### Thesis Prospectus 2022-23

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**MES Director Approval (date):**

1. **Working title of your thesis.**

*Zostera marina* and sea level rise: Estimating future habitat availability on armored shorelines in the Puget Sound.

1. **In 250 words or less, summarize the key background information needed to understand your research problem and question.**

The most recent IPCC report projections show that there will likely be a between 0.43m and 0.84m rise in global sea level by the year 2100, with some projections over 1m (IPCC, 2022). Many studies in the Puget Sound have attempted to model or quantify affects from sea level rise (SLR) on nearshore and intertidal habitats and have projected massive losses of some habitat types (Glick et al., 2007). In contrast to these losses of habitat, potential eelgrass habitat has been modeled to expand with sea level rise in some cases (Kairis & Rybczyk, 2009; Smith & Liedtke, 2022).

The eelgrass *Zostera marina* is a subtidal grass species that provides essential habitat in the Puget sound for many species including salmonids. The preferred habitat for the grass is between 0 and -2m MLLW on fine gravel to sandy substrate (Hannam et al., 2015). *Z. marina* sites are known to have large fluctuations in coverage and distribution and are able to migrate to suitable habitat if necessary (Frederiksen et al., 2004). Eelgrass may have the ability and available space to migrate in response to sea level rise, but extensive shoreline armoring may impede the supply of finer sediments for the required substrate.

Shoreline armoring of various types exist on about 30% of Puget sound shorelines (Morley et al., 2012). These structures can form a barrier between sediment sources to shorelines and reflect wave energy, which can lead to increasing beach sediment size and lowering beach elevation (Smith & Liedtke, 2022; Thom & Williams, 2001).

1. **State your research question(s).**

To what extent will shoreward migration of eelgrass in response to sea level rise be affected by shoreline armoring in the Puget Sound?

1. **Situate your research problem within the relevant literature. What is the theoretical and/or practical framework of your research problem?**

Studies of SLR in the Puget Sound have projected that some habitat types will undergo dramatic changes the end of the century. The models that are widely used to predict these changes rely on the assumption of conversion of nearshore habitat on a basis of elevation. While some habitats are projected to undergo devastating losses, eelgrass has been modeled to have expanded habitat (Glick et al., 2007; Kairis & Rybczyk, 2009). However in some cases these models omit or generalize erosion and accretion data (Smith & Liedtke, 2022).

Studies of SLR that discuss shoreline armoring recognize these structures as a physical barrier to landward migration of species. While armoring does present a barrier, it also is recognized to alter shoreline substrate, elevation, and slope. However, the existing studies of eelgrass habitat response to SLR do not appear to address shoreline armoring or its affects to habitat quality (Kairis & Rybczyk, 2009).

I intend to research this question because there appears to be a gap in the literature between the studies of shoreline armoring as a barrier, and the studies of its other affects. I see eelgrass as a species that fits into this gap because its subtidal habitat is unlikely to be physically obstructed by armoring in the event of SLR but may still be affected by it.

1. **Explain the significance of this research problem. Why is this research important? What are the potential contributions of your work? How might your work advance scholarship?**

Eelgrass is an important habitat for many species in the Puget Sound including various salmonids. Juvenile salmon as well as feeder fish use this habitat to forage for invertebrates during their transitional stages (Kennedy et al., 2018). Eelgrass is also considered by Washington State Department of Natural Resources to be a vital sign of the health of Puget Sound waters because of its sensitivity to environmental pressures like temperature, light availability and physical disturbance (Christiaen et al., 2022). Despite its sensitivity, eelgrass can also provide significant ecosystem services such as carbon storage, reducing sediment resuspension, and mitigation of ocean acidification (Christiaen et al., 2022). Many studies of SLR in the Puget Sound seem to focus on intertidal species than subtidal nearshore species as they are less at risk from inundation. When eelgrass is studied, the focus tends to be on the larger grass beds in river deltas where the gentle slope and high accretion rates may allow the grass to keep pace with SLR. My research could help to provide a clearer picture of the affects of SLR on eelgrass in fringing beds where narrow, steep shorelines may accentuate the influence of SLR.

