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Nekton assemblages along riprap-altered shorelines in Delaware Bay, USA: comparisons with adjacent beach

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ABSTRACT: Riprap-reinforced shorelines are becoming more prevalent as a result of increasing coastal development and sea level rise. Altered morphology at the land–water interface, associated with riprap shorelines, has the potential to reduce shore-zone habitat quality for associated nekton species. The shore-zone nekton assemblage within a temperate, mid-Atlantic coast, USA, estuary was examined to identify differences in habitat use between sandy beach and riprap shorelines. We found that riprap can have a negative effect on a local scale. Overall nekton density, species richness, and density of dominant species were higher along beach shorelines relative to adjacent riprap, in most instances. Nekton association with shoreline habitat appears to be consistent over the diel cycle. Densities of Atlantic silverside *Menidia menidia*, striped killifish *Fundulus majalis*, spot *Leiostomus xanthurus*, and white perch *Morone americana* were generally reduced along riprap. In some cases, riprap shorelines also had altered species assemblages. Thus, our findings provide evidence of altered habitat quality for shore-zone nekton associated with shoreline hardening. These impacts were, however, variable spatially and temporally. Further research is needed to identify the biophysical mechanisms associated with riprap shorelines that are most responsible for altered habitat quality.

KEY WORDS: Shoreline armoring · Riprap · Beach · Fish assemblage · Nekton density · Estuary · Delaware Bay

INTRODUCTION

The ecological importance of estuarine and ocean shore zones has been frequently highlighted in studies around the world (Lasiak 1984, Whitfield 1999, Félix et al. 2007, Able et al. 2013). Sandy beaches dominate the world's shorelines and are productive habitats that serve important functions as nursery areas and migration pathways for a variety of nekton species (Ruiz et al. 1993, Paterson & Whitfield 2000, McLachlan & Brown 2006, Marin Jarrin & Shanks 2011, Able et al. 2013), which support high densities of small, forage, and juvenile fishes (Whitfield 1999, McLachlan & Brown 2006, Félix et al. 2007). However, despite their importance, sandy beaches in estuaries and ocean shore zones often exist under substantial anthropogenic influence, one of which is shoreline armoring.

Shoreline armoring is the process of placing hardened structures along soft shorelines to reduce erosion and protect upland property (Bilkovic & Roggero 2008, Peterson & Lowe 2009). These structures usually consist of rock piles (riprap) or wooden or metal walls (bulkhead) placed in the intertidal zone. Such modification of natural shorelines can drastically reduce or completely remove intertidal habitat (Bilkovic & Roggero 2008). Additionally, armored shorelines reflect wave energy leading to higher rates of

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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 negatively impacting a range of fauna, particularly macroinvertebrate and nekton communities (Peterson et al. 2000, Toft et al. 2007, Bilkovic & Roggero 2008, Sobocinski et al. 2010, Balouskus & Targett 2012, Lawless & Seitz 2014). These negative effects have been demonstrated across a range of freshwater and marine systems (Peterson et al. 2000, Toft et al. 2007, Bilkovic & Roggero 2008, Balouskous 2012). Relatively few studies, however, have (1) focused on riprap-armored shorelines, possibly because traditional sampling methods are difficult to use and (2) examined these structures along open beach habitats.

The practice of converting natural shorelines to armored structures is prevalent among many coastal areas of the world and is continuing to occur at a rapid pace (Able et al. 1999, Davis et al. 2002, Bilkovic & Roggero 2008, Sobocinski et al. 2010) and usually corresponds to population growth within an area (Douglass & Pickel 1999). Climate change and an increasing rate of coastal development will intensify the demand for hardened shorelines to protect upland property from erosion, as predicted sea-level rise will result in increased rates of flooding (Najjar et al. 2000, Orth 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. Therefore, the present study investigated differences in nekton density and the composition of the species assemblage between sandy beach and riprap shorelines along Delaware Bay. Additionally, day versus night sampling was used to identify differences between beach and riprap shorelines over the diel cycle.

MATERIALS AND METHODS

Study area

Delaware Bay is a coastal plain estuary and is one of the largest estuaries on the USA east coast (Bryant & Pennock 1988, Pennock & Sharp 1994). Unvegetated shore zones comprise 74 % of the Delaware Bay shoreline and are characterized by shallow, gradually sloping sandy beaches which are often subject to wave erosion (de Sylva et al. 1962, Lathrop et al. 2006). The shore zone of Delaware Bay supports high densities of small forage and juvenile fishes, as well as feeding and spawning of adult fishes (Shuster 1959, de Sylva et al. 1962, Able et al. 2007, Boutin 2008). The fish fauna of Delaware Bay is dominated by species in the families Engraulidae, Atherinopsidae, Sciaenidae, Moronidae and Clupeidae (Able et al. 2007).

