relatively undigested) were included in diet analyses.

Fish diet was assessed based on the percent of total stomach content wet weight composed of each prey type. This was calculated for each fish according to the equation $\frac{prey\ type\ mass}{stomach\ content\ mass} x\ 100$ with stomach content mass being (total mass of stomach – mass of stomach wall). Stomach fullness was calculated for each fish according to the equation $\frac{stomach\ content\ mass}{total\ mass\ of\ fish - stomach\ content\ mass}\ x\ 100$.

Statistical Analysis

To ensure direct comparison of feeding habitats between shoreline types, analysis of data was separated by species, size class, site, and month of capture. The effect of shoreline type on stomach fullness was assessed using a randomization test of t-scores. Distributions of t-scores were gathered from 5000 repeated t-tests run on random rearrangements of gathered data. This method was used because it was more robust than a standard t-test due to non-normality and frequent occurrences of zero-values in the data.

Differences in prey composition between shoreline type and location of capture were analyzed using a multivariate approach with PRIMER (version 6). Similarity matrices were constructed using the Bray-Curtis similarity measure from the square root transformed mass of each prey type within an individual fish. Non-metric multidimensional scaling (MDS) based on similarity matrices was used to generate two dimensional plots depicting diet similarity between shoreline types. Group-average hierarchal cluster analysis of the similarity matrices was overlaid upon the MDS plot to identify biologically significant groupings based on similarity of diet.

Results

Food Habits

Weakfish

Stomach contents from 172 weakfish 30-175mm long were examined (Table 2.2; Appendix B). Overall stomach fullness values were similar between fish captured along beach and riprap in each subset (Table 2.3). Mysid shrimp were the dominant prey of these juveniles, with lower proportions of fishes, polychaetes, horseshoe crab larvae, and debris (Tables 2.4).

Groups of weakfish were examined as follows (number in each group was the same from beach and riprap shorelines. Individual fish were selected randomly from the larger group to equal the smaller): (Lewes, night, July, size=49-86mm, N=28); (Lewes, day, August, size=93-175mm, N=50); (Mispillion, day, July, size=30-92mm, N=28); (Port Mahon, day, July, size=48-97mm, N=50); (Port Mahon, day, August, size=62-110mm, N=44) (Table 2.2; Appendix B).

The diet composition of juvenile weakfish was similar between beach and riprap shorelines at the Lewes and Mispillion sites, composed primarily of mysid shrimp (Tables 2.4). Stomach fullness between beach and riprap shorelines did not differ significantly at any site or month (rand. test, t-score: $P>0.05$; Table 2.3). Weakfish at Port Mahon had a substantial proportion of their diet made up by horseshoe crab larvae (July: beach 29%, riprap 4.5%; August: beach 13.2%, riprap 55.6%; Table 2.4). MDS ordination of stomach content data from weakfish captured along beach and riprap shorelines overlapped greatly at each site, indicating similar food habits between shoreline types (Figures 2.2, 2.3, 2.4, 2.5, 2.6). Pooling all sampling sites onto a single MDS plot showed differences in diet by location as fish from Port Mahon form a discrete group due to the large contribution of horseshoe crab larvae in their diet (Figure 2.7).

Striped Bass

Stomach contents from 14 striped bass 185-556mm long were examined from daytime collections at Port Mahon during June to August (Table 2.2, Appendix B). The most important prey item was horseshoe crab larvae with lesser abundance of bay anchovy, amphipod, mysid shrimp, Atlantic silverside, blue crab, polychaete, juvenile weakfish, and debris) (Table 2.5).

Analysis of spatial patterns in the diet of striped bass reveals a similar proportion of prey items making up total stomach content between fish caught along both shoreline types (Table 2.5). Bay anchovy made up the second largest prey group in striped bass captured along the riprap (22.3%, Table 2.5) and were not present in the stomachs of fish captured along the beach. Stomach fullness between beach and riprap did not vary significantly in striped bass (rand. test, t-score: P=0.22; Table 2.3). MDS ordination of stomach content data from striped bass captured along beach and riprap shorelines overlapped greatly, indicating similar feeding habits between shoreline type (Figure 2.8).

Bluefish

Stomach contents from 70 bluefish 73-133mm long were examined from daytime collections at Lewes during July and August (Table 2.2; Appendix B). Dominant prey items were mysid shrimp, Atlantic silverside, and bay anchovy, with lesser abundance of polychaetes and debris (Table 2.6).

Groups of Bluefish were examined as follows: (number in each group was the same from beach and riprap shorelines. Individual fish were selected randomly from the larger group to equal the smaller): (Lewes, day, July, size=73-130mm, N=20); (Lewes, day, August, size=92-133mm, N=50) (Table 2.2; Appendix B).

Bluefish in July showed a difference in feeding between shoreline types, as fish along the beach fed primarily on small forage fishes (80.3% Atlantic silverside, 17.4% bay anchovy) and fish along riprap fed exclusively on mysid shrimp (Table 2.6). Stomach fullness did not differ significantly between beach and riprap shorelines (rand. test, t-score: P=0.36; Table 2.3). MDS ordination of stomach content data revealed distinct diets of bluefish along beach and riprap (Figure 2.9, 2.10, 2.11). A similarity level of 55%

produced mostly distinct beach and riprap groupings. Although not all bluefish stomach contents fit into a single beach or riprap group, overall diet differences were evident.

Stomach contents of bluefish captured in August from both shoreline types showed similar overall proportions of prey items (Table 2.6). Bluefish from both shorelines fed heavily on bay anchovy (beach:71.9%, riprap:72.7). Fish captured along the beach also preyed upon Atlantic silverside (24.6%) while bluefish captured along the riprap did not (Table 2.6). Stomach fullness between beach and riprap varied significantly suggesting a difference in feeding activity (rand. test, t-score: $P<0.01$; Table 2.3). MDS ordination of stomach content data from bluefish captured along beach and riprap shorelines overlapped greatly, indicating similar prey preferences between shoreline types (Figure 2.9, 2.10, 2.11).

Discussion

Although the concept that shoreline modification affects associated nekton communities is well established (, Peterson et al. 1999; Toft et al. 2007; Bilkovic and Roggero 2008), the current study is unique to have examined differences in fish diets between natural and hardened shorelines in an estuarine system. Bluefish were the only species to show differences in diet composition and feeding activity between beach and riprap shorelines. Stomach contents from bluefish captured in July showed contrasting levels of piscovoury from fish captured along the beach compares with those captured along the riprap. While diet composition was similar between shoreline type in bluefish captured in August, feeding activity was significantly higher along the beach. Weakfish and striped bass exhibited lower levels of piscivoury than bluefish and did not show differences in diet or feeding activity among shoreline type. Overall these results suggest that differences in shoreline morphology between beach and riprap have the potential to alter predator control on prey species, distributions of small fish prey, or both.

Due to the highly piscivorous diet exhibited by YOY bluefish in this study, these findings do not support the concept that all predatory fish are excluded from extreme shallow water habitat present among unhardened shorelines; however it is still likely that larger fishes are hindered in accessing these areas. In this regard, it is probable that beach shoreline still offers increased predator refuge relative to adjacent deeper water habitat and hardened shorelines. Additionally, the refuge offered by extreme shallow water habitat is likely a major driving factor for utilization of beach shore zones for small forage species.

It is possible that diet items from fish captured along a particular shoreline type could reflect feeding from other areas. However, as groups of fish analyzed for diet analysis were obtained from multiple days and seine-hauls, and only recently consumed prey items were included in diet analyses, it is likely that feeding occurred in the immediate area and is representative of the sampled shoreline type.

The diet composition of juvenile weakfish in the present study was generally similar to that found in other studies the Delaware Bay (Grecay and T.E. Targett 1996b; Lankford & Targett 1997; Boutin 2008). Diet consisted mainly of mysid shrimp, a prey that has been shown to improve growth and condition under both laboratory and field settings (Grecay and Targett 1996a; Lankford and Targett 1997). No effect of shoreline type was observed in either diet composition or stomach fullness (feeding activity) across sites and months. However, an effect of site was observed in overall diet composition, as weakfish at Port Mahon, the uppermost site, contained greatly reduced proportions of mysid shrimp. It seems likely that the importance horseshoe crab larvae in the diets of weakfish at Port Mahon was indicative of available prey in the area, rather than this prey category being otherwise selected for over mysid shrimp. Other studies have found that mysid shrimp dominate the diet of juvenile weakfish in shallow-waters of mid to lower Delaware Bay, while fish in the upper bay have diets dominated by other prey items (Grecay and Targett 1996b; Boutin 2008). Grecay & Targett (1996a) found that feeding on mysids by juvenile weakfish was significantly reduced under dark or turbid conditions in a laboratory setting. It is possible that increased turbidity levels further up the bay inhibits location and capture of this prey item.

Striped bass diet in the present was comprised of a smaller fish component than reported for similarly sized fish (>200mm) in other studies (Hartman and Brandt 1995; Nemerson & Able 2003). Dominance of young horseshoe crabs in striped bass diets in the present study was likely due to an abundance of this prey in the shore-zone at Port Mahon during June-August, as noted above for juvenile weakfish feeding. Both juvenile and adult striped bass are known to be non-selective opportunistic feeders, and as a result their diet generally reflects the overall prey availability in the immediate area (Nemerson & Able 2003).

Bluefish diet composition in the present study was generally similar to that found in other studies (Buckle and Conover 1997; Scharf et al. 2009) in the shore zone, with a large component composed of small fish prey. A contrast in diet composition was observed between shoreline types in 75 - 100mm long bluefish in July. Bluefish of this size were feeding almost entirely on small Atlantic silversides (10 – 20mm long)and bay anchovies (10 – 20mm long) along the beach, whereas bluefish along the riprap fed exclusively on mysid shrimp. Stomach fullness did not differ between beach and riprap shorelines. Since this particular size range of bay anchovy and Atlantic silverside was too small to be effectively sampled it was not possible to quantify relative abundances of these fish between beach and riprap shorelines; however large numbers of individuals from this size class were observed visually within the beach shore zone but not riprap. As a result of this it is likely that bluefish diets in July were representative of the prey communities along each respective shoreline type.

