

Aina Hori

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Abigail Ames, Katie Dobkowski, Timothy Dwyer, and Pema Kitaeff

Exploring the Relationship Between Bull Kelp (*Nereocystis luetkeana*) and Northern Kelp Crabs (*Pugettia producta*)

Introduction

Kelps are a vital primary producer which have been found along 25% of the world's coastlines in temperate and subpolar regions (Teagle et al. 2017; Rogers-Bennett and Catton 2019). Kelps form dense canopy forests maintaining high biodiversity, supporting both coastal communities and marine life as a foundational species and food source (Teagle et al. 2017). A single kelp can serve as three separate habitats: the blade, the stipe, and the holdfast (Teagle et al. 2017). Within the canopy there are juvenile salmonids, forage fish, and many invertebrates ranging in size from zooplankton to crustacean herbivores (Teagle et al. 2017; Shaffer et al. 2020). As a food source, kelps are consumed by humans and a variety of marine organisms ranging from sea urchins, mollusks, decapods, and fish (Springer et al. 2010; Dobkowski 2017). Here in the Salish Sea, bull kelp (*Nereocystis luetkeana*) is the dominant kelp forest (Dobkowski 2017). *N. luetkeana* is an annual kelp that must complete its life cycle within a single year, so its canopy is greatest during the summer and later senescens in the fall and winter (Siddon et al. 2008). With this, kelps are extremely vulnerable under changing ocean conditions as their abundance is dependent on sea surface temperature, salinity, and nutrient availability (Pfister et al. 2018). Previous studies indicate that the kelp beds throughout the Strait of Juan de Fuca and

the coast of Washington State are persistent, but the beds around south Puget Sound are declining (Pfister et al. 2018).

To understand the kelp forest abundance here in the Salish Sea and determine the best course of action for conservation, we must understand the various species interactions and ecological processes that occur within the community (Siddon et al. 2008). Crustacean herbivores have been found to strongly influence the kelp forest community structure (Dobkowski 2017). The Northern kelp crab (*Pugettia producta*) reside in kelp beds around the Pacific Northwest and prefer to feed on fresh *N. luetkeana* as opposed to other macroalgal species (Dobkowski 2017). *P. producta* use the pigments within *N. luetkeana* to camouflage and avoid predation (Hultgren and Stachowicz 2010). Furthermore, anthropogenic emissions are rising, and ocean waters are increasing in acidity which can induce changes in species interactions (Fieber and Bourdeau 2021). Research indicates that the increased pCO₂ also increases *P. producta*'s preference for their favored kelp as they are specialists (Fieber and Bourdeau 2021). When *P. producta* feed on the *N. luetkeana* pneumatocyst, *N. luetkeana* would lose its buoyancy source and the stipe would sink to the bottom of the sea floor (Springer et al. 2010). Furthermore, when *P. producta* feed on the *N. luetkeana* blades, the photosynthetic tissue is lost hindering its ability to further develop (Springer et al. 2010). Thus, it is crucial to understand *P. producta* feeding preferences within *N. luetkeana* forests.

To gather more data on *P. producta* as an herbivorous organism that relies on *N. luetkeana*, this research characterizes the abundance of *P. producta* on two different microhabitats: *N. luetkeana* bulbs/stipes and *N. luetkeana* blades at three sites around San Juan Island. I hypothesize that the number of *P. producta* I see will vary between the *N. luetkeana*

bulbs/stipes and blades. Furthermore, this research will highlight considerations that should be explored when outlining future *N. luetkeana* and *P. producta* population trajectories.

