

Sloping Shores:  
Unveiling the Impact of Rocky Coastline Topography  
on Mussels and Sea Stars

Does the distribution of *Mytilus* spp. and *Pisaster ochraceus* vary in distance from MLLW, and is this influenced by the slope of the beach?

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Changing Coastline SU23

## Introduction

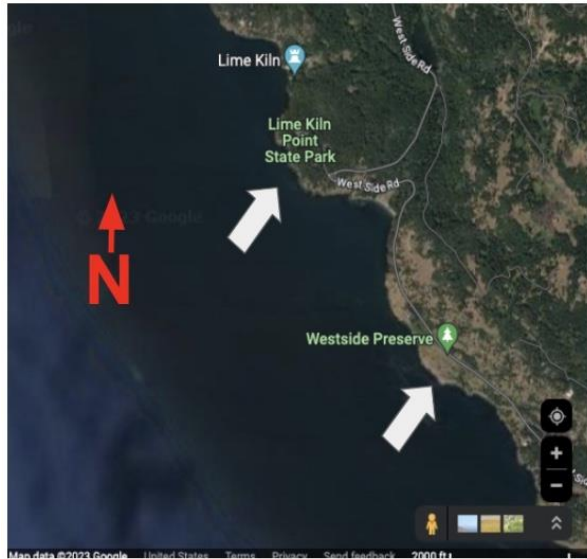
Rocky coastlines, with their jagged crevices and myriad boulders of all shapes and sizes, compose a rugged landscape that provides living space for an incredibly diverse array of organisms. Coastal habitats also provide a wealth of important ecosystem services, such as sediment exchange (Dethier et al., 2016), nutrient cycling, and water filtration (Jaramillo et al., 2021). Furthermore, they serve as natural barriers against storms, provide space for recreational activities, attract eco-tourism, and provide habitat for commercially important species (Arkema et al., 2015). However, the stability and functionality of these ecosystems are increasingly threatened by anthropogenic climate change, overfishing, pollution, recreation pressures, and development (Hawkins et al., 2007; Kunze et al., 2021).

Given the ongoing repercussions of climate change, it is imperative to comprehend the influence these stressors will have on the species that have outstanding impacts on the rest of their communities. This study focuses on mussels (*Mytilus californianus* & *Mytilus trossulus*) and sea stars (*Pisaster ochraceus*), both of which play critical roles in shaping the structure and diversity of intertidal ecosystems (Broitman et al., 2009; Paine 1966; Paine & Trimble 2004). As suspension feeders *Mytilus* spp. prey upon phytoplankton and are in turn preyed upon by *P. ochraceus* (Paine 1966). Thus, they play a crucial role in intertidal food webs by concentrating nutrients from the water column and making them available to predators occupying higher trophic levels (Blanchette et al., 2007; Paine 1966). *Mytilus* spp. can also exert negative influences on their surroundings because their dominance as space competitors can reduce biodiversity in their surroundings when they crowd out other species (Blanchette et al., 2007; Broitman et al., 2009; Paine 1966, Paine 2004). On the other hand, *P. ochraceus* is a keystone predator that performs a vital regulatory role in maintaining biodiversity by preventing the domination of *Mytilus* spp. (Paine 1966). By examining the influence of current environmental and geomorphic factors on these species, we can predict how they will respond to changing conditions and assess the potential cascading effects these responses will have throughout the intertidal.

