Puget Sound Shoreline Armoring: State of the Science Workshop

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Introduction

The widespread extent and continued construction of seawalls and bulkheads on Puget Sound's beaches has emerged as a significant issue in shoreline management and coastal restoration in the region. Concerns about the impacts of shoreline armoring and managing the potential risks to coastal property are in many ways similar to those in other places, but Puget Sound also poses unique challenges related to its sheltered setting, glacially formed geology, rich estuarine ecology, and historical development pattern.

The effects of armoring on shorelines are complex, involving both physical and biological science and requiring consideration of the cumulative impacts of small-scale activities over large scales of space and time. In addition, the issue is controversial, as it often places strongly held private interests in protecting shoreline property against broad public mandates to preserve shorelines for public uses and to protect environmental resources. Communities making difficult decisions about regulating shoreline activities and prioritizing restoration projects need to be informed by the best science available.

To address these issues, a scientific workshop was convened in May 2009, specifically to bring local and national experts together to review the state of the science regarding the physical and biological impacts of armoring on sheltered shorelines such as those of Puget Sound.

Coastal Armoring

Coastal armoring is the practice of constructing seawalls, bulkheads, and revetments along shorelines to prevent erosion and to stabilize areas for upland land uses. Armoring is widespread along developed coastlines around the world and is often viewed as both necessary and environmentally benign by its proponents, but it poses challenges for managers charged with protecting public shorelines and coastal habitats. In the United States, armoring has been an issue on the Atlantic, Gulf, and Pacific coasts (Griggs, 2005), on the Great Lakes and in Hawaii (Fletcher, 1997). Although the geographic settings vary dramatically, the concerns often are similar and include the effects on public access and beach recreation, the impacts on ecological resources, the balancing of public costs and private benefits in managing erosion, and the specter of the long-term loss of beaches in front of seawalls (Beatley and others, 2002). The issue is complicated by the long-term and cumulative nature of the impacts, the vulnerability of the coast to natural hazards, and the political and legal complexities of zoning and regulating private property.

Specific concerns about the impacts of armoring include its direct impact on the beach where it is constructed, the effect on access both to and along the beach, the loss of terrestrial sediment supply to the beach system, and localized erosion or changes to sediment transport caused by wave interaction with structures (Woodroffe, 2002; Griggs, 2005). Geologists also point to the progressive loss of the beach that occurs when a fixed structure is built on an eroding shoreline (passive erosion), particularly in light of ongoing and future rates of sea level rise. Many of these physical changes associated with armoring have consequences for nearshore ecosystems and their functions, including the direct burial and isolation of habitats and the introduction of fill or new substrates.

Scientific information becomes critical for informing regional and local decisions about armoring. Knowledge of erosion rates and mechanisms helps define the risk to coastal development, assess the rate of change of the natural environment, and quantify sediment budgets. Studies of the relationship between geomorphic and biological processes helps scientists understand the sensitivity or resilience of coastal ecosystems to anthropogenic modifications. Evaluation of erosion control methods helps to assess the efficacy and relative impacts of alternative measures (beach nourishment, for example) and to identify appropriate means of minimizing or mitigating impacts of structures.

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Much of the scientific research on beaches and armoring has been focused on sandy, open-ocean shorelines, particularly the barrier islands of the U.S. Atlantic and Gulf Coasts (see Krauss, 1988; Kraus and McDougal, 1996). This reflects the dense coastal development and high recreational and tourism value of those regions, the vulnerability and repeated damages from tropical storms and hurricanes, and the abundance of large-scale, often publicly funded coastal engineering projects. These projects include large community-scale seawalls, beach nourishment, and the maintenance of tidal inlets (dredging and jetty construction).

Armoring on sheltered coasts and estuarine beaches has received much less scientific attention, although many of the technical and policy issues are similar. Sheltered coasts are shorelines protected from open-ocean wave conditions, typically associated with large bays and estuaries. They represent a majority of the U.S. coastline length, and include large back-barrier systems such as Pamlico Sound and Mobile Bay and large estuaries and bays such as Chesapeake Bay, Long Island Sound, San Francisco Bay, and Puget Sound. They are characterized by lower wave energy and slower erosion rates, an irregular coastline comprised of smaller beaches and sediment compartments, a large diversity of coastal landforms, and productive, complex ecology typical of estuarine environments (Nordstrom, 1992; National Research Council, 2007). They often lie in close proximity to major urban areas, are heavily impacted by human development, often bear the legacy of historical modifications, and typically have different land development patterns and recreational uses than ocean beaches (Nordstrom, 1992).

