Landscape-Level Impacts of Shoreline Development on Chesapeake Bay Benthos and Their Predators

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ABSTRACT

Within the coastal zone, waterfront development has caused severe loss of shallow-water habitats such as salt marshes and seagrass beds. Little is known about the impact of habitat degradation and ecological value of subtidal shallow-water habitats, despite their prevalence. In coastal habitats, bivalves are dominant benthic organisms that can comprise over 50% of benthic prey biomass and are indicative of benthic production. We examined the effects of shoreline alteration in shallow habitats by contrasting the benthos of the subtidal areas adjacent to natural marsh, riprap, and bulkhead shorelines in three Chesapeake Bay subestuaries that differ in the level of shoreline development. In all cases, benthic abundance and diversity were higher in subtidal habitats near natural marsh than those near bulkhead shorelines; however, abundance and diversity were intermediate near riprap shorelines, and appeared to depend on landscape features. In heavily impacted systems such as the Elizabeth-Lafayette system, benthos adjacent to riprap was depauperate, whereas in less-developed tributaries (York River and Broad Bay), benthos near riprap was abundant and was similar to that near natural marsh shorelines. Furthermore, predator density and diversity were highest adjacent to natural marsh, intermediate near riprap, and low near bulkhead shorelines. There is thus a crucial link between natural marshes, benthic infaunal prey in subtidal habitats, and predator abundance. Restoration of living shoreline habitats is likely to have benefits for adjacent benthos and their predators. Protection and restoration of marsh habitats may be essential to the maintenance of high benthic production and consumer biomass in Chesapeake Bay. Moreover, the collective impacts of the system-wide, landscape-level features are felt from the benthos through higher trophic levels.

INTRODUCTION

Marine systems are suffering losses to biodiversity from overexploitation, introduction of invasive species, global climate change, and most importantly habitat degradation and loss. Habitat degradation is the largest threat to biodiversity in terrestrial systems and one of the largest threats in marine systems (1). The disturbing effects of biodiversity loss on other ecosystem services have been noted: "…rates of resource collapse increased and recovery potential, stability, and water quality decreased with declining diversity" (2). Causes of marine habitat degradation are many, but here we focus on effects of shoreline development and the relationships with local landscape features. With increases in population abundance and the tendency for people to live near the water (approximately 60% of the U.S. population resides within 100 km of the coast; 1), shoreline development has been increasing at an alarming rate. For example, within the Chesapeake Bay region, the population within the watershed has tripled in the last century (3). Along with this elevation in population, the need for homeowners and businesses to protect against erosion has also increased, which comes at the detriment of marshes and other natural habitats. Estuaries are the most modified and threatened of aquatic environments (4), thus changes in associated marine systems due to habitat modifications can be great in estuaries.

Natural marshes serve important ecosystem functions including protecting uplands from wave action, filtering runoff, cycling nutrients, and housing multiple species of macrofauna. A diverse benthic community resides within and adjacent to marshes, and these species provide essential habitat services (5).

Nutrient cycling, filtering of water-column plankton, and serving as prey for predators are among the most important functions of benthic communities. Increased abundance within these communities may increase secondary and tertiary productivity of the system (6).

The Chesapeake Bay is a drowned river valley with 50% of the bay at <6.5 m in depth (7). Consequently, the shallow-water habitats, particularly the polyhaline regions, are prominent and important (8) and have been designated with better "benthic condition" than deeper areas that may go hypoxic (9). Moreover, the shallow (<1.5 m), subtidal habitats near natural marshes often support high biomass and diversity (8). Within the shallow-water zone, shoreline type further influences the abundance and diversity of organisms that reside in adjacent subtidal habitats.

Shoreline alteration and benthic community resources have been studied at large spatial scales to examine regional patterns of land use and consequent impacts on benthos and predators. In a system with extensive bulkheading (Linkhorn Bay), there was low benthic diversity and abundance (10). At a regional scale, shoreline marshes were deemed important for bivalves (11). These benthic patterns likely translate to higher trophic levels, as predators of the benthos were negatively affected by altered shorelines (12, 13, 14).