Three sites were sampled along the western shore: Lewes, Mispillion, and Port Mahon (Fig. 1). Lewes and Mispillion are polyhaline, and Port Mahon is mesohaline. Sampling sites were selected based on the presence of riprap hardened shorelines adjacent to beaches. Shore-zone sediment in Lewes and Mispillion was coarse sand along both beach and riprap shorelines. Beach and riprap shorelines at Port Mahon had coarse sand sediment within ~10–12 m of the shoreline followed by a transition to mud >10–12 m from the shoreline. Slope of the land–water interface was significantly steeper along riprap shorelines than beach due to the inherent aspects of shoreline hardening (Fig. 2). Mean depth in the intertidal zone (at time of sampling) was 0.5 m deeper at the riprap relative to beach. Depth at 10 m offshore was the same, on average, between shoreline types. Slope of sub-tidal substrate (out to ca. 10 m) was slightly higher at beach (~7°) compared to riprap (~5°), on average.

Riprap at all sites was of similar construction, and although heterogeneous by nature, riprap rock sizes tend to be ~ 0.4–0.6 m in diameter (Fig. 2). Interstices

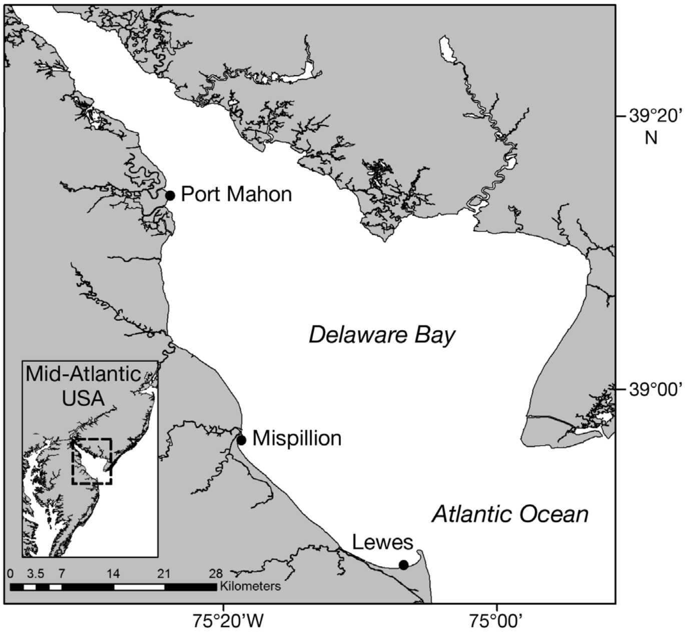

Fig. 1. Shore-zone sites along Delaware Bay sampled from June through September, 2012 and 2013. Each site consisted of adjacent stretches of beach and riprap

Fig. 2. Typical structural characteristics of the beach (left) and riprap (right) shorelines sampled

between rocks were present throughout riprap shorelines in varying sizes, most of which are large enough for small fish to access. Extensive green algae coverage was present along the intertidal zone of riprap shorelines at all sites (Fig. 2). Rockweed *Ascophyllum nodosum* covered a patchy distribution of sub-tidal rocks at Lewes and Mispillion, but was absent at Port Mahon.

Macrofaunal sampling

Fishes and crabs were sampled from June through late September 2012 and 2013 when faunal richness was typically the highest of the year (de Sylva et al. 1962, Able et al. 2007). Sampling occurred weekly at the Lewes and Mispillion sites in 2012 and bi-weekly at Lewes, Mispillion, and Port Mahon in 2013. Sampling at each site consisted of 4 seine hauls using a 36 m bag-seine net (1.2 m high; 3.5 mm mesh). A section of beach and riprap shoreline ~200–300 m long was chosen at each site, with the exception of the Port Mahon beach, which was ~75 m long. Two seine-hauls were conducted at randomly chosen stations within each site along both riprap and adjacent beach shorelines. Seining was done within 3 h of high tide and covered intertidal and shallow subtidal areas <1.5 m in depth. Daytime sampling took place at least 1 h after sunrise to 1 h before sunset. Sites were positioned along areas with little to no offshore structure (i.e. woody debris or rock). Night sampling was conducted bi-weekly along both shoreline types, at the Lewes site only, from June through late September 2013. Night sampling occurred at least 1 h after sunset to 1 h before sunrise.

The following procedure was used (after Steve Giordano, NOAA Chesapeake Bay Office) to quickly enclose the sampling area and minimize losses of large mobile nekton. One end of the net was held on the shoreline and the boat was moved along a half circle from this point, while the net was deployed off the bow to quickly (<45 s) enclose the area of water immediately adjacent to the ~20 m section of shore. Both ends of the net were then moved together along the shore. On riprap shorelines nekton were actively driven into the bag of the net by thrusting PVC poles into and around rock crevices. Once the ends were together the net was pulled in, forcing all enclosed nekton into the bag. Volume sampled was calculated for each tow to convert measures of abundance into density according to the following formula:

$$\text{Volume} = \frac{1}{6}\pi ab\left(\frac{\mathrm{d}_1 - \mathrm{d}_2}{2}\right) \tag{1}$$

with a being the length of enclosed shoreline, b being the distance between the shoreline and the apogee of the net, d_1 being onshore depth, and d_2 being offshore depth.

