Fish and Invertebrate Response to Shoreline Armoring and Restoration in Puget Sound

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Abstract. Puget Sound shorelines have been heavily modified, especially those associated with urban centers. Understanding the degree to which anthropogenic modifications affect nearshore fish and invertebrates, and how to best evaluate and enhance ecological functions, are key to restoring the health of Puget Sound and must be addressed by integrating science and management. The goals of this paper are (1) to summarize existing knowledge of armoring effects on shoreline biota, (2) to examine the ecological function of two case study restoration sites, and (3) to discuss the role of science in urban shoreline restoration and implications for management. Past research suggests that armoring removal could help restore shallow water ecosystems of nearshore intertidal beaches and re-connect aquatic and terrestrial realms. We present a synopsis of recent research, describing shoreline armoring removal and beach rehabilitation at the Olympic Sculpture Park (City of Seattle) and Seahurst Park (City of Burien). Riprap or seawalls at these sites were removed with the goal of enhancing shallow water habitats for juvenile Pacific salmon (predominantly Chinook and chum) whose populations are of special concern in Puget Sound. Results indicated that these sites showed ecological improvements compared to armored or pre-restored conditions, most noticeably in the intertidal elevation range where armoring was removed as compared to lower elevations affected only by beach regrading and sediment nourishment. Understanding such linkages between abiotic and biotic features of a beach ecosystem is vital to planning rehabilitation efforts along degraded shorelines, and will help guide the restoration of salmon habitat. Given the context and findings discussed in this paper, we advocate that science can be useful in restoration planning (1) prior to restoration in helping to define project goals, (2) during project design by incorporating data to optimize the likelihood of desirable ecological responses, and (3) after completion of restoration to illustrate successes and failures and allow for adaptive management.

Introduction

Shoreline modifications are prevalent in many aquatic systems worldwide, especially in urban areas dominated by humans. The effects of shoreline modifications on flora and fauna have recently expanded as a research topic, designed to help understand the impacts that shoreline developments have on the ecotone between aquatic and terrestrial realms (Chapman, 2003; Alberti and others, 2007; Toft and others, 2007; Bilkovic and Roggero, 2008; Defeo and others, 2009). An average of 27 percent of Puget Sound's natural shoreline is armored by retaining structures, increasing to approximately 65 percent near urban centers (Simenstad and others, 2010). Such structures usually consist of vertical seawalls and riprap boulder fields. The resulting changes along modified shorelines should be an important focus of research and management, and are key to understanding the current biotic health and potential for maintaining and restoring diverse shoreline ecosystems.

The workshop "Puget Sound Shorelines and the Impacts of Armoring: State of the Science" that generated these proceedings brought together a diverse array of scientists and managers to address the state of knowledge about the physical and ecological effects of shoreline armoring. As a contribution to better understanding the ecological effects, the goals of this paper are (1) to briefly summarize the knowledge about effects of armoring on shoreline biota, (2) to focus on the ecological function of two case study restoration sites, and (3) to discuss the role of science in restoration of urban shorelines and implications for management. We focus on the "marine shorelines" of Puget Sound proper, excluding those of deltas and river sub-estuaries that enter Puget Sound (for example, Duwamish, Skagit, Nisqually) that are dominated by marshes and mudflats. We summarize recent research and highlight monitoring results of shoreline armoring removals and beach rehabilitation at the Olympic Sculpture Park (City of Seattle) and Seahurst Park (City of Burien). These shorelines have had either riprap or seawalls removed, with different restoration approaches employed to enhance shallow water environments that are recognized to be important habitats of juvenile pacific salmon (*Oncorhynchus* spp., predominantly Chinook, *O. tshawytscha*; chum, *O. keta*; pink, *O. gorbuscha*; and coho, *O. kisutch*) (Simenstad and Cordell, 2000). We recognize that although it is not always possible in extremely modified habitats to technically "restore" original conditions, it is feasible to effectively rehabilitate or enhance habitats within urban constraints (Simenstad and others, 2005). We use the term "restoration" to describe a general goal, and the terms rehabilitation and enhancement for actions that are intended to make progress toward that goal.

