Puget Sound National Estuary Program

SHORELINE ARMORING VITAL SIGN STATE OF KNOWLEDGE

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EXECUTIVE SUMMARY

This report provides the technical support for the development of an Implementation Strategy for the Shoreline Armoring Vital Sign Indicator. It synthesizes the existing state of knowledge related to shoreline armor, its impacts, and restoration opportunities.

Progress on the Shoreline Armoring Vital Sign has been supported in large part by the work funded by the Marine and Nearshore Grant Program during 2010-2016. Since the 1990s, work led by the Puget Sound Nearshore Ecosystem Restoration Project and others has focused attention on the negative impacts of hard armor on the structure, processes and function of the Puget Sound shoreline. Workshops, summary reports, and synthesis papers by PSNERP and other groups laid the foundation for substantial effort in more recent years to identify opportunities and overcome barriers to recovery, including the development of social strategies and analysis of regulatory frameworks. This is reflected in this Implementation Strategy and another appendix, the Base Program Analysis. Because, unlike other Puget Sound Vital Signs, armor is itself a pressure, and because of the regional consensus that shoreline armor has deleterious impacts on nearshore habitats and species, the focus has naturally shifted to strategies for armor removal.

This report echoes findings elsewhere that the Vital Sign indicator is insufficient to track trends in shoreline armor, owing to: a lack of enforcement; omission of other potential deleterious shoreline alterations; and lack of information about shoreline type or soft shore alternatives implemented at project sites. Advances are underway to address what has been a major limitation, the existing baseline of **shoreline armor extent**, and the ability to answer basic questions, such as: (1) How much armoring is there and how is it distributed? (2) What type of shoreline is armored? and (3) What type of armoring (hard or soft) is placed at what tidal heights? The most recently-compiled and most comprehensive (though there are also local efforts) spatial dataset of armor extent has been produced by Coastal Geologic Services (CGS 2017a), and mapping protocols have been developed (Rishel 2016), piloted, and recommended for application to the high-priority shore areas identified in the CGS data. These data sets are now guiding prioritization of restoration activities.

Gaps that remain in the development of additional indicators for the Vital Sign include, for **tracking armoring on feeder bluffs:** (1) identifying additional historical images for remaining lengths of shore; and (2) developing a finer-grain classification system and applying it to identified feeder bluffs; and for tracking **soft shore alternatives:** (1) the lack of an obvious opportunity to identify soft shore projects when they are implemented, and (2) the need for a common protocol for describing soft shore projects.

External forces likely to affect trends in armor include climate change, and the increased risk of erosion owing to sea level rise and flooding. Erosion risk varies at the parcel scale, owing to underlying geology, local patterns in extreme events, and local variability in predicted relative sea level rise. This scale of variability suggests the needs for local-scale technical assistance to assess individual property risk and protection needs (see the Strategy "Increase and improve coastal process-based design and technical training"). There are also likely economic drivers of armoring, associated with property values, standing timber, etc., but at present there is a lack of analyses to allow for a full accounting of the influence of economics on armor pressure.

Research over the last 5-10 years has yielded substantial advances in understanding about the impacts of armor on nearshore structure, processes, and function. Primarily, armor interrupts the terrestrial-aquatic linkages that are a major component of any shore. The loss of terrestrial connection impacts the sediment quality and composition on beaches, eliminates the accumulation of beach logs and wrack, changes the depth profile of the intertidal zone and the influence of waves and tides on the shore. On the beach, there is less shade, fewer invertebrates, and fewer birds that consume invertebrate prey. In the water, the fish communities are different. There remain major gaps in our understanding about the impacts of armor on underwater communities and habitats, including in the deeper water zones, though preliminary work suggests relationships between armor and loss of deeper water vegetation.

There is a current emphasis on tracking the impacts of armor removal and beach restoration projects, including so-called "soft shore" approaches to shoreline restoration. Over two dozen projects are currently underway or have been monitored over the last several years, but the data have not yet been systematically evaluated and therefore the evidence of effectiveness remains anecdotal. Furthermore, understanding impacts of armor removal on ecosystems will take years to understand, and therefore ongoing monitoring of such projects is a priority. Similarly, there currently exists no link between the indicator target, or any other threshold of armor extent, and ecosystem function. There is a lack of understanding about how much armor needs to be removed in order to support the Puget Sound ecosystem.

As is true for most of the Vital Signs and Puget Sound recovery in general, there is a severe shortage of research and information that can be used to evaluate the impacts of armor and armor removal on human wellbeing and quality of life in Puget Sound. The links between armor and both subjective and objective indicators of human wellbeing – sense of place, economic vitality, recreation – are undoubtedly many and strong, and therefore analyses of the impacts of armor and effectiveness of armor removal should include research on social-ecological linkages in this context. This constitutes a major research gap that should be addressed.

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TABLES AND FIGURES

1. INTRODUCTION

This State of Knowledge report is prepared as an Appendix to the Shoreline Armoring Implementation Strategy (IS). It is intended to provide the scientific and technical foundation for the Implementation Strategy, within the scope of the Shoreline Armoring IS as determined during the IS planning and development process. It began as part of a Starter Package presented to the Interdisciplinary Team (IDT) at the start of the IS development process, and was intended to provide the scientific and technical context and scope for the IS. It underwent subsequent revision and expansion (a) subsequent to review by the PSEMP Nearshore Working Group and the IDT; and (b) in response to discussions that arose within the IS development process.

This State of Knowledge report, therefore, is not intended to be an exhaustive scientific review of shoreline structure, process and function. Several such reviews have been previously conducted by a broad collection of topical experts, and associated high-quality consensus reports have been produced in this region over the past decade. Some updates to those reports are contained herein. Indeed, entire workshops on the negative impacts of shoreline armoring have been conducted in the region over the past decade (e.g., Krueger et al. 2010, Shipman et al. 2010, Williams and Thom, 2001). Those findings, and findings from more recent research, are summarized herein (Tables 3-5). However, the primary intention of this report is to provide the technical support for and scientific foundation for the development of the Implementation Strategy for the Shoreline Armoring Vital Sign. Specific guidance for the bounds on this State of Knowledge review is below, and was developed as part of the Implementation Strategy Guidance in consultation with the Implementation Strategy Working Group. In addition to the guidance below, this State of Knowledge report has been adapted to meet the specific needs of the Implementation Strategy IDT along the way, incorporating additional information to inform potential strategies, and identifying possible barriers to recovery.

Components of a State of the Knowledge Report

- Assessment of ongoing research related to the Vital Sign
- Compilation of science gaps and key technical uncertainties
- Compilation of monitoring needs
- Synthesis of prior NEP-funded projects
- Synthesis of effectiveness evaluations at both the local project and regional scales
- Current state of decision-support tools, such as models, to measure the effectiveness of restoration actions
- Traditional knowledge related to the Vital Sign
- Evaluation of priority pathways in terms of cost and effectiveness

This State of Knowledge report reviews the relevant and recent information about how the Vital Sign is tracked, additional monitoring conducted to evaluate the condition of Puget Sound shorelines, drivers of armor that might influence future trends, ecosystem impacts of armor, efforts to reduce armor and their effectiveness, and the overall uncertainties and knowledge gaps associated with all of the above. Last, it summarizes existing tools and models available for supporting decisions that lead to recovery, and highlights major research needs that limit the potential for recovery.

2. VITAL SIGN STATUS AND TRENDS

HISTORIC BASELINE The most current information indicates that shoreline armoring occurs on approximately 29% of Puget Sound's 2500-mile shoreline (CGS 2017a). Armoring is not evenly distributed across Puget Sound basins, which range from approximately 10 – 63% armored (Schlenger et al. 2011). Armoring extent also differs substantially among system types (Table 1).

Table 1. Miles of Puget Sound armor by shoretype.

Shoretype	Total Miles
FB Exceptional	51
Feeder Bluff	585
FB, Talus	20
Transport Zone	393
Accretion Shoreform	337
NAD (all)	1,008
Pocket Beach	62
PB Artifiial	2

Data from CGS 2017a.

The rate at which new armor has been added in the most recent 10-15 years is strikingly lower than rates observed in the second half of the last century. The current net rate of new armor added in Puget Sound as a whole is approximately 0.325 miles per year (for 2011-2015) (PSP Vital Sign Data). In contrast, between 1972-1999 in Thurston County alone, an estimated 9.8 miles of armor was added, or 0.36 miles a year (Morrison et al. 1993), and Mason County added 0.78 miles of armor per year between 1985-1994. Thus the armor rates of the last 30 years of the 20th Century are higher by orders of magnitude than current estimated rate, which continues to decline. While armoring remains a concern, it is important to note that substantial progress has been made in identifying and addressing the problem.

2.1 VITAL SIGN DATA

There are major shortcomings identified with the current data used to track progress on this Vital Sign, the Hydraulic Project Approval (HPA) data, primarily because the HPA was designed to track permitted construction, including:

- The HPA data describe what is permitted rather than what was built;
- The HPA data are not a holistic metric that addresses vital shoreline functions and processes;
- The HPA data do not capture important variability in the shoreline type being modified, which matters for overall assessment of ecosystem function; and
- The HPA data exclude a suite of deleterious shoreline activities, such as armor repairs and permit noncompliance.

The first shortcoming is being partially addressed through work conducted by Coastal Geologic Services (CGS) to complete feeder bluff mapping in Puget Sound, and assess the level of armoring on feeder bluffs (see more below). The remaining gaps are being addressed through WDFW improvements to the HPA data collected (as mentioned in the main body, Section 2.4.2), and through the regulatory improvement strategy identified in the main body of this document.

2.2 OTHER EFFORTS TO TRACK THE VITAL SIGN

One major barrier to improving this Vital Sign has been the lack of data for the second and third Vital Sign indicators: feeder bluffs and soft shore restoration projects. Major efforts are underway to refine and enhance spatial shoreline datasets that include these additional classifications of shoreline modification.

2.2.1 FEEDER BLUFFS

Funded by the Estuary and Salmon Restoration Program (ESRP), Coastal Geologic Services (CGS) conducted surveys and analyses of Puget Sound feeder bluffs, including shoreline material type, armor elevation attributes, and condition. The work also identified sites where shoreline armoring is coincident with feeder bluffs (e.g., feeder bluff behind armor), which are potential areas of reduced sediment processes.

This new analysis indicates that 223 miles (34%) of Puget Sound's 657 miles of feeder bluffs are armored (Figure 1; Coastal Geologic Services 2017b). A higher proportion of feeder bluffs are armored in King, Pierce, and Snohomish Counties versus the other Puget Sound counties.

