Apr 21st, 9:00 AM - Apr 22nd, 4:45 PM

Effects of Shoreline Armoring on Physical Beach Characteristics in the Salish Sea, WA

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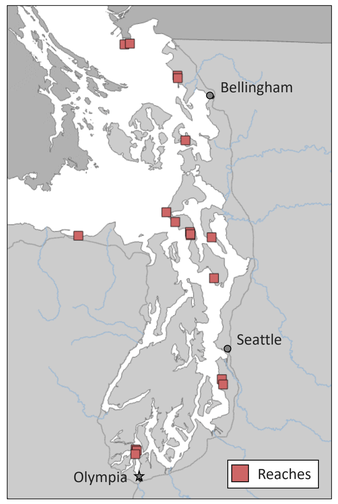
Introduction



To assess the effects of shoreline armoring on beach morphology, we compared physical beach characteristics of both the backshore and foreshore from adjacent sections of armored and unarmored shoreline at a variety of locations representing three shore types in the Salish Sea. Beach width, slope, and armor or bluff toe elevation was extracted from high-resolution lidar data[1] at 10 meter intervals alongshore, which offers a significantly more robust dataset than previous work. Findings from this research aim to provide insights about nearshore morphodynamics in the region, which can aid in optimizing armor removal restoration efforts.

Methods

Eighteen reaches were identified, each a minimum of 500 meters in length and represented one of three shore types: bluff-backed, accretionary, or transition zone, with approximately equal parts armored and natural shoreline. The table below summarizes conditions for the reaches included. Note, due to the small sample size and high variability, transition zone reaches were excluded from some analyses.

	Bluff-Backed	Accretionary	Transition Zone	TOTAL
Armor updrift	7	1	2	10
Natural updrift	4	3	1	8
TOTAL	11	4	3	18

The diagram to the right shows the general workflow used in this study. Data collection and processing was completed using ArcGIS Pro and Excel, and analysis was largely completed in R. All beach parameters were measured in both the foreshore and backshore zones as defined in the figure below.

Input Data: Digital Elevation Models (DEM)[1], Coastal Landforms[2], Tidal Datums from NOAA VDatum

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Extract Parameters from Cross-Shore Profiles (1563 profiles total): Beach width, slope, toe elevation

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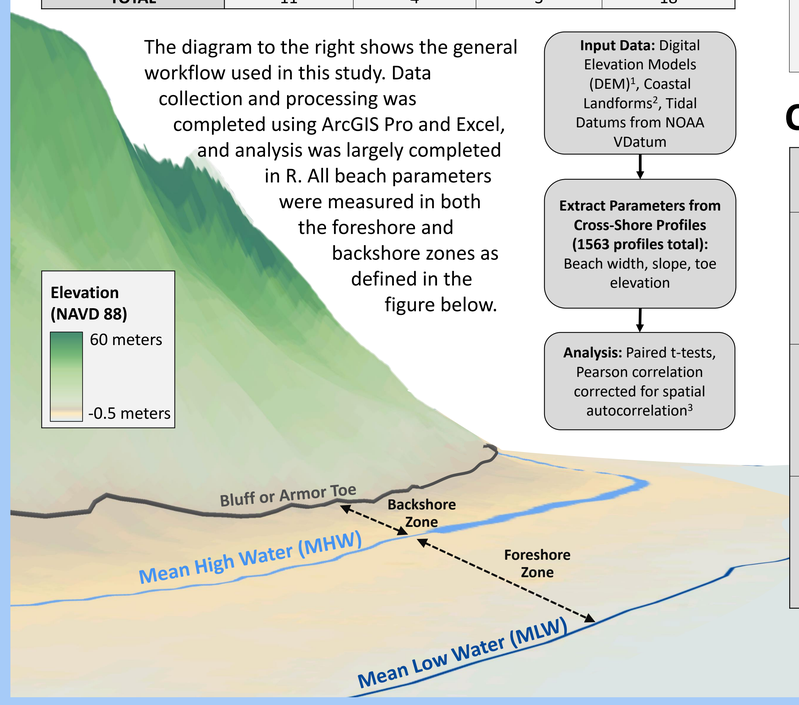
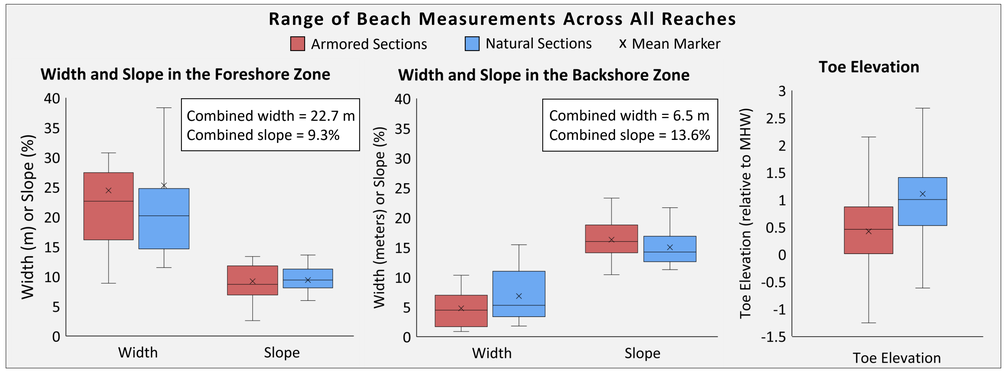
Analysis: Paired t-tests, Pearson correlation corrected for spatial autocorrelation[3]