Shoreline armoring is widespread in the Puget Sound and efforts are taking place to remove barriers and restore natural shorelines. However, with the increasing threat of rising water, landowners may decide to place more barriers to protect their assets (Smith & Liedtke, 2022). Understanding the extent of the environmental risk from shoreline armoring is important for decision makers considering either removal, construction, or preservation of these structures.

1. **Summarize your study design. If applicable, identify the key variables in your study. What is their relationship to each other? For example, which variables are you considering as independent (explanatory) and dependent (response)?**

I plan to use GIS spatial analysis and the open source Sea Level Affecting Marshes Model (SLAMM) to examine armored shorelines near eelgrass habitat (Clough et al., 2016). I intend to quantify the extent of eelgrass habitat in Puget Sound that may be affected by shoreline armoring, then select several site pairs for more focused analysis. I will select 3 site pairs in 4 regions of the Puget Sound: North Sound, Central Sound, Hood Canal, and South Sound. Site pairs of armored and unarmored beaches 1-5 km in length will be selected with the methods of Dethier et al. by attempting to match geomorphic and bathymetric characteristics, location in the same drift cell and close proximity of the pair member (Dethier et al., 2016). At each site I will measure beach slope, width, and armor elevation before using SLAMM to estimate habitat change.

Figure 1. Flowchart of Study Design.

Products of analysis will include: Summary statistics of eelgrass and armoring coverage, maps of habitat coverage, Comparisons of site pair data, site specific SLR inundation models, and habitat change projections. These products and data will be used to compare and discuss differences in potential habitat migration between armored and unarmored sites, as well as between regions and fringe and flat habitat types.

1. **Describe the data that will be the foundation of your thesis. Will you use existing data, or gather new data (or both)? Describe the process of acquiring or collecting data.**

Data will be gathered from existing spatial datasets. The Washington Department of Natural Resources will likely be the primary source of data. Open access datasets are currently available on the WSDNR website and data portal. Digital elevation models, bathymetry, and spatial layers of eelgrass presence, shoreline armoring, and beach characteristics will all be obtained through this source. The originators of this data as well as the WSDNR Submerged Vegetation Program will be contacted to obtain data or ensure the data is up to date.

1. **Summarize your methods of data analysis. If applicable, discuss any specific techniques, tests, or approaches that you will use to answer your research question.**

I will use ArcGIS Pro by Esri to complete my mapping, summary statistics and site analysis. Using buffering and selection tools on vector data I will create map layers of eelgrass habitat and armoring coverage over the Puget Sound region. With the attribute data of these layers, I will calculate summary statistics on eelgrass habitat, armoring presence, and armoring type.

Also, in ArcGIS Pro I will use raster analysis tools on Digital Elevation Models (DEM) to measure site slope, beach width, and elevation of armoring. DEMs will also be used to measure current potential eelgrass habitat and potential habitat in by 2100 under high, medium, and low risk SLR scenarios.

Site pairs will be modeled with the sea level rise modeling program SLAMM v.6.7 using DEMs and site-specific erosion and accretion data if available. SLAMM is a raster cell based spatial model that uses a flexible decision tree to simulate land cover change between coastal land classes. The model output will provide maps and projections of inundation and changes in habitat type as well as summary tabular data (Clough et al., 2016).

1. **Address the ethical issues raised by your thesis work. Include issues such as risks to anyone involved in the research, as well as specific people or groups that might benefit from or be harmed by your thesis work, perhaps depending on your results. List any specific reviews you must complete first (e.g., Human Subjects Review or Animal Use Protocol Form).**

My thesis work will likely have few direct ethical concerns. Data collection for my thesis will not involve human or animal subjects and will use primarily publicly available data.