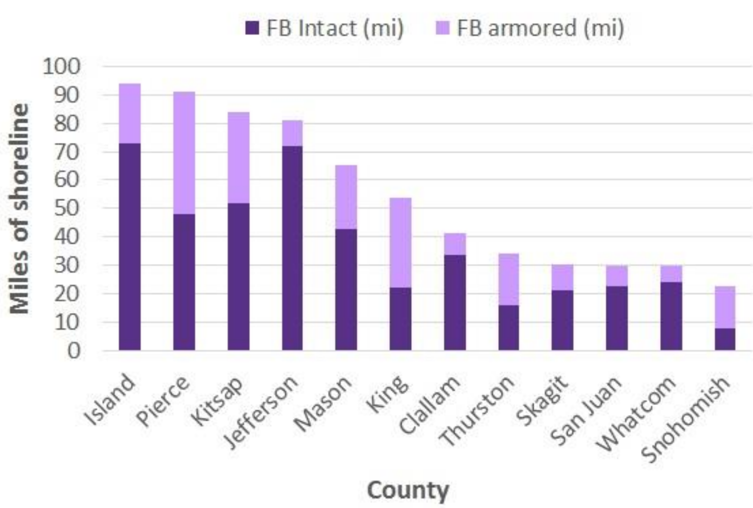

Figure 1. Status of feeder bluffs in Puget Sound

(modified from Coastal Geologic Services 2017b, Fig. 5) FB = feeder bluff

The uncertainty of these results was low: 0-15% of shoreline length classification was uncertain across most counties, with higher uncertainty in some areas (e.g., 33% in San Juan County) and some sites.

The key gaps that remain with respect to tracking the Vital Sign using the feeder bluff indicator are:

- additional historical imagery to match against current data to enable tracking change through time, which will require additional resources to acquire; and
- the coarse classification of feeder bluff types, which does not fully capture the potential contribution of feeder bluffs to ecosystem processes and functions.

A key component of feeder bluffs as a useful indicator beyond identifying their location and status is their erosion rates, to know their individual contribution to the overall sediment budget of the Puget Sound, as well as to local habitats. Work underway by CGS will quantify long-term feeder bluff erosion rates across Puget Sound. This work will complement ongoing efforts by the Department of Ecology to measure bluff erosion sediment volumes using boat-based Lidar (e.g. Kaminsky et al. 2014).

Additional ongoing work to collect information about the distribution of feeder bluffs and their role in supporting shoreline function in Puget Sound include:

- ESRP Learning Program funded the Department of Ecology to conduct a systematic collection using boat-based Lidar of high-resolution baseline data on beach and bluff topography, sediment texture, beach wrack, overhanging vegetation, and large woody debris along up to 320 miles of beaches, with 40 miles surveyed 3 additional times to document seasonal and episodic beach change. Grantee: (WRIA 9, Department of Ecology, Brian Lynn; end date: 4/2018

2.2.2 SOFT SHORE APPROACHES

The most recent and comprehensive summary of soft shore definitions, techniques, opportunities, barriers, and trends is found in Shipman (2017). Soft shore alternatives to armoring occur along a spectrum between hard armor and natural shorelines, and include the use of beach nourishment, large wood, vegetation and other approaches to create a shoreline that is more natural while offering a level of protection that is site-appropriate.

Soft shore approaches are currently considered a preferred alternative to hard armor where protection of property against erosion is required. However, very little is currently known about the impacts of soft shore approaches on nearshore structure, process, and function (see Section 7.1 for further information). Barriers to the implementation of soft shore projects include regulatory obstacles, the complexity of soft shore projects, property owner and/or contractor confidence, and the availability of technical guidance (Shipman 2017). Several mechanisms currently exist and are needed to encourage the use of soft shore alternatives, including regulatory programs, restoration programs, the offering of technical guidance, and incentive/outreach/education programs (Shipman 2017).

At present, there is no systematic collection of information about the extent of soft shore project implementation in Puget Sound, and current information is primarily anecdotal. One challenge in identifying soft shore projects is that they are by definition designed to mimic the appearance of natural shorelines, and are therefore difficult to detect using visual surveys. A close evaluation of the potential for the use of the HPA data to track soft shore features or techniques revealed that (a) using HPA data to track soft shore techniques carries the same challenges as using HPA data to track armor projects; and (b) soft shore features are inconsistently and poorly characterized in the permit data (Shipman 2017). Last, there is inconsistency in the definition of 'soft shore' among institutions and jurisdictions, as soft shore approaches encompasses a suite of techniques, making consistency in identification and definition difficult.

In summary, while soft shore approaches are broadly recommended when bank protection is necessary, they are not always feasible on an individual site, there is no clear method for tracking their installation, and there is a current dearth of information about their performance. A major gap in our understanding about soft shore techniques is their performance with respect to ecosystem function following the change in shoreline form. This remains a major data gap.

Shipman makes several recommendations:

1. Rather than characterizing projects as "soft" or "hard," consistent protocols should be developed for describing stabilization techniques, including soft shore methods, and attributes identified to reflect the scale or type of activity. These attributes could then be consistently reflected in HPA data.
2. Training in protocols will be necessary, and potentially the development of a separate tracking database.
3. Agencies and local jurisdictions should better coordinate the sharing of information about shoreline projects.

2.3 UNCERTAINTIES AND KNOWLEDGE GAPS

Several key uncertainties and knowledge gaps exist in our ability to track progress towards indicator targets and recovery. The uncertainties associated with the **HPA data** are described above, and include: lack of enforcement; omission of other potential deleterious shoreline alterations; and lack of information about shoreline type or soft shore alternatives implemented at project sites.

Another major limitation is in the existing baseline of **shoreline armoring extent**, owing to variable methods of documentation and regional inconsistencies (Shipman 2013). There are efforts underway to improve this dataset (see section 2.4 of the Implementation Strategy narrative, 'Improving indicators and targets'). Shipman (2013) highlights three important questions that could be answered with an improved, high-quality baseline inventory: (1) How much armoring is there and how is it distributed? (2) What type of shoreline is armored? and (3) What type of armoring (hard or soft) is placed at what tidal heights? The Partnership convened a workshop in May 2017 to address these questions, and a summary of those recommendations is below in Section 3.

Gaps that remain in **tracking armoring on feeder bluffs** include (a) identifying additional historical images for remaining lengths of shore; and (b) developing a finer-grain classification system and applying it to identified feeder bluffs.

Finally, the major challenge associated with tracking the degree to which **soft shore alternatives** are implemented is the lack of an obvious opportunity to identify soft shore projects when they are implemented, so they can be enumerated and tracked. Furthermore, soft shore projects occur along a gradient of design options, so a common protocol needs to be developed to consistently identify key features and components of soft shore projects.

3. MONITORING

Motivated by an assessment, echoed throughout this document, that the HPA permit database alone does not adequately or accurately document patterns of change in armor along Puget Sound shorelines, the Puget Sound Partnership hosted a workshop in May 2017 focused on improving the monitoring of shoreline armoring, in support of the Shoreline Armoring and Chinook Salmon Vital Signs. Participation in the workshop was broad, and the summary report from the workshop (in draft form at the time of writing this report, and therefore summarized here) provided several clear recommendations about monitoring shoreline armoring in the future.

In addition, evaluations of the existing indicators used to track the Shoreline Armoring Vital Sign are found in the above Section 2.

Last, the Shoreline Monitoring Toolbox provides protocols and methods to aid in a standardized approach to monitoring of shoreline habitat structure and function across Puget Sound.

3.1 RECOMMENDATIONS

Two "common indicators" that would inform the Chinook and Shoreline Armoring Vital Signs were recommended for development and tracking:

1. Extent of shoreline armor; and
2. Percent sediment source intact by drift cell

In addition, the workshop referred to Shipman (2017) for guidance on soft shore definition and mapping protocols.

EXTENT OF SHORELINE ARMOR

Current information: It was widely agreed that the best current source of data on extent of shoreline armor is the database compiled by Coastal Geologic Services (CGS), 90% of which is data collected via surveys between 2003-2017 (Coastal Geologic Services 2017). An assessment of the quality and age of Puget Sound coastal armor mapping data (MacLennan and Wagonner 2016) resulted in the development of protocols for mapping shoreline armor extent (Rishel 2016). Workshop participants identified these protocols as the preferred mapping protocol going forward, though substantial challenges remain. While the CGS data are consistent and rigorous, filling in the gaps across the entire Puget Sound remains a major challenge.

Next steps: The mapping protocol was piloted in 2016 with 347 miles of armor. These results were reviewed by the workshop participants, who recommended that the protocol be applied to the remaining 511 high-priority miles of shore identified in the CGS 2017 report.

PERCENT SEDIMENT SOURCE INTACT BY DRIFT CELL

Current information: The best current data on armor extent (CGS 2017) identifies armored and unarmored feeder bluffs, and the difference between extent armored feeder bluffs and extent unarmored feeder bluffs can be used as a proxy for percent sediment source intact by drift cell.

Next step: There remains no consensus on how to use the above metrics to track change in armor extent over time, and this was flagged as a future gap.

4. FACTORS CONTRIBUTING TO SHORELINE ARMORING

Historic causes of marine shoreline armoring include the construction of roads and railroads along the shoreline, and the reclamation of tideland for industrial development. Armoring also occurred in river deltas to protect agricultural dikes and levees. From the 1950s through the early 1970s, armoring on Puget Sound shorelines was associated with the intense development of residential communities with limited regulation. This legacy affects Puget Sound shorelines today. New armoring has continued to occur in Puget Sound with most of this new armoring associated with residential development or repairing and replacing older structures (Shipman 2010).

4.1 WHY DO LANDOWNERS ARMOR SHORELINE?

Some of the primary factors underlying decisions to install or retain shoreline armoring are the desire to protect land and property from real or perceived risks posed by erosion, desire for access to the waterfront/beach, aesthetic preferences, peer pressure, misperceptions about erosion risk, and lack of understanding of the negative impacts of armoring (Johannessen 2013b; Colehour + Cohen et al. 2014). Erosion is the top concern of waterfront property owners, region-wide (Johannessen 2013b; Colehour + Cohen et al. 2014). However, property owners may overestimate the erosion potential on their property or lack awareness about how hard armoring can degrade the quality and accessibility of their beach (Johannessen 2013a). In fact, many property owners see armor as a desirable, or even crucial, element in protecting shoreline properties (Colehour + Cohen et al. 2014; Keller 2012). Also, armoring occurs because regulations allow it, and there is lack of resources for enforcement of regulations designed to limit armoring.

4.2 EXTERNAL FACTORS LIKELY TO IMPACT THE VITAL SIGN STATUS AND TRENDS

External factors that may influence shoreline armoring include regional population growth, which directly impacts the demand for shoreline property; economic factors that influence the likelihood of landowners converting their undeveloped shoreline property; and increased erosion risk owing to climate change, and especially sea level rise and storm/wave increase.

4.2.1 CLIMATE

A changing climate brings rising sea levels and increased risk of coastal flooding and erosion to Puget Sound, variables likely to affect shoreline processes and exacerbate armor impacts or result in the need (or perception of need) for new armor protection. These impacts included inundation of land, coastal erosion, displaced coastal habitats, and increased impacts of extreme high tide events. Sea level rise will magnify the effects of storm surge and high wave heights on coasts. Sea level rise impacts will vary spatially in Puget Sound, in part owing to the mitigating (or compounding) effects of vertical land migration. Vertical land migration in an upward direction results in reduced relative sea level rise, while vertical land migration in a downward direction results in increased relative sea level rise. Vertical land migration varies spatially in Puget Sound, and therefore the impacts of sea level rise are spatially variable. Geographically local extremes (e.g., in flooding) will also impact local effects of sea level rise include local extremes.