All captured nekton were counted and measured to the nearest mm (for species with >20 individuals, a random subsample of 20 was measured): fork length (FL) for fishes with forked tails; total length (TL) for other fishes; carapace width for *Callinectes sapidus* (blue crab). The sampling technique was as far as possible identical along beach and riprap shorelines. Any differences in technique between the 2 shoreline types were designed to maximize sampling efficiency. Balouskous (2012) found that 2 rapidly repeated seine hauls collected >90% of individual fish and >95% of *C. sapidus* along both riprap and beach shorelines within the Delaware Coastal Bays. Sampling efficiency found among 2 repeated seine hauls was the same between beach and riprap shorelines. As a result of these findings, no catchability coefficient was applied to either shoreline type in the present study.

Data analysis

Due to differences in sampling frequency, data from 2012 and 2013 were analyzed separately. Student's *t*-test was used to test for significant ($\alpha = 0.05$) variation in total nekton density and species richness between beach and riprap shorelines at each site (Lewes, Mispillion, and Port Mahon). For individual species that accounted for >1 % of the total catch, significant differences in the density between beach and riprap shorelines was tested for each site with a randomization test ($\alpha = 0.01$). Randomization tests were used in place of Student's *t*-test to account for non-normally distributed data and the frequent occurrence of zeros resulting from the sub-setting of total nekton density data into individual species. Randomization tests go through permutations of data reshuffling to generate a distribution of potential scores that the observed score is compared to. This method is a non-parametric alternative to a *t*-test that is more robust to non-normally distributed data and frequent occurrence of zeros (Tebbs & Bower 2003), and was carried out using R software version 2.11.0 (R Core Development Team 2008). Critical level of significance was adjusted from $\alpha = 0.05$ to $\alpha = 0.01$ to account for multiple testing.

Differences in total nekton density and species richness between shoreline types, and between day and night at the Lewes site, were assessed using 2-factor ANOVA ($\alpha = 0.05$). Significant variation in the density of individual species accounting for >1 % of the total catch between shoreline type and day–night at Lewes was tested with a randomization test for a 2-factor ANOVA ($\alpha = 0.01$). Randomization tests were used in place of 2-factor ANOVA to account for non-normally distributed data and the frequent occurrence of zeros resulting from the sub-setting of total nekton density data into individual species. This method is a non-parametric version of a 2-factor ANOVA that is more robust to non-normally distributed data and frequent occurrence of zeros (Anderson & Ter Braak 2003), and was carried out using R software version 2.11.0 (R Core Development Team 2008). Critical level of significance was adjusted from $\alpha = 0.05$ to $\alpha = 0.01$ to account for multiple testing.

Differences in species assemblage compositions were analyzed for each year and site with a multivariate approach using the non-metric multidimensional scaling (NMDS) and adonis procedures. For these analyses the vegan package within R software version 2.11.0 was used (R Core Development Team 2008, Oksanen et al. 2008). Density data was square-root transformed and similarity matrices were constructed for each site using the Bray-Curtis similarity measure. NMDS based on similarity matrices was used to generate 2D plots depicting similarity of faunal assemblages between beach and riprap at each site. Spider diagrams were overlaid upon 2D NMDS plots to show group centroids and spread. To show similarity of faunal assemblages between shoreline type and day versus night at Lewes, 3D NMDS was used. Ellipsoids encompassing 50 % similarity of each day–night and shoreline type grouping were added to better highlight group differences. Significant variation in species assemblage was tested using the adonis function in the vegan package (Oksanen et al. 2008). This function performs a permutational multiple analysis of variance (PERMANOVA) using Bray-Curtis similarity matrices to assign variation in species assemblage data to explanatory variables (shoreline type, day vs. night). The number of permutations used in these analyses was 999.

RESULTS

The shoreline sites sampled in this study spanned a salinity gradient ranging from polyhaline to mesohaline. The 3 sites had mean (all months pooled) salinities of 18‰ at Port Mahon, 22.7‰ at Mispillion, and 24.5‰ at Lewes, following a general trend of increasing salinity towards the bay mouth. Mean temperatures were 22.8°C at Lewes, 25.9°C at Mispillion, and 26.4°C at Port Mahon, with a trend of temperature increasing in the up-bay direction. No difference in temperature or salinity was observed between beach and riprap shorelines within a given site.Mean ± SE species richness per seine haul was higher along beach shorelines than along riprap at both Lewes (beach: 7.2 ± 0.5, riprap: 5.0 ± 0.5; $p = 0.003$) and Mispillion (beach: 7.7 ± 0.4, riprap: 3.5 ± 0.4; $p = 0.001$) during 2012 (Fig. 3). Data from 2013 showed mean species richness per seine haul was higher along beach shorelines than along riprap at Mispillion (beach: 6.1 ± 0.3, riprap: 4.5 ± 0.4; $p = 0.005$), but not Lewes (beach: 5.2 ± 0.6, riprap: 5.0 ± 0.5; $p = 0.809$) or Port Mahon (beach: 8.1 ± 0.6, riprap: 7.1 ± 0.5; $p = 0.235$) (Fig. 3). Total macrofauna density was higher