My research may have implications for landowners, managers, and legislators. The results of my research may contribute to development of guidelines or regulations that restrict the placement of shoreline modifications. Restriction or removal of these modifications or could result in damage of property or increase health risks during potential extreme high water events. There may be certain people or groups that would be disproportionately affected by these effects, but it is difficult to predict prior to spatial analysis.

1. **List specific research permitsor permissions you need to obtain before you begin collecting data (e.g. landowner permissions, agency permits).**

There are currently no permits or permissions that I need to obtain. All the data that I intend to use is public access and will likely not be sensitive or proprietary. As I continue researching, I may find that there is data that I need to request access to but I expect that it will only require personal requests to obtain.

1. **Reflect on how your positionality as a researcher could affect your results and how you will account for this in the research process.**

I am approaching this research with the belief that I and all other human beings are an integral part of our ecosystem. As a part of this system, I believe we have a responsibility to minimize damage to our environment from our activities. I also believe that we have responsibilities to repair past damages to our environment and find ways to mitigate anthropogenic climate change when possible.

These perspectives will likely create unconscious biases in my thought processes when considering data that concerns the effects of man-made structures on the environment. These biases may have even influenced the selection of my topic, as my prior belief in the negative impacts of armoring allowed me to find the research gap that I am seeking to fill. However, I will try to account for these biases by reporting all my methods and findings in my thesis document despite their conclusions and refusing to cherry pick results that confirm my beliefs.

1. **Provide at least a rough estimate of the costs associated with conducting your research, if any.  Provide details about each budget item so that the breakdown of the final cost is clear.**

My research should not incur any cost. The software that I intend to use is either provided by The Evergreen State College (ArcGIS Pro), or free to download (SLAMM).

1. **Provide a detailed working outline of your thesis.**
2. **Introduction**
3. **Literature Review**
   1. Roadmap
   2. Ecology of *Zostera marina*
      1. *Species description*
      2. *Habitat description*
      3. *Ecosystem services*
   3. Sea level rise.
      1. *Causes and effects of Sea level rise*
      2. *Projections and Models*
   4. Shoreline armoring
      1. *What is shoreline armoring?*
      2. *Extent of armoring in the Puget sound*
      3. *Affects to nearshore habitat*
   5. *Z. marina* habitat change and response to sea level rise
      1. *Substrate and accretion*
      2. *Elevation and slope*
      3. *Projected future habitat area*
   6. Conclusion
4. **Methods** 
   1. Study Area
      1. *Region*
      2. *Site selection*
   2. Data Sources
      1. *Vector Data*
      2. *Digital Elevation Models*
   3. Spatial Analysis
      1. *Summary Statistics*
      2. *Elevation profiles*
   4. Sea Level Rise Modeling
      1. *SLAMM*
      2. *Erosion and accretion*
5. **Results** 
   1. Puget Sound
      1. *Eelgrass habitat*
      2. *Armoring*
   2. Regions
      1. *North Sound*
      2. *Central Sound*
      3. *South Sound*
      4. *Hood canal*
   3. Models
6. **Discussion**
   1. Current Habitat
   2. Projected Habitat
   3. Site Comparison
   4. Further Research
7. **Conclusion**
8. **References**
9. **Provide a specific work plan and a timeline for each of the major tasks in the work plan. Be as realistic and specific as you can at this point, including the deadlines for Spring quarter.**