Several recent reports address sea level rise potential in Puget Sound (Mauger et al. 2015, National Research Council 2012, Mote et al. 2008) The most recent (Mauger et al. 2015) includes sea level rise predictions of 15-54 inches in Puget Sound by 2100. Local sea level rise impact assessments and adaptation/resilience plans are underway throughout Puget Sound, and a major effort to provide support in the form of updated local sea level rise risk, and locally-defined needs and strategies, is being conducted by the Washington Coastal Hazards Resilience Network. A major part of that Washington Coastal Resilience Project is improving the forecast and communication of local risk from sea level rise. This local-scale approach is currently being piloted in three jurisdictions. A key component of the Washington Coastal Resilience Project is developing probabilistic estimates of sea level rise, which allows communities more flexibility in developing locally appropriate adaptation strategies. More on the specific models being used in predicting climate change risk is found in Section 8.

Detailed information about sea level rise, storm surge, and wave height are provided in Table 2.

Table 2. Climate-related stressors for marine shoreline armor

Climate variable	Example Impacts	Observed changes	Projected changes	Seasonal and natural sources of change	Confidence in prediction	Citations
Sea level rise	Inundated lands, displaced coastal habitats, coastal erosion, coastal bluffs may erode more quickly, increased impacts of extreme high tide events and storm surge, increased frequency of coastal river flooding, changes in sediment delivery	Global average sea level rose about 8 inches from 1900 to 2009. In Seattle, sea level rose by 8.6 inches from 1900 to 2008 (+0.8 in/decade). The northwest Olympic peninsula experienced tectonic uplift. As such, relative sea level dropped by 5.2 inches from 1934 to 2008 at Neah Bay.	Global sea level is projected to increase by 11-38 inches by 2100, depending on the amount of greenhouse gas emissions. In Puget Sound, sea level is projected to increase by 14-54 inches by 2100 but there will be some local variability that could be outside of this range.	Tectonic rebound and vertical land movement is occurring across much of Washington. In some locations, the uplifting land is able to mask some of the increases in sea level while in areas of subsidence local sea level rise will outpace global trends. Variable wind speed and directions can temporarily enhance or decrease local sea level. ENSO has also been shown to temporarily affect sea level height in the Puget Sound region. Changes in sediment delivery to coastal systems are relatively unknown.	Global estimates have a medium confidence namely due to the potential for the sudden collapse of the Antarctic ice sheet and changes in outflow from Greenland ice sheet. If these increased substantially, global sea level could rise above 2100 estimated sea levels.	Increased landward movement of beaches (shore recession) (Shipman 2010, MacLennan et al. 2013b, Mauger et al. 2015) Increased bluff erosion (MacLennan et al. 2013b, Kaminsky et al. 2014, Mauger et al. 2015) Increased inundation (MacLennan et al. 2013a, Mauger et al. 2015) Increased frequency of coastal flooding (Mauger et al. 2015) "Coastal squeeze" (Whitman and Hawkins 2013)
Storm surge	Inundated lands, displaced coastal habitats, coastal erosion, coastal bluffs may erode more quickly	There is no evidence of a change in storm surge in Puget Sound. One study has shown that change in extreme tidal height (due to sea level rise) overwhelms any signal from an increase in surge.	The frequency and intensity of storms able to produce damaging storm surge are not projected to change. However, sea level rise is predicted to amplify the impacts of storm surge and increase the frequency of extreme coastal flood events.	Unknown	Medium. There are no published studies that have evaluated increase in storm surge in Puget Sound, but one study found that observed trends are a function of sea level rise, not storm intensity.	Mauger et al. 2015, Woodworth & Blackman 2004

Climate variable	Example Impacts	Observed changes	Projected changes	Seasonal and natural sources of change	Confidence in prediction	Citations
Wave height	Inundated lands, displaced coastal habitats, coastal erosion, coastal bluffs may erode more quickly	There is no evidence that wave height has changed in Puget Sound.	Wave height is not expected to change in Puget Sound, where waves are largely driven by winds. Some areas such as the Strait of Juan de Fuca are more exposed to coastal wave forces and may be more vulnerable.	Unknown	Unknown	Mauger et al. 2015, MacLennan et al. 2013a, Kaminsky et al. 2014

4.2.2 OTHER

REGIONAL POPULATION GROWTH

It is unclear how population growth will affect trends in shoreline armoring. Scenario modeling predicts that under "Status Quo" shoreline management scenarios, and given the attention to armor and its ecosystem impacts in the region as well as Shoreline Master Program updates presently or shortly coming online (Puget Sound Partnership Vital Signs website), trends in armoring may not increase beyond current rates (Byrd et al. 2011). This is despite the number of households in the Puget Sound region being expected to grow 40% by 2040 (Puget Sound Regional Council). Currently, 52% of residential shoreline parcels in Puget Sound are unarmored (Colehour & Cohen 2014). On these unarmored parcels, 27% of landowners are not concerned about erosion while only 2% plan to install armor in the 5 years following the survey (Colehour & Cohen 2014).

ECONOMIC FACTORS

Economic factors that influence the amount of armor in Puget Sound are variable, and likely associated with shoreline use, shoreline type, and property ownership. Puget Sound shorelines provide economic benefits to the region, and there are economic tradeoffs to armoring shorelines. As one example, the armored ports of Seattle and Tacoma combined are the fourth largest U.S. port by export value, bringing in $138.1 billion in total (direct and supportive) economic value, and supporting 48,000 jobs (Northwest Seaport Alliance 2017). At the same time, shellfish in Puget Sound, dependent upon healthy shorelines, have an economic value of nearly $100 million annually (Puget Sound Institute 2015). In addition, changing preferences that include a preference for natural landscapes may increase the value of unarmored parcels. At the scale of individual waterfront properties, the economic values of development versus leaving shorelines natural, or of sales of standing timber, are potential drivers of armor but have not to date been calculated.

5. ECOSYSTEM IMPACTS OF ARMOR

The impacts of shoreline armor on the ecosystem are substantial, and have been the focus of synthesis reports (Shipman et al. 2010, Williams and Thom 2001, and others) and research efforts regionally and in coastal ecosystems elsewhere, particularly as climate change impacts on shorelines increase. Armor directly and indirectly degrades nearshore physical and biological processes. The impacts can result in both structural changes in the ecosystem and functional responses from biological communities (Figure 2). Shoreline armor impacts on the ecosystem are increasingly severe the lower (more waterward) the armor is relative to the shoreline.

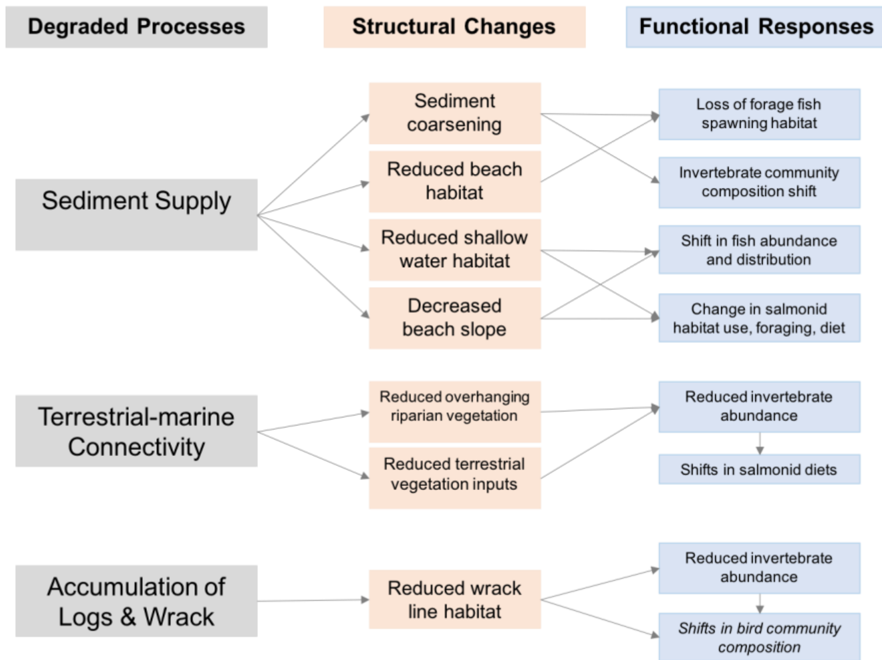

Figure 2. Conceptual model of ecological impacts of armor on beaches. Italics indicate low confidence or limited data.

Adapted from Simenstad et al. 2006.

5.1 BIOPHYSICAL IMPACTS

5.1.1 DEGRADED PROCESSES

Shoreline armor can reduce the amount of sediment able to enter adjacent waters. Key processes found to be degraded on armored beaches include: sediment supply to beaches from feeder bluffs, terrestrial-marine connectivity, accumulation of beach logs and wrack. It can be difficult to measure direct impacts of armor on sediment dynamics and associated structural changes because sediment supply and dynamics operate across a range of temporal and spatial scales and armor impacts differ across these scales.

Some research has shown that armor can reduce sediment supply to beaches, especially the delivery and alongshore transport of fine sediments within armored drift cells. Armor can also disconnect marine and terrestrial systems and reduce the accumulation of wrack on logs on beaches.

A detailed accounting of measured impacts on nearshore and beach processes is in Table 3.

5.1.2 STRUCTURAL CHANGES

The degradation of beach processes above has been shown to have several associated impacts on beach structural changes, including

- decrease in beach slope
- reduction in the amount of available beach and shallow water habitat
- increase in the grain size (i.e., coarsening) of beach sediments
- loss of terrestrial subsidies
- loss of shade, increase in sediment temperature

The documented impacts on beach structure of shoreline armor are detailed in Table 4.

5.1.3 FUNCTIONAL RESPONSES

Interrupted processes and changes to habitat structure associated with armoring may have consequences for the biota that live or rely upon nearshore ecosystems, including: loss of forage fish spawning habitat; density and community composition of invertebrates; abundance and distribution of fish (including salmonids); salmonid diet composition; bird density and composition (less certainty); herring egg mortality (less certainty).

Table 5 summarizes the documented impacts on nearshore habitat function associated with shoreline armor.

5.1.4 UNCERTAINTIES AND KNOWLEDGE GAPS

While a considerable amount of effort has been directed towards understanding and quantifying the impacts of armor on ecosystem process, structure, and function, some major uncertainties remain.

1. Impacts of armor on salmonid foraging and diets are complicated by variability in prey availability across habitat type, species- and life-stage-specific preferences.
2. At present, there is little understanding about the impacts of armor and/or armor removal on subtidal habitat characteristics and biological endpoints, such as eelgrass or use of subtidal habitats by fish and invertebrates (but see Munsch et al. 2015b and citations in Munsch et al. 2017).
3. Feeder bluff erosion rates and sediment budgets remain uncertain as, in turn, do the resulting patterns of shoreline change, impacts of armor over longer periods of time, and shoreform-type specific responses.
4. The relative importance and dynamics of alongshore sediment transport waterward or adjacent to armored sites is poorly understood.