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Armoring Impacts on Shoreline Habitats and Biota

Shallow water intertidal habitat in Puget Sound is an important ecosystem feature and is the main location of aquatic shoreline armoring and its associated impacts. Efforts to restore or enhance nearshore areas recently have increased, in part driven by the listing of Chinook salmon as threatened under the Endangered Species Act in 1999. Juvenile Chinook salmon in the Pacific Northwest use estuarine and nearshore habitats during outmigration and rearing, as do other salmonids such as juvenile chum salmon (Simenstad and others, 1982). Surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*) also use beaches as habitat for spawning. Consequently, shoreline armoring in Puget Sound can affect nearshore fish abundance, distribution, and behavior patterns (Toft and others, 2007), as well as survival of eggs in beach spawning surf smelt (Rice, 2006). Also, removal of supralittoral vegetation can affect some nearshore fish species, demonstrating that terrestrial processes interact with aquatic ecosystems (Romanuk and Levings, 2006).

Invertebrates that are important prey for nearshore fish can be negatively affected by shoreline armoring (Romanuk and Levings, 2003; Sobocinski and others, 2010). Shoreline modifications affect aquatic community patterns in other systems as well, usually decreasing densities or altering assemblage structure (Peterson and others, 2000; Chapman, 2003; Cruz Motta and others, 2003; Moschella and others, 2005), but occasionally somewhat positive effects are detected because of added unique structures that attract some different organisms than what occurred naturally (Glasby, 1998; Davis and others, 2002). However, it is also important to note that these additional species can be non-indigenous (Glasby and others, 2007). Mechanisms causing negative effects are often related to physical alterations associated with truncating the intertidal zone, such as degrading habitat and shoreline vegetation, creating a steeper physical profile, limiting the sediment supply, and reflecting wave energy (Williams and Thom, 2001); however, many of these causal linkages remain untested in their specific effects on biota. Nearshore restoration often emphasizes improving habitat conditions for invertebrates that are important food for fish, but whether altered systems can be restored by removal of the modifications and enhancement of the intertidal beach remains poorly investigated.

The scale of the direct effects of armoring is related to the tidal elevation to which the armoring footprint extends: (1) within terrestrial and supralittoral, (2) into intertidal, and (3) across the entire beach profile into subtidal waters. Impacts to shoreline biota can often be more extreme where shoreline armoring extends into deeper subtidal areas, severely truncating the nearshore and destroying the natural gradual slope of the intertidal zone. Where this happens, pelagic fish that typically spread out along the intertidal area at high tide must inhabit deep water directly along shore (Toft and others, 2007). However, shoreline armoring at higher tidal elevations can still affect fish feeding. For example, juvenile Chinook salmon consumed less terrestrial/riparian prey (insects) at sites with supratidal and intertidal retaining structures compared to those feeding at unarmored beaches (Toft and others, 2007). Invertebrate assemblages also are negatively affected by the amount of seaward armoring, as shoreline modifications that encroach into intertidal beach elevations below Mean Higher High Water (MHHW) have a greater impact on benthic macroinvertebrates than those installed higher than MHHW (Sobocinski and others, 2010).

Two main points are implicit in these studies: (1) armoring that extends into the subtidal affects pelagic fish distributions, and (2) armoring at any elevation affects fish feeding and the aquatic-terrestrial connection. This suggests that urban restoration within Puget Sound should mainly focus on:

- Restoring shallow water ecosystems of nearshore intertidal beaches.
- Restoring connectivity across aquatic and terrestrial realms.

Alleviating impacts of armoring through restoration will be examined using two case studies, which offer insight into the types and benefits of rehabilitation that are feasible along modified Puget Sound shorelines. The studies are briefly described here, and an overview of the results is summarized from methods and analysis presented elsewhere (Toft and others, 2008; Toft, 2009).