We would expect higher-trophic-level predators (e.g., blue crabs) to be affected by benthos because their diet may include up to 50% bivalves (15). Moreover, crab densities are increased where prey densities are elevated (i.e., bottom-up control of predators occurs) (16). We therefore examined the effects of shoreline development upon the benthic community and epibenthic predators in shallow subtidal areas of the Elizabeth-Lafayette River system, the York River, and Broad Bay (in the Lynnhaven River system).

The tributaries within Chesapeake Bay vary in degree of shoreline development, which may influence the relative abundance of benthos and predators within each system. In the York River, which is about 50 km long, ~86% of the distance along the shoreline is natural marsh, whereas ~6% is developed (riprap, bulkhead, groin, or miscellaneous) and ~8% is upland (17). The Lynnhaven system, including Broad Bay (about 2.5 km long), has a large percentage of shoreline with natural marsh (~78.4%), 11.2% developed with bulkhead only, and 5.2% developed with only riprap (P.G. Ross, pers. comm.). In contrast, the Elizabeth-Lafayette system (about 8 km long) is highly impacted, with over 50% of its shoreline developed, and it has been described as "an urban, highly developed region… [where] few shoreline miles remain unaltered" (18). Thus, these three systems vary in shoreline development (Fig. 1) and provide an interesting contrast for examining impacts of shoreline development on benthos and predators. Our unique contribution is a synthesis of the importance of landscape features and variations in the degree of shoreline development among the three different systems that contribute to changes in benthos and predators.

METHODS

Using a random points program for ArcMap software, for each river we chose 6-15 independent, subtidal sites in marsh creeks adjacent to (<5 m from shore) natural *Spartina* marshes, 6-8 sites adjacent to bulkhead (vertical seawall) structures, and 5-8 sites adjacent to riprap (rocks placed on a slope for erosion control) shoreline structures. For each site, we chose areas with >50 continuous m of the shoreline type. We had replicates of each shoreline type in each river system and a different number of total sampling sites for the Elizabeth-Lafayette system (18 sites), the York River (16 sites), and Broad Bay (31 sites). Trawling was conducted to collect predators at all sites in the York River and Elizabeth-Lafayette and 10 of the 31 sites in Broad Bay.

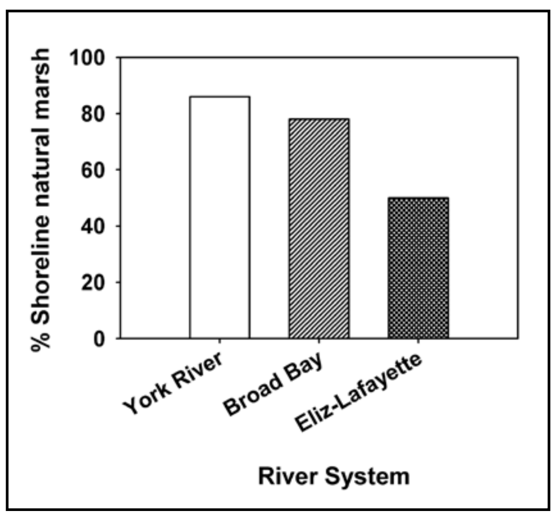

Figure 1. *Approximate percentage of shoreline comprised of natural marsh during surveys from 1999-2006.*

Bivalves were quantified using suction sampling gear, which samples 0.17 m^2 surface area and penetrates 40-60 cm into the sediment. This is essential for accurate estimation of densities of large bivalves that dwell 30-40 cm deep and are sparse (19). On the suction apparatus, we used a 1-mm-mesh bag and sieved contents on a 1 mm-mesh screen. All bivalves retained on the screen were identified to species, measured, and frozen for biomass estimates. At each site, we measured physical variables including water temperature, salinity, dissolved oxygen (DO), turbidity, water depth, and sediment grain size. Since systems were generally evaluated separately, one-way ANOVAs using shoreline treatment as the factor for each separate river system were performed. The exception to this rule was one instance when we pooled predator data for the York and Lafayette systems for a 2-way ANOVA with river and shoreline as factors.