Table 3. Degraded processes due to shoreline armoring

Process	Impact	Uncertainties	Confidence Level
Sediment supply and sediment dynamics	Armoring parallel to shore blocks sediment supply from feeder bluffs to beaches (Shipman et al. 2010, Johannessen et al. 2005, Johannessen and Chase 2005, Simenstad et al. 2011). At the scale of individual sites, and over relatively short timeframes, no significant differences were observed in sediment composition between paired armored and unarmored sites (Dethier et al. 2016a, Herrera 2005). At larger scales (i.e., drift cell), armoring can increase sediment transport from beaches and result in coarser sediments (Johannessen & MacLennan 2007, Fresh et al. 2011).	Impacts of wave action and altered hydrodynamics The relative importance and dynamics of alongshore transport of sediments along or adjacent to armored sites (Ruggiero 2009, (Schlenger et al. 2011) Erosion rates, sediment budgets, and patterns of shoreline change across different shoreforms Sensitivity of beaches to changes in sediment supply and water level changes over longer time periods	<u>High</u> Armor blocks sediment delivery <u>Medium</u> Impacts on sediment size distribution, and impacts on fines in particular, at local scales
Terrestrial-marine connectivity	Armoring reduces connectivity between terrestrial systems and marine habitats and food webs (Heerhartz et al. 2014, Dethier et al. 2016a, Toft et al. 2014), and reduces inputs of terrestrial vegetation to beaches (Dethier et al. 2016a, Heerhartz et al. 2014, Sobocinski et al. 2010, Toft et al. 2014). Armoring reduces the amount of overhanging trees adjacent to beaches (Dethier et al. 2016a, Heerhartz et al. 2014, Higgins et al. 2005), and armored beaches are less shaded (Herrera 2005).		HIGH
Accumulation of logs and wrack	Armoring reduces the abundance of large woody debris on beaches (Dethier et al. 2016a, Heerhartz et al. 2014, Holsman and Willig 2007, Higgins et al. 2005, Tonnes		HIGH

Process	Impact	Uncertainties	Confidence Level
	2008). Armoring reduces the amount of beach wrack (Dethier et al. 2016a, Heerhartz et al. 2014, Sobocinski et al. 2010, Toft et al. 2014). Lower accumulation and total area of beach logs is associated with lower rates of sediment delivery (Hood et al. 2016)		

Table 4. Structural changes due to shoreline armor

Structural Change	Impact	Uncertainties	Confidence
Beach slope	• Armor decreases lower-beach slope (Dethier et al. 2016a; but see Herrera 2005 showing no significant effect on slope) • Armor reduces the elevation of the toe of the bluff or armoring (Heerhartz et al. 2014, Herrera 2005).	• Impacts on beach slope depend upon the depth of the armor. • Armoring can amplify the effects of wave action on passive erosion, resulting in scour, though there are limited local examples and this process may occur over longer timeframes (Shipman et al. 2010).	MEDIUM
Beach habitat area	• Armor can result in reduced beach width over short (Dethier et al. 2016a, Herrera 2005) and longer time frames as beach migration is prevented (Whitman and Hawkins 2013). • Armor can reduce upper beach and backshore habitats (Shipman et al. 2010, Herrera 2005). • Armor reduces beach width (Hood et al. 2016)		HIGH
Beach substrate	• Armor can reduce the amount of upper-shore fine-grain sediments and result in coarser sediments at larger scales (i.e., drift cell) (Dethier et al. 2016a). • Drift cells with impaired sediment delivery processes (but not by armor) have coarser sediments (Parks et al. 2013) • Beach substrate temperatures are elevated at armored sites (Morley et al. 2012, Rice 2006, Tonnes 2008) • Inconsistent effects of armor on sediment distribution and composition (McBride et al. 2016)	• Local-scale effects of armor on sediment grain size have not often been measured, likely owing to the longer time scale of the response (Dethier et al. 2016a, Herrera 2005). • Sediment signals are likely masked by geology, topography, and wave energy	• HIGH Temperature • MEDIUM Grain size & distribution

Structural Change	Impact	Uncertainties	Confidence
Shallow water habitat	Armor that extends into subtidal areas truncates intertidal shallow water habitat (Toft et al. 2007).	Impacts on habitats deeper than intertidal have not been measured, though effort has not been high. Given links between intertidal and subtidal habitats, it is reasonable to assume armor may impact subtidal zones, though those effects may occur over long time scales.	MEDIUM
Terrestrial subsidies	Armor reduces inputs of terrestrial vegetation to beaches (Dethier et al. 2016a, Heerhartz et al. 2014, Sobocinski et al. 2010, Toft et al. 2014). Armor reduces overhanging trees adjacent to beaches (Dethier et al. 2016a, Heerhartz et al. 2014, Higgins et al. 2005)		HIGH
Temperature regime	Armor reduces shade on the beach (Herrera 2005), resulting in elevated substrate temperatures (Rice 2006).		MEDIUM

Table 5. Functional changes due to shoreline armor

Functional Response	Impact	Uncertainties	Confidence
Forage fish spawning	Armor causes the direct loss of forage fish spawning habitat when it is buried under the armor itself (Carrasquereo-Verde et al. 2005, Whitman and Hawkins 2013). Under SLR scenarios, loss of forage fish spawning habitat can come from "coastal squeeze," where beach migration is prevented by armor (Whitman and Hawkins 2013, Krueger et al. 2010). Armor can degrade or eliminate forage fish habitat quality by altering the substrate grain size important for forage fish spawning (Carrasquereo-Verde et al. 2005, Parks et al. 2013). A negative but nonsignificant effect of armor on the proportion of live versus dead surf smelt embryos was observed in North Puget Sound beach samples (Selch 2015)	Beach migration and coastal squeeze dynamics occur over long time scales and are therefore difficult to measure. Changes in sediment grain size owing to armor are difficult to measure because sediment dynamics are transient and occur over long time periods. It is difficult to measure loss of forage fish spawning from armor in part because forage fish spawning monitoring has been unsystematic, and because of the lack of pre-armor monitoring data.	<u>HIGH</u> Direct burial of forage fish spawning habitat by armor <u>MEDIUM</u> Loss of forage fish spawning owing to changes in sediment grain size from armor
Invertebrate density	Armor impacts abundance, diversity and community composition of many benthic and terrestrial invertebrates on beaches (Morley et al. 2012, Sobocinski et al. 2010, Dethier et al. 2016a, Heerhartz et al. 2014). The effects vary by tidal elevation, where armor directly reduces invertebrate abundance and diversity at high elevations, indirectly reduces invertebrate abundance and diversity at lower tidal elevations, and eliminates beach wrack invertebrates (Heerhartz et al. 2015, Toft		HIGH

Functional Response	Impact	Uncertainties	Confidence
	et al. 2014). Shellfish (e.g. clams) that require fine-grained sediments can be impacted when substrates change (Dethier et al. 2006). Different invertebrate communities are found in association with different nearshore substrate types (Munsch et al. 2015a).		
Fish abundance and distribution	Armor extending into subtidal areas, creating deeper waters, alters the distribution of juvenile fish using nearshore habitats (Toft et al. 2007, Munsch et al. 2016). Seawalls, sandy beach, and rip-rap-buttressed beaches in Elliott Bay have different fish community compositions, linked to fish-substrate associations (Munsch et al. 2015b).	Limited studies	MEDIUM
Salmonid abundance, distribution, diet	Restored sites had higher juvenile salmon densities than armored sites (Toft et al. 2013). Armor alters juvenile salmon distribution and movement patterns (Heerhartz and Toft 2015). Impacts on diet vary by species (Munsch et al. 2015a, Morley at el. 2012, Heerhartz and Toft 2015), but terrestrial insects are lost from salmonid diets at armored sites (Toft et al. 2007).	Impacts on salmonid foraging and diets are complicated by variability in prey availability across habitat type, species- and life-stage-specific preferences	MEDIUM

Functional Response	Impact	Uncertainties	Confidence
Bird species composition	The most common species of bird foraging on beaches differed between unarmored (Song sparrow) and armored (American crow) beaches, and their foraging habitats (wrack and logs on unarmored sites) varied (Heerhartz 2013). Local armor and shoreline urbanization had negative effects on the abundance of two out of 11 functional feeding guilds of Puget Sound seabirds (Good et al. 2016)	Limited studies; variability by guilds	LOW
Herring egg survival	Shoreline armor is weakly linked to higher herring egg mortality rates (Shelton et al. 2014).	Most experts expect armor impacts to be weakened with distance from the beach. However, there is limited investigation into subtidal effects, which are also complicated by covariates associated with urban watersheds	LOW

5.2 IMPACTS ON HUMAN WELLBEING AND QUALITY OF LIFE

Human wellbeing impacts of armoring and armor removal, and feedbacks from human wellbeing conditions to decisions that influence armoring constitute a major knowledge gap. An example of the importance of feedbacks between human wellbeing and different ecosystem components was demonstrated by Donatuto et al. (2014), showing that indigenous community health, defined in terms of human wellbeing benefits of the Puget Sound ecosystem, can inform shoreline planning strategies, with feedbacks to shoreline change, access to shellfish, and human wellbeing benefits in the context of climate change and sea level rise. Further explorations could evaluate how deleterious impacts of shoreline armor on nearshore species, such as herring, feedback to human wellbeing benefits derived from access to shoreline spaces; the tradeoffs between socio-economic benefits accrued by the armor construction/engineering community and human wellbeing benefits of armor removal; and the environmental justice implications of the distribution of those benefits among different Puget Sound communities with different access to shoreline spaces.

There is economic value in the shoreline armor industry, and the benefits derived from both natural and armored shorelines are diffuse and spread among multiple human constituencies inside and outside of the region. Even while limiting the focus of armor removal to private landowners, as is the suggestion of this Implementation Strategy, there are numerous economic considerations not currently included in the estimates of armor or armor removal impacts. A comprehensive economic evaluation of the costs of armor, of armor removal or soft shore alternatives, has not been conducted (to the author's knowledge), but would be necessary to fully evaluate the impacts of shoreline armor to the Puget Sound social-ecological system.

According to Caldwell and Segall (2007), coastal easements and/or straightforward statutory prohibitions on hard shoreline armoring may, "produce results economically superior to armoring." While shoreline armor can increase property values for initial property owners who install armor, armor actually decreases property values for those living inland (but in close proximity to the nearshore). Furthermore, the more shoreline properties armored within a particular community, the more likely a decrease in property value for those particular armored properties. Additionally, beach nourishment (or the removal of hard shoreline armor and the installation of soft or natural shoreline infrastructure that allows natural shore processes) can increase property values without any costs associated with hard armoring.

Recent development of the human dimension Vital Signs allow for the evaluation of such linkages and tradeoffs and, ultimately, comprehensive understanding of the true costs and benefits of Puget Sound recovery actions. The following human wellbeing Vital Signs could be included in future evaluations of the relationship between human wellbeing and shoreline armoring: Local Foods, Outdoor Activities, Economic Vitality, Sense of Place, Cultural Practices, Sound Stewardship, and Good Governance.

6. CURRENT APPROACHES TO REDUCING SHORELINE ARMOR IMPACTS

Current and ongoing approaches to reducing the impacts of shoreline armoring fall into four primary categories of action: (1) improving regulatory effectiveness, (2) developing strategies to motivate desired armoring behaviors by individuals, (3) increasing technical capacity to support armor removal processes and the contracting community; and (4) investing in restoration projects and property acquisition. The Marine and Nearshore Lead Organization Grant Program focused on supporting efforts along all of these trajectories (Kinney et al. 2015, 2016a, 2016b), with substantial advances that have informed the current Implementation Strategy.