Case Study 1: Olympic Sculpture Park

The Olympic Sculpture Park was created by the Seattle Art Museum on 3.4 ha of waterfront property along Elliott Bay in downtown Seattle, Washington. A main design goal was to improve habitat along the shoreline that would provide public access and benefit wildlife resources, including outmigrating juvenile salmon. Before the site was constructed, the shoreline consisted of seawall and riprap with minimal upland vegetation, which severely truncated available intertidal habitat and access to riparian resources. Two shoreline enhancements were created: (1) a pocket beach was excavated from the riprap, and (2) a compacted-sediment “habitat bench” was created along the seawall (fig. 1). Both features extend from shore to a tidal elevation of approximately 0.0 m Mean Lower Low Water (MLLW). Dunegrass (*Elymus mollis*) and riparian vegetation were planted along the pocket beach, and riparian vegetation also was planted along the walkway above the habitat bench.

Monitoring at this site is ongoing, and data have been analyzed from pre-restoration (2005) and post-restoration (2007) periods, bracketing construction in 2006 and opening of the park in January 2007. Monitoring has included quantitative surveys of fish, epibenthic invertebrates, and terrestrial insects pre- and post-restoration, with additional

Figure 1. Photographs of the Olympic Sculpture Park (*A*) pre-restoration, (*B*) post-restoration at the pocket beach, and (*C*) habitat bench. The pocket beach replaced riprap armoring, and the habitat bench is a shelf that projects from the base of the seawall. The habitat bench is not visible in (*B*) as it is inundated at high tide; (*C*) shows the habitat bench at low tide with kelp beds on the seaward side.

inclusion post-restoration of benthic invertebrates, algae, riparian vegetation, and physical beach structure (Toft and others, 2008). Pre-restoration monitoring showed that several species of juvenile salmon (mostly chum and Chinook) occupied the urban shoreline, with peak abundances occurring from April through July. Given the presence in the area of juvenile salmon, it was hoped that shoreline habitat improvements would benefit them.

Initial results from pre- and post-restoration fish monitoring indicated that the pocket beach and habitat bench had significantly higher densities of juvenile salmon in shallow water transects than the adjacent stretch of riprap (table 1; Toft and others, 2008). Also, 94 percent of fish captured in the pocket beach were juvenile salmon, showing that the target salmon habitat was utilized effectively. Epibenthic invertebrates and terrestrial insects showed improvements, generally with increased taxa richness, densities, and shifting assemblage structure compared to pre-restoration conditions and to adjacent stretches of armored shorelines (table 1). Overall, monitoring has indicated that although there is significant public use of the park and restoration activities were constrained by urban features, the beach structure is relatively stable and there has been a rapid development of aquatic and terrestrial biota.

Table 1. Summary of biological monitoring post-restoration compared to pre-restoration and to reference beaches at the Olympic Sculpture Park (Habitat Bench and Pocket Beach) and Seahurst Park.

[Data summarized from technical reports (Toft and others, 2008; Toft, 2009) with analysis by univariate ANOVA and multivariate ordination techniques. Symbols represent statistical differences: + increase, “nd” no difference, – decrease, blank = not measured]

Olympic Sculpture Park:

Results after 1 year restoration compared to pre-restored (Pre) and reference armored shorelines (Ref).
Assemblage structure represents taxonomic composition change away (+) from armored shorelines.

	Olympic Park – Habitat Bench					
	Insects		Epibenthic invertebrates		Juvenile salmon	
	Pre	Ref	Pre	Ref	Pre	Ref
Density	nd	+	+	+	nd	+
Taxa richness	nd	+	+	+		
Assemblage structure	+	+	+	+		

	Olympic Sculpture Park – Pocket Beach					
	Insects		Epibenthic invertebrates		Juvenile salmon	
	Pre	Ref	Pre	Ref	Pre	Ref
Density	nd	+	+	nd	nd	+
Taxa richness	+	+	+	+		
Assemblage structure	+	+	+	nd		

Seahurst Park:

Results after 3 years restoration compared to pre-restored (Pre) and reference natural beach (Ref).
Benthic invertebrates monitored at three tidal elevations: +12, +8, and +5’ MLLW.
Assemblage structure represents taxonomic composition change towards (+) or away (-) from reference natural beach.

