

POLICY PERSPECTIVE

Shoreline Armoring in an Inland Sea: Science-Based Recommendations for Policy Implementation

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Armoring; policy; restoration; beaches; sediments; ecosystem goods and services; coastal management; seawalls; shoreline development.

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Abstract

Shoreline armoring can impact a variety of ecosystem functions, goods and services provided by beaches. Shoreline managers struggle to balance genuine need for armoring to protect infrastructure versus unacceptable losses of ecosystem functions—whether these be in beaches, sand dunes, or marshes. We use our recent research effort in the Salish Sea, Washington, as a case study to illustrate how highlighting the negative consequences of shoreline armoring to publicly important ecosystem functions may help to strengthen implementation of policy and prioritize restoration actions. We focus on two distinct mechanisms of armoring impact that link strongly to key beach functions, and recommend: (1) where armoring is clearly necessary, place or move it as high on the beach as possible. Armoring emplaced relatively low on the shore is more likely to affect a variety of ecosystem functions from forage fish spawning to beach recreation; (2) prioritize protection or restoration (armor removal) of feeder bluffs that are critical for sediment supply to the beach; this sediment is essential to the maintenance of beach functions. In addition, we recommend that nature-based alternatives to armoring be given preferential regulatory consideration and that outreach efforts clarify the advantages of these engineering methods.

Introduction

Anthropogenic modifications of coastlines are common worldwide, including abundant stabilization of the shoreline with various sorts of walls, referred to as armoring. Recent conservative estimates put the amount of armored shoreline in the continental U.S. at 14% (Gittman *et al.* 2015), with very high proportions near population centers. Estimates for the amount of hard engineering in Europe, the United States, Australia, and Asia are much higher, at more than 50% (Dafforn *et al.* 2015; Manno *et al.* 2016). However, only in the past few decades has there been exploration of the unintended negative consequences of these shoreline alterations. Armoring impacts a variety of ecosystem functions, goods, and services (EFGS) (Millennium Ecosystem Assessment 2005), the benefits gained by humans that are provided by beaches (Table 1). These may include “supporting” services such

as primary production, “regulating” services such as mitigation of eutrophication, “provisioning” services such as shellfish, and “cultural” services such as recreation. However, impacts of armoring may not be apparent to the public because they are often very gradual or are invisible below the ocean surface, whereas the benefits of armoring in terms of property protection and shoreline aesthetics are obvious. These tradeoffs and the uncertainties inherent in quantifying impacts mean that regulations proposed to restrict armoring are readily resisted or weakened. We argue that we now know enough about negative environmental consequences of shoreline armoring in a variety of physical environments and thus we can make clear science-based recommendations for firmer implementation of stronger policies and regulations. A key tool for this effort may be linking EFGS, which the public and politicians can relate to, with decision-making (Ruckelshaus *et al.* 2015).

Table 1 Direct and indirect mechanisms by which shoreline armoring affects beach ecosystem functions, goods, and services

| Functions, goods, and services | Mechanism | | | |
|---|-----------------------|----------------------|----------------------|-----------------|
| | Encroachment | Loss of connectivity | Sediment impoundment | Wave reflection |
| Recreation, nonconsumptive: park use and outdoor education | Indirect – Indirect + | Indirect – | Indirect – | Indirect – |
| Recreation, consumptive: shellfish, seaweed, and fish | | Indirect – | Indirect – | |
| Forage fish spawning: surf smelt and sand lance ^a | Direct – | Direct – | Direct – | Direct – |
| Trophic support: supply of insects, crustacea, and worms ^b | Direct – | Direct – | Indirect – | |
| Nutrient cycling: from marine and terrestrial wrack ^c | Direct – | Direct – | Indirect – | |
| Habitat provision: logs and wrack microhabitats ^d | Direct – | Direct – | Indirect – | Direct – |
| Groundwater filtering ^e | Direct – | Direct – | Indirect – | Indirect – |
| Resilience to sea-level rise ^f | Direct – | Indirect – | Direct – | Direct – |