While the role of many factors, such as temperature (Blanchette et al., 2007; Broitman 2009; Kunze et al., 2021; Raymond et al., 2022), UV radiation (Burnaford & Vasquez 2008), and disease (Miner et al., 2018) in defining the ranges of these species have been extensively studied, the influence of local geomorphology remains less explored. Therefore, this report presents the findings of a survey that investigated the influence of topography on the distribution and abundance of *Mytilus* spp. and *P. ochraceus*. We predicted that *Mytilus* spp. would be more common on steeper slopes because studies have shown that bivalves are susceptible to desiccation and heat stress (Broitman et al., 2009; Raymond et al., 2022), and steeper slopes may provide more refuge from the sun than a flat slope. Additionally, waves breaking on a vertical rock face may produce more spray that can help cool *Mytilus* spp. during low tide, while simultaneously providing more opportunities for filter feeding (Blanchette et al., 2007) Finally, we hypothesized that *P. ochraceus* would be drawn to these steeper areas because of their predilection for feeding upon *Mytilus* spp. (Paine 1966; Paine & Trimble 2004), and because previous studies have demonstrated that *P. ochraceus* avoids photosynthetically active solar radiation by sheltering in shaded areas (Burnaford & Vasquez 2008). Overall, the results of our study did not suggest that slope was

correlated to *Mytilus* spp. distribution patterns, but higher abundances were found on steeper slopes.

## Methods



To examine the distribution patterns of *Mytilus* spp. and *P. ochraceus* in the rocky shore, we chose two study sites, Lime Kiln Point State Park, and Westside Preserve, on San Juan Island, WA (Figure 1). San Juan Island, located northwest of the Olympic Mountains, experiences cool, temperate climates. The substrate here is composed of thin-bedded graywacke, shale, argillite, slate, schist, grit, conglomerate, limestone, and coal (Pakunski et al., 2013). The common rocky shores found on this island are favored by *Mytilus* spp. and *P. ochraceus* since they provide hard surfaces for these organisms to attach to (Paine et al., 1974).

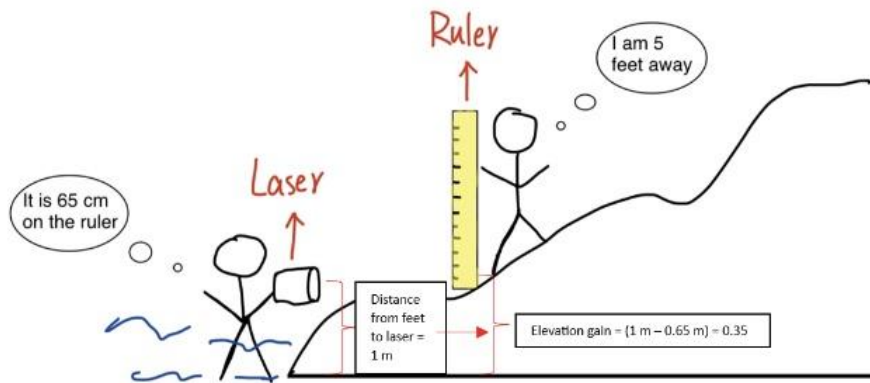


Figure 2. Schematic diagram of method used to conduct the beach profiles.

After selecting the study sites, the next step involved analyzing the physical characteristics of both beaches. We began by creating beach profiles, which provided a visual and quantitative representation of the shape and

elevation of each study area from the waterline to the lichen line. Mean lower low water (MLLW), served as our waterline reference point for measuring and comparing tidal heights. MLLW represents the average height of the lower of the two daily low tides over a specific period, typically calculated over 19 years (Meyer et al., 2006). Due to its consistency over time, scientists can compare data collected at different locations and during different periods. To conduct the beach profile, one group member stood in the water with a Nikon terrestrial laser scanner and projected the beam onto a ruler to record the elevation changes. Another person moved away from the waterline in 5-foot intervals and recorded the position of the laser on the ruler (Figure 2). In order to ensure methodological consistency, distances and elevations were recorded in feet to assess potential variations in slopes across different sites.



Figure 3. Quadrat area. The red line delineates our studying site in Lime Kiln Park divided into 24 cells. The green line separates each cell into four parts.

As Figure 3 demonstrates, we divided the study site into a 12-meter by 27-meter grid, which we then partitioned into 24 cells. The first two rows of cells (closest to the water line) represented the “low” intertidal region, the next two represented the “mid” region, and the final two belonged to the “high” region. Each cell was further subdivided into four sections and assigned a letter (A, B, C, or D). Letters were randomly selected for the placement of a quadrat. Because each

region consisted of eight cells, a total of eight quadrats were placed in each region. Within each quadrat, we measured the percent cover of *Mytilus* spp. and recorded their position. Any *P. ochraceus* we encountered within our study area was counted and their position was recorded. After all data was collected, graphs of the beach profiles and of species percent cover were generated in Microsoft Excel.

