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Effects of shoreline stabilization and environmental variables on benthic infaunal communities in the Lynnhaven River System of Chesapeake Bay

Amanda S. Lawless *, Rochelle D. Seitz

Virginia Institute of Marine Science, The College of William and Mary, PO Box 1346, Gloucester Point, VA 23062, USA

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ABSTRACT

Coastlines worldwide are being altered due to shoreline hardening and stabilization and while highly altered systems are subject to change, variability exists in how shoreline hardening affects benthic communities depending on the landscape features of the system and regional production. Oyster reefs have been used to stabilize shorelines and offer a potentially positive effect on shoreline communities. In a field survey, we used 29 sites throughout the Lynnhaven River System, a highly developed yet productive subestuary of Chesapeake Bay, to determine effects of shoreline type (natural marsh, oyster shell reef, rip-rap, and bulkhead), sediment characteristics (grain size and total organic carbon and total nitrogen), and predators on benthic infaunal density, biomass, and diversity. An information-theoretic approach was used to determine which of several hypothesized Generalized Linear Models were supported by the data. Shoreline type was the best predictor of benthic infaunal density, with oyster reefs having the highest benthic density and bulkhead the lowest. In contrast, sediment characteristics and predators were the best predictors of benthic infaunal biomass and diversity. The Lynnhaven system is shallow (~2.5 m), and nearly 78% of the shoreline is natural marsh, which promotes high regional benthic productivity that may mask small-scale effects of shoreline stabilization on infauna. Our findings contrast with previous studies in moderately productive systems where altered shorelines had substantial direct effects on the benthos, suggesting that further studies need to take place across various systems among a range of upland usages to help clarify the impact of local shoreline stabilization versus regional watershed usage on benthic communities. Our results highlight that high ecosystem productivity is important for resilience to local shoreline modification.

1. Introduction

The Chesapeake Bay watershed has experienced a tripling of its population in the last century causing vital natural habitats to be altered or destroyed through the anthropogenic process of shoreline hardening and stabilization (Boesch and Greer, 2003). Sheltered coastal areas suffer land loss from erosion and high waters (NRC, 2007), and landowners often turn to shoreline stabilization methods that may involve removal of natural coastal habitat. Shoreline hardening and stabilization consists of replacement of natural shoreline (i.e., marsh) with rip-rap (large rock revetments) or bulkhead (a seawall constructed of metal, wood, concrete or plastic) along the shore. Restored oyster reefs are also being used for erosion control and shoreline stabilization. The reefs can be used as "living shoreline" biogenic erosion protection structures, which are becoming more prevalent (NRC, 2007; Piazza et al., 2005; Scyphers et al., 2011).

Though the impact of armoring a few properties is small, multiple structures along a shoreline can "change the coastal environment and the ecosystem services" (NRC, 2007). Both shoreline hardening and installment of oyster reefs could have a direct effect on the associated subtidal benthic infaunal community (Scyphers et al., 2011). The issue of the potential loss of natural resources in estuaries is of such high importance that the Environmental Protection Agency, Army Corps of Engineers, and Cooperative Institute for Coastal and Estuarine Environmental Technology directed the NRC to examine potential negative impacts of such shoreline stabilization practices (NRC, 2007). This study adds information on the effects of shoreline stabilization within a region of relatively high faunal biomass and productivity.

Large-scale watershed urbanization can degrade water bodies and living resources. Watersheds associated with high urban land use can have biotic communities with lower species diversity, lower trophic complexity, altered food-web dynamics, and reduced habitat diversity (Holland et al., 2004; Kemp et al., 2005; King et al., 2005). Increased urbanization within the Chesapeake Bay watershed has had negative effects on the benthic community when as little as 12% of the watershed is developed (Bilkovic et al., 2006; Dauer et al., 2000).

* Corresponding author at: Department of Malacology, The Academy of Natural Sciences, Drexel University, 1900 Benjamin Franklin Parkway, Philadelphia, PA 19103, USA. Tel.: +1 215 299 1174; fax: +1 215 299 1170.
E-mail address: lawless@ansp.org (A.S. Lawless).

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At smaller spatial scales, aquatic species are negatively affected by altered shorelines. Marine and freshwater assemblages associated with altered shorelines have lower abundance and diversity than assemblages near natural shorelines (Balouskus and Targett, 2012; Brauns et al., 2007; Morley et al., 2012). In Chesapeake Bay, some nekton assemblages were more diverse along natural marsh and rip-rap compared to bulkhead shorelines (Bilkovic and Roggero, 2008). Abundance and diversity of benthic infauna and predators in large, deep-water Chesapeake Bay tributaries were lower adjacent to bulkhead as compared to natural marsh or rip-rap shorelines (Seitz et al., 2006). Landscape-level effects can determine whether infaunal differences by shoreline are readily apparent (Bradley et al., in revision; Seitz and Lawless, 2008).

Artificial reefs have variable effects on benthic communities. Benthic abundance may increase (Davis et al., 1982), decrease (Ambrose and Anderson, 1990), or remain unchanged near reef edges (Langlois et al., 2006). Numerous physical and biological processes have been proposed as mechanisms for these alterations such that it is hard to predict the effect of an oyster reef on the adjacent benthos in any particular ecosystem, whether at small or large spatial scales.