The National Research Council recently examined the complex issues associated with managing erosion on sheltered coasts (National Research Council, 2007). As with the science, policy development on these shorelines has not kept pace with similar efforts on exposed shorelines (Nordstrom, 1992). Even in states where armoring is strongly scrutinized on ocean beaches, armoring of estuarine shorelines often receives little attention. In its findings, the National Research Council (2007) stressed the importance of understanding cumulative impacts, the need for regional planning that takes into account sediment considerations, and the importance of better protecting a full suite of ecosystem services. The report also emphasized the need for better scientific understanding of shoreline processes and of alternative approaches to managing eroding coastlines.

Puget Sound

Puget Sound, the second largest estuary in United States, has roughly 4,000 km of sheltered coastline, much of it consisting of eroding bluffs, narrow mixed sand and gravel beaches, and heavily modified urban and industrial shorelines. Approximately one-third of this shoreline has been armored and the expectation is that this will continue, particularly in the face of regional population trends and potentially increased rates of sea level rise. Armoring has been suggested to alter physical processes such as coastal sediment supply and transport, the interaction of waves with beaches, and groundwater flows to the beach, as well as impacting ecological functions, such as spawning, detritus production and food web processes, and the maintenance of beach and nearshore habitats.

Relatively little field research and predictive modeling have been carried out on Puget Sound beach environments, related to either geomorphic or ecologic processes. Numerous technical reports have been produced and numerous reviews have been done of relevant research from both this and from other regions, but there remains a great need for more extensive and more rigorous scientific research into the behavior of the Puget Sound nearshore system and the impact of human activities on its future condition.

Several major initiatives have recently increased the need for better scientific understanding of Puget Sound shorelines and of the impacts of armoring, in particular. The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) has developed strategies for restoring coastal habitats, with an emphasis on protecting and re-establishing key ecosystem processes such as sediment delivery. The Puget Sound Partnership (PSP), a new state agency as of 2006, is actively prioritizing scientific studies, restoration objectives, and policy changes aimed at improvements to the entire Puget Sound basin, including coastal environments. The Washington Department of Ecology is working with local governments across Puget Sound to update existing Shoreline Master Programs to conform to new state guidelines that mandate the protection of ecological functions along Puget Sound's shoreline and that generally demand closer scrutiny of shoreline armoring.

These state-wide efforts require more scientific information and more technical guidance related to shoreline armoring and the restoration of degraded shorelines. Recognizing this need, scientists and technical staff from the U.S. Geological Survey, the Corps of Engineers, state and federal agencies, and the University of Washington secured funding to host a scientific workshop on the subject of shoreline armoring.

Ultimately, a better understanding of the impacts of armoring on sheltered and estuarine shorelines will provide the scientific basis for guiding principles and recommendations that lead to better decisions related to locating and regulating shoreline armoring. Specific objectives of the workshop were to:

- Summarize the state of science regarding physical and biological impacts of armoring on estuarine shorelines like those of Puget Sound;

- Inform conceptual models that integrate physical and biological knowledge and assess levels of certainty of knowledge;
- Identify and prioritize information and data needs that will advance our understanding of the impacts of armoring on Puget Sound beaches.

The workshop was held on May 16–19, 2009, at Alderbrook on Hood Canal, Washington. Workshop participants mostly were scientists from physical and biological disciplines, including experts from other regions with experience in shoreline geology, coastal ecology, and the specific issue of shoreline armoring. Of the 38 participants, 23 delivered presentations and 22 contributed papers to these Proceedings. In addition to the technical presentations, the workshop included a poster session, a half-day field trip, and a summary discussion employing breakout groups. A literature review also was prepared in conjunction with the workshop (Coyle and Dethier, 2010, this volume). In addition, the Puget Sound Partnership organized a separate forum for shoreline planners and resource managers on the day following the workshop in which several speakers summarized the important conclusions from the workshop.