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| --- | --- | --- | --- | --- |
| **Week of Quarter** | **Month** | **Thesis deadlines** | **Task** | **Sub task** |
| Winter 0 | January |  | Data collection/ Build Geodatabase | Revise Literature Review |
| Winter 1 | January |  | Map Current Coverage/ summary stats | Revise Literature Review |
| Winter 2 | January | Meet Reader | Site Selection | Write methods |
| Winter 3 | January |  | Site Analysis | Write methods |
| Winter 4 | February | Meet Reader | Site Analysis | Write methods |
| Winter 5 | February |  | SLAMM modeling | Write methods/ Results |
| Winter 6 | February | Meet Reader | SLAMM modeling | Write methods/ Results |
| Winter 7 | February |  | Buffer | Buffer |
| Winter 8 | March | Meet Reader | Write Methods | Create Map Layouts |
| Winter 9 | March |  | Write Results | Create Map Layouts |
| Winter 10 | March | Meet Reader | Write Discussion | Create Map Layouts |
| Winter 11 | March |  | Write Discussion | Create figures |
| Spring 1 | April | Meet reader | Buffer | Buffer |
| Spring 2 | April | Complete Draft Thesis | Editing | Editing |
| Spring 3 | April | Meet Reader | Create Figures | Editing |
| Spring 4 | April |  | Create Figures | Editing |
| Spring 5 | May | Request to Present/ Extend. Meet Reader | Revision and Editing | Editing |
| Spring 6 | May |  | Revision and Editing | Editing |
| Spring 7 | May | Meet Reader | Create Presentation | Editing |
| Spring 8 | May | Thesis presentations | Presentation | Editing |
| Spring 9 | June | Final Draft Thesis | Editing | Editing |
| Spring 10 | June |  |  |  |
| Spring 11 | June |  |  |  |

1. **Who (if anyone), beyond your MES thesis reader, will support your thesis (in or outside of Evergreen)? Be specific about who they are and in what capacity they will support your thesis. If you are working with an outside agency or expert, be specific about their expectations for your data analysis or publication of results.**

I may seek support from Mike Ruth during my thesis process. Mike Ruth is a member of The Evergreen State College faculty and I have communicated with him regarding potential questions during my thesis process. His support would likely be needed for technical questions about GIS analysis and software.

1. **Provide the 5 most important references you have used to identify the specific questions and context of your topic, help with issues of research design and analysis, and/or provide a basis for interpretation. Annotate these references with notes on how they relate to/will be helpful for your thesis. For any other sources cited in your prospectus in other answers, provide a complete bibliographic citation here as well.**

**Davis, M. J. (2019). *Dynamic habitat models for estuary-dependent Chinook salmon: Informing management in the face of climate impacts*. University of Washington. [Thesis]**

A study in the Nisqually delta using isotope analysis of salmon stomachs, a bioenergetics model, and a marsh accretion model. They demonstrated the advantages for juvenile salmon for foraging in tidal forests and salt marshes

The Authors created the “Monitoring-based Simulation of Accretion in Coastal Estuaries” (MOSAICS) model to evaluate SLR effects and sediment management effects. The model used datasets of water levels, vegetation surveys, elevation change, suspended sediment, and a 3m resolution DEM. The model projection results fell between the results of the WARMER (projected more habitat retention) and SLAMM (projected more habitat loss) models.

This thesis will be useful in comparing several mechanistic SLR models with varying levels of complexity. It will also help in describing the local benefits of nearshore habitat for salmonid species.

**Dethier, M. N., Raymond, W. W., McBride, A. N., Toft, J. D., Cordell, J. R., Ogston, A. S., Heerhartz, S. M., & Berry, H. D. (2016). Multiscale impacts of armoring on Salish Sea shorelines: Evidence for cumulative and threshold effects. *Estuarine, Coastal and Shelf Science*, *175*, 106–117.** [**https://doi.org/10.1016/j.ecss.2016.03.033**](https://doi.org/10.1016/j.ecss.2016.03.033)

This study collected data from pairs of armored and unarmored shoreline sites at 65 locations around the Puget sound where they surveyed biological and geomorphic parameters. They used statistical analysis to determine significant effects of a “relative encroachment” and “proportion of drift cell armored” parameters on a variety of response variables including beach slope, width and several levels of sediment grain size. This study relates to my research by providing evidence for armoring affects to beach substrate and elevation. In my research, I may be able to use both the results of the study and methodology for comparing armored and unarmored sites.