^aRice 2006; Penttila 2007; Quinn *et al.* 2012

^bDethier 1990; Heerhartz *et al.* 2015; Heerhartz & Toft 2015

^cDugan *et al.* 2008; Heerhartz *et al.* 2014

^dHeerhartz *et al.* 2014; Dethier *et al.* 2016

^eMcIntyre *et al.* 2015

^fShipman 2010; Berry *et al.* 2014; Johannessen *et al.* 2014

Encroachment = covering the upper shore with armoring and thus eliminating natural habitats. Loss of connectivity = breaking linkages of materials, energy, and organisms between land and sea. Sediment impoundment = preventing sediment from eroding from banks and bluffs and reaching beaches. Wave reflection = causing storm waves to reflect off armoring rather than running gradually up a beach, leading to beach scour. Types of impact of each mechanism are given for each function; Blank = no known impact, – = negative, + = positive. A sampling of references for information on impacts is given, mostly from the Salish Sea. See Supporting Information for more details and references.

One of the challenges with quantifying impacts of armoring is that the mechanisms by which it alters shorelines are diverse, dependent on regional context (wave energy and geomorphology), and likely to manifest at different scales of space and time. In addition, while some direct impacts are documented, indirect impacts are often hypothesized but difficult to demonstrate. Recent reviews have summarized how armored shorelines can affect beach shape and hydrodynamic processes (Bernatchez & Fraser 2012; Nordstrom 2014), local biodiversity (Chapman & Underwood 2011; Gittman *et al.* 2016a), and accumulation of beach wrack along with the primary and secondary consumers that depend on it (Dugan *et al.* 2011). In marsh habitats, armoring may entirely cover and eliminate the marsh and all of its attendant functions (e.g., Bozek & Burdick 2005; Gittman *et al.* 2015). For high-energy sandy beaches, two clear impacts are impoundment of sand that would otherwise “feed” the beach, and prevention of shoreline retreat (natural beach migration with erosion and sea-level rise) (e.g., Berry *et al.* 2014), resulting in narrowing and coarsening of the beach. Other mechanisms of impact include loss of connectivity across the land-sea ecotone (Heerhartz *et al.* 2014), and hydrodynamic effects such as active erosion caused by wave reflection from seawalls (Ruggiero 2010).

Disentangling these mechanisms and ascribing cause-and-effect for indirect impacts can make it difficult to convince the public and regulators about the need for action. Agardy (2015) notes: “Even with strong bases for science-

based actions... the unavoidable uncertainties are often used to prevent action and allow business-as-usual” (see also, Green *et al.* 2015; Zaucha *et al.* 2016). If the public observes change, perceives at least some of it as “bad,” and becomes convinced (e.g., by knowledge brokers, Naylor *et al.* 2012) that human actions are causing it, then it is socially and politically easier to make progress toward un-doing the change. All of this must happen before management interventions such as removing armoring can gain momentum. An added difficulty is that geomorphological impacts tend to occur over years, making them “slow disasters,” unlike fires whose impacts play out over hours or days; thus risk aggregation is slow, and incentives to act quickly are reduced (Moritz & Knowles 2016). Interventions are also unlikely to produce rapid results. Finally, issues of jurisdiction and governance are unusually complex at the land-sea border, so that any change in policy is likely to involve multiple agencies with different mandates (Zaucha *et al.* 2016).

Here, we use our research in Washington State as a case study for considering how discussion of EFGS may enable the strengthening of support for regulatory and restoration actions. Puget Sound, in the southern Salish Sea, is a fjord-like estuary where most beaches consist of a mix of sand and gravel; this is predominantly derived from the episodic erosion of glacial and interglacial deposits and is distributed by longshore transport (Shipman 2010). Wave regime and local geology are the primary drivers of modern beach geomorphology.

Because of a lack of research on armoring impacts along such mixed-sediment beaches, local regulators have until recently had little data on which to base efforts to strengthen or enforce regulations for restricting armoring. However, recent research summarized below, combined with numerous efforts toward public education on marine-conservation issues, leads us to believe that the public may be ready to hear arguments that shoreline armoring is damaging the marine resources of the area. There is extensive press (e.g., Hamel *et al.* 2015) about declining salmon, seabirds, and orca whales in the Salish Sea, and many long-term residents have anecdotes about shrinking beaches and fewer clams. However, these perceptions may be counterbalanced by fears about rising sea levels and the increased shoreline erosion that will likely result. Broad claims that all armoring has adverse impacts may get little traction (Russell-Smith *et al.* 2015), but the data now indicate specific circumstances where impacts may be greater than others (see below). We recognize that policy-makers must consider issues besides environmental impacts (Rose & Parsons 2015), but we now have an opportunity to make specific recommendations regarding regulations and restoration priorities that acknowledge tradeoffs and target the most serious issues.