Bluefish in August were 100 to 125mm long and had a similar diet, consisting primarily of small bay anchovies (10-20mm) at both shoreline types. A smaller component of the diet of bluefish along the beach consisted of small. Atlantic silversides, indicating their continued presence along the beach in August. It is noted that weakfish captured from the same stretch of riprap in August were feeding almost exclusively on mysids, suggesting that this prey was still present in high concentrations. Bluefish may have undergone a size-related diet shift from July to August and ceased foraging on mysid shrimp in favor of bay anchovy along riprap shoreline. Since this diet shift was only observed at riprap shorelines it suggests that bluefish captured in July 75-100mm preferred fish prey as opposed to invertebrates but could compensate for relatively low densities of fish prey along the riprap by feeding on mysid shrimp. However, the diet shift to piscivory observed in bluefish in the present study was relatively later in ontogeny compared with bluefish in New York estuaries where YOY bluefish diet was dominated by fishes from the early onset of summer when individuals were <55mm in length (Scharf et al 2009). Although diet composition of bluefish in August in the present study was similar between shoreline types, stomach fullness was significantly higher in fish along the beach indicating a higher level of feeding activity. Difference in feeding activity may reflect a higher prey concentration along the beach.

In order to gain a more complete understanding of the impacts of shoreline modification, it is necessary to assess differences in shore zone habitat quality and functional value for estuarine fishes. This study shows a difference in faunal density, species composition, and habitat usage among beach and riprap shorelines. These differences are observable at the level of both community and individual species.

Table 3.1 Name and descriptions of prey categories used in diet analyses.

Category Name	Description
Blue Crab	*Callinectes sapidus:* Whole individuals (megalopal, juvenile, and adults) and parts
Mysid	Mysid Shrimp, largely *Neomysis americana*
Amphipod	Amphipods
Decapod	Crangon sp.
Horseshoe Crab Larvae	*Limulus polyphemus* eggs and larvae
Fishes	Whole fish (all life stages) and fish remains including scales and bones
Polychaete	Whole individuals and parts
Debris	Organic and inorganic debris

Table 3.2 Groups of predatory fish species used for diet analyses. Groups were chosen by size-class, month, and location captured to make direct comparisons between shoreline type. Sample size was divided evenly between beach and riprap. Average size ± standard error is shown for each group.

				Beach			Riprap		
	Site	**Month**	**Sample Size**	**Min Size**	**Max Size**	**Average Size**	**Min Size**	**Max Size**	**Average Size**
Bluefish	Lewes	July	20	76	96	86.6±10.5	73	92	81.8±5.6
	Lewes	August	50	100	126	111±8.5	92	133	106.92±9.9
Striped Bass	Port Mahon	June-August	14	197	340	254.4±46.1	185	556	292.9±128.4
Weakfish	Lewes	July	28	49	86	74.5±9.6	55	78	67.8±6.6
	Lewes	August	22	93	175	120.6±21.8	105	152	129.2±18.0
	Mispillion	July	28	30	63	44±9.4	49	92	64.1±10.7
	Port Mahon	July	50	48	97	71.8±12.0	50	95	70.6±11.5
	Port Mahon	August	44	62	110	84.7±13.6	65	101	82.0±10.1

Table 3.3 Stomach fullness values ± standard error for all groups of predatory fish captured along beach and riprap shorelines in Delaware Bay, June to August 2013. Significant differences in mean stomach fullness between shoreline types are denoted by asterisks according to the following criteria: P<0.05 = *; P<0.01 = **; P<0.001=***.

	Site	Month	Sample Size	Stomach Fullness Beach		Riprap
Bluefish	Lewes	July	20	1.81±2.9		1.07±0.73
	Lewes	August	50	0.95±0.83	**	0.52±0.35
Striped Bass	Port Mahon	June-August	14	1.05±1.33		1.41±2.08
Weakfish	Lewes	July	28	2.26±1.85		1.96±0.93
	Lewes	August	22	1.29±0.72		1.62±0.83
	Mispillion	July	28	4.02±3.96		2.84±1.53
	Port Mahon	July	50	2.50±1.74		2.38±1.79
	Port Mahon	August	44	1.83±1.69		2.34±1.53

Table 3.4 Percentage of prey categories by wet weight in weakfish (*Cynoscion ragalis*) along beach and riprap shorelines in the shore zone of Delaware Bay, July and August 2013. Data is displayed for each subset of weakfish, chosen by size-class, month, and location captured to make direct comparisons between shoreline type. Number of fish sampled (N) is shown for each subset.

Lewes: July, Night	**N=28**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	85.9	99.7
Amphipod	0.8	0.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	0.0	0.0
Fishes	13.4	0.0
Bay Anchovy	13.4	0.0
Weakfish	0.0	0.0
Polychaete	0.0	0.0
Organic Debris	0.0	0.3

Lewes: August, Night	**N=22**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	94.1	74.9
Amphipod	0.0	0.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	0.0	0.0
Fishes	5.9	25.1
Bay Anchovy	5.9	25.1
Weakfish	0.0	0.0
Polychaete	0.0	0.0
Organic Debris	0.0	0.1

Table 3.4 Continued.

Mispillion: July, Day	**N=28**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	98.4	77.1
Amphipod	0.0	0.0
Decapod	0.0	4.6
Horseshoe Crab Larvae	0.0	0.0
Fishes	0.0	6.8
Bay Anchovy	0.0	6.8
Weakfish	0.0	0.0
Polychaete	1.2	6.8
Organic Debris	0.4	4.7

Port Mahon: July, Day	**N=50**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	27.3	29.6
Amphipod	0.0	0.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	29.0	4.5
Fishes	24.6	44.9
Bay Anchovy	24.6	14.9
Weakfish	0.0	30.0
Polychaete	19.1	17.9
Organic Debris	0.0	3.1

Port Mahon: August, Day	**N=44**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	47.7	36.4
Amphipod	0.4	0.0
Decapod	3.2	0.0
Horseshoe Crab Larvae	13.2	55.6
Fishes	8.2	0.0
Bay Anchovy	0.0	0.0
Weakfish	8.2	0.0
Polychaete	21.3	5.7

Organic Debris	6.0	2.3

Table 3.5 Percentage of prey categories by wet weight in Striped Bass (*Morone saxatilis*) along beach and riprap shorelines in the shore zone of Delaware Bay, June to August 2013. Number of fish sampled (N) is shown.

Port Mahon: June-August, Day	**N=14**	
Prey Category	**Beach**	**Riprap**
Blue Crab	4.2	0.0
Mysid	0.0	0.0
Amphipod	0.0	3.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	86.4	64.0
Fishes	8.2	23.3
Atlantic Silversides	0.1	1.0
Bay Anchovy	0.0	22.3
Weakfish	8.0	0.0
Polychaete	0.0	0.2
Organic Debris	1.2	9.6

Table 3.6 Percentage of prey categories by wet weight in bluefish (*Pomatomus salatrix*) along beach and riprap shorelines in the shore zone of Delaware Bay, July to August 2013. Data is displayed for each subset of bluefish, chosen by size-class, month, and location captured to make direct comparisons between shoreline type. Number of fish sampled (N) is shown for each subset.

Lewes: July, Day	**N=20**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	2.3	100.0
Amphipod	0.0	0.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	0.0	0.0
Fishes	97.7	0.0
Atlantic Silverside	80.3	0.0
Bay Anchovy	17.4	0.0
Polychaete	0.0	0.0
Organic Debris	0.0	0.0

Lewes: August, Day	**N=50**	
Prey Category	**Beach**	**Riprap**
Blue Crab	0.0	0.0
Mysid	0.0	0.4
Amphipod	0.0	0.0
Decapod	0.0	0.0
Horseshoe Crab Larvae	0.0	0.0
Fishes	96.5	72.7
Atlantic Silverside	24.6	0.0
Bay Anchovy	72.7	72.7
Polychaete	0.0	5.3
Organic Debris	3.5	21.6

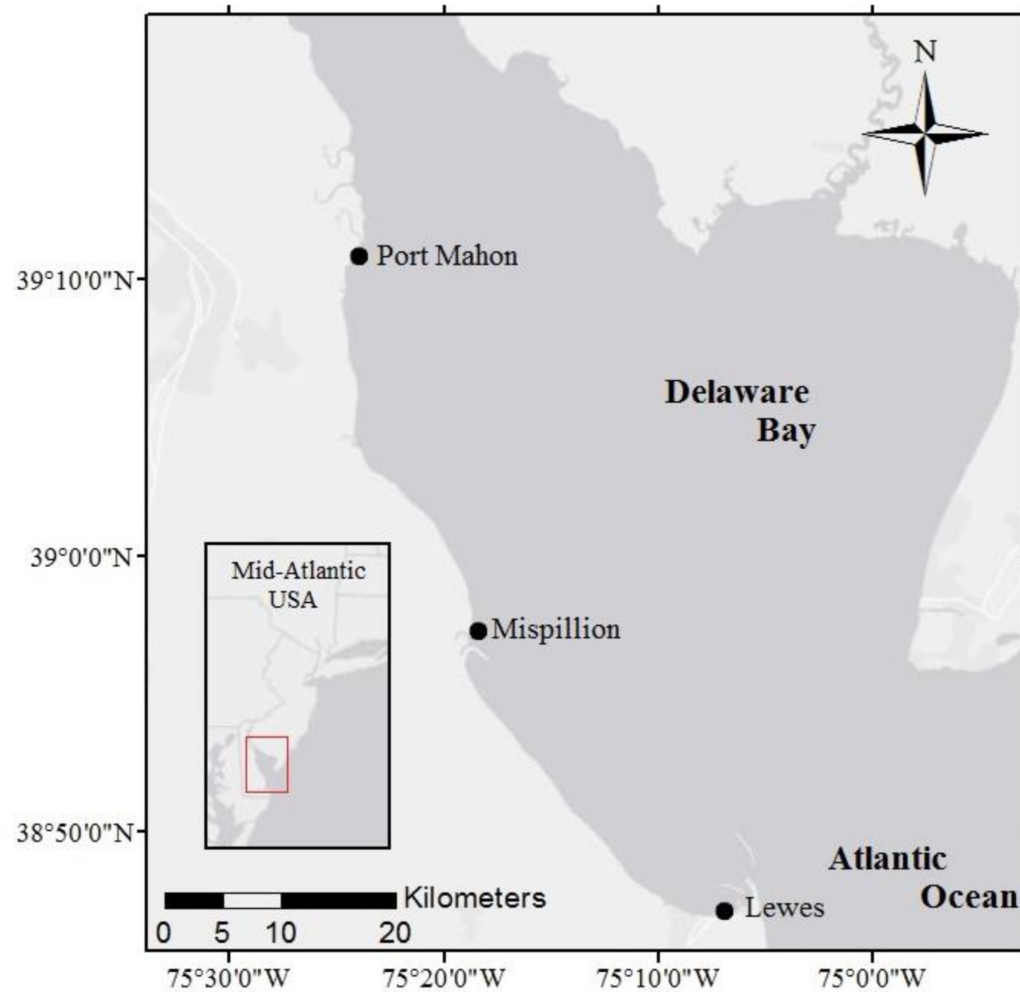

Figure 3.1 Shore zone sites along the western shore of lower Delaware Bay where fish collection took place, June through September 2013. Each site contained a stretch of beach adjacent to a stretch of riprap.