	Benthic invertebrates + 12		Benthic invertebrates + 8		Benthic invertebrates + 5	
	Pre	Ref	Pre	Ref	Pre	Ref
Density	+	nd	+	–	–	–
Taxa richness	+	+	+	+	nd	+
Assemblage structure	+	nd	nd	–	–	–

Case Study 2: Seahurst Park

Seahurst Park is within the city of Burien, approximately 15 km south of downtown Seattle, Washington. Restoration completed in February 2005 replaced a 300-m section of seawall with a more gradual and natural slope, added gravel and cobble to the beach, and planted riparian vegetation in the uplands (fig. 2). Monitoring at the restored site and at an adjacent reference beach is ongoing, and data have been analyzed from pre-restoration (2004) and two post-restoration periods (2006 and 2008). Benthic macroinvertebrates have been the focus of biological monitoring (Toft, 2009) because they are closely linked to physical characteristics of beaches (Dethier and Schoch, 2005), and talitrid amphipods in the supralittoral are impacted by armoring and may be a good predictor of beach health (Dugan and others, 2008; Sobocinski and others, 2010). Sampling was conducted at tidal elevations that spanned the face of the former seawall (+12 ft MLLW), the base of the seawall (+8), and the lower beach regrade (+5).

Compared to the reference site, benthic invertebrate densities typically were lower at the restored site, whereas taxa richness was higher (table 1; Toft, 2009). Compared to pre-restoration armored conditions, densities and taxa richness improved at the restored site at the higher tidal elevations specific to where armoring was removed (+12- and +8 ft MLLW). Invertebrate assemblages were distinct from each other at lower tidal elevations where the beach regrade and sediment nourishment occurred, which could either be a response to the early restoration stage or to possible physical differences between the sites. The results from initial monitoring reported by Toft (2009) and other studies at Seahurst Park are conceptualized in figure 3. Negative biotic responses as a result of armoring and positive responses as a result of restoration are most apparent at higher tidal elevations of direct armoring location and removal, with fewer impacts of armoring and benefits of restoration occurring below armored locations, where restoration activities included beach regrade and sediment nourishment.