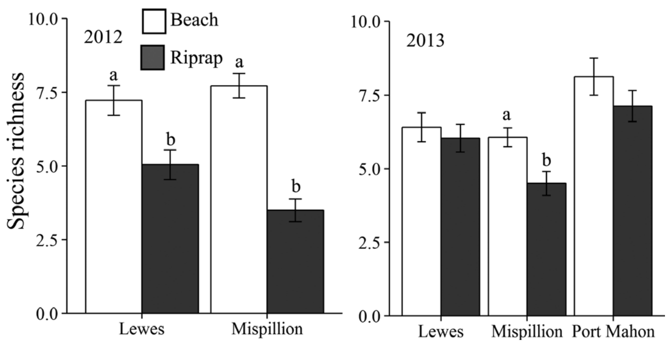

Fig. 3. Mean species richness per seine haul at beach and riprap shorelines sampled from June through September, 2012 and 2013. N = 22 and 16 for each shoreline type and site combination in 2012 and 2013, respectively. Species richness bars with different subscripts within a site are significantly different from each other ($p < 0.05$); error bars: ±SE

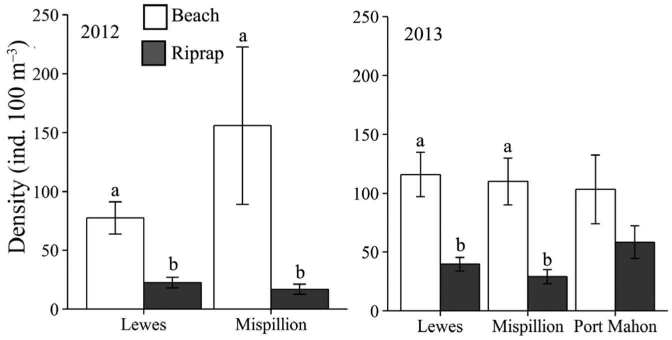

Fig. 4. Mean density (ind. 100 m^{-3}) per seine haul of combined macrofauna along beach and riprap shorelines sampled from June through September, 2012 and 2013. N = 22 and 16 for each shoreline type and site combination in 2012 and 2013, respectively. Density bars with different subscripts within a site are significantly different from each other ($p < 0.05$); error bars: ±SE

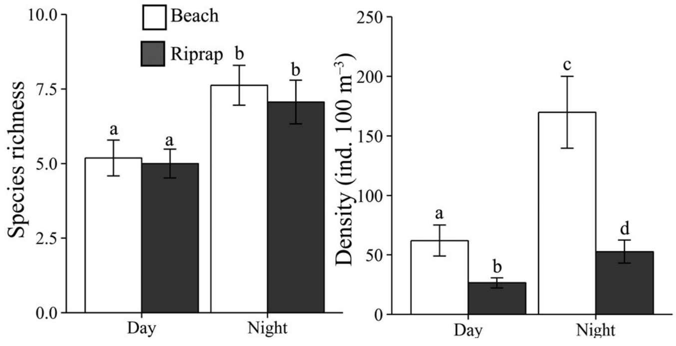

Fig. 5. Mean species richness and mean density (ind. 100 m^{-3}) of combined macrofauna along beach and riprap shorelines during daytime versus nighttime at Lewes, June through September, 2013. N = 16 for each shoreline type and diel period combination. Species richness and density bars with different subscripts within a diel period are significantly different from each other ($p < 0.05$); error bars: ±SE

along beach compared to riprap at both Lewes (2012: $p < 0.01$; 2013: $p = 0.02$) and Mispillion (2012: $p = 0.04$; 2013: $p < 0.01$) during 2012 and 2013 (Fig. 4). There was no significant variation in macrofauna density between shoreline types at Port Mahon ($p = 0.173$) (Fig. 4).

Day–night sampling at Lewes showed mean species richness per haul was higher during night hours than during the day (day: 5.1 ± 0.4, night: 7.3 ± 0.5; $p < 0.001$) but was similar between beach and riprap shorelines (beach: 6.4 ± 0.5, riprap: 6.0 ± 0.5; $p = 0.553$) with no interaction ($p = 0.766$) (Fig. 5). Total macrofauna density was higher during night hours and along beach shorelines than during the day and along riprap shorelines with no interaction between factors (shoreline type: $p < 0.01$; day–night: $p < 0.01$; shoreline type:day–night: $p = 0.058$) (Fig. 5).

The densities of several dominant species (>1% of total catch at site and year) were consistently different between beach and riprap shorelines (Tables 1 & 2). All but one species that exhibited a significant relationship with shoreline type were found in higher densities along beaches (Tables 1 & 2). Only bay anchovy *Anchoa mitchilli* was found in higher density along riprap, but only at 1 site and in 1 year (Mispillion in 2013). Densities of *A. mitchilli*, weakfish *Cynoscion regalis*, and spot *Leiostomus xanthurus* were significantly higher at night along both beach and riprap shorelines (Table 3). Density of bluefish *Pomatomus saltatrix* was significantly higher during the day along both beach and riprap shorelines. Density of Atlantic silverside *Menidia menidia* was higher along the beach during both day and night (Table 3).