RESULTS

Physical Variables

All three systems were generally similar in salinity, DO, and sediment type. In the York River, salinity was 18-19, in the Elizabeth-Lafayette it was 16-19, and in Broad Bay it was 19-22. All of these shallow-water systems were normoxic, and sediments were muddy sand or sand in general.

The Benthic Community – York, Elizabeth-Lafayette, and Broad Bay

The benthic community included bivalves such as *Macoma balthica*, *M. mitchelli*, and *M. tenta*, the stout razor clam *(Tagelus plebeius)*, the hard clam *(Mercenaria mercenaria)*, as well as *Mulinia lateralis*, *Aligena elevata*, *Anadara* sp., *Gemma gemma*, and the angel wing clam *(Cyrtopleura costata)*. The most numerous clams were *M. balthica* and *T. plebeius*, which comprised 40% and 36% of all clams, respectively, in the Elizabeth-Lafayette system (8). We also collected several species of polychaetes, some phoronids, and small crustaceans.

In the York River, infaunal species density and diversity were significantly higher near natural marsh and riprap habitats than near bulkhead habitats, though near riprap, diversity and density were intermediate and not significantly different than natural marsh habitats (Fig. 2a,b). In the Elizabeth-Lafayette, total bivalve densities were greater near natural marsh than riprap or bulkhead (Fig. 3a). Bivalve diversity did not change appreciably with shoreline type (Fig. 3b). Densities of the deposit-feeding bivalve *M. balthica* were significantly different among shoreline types in the Elizabeth-Lafayette (Fig. 4a): densities were highest near natural marsh whereas densities near riprap were low and similar to those near bulkhead. For the suspension-feeding bivalve *T. plebeius*, there was no significant difference in densities among shoreline types (Fig. 4b).

In Broad Bay, bivalve abundance was higher near natural marsh and riprap than bulkhead, and this difference was marginally significant (Fig. 5a; ANOVA on log-transformed data). Bivalve species richness was higher near natural marsh and riprap compared to bulkhead shorelines, but this difference was not significant (ANOVA: df = 2, 31, F = 2.02, p = 0.150). Shannon-Wiener bivalve diversity was significantly greater adjacent to natural marsh and riprap than bulkhead shorelines (Fig. 5b; ANOVA on log-transformed data, Tukey test). In Broad Bay, densities of the facultative deposit-feeding bivalve *M. balthica* (Fig. 6a) and the suspension-feeding bivalve *T. plebeius* (Fig. 6b) did not differ significantly among shoreline types, though the highest densities occurred near riprap and natural marsh, while lowest densities occurred near bulkhead.