Methods

We visited a total of three sites around San Juan Island, Washington, USA: Cattle Point (48.4504°N, 122.9635°W), Deadman's Bay (48.5124° N, 123.1488° W), and Eagle Cove (48.4618°N, 123.0328°W) (Figure 1). Cattle Point is located on the south end of San Juan Island and provides bedrock habitats for marine organisms. Secondly, Deadman's Bay also provides bedrock habitats for marine organisms, but this site is located on the west side of San Juan Island. Lastly, Eagle Cove is also located on the west side of San Juan Island, but primarily consists of sandy ocean floors. Over a two-week period in August 2021 each of these locations were visited twice, once during a low tide and once during a high tide on different days. We used the National Oceanographic Atmospheric Administration's (NOAA) Tide Predictions site and San Juan Islands Marine Forecast to plan the best times to go out into the field for data collection. This research requires good underwater visibility, so if this was not the case when arriving at the site, data was not collected. Furthermore, safety is the most important consideration when collecting data in the water, so we did not go out when whitecaps were seen from shore. These locations and tidal times were chosen as members of my research team were collecting data to add to previous data collected at these sites.



Figure 1 Data Collection Sites Around San Juan Island

I collected *P. producta* abundance data via a roving snorkeler survey while swimming from one edge of the kelp bed to the other edge to minimize pseudoreplication (Hurlbert 1984). Using a pencil and slate, I recorded the number of *P. producta* I saw on *N. luetkeana* stipes/bulbs and *N. luetkeana* blades using box tallies. Using an apple watch, I also recorded the start and end time of the roving snorkeler survey to standardize the varying time at each location by later calculating the number of crabs seen in each *N. luetkeana* location per minute as survey durations varied between 9 to 22 minutes.

All data analyses were conducted in R version 4.1.1 using the base package to conduct a two-way ANOVA. The two independent variables include the *N. luetkeana* location and San Juan Island sites while the dependent variable is the number of *P. producta* found per minute.

Results

After running a two-way ANOVA test, we conclude that the *N. luetkeana* location (bulb and stipe versus blade) and general site (Cattle Point, Deadman's Bay, Eagle Cove) variables combined do not show significant results when looking at the number of *P. producta* per minute ($p = 0.6627$). However, when solely looking at the influence of *N. luetkeana* location on the number of *P. producta* per minute, there is a significant relationship ($p = 0.0301$). Figure 2

showcases blue boxes which represent the data corresponding to the number of *P. producta* that were seen on the blades and pink boxes which represent the number of *P. producta* that were seen on the bulb and or stipe. Looking at these two categories, we see that the blue boxes have a higher median than the pink boxes which mean that more *P. producta* were found on the *N. luetkeana* blades. This correlation was seen at all three data collection sites. Nonetheless, the number of *P. producta* seen per minute does not significantly differ across the varying sites ($p = 0.6499$).