Summary of the Papers

The 22 publications in these Proceedings are organized into five categories:

- Puget Sound Setting and Context
- National Perspective and Human Dimensions
- Coastal Geologic and Oceanographic Processes
- Beach Processes and Ecological Response
- Management Needs

Puget Sound Setting and Context

The paper by Quinn (2010, this volume) describes Puget Sound as a large, productive estuary shaped by complex geological forces and surrounded by numerous watersheds, including some in Canada. Over the last 200 years, human impacts have changed from dispersed influence of local native tribes to the results of occupation by millions of people and diverse extractive activities (for example, logging and fishing) and development patterns (dense urban and extensive residential development). Quinn (2010, this volume) describes the complex jurisdictional issues in the nearshore, making regulation and protection of shorelines difficult.

Shipman (2010, this volume) describes Puget Sound's shoreline as strongly influenced by its glacial history and characterized by a steep bluff-dominated coastline with narrow mixed sand and gravel beaches, a coastal sediment system largely fed by bluff erosion, and an irregular coastline divided into hundreds of individual littoral cells. Approximately one-third of the shoreline is armored, much of it in the form of bulkheads and seawalls associated with residential construction.

Dethier (2010, this volume) discusses beach types in Puget Sound as diverse in terms of wave exposure and therefore sediment types, with corresponding variation in biological communities. Beaches range from soft mud with eelgrass, clams, and oysters to "mixed-coarse" substrates with cobbles and sand, which have high plant and animal biodiversity and productivity. Sandy and pebbly beaches are common and tend to have simpler biotic communities because of the instability of the substrate. These varied beach communities link to adjacent terrestrial and marine ecosystems in a variety of ways, some of which are disrupted by armoring.

Myers (2010, this volume) describes how the Puget Sound Nearshore Ecosystem Restoration Project conducted an analysis of change in nearshore ecosystems from the mid-1880s to present in order to identify what anthropogenic drivers have changed Puget Sound's nearshore since European settlement of the region, and where those changes occurred. The key elements of this analysis are that it is documented comprehensively over the entire Puget Sound basin, directly related to physical and ecological change in ecosystem-scale processes, spatially explicit, and integrated within the framework of a geomorphic classification system. Shoreline armoring is one of the stressors considered in this analysis; armoring occurs along 27 percent of Puget Sound. The percent of armored shoreline varies considerably (9.8–62.8 percent) across the major sub-basin regions of Puget Sound. The South-Central Puget Sound sub-basin (area around the city of Seattle) is the most heavily armored of the sub-basins, with 63.0 percent of the shoreline armored.

Carman and others (2010, this volume) explain that regulation of shoreline armoring on Puget Sound primarily occurs through the Hydraulics Act, which is administered by the Washington Department of Fish and Wildlife, and the Shoreline Management Act, which is administered by the Washington Department of Ecology and local governments. These laws guide how and where structures are built, but both include constraints that limit their ability to strictly regulate armoring on residential property. The paper also notes that most new armoring structures are associated with residential development.

National Perspective and Human Dimensions

The paper by Nordstrom and others (2010, this volume) describes plans to monitor a beach-feeding project on the bay shoreline of Fire Island, New York. Existing armoring has impacted sediment transport and increased erosion on natural portions of this low energy shoreline, and feeding is intended to restore beach processes and habitat without the excessive offshore sedimentation and habitat disruption that might accompany conventional beach nourishment. The monitoring study will employ instrumentation and frequent measurements during the storm season to evaluate sediment transport rates and pathways, beach morphologic changes, and impacts on biota.

O'Connell (2010, this volume) describes several beneficial and adverse effects of shoreline armoring, utilizing experience from coastal zone management in the states of Massachusetts and Hawaii. Shoreline armoring can protect valuable waterfront real estate, maintain home values, and reduce loss of private and public infrastructure. Adversely, armoring can result in the loss or alteration of important coastal habitat, or in some cases hasten the loss of beach sediments. Data are presented from the diverse perspectives of Massachusetts and Hawaii, providing examples of the importance of this issue to state and local economies.