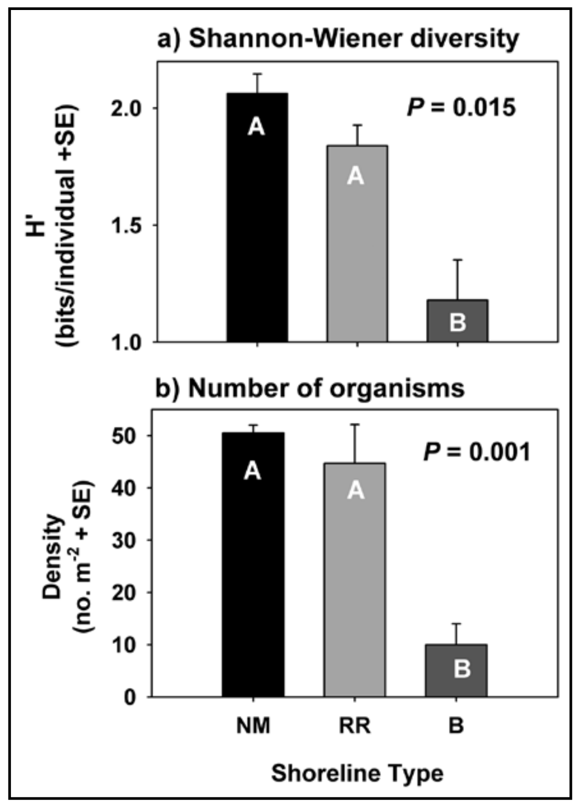

Figure 2. *(a) Mean number of organisms* m^{-2} *(+SE) and (b) mean Shannon-Wiener diversity (+ SE) of all benthic infauna in a subset (2-3 per habitat) of shallow subtidal sites adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in the York River. P-value from ANOVA listed. Different capital letters indicate significant differences (Tukey test, modified from 8).*

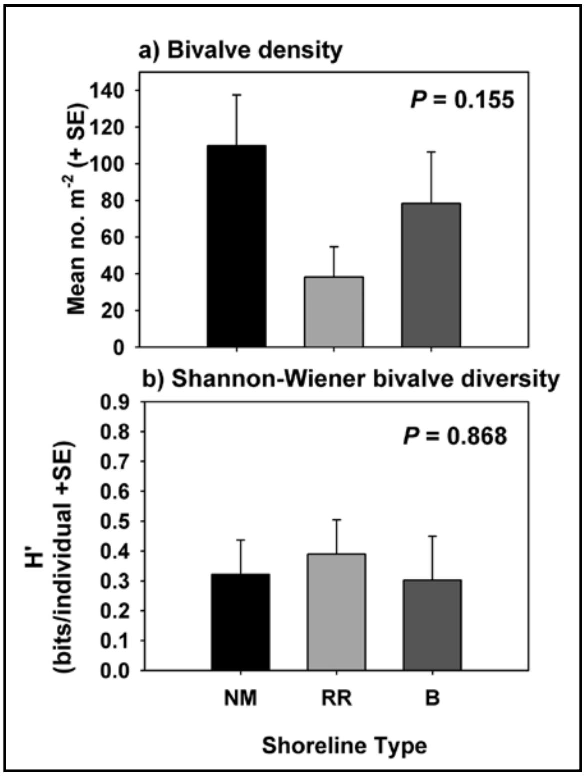

Figure 3. (a) Mean number of bivalves m^{-2} (+SE) and (b) mean Shannon-Wiener bivalve diversity per sample in habitats adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in the Elizabeth-Lafayette system (modified from 8).

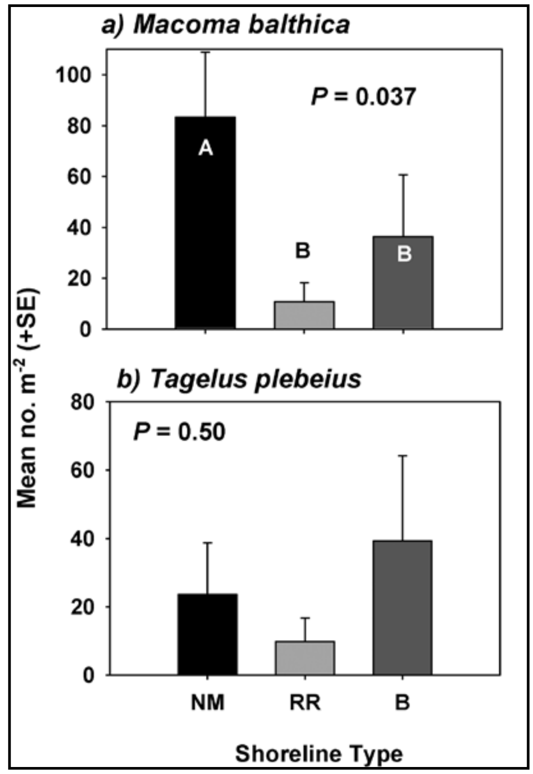

Figure 4. Mean number of clams m^{-2} (+SE) in habitats adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in the Elizabeth-Lafayette system for the bivalves (a) Macoma balthica and (b) Tagelus plebeius. Note that scales are different (modified from 8).

