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Ecological response and physical stability of habitat enhancements along an urban armored shoreline

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ABSTRACT

Shoreline armoring is prevalent worldwide and has resulted in substantial habitat alteration in heavily urbanized areas. The biological and physical processes associated with these shorelines have in many cases been compromised, which has led to a recent focus on how to design and implement projects to restore some of the lost or impaired functions, termed enhancement. We describe a multi-year effort testing whether an enhanced site has improved conditions in Seattle, WA, USA, along urban marine shorelines of Puget Sound. The Olympic Sculpture Park opened in January 2007 and included construction of two shallow-water features: a low-terrace habitat bench placed in front of an existing seawall, and a constructed pocket beach that replaced existing riprap. Riparian vegetation was also planted in the uplands replacing impervious surfaces and manicured lawn. We measured the functions of these sites by sampling both before and after enhancements (2005, 2007, and 2009), and comparing to adjacent armored shorelines. Although we are limited in our ability to make generalizations beyond this specific site due to only having one replicate of each shoreline type, the unique aspects of this urban enhancement make it useful as a case study that can apply to other urban systems. Fishes that are dependent on shallow water habitat were a main focus of sampling, specifically outmigrating juvenile salmon (*Oncorhynchus* spp.) and larvae of other species. Terrestrial and aquatic invertebrates were also assessed, both as a metric for habitat quality and as a determinant of available prey resources for juvenile salmon. Physical features of the created habitats were monitored in post-enhancement years to measure their stability. Results showed that shoreline enhancements increased densities of larval fishes and juvenile salmon and measurements of juvenile salmon feeding behavior dependent on the year, and provided habitat for invertebrate assemblages that were different from armored shorelines and had high taxa richness. Physical resilience depended on both natural processes and human activities, demonstrating the need to incorporate anthropogenic use into the management of urban shorelines.

1. Introduction

Artificial armoring is a common feature of shorelines in many aquatic systems, especially in highly developed urban areas. Recent research has documented the detrimental effects of armoring on the ecotone between aquatic and terrestrial realms (Toft et al., 2007; Bilkovic and Roggero, 2008; Dugan et al., 2008; Defeo et al., 2009; Bulleri and Chapman, 2010; Shipman et al., 2010; Chapman and Underwood, 2011). However, there are only a few studies of habitat restoration along armored shorelines in urbanized settings where size and location of the restoration are severely limited. These studies have focused on beach nourishment (Peterson and Bishop, 2005; Defeo et al., 2009), managed realignment (French, 2006), creation of small wetlands (Grayson et al., 1999; Cordell et al., 2011), or incorporation of vegetation and ecological engineering with armoring (Chapman and Underwood, 2011), often referred to as "living shoreline" in the Gulf and Atlantic coasts of the USA (Erdle et al., 2006).

Understanding the current status of armored shorelines and potential for restoration in degraded systems is an important topic worldwide (NRC, 2007; Defeo et al., 2009). Novel designs and research pertaining to the value of benefits are needed to guide this emerging field of urban restoration. Interactions between people and nature are inevitable in urban landscapes but can lead to opportunities to improve city life (Standish et al., 2012), and principles of ecological engineering are defined to bridge human and ecological values (Mitsch, 2012). Nursery function of shorelines is one of

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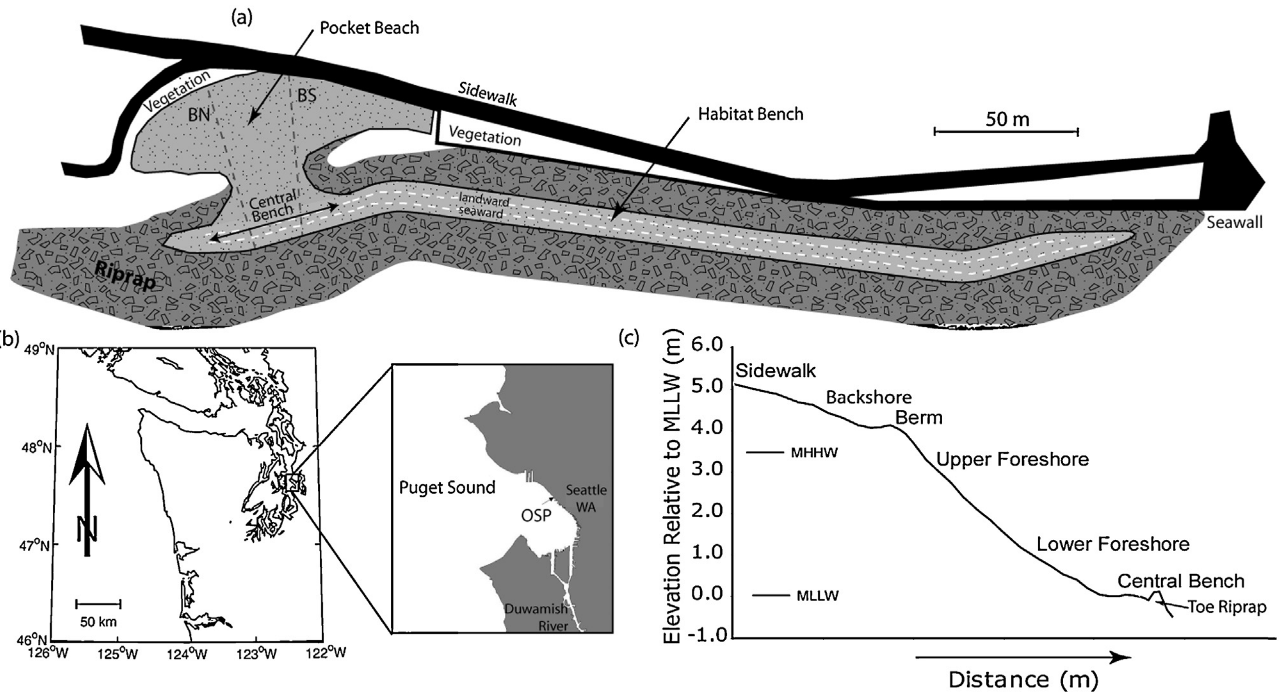