## Results

The final beach profiles did not show any significant differences between the slopes in the two study sites. Both beaches gained elevation with increasing distance from MLLW, with an 8 feet peak in Westside Preserve (Figure 5) and 11 feet peak in Lime Kiln State Park (Figure

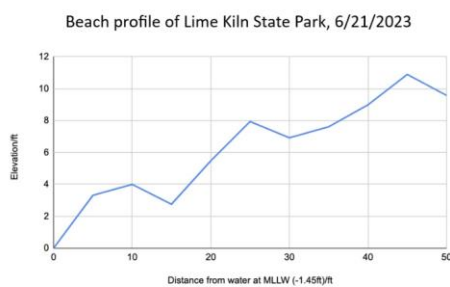


Figure 4. Beach profile of Lime Kiln State Park, San Juan Island, WA.

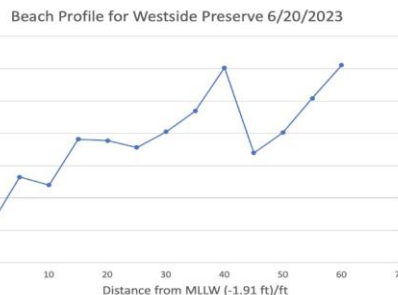


Figure 5. Beach profile of Westside preserve, San Juan Island, WA.

4).

In both Westside Preserve and Lime Kiln State Park, the denser population of *M. Californianus* was clustered in the medium intertidal zone (4 to 8 feet from the MLLW) consistently, as seen in Figures 6 and 7. However, the distribution of *M. trossulus* showed a difference in the distribution pattern in these two sites. All *M. trossulus*

observed in the Westside Preserve were distributed in the middle intertidal zone, but in Lime Kiln State Park all the sampled individuals were in the lower intertidal zone. The *P. ochraceus*, which was counted by abundance, were distributed in the lower intertidal zone consistently.

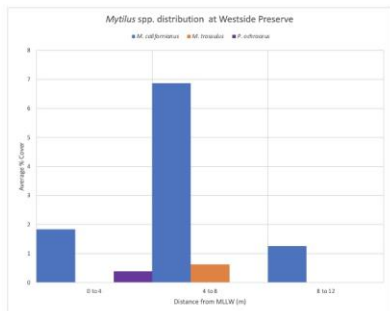


Figure 6. Species distribution, relationship between percent cover and distance from MLLW, of *Mytilus* spp. and *P. ochraceus*, at Lime Kiln State Park.

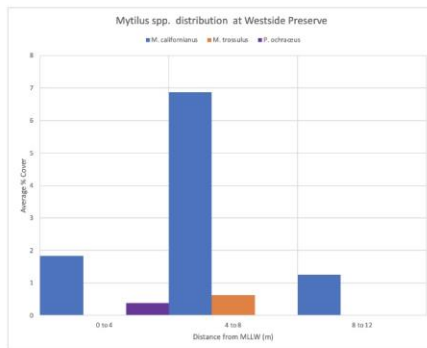


Figure 7. Species distribution, relationship between percent cover and distance from MLLW, of *Mytilus* spp. and *P. ochraceus* at Westside Preserve.