Predators – York, Elizabeth-Lafayette, and Broad Bay

In the York and Elizabeth-Lafayette systems, we collected many predators including spot *(Leiostomus xanthurus)*, croaker *(Micropogonias undulates)*, oyster toadfish *(Opsanus tau)*, silver perch *(Bairdiella chrysoura)*, summer flounder *(Paralychthys dentatus)* (predators did not include fish such as anchovies and silversides), as well as blue crabs *(Callinectes sapidus)*, spider crabs, and mud crabs. In the York River, the abundance of predators near natural marsh was slightly higher than that near riprap or bulkhead shorelines. This pattern held for both fish (Fig. 7a) and for total crabs (Fig. 7b), though these differences were not significant (Fish ANOVA: $p = 0.592$; Crab ANOVA: $p = 0.628$). In the Elizabeth-Lafayette, fish abundance did not change with shoreline type (Fig. 7a; ANOVA: $p = 0.973$). However, crab abundance was higher adjacent to natural marsh than riprap or bulkhead shorelines (Fig. 7b), though this difference was not significant (ANOVA: $p = 0.359$). In pooled data from both the York and Elizabeth-Lafayette river systems, crab densities were significantly higher near natural marsh than riprap or bulkhead shorelines (Fig. 7b; 2-way ANOVA with River and Shoreline as factors; Shoreline $p = 0.033$, Tukey test). However, fish did not show this significance with pooled data (Fig. 7a; ANOVA: Shoreline $p = 0.876$).

In our trawl samples in Broad Bay, we collected 12 species of fish as well as blue crabs *(C. sapidus)* at the ten sites. Similar to patterns in the York and Elizabeth-Lafayette rivers, abundance of predatory fish (i.e., not including anchovies and silversides) and crabs was greatest near natural marsh, intermediate near riprap, and lowest near bulkhead. Pooled data with fish and crabs were nearly significant (Fig. 7; ANOVA: $P = 0.097$) (Fig. 7).

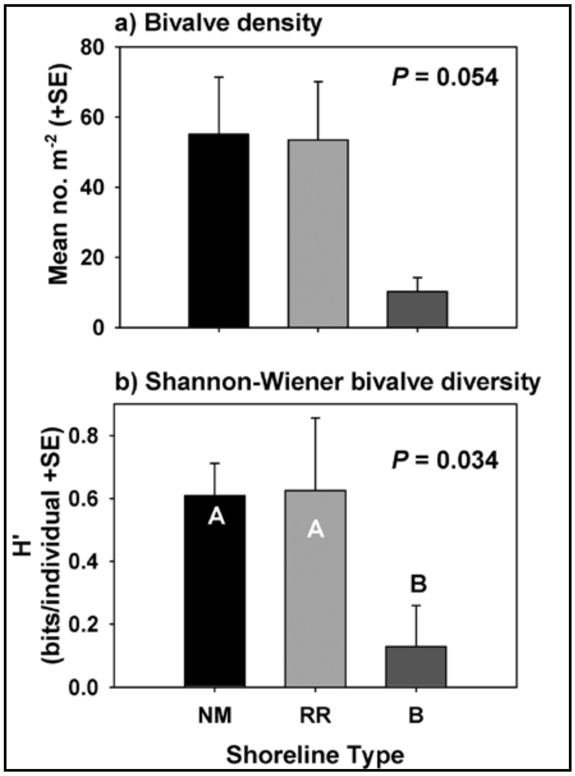

Figure 5. *(a) Mean number of bivalves m*$^{-2}$ *(+SE) and (b) mean Shannon-Wiener bivalve diversity per sample in habitats adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in Broad Bay (modified from Lawless, in prep.)*