Goods and services of Salish Sea beaches: why should people care?

If policies and regulations related to shoreline armoring are to change, success is more likely if we focus on the aspects of armoring that appear to have the greatest impacts on EFGS, and that affect the public personally (Zauch *et al.* 2016). The ecosystem services that people relate to vary considerably among individuals and groups, so bringing diverse EFGS into the discussion may be helpful. The primary positive benefit of shoreline armoring is clear: it protects property and infrastructure from erosion caused by wave damage. The negative aspects relate primarily to characteristics of the beaches seaward of the armoring. As is true for beaches worldwide, those of the Salish Sea provide a variety of EFGS (Figure 1). Details about these functions and relevant references are given in Supporting Information and are summarized in Table 1. Beach EFGSs include high real estate prices for water access and views, intense and diverse recreational activities in public parks (Figure 1a), and ecological and geomorphic functions. Natural beaches are productive and supply food to nearshore food webs, including to juvenile salmon and ultimately to both humans and orca whales. They provide essential habitat for organisms that degrade marine and terrestrial detritus, and for terrestrial birds and mammals. They are the sole spawning habitat

for certain “forage fish” that are key elements in marine food webs. Natural beaches are geomorphically resilient, as they respond more flexibly to storm events and can shift landward to accommodate rising sea levels. Other functions are discussed in Supporting Information.

Recommendations: using science to improve management

Shoreline armoring impacts ecosystem functions through different mechanisms, affecting beaches both directly and indirectly (Table 1). In this section, we highlight two specific concerns where policy improvements could reduce impacts of armoring on the Salish Sea and in other regions. These include the waterward position of the seawall and the impact of erosion control on sediment supply.

Of the impact mechanisms detailed in Table 1, all except sediment impoundment are likely to be increasingly severe the lower the armoring is on the beachface. In the Salish Sea, we found a threshold in the elevation of armoring—about 0.5 m below local Mean Higher High Water—below which there is an abrupt drop in the number of beach logs and the amount of wrack that accumulates (Dethier *et al.* 2016). When structures extend below this elevation, there is no upper beach on which material can be retained between high tides (Figure 1b). Other beach biotas depend on these habitat elements. Juvenile fish such as salmon swimming alongshore prefer to do so in shallow water (presumably to avoid predation); where structures extend lower on the beach, there is less shallow water habitat at high tide. Fish that preferentially spawn high on the beachface find suitable habitat reduced or eliminated by structures built across the beach (Quinn *et al.* 2012). In addition, structures lower on the beach result in more frequent interaction with more energetic waves, increasing scour and even alongshore transport (Ruggiero 2010), impacting the amount and stability of appropriately sized spawning substrate. While new seawalls in Washington are required to be built as high on the beach as possible, many older structures extend below this elevation. A clear recommendation is that when older structures need to be replaced, they be relocated at least as high as the current allowable elevation. Restoration programs could offer funding and guidance to encourage the relocation or removal of structures that extend to lower beach elevations.

The second critical mechanism of impact in our case study area is sediment impoundment (Figure 1c, Table 1). On Puget Sound, bluff erosion is a significant source of beach sediment (Shipman 2010) and armoring prevents the replacement of fine sediment that is



Figure 1 Examples of EFGS or their losses on beaches in Puget Sound. (a) Recreational enjoyment in a natural area of Seahurst Park; (b) condominiums built on fill retained by a low-elevation concrete bulkhead; such armoring impacts EFGS by all four mechanisms in Table 1; (c) former feeder bluff with sediment impounded by armoring; and (d) stairs to the beach protected by a rock bulkhead. All photos by Hugh Shipman.