## Survey Discussion

Our results showed some variation within the distribution patterns of intertidal species with the increasing distance from the MLLW. *M. californianus* had the greatest abundance on both beaches we surveyed, with the highest densities occurring within the medium intertidal zone (4 to 8 feet) from the MLLW. The unobserved spatial distribution patterns of *M. trossulus* underscore the need for further research to observe the relationship between *M. trossulus* distribution and intertidal zonation. Moreover, we did not observe any difference in the distribution of any of our species between Westside Preserve and Lime Kiln Point State Park. These two beaches had very similar slopes, so we are unable to conclude if the slope has any effect on *Mytilus* spp. distribution. We believe predation in the lower intertidal zone may set the observed lower boundary of their distribution (Paine 1966; Paine & Trimble 2004) and the thermal tolerance of the organisms could set the upper boundary (Blanchette et al., 2007; Broitman 2009; Kunze et al., 2021; Raymond et al., 2022). These two factors would contribute to the higher mortality of *M. Californianus*, resulting in a higher density of the population in the mid-intertidal zone (Blanchette et al., 2007). Our study was limited by both gear and time. With more time we would be able to observe the relationship between slope and time but unfortunately, we were unable to find new sites after beginning the survey. Our results still suggest that abiotic and biotic factors could be the key to controlling *Mytilus* spp. distribution and abundance.

## Anticipated Future Results

Drawing from the findings obtained through our comprehensive field surveys, we have formulated several predictions pertaining to the future distribution of *Mytilus* spp. and *P. ochraceus* within the intertidal ecosystem. The increasing temperature led by global warming will affect the ocean in multiple aspects, including the change in disease prevalence, rising sea level, increasing atmospheric temperature, and decreasing oceanic pH (Broitman et al., 2009). The influence of one factor can be intuitive when it is the sole factor interacting with a species. But factors can also interact with each other

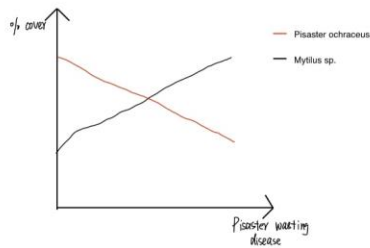


Figure 8. The number of *P. ochraceus* and *Mytilus* spp. fluctuate with sea star wasting disease

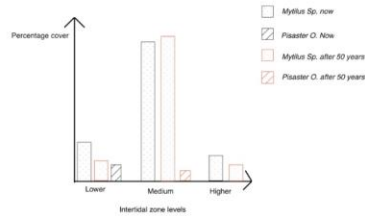


Figure 9. The number of *P. ochraceus* and *Mytilus* spp. change with global warming

and with the environment, which confounds our ability to infer the full significance of any one factor (Kunze et al., 2022). Firstly, the number of *P. ochraceus* and *Mytilus* spp.

will present a reverse ratio (Figure 8). Hence, we predict that the prevalence of Sea Star Wasting Disease may result in an augmented percentage cover of *Mytilus* spp., and vice versa; however, it is important to note that our understanding of the disease's drivers remains incomplete (Miner et al., 2018). Available evidence suggests that factors such as temperature may potentially exacerbate the virulence and transmission rate of the disease, although the intricate relationship between temperature and Sea Star Wasting Disease is multifaceted and not entirely comprehended (Miner et al., 2018).

In addition, if the sea level increases because of the melting ice caps (driven by rising atmospheric temperatures), the range of *Mytilus* spp. will shift to higher elevations as the MLLW mark encroaches further inland (Figure 9). Thereafter, the *P. ochraceus* could follow them to access their prey, so their distribution will shift towards higher elevations as well. However, as atmospheric temperatures increase, *Mytilus* spp. could experience heat stress and even mortality at high elevations, this could lead to a decreased abundance of *Mytilus* spp., and even drive their distribution back towards the waterline (Broitman et al., 2009; Kunze et al., 2021).

Decreasing seawater pH could also result in a distribution closer to the MLLW. *Mytilus* spp. utilize calcium carbonate to build their shells, and because carbonate will be less available in an acidic ocean, *Mytilus* spp. will need more time submerged where they can feed more to acquire more calcium carbonate (Blanchette et al., 2007). This allocation of energy to shell building would require energy to be taken from other activities like mating, which would result in fewer offspring (Sui et al., 2015). In conjunction with the aforementioned factors, our conclusion suggests that the habitat range of *Mytilus* spp. is likely to contract under the influence of ongoing global warming. The effects brought by climate change on the interactions between predators and prey are very complex, requiring further research to be conducted to draw a more conclusive result (Kunze and Rolfer, 2021).