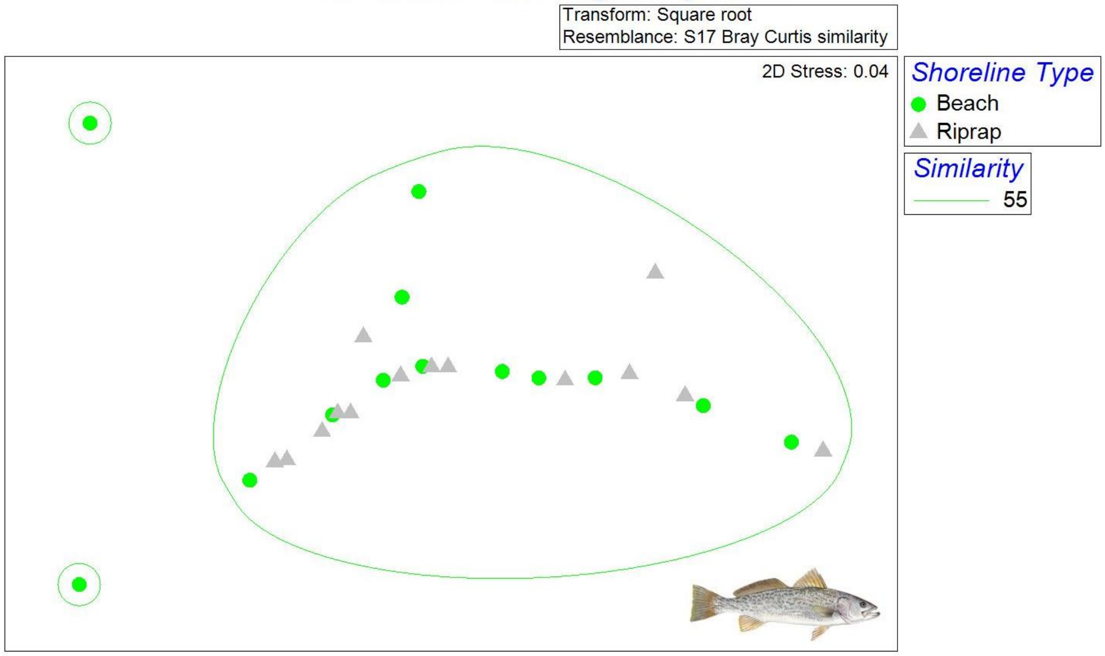

Figure 3.2 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the night in the shore zone of the Lewes site, July 2013.

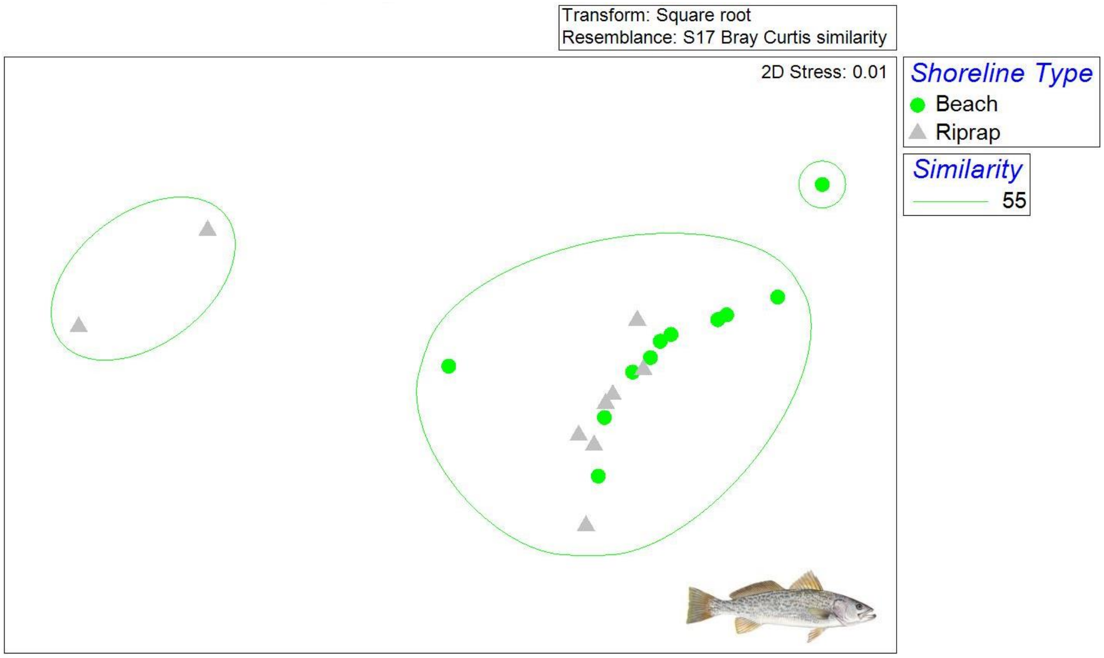

Figure 3.3 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the night in the shore zone of the Lewes site, August 2013.

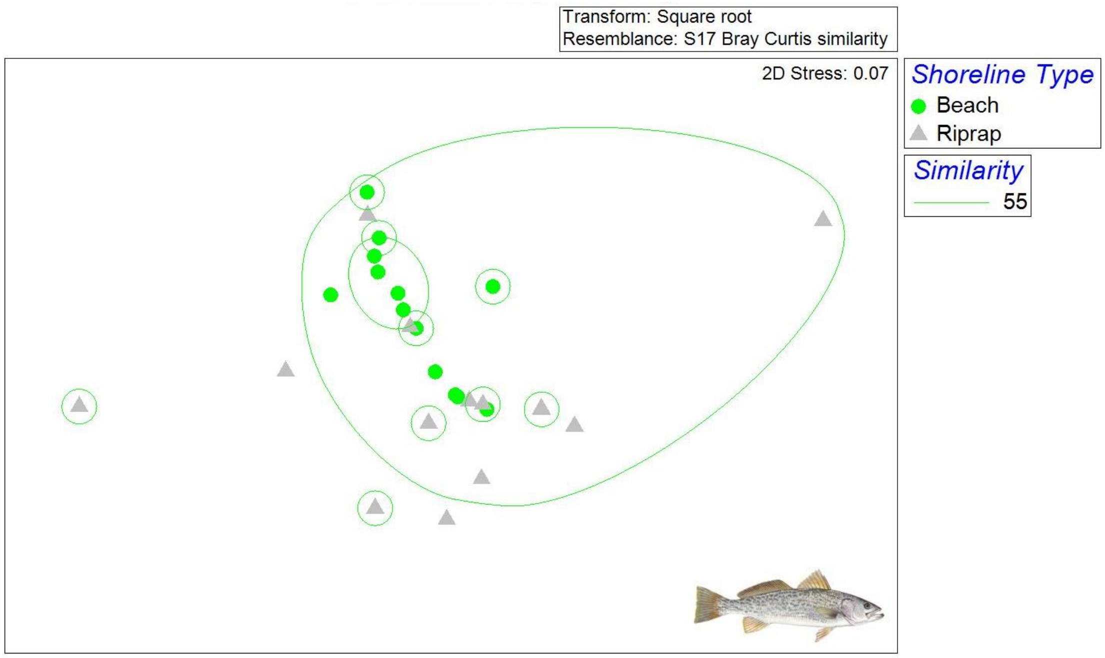

Figure 3.4 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the day in the shore zone of the Mispillion site, July 2013.

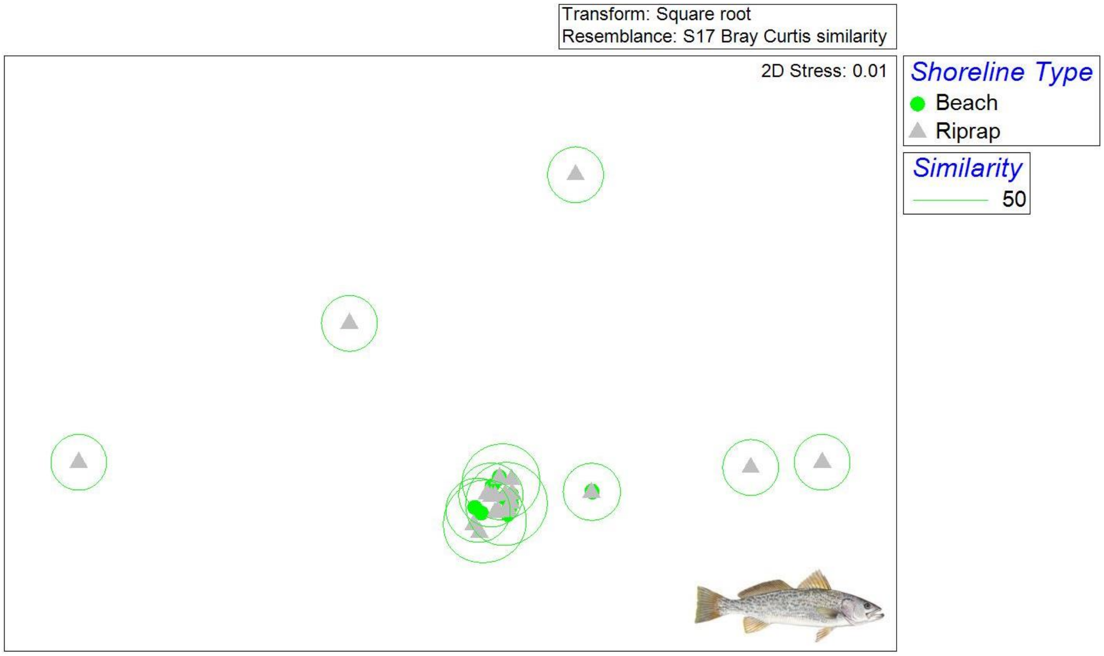

Figure 3.5 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the day in the shore zone of the Port Mahon site, July 2013.