Fig. 1. (a) Plan view drawing of the Olympic Sculpture Park shoreline enhancements with approximate physical sampling locations of the beach north (BN) and beach south (BS) transect lines, seaward and landward transect lines at the habitat bench, and adjacent riprap and seawall sites, (b) location map, and (c) cross-section of the pocket beach.

many ecosystem services that can be affected by development, and habitat restoration can benefit not only fishery resources but also recreation, aesthetic quality, and other services that if engineered correctly may not impede important aspects of coastal protection (Guerry et al., 2012).

Although it is usually impossible to restore original conditions to extremely modified shorelines, it can be feasible to enhance or rehabilitate shorelines within urban constraints (Simenstad et al., 2005), often using principles of ecological engineering (Chapman and Underwood, 2011; Mitsch, 2012). We therefore use the term *enhancement* for actions that are intended to make progress toward the goal of *restoration*. Along a gradient of modified to unmodified shorelines, there is a progression from fully armored to historic natural conditions, with varying degrees of enhancement, restoration, and current natural conditions in between. The Seattle Art Museum incorporated enhancements along the shoreline of the Olympic Sculpture Park, which opened in January 2007 along a highly urbanized marine shoreline of Puget Sound in Seattle, WA, USA (Fig. 1). In order to provide both public access and ecological benefits, a pocket beach and habitat bench were created in shallow nearshore waters with plantings of vegetation and placement of sediments and driftwood on the beach (Fig. 2). These features replaced seawall and riprap armoring, with an overall goal of supporting higher diversity and numbers of fishes and invertebrates.

This project is of great interest in the Puget Sound region as an example of habitat enhancement along urban shorelines, and has therefore been a focus for an extensive monitoring plan that is meant to inform future projects. Similar projects have been either planned or recently implemented along stretches of Seattle shoreline, in other cities such as Bellingham, Olympia, and Everett, and also along non-urban shorelines such as in park settings. The Park is in a key area for rearing and migration of juvenile salmonids (Toft et al., 2007), especially Chinook salmon (*Oncorhynchus tshawytscha*) that are listed as threatened under the Endangered Species Act and chum salmon (*O. keta*), both of which use nearshore habitats more than other species of salmon. Larval fishes are also a focus of shallow water enhancements, particularly those of forage fishes that are nearshore spawners (Penttila, 2007).

Research worldwide has started to document how estuarine and coastal shoreline habitats can affect nearshore fish distribution, abundance, and nursery functions. For example, fish assemblages have been found to differ due to environmental variables of habitat types in the west coast of Australia (Valesini et al., 2004), Chesapeake Bay, USA (Bilkovic and Roggero, 2008), and Puget Sound, USA (Toft et al., 2007). Shoreline armoring can negatively impact fish prey such as terrestrial insects (Toft et al., 2007) and aquatic invertebrates to varying degrees, depending on how low in tidal elevation the armoring encroaches (Peterson et al., 2000; Chapman, 2003; Cruz Motta et al., 2003; Romanuk and Levings, 2003; Moschella et al., 2005; Sobocinski et al., 2010). These types of impacts can limit the opportunity for shoreline-oriented fishes such as juvenile salmon to feed and benefit from a site (Simenstad and Cordell, 2000). Shoreline modifications can also add hard structures uncharacteristic of the habitat, which in certain cases attract atypical and sometimes non-indigenous organisms (Glasby, 1998; Davis et al., 2002; Glasby et al., 2007). Overall, enhancement of armored shorelines seeks to improve nearshore conditions for native fishes and invertebrates.

Artificial beaches are becoming increasingly popular for shore protection worldwide. Where shoreline erosion has traditionally been controlled by hard structures such as seawalls, creating coarse clastic beaches (i.e., nourished with sediments that range from sand to boulders) can provide an alternative solution, as well as improve habitat. Coarse clastic beaches can presumably decrease potential adverse impacts of harder shoreline stabilization such as increased wave energy, scour, and interruption of sediment supply to coastal systems (Shipman et al., 2010). This can restore or enhance natural beach processes and habitats, and create recreational and ecological opportunities that did not exist before. However, many of the impacts of establishing nourished beaches are unknown with