## Experimental Question

Our objective is to investigate how temperature can affect the distribution of *Mytilus* spp., and if slope and elevation from the water could have an influence as well. Mussels, specifically *M. californianus* exist in a well-defined band along the rocky shoreline, the upper limit of this is thought to be set by desiccation, and predation from *Pisaster ochraceus* sets the mussel's lower limit (Paine, 1974). *M. californianus* has a temperature limit of 36 degrees C, for more than 2 hours for 3 days, when exposed the

mussels experienced a rate of 100% mortality (Broitman et al., 2009). Climate change is predicted to warm the globe by up to 10.2 degrees F, and while this will not elevate aerial temperatures to 36 C, this could still cause biological stress and even mortality to occur in mussel beds (Wuebbles et al., 2017). To understand what could happen to our intertidal zones as climate change progresses, we are going to investigate how mussels grow and survive under high aerial temperatures on differently sloped beaches.

### **Experimental Methods**

Our method is based on a similar study by Kordas et al. (2014), however, we will also be selecting two sites, one with a steep slope,  $>10^\circ$ , and one with a shallower slope,  $0-10^\circ$ . Since our beach profiles were not very different between Lime Kiln and Westside Preserve, we will select other beaches to survey. At each site we will build three 27 m x 4 m cages, these will represent our study area. The high zone will range from 12-8 meters above MLLW, the middle 8-4 meters, and the lower 4-0 meters. This will keep predation from affecting our results by isolating the *Mytilus* spp. from other organisms, this will not keep other organisms from settling on our settlement plates. We expect to see other organisms also settling on our plates, but we will only report *Mytilus* spp. because they are our organisms of study. In each zone, we will place 8 settlement plates. These are plastic 1 meter by 1 m plates with settlement substrate on top for organisms to attach, 4 black and 4 white will be placed in each cage. The black settlement plates will warm more than the white plates because the pigment absorbs more sunlight and simulates the warming, we think mussels will experience in future climate scenarios. Each plate will be equipped with a temperature logger for daily measurements, these will be placed in the plate. Percent cover and abundance measurements on *Mytilus* spp. that settled will be taken once a month for 1 year for each plate. The temperature will be recorded from the daily temperature logger and averaged to find the average monthly temperature for black and white plates. This will allow us to observe how many larvae successfully anchor and survive for a moderate period.

### **Anticipated Results**

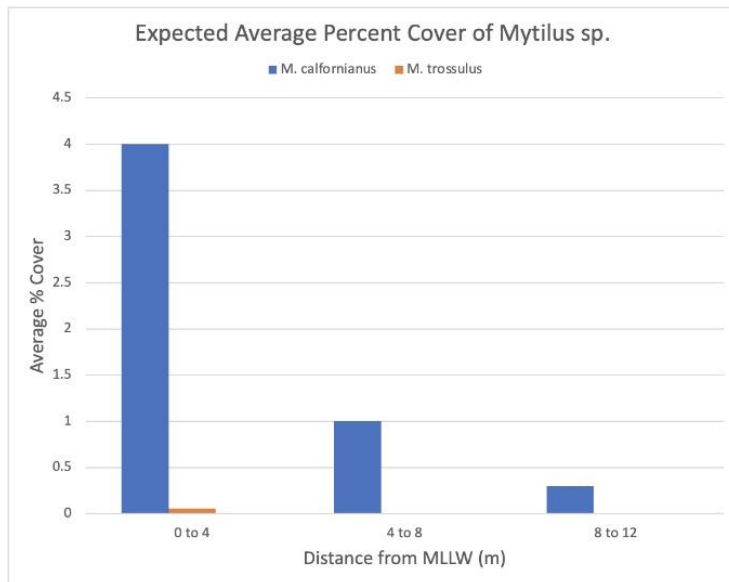


Figure 10: Percents cover per intertidal zone predictions for the experimental results of *Mytilus* spp.