naturally winnowed from beaches by waves over time. Many ecological functions as well as recreational uses decline as beaches get coarser (Dethier *et al.* 2016); for example, forage fish, which are a key link in food webs up to the iconic orca whales, require a mix of sand and gravel to spawn on the upper beach (Penttila 2007). These potential impacts also lead to straightforward policy recommendations. While eroding banks and bluffs are widespread around the Salish Sea, much beach-building sand and gravel come from a limited subset of these, locally referred to as feeder bluffs (Figure 1c). These bluffs have been mapped (Shipman *et al.* 2014, <https://fortress.wa.gov/ecy/publications/parts/1406016part2.pdf>), providing a clear spatial basis for targeting preservation and restoration efforts. Concern about diminishing sediment supplies suggests creating policies for feeder bluffs that (1) prohibit

new seawalls, (2) discourage replacement or expansion of failed armor, and (3) incentivize removal of armor. For armored feeder bluffs, simply moving armoring higher up the shore does not restore sediment supply, so the focus must be on removal of the structure—i.e., a different response than for low-elevation impacts. Washington has had some success in reducing new seawalls on feeder bluffs, but the effort is challenging as these sites are often where erosion and landslide hazards are most severe. The state requires that new armor only be constructed where there is an imminent threat to existing upland development, but this can lead to complex geotechnical arguments between proponents and agency experts. This type of conflict between land owners and coastal managers suggests that there is a need for increased emphasis on preventing development above feeder bluffs in the first place to minimize future problems. Policies could involve

instituting and enforcing large setbacks, creating incentives for the relocation of at-risk structures, and acquiring and preserving particularly high-value feeder bluffs.

In contrast, flexibility in regulations should be able to accommodate situations where armoring has fewer impacts, e.g., where little sediment supply is impounded or impacts are easier to mitigate. In some cases, stabilization structures can be kept small or may be designed so that they can be relocated after significant erosion events, retreating with the coastline (e.g., Hill 2015). Vegetation can be planted to reduce impacts from seawall construction on riparian areas. Steps to the beach are common and most may have limited impacts on EFGS, although such structures raise concerns if there is a chance that they will facilitate additional at-risk development or lead to a need for bank stabilization in the future (e.g., Figure 1d).

The framework for regulating armoring differs from state to state in the United States. In Washington State, management occurs primarily through the state's Shoreline Management Act (SMA) and Hydraulics Code, which together restrict the conditions and methods under which armoring can be constructed. The SMA is administered by local governments and addresses most shoreline activities, including stabilization structures. State Guidelines make it increasingly difficult to build new armoring except when there is an imminent threat to an upland structure, but restrictions on replacing existing structures are less strict. The Hydraulics Code is implemented by the Washington Department of Fish and Wildlife and is intended to reduce impacts on fish. Hydraulics Projects Approvals are required for any armoring structure and typically include conditions on the methods and timing of construction, but rarely can prohibit structures altogether.

The Puget Sound Partnership has identified both regulatory measures and restoration actions to reduce impacts (Puget Sound Partnership (PSP) 2014). Recent permit data indicate that the rate of new armoring appears to be decreasing, while the number of bulkheads being removed through restoration is increasing (Hamel *et al.* 2015). However, other analyses (Kinney *et al.* 2015) show that a significant proportion of armoring is either built without permits or is not constructed to permit specifications (e.g., elevation), indicating the need for more effective implementation of existing policies, including inspections and better enforcement. These actions require substantial political will and funding, which again speaks to the need for heightened awareness of impacts to EFGS of beaches.

In Washington and elsewhere, there is increasing interest in softer shoreline protection techniques, or "living shorelines," which use nature-based approaches (such as

establishing dune grasses or oyster reefs) to reduce erosion and improve ecosystem functions (e.g., Hill 2015; Popkin 2015; Sutton-Grier *et al.* 2015; Gittman *et al.* 2016b). In the Salish Sea, softer designs to reduce erosion often include logs anchored into the upper shore to absorb wave energy, nourishment with sand and gravel, and planting of native vegetation to provide some of the shade and terrestrial-marine connectivity that is generally lost with armoring. These living designs also enhance recreation and restore many of the ecosystem functions listed in Table 1. On Puget Sound, the state's Shoreline Management Act requires that property owners examine the feasibility of such soft alternatives and can only consider conventional armoring as a last resort (Carman *et al.* 2010). Recent guidance on the design and construction of soft shoreline structures on Puget Sound (Johannessen *et al.* 2014) supports both property owners and government agencies in selecting better approaches, but implementation remains difficult because the effectiveness of these techniques is not well established. Additional guidance products and increased technical assistance are needed to educate contractors as well as homeowners not only about the benefits of softer techniques in terms of expense and complexity, but also long-term resilience and ecosystem functions. Naylor *et al.* (2012) and Popkin (2015) note the importance of changing not only regulations but also the permitting process to further incentivize property owners to opt for lower impact structures. Where it is not possible to avoid or remove armoring, current research in "ecological engineering" is exploring ways of adding habitat and biodiversity value to hard defenses, both in Washington (Cordell *et al.* 2017) and internationally (Naylor *et al.* 2012; Firth *et al.* 2013; Nordstrom 2014; Dafforn *et al.* 2015). Monitoring of soft-shore and ecological engineering projects and subsequent outreach on effective techniques are essential to provide the feedback that can encourage future efforts.

