Completion Report

Period 2/1/2013 - 1/31/2014

Project R/OCEH-2 - Impacts of Armoring on Puget Sound Beaches Diverse Effects on Diverse Scales

STUDENTS SUPPORTED

Heerhartz, Sarah, sarmarie@u.washington.edu, University of Washington, School of Aquatic and Fisheries Sciences, status cont, field of study Marine Ecology, advisor C.A. Simenstad and M.N. Dethier, degree type PhD, degree date 2013-12-01, degree completed this period Yes
Student Project Title Shoreline armoring disrupts marine-terrestrial connectivity across the nearshore ecotone

Involvement with Sea Grant This Period Graduate student funded largely by WSG

Post-Graduation Plans Currently seeking postdoctoral positions

Marks, Julia, marksj3@uw.edu, University of Washington, Oceanography, status new, no field of study, no advisor, degree type BA, degree date 2014-06-01, degree completed this period No
Student Project Title none

Involvement with Sea Grant This Period Hourly work helping in field and lab.

Post-Graduation Plans none

Reynolds, Ben, brr2@uw.edu, University of Washington, Oceanography, status new, no field of study, no advisor, degree type BA, degree date 2014-06-01, degree completed this period No
Student Project Title none

Involvement with Sea Grant This Period Hourly work helping in field and lab.

Post-Graduation Plans none

Simans, Kevin, kevdude2@uw.edu, University of Washington, Oceanography, status new, no field of study, no advisor, degree type BA, degree date 2014-06-01, degree completed this period No
Student Project Title none

Involvement with Sea Grant This Period Hourly work helping in field and lab.

Post-Graduation Plans none

CONFERENCES / PRESENTATIONS

“Impacts of Armoring on Puget Sound Shorelines”. Presentation by Megan Dethier. WDFW and UW Brown Bag Seminar Series, Olympia, WA. Audience almost entirely personnel from state,

county, and federal agencies, including many managers and policy-makers., public/profession presentation, 75 attendees, 2014-01-08
"Intertidal habitat". Presentation by Megan Dethier. Cherry Point Aquatic Reserve Forum. Sponsored by ReSources and the Cherry Point Aquatic Reserve Citizen Stewardship Committee. Bellingham Technical College., public/profession presentation, 50 attendees, 2013-11-09
"Impacts of armoring on Puget Sound shorelines". Seminar by Megan Dethier. Friday Harbor Laboratories seminar series, University of Washington., public/profession presentation, 60 attendees, 2013-05-15
"Impacts of armoring on Puget Sound shorelines". Presentation by Megan Dethier. Sound Shoreline Science Forum, sponsored by Futurewise. Friday Harbor, WA., public/profession presentation, 42 attendees, 2013-05-17
"Effects of shoreline armoring on beach wrack subsidies to the nearshore ecotone" Presentation by Sarah Heerhartz at the Coastal and Estuarine Research Federation meeting, San Francisco., public/profession presentation, 50 attendees, 2013-11-05

ADDITIONAL METRICS

K-12 Students Reached	Acres of degraded ecosystems restored as a result of Sea Grant activities
Curricula Developed	Resource Managers who use Ecosystem-Based Approaches to Management
Volunteer Hours	HACCP - Number of people with new certifications
Cumulative Clean Marina Program - certifications	

PATENTS AND ECONOMIC BENEFITS

No Benefits Reported This Period

TOOLS, TECH, AND INFORMATION SERVICES

Description		Developed	Used	Names of Managers	Number of Managers
Suite of methods for quantifying beach parameters (wrack and log accumulation,	Actual (2/1/2013 - 1/31/2014)	0	1	2013 used = 2 - WDFW and Skagit Coop biologists; (2014 anticipated = 10 - potential use by South Puget Sound Salmon Enhancement Group, North Olympic Salmon Coalition, and Northwest Straits	2
	Anticipated (2/1/2014 - 1/31/2015)	0	0		

sediment types, beach profiles, juvenile clam abundance) that could be impacted by armoring.	Foundation; included in Shoreline Monitoring Toolbox of PSEMP Nearshore Work Group.)

HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

ADDITIONAL MEASURES

Safe and sustainable seafood

Number of stakeholders modifying practices
Actual (2/1/2013 - 1/31/2014) 0
Anticipated (2/1/2014 - 1/31/2015) 0

Number of fishers using new techniques
Actual (2/1/2013 - 1/31/2014) 0
Anticipated (2/1/2014 - 1/31/2015) 0

Sustainable Coastal Development
Actual (2/1/2013 - 1/31/2014) 0
Anticipated (2/1/2014 - 1/31/2015) 0

Coastal Ecosystems
Actual (2/1/2013 - 1/31/2014) 0
Anticipated (2/1/2014 - 1/31/2015) 0
Armor removal efforts initiated or being permitted at 5 locations, in each case with advice from our team on monitoring methods; Cornet Bay, Seahurst Park, Howarth Park, Cooper Point, Discovery Bay (no restoration activities complete, so no communities reported for 2013)

PARTNERS

Partner Name City of Burien
Partner Name Nearshore Habitat Program, Washington State Department of Natural Resources
Partner Name Puget Sound Partnership
Partner Name Skagit River System Cooperative, type Other, scale Tribal
Partner Name University of Washington
Partner Name Washington State Department of Ecology
Partner Name Washington State Department of Fish and Wildlife