The first two topics are addressed in a companion appendix, the Base Program Analysis, and the third topic is addressed in depth in the main Implementation Strategy narrative. The fourth topic is reviewed here. Here we review barriers and opportunities for armor removal and restoration as well as soft protection use, primarily for residential property owners. In addition, our level of knowledge surrounding the effectiveness of these actions for both property protection and ecosystem structure and function is reviewed. Cost estimates are provided for a subset of removal and restoration projects to provide a template for cost effectiveness discussions.

This review focused on residential properties for a number of reasons including: a large percentage of shorelines are residential; most armor removal to date is occurring on public lands; and privately held commercial or industrial lands are most likely zoned and being used for marine-dependent uses that are not consistent with armor removal or restoration. However, this is not to exclude these ownership types from discussion in the development of the Shoreline Armoring Implementation Strategy.

6.1 ARMOR REMOVAL, BEACH RESTORATION, AND USE OF SOFT SHORE PROTECTION

6.1.2. BARRIERS

Key barriers to removing armor include concerns about property and safety, high costs, lack of awareness of the potential benefits, and limited data on environmental tradeoffs. HPA data show that removals are greatest on government-owned lands.

SOCIAL BARRIERS TO RESIDENTIAL ARMOR REMOVAL, REPAIR, AND SOFT PROTECTION

In a survey by Colehour + Cohen et al. (2014), 84% of landowners had never considered removing armor from their property. Erosion is the top concern of waterfront property owners, region-wide (Johannessen 2013b, Colehour + Cohen et al. 2014) and many property owners are not aware of just how slowly erosion is actually occurring, or how hard armor can degrade the quality and accessibility of their beach (Johannessen 2013a). Thus, many property owners see armor as a desirable, or even crucial, element in protecting shoreline properties (Colehour + Cohen et al. 2014, Keller 2012) and, when it comes to alternatives to hard armor, some believe that soft shore protection is expensive and might not work (Keller 2012). Finally, landowners perceive permitting as being so expensive and time consuming that some choose to forgo the process, install unpermitted armor, and face penalties (Johannessen 2013a, Futurewise 2014).

ECONOMIC BARRIERS TO RESIDENTIAL ARMOR REMOVAL, REPAIR, AND SOFT PROTECTION

The cost of removal projects is a barrier that must be overcome in order for a social marketing effort around armor removal to succeed. Currently, there are not adequate financial incentives in place to overcome the cost barrier (Colehour + Cohen et al., 2014). Moreover, landowners are concerned about the safety of investments they have made in their property (Colehour + Cohen et al., 2014) resulting in risk-averse behavior.

TECHNICAL BARRIERS TO RESIDENTIAL ARMOR REMOVAL, REPAIR, AND SOFT PROTECTION

There is a lack of regional capacity for specialized technical support on geological and engineering issues associated with shoreline projects. Construction contractors are more familiar with hard armor than soft shore projects. There is also insufficient communication and spread of accessible, user-friendly engineering standards of practice to encourage soft shore design.

6.1.3. OPPORTUNITIES

Recent work has highlighted opportunities for accelerating armor removal and the use of soft protection techniques. Although most landowners had not considered armor removal, 14-18% of landowners surveyed region-wide were receptive to the idea of removing armor or replacing it with engineered soft shore protection (Colehour + Cohen et al., 2014). Landowners also want to see and hear about successes with alternatives to hard armor from other shoreline property owners (Colehour + Cohen et al., 2014). In addition, educational programs and focused outreach based upon the Marine Shorelines Design Guidance (MSDG) approach may help change widespread perceptions regarding the effectiveness and necessity of bulkheads for shore protection. Moreover, permit compliance can increase when there is property owner notification and education about regulations (Futurewise 2014). Incentive programs are in place and growing to encourage private landowner armor removals (see Appendix IIc, Base Program Analysis, for more on this topic). Last, major opportunities exist for armor replacement projects to be modified into removal projects, replacement with softer alternatives, or movement landward.

6.1.4 EFFECTIVENESS

Not enough evaluation and monitoring data exist to draw conclusions about the effectiveness of armor removal, soft shore design, or beach restoration on restoring ecosystem processes that were degraded by hard armor. In recent years, there has been an increase in data collection, but to date these data have not been extensively analyzed or synthesized. There is also limited information on the effectiveness of restoration actions for property damage prevention and climate change resilience. However, where data exist, results are consistent and generally positive. In one example, nearshore habitat enhancement (at the Olympic Sculpture Park) increased abundance and feeding of larval fishes and juvenile salmonids (Toft et al. 2013). This restoration also saw a dramatic increase in the different types of invertebrates that are important food sources for young salmon. Many of the physical and biological characteristics and processes that are impacted by armor removal may recover over long periods of time, and therefore it may be difficult to evaluate the benefits of armor removal in the short term. At least two dozen armor removal and/or beach restoration projects are underway or planned that are currently or will be monitored for associated ecosystem responses (See Table 6 for projects).

There is limited information available on the relative effectiveness of restoration or soft protection techniques for property protection. One example from Weaverling Spit suggests that soft shore techniques may be better for property protection than hard armor in some situations (Dorfmeier and Fore 2016). A side-by-side comparison at this site during a winter storm showed no damage at a soft shore restoration site but major damage at site with a bulkhead, including beach erosion, water trapped behind the seawall, and damage and flooding to buildings. This remains one of the few case studies where soft shore impacts have been assessed. Some soft shore projects have been monitored for their effectiveness, but the data have not been systematically explored and analyzed. Such analysis should be a short-term priority, given the substantial amount of effort devoted to implementing armor removal and soft shore design alternatives.

The Shoreline Monitoring Toolbox (http://wsg.washington.edu/toolbox) has been developed by the Puget Sound Ecosystem Monitoring Program's Nearshore Workgroup and Washington Sea Grant to provide standardized approaches to monitoring Puget Sound shorelines, including the effects of restoration. These approaches could be applied broadly at armor removal sites to generate a better set of information about ecosystem responses to armor removal and other restoration actions.

Importantly, there has been limited effort to date focused on recovery from armor beyond the upper intertidal and supra-tidal zones. One study in Elliott Bay evaluated the impacts of beach nourishment approaches, and found that species compositions at nourished beaches are different from those found at nearby seawalls (Munsch et al. 2015b). Understandably, the bulk of effort has been focused on habitat zones closest to the armor disturbance. However, given uncertainty about the timing of responses in sediment distribution at all tidal depths, among other processes, there remains a lack of certainty about how armor and armor removal may impact habitat and species deeper in the tidal zone. There are also relatively few controlled studies on ecological responses to soft shore designs (e.g., Munsch et al., 2015a; Toft et al., 2014; Toft et al., 2013). This limits our ability to identify mechanisms behind variable responses, optimize future project planning, and ensure management actions are delivering desired outcomes. For example, soft shore restoration is intended to provide shallow areas that small fish prefer to escape from larger fish that can eat them in deeper water. Monitoring is needed to evaluate the effectiveness of soft shore design for providing that function.

PSP EFFECTIVENESS PROJECT CASE STUDY

The PSP Effectiveness Project reviewed results of removing armor at a few locations for which data were available including: (1) removal of 1/3 mile of armor on Bainbridge Island (Adams et al. 2015), (2) removal of 1000 feet of rock bulkhead at Weaverling Spit on Fidalgo Bay (Selleck et al. 2016a), (3) removal of 4300 feet of armor in Seahurst Park in Burien (Selleck et al. 2016b), and (4) restoration of 1600 feet of shoreline at Cornet Bay at Deception Pass State Park (Selleck et al. 2016c). Positive outcomes included: forage fish spawned immediately after restoration and construction was completed (Seahurst, Weaverling Spit, Ala Spit); removing the seawall allowed delivery of sand from the adjacent hillsides to the beach (Seahurst); and soft shore restoration increased abundance of plants close to the water's edge (Bainbridge, Seahurst, Cornet Bay). However, these are single or short-term observations that are positive signs, but not conclusive results.

Table 6. Ongoing monitoring of restoration / armor removal projects

Site	Treatment(s)	Armor removal year	Sampling years	Metrics	Lead Entity(ies)
Anna Smith Park	Pre-, Post-, Reference	2012	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW
Bowman Bay†	Pre-, Post-, Reference	2015	2015, 2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	DFW, UW, NW Straits Foundation
Brown Island†	Pre-, Post-, Reference	2015	2015, 2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	DFW, UW, Friends of the San Juans
Burfoot Park	Pre-, Reference	Planned	2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW
Cornet Bay State Park	Pre-, Post-, Reference	2012	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW, Island County MRC, NW Straits Foundation
Dabob Bay	Pre-, Post-, Reference	2009	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW
Dawley	Pre-, Reference	Planned	2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW
Dockton Park	Pre-, Post-, Reference	2013	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW, Vashon Nature Center
Edgewater	Pre-, Reference	2016	2015, 2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW, UW, ERSP Learning Project
Ediz Hook	Armor removal, beach restoration, beach nourishment			Sediment, Beach profile, LWD	Lower Elwha Klallam Tribe, DNR

Site	Treatment(s)	Armor removal year	Sampling years	Metrics	Lead Entity(ies)
Family Tides (no armor; beach restoration only)	Pre-, As-built, Post-, Reference	2015	2015, 2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	DFW, UW, Friends of the San Juans
Fort Townsend State Park†	Pre-, As-built, Reference	2015		Beach profile, logs, wrack, riparian cover, sediment, forage fish	NW Straits Foundation
Howarth Park†	Pre-, Reference, As-built	2016	2015, 2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW, UW, Snohomish County Parks
Kopachuk State Park		2006			
Maury Island†			Planned for 2017		King County
Maylor Point	Pre-, Reference	2017	2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW
Meadowbrook†					
Penrose Point	Pre-, Post-, Reference	2013	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW
Powel property	Pre-, Post-, Reference	2012	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW
Seahorse Siesta	Pre-, Reference	2017	2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW, NW Straits Foundation, Washington Sea Grant
Seahurst Park (two sites)†	Pre-, Post-, Reference	2005 (I), 2014 (II)	2016	Wrack line & composition, LWD, Sediment, Beach profile, Riparian vegetation, Forage fish, Wrack invertebrates, Terrestrial insects, amphipod stable isotopes	UW, City of Burien
Snyder property	Pre-	planned	2014	Sediment, Beach profile, surface epifauna and algae, Riparian vegetation	WA Sea Grant

Site	Treatment(s)	Armor removal year	Sampling years	Metrics	Lead Entity(ies)
Titlow Beach†	Pre-, Reference, As-built		2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW, South Puget Sound Salmon Enhancement Group
Waterman	Pre-, Reference, As-built		2016	Wrack line, LWD, Sediment, Beach profile, Marine riparian, Forage fish	DFW

†Marine & Nearshore Lead Organization NEP-funded (at least partial) project.
Notes: WDFW project lead Hannah Faulkner, UW project lead Jason Toft, funded by WA Sea Grant

Table 7. Forage fish monitoring at armored sites

Site	Sampling years	Metrics	Sponsor(s)
Maple Grove, Island County	2016	Forage fish	NW Straits Foundation
Pitship, Clallam County	2016	Forage fish	NW Straits Foundation

6.2 ACQUISITION AND PRIORITIZATION

Acquisition of unarmored and high-quality property in order to permanently protect appears to be less costly than restoring armored shorelines (Table 8). The relative cost among approaches may depend on the timescale and long-term stewardship and enforcement needs. Factors such as real estate values, presence of infrastructure that needs to be protected or relocated, presence of archeological resources, and public access, influence the per unit costs of armor removal and beach restoration projects. However, the magnitude of these effects has not been quantified. Table 8 shows calculations of armor removal costs for recent projects.