Communicating recommendations

There is an increasing body of literature on how to more effectively translate science into policy, actions, and decisions, including using the leverage of the ecosystem services approach (Ruckelshaus *et al.* 2015; Zaucha *et al.* 2016). This translation is needed to ensure that problem-focused research actually gets used by decision makers. Scientists are not always effective at communicating with diverse groups about such findings and recommendations (e.g., Rose & Parsons 2015). Knowledge brokers and guidance documents (Naylor *et al.* 2012) can improve our ability to engage and effect changes in attitudes in the wider community by delivering academic

and applied science in a useful way to those who need it (Russell-Smith *et al.* 2015). Social and ecological information needs to be integrated, and tradeoffs explicitly acknowledged (Kittinger *et al.* 2014). Four main target groups for such outreach in our case study region are:

- 1) Scientists. This is readily accomplished with publications and regional professional meetings.
- 2) Managers. Efforts in this direction include nontechnical articles such as this one, presentations at workshops, and directly to agency groups.
- 3) The general public. Greater public awareness of the marine environment can improve acceptance of responsibility for conservation, increased pressure on politicians and regulators, and greater support for environmental initiatives including volunteering time (Morris *et al.* 2016). The Puget Sound region has an engaged public, and researchers can work directly with the numerous organizations that bridge the gap between science and the public. Regional groups include the Puget Sound Partnership (<http://www.psp.wa.gov/>), the Shore Friendly campaign (<http://www.shorefriendly.org/>), the Northwest Straits Commission (<http://www.nwstraits.org/our-work/forage-fish/>), and the Sound Waters Stewards (<http://soundwaterstewards.org/>). Research into social marketing is exploring incentives to remove armoring in cases when it is not actually needed to protect homes (http://wdfw.wa.gov/grants/ps_marine_nearshore/files/final_report.pdf).
- 4) Politicians. Links to this key group are indirect, probably coming most effectively from agency personnel and an active citizenry. The challenge is making the need for tightening restrictions on armoring more compelling than are counterarguments that protecting shoreline development justifies the potential cumulative impacts on coastal ecosystems. We can emphasize the monetary as well as human well-being values of natural beaches (Ruckelshaus *et al.* 2015), and the fact that there are alternatives to armoring that are both cost-effective and can improve EFGS.

Conclusions

Armoring a shoreline involves putting a static structure into a dynamic environment, where impacts and interactions are diverse and unpredictable. Any armoring can have impacts on beach EFGS and these impacts are likely to be cumulative, since relatively small actions are widespread and because effects of structures tend to increase over time. Shoreline defense structures are controversial worldwide as shoreline managers struggle to balance genuine need for protection against unaccept-

able losses of EFGS—whether these be in marshes, sand dunes, riparian habitats, or beaches. While we have primarily discussed EFGS and armoring issues in the southern part of the Salish Sea, both the results of our research and the policy recommendations will apply elsewhere, although the specific mechanisms and issues may be different. Our policy recommendations, based on scientific research in the Salish Sea, can aid restoration decisions by focusing on how to minimize the loss of EFGS benefits. In the face of increasing levels of coastal urban growth and sea-level rise, there is great potential for restoration to not only enhance shoreline health but also better protect coastal communities using more natural approaches (Arkema *et al.* 2013). This new scientific information has already increased awareness of the tradeoffs associated with shoreline armoring among resource managers, property owners, and local governments. It provides a foundation that agencies can use to review shoreline projects and to support decisions about where and where not to armor.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Supporting Information

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