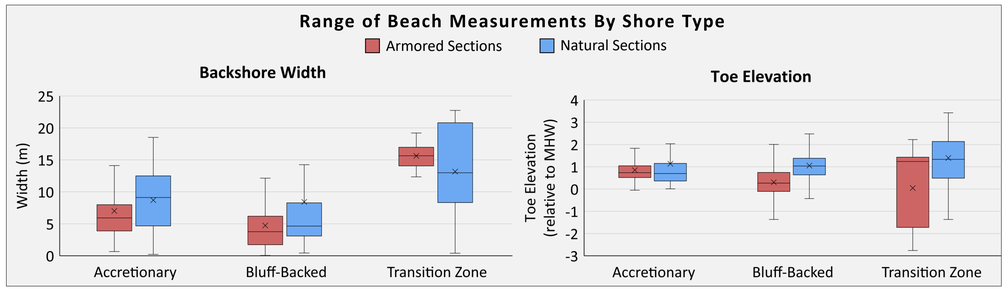


Results

In the foreshore, average width and slope were similar between armored and unarmored sections. In the backshore, average width was lower in armored sections than natural sections by all measures, and slope was slightly higher in armored sections. Toe elevation was lower by all measures in armored sections compared to natural sections. The plots below display the ranges of beach parameters.



Ranges varied by shore type. Backshore width was lower in armored sections of bluff-backed reaches and accretionary reaches. Backshore width was less variable and toe elevations more variable in armored sections of transition zones, however this pattern may be due to the small number of transition zone reaches included. Toe elevation of armored sections was slightly lower on accretionary beaches and significantly lower on bluff-backed beaches. Ranges of backshore width and toe elevation by shore type are shown in the plots below.



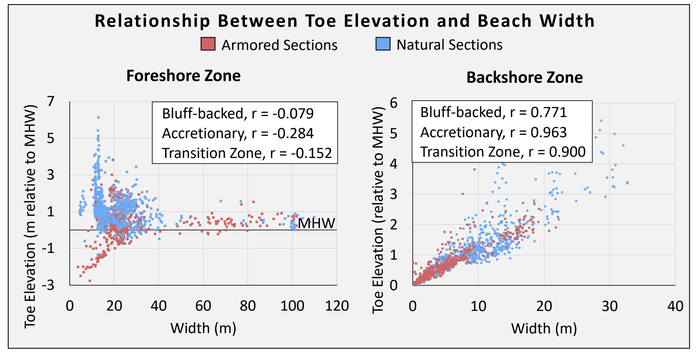
Comparison of Armored and Unarmored Beach Metrics