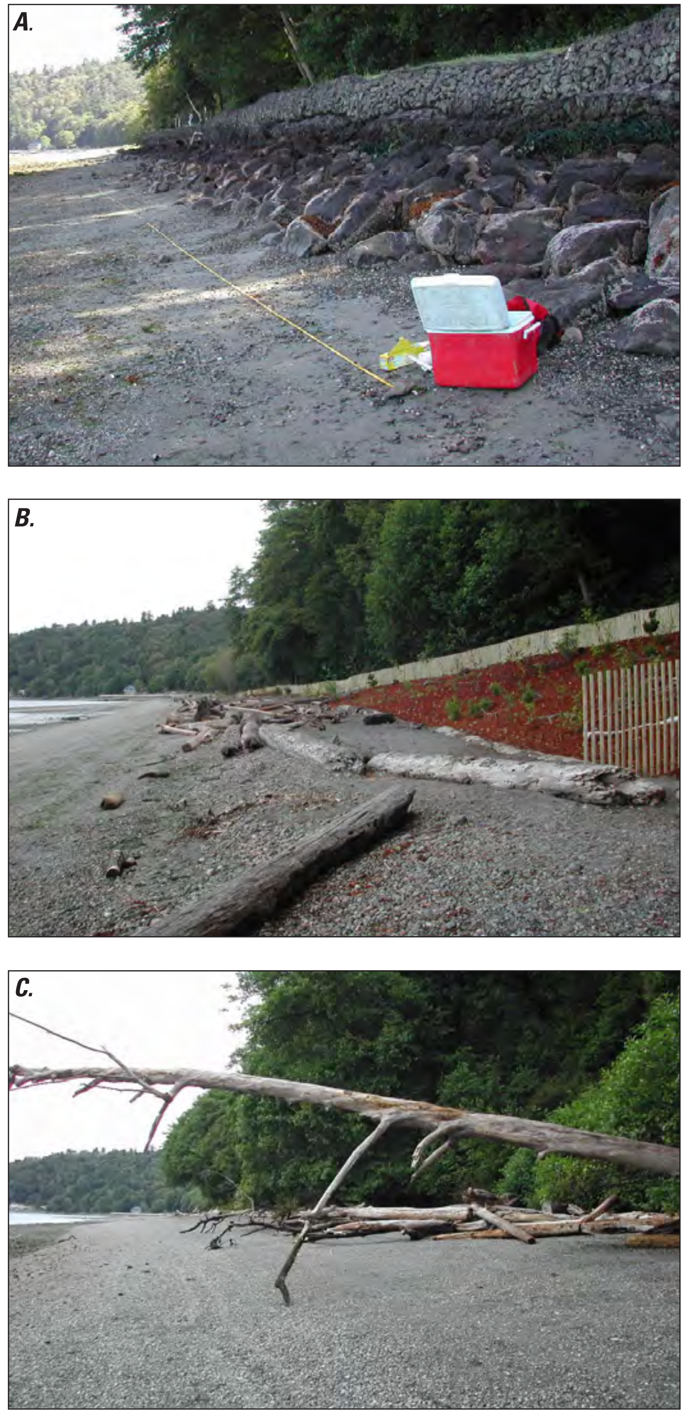

Figure 2. Photographs of Seahurst Park (*A*) pre-restoration, (*B*) post-restoration, and (*C*) reference beach. Location of the transect in (*A*) is at a tidal elevation of approximately +8 feet MLLW.