IMPACTS AND ACCOMPLISHMENTS

Title Washington Sea Grant research offers needed tools to track environmental effects of beach

restoration and armoring

Type impact

Relevance, Response, Results Relevance About a third of Puget Sound's 2,500 miles of shoreline are altered, and many beaches have been extensively armored with bulkheads and other hard materials. The Puget Sound restoration plan establishes armor removal and beach restoration as a regional priority, and a net decrease in armored shorelines is one of the 2025 restoration targets. However, despite its importance as a regional priority, there is little objective scientific information available to assess armoring impacts and restoration responses. Response Washington Sea Grant-funded researchers monitored and compared key ecological indicators at 31 pairs of armored and unarmored beaches on South and Central Puget Sound. The study provided groundbreaking data that identified the physical and biological characteristics of shoreline environments that may be affected by armoring, including beach wrack, riparian vegetation, important invertebrate populations, sediments, and bird and fish populations. Results The study has provided the impetus for a systematic evaluation of armored and unarmored sites throughout Puget Sound, and state agencies now are funding its extension to northern beaches. Managers recognize the importance of monitoring shoreline changes, and the study-identified indicators and measurement procedures are being used to establish sound-wide monitoring protocols. In January, researchers were invited to the state capital to present their findings to city, county, state, and federal resource managers and policymakers.

Recap Washington Sea Grant-sponsored research provides long-needed data and protocols for evaluating beach armoring impacts and shoreline restoration benefits, leveraging state funds to expand this research.

Comments Primary Focus Area OCEH (HCE) Secondary Focus Area COCC (SCD) State Goals Protect and restore marine, coastal and estuarine habitats (HCE Restore). Assist coastal communities and marine-dependent businesses in planning and making decisions that provide local and regional economic benefits, increase resilience and foster stewardship of social, economic and natural resources (SCD Efficiency).

Related Partners , Skagit River System Cooperative, City of Burien, Nearshore Habitat Program, Washington State Department of Natural Resources, ,

PUBLICATIONS

Title Shoreline Armoring in Puget Sound

Type Internet Resources, Topical Websites Publication Year 2014 Uploaded File none URL https //sites.google.com/a/uw.edu/shoreline-armoring/

Abstract This website provides information on research that is currently under way to identify the physical and biological impacts of shoreline armoring in Puget Sound. The Puget Sound Partnership has identified armoring as a significant threat to the health of the Sound and a key feature in need of restoration. Research is needed to understand impacts of armoring and to determine under what circumstances armoring has negative effects. We are investigating

physical and biological features of paired armored and unarmored beaches throughout Puget Sound. This broad survey of sites will provide information about large-scale and long-term changes associated with armoring, and how these might vary among locations.

Citation (website - see url)

Copyright Restrictions + Other Notes

Journal Title none

Title Shoreline armoring in an estuary alters community composition and reduces the abundance of wrack-associated invertebrates in the nearshore ecotone

Type Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year 2014 Uploaded File none URL none

Abstract Beach wrack is an organic subsidy that supports supralittoral invertebrate communities in many coastal systems. When beaches are fringed with riparian vegetation, wrack is sourced from both marine and terrestrial ecosystems in the form of detached macroalgae and seagrass and terrestrial leaf litter. Previous research has shown that shoreline armoring disrupts marine-terrestrial connectivity and alters the amount and composition of beach wrack. We sampled invertebrates associated with beach wrack at 29 paired armored and unarmored beaches in central and south Puget Sound, WA. Invertebrate assemblages were significantly different between armored and unarmored beaches. Unarmored invertebrate assemblages were characterized by talitrid amphipods and adult and larval dipteran and coleopteran insects (flies and beetles) and correlated with the amount of beach wrack and logs, the proportion of terrestrial material in wrack, and the maximum elevation of the beach.

Citation Sarah Heerhartz, Megan Dethier, Jason Toft, Jeffery Cordell, Andrea Ogston, Charles Simenstad, in review.

Copyright Restrictions + Other Notes

Journal Title Estuaries and Coasts

Title Are bulkheads bad for Puget Sound?

Type Reprint from a Newsletter, Magazine, or Other Periodical (not peer reviewed; see RR for peer-reviewed reprints) Publication Year 2013 Uploaded File none URL none

Abstract Enviros and waterfront owners have argued the question for years. UW biologist Megan Dethier is out to find the answer.

Citation Scigliano, E. 2013. Crosscut 2013.11.4

Copyright Restrictions + Other Notes Picked up by UW News Service, Nov. 2013

Journal Title crosscut.com

Title Effects of shoreline armoring on beach wrack subsidies to the nearshore ecotone in an estuarine fjord.