The overall species assemblage consisted primarily of small-bodied species or young-of-the-year through juveniles of larger-bodied fishes <200 mm in length. While small sample sizes among size classes of individual species in most cases prevented statistical comparison, size distribution of all species appeared to be the same between beach and riprap. A few larger *C. regalis* and striped bass *Morone saxatilis* >200 mm were captured. However, although their low numbers prevented a statistical comparison between shoreline types, these larger individuals were captured along beach and riprap in about equal numbers (*C. regalis*: riprap = 2, beach = 3; *M. saxatilis*: riprap = 6, beach = 10).

NMDS ordination of shore-zone density data in 2012 and 2013 shows distinct beach and riprap species assemblages at Lewes and Mispillion, but not at Port Mahon (Figs. 6 & 7). 3D NMDS ordination of shore-zone density data from day–night sampling at Lewes shows distinct diel and beach–riprap groups

Table 1. Total number, percent catch and mean densities per seine haul of dominant (>1 % total catch) fishes, and *C. sapidus*, in the shore zone of Delaware Bay (see Fig. 1) from June through September, 2012. Significant differences in mean density between beach and riprap: $^{*}p < 0.01$, $^{**}p < 0.005$, $^{***}p < 0.001$

	Total		Density (ind. 100 m^{-3})		p
	No.	% catch	Beach	Riprap	
Lewes					
Menidia menidia	810	32.39	24.49	5.77	$<0.001^{***}$
Bairdiella chrysoura	545	21.79	12.41	6.08	0.23
Anchoa mitchilli	252	10.08	7.43	1.46	0.010^{*}
Micropogonias undulatus	224	8.96	11.68	2.41	0.10
Leiostomus xanthurus	138	5.52	8.05	0.52	$<0.001^{***}$
Hyporhamphus unifasciatus	110	4.40	0.47	1.91	0.04
Mugil sp.	74	2.96	0.78	1.16	0.50
Menticirrhus saxatilis	57	2.28	2.61	0.12	0.002^{**}
Pomatomus salatrix	42	1.68	0.31	0.73	0.10
Cynoscion regalis	33	1.32	0.19	0.64	0.07
Callinectes sapidus	31	1.24	0.27	0.74	0.12
Strongylura marina	26	1.04	0.48	0.47	0.48
Trachinotus carolinus	26	1.04	1.79	0.00	$<0.001^{***}$
Mispillion					
Menidia menidia	1006	39.81	66.14	2.94	$<0.001^{***}$
Fundulus heteroclitus	357	14.13	50.85	0.00	0.05
Anchoa mitchilli	348	13.77	4.78	6.28	0.23
Fundulus majalis	130	5.14	6.62	0.00	$<0.001^{***}$
Brevoortia tyrannus	107	4.23	0.10	2.99	0.45
Bairdiella chrysoura	98	3.88	4.23	0.50	$<0.001^{***}$
Mugil sp.	89	3.52	5.03	0.21	0.02
Morone saxatilis	81	3.21	3.81	0.18	$<0.001^{***}$
Leiostomus xanthurus	70	2.77	4.80	0.18	$<0.001^{***}$
Callinectes sapidus	59	2.33	2.61	1.09	0.10
Cynoscion regalis	38	1.50	0.50	0.99	0.11
Menticirrhus saxatilis	36	1.42	0.89	1.12	0.41
Morone americana	27	1.07	1.25	0.00	0.002^{**}

(Fig. 8). PERMANOVA shows that shoreline type significantly explained 13.1 and 19.9 % of the variation in species assemblage at Lewes (shoreline type: *F* = 3.013, R = 0.131, $p < 0.01$) and Mispillon (shoreline type: *F* = 4.964, R = 0.199, $p < 0.01$), respectively, during 2012. In 2013, shoreline type significantly explained 29.9 % of the variation in species assemblage at Mispillion (shoreline type: *F* = 5.979, R = 0.299, $p < 0.01$); however, shoreline type was insignificant at explaining variation in data from Lewes (shoreline type: *F* = 1.752, R = 0.111, p = 0.072) and Port Mahon (shoreline type: *F* = 0.954, R = 0.064, p = 0.458). Shoreline type and diel period significantly explained 12.1 and 12.7 % of the variation in species assemblage as shown by PERMANOVA on day–night data from Lewes (shoreline type: *F* = 4.526, R = 0.121, $p < 0.01$; day–night: *F* = 4.7533, R = 0.127, $p < 0.01$; interaction *F* = 0.122, R = 0.003, p = 1.000).

DISCUSSION

This study demonstrates differences in nekton density along riprap compared to sandy beach shorelines. In most cases there was a decrease in total nekton density along riprap, as well as reduced densities of several dominant species. In general, our findings support earlier studies in rivers and low energy estuarine shorelines, which show lower densities of fishes along hardened shorelines (Peterson et al. 2000, Toft et al. 2007, Bilkovic & Roggero 2008).