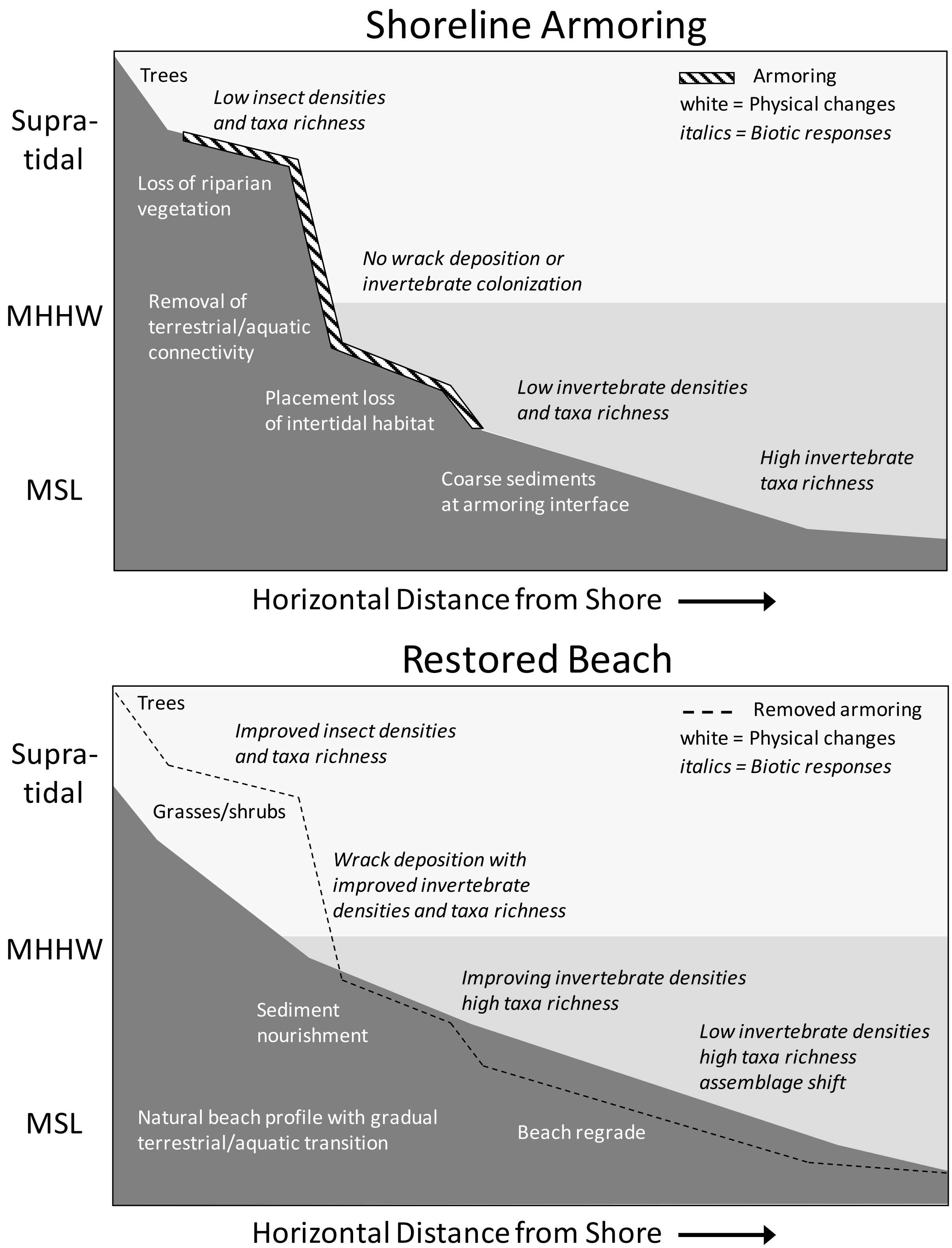

Figure 3. Conceptual diagram of Seahurst Park (Burien, Washington) monitoring summarized from data collected during armored and restored conditions. Mean Higher High Water (MHHW) represents the approximate high-tide line, and Mean Sea Level (MSL) the approximate mid-tide elevation on the beach profiles. Main invertebrate datasets summarized from Toft, 2009, with 'armored' insects and sediments from Sobocinski and others, 2010, 'restored' insects from Armbrust and others, 2009, and physical profile outlines based on Johannessen and Waggoner, 2009.

Conclusions and Future Opportunities

The Olympic Sculpture Park and the Seahurst Park have shown ecological improvements attributable to the restoration actions, but questions about longer-term restoration effects will remain unanswered until the sites become more stable in ecological and physical structure (Simenstad and Thom, 1996). At the Olympic Sculpture Park, the first year of post-restoration monitoring showed general improvements compared to adjacent armored shorelines. In this instance of beach enhancement in a constrained urban setting with no reference natural beaches, we have documented short-term benefits. At Seahurst Park, the first 3 years of post-restoration monitoring have shown mixed results compared to an adjacent reference natural beach. Measures of the invertebrate community improved at higher tidal elevations where the armoring directly impacted the beach, but have been somewhat degraded at lower tidal elevations where the beach was regraded and nourished with sediments. Attention should be given in similar restoration designs to maximize improvements at armored locations, and minimize them at non-armored locations that may be affected by construction or beach nourishment activities. These problems might be alleviated if long-term monitoring shows that beaches stabilize through time, although this will probably depend in part on site and local processes (Dethier and Schoch, 2005).

By examining these two case studies and the relation between nearshore biota and shoreline armoring, it becomes clear that restoring shorelines in Puget Sound can help establish and maintain connections between terrestrial riparian and aquatic intertidal zones, even in extensively modified urban settings. Understanding the impacts of shoreline armoring and the potential for restoration can improve our ability to manage the interactions between human development and nearshore ecosystems. Within this context and given our early findings at the two case study sites discussed in this paper, we detail our understanding of the role of science in urban restoration and implications for management based on the following questions:

How can science be most useful to managers? Linking scientific knowledge about endangered juvenile salmonid use of nearshore ecosystems to policy decisions on habitat use and restoration goals is imperative for successful habitat restoration. In restoration planning, science can be useful (1) prior to restoration in helping to define project goals, (2) during project design by incorporating data to optimize the likelihood of desirable ecological responses, and (3) after completion of restoration to document performance, to identify problems, and to provide critical information for adaptive management.