Costs of restoration and acquisition projects partially funded through the National Estuary Program since 2011 indicate that protection of unarmored beaches is less expensive than armor removal. Seven beach restoration projects involving removal of just less than 1 mile of armor cost almost $8 million, while acquisition of 373 acres with 2.85 miles of shoreline cost $10.5 million (See cost estimates in Table A8 for a subset of public and private projects in Table A9). Purchase of conservation easements is even less expensive than outright acquisition, and could appeal to landowners not wanting to sell their property. Analysis of fee simple acquisition versus conservation easement purchases from 2010-2015 in King County found land purchase cost an average of $47,000 per acre and conservation easements cost an average of $6,000 per acre (King County 2015).

Table 8. Costs of projects that include removal of shoreline armor [1]

Project name	Miles Removed	Feet Removed	Cost	Cost per Linear Foot	Cost also includes
Public access property: Average Cost = $1801/ft					
Bowman Bay Project #13-1235	0.1	528	$324,020	$614	
Maury Island Project #14-2226	0.14	700	$637,581	$910	
Cornet Bay	0.3	1600	$810,000	$1080	Remove creosote 79 tons of creosote contamination, add gravel, install 24,000 ft^2 of plantings and logs, upgrade facilities
Ft. Townsend Project #13-1234	0.06	317	$505,468	$1,595	
Seahurst Park Project #09-1415	0.5	2640	$4,307,743	$1,632	Remove 21,000 cubic yards of material, add of 27,000 cubic yards of sand, reroute 3 streams, create wetland,

[1] These costs are for actual project construction only. Many projects also include acquisition, and those costs are not included here.

Project name	Miles Removed	Feet Removed	Cost	Cost per Linear Foot	Cost also includes
					relocate fish ladder, upgrade park facilities, expand parking lot, upgrade trails, playground, vehicle access, picnic areas, and installed new plants
Howarth Park [Project #13-1106]	0.08	422	$1,138,764	$2,698	
Titlow Beach [Project #15-1447]	0.03	158	$644,065	$4,076	Remove buildings and contaminated soil
Private property: Average Cost = $282/ft					
Powel property, Bainbridge Island	0.3	1544	$223,500	$145	
Brown Island [Project #13-1177]	0.03	166	$47,750	$287	
Weaverling Spit	0.19	1000	$414,300	$414	Add 2000 tons of sand, install plants and large logs

Data were obtained from PRISM Project Snapshots and Habitat Work Schedule to report the cost by project and linear foot of shoreline armor removal. When detailed cost break-downs were available, only costs for design, permits, and shoreline armor removal were included. When individual component costs could not be resolved, additional costs are noted in the table. Costs are not adjusted for inflation.

6.3 KNOWLEDGE GAPS AND UNCERTAINTIES

Previous work related to restoration projects and acquisition has identified some key knowledge gaps and uncertainties. For example, a widely-acknowledged challenge is identifying where and how much armor to remove or where to protect (site prioritization). Such prioritization is a complicated assessment that involves calculating potential ecosystem function at each site; contribution of restoration actions to recovery of multiple Vital Signs; effectiveness of all suitable recovery actions for restoring benefits associated with multiple Vital Signs; potential future risk owing to climate change; assessment of cost of restoration; and an overall assessment of how much armoring needs to be removed to achieve the desired level of ecosystem response. Answering this question requires additional research linking restoration interventions to ecosystem responses, regional models of risk owing to climate change, cost/benefit analyses at the site level, and regional model that aggregates site-level metrics to overall ecosystem benefits. Such analyses and models do not currently exist.

7. RESEARCH AND MONITORING NEEDS AND UNCERTAINTIES

Research and monitoring needs, and uncertainties identified throughout this document are aggregated and summarized below. In addition, a list of key uncertainties associated with the strategies was developed during the Implementation Strategy process. The latter are listed in the Implementation Strategy narrative; the remaining uncertainties are listed here.

7.1 RESTORATION PRIORITIZATION AND ECOSYSTEM FUNCTION

- Where and how much intact or "natural" shoreline is needed to support populations of species that depend upon shorelines and nearshore habitats, including salmonids, forage fish, and invertebrates? What are appropriate ecosystem function objectives, and what are the quantitative links between amount of armor and those objectives? How do restoration actions at the parcel level scale up to ecosystem function? Research at the drift cell scale or larger is needed to identify potential thresholds in ecosystem function and process, both in terms of negative impacts of armor and positive responses to restoration (matches a Priority Gap identified by the PSEMP Nearshore Working Group).

7.2 TRACKING THE VITAL SIGN

- **HPA data**: What other potential deleterious shoreline alterations are occurring? What shoreline types or soft shore alternatives are implemented at project sites? Better protocols are needed for collecting project attributes and extracting relevant data from the HPA (matches a Priority Gap identified by the PSEMP Nearshore Working Group). At present, whether the HPA dataset can include better metrics for tracking armor is unclear.
- **Shoreline armoring extent:** (1) How much armoring is there and how is it distributed? (2) What type of shoreline is armored? and (3) What type of armoring (hard or soft) is placed at what tidal heights? (matches a Priority Gap identified by the PSEMP Nearshore Working Group)
- A**rmoring on feeder bluffs** gaps include (a) identifying additional historical images for remaining lengths of shore; and (b) developing a finer-grain classification system and applying it to identified feeder bluffs.
- Tracking **soft shore alternatives:** current exists no consistent identification/tracking; no consistent protocols or components used.
- What is the percent sediment source intact by drift cell?

7.3 FUTURE IMPACTS ON ARMOR

- Local-scale sea level rise and flood risk forecasts for all Puget Sound jurisdictions

7.4 ARMOR IMPACTS AND RESTORATION EFFECTIVENESS

- Impacts of armor and armor removal on subtidal habitat characteristics and biological endpoints, such as eelgrass or use of subtidal habitats by fish and invertebrates

- Evaluation of impacts of armor on, and tradeoffs among, human dimension Vital Signs: Local Foods, Outdoor Activities, Economic Vitality, Sense of Place, Cultural Practices, Sound Stewardship, and Good Governance
- Impacts of armor and armor removal on salmonid foraging and diets across habitat type, species- and life-stage-specific preferences
- Feeder bluff erosion rates and sediment budgets
- Impacts of armoring over longer periods of time on ecosystem structure, processes and function

8. DECISION SUPPORT AND MODELS

8.1 RESEARCH TO SUPPORT DECISION MAKING

BASELINE DATA

Several efforts are underway to improve baseline information on the amount, type, and location of existing armor in Puget Sound, against which changes can be compared and tracked, both as a way of improving the Vital Sign tracking, and to better inform restoration needs and priorities. Such high-quality baseline data is of critical importance in making decisions about restoration and improving the health of the Puget Sound nearshore. Without knowing where the armoring is, it is difficult to assess the overall impact of armoring on the ecosystem, and to target locations for restoration. A discussion of the ongoing efforts to improve baseline data is found in Section 2 of this document.

CLIMATE VULNERABILITY ASSESSMENT AND ADAPTATION

The potential for armor removal is intrinsically tied to the risk of erosion. Decisions about which sites to protect, and which sites can be restored, are therefore intrinsically tied to understanding not only the underlying geology at a site, but also the influence of current and future risk from flooding. The vulnerability of coastal communities to climate change impacts, particularly sea level rise and storm surge, has resulted ongoing and proposed research efforts to provide communities with tools they need to conduct climate adaptation planning. Such projects have been conducted in the San Juan Islands (MacLennan et al. 2013a, 2013b, Friends of the San Juans 2014), and are being piloted by the Washington Coastal Resilience Network in the city of Tacoma and Island County to increase the state's capacity to prepare for coastal threats (http://www.wacoastalnetwork.com/washington-coastal-resilience-project.html). Key to this approach is developing sea level rise predictions in a probabilistic framework to allow communities more options and information to support their adaptation planning. Also included are local assessments of vertical land migration, storm surge and wave impacts, and erosion risk, work that is being led by the Coastal Resilience consortium of USGS, Washington Sea Grant, UW

Climate Impacts Group, Rutgers University, and Adaptation International. In addition to the work performed to predict sea level rise, underpinning this work are several tools that use downscaled climate models for predicting coastal impacts currently in development in the region:

- CoSMoS: the USGS Coastal Storm Modeling System (CoSMoS) provides detailed predictions about the coastal flooding effects of sea-level rise, storm surge, and river flooding from climate change, and is presently being adapted to Puget Sound. An initial stakeholder workshop was held in September 2017, and development continues.
- The USGS Puget Sound Ecosystem Portfolio Model (PSEPM) is a decision-support tool that uses scenarios to evaluate where, when, and to what extent future population growth, urban growth, and shoreline development may threaten the Puget Sound nearshore environment (Byrd et al. 2011), with a particular emphasis on feeder bluffs. Potential uses include: predicting future armor trends related to regional population growth, and prioritizing sites for protection/restoration based on vulnerability to erosion from climate change. Updated information on the abundance and distribution of feeder bluffs could be incorporated into PSEPM.

ECOSYSTEM SERVICES VALUATION OF ARMOR REMOVAL

Ecosystem services valuation can support decision-making by illustrating tradeoffs between, for example, ecosystem services and hard armor. Earth Economics (2011) conducted a Sound-wide ecosystem services valuation, estimating the per-acre value of beaches from $23.7-$86.8k, for providing aesthetic/recreational and coastal protection values. In Clallam County, unarmored sections of feeder bluff provided three times the economic value that armored sections provided (Flores et al. 2013). Ecosystem services valuations can be used as powerful communication tools in campaigns to develop public support for restoration programs.

8.2 RESTORATION PRIORITIZATION

A number of prioritization efforts are underway focused on increasing/encouraging sediment supply to beaches at the county scale:

- Diefenderfer et al. have built a restoration prioritization tool based upon restoring self-sustaining shoreline functions for Jefferson County (Diefenderfer et al. 2006) with application to other jurisdictions (Diefenderfer et al. 2009).
- NW Straits Foundation and CGS are collaborating on a project in Island and Jefferson Counties to identify feeder bluff restoration sites for restoration prioritization, conduct outreach with landowners, and conduct restoration conceptual designs (Project #14-2196).

- Kitsap County has conducted an analysis of sediment sources/supply to prioritize restoration (Kitsap County Sediment Source Analysis and Restoration Prioritization Study).