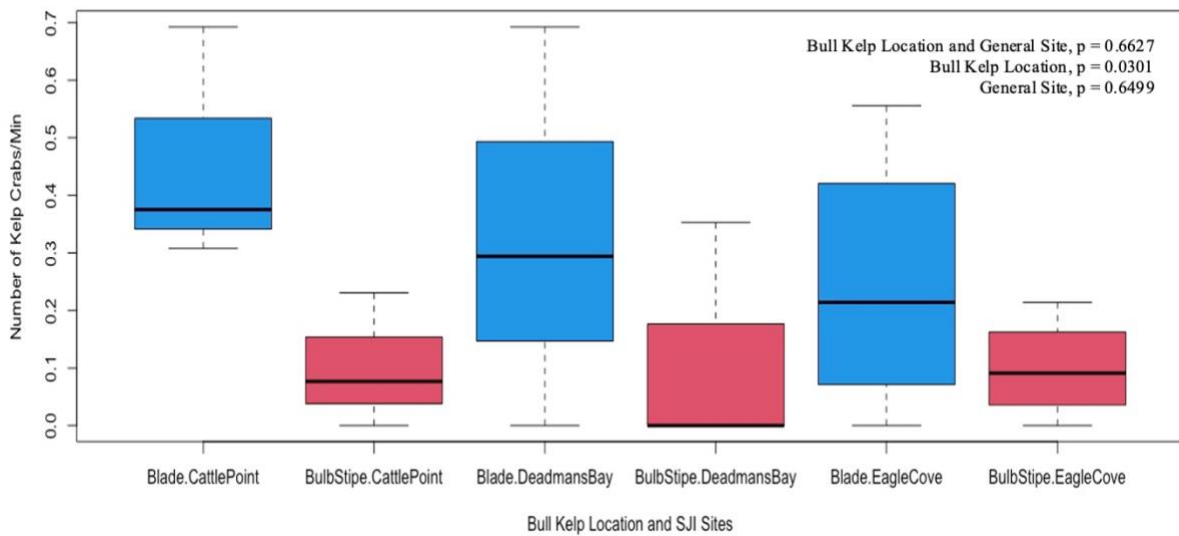


Figure 2 Number of Kelp Crabs/Min Found on Bull Kelp Locations Across San Juan Island Sites

The independent variables being displayed include the bull kelp location (bulb and stipe vs. blade) and the three San Juan Island sites (Cattle Point, Deadman’s Bay, and Eagle Cove). The dependent variable being displayed is the number of kelp crabs found per minute. These box plots show the median (bolded horizontal line), maximum value (top whisker line), minimum value (bottom whisker line), 75th percentile (top of box), and the 25th percentile (bottom of box).

Discussion

Characterizing and analyzing *P. producta* abundance on varying *N. luetkeana* locations provide insight into this ecologically significant species interaction. This relationship is vital to

understand as crustacean herbivores have been proven to structure the *N. luetkeana* community (Dobkowski 2017). Through my data collection and analysis, I found more *P. producta* per minute on *N. luetkeana* blades as opposed to *N. luetkeana* bulbs and stipes thus supporting my hypothesis. These results suggest that this is where *P. producta* are spending more time which may be due to increased protection within the *N. luetkeana* blades which form dense canopies. If not for protection, *P. producta* are most likely spending greater time on the *N. luetkeana* blades for food. Previous research conducted on feeding preferences reveal that *N. luetkeana* blades are preferred over *N. luetkeana* bulbs and stipes (Dobkowski et al. In Progress). Researchers have also found higher C:N ratios within the blades as opposed to the stipes indicating higher nutritional value (Dobkowski et al. In Progress). Furthermore, the morphology of the *N. luetkeana* bulb and stipe in comparison to the blades may explain this preference. *N. luetkeana* bulbs and stipes have a much thicker structure as opposed to the blades and may require more energy to access. Lastly, *N. luetkeana* blades also have much greater surface area to feed upon as opposed to the *N. luetkeana* bulbs and stipes.

With all these plausible impacts, it is vital to conduct further research on this relationship between *N. luetkeana* and *P. producta* to ensure that there is a healthy and balanced kelp forest here in the Salish Sea. There is an urgent need for this research as *N. luetkeana* is being influenced by these biotic factors in addition to the abiotic factors with ongoing changes in ocean conditions due to the climate crisis (Pfister et al. 2018). Conducting observational studies to determine *P. producta*'s reliance on *N. luetkeana* blades for habitat in comparison to feeding will provide further insight into future populations of *N. luetkeana*. If *P. producta* rely on *N. luetkeana* more so for food as opposed to the habitat services it provides, it is important to continue monitoring *N. luetkeana* forests where *P. producta* reside, especially as oceanic

conditions change. It is necessary for the marine biology community to understand the limits of abiotic stressors coupled with the loss of photosynthetic tissues because of herbivory. If *N. luetkeana* result in slower growth or decreased abundance, many organisms ranging from sea urchins, mollusks, decapods, and fish could also experience shifts in abundance due to cascading ecosystem effects. Thus, it is more important than ever to monitor the abundance and health of this community that supports many marine organisms and individuals within coastal communities (Springer et al. 2010; Dobkowski 2017). This research moves the marine science community towards understanding the relationship between two ecologically significant species and provides us with insight to accurately predict future population abundances and identify conservation strategies for both *N. luetkeana* and *P. producta*.

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