What can monitoring restoration actions/projects tell us? Pre- and post-restoration monitoring gives valuable information on the status of site development. Without this information, it is not only impossible to assess the performance and ultimate outcomes of restoration or rehabilitation, but also impossible to determine what changes to incorporate to ensure improved performance and likelihood of beneficial outcomes in the future. Even in urban environments where natural "reference" shorelines are rare, monitoring can be effective if it compares conditions at restored sites before and after restoration and to adjacent habitats. This places the restored site in context to its surroundings and measures if it has accomplished management goals of improvement. With the large amounts of money often spent to restore habitats, it seems errant not to adequately fund monitoring to measure restoration performance and achievement of goals.

How can data on completed projects benefit restoration designs throughout Puget Sound? Verifiable data is an essential component for developing future restoration designs, guiding shoreline armoring removal, and restoring beach processes. This is especially applicable to supplying creative solutions in cases where original habitat cannot be restored, but rehabilitation or enhancement from altered conditions is desired (Simenstad and others, 2005). Predicting the amount of active management required to maintain created habitats such as the beaches described here is difficult, because they are developing within urban landscapes that lack some natural flexibility and resilience to storms and other physical processes (Nordstorm, 2000), and have sediment supplies reduced by shoreline development (Komar, 1998). However, research on the two case studies described here has shown that the sites are initially stable, with minimal sediment transport and no immediate needs for re-nourishment (Toft and others, 2008; Johannessen and Waggoner, 2009).

How can experimental designs be optimized to assess restoration and urbanization? Without data, unknowns remain unknown. With data, knowledge is gained, but the extent gained depends on the data quality. The power and strength of data are optimized when focused experimental designs produce precise data that can overcome weaknesses due to natural variation. We recommend paying particular attention to statistical power, development of testable hypotheses, inclusion of multiple reference/comparison sites, and long-term monitoring. In urban restoration settings this kind of data, coupled with clearly developed questions and potential outcomes, will be of the most use to scientists and managers (Michener, 1997).

What questions and practices are most important for the future? Basic questions still remain on the mechanisms and degree to which shoreline armoring affects ecological and physical beach processes. Questions examining spatial and temporal variability will require focused research to assess the functioning and resilience of these systems under alternative restoration and rehabilitation actions. Connectivity across the terrestrial-aquatic interface must be highlighted as a vital component of the shoreline ecosystem, and should not be separated into different parts but rather combined as one ecological unit. Integrating physical and biological datasets from the experimental design phase onward should be emphasized in order to provide a more complete understanding of system function.

One overarching question should be considered when issues of shoreline armoring and restoration arise: In another decade's time, what information are you going to wish you had collected? If that question is not continually addressed, progress will be limited. This is important to consider, as current rates of new shoreline armoring substantially exceed removal rates in Puget Sound (Randy Carman, Washington Department of Fish and Wildlife, presentation at workshop of these proceedings, May 12, 2009); therefore, we are not even dealing with the status quo because restoration is not keeping up with development. This will increasingly be an issue because of the "coastal squeeze" of sea-level rise with shoreline development, placing more pressures on the aquatic-terrestrial ecotone on sheltered coasts (National Research Council, 2007; Defeo and others, 2009). Discussion of these issues in the scientific literature focuses on sandy beaches instead of the more atypical mixed sediment beaches of Puget Sound (Nordstrom, 2000; Defeo and others, 2009), and warrants more research. The workshop that generated these proceedings was a key step in furthering our understanding of shoreline armoring and its effects on nearshore ecosystems, and continued dialogue will be necessary in attempts to improve the health of Puget Sound shorelines.

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