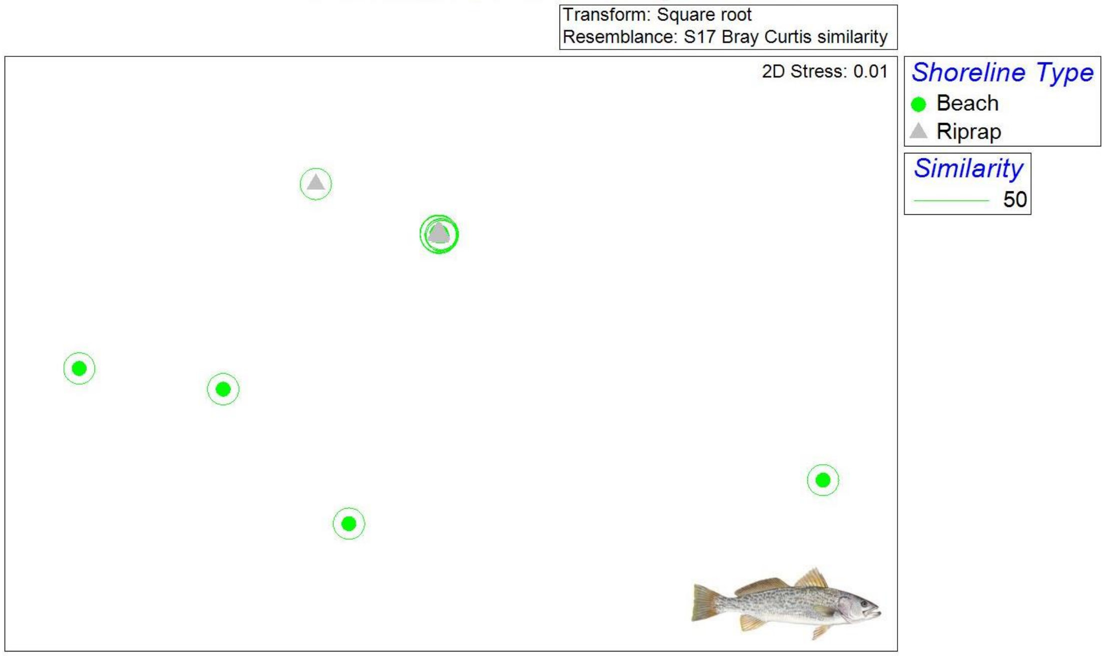

Figure 3.6 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the day in the shore zone of the Port Mahon site, August 2013.

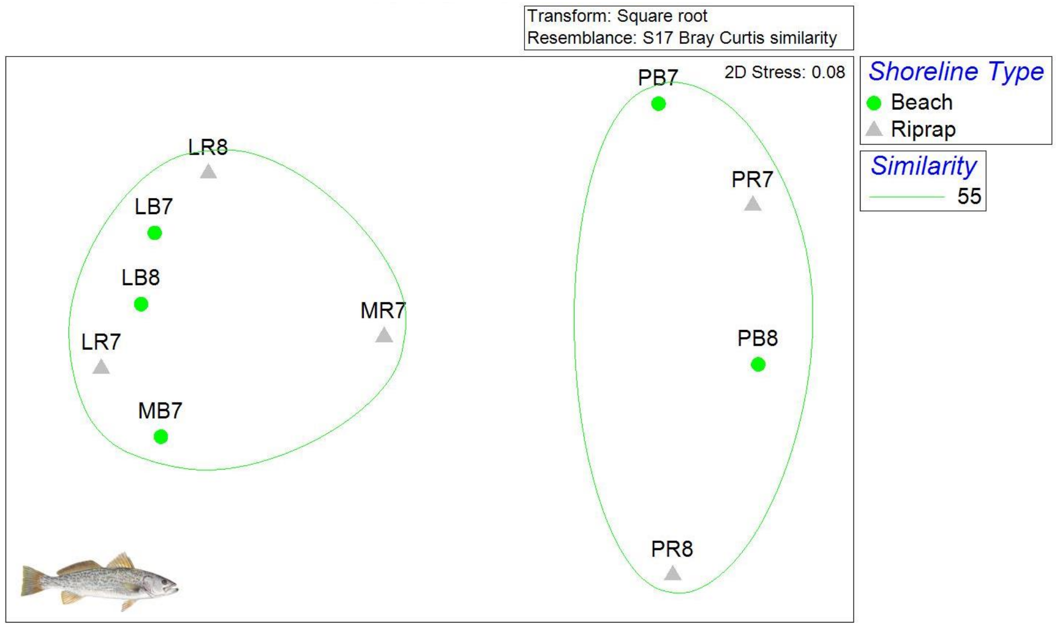

Figure 3.7 Non-metric multidimensional scaling (MDS) based on averages of combined diets per site of juvenile weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines in the shore zone of the Lewes (night), Mispillion (day), and Port Mahon (night) sites, August 2013.

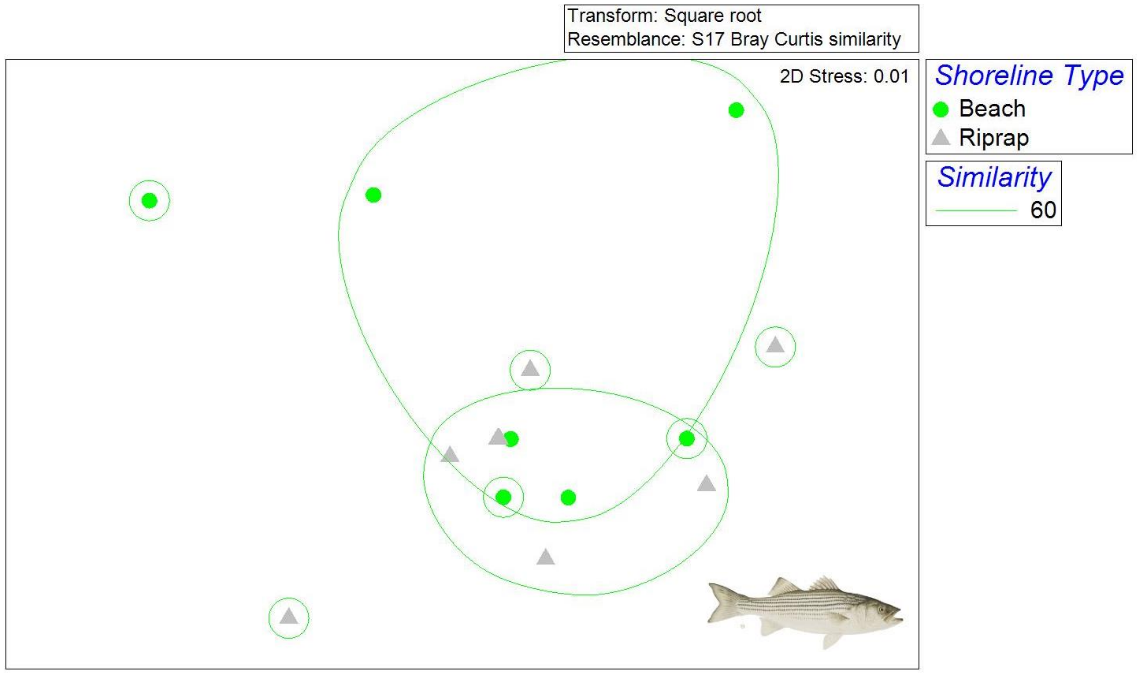

Figure 3.8 Non-metric multidimensional scaling (MDS) based on overall diet composition of striped bass (*morone saxaitalis*) captured a long beach and riprap shorelines during the day in the shore zone of the Port Mahon site, June to August 2013.

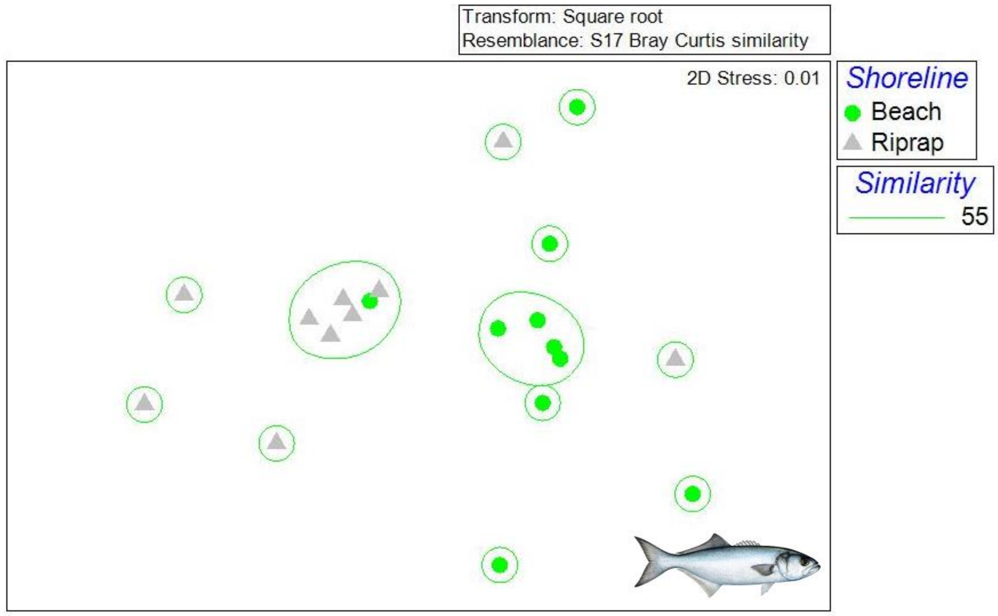

Figure 3.9 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile bluefish (*Pomatomus salatrix*) captured a long beach and riprap shorelines during the day in the shore zone of the Lewes site, July 2013.

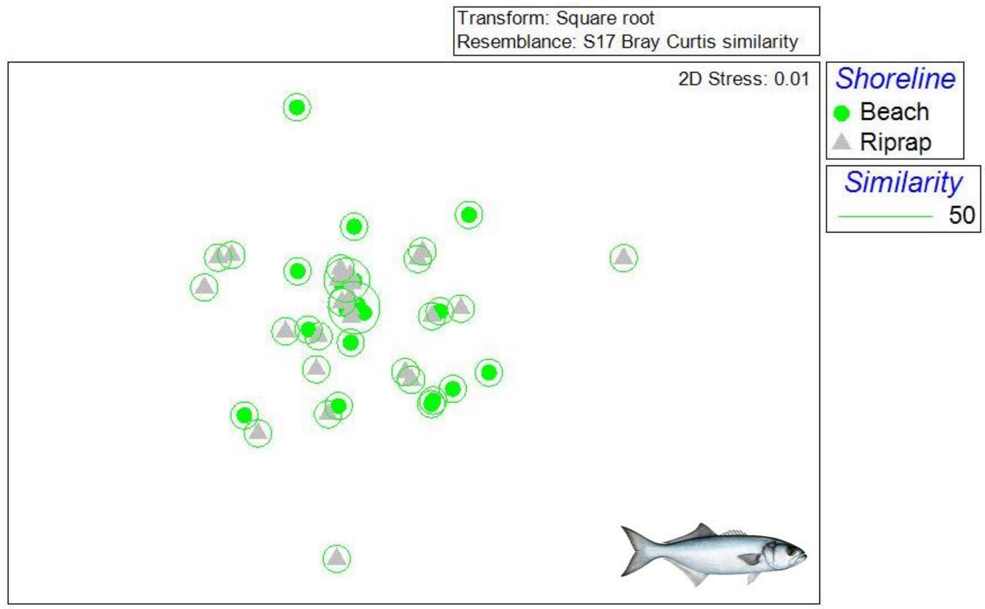

Figure 3.10 Non-metric multidimensional scaling (MDS) based on overall diet composition of juvenile bluefish (*Pomatomus salatrix*) captured a long beach and riprap shorelines during the day in the shore zone of the Lewes site, August 2013.