Type Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year 2014 Uploaded File none URL http //dx.doi.org/10.1007/s12237-013-9754-5

Abstract The ecological significance of algal and seagrass wrack subsidies has been well-documented for exposed-coast sandy beaches but is relatively unstudied in lower-energy and mixed-sediment beaches. In marine nearshore environments where beaches are fringed with riparian vegetation, the potential for reciprocal subsidies between marine and terrestrial ecosystems exists. Within the marineterrestrial ecotone, upper intertidal "wrack zones" accumulate organic debris from algae, seagrass, and terrestrial plant sources and provide food and habitat for many organisms. Human modification also occurs within this ecotone, particularly in the form of armoring structures for bank stabilization that physically disrupt the connectivity between ecosystems. We conducted detailed wrack and log surveys in spring and fall over 3 years at 29 armored– unarmored beach pairs in Puget Sound, WA, USA. Armoring lowered the elevation of the interface between marine and terrestrial ecosystems and narrowed the width of the intertidal transition zone. Armored beaches had substantially less wrack overall and a lower proportion of terrestrial plant material, while marine riparian zones (especially trees overhanging the beach) were an important source of wrack to unarmored beaches. Armored beaches also had far fewer logs in this transition zone. Thus, they lacked biogenic habitat provided by logs and riparian wrack as well as the organic input used by wrack consumers. Results such as these that demonstrate armoring-associated loss of connectivity across the marine-terrestrial ecotone may be useful in informing conservation, restoration, and management actions.

Citation Heerhartz, S.M., M. N. Dethier, J. D. Toft, J. R. Cordell, and A. S. Ogston. 2014. Effects of shoreline armoring on beach wrack subsidies to the nearshore ecotone in an estuarine fjord. In press, Estuaries and Coasts.

Journal Title Estuaries and Coasts

Title Shoreline armoring disrupts marine-terrestrial connectivity across the nearshore ecotone

Type Full theses / Dissertations Publication Year 2013 Uploaded File none URL none

Abstract As the interface between land and sea, the nearshore (marine-terrestrial) ecotone converges at the intertidal zone, where the exchange of organic materials between ecosystems occurs in the form of beach wrack piles of seaweed, seagrass, and terrestrial plant debris suspended in water and deposited on shore as the tide ebbs. The ecological significance of algal and seagrass wrack subsidies has been well-documented for exposed-coast sandy beaches but is relatively unstudied in lower-energy and mixed-sediment beaches. In the nearshore ecotone where beaches are fringed with riparian vegetation, the potential for reciprocal subsidies between

marine and terrestrial ecosystems exists. Human modification also occurs within this ecotone, particularly in the form of armoring structures for bank stabilization that physically disrupt the connectivity between ecosystems. I conducted detailed surveys of beach physical parameters, wrack and log accumulations, and supralittoral invertebrates in spring and fall over 3 years at 29 armored-unarmored beach pairs, and behavioral observations of juvenile salmon (Oncorhcynchus spp.) and birds at 6 pairs in Puget Sound, WA, USA. Armoring lowered the elevation of the interface between marine and terrestrial ecosystems and narrowed the width of the intertidal transition zone. Armored beaches had substantially less wrack overall and a lower proportion of terrestrial plant material in the wrack, while marine riparian zones (especially trees overhanging the beach) were an important source of wrack to unarmored beaches. Armored beaches also had far fewer logs in this transition zone. Invertebrate assemblages were significantly different between armored and unarmored beaches. Unarmored invertebrate assemblages were characterized by talitrid amphipods and adult and larval dipteran and coleopteran insects (flies and beetles, including some types that have been shown to contribute to juvenile salmon diets in other studies) and correlated with the amount of beach wrack and logs, the proportion of terrestrial material in wrack, and the maximum elevation of the beach. Shoreline type (armored or unarmored) influenced juvenile salmon distribution, however their feeding rates were relatively high at all sites, thus decreased prey availability (i.e. fewer marine riparian and/or wrack-associated insects) or altered prey resources are likely the most detrimental effects of armoring on these fish in the nearshore ecotone. Terrestrial birds, particularly Song Sparrows (Melospiza melodia) were commonly observed foraging among beach wrack and logs at unarmored beaches, but were largely absent from armored beaches. Based on my results, I developed a conceptual model summarizing marine-terrestrial connections across the nearshore ecotone and the disruptive effects of armoring. This study demonstrates that shoreline armoring disrupts marine-terrestrial connectivity, affecting the amount and type of organic material delivered to the nearshore ecotone in the form of wrack and logs, the abundance and taxonomic composition of supralittoral invertebrates, and the distribution and behavior of secondary consumers (juvenile salmon and birds). The results of my dissertation provide new information on relationships between physical and biological variables in the nearshore ecotone and connections between marine and terrestrial ecosystems that may be useful in informing conservation, restoration, and management actions.

Citation Heerhartz, Sarah Marie. PhD Dissertation, School of Aquatic and Fishery Sciences, University of Washington.

Journal Title none

Title Movement patterns and feeding behavior of juvenile salmon (Oncorhynchus spp.) along armored and unarmored estuarine shorelines

Type Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year 2014 Uploaded File none URL none