Because we did not see a difference in *Mytilus* spp. distribution with slope from our survey results, we expect no difference between the beach treatments. However, we anticipate that the upper limit of the mussels will be lower and a higher proportion of mussels will be in the lower 4 meters to avoid desiccation on the black plates. We draw this expectation since *Mytilus* spp. could experience biological stress and even mortality when exposed to high aerial temperatures (Broitman et al., 2009; Raymond et al., 2009).

Because the black plates will create an environment with higher temperature, we expect to see signs of thermal stress in those organisms and a shift in abundance toward the lower, cooler, intertidal zones.

## Synthesis

As the progression of climate change continues, our findings hold significant implications for the future dynamics of intertidal ecosystems. We hypothesize that the expanding ocean temperatures will lead to a contraction in the range of *Mytilus* spp., consequently resulting in a decrease in their overall abundance. This decline in *Mytilus* spp. abundance may create opportunities for the recruitment of other species, thereby altering the intertidal dynamics through the reduction of a key species.

Moreover, considering the significant population declines in *P. ochraceus* due to Sea Star Wasting Disease, a reduction in *Mytilus* spp. abundance could further jeopardize the sea star populations. Our survey and experimental results contribute valuable evidence regarding the influence of temperature, although it is essential to recognize that climate change affects numerous interacting factors. By studying these factors in conjunction, we gain insight into the holistic effects that may arise from climate change. However, comprehending the individual impacts of these stressors is equally crucial in elucidating the driving forces behind the observed changes.

## Questions:

Does temperature stress affect *Mytilus* spp. or *P. ochraceus* more?

Does temperature stress affect *M. californianus* or *M. trossulus* more?

Are *M. californianus* and *M. trossulus* equally successful in space competition? Which would dominate the intertidal if they were both freed from predation pressure?

Do morphological differences between *M. californianus* and *M. trossulus* cause them to have different ecological impacts? If they were left free to proliferate, would intertidal communities be affected differently depending on which species of *Mytilus* was dominant?

How would declining ocean pH affect *Mytilus* spp. vulnerability to other predators?

Would the average shell thickness be reduced enough for a new species to become a secondary keystone predator that could fill *P. ochraceus*' regulatory role if sea star wasting disease eliminated it from the region?

What effects would change to the abundance/distribution of *Mytilus* spp. and *P. ochraceus* have on other organisms?

Why are *Mytilus* spp. in higher elevation crevices and not lower elevation crevices?

At Lime Kiln Point State Park, why are *M. trossulus* mainly in tidepools, while *M. californianus* reside more on open rock? Is this observed pattern consistent at other beaches?

If primary production around the study beaches declined, how would the distribution of *Mytilus* spp. in the intertidal change?

Are ocean acidification and higher temperature equally detrimental to *Mytilus* spp.? If ocean acidification and global warming continue to progress at their same respective paces, which stressor will be more responsible for driving shifts in *Mytilus* spp. zonation?

Will either decreasing pH values or increasing temperatures increase the rates at which *P. ochraceus* populations are infected by the sea star wasting disease?

How will the *Mytilus* spp. residing on steep shores with strong waves build the shells? Will the decreasing pH values in future bring more devastating effects to them compared with the *Mytilus* spp. inhabiting other areas?

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## Attributions

- a. Project idea: Aidan, Sally, Jenna
- b. Field work: Aidan, Passion, Sally, Jenna
- c. Graphing (pilot data, anticipated results): Jenna, Passion, Aidan, Sally
- d. Illustrations for species, location, methods: Aidan, Passion, Jenna, Sally
- e. Questions: Jenna, Aidan, Passion
- f. Writing: Aidan, Passion, Jenna
- g. Editing & proofreading: Aidan, Passion, Jenna
- h. Making presentation slides: Passion, Aidan, Jenna, Sally
- i. Writing presentation script: Passion, Aidan, Jenna