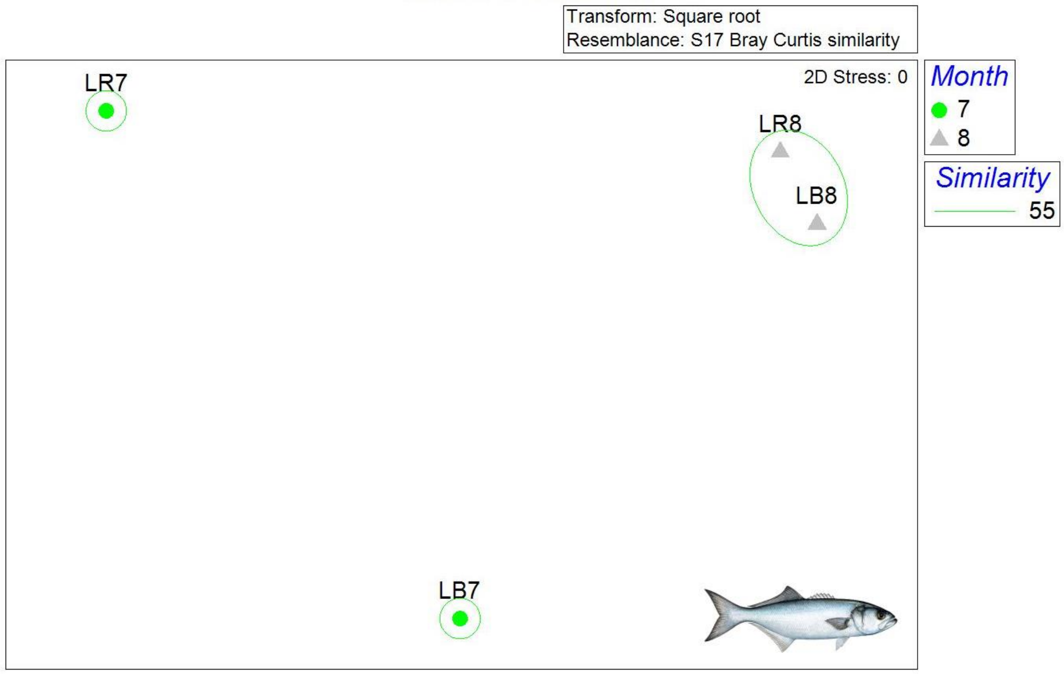

Figure 3.11 Non-metric multidimensional scaling (MDS) based on combined diets per month of juvenile bluefish (*Pomatomus salatrix*) captured a long beach and riprap during the day shorelines in the shore zone of the Lewes, July and August 2013.

CONCLUSION

This study shows a large contrast in shore zone habitat usage by nekton between hardened and unhardened shorelines with differences between beach and riprap shorelines apparent at the community level as well as within individual species. Overall faunal density among two out of three sites and the densities of several dominant species were significantly higher along beach shorelines than along riprap. Distinct fish and crab assemblages were also apparent between beach and riprap shorelines. Usage of shore zone habitat also changed among several abundant species between day and night hours.

Striped bass and weakfish diets did not show changes in prey composition or feeding intensity among shoreline types. However, weakfish diet composition shifted among sites, indicating an effect of location on either prey selectivity or availability. Bluefish diet reflected differences in the predation of prey species associated with shoreline type in the month of July, with individuals captured along the beach foraging on fish prey and those captured along the riprap foraging on mysid shrimp. Bluefish captured in August exhibited similar diet composition overall, but different stomach fullness values indicating a difference in feeding intensity. In general, the results from this study demonstrate altered usage and function of shore zone habitat along hardened shorelines and changes to overall use of shore zone habitat between day and night hours.

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Appendix A

FREQUENCY OF SPECIES CAPTURE

Table A1 Percentage of seine-hauls for which each species was captured within the shore of Delaware Bay from June through September 2012. Species are listed in descending order of overall capture percentage.

Species (common name)		Lewes	Mispillion	Overall
Atlantic Silverside	*Menidia menidia*	90.9	77.3	84.1
Bay Anchovy	*Anchoa mitchilli*	61.4	77.3	69.3
Silver Perch	*Bairdiella chrysoura*	36.4	47.7	42.0
Spot	*Leiostomus xanthurus*	36.4	36.4	36.4
Blue Crab	*Callinectes sapidus*	22.7	40.9	31.8
Weakfish	*Cynoscion regalis*	25.0	34.1	29.5
Atlantic Croaker	*Micropogonias undulatus*	40.9	11.4	26.1
Northern Kingfish	*Menticirrhus saxatilis*	31.8	20.5	26.1
Mullet Sp.	*Mugil sp.*	29.5	20.5	25.0
Striped Bass	*Morone saxatilis*	11.4	36.4	23.9
Striped Killifish	*Fundulus majalis*	2.3	40.9	21.6
Florida Pompano	*Trachinotus carolinus*	22.7	18.2	20.5
Bluefish	*Pomatomus salatrix*	31.8	4.5	18.2
Halfbeak	*Hyporhamphus unifasciatus*	31.8	0.0	15.9
Black Drum	*Pogonias cromis*	6.8	18.2	12.5
Atlantic Needlefish	*Strongylura marina*	15.9	6.8	11.4
Lady Crab	*Ovalipes ocellatus*	20.5	0.0	10.2
Sandbar Shark	*Carcharhinus plumbeus*	0.0	20.5	10.2
White Perch	*Morone americana*	0.0	18.2	9.1
Mummichog	*Fundulus heteroclitus*	6.8	9.1	8.0
Menhaden	*Brevoortia tyrannus*	4.5	9.1	6.8
Northern Puffer	*Sphoeroides maculatus*	11.4	0.0	5.7
Pinfish	*Lagodon rhomboides*	11.4	0.0	5.7
Butterfish	*Peprilus triacanthus*	6.8	2.3	4.5
Lookdown	*Selene vomer*	6.8	2.3	4.5
Striped Burrfish	*Chilomycterus schoepfii*	6.8	2.3	4.5
Summer Flounder	*Paralichthys dentatus*	9.1	0.0	4.5
Hogchocker	*Trinectes maculatus*	4.5	2.3	3.4
Northern Pipefish	*Syngnathus fuscus*	4.5	0.0	2.3
Red Drum	*Sciaenops ocellatus*	4.5	0.0	2.3
Winter Flounder	*Pseudopleuronectes americanus*	4.5	0.0	2.3

Table A2 Percentage of seine-hauls for which each species was captured within the shore of Delaware Bay from June through September 2013. Species are listed in descending order of overall capture percentage.

Species (common name)		**Lewes**	**Misspillion**	**Port Mahon**	**Overall**
Atlantic Silverside	*Menidia menidia*	90.6	87.5	87.5	88.5
Bay Anchovy	*Anchoa mitchilli*	71.9	65.6	87.5	75.0
Blue Crab	*Callinectes sapidus*	34.4	62.5	87.5	61.5
Weakfish	*Cynoscion regalis*	21.9	62.5	78.1	54.2
Bluefish	*Pomatomus salatrix*	65.6	21.9	21.9	36.5
Spot	*Leiostomus xanthurus*	18.8	46.9	40.6	35.4
Silver Perch	*Bairdiella chrysoura*	37.5	25.0	25.0	29.2
American Eel	*Anguilla rostrata*	3.1	12.5	65.6	27.1
Striped Bass	*Morone saxatilis*	0.0	18.8	62.5	27.1
Northern Kingfish	*Menticirrhus saxatilis*	18.8	6.3	43.8	22.9
Florida Pompano	*Trachinotus carolinus*	15.6	15.6	15.6	15.6
Black Drum	*Pogonias cromis*	9.4	6.3	25.0	13.5
Menhaden	*Brevoortia tyrannus*	15.6	3.1	21.9	13.5
White Perch	*Morone americana*	0.0	21.9	15.6	12.5
Hogchoker	*Trinectes maculatus*	0.0	0.0	31.3	10.4
Mullet	*Mugil Sp.*	15.6	9.4	6.3	10.4
Striped Killifish	*Fundulus majalis*	3.1	21.9	6.3	10.4
Atlantic Croaker	*Micropogonias undulatus*	12.5	15.6	0.0	9.4
Calico Crab	*Ovalipes ocellatus*	21.9	0.0	0.0	7.3
Summer Flounder	*Paralichthys dentatus*	15.6	3.1	3.1	7.3
Blueback Herring	*Alosa aestivalis*	0.0	3.1	12.5	5.2
Sheepshead Minnow	*Cyprinodontidae variegatus*	0.0	0.0	15.6	5.2
Lookdown	*Selene vomer*	9.4	0.0	0.0	3.1
Northern Puffer	*Sphoeroides maculatus*	9.4	0.0	0.0	3.1

Table A2 Continued.

Species (common name)		Lewes	Misspillion	Port Mahon	Overall
Cownose Ray	*Rhinoptera bonasus*	0.0	6.3	0.0	2.1
Gizzard Shad	*Dorosoma cepedianum*	0.0	6.3	0.0	2.1
Atlantic Needlefish	*Strongylura marina*	0.0	3.1	0.0	1.0
Crevalle Jack	*Caranx hippos*	0.0	0.0	3.1	1.0
Halfbeak	*Hyporhamphus unifasciatus*	3.1	0.0	0.0	1.0
Mummichog	*Fundulus heteroclitus*	0.0	0.0	3.1	1.0
Northern Pipefish	*Syngnathus fuscus*	3.1	0.0	0.0	1.0
Northern Stargazer	*Astroscopus guttatus*	3.1	0.0	0.0	1.0
Pinfish	*Lagodon rhomboides*	3.1	0.0	0.0	1.0
Southern Stingray	*Dasyatis americana*	3.1	0.0	0.0	1.0
Striped Burrfish	*Chilomycterus schoepfii*	0.0	0.0	3.1	1.0
Striped Cusk-Eel	*Ophidion marginatum*	0.0	3.1	0.0	1.0
Winter Flounder	*Pseudopleuronectes americanus*	3.1	0.0	0.0	1.0

Table A3 Percentage of seine-hauls for which each species was captured within the shore of Lewes during day and night hours from June through September 2013. Species are listed in descending order of overall capture percentage.