Abstract Estuarine nearshore environments are important habitats for many organisms, including juveniles of several Pacific salmon species (Oncorhynchus spp.). These habitats provide shallow

water and high prey productivity, but are increasingly modified by anthropogenic activity including shoreline armoring, which disrupts connectivity between aquatic and terrestrial realms and artificially steepens the shore. Such effects may have adverse consequences for juvenile salmon, particularly Chinook (O. tshawytscha) and chum (O. nerka), which are known to rely on shallow, productive nearshore habitats for foraging and refuge from predators during their outmigration from natal streams to the sea. We developed snorkel methods to quantify feeding rates, movement rates, and path complexity of juvenile salmon along armored and unarmored shorelines in Puget Sound, WA, USA. We found that juvenile salmon had relatively high feeding rates along all shoreline types, but that path straightness and movement rates showed some variation between armored and unarmored sites. Feeding fish swam in more complex paths and were observed in larger schools than non-feeding fish, and path straightness and movement rate were negatively correlated with proportion of time feeding. Feeding behavior, school size, and movement rates also showed variation by species. Shoreline type (armored or unarmored) influenced juvenile salmon distribution, and unarmored shorelines appear to accommodate a greater diversity of movement patterns than armored shorelines. Our results show that juvenile salmon feed at high rates along armored and unarmored estuarine shorelines, thus decreased prey availability or altered prey resources are likely the most detrimental effects of armoring in estuarine nearshore ecosystems.

Citation In review, Environmental Biology of Fishes

Copyright Restrictions + Other Notes

Journal Title none

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

Type influenced Period 2013-07-01 2015-06-30Amount $69405

Purpose Broad monitoring study of the shorelines of Puget Sound, which has many ties to this WSG project

Source WaDNR

Type influenced Period 2013-02-01 2014-01-31Amount $142068

Purpose To expand WSG work into northern Puget trough using WSG methods and some personnel (funding to Skagit River System Cooperative, with subcontract to UW); plus extensive match from Tribes

Source WDWF (EPA funding)

COMPLETION NARRATIVE

Uploaded File Dethier_8189_completio....7.pdf

COMPLETION (FINAL) REPORT NARRATIVE

Impacts of Armoring on Puget Sound Beaches: Diverse Effects on Diverse Scales

Main Participants: Megan Dethier, Sarah Heerhartz, Andrea Ogston, Jason Toft, Jeff Cordell (all University of Washington); Helen Berry (Wa DNR); many student helpers

Rationale

Shoreline armoring is hypothesized to be significantly detrimental to the health of the Puget Sound ecosystem. Armoring is listed as a significant "threat" in the Action Agenda of the Puget Sound Partnership, and as a key focus for restoration and adaptive management in the Partnership's Biennial Science Work Plan. It is also noted as a factor that disrupts natural processes in the conceptual models of the Puget Sound Nearshore Ecosystem Restoration Project. Numerous armor-removal projects are underway or are being considered. Yet there are surprisingly few data documenting actual negative impacts of armoring on physical or biological features of nearshore ecosystems, especially for the kind of gravel beaches that dominate Puget Sound. Scientists need to be able to provide managers and policy makers with a clear biological and physical narrative about the impacts of armoring that is backed by hard data. To do this we need to better characterize the local habitat and ecosystem functions that are lost through burial or truncation of beaches. Current estimates of the proportion of all Puget Sound's shorelines that are armored are around 30% (PSP Action Agenda; PSNERP Change Analysis dataset) and the proportion for south-central Puget Sound is much higher, around 64%. The demand for shoreline protection structures is almost certain to increase with heightened concerns about erosion caused by sea-level rise; without convincing scientific evidence about the environmental costs of armoring, the economic benefits of armoring (protection of property) are likely to be paramount in the public perception.

Project Objectives

Our long-term objective was to gain a better understanding of the impacts of shoreline armoring on the physical and ecological dynamics of Puget Sound beaches. Demonstrating whether armoring has significant impacts on ecosystem functions, goods, and services (and whether removal of armoring restores these functions) requires long-term and large-scale interdisciplinary studies. Armoring marine shorelines may alter natural processes at a variety of spatial and temporal scales; some, such as 'starving' the beach of sediments, may take decades to become visible.

Methodology

Research on armoring impacts, and conversely on armoring removal and beach nourishment, has been limited in part by the difficult issues of the broad spatial and temporal scales over which armoring is thought to affect nearshore ecosystems. In addition, because impacts of armoring involve linkages between physical (wave energy, grain sizes, current flow) and biological processes (accumulation of deposited beach wrack, insect recruitment, marine invertebrate recruitment, etc.), informative research needs to be interdisciplinary. We used a

combination of intensive local-scale observations and experiments with extensive, rapid surveys across multiple environments to maximize the applicability of our findings.

In our original proposal we planned to focus much of our research effort on before-after studies of a major armor-removal and restoration effort at Seahurst Park in south-central Puget Sound. We anticipated that this would provide an opportunity for an integrated, cooperative research effort to fill some of the data gaps described above and to demonstrate how this information can be used to improve future restoration efforts. However, the Seahurst project was delayed for over 3 years by local and federal permit processes and then by lack of federal funding, so our research was channeled into other efforts. Our original "Broader-Scale research" plan was to perform rapid surveys of 10 pairs of beaches (armored and unarmored) around central Puget Sound. Instead, we expanded these rapid surveys to 25 pairs of sites in central Sound and then added an additional 6 pairs of sites in southern Puget Sound (Figure 1), which were different energetically and biologically from the central Sound sites. Some of these pairs of beaches were surveyed 2-4 times a year to look for regular seasonal changes in physical and biological characteristics of the upper shore.