Although shoreline type explained only ~20 % of variation in the species assemblage in most cases, this still likely represents an important difference. The NMDS plots reveals distinct beach and riprap groups in most cases, while also showing a large spread within groups. This spread is due to seasonal variation in species assemblages which effectively masks the variation due to shoreline type. Extensive sampling efforts confined to a short temporal window would likely provide clearer distinctions between beach and riprap species assemblages.

Altered nekton assemblages along riprap may reflect a number of physical characteristics of these shorelines. Increased depth at the land–water interface of riprap shorelines may alter predator–prey dynamics. While the few large piscivores captured in this study appeared equally distributed between beach and riprap shorelines, it was not possible to determine how far offshore they were located, since seine net sampling extended ~10 m offshore. Along riprap shorelines, greater depth very close to shore could allow increased access to this area by large piscivores relative to beach habitat, where shallow water close to shore could isolate large-bodied fish further out. Thus, beach habitat may function as shallow water refuge for small-bodied pelagic fishes in Delaware Bay and other estuaries in the USA Mid-Atlantic coastal region (Vasconcellos et al. 2011).

The similarity in nekton density, and species assemblage, between beach and riprap shorelines at the Port Mahon site is illustrative of potential scale affects. The small stretch of beach at this site was

Table 2. Total number, percent catch and mean densities per seine haul of dominant (>1% total catch) fishes, and *C. sapidus* in the shore zone of Delaware Bay (see Fig. 1) from June through September, 2013. Significant differences in mean density between beach and riprap: $^{*}p < 0.01$, $^{**}p < 0.005$, $^{***}p < 0.001$

	Total		Density (ind. 100 m^{-3})		p
	No.	% catch	Beach	Riprap	
Lewes					
Menidia menidia	798	56.60	42.80	10.67	0.002**
Anchoa mitchilli	201	14.26	4.20	6.40	0.198
Pomatomus salatrix	113	8.01	4.13	2.98	0.334
Bairdiella chrysoura	77	5.46	1.91	2.29	0.413
Mugil sp.	55	3.90	2.13	1.01	0.336
Brevoortia tyrannus	49	3.48	3.21	0.11	0.173
Callinectes sapidus	38	2.70	0.40	1.52	0.068
Mispillion					
Menidia menidia	1508	70.70	90.74	11.99	<0.001***
Cynoscion regalis	201	9.42	2.77	7.04	0.140
Anchoa mitchilli	185	8.67	1.20	7.30	<0.001***
Callinectes sapidus	45	2.11	1.97	1.29	0.200
Fundulus majalis	44	2.06	3.61	0.00	0.003**
Leiostomus xanthurus	39	1.83	3.17	0.19	<0.001***
Morone americana	34	1.59	2.35	0.05	0.008*
Port Mahon					
Menidia menidia	568	24.42	24.85	11.58	0.078
Brevoortia tyrannus	502	21.58	24.94	4.63	0.183
Anchoa mitchilli	347	14.92	16.07	5.09	0.019
Cynoscion regalis	318	13.67	16.57	11.72	0.284
Callinectes sapidus	228	9.80	3.42	14.43	0.035
Alosa aestivalis	74	3.18	4.72	0.25	0.242
Anguilla rostrata	50	2.15	2.12	1.49	0.219
Trinectes maculatus	46	1.98	2.55	2.10	0.408
Leiostomus xanthurus	42	1.81	2.02	1.44	0.352
Menticirrhus saxatilis	39	1.68	2.16	0.59	0.022
Morone saxatilis	32	1.38	1.51	0.58	0.010*

likely not large enough to support a sufficiently distinct fish and *C. sapidus* assemblage. The Lewes and Mispillion sites were composed of 18 and 34% riprap, respectively, with the remaining shoreline made up of sandy beach; whereas Port Mahon was 95% riprap and only 5% beach. Short-term movement of nekton between beach and riprap likely obscured a shoreline-type effect at this site. Partyka & Peterson (2008) found that the presence of suitable habitat was less important than the spatial arrangement of habitat. It is possible that the relative habitat value of the Port Mahon beach was less than that of Lewes or Mispillion due to the spatial arrangement of beach and riprap in the area, particularly the limited connectivity of the beach with other beach habitat in the area.

Many approaches to sampling fish assemblages are limited to some degree by the sampling gear and methods used (Able et al. 2009). Differences in sampling efficiency between beach and riprap shorelines could have influenced density estimates. The complex structure of riprap has the potential to lower sampling efficiency of seining. However, sampling was conducted by deploying the net rapidly by boat using the methodology developed

Table 3. Total number, percent catch and mean densities per seine haul (individuals per 100 m^3) of dominant (>1% total catch) fishes, and *C. sapidus* in the shore zone of Lewes, Delaware Bay (see Fig. 1) from June through September, 2013. Significant differences in mean density between shoreline type and diel period: $^{*}p < 0.01$, $^{**}p < 0.005$, $^{***}p < 0.001$