Species (common name)		Day Lewes	Night Lewes	Overall
Atlantic Silverside	*Menidia menidia*	90.6	84.4	87.5
Bay Anchovy	*Anchoa mitchilli*	71.9	100.0	85.9
Blue Claw Crab	*Callinectes sapidus*	34.4	75.0	54.7
Bluefish	*Pomatomus salatrix*	65.6	18.8	42.2
Weakfish	*Cynoscion regalis*	21.9	62.5	42.2
Atlantic Croaker	*Micropogonias undulatus*	12.5	53.1	32.8
Northern Kingfish	*Menticirrhus saxatilis*	18.8	43.8	31.3
Silver Perch	*Bairdiella chrysoura*	37.5	18.8	28.1
Spot	*Leiostomus xanthurus*	18.8	37.5	28.1
Summer Flounder	*Paralichthys dentatus*	15.6	31.3	23.4
Calico Crab	*Ovalipes ocellatus*	21.9	18.8	20.3
Atlantic Needlefish	*Strongylura marina*	0.0	37.5	18.8
Mullet	*Mugil Sp.*	15.6	21.9	18.8
Florida Pompano	*Trachinotus carolinus*	15.6	18.8	17.2
Atlantic Breif Squid	*Lolliguncula brevis*	0.0	21.9	10.9
Menhaden	*Brevoortia tyrannus*	15.6	6.3	10.9
Northern Puffer	*Sphoeroides maculatus*	9.4	12.5	10.9
Lookdown	*Selene vomer*	9.4	9.4	9.4
American Eel	*Anguilla rostrata*	3.1	9.4	6.3
Winter Flounder	*Pseudopleuronectes americanus*	3.1	9.4	6.3
Black Drum	*Pogonias cromis*	9.4	0.0	4.7
Northern Stargazer	*Astroscopus guttatus*	3.1	6.3	4.7
Striped Burrfish	*Chilomycterus schoepfii*	0.0	9.4	4.7
Hogchoker	*Trinectes maculatus*	0.0	6.3	3.1
Oyster Toadfish	*Opsanus tau*	0.0	6.3	3.1
Striped Killifish	*Fundulus majalis*	3.1	3.1	3.1
Halfbeak	*Hyporhamphus unifasciatus*	3.1	0.0	1.6
Mummichog	*Fundulus heteroclitus*	0.0	3.1	1.6
Northern Pipefish	*Syngnathus fuscus*	3.1	0.0	1.6
Pinfish	*Lagodon rhomboides*	3.1	0.0	1.6
Smooth Dogfish	*Mustelus canis*	0.0	3.1	1.6
Southern Stingray	*Dasyatis americana*	3.1	0.0	1.6
Striped Bass	*Morone saxatilis*	0.0	3.1	1.6
Striped Cusk-Eel	*Ophidion marginatum*	0.0	3.1	1.6

Appendix B

LENGTH FREQUENCY OF PREDATORY SPECIES

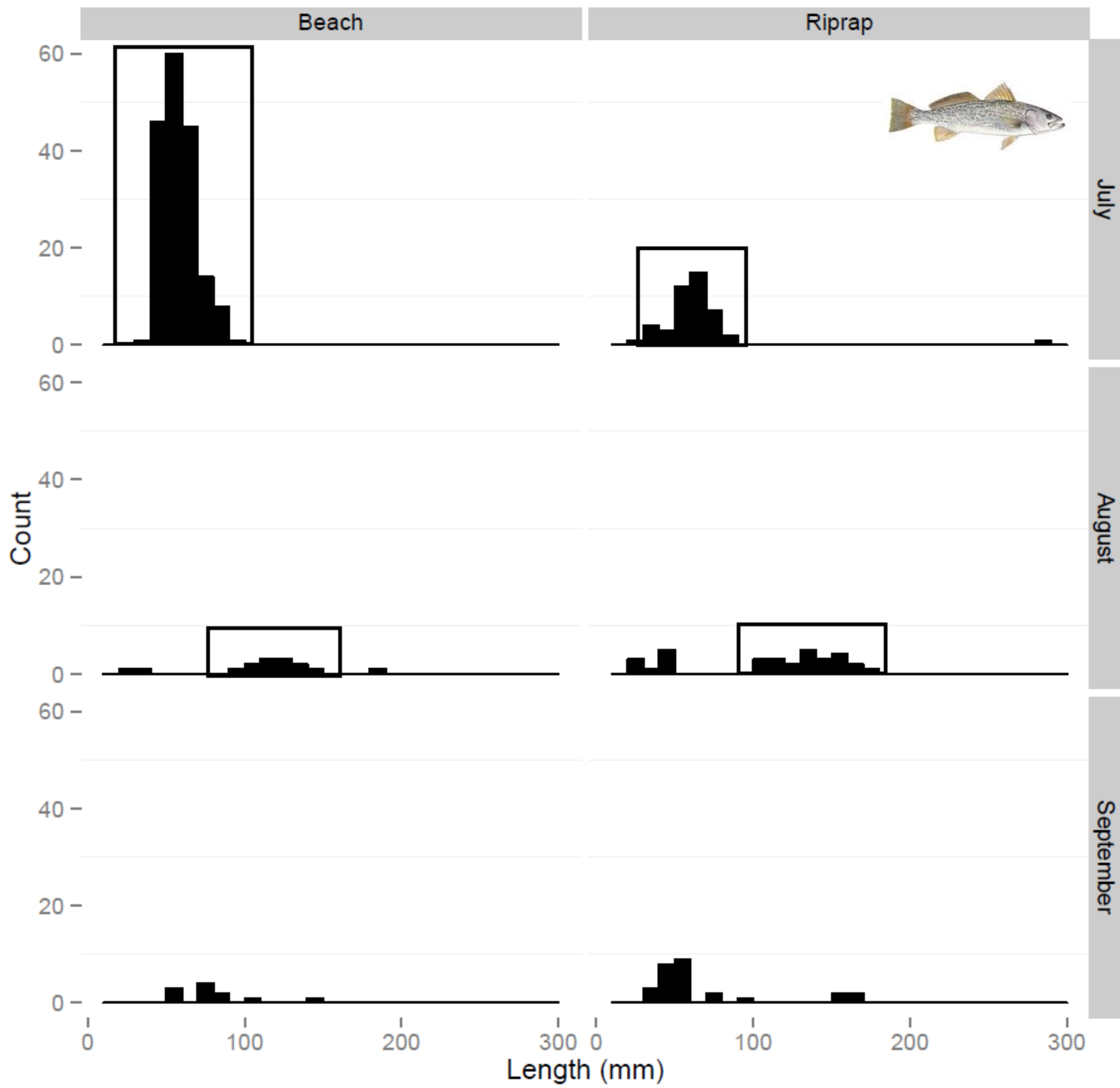

Figure B1 Length frequency plot displaying all weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the night at Lewes in Delaware Bay, June to September 2013. Boxed areas show groups of fish used in diet analysis.

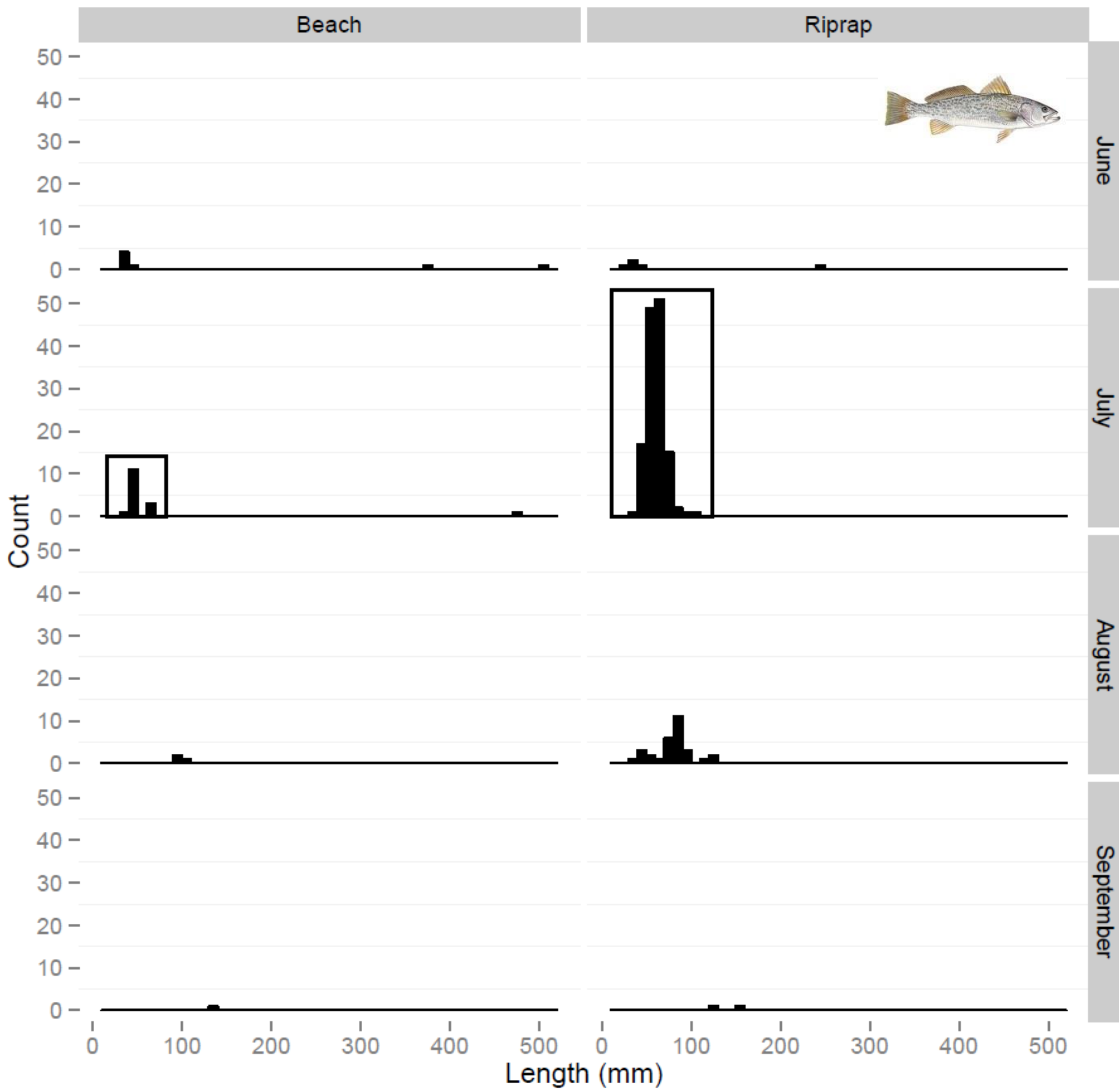

Figure B2 Length frequency plot displaying all weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the day at Mispillion in Delaware Bay, June to September 2013. Boxed areas show groups of fish used in diet analysis.