At all sites we gathered data on physical setting (character of the backshore, overhanging vegetation, location in the drift cell, etc.), beach topography (surveyed), and sediment grain sizes. We also collected biological data and samples including abundance and types of logs and wrack, abundance and types of insects, crustaceans, and worms in the wrack line, and abundance and types of juvenile clams at Mean Low Water. Invertebrate communities were characterized using both quantitative surveys of wrack line biota and short-term traps to catch amphipods (beach hoppers) and insects. For a subset of these sites we also sampled juvenile clams at Mean Lower Low Water. Our field work generated almost 2000 samples from the wrack zone; we identified, counted, and/or weighed wrack, amphipods, insects, and other organisms found in the wrack line samples (725 samples), pitfall traps (500 samples), fallout traps for insects (80 samples), and wrack tubes to study rates of decomposition (264 samples). Sarah Heerhartz, the graduate student supported by this funding, and a number of UW undergraduates and recent graduates working under her conducted this laborious sorting and taxonomic work. We also completed processing of 840 small sediment samples to extract, identify, and measure juvenile clams from the field surveys (work done by Dethier) and of hundreds of beach sediment samples for grain size analyses (work done by Oceanography undergraduates, largely volunteers).

In addition, the fact that by spring 2012 we had a well-established methodology and well-trained crew enabled the PI (Dethier) to work with the Skagit River System Cooperative to apply for and receive 2 years of funding from the Washington Department of Fish and Wildlife to expand this research into the northern Salish Sea. That effort is ongoing, especially data analyses. It represents a geographic expansion that greatly increases the strength and scale of inference of our Sea Grant-funded results.

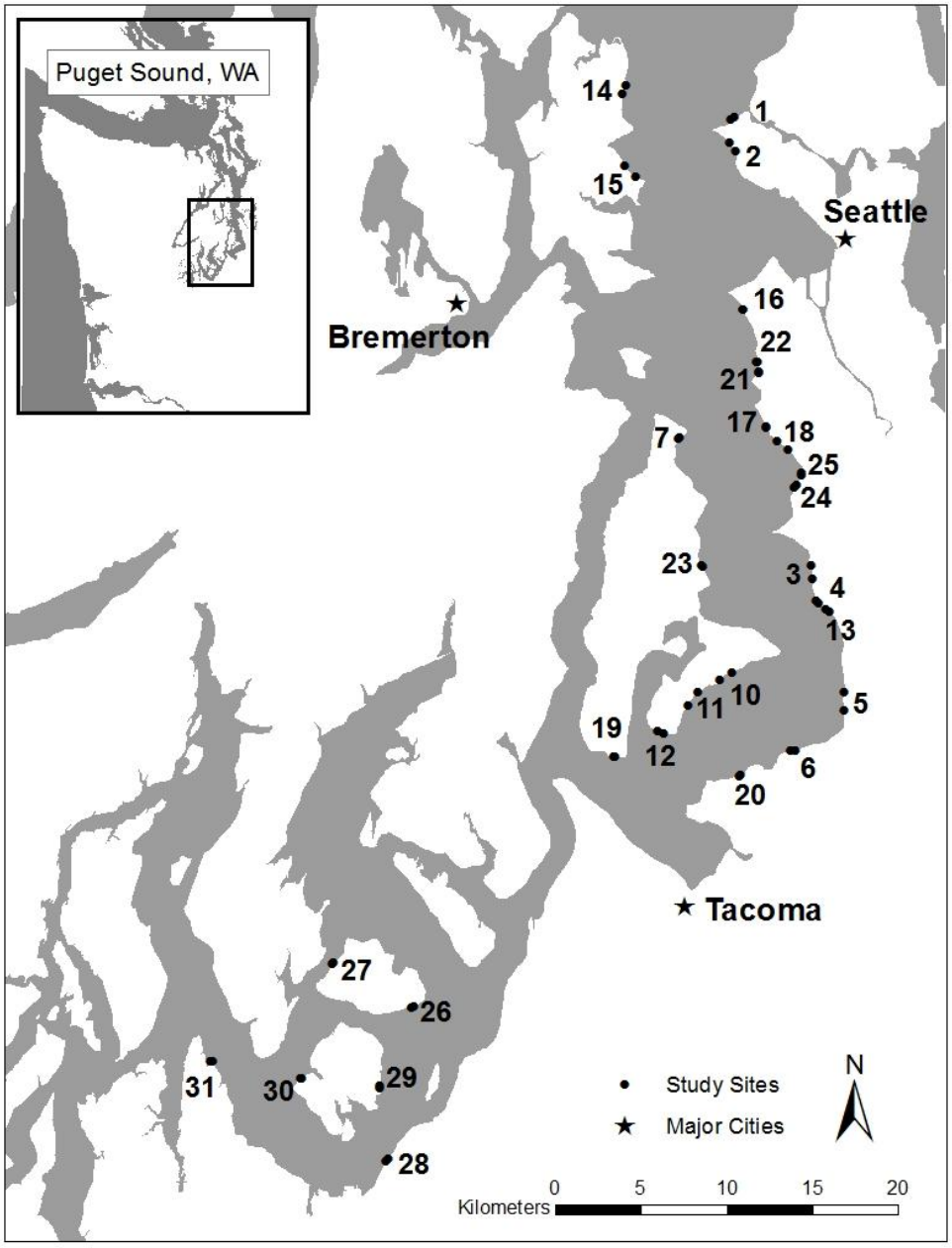

Figure 1. Study site locations. Each number indicates a pair of sites. Two pairs of sites (#8 and 9) were dropped from analysis because the 'paired' beaches were not well matched.