- The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) beach strategies (Cereghino et al. 2012) provide a coarse scale, regional prioritization for protection and restoration in Puget Sound based on the PSNERP geodatabase (http://wagda.lib.washington.edu/data/geography/wa_state/#PSNERP). ESRP at the Department of Fish and Wildlife is leading efforts to revise the PSNERP beach strategies developed in 2012. The 2012 strategies identify candidate sites for protection, restoration, or enhancement Puget Sound-wide across four shoreform types. The 2012 strategies (Cereghino et al. 2012) assesses area geographic distribution and proposes metrics for categorizing site degradation and restoration potential at the drift cell scale. The revision would update the data underlying the strategies to increase the resolution of the results to candidate sites as well as elicit stakeholder input to formulate the management questions that the revised strategies will address. This is funded through the ESRP Learning Program as the project: "Identifying target beaches to restore and protect" (Project #14-2308) to Coastal Geological Services. They will: conduct an assessment of existing armor data, including data collection and compilation; address some armor data gaps via direct mapping; refine existing geodatabases; develop potential regional beach restoration strategies with stakeholders; develop a web-based mapping tool; and develop beach strategy training curriculum.

- Existing research on armoring impacts has pointed to evaluating the impact on sediment supply processes when considering restoration and acquisition actions. At the drift cell scale, the volume, rate, and distribution of sediment affects beach structure (width, slope, and substrate per Dethier et al. 2016a) and is also likely to drive shoreline response to sea level rise (Johannessen et al. 2014). Suggestions for attributes to consider when evaluating restoration or protection at specific locations include:
    - the scale of the project relative to the size of its drift cell;
    - percent of the drift cell with functional sediment dynamics (Puget Sound Recovery Implementation Technical Team 2015);
    - the location of armor relative to mean higher high water (Dethier et al. 2016b)
    - extent and distribution of uninterrupted transport zones (Puget Sound Recovery Implementation Technical Team 2015).

Table 9. Models and tools for addressing key uncertainties and knowledge gaps

Uncertainty or Knowledge Gap	Description	Model(s)/Tool(s)	Tool Readiness	Advantages/Disadvantages	Timeframe (Short, Medium, or Long-term solution)	Relative Cost (Low, Medium, or High Cost)	Relative Impact on Vital Sign
Armor threshold	Amounts of Puget Sound armor linked to thresholds or breakpoints in ecosystem function	Mechanistic models linking armor to structure, function, process	Not in development	Complex and data dependent	Long-term solution	High Cost	Low impact on Vital Sign; high impact on ecosystem recovery
Baseline of armor extent	Rigorous tally of amount of armor on Puget Sound shore, where armor is, and type of shoreline armored	Mapping	Ready (Rishel 2016)	Widespread agreement that this indicator is preferred to current armor indicator. Protocol has been developed and piloted. Not clear how it would be monitored; no current monitoring program for tracking change in baseline (trends).	Medium	Medium	High. Better tracking and new monitoring program
Soft shore alternatives	Tracking of sort shore projects being implemented	Unknown	Not in development	Comprehensive review in Shipman 2017b.	Long-term solution	Medium	High. Currently not tracked.
Feeder bluff distribution	Mapping of feeder bluffs and feeder bluff armoring	Mapping, matching to historical photographs	Partially complete	Method already developed. Major progress towards additional vital sign indicator. Can help with prioritization. More comprehensive picture of shore.	Short-term	Low	Medium

Table 9. Models and tools for addressing key uncertainties and knowledge gaps (continued)

Uncertainty or Knowledge Gap	Description	Model(s)/Tool(s)	Tool Readiness	Advantages/Disadvantages	Timeframe (Short, Medium, or Long-term solution)	Relative Cost (Low, Medium, or High Cost)	Relative Impact on Vital Sign
Risk from sea level rise	Local-scale assessment of potential risk to property from erosion owing to sea level rise and flooding	Probabilistic predictions of local-scale sea level rise, inclusive of vertical land migration and local extremes	In progress by Washington Coastal Resilience Project	Highly valuable in local-scale planning. Highly complex.	Medium (next 1-3 years)	High cost, partially funded	High impact
Impacts of armor on fish abundance, distribution, food web interactions; especially salmon and herring	How does armor impact the use of nearshore habitats by fish, the availability of prey for fish, the community composition at sites? Local- and regional-scale	Field observations at armored, armor removal, and reference sites; statistical analyses; modeling to evaluate regional-scale impacts	Project funded, work TBD in 2018-2019	Basic ecological research. Scaling up to regional-level thresholds and needs for fish populations and food webs is difficult.	Medium	Medium cost	High impact

Note: Where models are under development, the lead entities involved are listed. Those tools not currently under development represent a need without an identified lead.

Table 9. Models and tools for addressing key uncertainties and knowledge gaps (continued)

Uncertainty or Knowledge Gap	**Description**	**Model(s)/Tool(s)**	**Tool Readiness**	**Advantages/Disadvantages**	**Timeframe (Short, Medium, or Long-term solution)**	**Relative Cost (Low, Medium, or High Cost)**	**Relative Impact on Vital Sign**
Multi-attribute tradeoff analyses	What are the tradeoffs of armor (and/or armor removal) between ecological, economic, and social benefits?	(1) Multi-attribute utility analysis; (2) qualitative network modeling; (3) systems analysis	(1) Will be developed in 2019, funding permitted; (2) Tool is freely available, there is local expertise, model would need to be parameterized; (3) Tool is developed, non-local expertise, model would need to be parameterized	(1) Research group formed and in planning stages; supports decisions based on cost-benefit analysis framework; based on economic theory; can be used to compare strategies (2) Simple approach already vetted in region; simple to explain; developed in collaborative setting; used to evaluate impacts of decisions on performance of different ecosystem components; (3) Prepackaged software; external expertise required; developed in collaborative setting; used to evaluate impacts of decisions on performance of different ecosystem components	(1) Medium (1-2 years); (2) Medium (1 year); (3) Medium (1-2 years)	(1) Medium; funding partially secured; (2) Low; (3) Medium	High impact for decision support for this and other ISs

9. RELATED STRATEGIES

9.1 REGIONAL

The 2012 Tribal Habitat Priorities document included several priorities related to shoreline armoring pressure on the nearshore ecosystem (Table 9). An updated Tribal Habitat Strategy is under development by the Tribal Management Conference. When the document is available, a discussion about the connections with the Implementation Strategy will occur.

Table 10. Tribal habitat priorities addressing shoreline armoring pressure on the nearshore ecosystem and salmon recovery

Tribal Habitat Priority		Protection	Restoration	Science/ Monitoring
Protect ecosystem processes required to support the habitat necessary to meet salmon recovery goals of viable, harvestable populations.				
	Identify changes to Federal, State, tribal and local statutes, regulations and policies to prevent continued habitat loss (e.g. Shoreline Management Act, Growth Management Act)	x		
	Agencies clearly identify, define, implement and enforce quantitative metrics for essential habitat required under existing authorities.	x		
	Develop a comprehensive public outreach, awareness, and behavior change program to promote public stewardship of Puget Sound resources.	x		
Implement and improve consistency, coordination of enforcement and alignment of federal, state and local regulations for the protection of priority nearshore, estuary and floodplain habitat.				
	Appropriate entities ensure effective coordination and enforcement of existing regulations (e.g. WDFW enforces Hydraulic Code provisions)	x		
	Where inconsistencies exist between current regulations and the desired ecosystem protection and restoration, the affected agencies will consult and align their authorities to achieve this objective.	x	x	
	Align Federal, State, and local agencies' resources and regulatory jurisdictions to implement large scale process restoring projects.		x	
Increase opportunity, focus and effectiveness of incentive based approaches, including non-financial incentives, for the protection and restoration of priority floodplain, wetland, estuary and nearshore habitat.				
	Identify and prioritize key habitat.	x	x	
	Protect key habitat through land purchase, conservation easements, purchase of development rights or tax incentives	x		
	Develop regulations that allow continued land use consistent with protection and recovery targets, but make conversion to other uses prohibitive.	x		
	Develop programs that recognize good stewards of key habitat and help them identify efficiencies, new markets, etc.	x		

Table 10. Tribal habitat priorities addressing shoreline armoring pressure on the nearshore ecosystem and salmon recovery (continued)

Address key institutional, financial and community barriers to priority habitat restoration projects.				
	Overcome institutional barriers to align funding sources to implement large scale projects (e.g. PSNERP projects)		x	
Develop and implement monitoring programs to evaluate viable salmonid population (VSP) parameters				
	Monitor key habitat status and trends indicators for floodplain, channel migration zone, wetland, estuary, nearshore and Salish Sea habitat			x
	Monitor effectiveness of restoration projects, Best Management Practices and buffers.		x	x
	Establish geographically appropriate measures to evaluate actions (reach, drift cell, etc).			x
	Monitor the implementation and effectiveness of regulations intended to protect salmon habitat and make changes as necessary.	x		x

Adapted from Tribal Habitat Priorities 2012

PRESSURES ASSESSMENT AND ACTION AGENDA SUB-STRATEGY RATING ANALYSIS

In 2014, PSP worked with the Science Panel to complete the first Puget Sound Pressures Assessment, or PSPA. The study used a systematic, expert-elicitation based approach to evaluate the potential impact of stressors on assessment endpoints (habitats and species). One stressor considered was shoreline hardening. PSPA results the identified human activities causing stress on the system ('pressure sources'), the geographic distribution of stressors and their sources, as well as the most vulnerable 'endpoints' and relative certainty of stressor-endpoint relationships. The two human activities suggested by PSPA to be the most important pressure sources for shoreline hardening were Marine Shoreline Infrastructure and Marine Levees, Floodgates, and Tidegates.

Between 2012 and 2015, the importance of each substrategy in the Action Agenda was evaluated by experts for its connection to and importance for the recovery of each Vital Sign. The analysis was completed in 2012 and updated in 2015 with new results from the PSPA. The substrategies with the greatest potential impact on Shoreline Armoring pressure sources (Marine Shoreline Infrastructure and Marine Levees, Floodgates, and Tidegates) and the Vital Sign were identified (Table 11).

Table 11. Key Action Agenda Substrategies that address the Shoreline Armoring Vital Sign

	Pressure Source		Shoreline Armoring Vital Sign
Action Agenda Substrategy	Marine shoreline infrastructure	Marine Levees, Floodgates, Tidegates	
1.3 Improve, strengthen, and streamline implementation and enforcement of laws, plans, regulations, and permits consistent with protection and recovery targets	0.78	0.10	0.55

1.4 Ensure full, effective compensatory mitigation for impacts that cannot be avoided	0.59	0.27	0.33
2.2 Implement and maintain priority freshwater and terrestrial restoration projects	0.52	0.76	0.36
6.1 Implement high-priority projects identified in each salmon recovery watershed's three-year work plan	0.53	0.96	0.33
6.5 Maintain and enhance the community infrastructure that supports salmon recovery	0.73	0.47	0.43
8.1 Use complete, accurate and recent information in shoreline planning and decision-making at the site-specific and regional levels	0.76	0.35	0.50
8.2 Support local governments to adopt and implement plans, regulations, and policies that protect the marine nearshore and estuaries, and incorporate climate change forecasts	0.75	0.13	0.43
8.3 Improve, strengthen, and streamline implementation and enforcement of laws, regulations, and permits that protect the marine and nearshore ecosystems and estuaries	0.84	0.13	0.60
16.1 Permanently protect priority nearshore physical and ecological processes and habitat, including shorelines, migratory corridors, and vegetation, particularly in sensitive areas such as eelgrass beds and bluff-backed beaches	0.75	0.05	0.44
16.2 Implement prioritized nearshore and estuary restoration projects and accelerate projects on public lands	0.83	0.50	0.67
16.3 Remove armoring, and use soft armoring replacement or landward setbacks when armoring fails, needs repair, is non protective, and during redevelopment	0.86	0.25	1
18.2 Increase access to and knowledge of publicly owned Puget Sound shorelines and the marine ecosystem	0.31	0.00	0.33

Only those with a moderate to high level of expert consensus on the substrategy importance to the Vital Sign are included. Each substrategy is assessed on its ability to address the two pressure sources and its overall impact on the Vital Sign. Shown are mean values from expert rankings of the ability of each substrategy to address each Pressure Source, color coded as high (yellow), moderate (green), low (gray), very low (white), with a maximum value of one. In the far right column, separate scores are shown for the ability of each substrategy to address the Vital Sign overall, also color coded: darker red are higher values,s with a maximum value of one.