	Total		Density (ind. 100 m^{-3})				p		
	No.	% catch	Beach		Riprap		Shoreline	Day–night	Shoreline: day–night
			Day	Night	Day	Night			
Anchoa mitchilli	2081	39.58	4.20	62.97	6.40	32.94	0.194	<0.001***	0.135
Menidia menidia	2048	38.95	42.80	73.01	10.67	4.98	<0.001***	0.195	0.060
Cynoscion regalis	316	6.01	0.19	17.40	0.39	5.07	0.393	<0.001***	0.368
Callinectes sapidus	170	3.23	0.40	3.33	1.52	4.55	0.424	0.014	0.974
Pomatomus salatrix	124	2.36	4.13	0.72	2.98	0.05	0.527	<0.001***	0.840
Bairdiella chrysoura	86	1.64	1.91	0.14	2.29	0.34	0.716	0.015	0.906
Mugil Sp.	72	1.37	2.13	1.01	1.01	0.11	0.374	0.366	0.937
Leiostomus xanthurus	57	1.08	0.26	3.26	0.17	0.56	0.046	0.007*	0.074
Brevoortia tyrannus	53	1.01	3.21	0.35	0.11	0.00	0.066	0.333	0.451

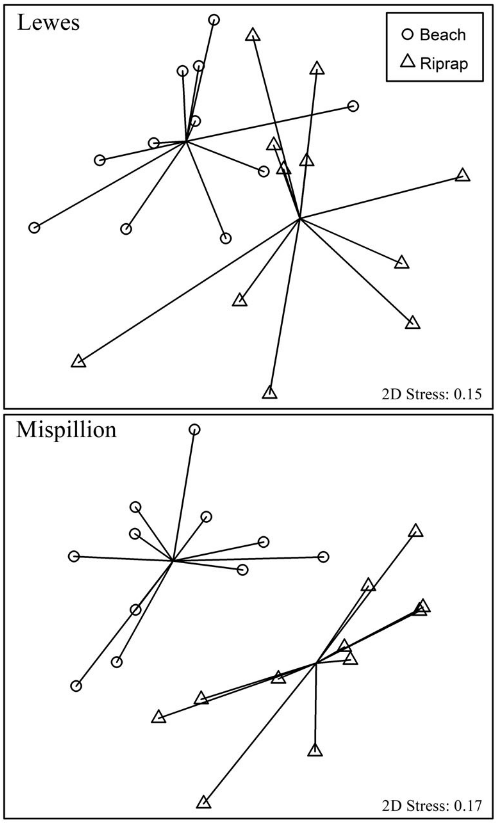

Fig. 6. Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis similarities from square-root-transformed species assemblage data in the shore zone of Lewes and Mispillion, June through September, 2012. Spider plots (R version 3.1.3, vegan package) are overlaid to show beach and riprap group centroids

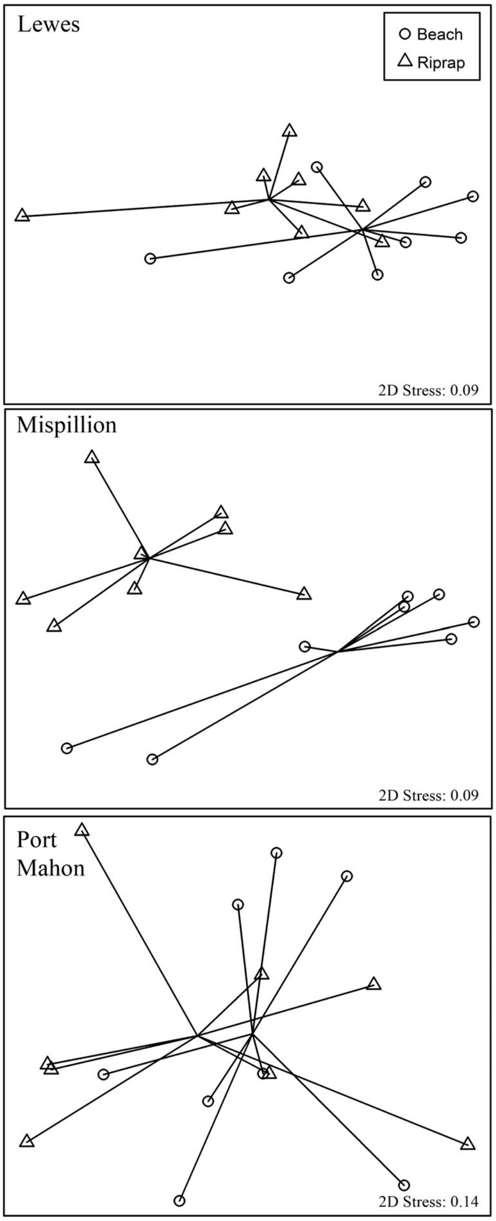

Fig. 7. Non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis similarities from square-root-transformed species assemblage data in the shore zone of Lewes, Mispillion, and Port Mahon, June through September, 2013. Spider plots (R version 3.1.3, vegan package) are overlaid to show beach and riprap group centroids

by Steve Giordano, NOAA Chesapeake Bay Office, specifically to minimize this possibility. Kornis et al. (unpubl.) calculated seine capture efficiency across a range of natural and altered shorelines, including riprap, by conducting 4× depletions at 9 sites of each shoreline type using the same techniques employed here. Species-specific catchability values generated from Leslie depletion models were within 0.1 for all species, suggesting a negligible impact of shoreline type on seining efficiency (Kornis et al. unpubl.). Consequently, lower nekton density and species richness along riprap shorelines, and the rather distinct differences in assemblage structure between beach and riprap found in the present study, are considered to be due to differences in habitat quality rather than sampling efficiency.