Major Findings

Beaches in Puget Sound vary naturally in both geomorphology and biology because of the huge variation in wave energy, geologic history, presence and type of backshore, and many other factors that are independent of armoring. Finding a "signal" of any impact of armoring thus involves finding ways to filter out this natural "noise." Our method consisted of comparing pairs of beaches that were near each other and differed in armoring but not in wave energy, aspect, and other key physical variables. This allowed us quantify the effects of armoring better than has yet

been possible in such a physically complex and heterogeneous environment. Paired analyses also have a much higher statistical power than other kinds of analyses, because they only compare "matched" beaches and thus filter out much of the natural variation.

Physical Monitoring.

Biological impacts of armoring can result from changes in the physical characteristics of beaches, especially sediment composition. Physical impacts of armoring on wave reflection and sediment supply and transport were studied with detailed beach profiles and deployment of wave gauges by the Ogston Sediment Dynamics group at the UW School of Oceanography. Physical characteristics such as wave energy, sediment sources, and width of the low-tide terrace are highly variable among the selected pairs of armored/unarmored beaches. Seasonal monitoring of beach morphology and grain sizes suggested that seasonal changes in these characteristics are masked by larger effects of abrupt, short-term events, e.g. storms that carry away fine sediments. Our data show slightly steeper beach foreshores (upper beach) and larger sediment sizes at armored beaches relative to their unarmored equivalents; these physical factors may impact the spatial extent and habitat quality of intertidal environments, although grain size differences between the armored/unarmored beaches are complex. A major concern is loss of the sediment grain sizes needed by surf smelt and other forage fish for depositing eggs on the high shore; WDFW and other groups are studying this effect. At our sites, armored beaches were truncated by an average of 8.9 m horizontally and 0.9 m vertically, thus reducing beach area substantially.

To characterize the impact of armoring on waves, a focused experiment was conducted with a pair of wave gauges deployed during the fall-winter storm period near unarmored (reference) and armored sites at Seahurst Park and at another location in central Sound for short periods during the fall 2011 and winter 2012, and for a lengthy period in fall 2012. As with other measured parameters, natural variability makes it difficult to quantify an armoring effect. The data from Seahurst Park suggest that close to armoring, wave heights are increased during storm events. When wave gauges are deployed farther away from armoring, no effect is visible. These physical data are in a manuscript under preparation by Ogston and other team members.

Wrack Zone Effects.

1. Armoring the shoreline substantially impacts a number of parameters on the upper shore. Armored shorelines have less riparian vegetation, and substantially reduced accumulations of logs and marine and terrestrial wrack (detritus) (Figure 2). Armored beaches have particularly low accumulations of terrestrial-source wrack (leaves, needles, sticks), suggesting that the lack of local sources (because of reduced riparian vegetation) has a direct consequence to this metric. Logs buffer the impacts of storm waves, and other studies have shown some benefits of logs in providing habitat for various animals. Beach wrack, while regarded as a nuisance by some homeowners, serves important ecosystem functions (see below). These results are described in a peer-reviewed paper in press in *Estuaries and Coasts.*