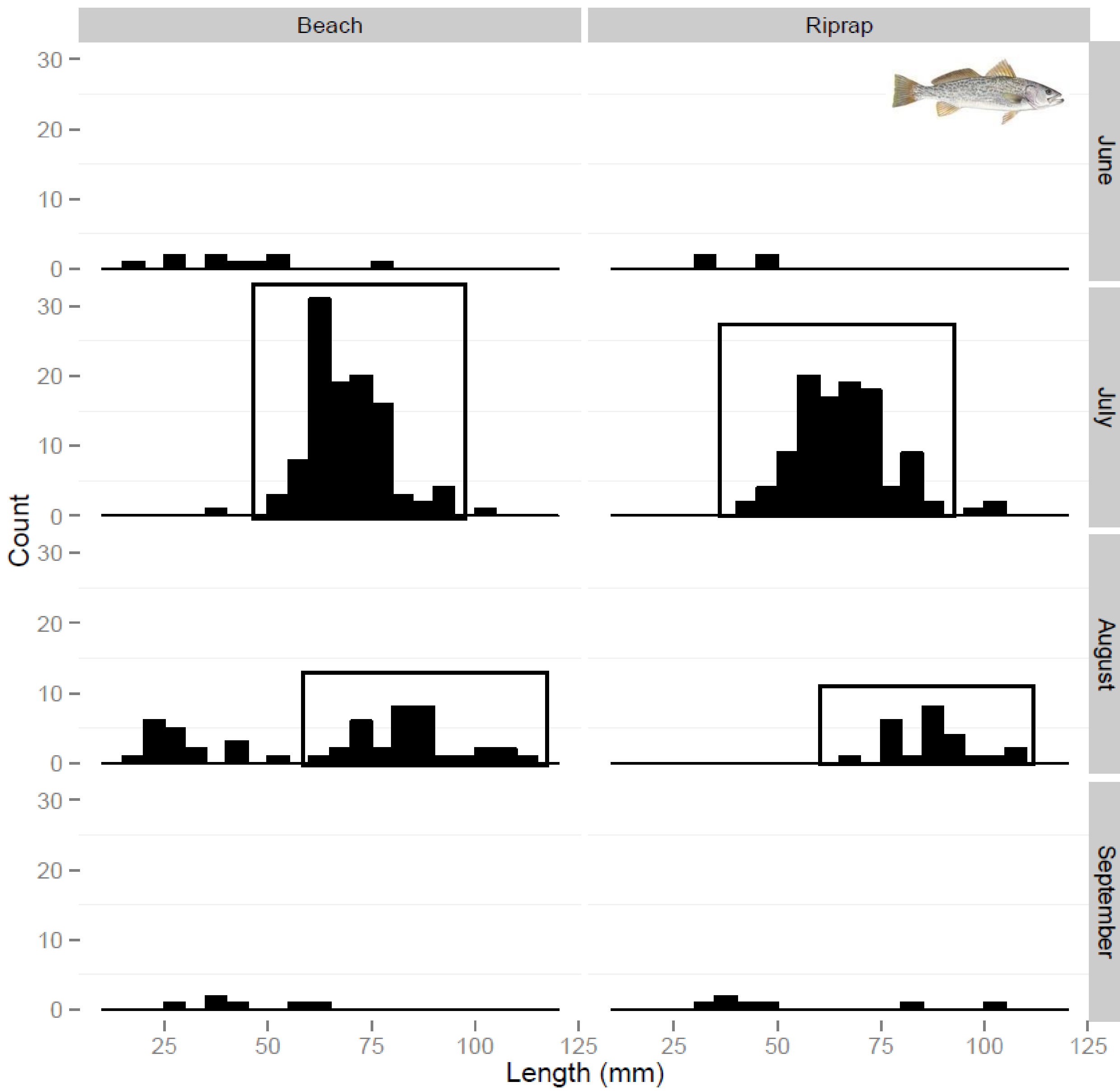

Figure B3 Length frequency plot displaying all weakfish (*Cynoscion ragalis*) captured a long beach and riprap shorelines during the day at Port Mahon in Delaware Bay, June to September 2013. Boxed areas show groups of fish used in diet analysis.

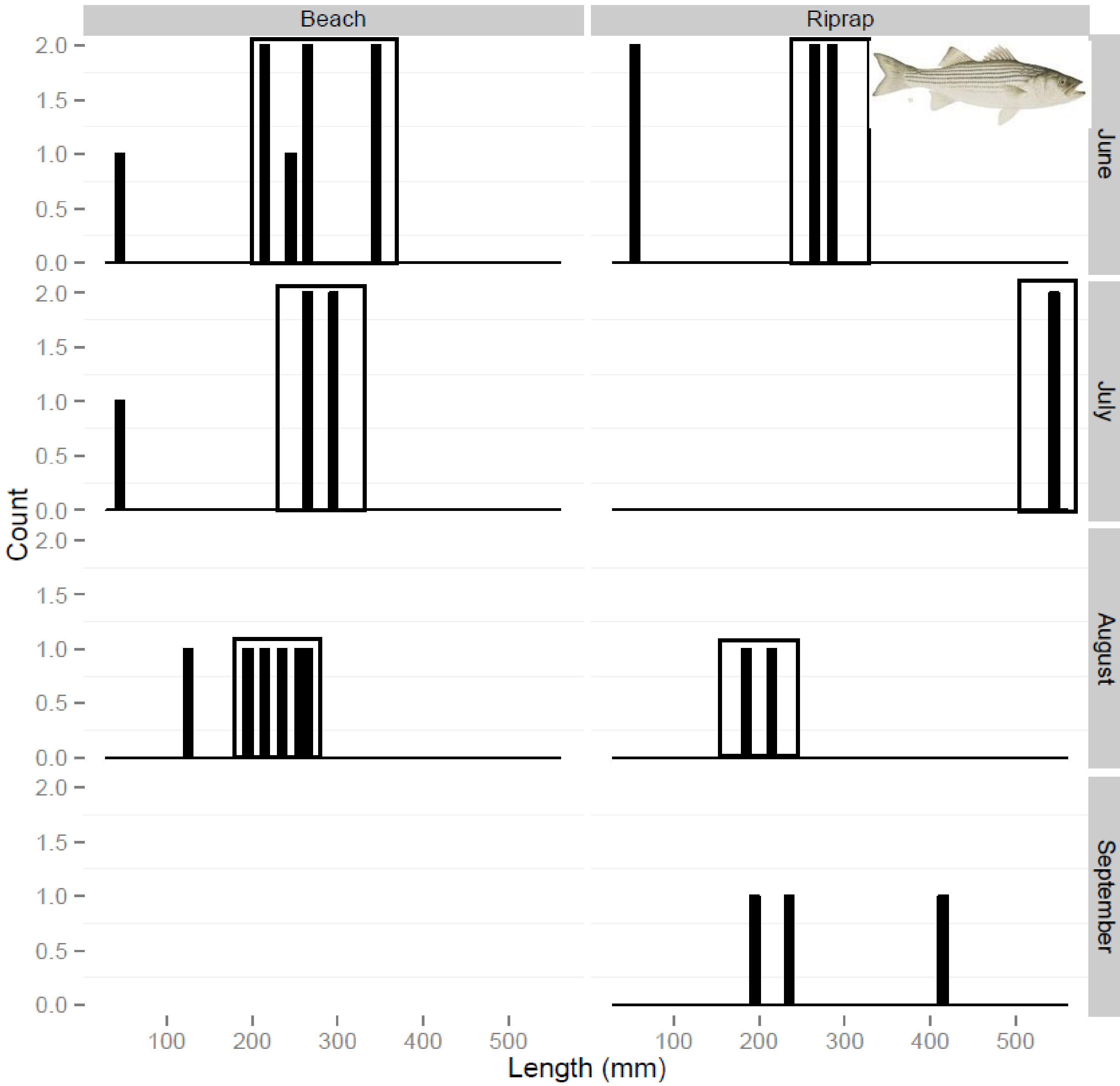

Figure B4 Length frequency plot displaying all striped bass (*morone saxaitalis*) captured a long beach and riprap shorelines during the day at Port Mahon in Delaware Bay, June to September 2013. Boxed areas show groups of fish used in diet analysis.