**Finlayson, D. (2006). The geomorphology of Puget Sound beaches. Puget Sound Nearshore Partnership Report No. 2006-02. Published by Washington Sea Grant Program, University of Washington, Seattle, Washington.**

Puget sound shorelines are characterized by low energy waves, mixed gravel and sand beach composition, and meso to macro tidal environments. Waves are generally created through local wind patterns, with near absent input from ocean swell. Most beach profiles exhibit a steep foreshore with coarse substrate, followed by a flatter low tide terrace with finer sediments. The subtidal wall generally rises steeply up to the terrace at around -4 to -2m MLLW. The shore is normally under 300m wide and ends at coastal bluffs. The tidal distribution curve in Puget Sound is skewed above MSL. This concentrates wave energy on the upper shore and may reduce sediment transport in lower tidal zones.

This report will be useful in understanding and modeling the geomorphology of Puget sound shorelines that are occupied by eelgrass. These concepts are also important for understanding the affects of shoreline armoring.

**Hannam, M., Dowty, P., Christiaen, B., Berry, H., Ferrier, L., Gaeckle, J., Stowe, J., & Sutton, E. (2015). *Depth Distribution of Eelgrass in Greater Puget Sound* (p. 68). Nearshore Habitat Program, Aquatic Resources Division, WSDNR.**

This report is an analysis of the depth distributions of eelgrass in the Puget sound between 2004 and 2012 using data from WSDNR Submerged Vegetation Monitoring Program. They compare depth distributions from multiple regions of the Puget Sound as well as “fringe” and “flat” habitat types. This report will be useful as a reference for estimating potential eelgrass habitat using bathymetric data and for characterizing differences between habitat types.

**Kairis, P. A., & Rybczyk, J. M. (2010). Sea level rise and eelgrass (Zostera marina) production: A spatially explicit relative elevation model for Padilla Bay, WA. *Ecological Modelling*, *221*(7), 1005–1016.** [**https://doi.org/10.1016/j.ecolmodel.2009.01.025**](https://doi.org/10.1016/j.ecolmodel.2009.01.025)

This study converted the Relative Elevation Model (REM) in order to make a spatially explicit mechanistic elevation model that could interface with ArcGIS grids. The model can provide bathymetry, primary productivity and biomass output on ArcGIS grids that can be made into rasters. This study parallels my research in its attempt to predict the affect of SLR on *Z. marina* habitat using bathymetric and accretion data, but there is no mention of shoreline armoring. Results show an increase in eelgrass coverage with the caveat that they had no measure of the eelgrasses ability to occupy the new area. This study will be useful in understanding the limitations of modeling and the difficulties of predicting accretion and biological responses in complex environments.

**Smith, C. D., & Liedtke, T. L. (2022). Potential effects of sea level rise on nearshore habitat availability for surf smelt (Hypomesus pretiosus) and eelgrass (Zostera marina), Puget Sound, Washington. In *Potential effects of sea level rise on nearshore habitat availability for surf smelt (Hypomesus pretiosus) and eelgrass (Zostera marina), Puget Sound, Washington* (USGS Numbered Series No. 2022–1054; Open-File Report, Vols. 2022–1054). U.S. Geological Survey.** [**https://doi.org/10.3133/ofr20221054**](https://doi.org/10.3133/ofr20221054)

This is a study on a Bainbridge Island beach with both armored and unarmored beach sections using bathymetric, geomorphological, and biological surveys and the Sea Level Affecting Marshes Model (SLAMM). The comparison between SLR affects to unarmored and armored shorelines relates very closely to my question. In the study, eelgrass habitat was estimated by the researchers as there is not a habitat class in SLAMM that matches, but this model may still be a viable option for use in my thesis research. I may be able to input a new habitat class in SLAMM to account for eelgrass or I may use the same method of estimation used in this study. Projected eelgrass habitat increased but changes in accretion, slope and scour were not modeled. I will be able to use both the study results as well as study design ideas from this paper.

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