Griggs (2010, this volume) describes the status of shoreline armoring in the state of California, which has over 100 mi of coastal protection. In California, armoring issues include limitations of beach access, visual impacts, loss of beach as a result of the placement of the structure, loss of sand supply from eroding bluffs, and passive erosion, or loss of beach fronting a seawall as sea-level rises. Long-term beach monitoring data along the coast in Monterey Bay suggest that shoreline armoring there did not cause additional active erosion of beach sand, possibly a result of the high littoral or longshore transport rates in the area. In California, the use of soil-nail walls or sprayed concrete, which is colored and textured to match native rocks and cliffs, has become more popular. These structures may reduce negative visual impacts, but do not minimize other negative impacts of shoreline armoring.

Roberts (2010, this volume) describes a 2007 report by the National Research Council that examined the impacts of shoreline management, especially stabilization, on sheltered coastal environments. Many of the conclusions of that report are relevant to Puget Sound, especially the importance of considering cumulative impacts and of changing the regulatory environment to make it simpler to install non-structural solutions to shoreline erosion problems.

Currin and others (2010, this volume) discuss how North Carolina shorelines are experiencing rapid erosion, making efforts to stabilize the shoreline common. Alternatives to armoring that are currently being promoted include several "living shoreline" techniques that incorporate use of natural shoreline vegetation, especially salt marshes; these not only reduce erosion but provide a variety of other ecosystem services. Like Roberts (2010, this volume), this paper discusses how the current system for permitting shoreline stabilization projects does not favor these living shoreline methods.

Leschine (2010, this volume) discusses the implications of the lack of human dimensions research on the interactions of people with seawalls and other engineered features and how this may relate to restoration of nearshore ecosystems. Such engineered features represent a dilemma because they protect property from erosion or wave attack and thus can make a positive contribution to human well being. Conversely, they also can negatively affect a variety of other ecosystems goods and services. However, we currently lack an understanding of how people in the region value the numerous tradeoffs across ecosystem functions, goods, and services associated with armoring Puget Sound's shores. Integrating human-dimensions and natural scientific research can help expand scientific understanding relevant to nearshore ecosystem restoration.

Coastal Geologic and Oceanographic Processes

Komar and Allan (2010, this volume) discuss "build with nature" alternatives to shoreline armoring. They provide details from a case example at Cape Lookout State Park on the Oregon coast. They first describe the nature of the erosion problem, then the design, construction, and monitoring of a cobble berm as natural shoreline protection.

Osborne and others (2010, this volume) describe direct measurements and observations of gravel transport, beach sediment characteristics, beach erosion and accretion, and forcing mechanisms along a mixed-sand-gravel beach on Bainbridge Island, Puget Sound, Washington. The beach at this study site is backed by shoreline armoring structures and has been exposed to waves from storms and passenger-only fast ferries. The long term observations of changes in beach morphology, transport patterns, and sediment size and volume variations are consistent with the observation that this site is sediment-supply limited. It is undergoing long term passive erosion, most likely as a result of construction of bulkheads along the length of the study area.

Johannessen (2010, this volume) describes how sediment eroded from coastal bluffs is the primary source of sediment for many Puget Sound beaches, leading to concerns about the impact of shoreline armoring on sediment budgets and beach sediment supply. This paper describes a field-based methodology developed on Puget Sound to identify both historic and existing bluff sediment sources (locally referred to as "feeder bluffs"). This work has been carried out in portions of Puget Sound and confirms a substantial loss of historical sediment supply. The mapping is being used by local and state agencies and other organizations to identify shorelines for protection and restoration actions.

Beach Processes and Ecological Response

Rice (2010, this volume) argues that some of the clearest impacts of shoreline modifications on biota in Puget Sound are reduced survival of embryos of forage fish on upper beaches, as well as loss of high-shore invertebrates. Broad marine bird surveys also suggest a negative correlation with human development patterns. However, few studies are explicitly designed to address biotic patterns associated with human impact; such directed studies are needed to improve our understanding and management of the biological effects of shoreline armoring in Puget Sound.

Toft and others (2010, this volume) discuss how careful studies of restoration actions involving removal of shoreline armoring, with controls, can inform our understanding of armoring impacts. Two such case studies suggested that key links between terrestrial and marine systems that may be disrupted by armoring include the availability of habitat and food items for juvenile salmon; these prefer to forage in gently sloping shallow water and consume insects that drop from riparian vegetation, both of which tend to be absent on armored shores. High-shore invertebrates also return fairly quickly once armoring has been removed. The authors list suggestions for key further research.