This study occurred in the Lynnhaven River System (LRS), which provides a contrast to systems examined previously because the watershed is highly altered (72% developed as residential, commercial, or industrial property) yet the majority of the shoreline (78%) is natural marsh. Lynnhaven appears to have high benthic density at 3000–7000 individuals/m^2 except for lower benthic density and diversity in the Linkhorn Bay portion of the system (~400/m^2), which results from urban development and urbanization of the shoreline (Tourtellotte and Dauer, 1983). The benthic infaunal biomass is also relatively high compared to other Chesapeake Bay polyhaline tributaries (Seitz et al., 2009). Nearshore areas and associated benthos are susceptible to anthropogenic stressors because they serve as an interface between terrestrial and open-water environments (Goforth and Carman, 2005), and thus were the focus of this study. The effects of shoreline stabilization in a subestuary with a highly altered watershed, high benthic density and biomass, relatively shallow depth (~2.5 m), and a large percentage of shoreline as natural marsh are little known and this system was therefore targeted for our study.

The objective of this study was to determine whether shoreline stabilization (four treatments: natural marsh, restored oyster shell reef, rip-rap, and bulkhead), as well as co-varying physical and biotic variables, were important in predicting the density, biomass, and diversity of benthic infaunal organisms in a productive system using various competing models and model comparison with Akaike's Information Criterion (AIC). Compared with other more traditional statistical methods, AIC is useful in comparing hypotheses against one another using likelihood methods (Ralph et al., 2013), and AIC can be used when examining multiple variables and determining which are important in predicting density, biomass, and diversity. The inclusion of oyster shell reef as a shoreline type in our comparison among habitats is novel and important because of the increasing prevalence of oyster reefs in restoration activities and as a stabilization feature along shorelines. Some of the main physical and biotic drivers of benthic density, biomass, and diversity among shoreline habitats were measured, including temperature, salinity, dissolved oxygen, sediment composition (i.e., grain size, TOC, and TN), and predator abundance (Dauer et al., 1982; Hines et al., 1990; Snelgrove and Butman, 1994; Virnstein, 1977), which gave insight into the driving factors underlying benthic infaunal community structure.

2. Material and methods

2.1. Site selection

This study was conducted in the Lynnhaven River System (LRS), the southern-most subestuary in Chesapeake Bay, located near Cape Henry and Virginia Beach, Virginia. The LRS consists of Lynnhaven Bay, Broad Bay, Linkhorn Bay, and the Eastern Branch and Western Branch of the Lynnhaven River; it is 17,353 ha in area; has 241 km of shoreline; and has a mean water depth of 2.5 m. Twenty-nine shoreline sites were randomly selected throughout the LRS (Fig. 1) from a grid comprising all sites that met *a priori* criteria, and defined as natural marsh, restored oyster shell reef, rip-rap, or bulkhead. To be selected for the study, all sampling sites had to meet 4 criteria. Specifically, each site had to (1) encompass at least 50 consecutive meters of a shoreline type, (2) be adjacent to only one shoreline type, (3) be in waters no deeper than 1.2 m and (4) if the shoreline was bulkhead, it could not be wooden due to the potential negative effect of chemical leaching on infauna (Weis et al., 1998). Eight replicates for each of 3 shoreline types (natural marsh, rip-rap, and bulkhead) were randomly selected and 5 intertidal restored oyster shell reefs were sampled because these were the only reefs that met the criteria. A bootstrap simulation was run on each response variable to determine whether the number of replicates per treatment was sufficient based on an acceptable decrease in standard error. Though we would have ideally included 8 oyster reef replicates, we included the maximum possible that met our criteria (5), which may have led to an increased standard error for this shoreline type. There is always a logistical trade-off between the number of independent replicates per treatment and within-site non-independent pseudo replicates (i.e., multiple samples from one site) that can be taken (Hurlbert, 1984). We took as many independent replicates as possible (one per site) to attempt to characterize the shoreline treatments as well as possible within our logistical limitations.

2.2. Physical, benthic, and predator sampling

At each site, in July and August 2006, we measured water temperature, salinity, and dissolved oxygen (DO) using a YSI meter. Grain size (reported as % sand and gravel [hereafter % sand & gravel], using standard wet sieving and pipetting) (Folk, 1974) and carbon, hydrogen, nitrogen (CHN) of the sediment were also measured. These samples were taken in association with benthic macrofaunal samples (described below) using a 2.5-cm-diameter surface-sediment core.

At each site, one benthic sample was taken at a randomly selected location 4 m seaward from the edge of the shoreline. Shoreline edge was defined as the most seaward extent of the sampled habitat (i.e., marsh plants, rip-rap boulders, oysters, or seawall). Samples were collected using a suction apparatus that removed all sediment and organisms within a cylinder of 0.11 m^2 surface area to ~40 cm depth (Hines and Comtois, 1985). Sediment and infauna were collected in a 1-mm-mesh bag and sieved on a 1-mm-mesh screen. Though this mesh size misses small macrofauna and some new recruits, our study targeted large-biomass organisms that might be most important for higher trophic levels, as similar studies have previously (Bergman and Hup, 1992; Edgar and Barrett, 2002; Sutherland et al., 2000). Little information on spatial patterns is lost with coarser mesh sizes, yet the tradeoff is that greater replication can be accomplished (James et al., 1995). Samples were sorted in the lab, all individuals were identified to the lowest taxonomic level (usually species), and shell length of each bivalve was measured. In 3 cases where the sample was unusually large, the entire sample was sieved on 1 cm mesh to remove, identify, and count the larger organisms, the sample was then homogenized, and ¼ of the sample was randomly selected (sub-sample) and sorted. The numbers of identified organisms in the sub-sample were multiplied by 4 to obtain the number used to represent the entire sample. The Shannon diversity index (H′ [log base *e*]; Gray, 2000), which integrates species richness and evenness, was calculated using Primer v.6.1.6 software (Clarke and Warwick, 2001).

Biomass estimates for all organisms were calculated using ash-free dry weight (AFDW). Polychaetes, crustaceans, and bivalves were dried to a constant weight and ashed in a muffle furnace at 550 °C for 6 h to obtain ash weight. Regressions of shell length (SL) to AFDW were