The 2018 Action Agenda update included Regional Priorities for Shoreline Armoring that are aligned to the strategies contained in this Implementation Strategy.

9.2 2016 NEAR TERM ACTIONS (NTAS) RELATED TO SHORELINE ARMORING

When submitting NTAs to the 2016 Action Agenda, project owners were asked to identify Vital Signs and specific indicators for which their project had primary or secondary relevance. These assignments were reviewed by Puget Sound Institute and the Shoreline Armoring Implementation Strategy planning team as well as an additional review at all NTAs to evaluate additionally relevant NTAs. Table A15 contains NTAs directly related to the Shoreline Armoring Vital Sign and its indicators. Table A16 includes NTAs related to the ecological effects of armoring while Table A17 includes salmon-recovery related NTAs where owners identified a shoreline armoring connection.

Table 12. 2016 Near Term Actions (NTAs) directly related to the Shoreline Armoring Vital Sign and its indicators.

NTA	NTA Title	Owner	Pathway
2016-0089	Community-scale Sea Level Rise and Coastal Hazard Assessment in Puget Sound	UW - Climate Impacts Group and Washington Sea Grant	Climate vulnerability assessment and adaptation
2016-0140	Advancing Sea Level Rise (SLR) Adaptation in San Juan County	Friends of the San Juans	Climate vulnerability assessment and adaptation
2016-0190	Climate Change Vulnerability Assessment and Adaptation Plan	Kitsap County	Climate vulnerability assessment and adaptation
2016-0204	Climate Action Planning and Implementation on the N. Olympic Peninsula	North Olympic Peninsula Resource Conservation & Development Council	Climate vulnerability assessment and adaptation
2016-0293	Puget Sound Integrated Coastal Inundation Modeling and Mapping	U.S. Geological Survey	Climate vulnerability assessment and adaptation
2016-0001	Shoreline Armoring Reduction Project	Northwest Straits Foundation	Incentives and Capacity
2016-0104	Hood Canal Shoreline Outreach and Technical Assistance	Washington State University	Incentives and Capacity
2016-0106	Puget Sound Shore Stewards	Washington State University Extension	Incentives and Capacity
2016-0107	Engaging the Community in Strait Ecosystem Recovery	WSU Extension	Incentives and Capacity
2016-0139	Permanent Marine Shoreline Protection in San Juan County	Friends of the San Juans	Incentives and Capacity
2016-0145	Shoreline Stewardship Technical Assistance Program	San Juan Islands Conservation District	Incentives and Capacity
2016-0171	MRC Port Susan	Snohomish County Marine Resources Committee	Incentives and Capacity
2016-0172	Expand Conservation District Shore Friendly Programs across Puget Sound	Mason Conservation District	Incentives and Capacity
2016-0197	Discovery Bay Landowner Outreach	Jefferson Co. MRC (Marine Resources Committee)	Incentives and Capacity
2016-0236	Shore Friendly Incentives in King, Snohomish and Pierce Counties	Futurewise	Incentives and Capacity
2016-0268	Expand Conservation District Shoreline Technical Assistance in Puget Sound	Puget Sound Conservation District (PSCD) Caucus	Incentives and Capacity

NTA	NTA Title	Owner	Pathway
2016-0327	Marine Shoreline Technical Assistance & Project ID for Home/Landowners	King Conservation District	Incentives and Capacity
2016-0380	Marine Shoreline Design Guidelines: Eng. Tech Assist, Training & Outreach	Washington Department of Fish and Wildlife	Incentives and Capacity
2016-1219	Green Shores for Home (GSH) Phase II - Implementation Phase	Washington Sea Grant	Incentives and Capacity
2016-0049	Online application and database management tool for HPAs	Washington Department of Fish and Wildlife (WDFW)	Regulation
2016-0116	WRIA 9 Marine Shoreline Monitoring and Compliance Project	King County Department of Natural Resources and Parks	Regulation
2016-0132	Improve effectiveness of State Hydraulic Code rules	WA Department of Fish and Wildlife	Regulation
2016-0280	Regional Local Regulatory Compliance Tracking Systems Pilot	Jefferson County Public Health	Regulation
2016-0350	Improving implementation of shoreline modification regulations	DFW	Regulation
2016-0377	State Hydraulic Code Compliance Assurance Program	Washington Department of Fish and Wildlife	Regulation
2016-0397	Hood Canal County-wide Planning Policy Assessment	Hood Canal Coordinating Council (HCCC)	Regulation
2016-0002	Bowman Bay Armor Removal Planting Maintenance	Northwest Straits Foundation	Restoration and acquisition
2016-0003	Shannon Point Feeder Bluff Armoring Removal	Northwest Straits Foundation	Restoration and acquisition
2016-0005	Lummi Island Quarry Habitat Restoration Project	Northwest Straits Foundation	Restoration and acquisition
2016-0064	Lowman Beach Park seawall removal	Seattle Parks and Recreation	Restoration and acquisition
2016-0065	Myrtle Edwards Park shoreline improvement	Seattle Parks and Recreation	Restoration and acquisition
2016-0080	Dungeness Feeder Bluff Conservation	Coastal Watershed Institute (CWI)	Restoration and acquisition
2016-0085	Cornet Bay Pier Retrofit #2016-0085	Northwest Straits Foundation	Restoration and acquisition
2016-0088	Maylors Point Feeder Bluff Armoring Removal	Northwest Straits Foundation	Restoration and acquisition
2016-0090	Seahorse Siesta Feeder Bluff Armor Removal	Northwest Straits Foundation	Restoration and acquisition
2016-0092	Titlow Estuary Restoration	South Puget Sound Salmon Enhancement Group	Restoration and acquisition
2016-0094	Henderson Inlet Habitat Protection & Restoration	Capitol Land Trust	Restoration and acquisition
2016-0122	Oak Harbor Marina Beach Soft Armoring Project	City of Oak Harbor Marina	Restoration and acquisition
2016-0134	Spring Beach Acquisition	King County WLR	Restoration and acquisition
2016-0160	DNR Aquatic Restoration Program McNeil Island Shoreline Restoration	Washington State Department of Natural Resources	Restoration and acquisition
2016-0166	Dockton Park Bulkhead Removal	King County WLR	Restoration and acquisition
2016-0180	Piner Point Acquisition and Restoration	King County WLR	Restoration and acquisition
2016-0181	Scheuerman Creek riparian and marine shoreline restoration	Seattle Public Utilities)	Restoration and acquisition

NTA	NTA Title	Owner	Pathway
2016-0196	West Central Nearshore Restoration Prioritization and Armor Removal	Kitsap County	Restoration and acquisition
2016-0242	Port Angeles Harbor Beach Restoration and Shoreline Softening	City of Port Angeles, Department of Natural Resources	Restoration and acquisition
2016-1236	Beach Lake Acquisition and Restoration	Coastal Watershed Institute (CWI)	Restoration and acquisition
2016-0123	Beach Strategies for Nearshore Restoration and Protection in Puget Sound	Coastal Geologic Services	Science and Monitoring
2016-0221	A queryable spatial data service for habitat restoration projects (GLAD)	WDFW	Science and Monitoring
2016-0393	Hood Canal Nearshore Inventory, Assessment and Prioritization	Hood Canal Coordinating Council (HCCC)	Science and Monitoring
2016-0398	Strategic mapping of priority drift cells for protection and restoration	WA Dept of Ecology	Science and Monitoring

NTAs have been assigned to one of five thematic pathways: climate vulnerability assessment and adaptation; incentives and capacity; regulation; restoration and acquisition; and science and monitoring.

Table 13. 2016 Near Term Actions (NTAs) related to the ecological effects of shoreline armoring and restoration

NTA ID	NTA Title	Owner	Pathway
2016-0060	West Sound Eelgrass Monitoring Program	Suquamish Tribe	Science and Monitoring
2016-0079	Forage Fish Survey and Baseline Habitat Map for Commencement Bay	Citizens for a Healthy Bay	Science and Monitoring
2016-0119	Shoreline Monitoring Toolbox - protocol implementation and data management	Washington Sea Grant	Science and Monitoring
2016-0165	Eelgrass and Forage Fish Mapping in Snohomish County	Snohomish County Marine Resources Committee (MRC)	Science and Monitoring
2016-0328	Monitoring effectiveness of shoreline restoration	Puget Sound Institute, University of Washington Tacoma	Science and Monitoring
2016-0354	Habitat Evaluation Procedures	Seattle Department of Construction and Inspection	Science and Monitoring
2016-0392	Critical forage fish habitat identification and protection	WA Department of Fish and Wildlife	Science and Monitoring

NTAs have been assigned to one of five thematic pathways: climate vulnerability assessment and adaptation; incentives and capacity; regulation; restoration and acquisition; and science and monitoring.

Table 14. 2016 Near Term Actions (NTAs) related to the salmon recovery where NTA owners identified a shoreline armoring connection

NTA ID	NTA Title	Owner
2016-0376	Puget Sound Chinook Recovery Nearshore Chapter Update	Washington Department of Fish and Wildlife
2016-0144	Updating the San Juan salmon recovery chapter	San Juan County WRIA 2 Lead Entity
2016-0308	Hood Canal Chinook Salmon Recovery Plan Update	Hood Canal Coordinating Council (HCCC)
2016-0396	Hood Canal Steelhead Recovery Plan Development	Hood Canal Coordinating Council (HCCC)

NTAs have been assigned to one of five thematic pathways: climate vulnerability assessment and adaptation; incentives and capacity; regulation; restoration and acquisition; and science and monitoring.

10. ACRONYMS

CGS	Coastal Geologic Services
Ecology	Washington Department of Ecology
ESRP	Estuary and Salmon Restoration Program
HCCC	Hood Canal Coordinating Council
HPA	Hydraulic Project Approval
HRCD	
IDT	Interdisciplinary Team
IS	Implementation Strategy
MSDG	Marine Shoreline Design Guidelines
NEP	National Estuary Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PSEMP	Puget Sound Ecological Monitoring Program
SMP	Shoreline Master Program
WRIA	Water Resources Inventory Area

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