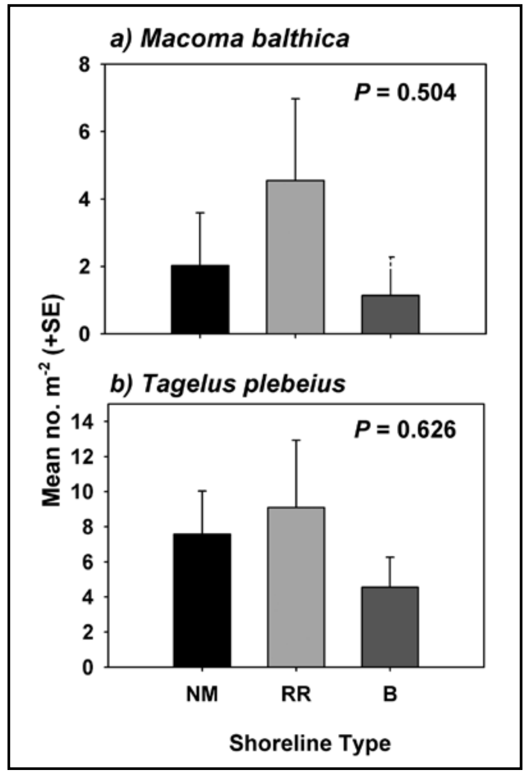

Figure 6. *Mean mean number of clams m*$^{-2}$ *(+SE) in habitats adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in Broad Bay for the bivalves (a) Macoma balthica and (b) Tagelus plebeius. Note that scales are different (modified from Lawless, in prep.).*

DISCUSSION

Density and diversity of benthic bivalves were greatest adjacent to natural marsh habitats compared to riprap or bulkhead shorelines in all three systems studied, the York River, Elizabeth-Lafayette, and Broad Bay. The York River was the most natural of the three systems (86% natural marsh; 17). This system is less developed and larger (at 50 km long) than the Elizabeth-Lafayette (8 km long) or Broad Bay (2.5 km long) systems, and bivalve abundance and benthic community diversity were greater in *both* natural marsh *and* riprap than in bulkhead habitats. The communities adjacent to riprap were intermediate in abundance and diversity. We hypothesize that the York River system has much larger expanses of unaltered marsh habitat available to subsidize adjacent developed shorelines, and therefore riprap habitats are not as negatively influenced by development as those in more heavily developed systems. The Lynnhaven system is also relatively natural (78% marsh), and in Broad Bay the benthos adjacent to riprap was similarly intermediate in abundance and diversity. These data suggest that there may be some small level of development (i.e., <10%) that has no discernible negative impact. Again, the landscape features of the system allow deficient habitats to be re-populated by nearby communities. Populations next to bulkheads may also be re-populated by nearby natural marsh but may remain at low density and diversity because these habitats lack other essential features that occur in both natural marsh and riprap systems (e.g., delivery of nutrients or carbon from upland). In contrast, the Elizabeth-Lafayette system is highly developed (over 50% of shoreline developed; 18), and the overall density and diversity of benthic invertebrates was significantly lower in both riprap and bulkhead shorelines compared to natural marsh. The overall system is apparently so degraded that intermediate habitats (i.e., those near riprap) are not effectively re-populated by other habitats in the system.