Summary of Paired T-Test Results			T-Statistic	P-Value
ALL REACHES	Foreshore	Width	-0.402	0.347
		Slope	-0.304	0.383
	Backshore	Width	-2.107	0.027
		Slope	1.696	0.114
	Toe Elevation		-2.673	0.018
BLUFF-BACKED	Foreshore	Width	0.548	0.298
		Slope	-1.369	0.100
	Backshore	Width	-3.252	0.004
		Slope	1.546	0.078
	Toe Elevation		-3.361	0.007
ACCRETIONARY	Foreshore	Width	-1.298	0.140
		Slope	1.024	0.191
	Backshore	Width	-0.167	0.438
		Slope	0.663	0.277
	Toe Elevation		-0.478	0.333

Paired t-tests of the average beach width and slope in armored and natural sections of each reach were run to determine if significant differences were present. The results for the paired t-tests are summarized in the table to the right. At a 95% confidence interval, backshore width and toe elevation were significantly lower in armored sections compared to their adjacent natural sections. When tested within shore types, backshore width and toe elevation were significant at a 99% confidence interval, however there was no significance in either measure along accretionary reaches.

Toe Elevation Correlations

Our data suggests that beach width is related to bluff or armor toe elevation, shown on the plots below. In accretionary reaches and transition zones, there is a strong positive correlation between backshore width and toe elevation, where backshore width increases as toe elevation increases.



Foreshore width and toe elevation are not correlated across all shore types, however there is a correlation between toe elevation and foreshore width in transition zones when toe elevation is below MHW (r = 0.850). 24% percent of toe elevations from profiles on armored beaches were below MHW, whereas only 4% of toe elevations from profiles on natural beaches, all of which were bluff-backed, and possibly composed of erosion-resistant substrate, had toe elevations below MHW.

Preliminary Conclusions

- Bluff-backed reaches had strong significant differences in toe elevations and backshore width between armored (lower and narrower) and natural sections (higher and wider), but there was no significance in accretionary reaches. Armor removal restoration efforts may be **most effective along bluff-backed shorelines** where the **armor toe is lower than the adjacent bluff toe**.
- Foreshore beach slope was not significantly different in armored and natural sections, and therefore **beach slope may not be a good measure** of restoration success.
- Toe elevation and backshore width are correlated in accretionary reaches and transition zones. In these shore types, armor removal should **focus on locations where the armor toe is significantly lower** on the beach than adjacent natural shorelines.

Discussion and Next Steps

Beach parameters varied significantly between individual reaches. This is likely due to external factors not accounted for in this research such as wave exposure and sediment size. The high number of transects included here allows for further testing on a site-specific scale that may result in additional criteria for prioritizing and monitoring armor removal efforts in the Salish Sea.

[1]WA Dept. of Ecology (2018). Puget Sound Shoreline DEMs [Digital Elevation Models]. Olympia, WA: Coastal Monitoring and Analysis Program

[2]WA Dept. of Fish and Wildlife ESRP. (2019). Coastal Landforms [Data File]. Retrieved from https://fortress.wa.gov/ecy/coastalatlas/tools/map

[3]Clifford, P., Richardson, S., & Hemon, D. (1989). Assessing the Significance of the Correlation between Two Spatial Processes. *Biometrics*, *45*(1), 123. https://doi.org/10.2307/2532039

[4]Weiner, H.M., G.M. Kaminsky, A. Hacking, D. McCandless, K. Bolles, M. Gostic, J. Liljegren, and H. Drummond, 2018. Mapping Bluffs and Beaches of Puget Sound to Quantify Sediment Supply, Estuary and Salmon Restoration Program Learning Project Final Report. Shorelands and Environmental Assistance Program, Washington State Department of Ecology, Olympia, WA. Publication #18-06-008. Available at: https://fortress.wa.gov/ecy/publications/summarypages/1806008.html