Menidia menidia dominated along both sandy beach and riprap shorelines and were present in almost all seine hauls, but were generally more abundant along beach shorelines. This species is known to be abundant in shallow water habitat and among the most abundant forage fish in USA Mid-Atlantic coast estuarine food webs (de Sylva et al. 1962, Able & Fahay 2010). In a comparison of egg deposition by *M. menidia* along different shoreline types, Balouskus & Targett (2012) found that this species spawns preferentially along *Spartina* marsh shores, and even less on beach than riprap, so it is unlikely that spawning

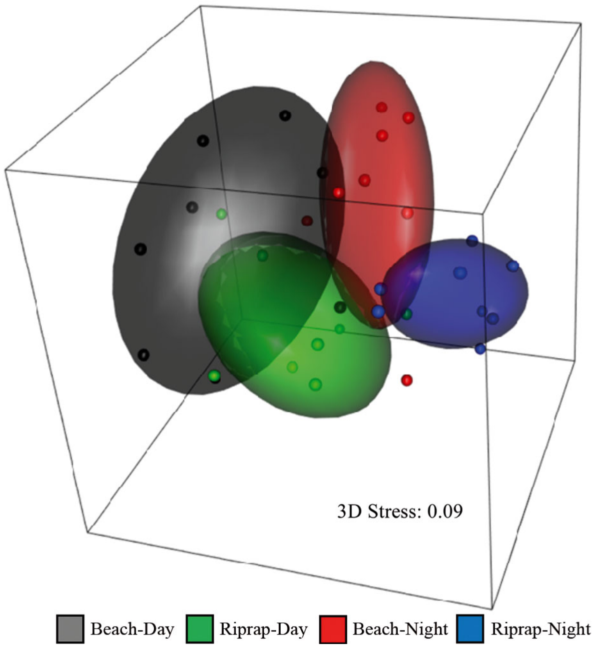

Fig. 8. 3D non-metric multidimensional scaling (NMDS) ordination of Bray-Curtis similarities from square root transformed species assemblage data in the shore zone of Lewes, June through September, 2013. Ellipsoid clusters (R version 3.1.3, vegan & rgl packages) are delineated at the 50% level of similarity for each shoreline type and diel period group

behavior is a driving factor for the preference of beach over riprap by this species.

Leiostomus xanthurus made up a substantial component of the shore-zone assemblage at all sites, and was consistently most abundant along beach shorelines during both years. Balouskous (2012) also found higher density of *L. xanthurus* along unhardened shorelines in tributaries of the Delaware Coastal Bays. Foraging by this benthivore is potentially more efficient along unaltered shorelines, as these areas have been shown to support greater densities of benthic invertebrates (Sobocinski et al. 2010, Lawless & Seitz 2014), and may be a potential driver for greater density at beach habitat.

Northern kingfish *Menticirrhus saxatilis* and juvenile *M. saxatilis* were less abundant species and displayed inconsistent abundance relationships with shoreline type, but whenever a significant difference was seen, they both had higher density along beach than riprap. Florida pompano *Trachinotus carolinus* was only present at the Lewes site in 2012 and was only caught along beach habitat; it was, however, was a fairly consistent catch along the beach during that year.

Diel differences in the nekton assemblage were observed in this study, with total nekton density and species richness being markedly higher during nighttime. Additionally, *Anchoa mitchilli*, *Cynoscion regalis*, and *L. xanthurus* were more dense along both beach and riprap shorelines during the night while *Pomatomus saltatrix* was more dense during the day. Thus, association with either beach or riprap habitat by a particular species appears to be consistent over the diel period. A number of behavioral mechanisms could account for differences in day–night habitat use, such as a well-documented behavior in *A. mitchilli* and other clupeiform fishes to inhabit deeper water during light hours (Vouglitois et al. 1987, Hagan & Able 2008). However, this is not the focus of the present study, and potential mechanisms driving diel migration are discussed further in Torre et al. (unpubl.).

Within the context of widespread and escalating use of armored shorelines, it is increasingly important to determine how riprap alters shore-zone ecosystems. This study demonstrated that riprap shorelines generally have lower nekton densities and an altered species assemblage compared with adjacent sandy beach shorelines. Instances in which these effects were not evident illustrate the need for further research to explore the precise biophysical mechanisms associated with riprap shorelines that are most responsible for altered habitat quality. Additionally, other geographical areas need to be studied to investigate impacts of altering beach habitat with riprap structure in locations with different nekton species assemblages.

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