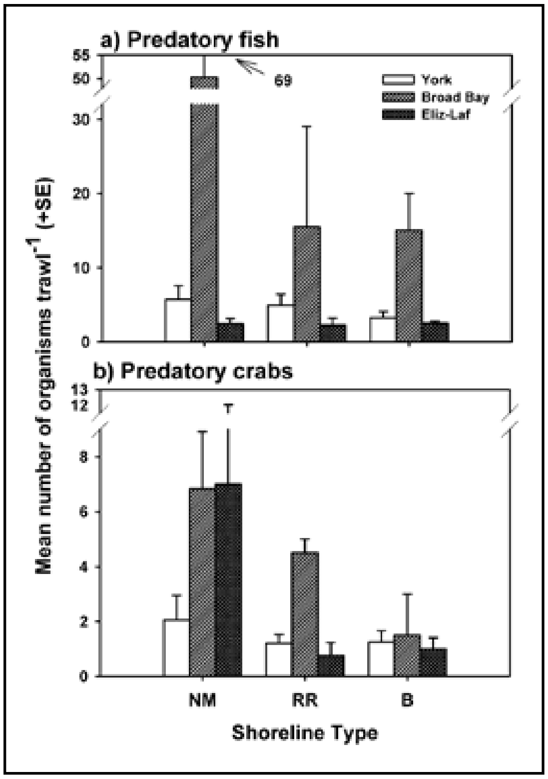

Figure 7. Mean number of predators (+ SE) per 20 m^2 area trawled in habitats adjacent to natural marsh (NM), riprap (RR), or bulkhead (B) shorelines in the Elizabeth-Lafayette, York River, and Broad Bay systems for (a) Predatory fish (i.e., not including anchovies and silversides that would not feed on benthos) and (b) Predatory crabs. Note that +SE for Broad Bay ends off of the visible scale at 68 fish trawl^{-1} (modified from 8 and Lawless, in prep.).

We suggest that the beneficial effects of the marsh may arise because the allochthonous input of carbon from marsh materials may be an important food source for benthos (20), particularly for deposit-feeding infauna (e.g., *M. balthica*). However, the important input of carbon from the marsh is reduced where shorelines are covered with riprap or bulkhead. This may also explain why organisms that are not deposit feeders (e.g., *T. plebeius*) are not affected by shoreline type, since they may rely on water-column food sources. Another possibility is that the alteration of the shoreline changes the hydrodynamics such that higher current flow impedes settlement of some benthic organisms. The only study of which we are aware that demonstrates negative effects of shoreline development upon the subtidal benthic community was one that examined the impact of toxics in CCA-treated wooden bulkheads (21). In our study, only some of the bulkhead shorelines used treated wood, so a negative impact of chemically treated wood could only partially explain our results.

Most developed shorelines in all three systems we studied not only had negative impacts on benthic infauna in subtidal habitats adjacent to the shoreline, but also had detrimental effects on higher trophic levels. In all cases the abundance of predators was highest near natural marsh. In the York River, predator abundance was intermediate near riprap shorelines. Conversely in the Elizabeth-Lafayette, fish predators were low adjacent to all habitats, whereas crab predators were only high near natural marsh but not near riprap. This suggests that the low predator densities may reflect the overall degradation of this system, or that the low to moderate densities of benthic prey associated with riprap are not high enough for predators to feed in those areas. In Broad Bay, densities of higher trophic levels were low near both riprap and bulkhead, which is more in line with the pattern in the highly degraded Elizabeth-Lafayette. Though the benthos in Broad Bay seemed to be subsidized somewhat by adjacent natural habitats, predators may search and feed in only the most productive benthic habitats, and thus are not found in the riprap habitats with slightly lower densities of infauna. A similar general pattern of predator and prey densities in all three systems suggests there is a functional relationship between predators and prey whereby predators may be concentrating in habitats with elevated prey densities (i.e., bottom-up control). We have previously shown evidence for bottom-up control of the blue crab by its principal prey (i.e., clams) in the York River (16), and the findings of this study also are consistent with bottom-up control. Although elevated densities of prey and predators in marsh habitats may have been caused by an independent factor, we suggest that reduced infaunal densities adjacent to developed shorelines diminished predator densities and likely diminished corresponding production of the system.

We have provided convincing evidence that a key link exists between salt-marsh habitat, food availability for predators, and predator abundance. Consequently, protection and restoration of salt-marsh habitats may be essential to the maintenance of high benthic production and consumer biomass in estuarine systems. The results herein provide strong evidence that restoration of marshes can be extremely important for adjacent benthic and epibenthic higher-trophic-level communities and suggest that "if you build it, they will come." This demonstration of the critical influence of marsh habitats on adjacent subtidal communities should be encouraging for those involved with the establishment of "Living Shorelines" that includes creation of marsh habitat.

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