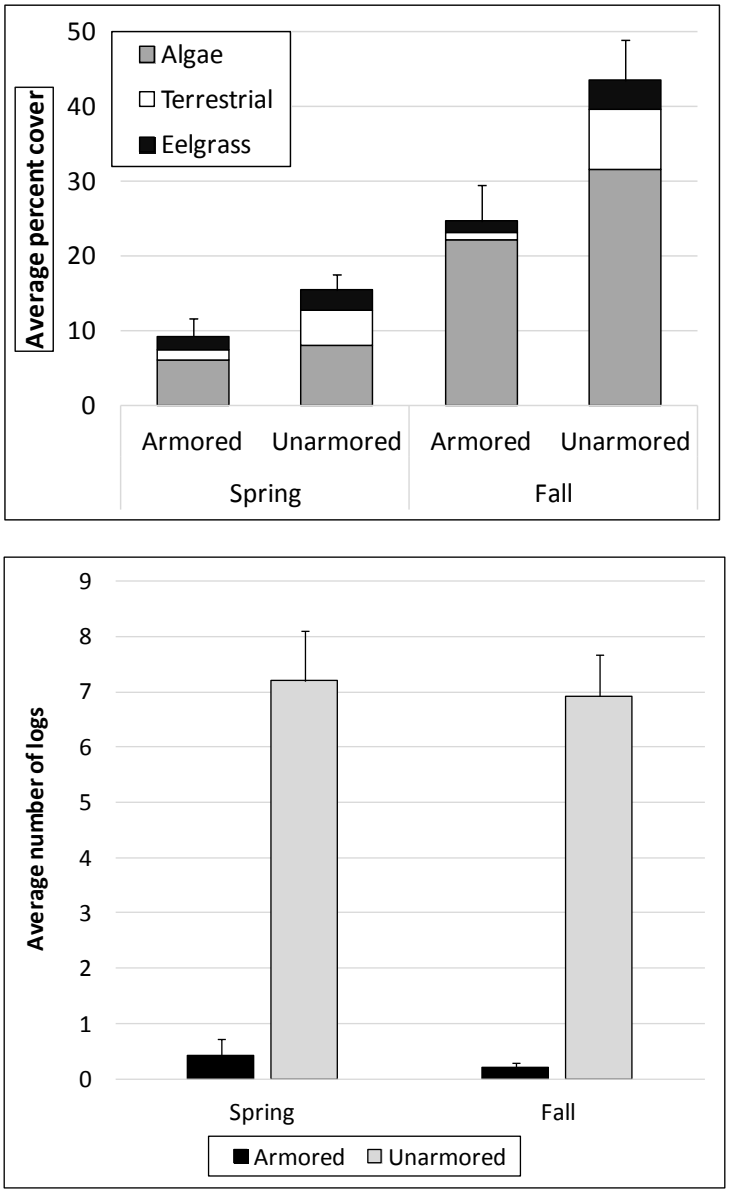

Figure 2. Average percent cover and composition of wrack (top panel) and number of logs (bottom panel) at armored and unarmored beaches in spring (N = 24 beach pairs) and fall (N = 27 pairs). Error bars represent standard error among the mean per-beach values.

2. Beach wrack, especially accumulations of detached seaweeds and seagrasses, creates a moist habitat and a food resource for a diverse group of invertebrates. These include amphipods (beach hoppers), insects, and small worms. Because shoreline armoring greatly reduces wrack accumulation, armored beaches have much lower numbers of these invertebrates (Figure 3). Invertebrates are responsible for gradual consumption and decomposition of the accumulated wrack, and are in turn a food resource for other organisms, including shorebirds, terrestrial birds, and fishes. Wrack decomposition rates (using short-term experimental decomposition experiments at selected beaches) are reduced when there are fewer amphipods, as is the case at armored beaches. Results on

invertebrate communities are in a manuscript currently being peer-reviewed in *Estuaries and Coasts.*

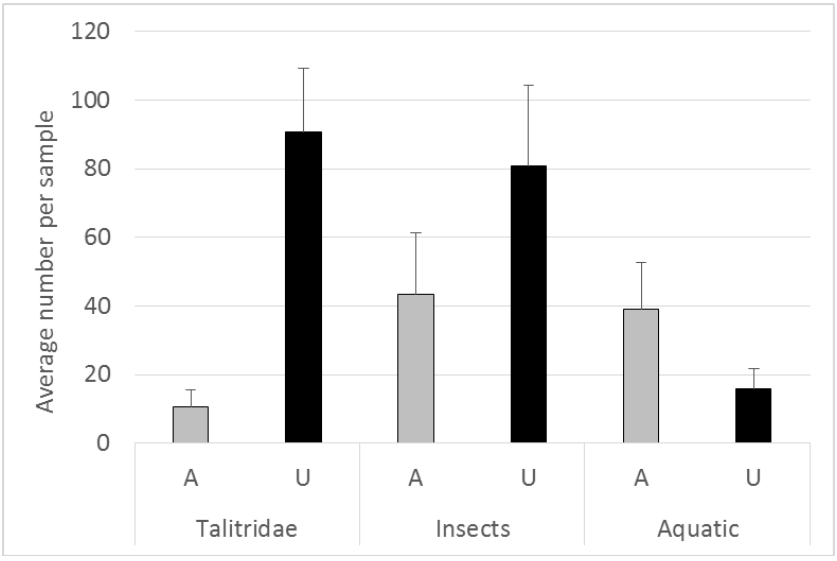

Figure 3. Summary of average invertebrate abundances from wrack samples. Armored (A) means are shown in gray, unarmored (U) means shown in black. Error bars represent standard error of the mean. Differences in armored and unarmored means were statistically significant for all taxa groups shown here.

Effects on Juvenile Salmon.

To understand some of the food web implications of the large differences in abundances of logs, wrack, invertebrates, and overhanging vegetation found at armored vs. unarmored beaches, Sarah Heerhartz undertook a project to quantify abundance and behavior of juvenile salmon at high tide at armored and unarmored sites in central Sound. This was accomplished by conducting shallow water snorkel surveys during peak outmigrations of juvenile chum salmon in April-May, and juvenile Chinook salmon in June-July. She developed methods to quantify feeding rates, movement rates, and swimming path complexity of juvenile salmon, and found that they had relatively high feeding rates along all shoreline types. If armored beaches have decreased availability of key prey items but juvenile fishes are trying to forage there, this could have detrimental effects on fish energetics. Swimming-path straightness and movement rates showed some variation between armored and unarmored sites. Feeding behavior, school size, and movement rates also varied with fish species. Unarmored shorelines appear to accommodate a greater diversity of movement patterns than armored shorelines. These results are currently being peer-reviewed in *Environmental Biology of Fishes.*

Effects on Terrestrial Birds.

Terrestrial birds and shorebirds also forage on Puget Sound beaches, and Dr. Heerhartz worked out methodologies for quantifying beach use by terrestrial birds (from land). Her data suggest that a variety of terrestrial birds use the backshore of Puget Sound beaches for foraging (among logs or in the wrack line), and that these foraging opportunities may be quite different on armored shores. Armored shores are used by more gulls and crows, while unarmored shores had more individuals and species of songbirds, especially Song Sparrows (Figure 4). Birds observed

on unarmored beaches spent proportionately more time foraging than on armored beaches, presumably consuming talitrid amphipods and insects found among beach wrack and logs. Thus terrestrial birds appear to benefit from beach wrack subsidies. These data are in a chapter of Heerhartz' dissertation, and will likely ultimately appear in a peer-reviewed summary paper.