Krueger and others (2010, this volume) describe how surf smelt and Pacific sand lance are key parts of the Puget Sound food web, providing food for many sea birds, marine mammals and fishes. Shoreline armoring might be the greatest threat to surf smelt and sand lance spawning habitat, as armoring affects beach morphology and results in the direct loss of spawning habitat. In addition to shoreline armoring, sea level rise is likely to cause widespread loss of spawning habitat for these two species. The discontinuous geographic distribution of spawning occurrence and egg abundance suggest that loss of a relatively small number of spawning beaches might have a large detrimental effect on egg abundance. Although some regulatory protection of surf smelt and sand lance spawning habitat currently exists, they fail to take expected environmental change and spatio-temporal variation in spawning into account.

Ruggiero (2010, this volume) reviews various published studies exploring seawall impacts on sediment dynamics. The effect of seawalls on beaches has been found to be most sensitive to the position of the seawall within the surf zone, the beach slope, and the reflection coefficient. However, it has not been conclusively confirmed in the field or the laboratory whether currents and sediment transport rates will increase or decrease in front of a hardened shoreline, as compared to a non-armored section of beach, and whether the sedimentary environment will be significantly modified. This paper suggests pilot investigations specific to the Puget Sound consisting of beach monitoring, field experiments, and modeling efforts that could help improve understanding of these processes and the effects of shoreline armoring on beaches.

Dugan and Hubbard (2010, this volume) describe how on Southern California sandy beaches, armoring of eroding bluffs substantially reduces beach width, abundances of invertebrates, and numbers of foraging and roosting shorebirds, gulls, and seabirds. Predicted sea level rise will further reduce this critical habitat area and the food it contains for birds and other vulnerable species.

Jackson and others (2010, this volume) describe how alteration of estuarine shores to increase their economic value is a long practiced tradition in the United States. Recent attention in Delaware Bay has focused on natural and human-induced changes occurring to sandy landward-migrating barriers that front marsh systems. These changes are important for the American horseshoe crab that annually spawn in the foreshores of these barriers. Erosion of the foreshore during storms can result in either the removal of sediment from the upper foreshore and deposition on the lower foreshore or the horizontal landward displacement of the foreshore. Beach nourishment may be a preferable alternative over building bulkheads for preserving habitat value for the horseshoe crab, but nourishment can decrease habitat value as well as enhance it, depending on morphology and sediment characteristics of the pre-nourished beach.

Management Needs

Barnard (2010, this volume) describes how documents that provide “design guidance,” such as those summarizing the best available science related to methods for streambank protection, can be critical to help managers and engineers create environmentally sound projects. No such guidance document is available for shoreline armoring projects except for the Corps of Engineers’ Coastal Engineering Manual, which emphasizes open-coast sandy beaches and thus is not entirely relevant to Puget Sound conditions. A “Marine Shorelines Design Guidance” document is being planned for Puget Sound; it will consider unique local conditions including the importance of drift cells and sediment supply, and discuss benefits and impacts of different techniques for stabilizing eroding shorelines.

Cereghino (2010, this volume) describes how protecting private property from erosion is in direct conflict with protecting the “public trust resource” of sediment supply to beaches. Restoration programs struggle with trying to solve a large-scale, cumulative problem with piecemeal small-scale projects on individual parcels. Restoration “systems” that span organizational boundaries may have greater success; these integrate planning, learning, land stewardship, and communication among stakeholders into the more traditional restoration activities of project development and funding.

Summary

The papers in this proceedings volume reflect the geological, ecological, and regulatory complexities of shoreline armoring issues. The Discussion Summary at the end of this volume begins to explore some of the research that workshop participants felt would improve understanding of armoring impacts. This report only touches on the human dimensions of shoreline armoring, such as historical and cultural values, public use and access, and property rights, and these would be highly appropriate topics for another workshop. In addition, these papers do not examine in detail the design and engineering aspects of erosion control methods and the development of “greener” or “softer” alternatives to conventional armoring, topics also worthy of further exploration.

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