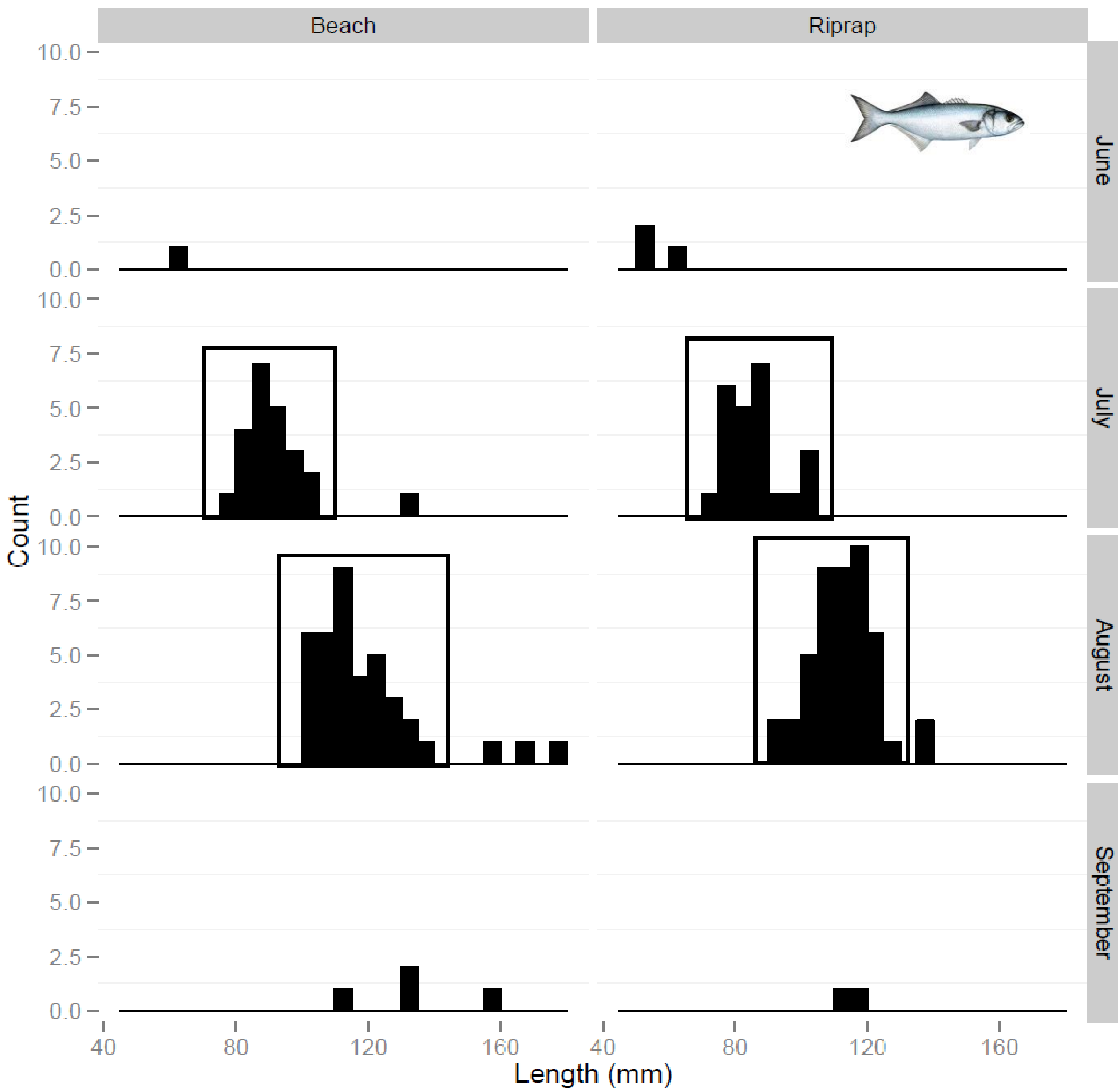

Figure B5 Length frequency plot displaying all bluefish (*Pomatomus salatrix*) captured a long beach and riprap shorelines during the day at Lewes in Delaware Bay, June to September 2013. Boxed areas show groups of fish used in diet analysis.

RECEIVED
FEB 25 2014
IACUC CR

University of Delaware
Institutional Animal Care and Use Committee

Annual Review

(Please complete below using Arial, size 12 Font.)

Title of Protocol: Ecology and Physiological Ecology of Estuarine and Coastal Marine Fishes

AUP Number: 1131-2014-1	← **(4 digits only)**

Principal Investigator: Dr. Timothy Targett

Common Name: Juvenile Weakfish, Juvenile Summer Flounder, Juvenile Striped Bass, Mummichog, Atlantic silverside, Bay anchovy, Silver perch, Atlantic Croaker, Spot, Mullet, Striped killifish, Atlantic menhaden, Halfbeak, Northern Kingfish

Genus Species: : *Cynoscion regalis, Paralichthys dentatus, Morone saxatilis, Fundulus heteroclitus, Menidia menidia, Anchoa mitchilli, Bairdiella chrysoura, Micropognias undulatus Leiostomus xanthurus, Mugilidae sp., Fundulus majalis, Brevoortia tyrannus, Hemiramphus sp., Menticirrhus saxatilis*

Pain Category: ***(please mark one)***

USDA PAIN CATEGORY: ***(Note change of categories from previous form)***	
Category	**Description**
☐ **B**	Breeding or holding where NO research is conducted
☐ **C**	Procedure involving momentary or no pain or distress
☐ **D**	Procedure where pain or distress is alleviated by appropriate means (analgesics, tranquilizers, euthanasia etc.)
X E	Procedure where pain or distress cannot be alleviated, as this would adversely affect the procedures, results or interpretation

Official Use Only

IACUC Approval Signature: [signature]

Date of Approval: 4-1-2014

Principal Investigator Assurance

1.	I agree to abide by all applicable federal, state, and local laws and regulations, and UD policies and procedures.
2.	I understand that deviations from an approved protocol or violations of applicable policies, guidelines, or laws could result in immediate suspension of the protocol and may be reportable to the Office of Laboratory Animal Welfare (OLAW).
3.	I understand that the Attending Veterinarian or his/her designee must be consulted in the planning of any research or procedural changes that may cause more than momentary or slight pain or distress to the animals.
4.	I declare that all experiments involving live animals will be performed under my supervision or that of another qualified scientist listed on this AUP. All listed personnel will be trained and certified in the proper humane methods of animal care and use prior to conducting experimentation.
5.	I understand that emergency veterinary care will be administered to animals showing evidence of discomfort, ailment, or illness.
6.	I declare that the information provided in this application is accurate to the best of my knowledge. If this project is funded by an extramural source, I certify that this application accurately reflects all currently planned procedures involving animals described in the proposal to the funding agency.
7.	I assure that any modifications to the protocol will be submitted to the UD-IACUC and I understand that they must be approved by the IACUC prior to initiation of such changes.
8.	I understand that the approval of this project is for a maximum of one year from the date of UD-IACUC approval and that I must re-apply to continue the project beyond that period.
9.	I understand that any unanticipated adverse events, morbidity, or mortality must be reported to the UD-IACUC immediately.
10.	I assure that the experimental design has been developed with **consideration of the three Rs: reduction, refinement, and replacement, to reduce animal pain and/or distress and the number of animals used in the laboratory.**
11.	I assure that the proposed research does not unnecessarily duplicate previous experiments. *(Teaching Protocols Exempt)*
12.	I understand that by signing, I agree to these assurances. Timothy E. Targett (signature) 2-23-2014 Signature of Principal Investigator Date

SIGNATURE(S) OF ALL PERSONS LISTED ON THIS PROTOCOL

I certify that I have read this protocol, accept my responsibility and will perform only the procedures that have been approved by the IACUC.

Name	Signature
1. Michael P. Torre	
2. Rachel L. Dixon	
3. Max Davidson	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	
13.	
14.	
15.	

IACUC approval of animal protocols must be renewed on an annual basis.

1. Previous Approval Date: 4/1/2013

Is Funding Source the same as on original, approved AUP?

X Yes ☐ No

If no, please state Funding Source and Award Number:

2. Record of Animal Use:

Common Name	Genus Species	Total Number Previously Approved	Number Used To Date
1. Weakfish	Cynoscion regalis	350	20
2. Summer flounder	Paralichthys dentatus	220	50
3. Mummichog	Fundulus heteroclitus	900	400
4. Striped Bass	Morone saxatilis	400	200
5. Atlantic silverside	Menidia menidia	3600	1500
6. Silver Perch	Bairdiella chrysoura	1300	250
7. Striped killifish	Fundulus majalis	250	150
8. Atlantic croaker	Micropogonias undulatus	450	300
9. Atlantic menhaden	Brevoortia tyrannus	240	40
10. Bay anchovy	Anchoa mitchilli	1200	250
11. Spot	Leiostomus xanthurus	400	300

12. Mullet sp.	Mugil sp.	350	50
13 Northern kingfish	Menticirrhus saxitilis	180	40
14. Halfbeak	Hemiramphus sp.	220	40
12. Various species		500	100

3. Protocol Status: *(Please indicate by check mark the status of project.)*

Request for Protocol Continuance:

X A. Active: Project ongoing

☐ B. Currently inactive: Project was initiated but is presently inactive

☐ C. Inactive: Project never initiated but anticipated starting date is:

Request for Protocol Termination:

☐ D. Inactive: Project never initiated

☐ E. Completed: No further activities with animals will be done.

4. Project Personnel: Have there been any personnel changes since the last IACUC approval? X Yes ☐ No

If Yes, fill out the Amendment to Add/Delete Personnel form to "Add" Personnel.

Project Personnel Deletions:

Name	Effective Date
1. Katherine A. Bogue	Dec 1 2013
2.	

5. **Progress Report:** If the status of this project is 3.A or 3.B, please provide a brief update on the progress made in achieving the aims of the protocol.

For project (A): The fish assemblage was sampled biweekly during 2013 at 3 locations (Lewes Ferry Terminal, Mispillion, Port Mahon) from May-October. Sampling at each location occurred at least one hour after sunrise and one hour before sunset. Sampling took place at 2 sites for each stretch of shoreline. Sites are randomly chosen from the 5 possible sites along each stretch of shoreline. Fish were collected a single tow of a 36m bag-seine net deployed by boat. Captured fish are counted, and a subsample of up to 20 individuals per species is measured (fork length for fishes with forked tails, total length for everything else). Predatory fish are stunned with a blow to the head and immediately placed on dry ice and later stored in a -80c freezer for diet analysis. The rest of the catch is released alive adjacent to the shoreline where they were collected. Night sampling was also be conducted weekly, but only at the Lewes site. Sampling methodology was identical to that described above. The other component of our work in 2013 was tagging spot (256) and Atlantic croaker (137) with Visible Implant Elastomer (Northwest Marine Technology), using standard procedures, to study movement patterns. VIE tags are injected as a 1mmX2mm spot of liquid that soon cures into a pliable, biocompatible solid. Fish will be tagged just under the skin using an NMT syringe injector and immediately released alive at the capture location. None were recaptured.

For Project (B): Juvenile striped bass were obtained from aquaculture facilities at GenOn's Patuxent River Chalk Point Generating Station in MD. Planned growth experiments were attempted in the temperature- and photoperiod-controlled room, using the computer-controlled recirculating aquarium systems, described in the latest approved protocol #1131. Survivorship was poor, due largely to a disease issue in the aquacultured fish, and the experiment had to be abandoned. Instead, mummichogs, striped killifish, and Atlantic silversides were collected from the field and, along with the remaining striped bass, were used in a series aquatic surface respiration (ASR) experiments. These behavioral observations of ASR were conducted in the same temperature and photoperiod-controlled lab as used in growth experiments. Fish were exposed to replicate DO/pH treatment combinations over a period of 48 hours, as described in the latest approved protocol #1131. Fish were subsequently euthanized via cranial concussion and pithing for tissue analyses.

6. **Problems or Adverse Effects:** If the status of this project is 3.A or 3.B, please describe any unanticipated adverse events, morbidity, or mortality, the cause if known, and how these problems were resolved. If there were none, this should be indicated.

As noted above, survivorship of juvenile striped bass obtained from the aquaculture facilities at GenOn's Patuxent River Chalk Point Generating Station in MD was poor, due largely to a disease issue. The growth experiment had to be abandoned. .