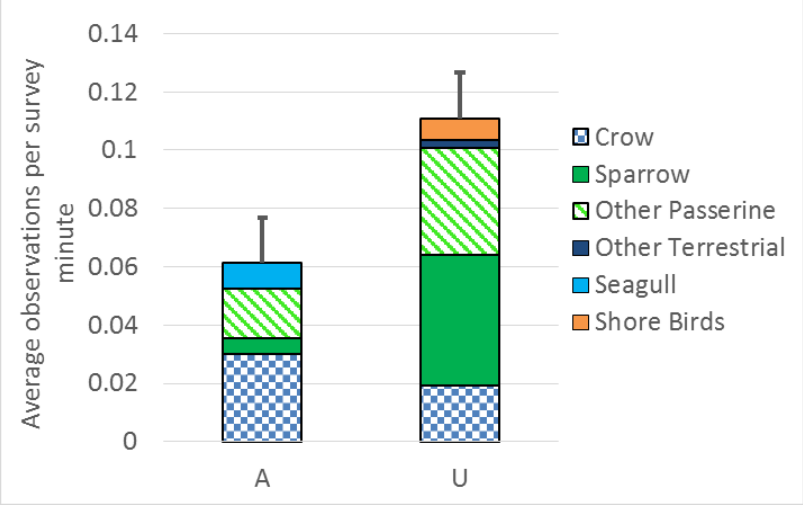

Figure 4. Total number of individual observations per survey minute in each bird group at armored and unarmored beaches.

Lower-Shore Impacts.

Short-term impacts of armoring in the mid or low shore were not evident based on our work with juvenile clams. Armoring had no discernible effect on mid-shore sediment grain sizes or numbers of juvenile clams (either naturally present on the beach, or recruiting into sterile sediment cores). However, because clams and many other intertidal organisms (including eelgrass, and spawning forage fish) depend on particular sediment types, if armoring alters sediments over longer term scales, it is likely to impact these organisms.

Broader-Scale Impacts.

Our paired-beach data should ultimately allow us to examine whether there are threshold effects related to the location of armoring on the shore, e.g. whether armoring at higher elevations has significantly fewer impacts on beaches than armoring placed at lower elevations. These analyses are in progress. A threshold question that is harder to address is "how much armoring does it take to impact entire shorelines" – i.e. how are cumulative effects manifested? Armoring by definition reduces erosion and thus prevents bluff sediments from reaching the beach. These sediments are what create Puget Sound's beaches and if enough bluffs are armored, beaches will become sand-starved. However, because this process may take years or decades, quantifying it is challenging. Our additional parallel research in the northern Salish Sea (mentioned in *Methodology*) adds another 34 pairs of sites from near Everett to the Canadian border; eventual combining of these datasets will greatly strengthen our ability to quantify broad effects of armoring. Analyses of these data show considerable promise; for example, some parameters such as amount of wrack show a relationship with proportion of the drift cell that is armored, allowing us to quantify a cumulative effect. We are trying to examine thresholds relating to armoring elevation by quantifying the height of armoring relative to Mean Higher

High Water; a preliminary analysis suggests the number of logs on the upper shore undergoes a rather abrupt decline when the armoring reaches a particular elevation. Ultimately we envision the North, Central, and South Puget Sound datasets being combined for many analyses and being included in a peer-reviewed summary paper.

Significance of the Results

Armored shorelines are presently a major landscape component along Puget Sound beaches, and research conducted in this study and by others in different regions indicates that armoring is detrimental to natural physical and biological processes. Results from this study provide new, local information on the biological and physical characteristics of armored, unarmored, and restored shorelines. These details can be used to estimate overall impacts of armored shorelines in Puget Sound, and help guide future restoration efforts. For example, if our data indicate that only armoring emplaced below Ordinary High Water has quantifiable biological and physical impacts (at least in the short term), then this will have clear management implications both for policy regarding new armoring projects, and for prioritizing restoration projects where armor-removal is being considered. Projects to remove shoreline armoring are anticipated to be high priorities in two regional restoration efforts, the Puget Sound Partnership's Action Agenda and the Puget Sound Nearshore Ecosystem Restoration Project. In addition, the NOAA Northwest Fisheries Science Center is tasked with generating "ecological stress-response" information for Puget Sound, and armoring is regarded as one important stressor. Our broad survey of many beaches around the Sound should provide key information on this issue.

These data will be useful to many state agencies (e.g., WDFW, Dept. of Ecology) as well as County, City, and local governments as they consider policy and regulations that relate to armoring or its removal. A talk given by the PI in Olympia in January 2014 was extremely well attended by city, county, state, and federal policy makers and resource managers. Both Dethier and Heerhartz will be giving talks on this research at the Salish Sea Ecosystem Conference in April 2014, further broadening our audience. In addition, the location of a key study site in a city park provides an opportunity for substantive interaction between scientists, planners, and the wider community. This project creates a feedback mechanism between scientific studies, public and professional outreach, and management.