Investigating Bull Kelp decline in the Saturna Island Interim Sanctuary Zone

by

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Declaration of Committee

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Title:	**Investigating Bull Kelp Decline in the Saturna Island Interim Sanctuary Zone**
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Abstract

Kelp is an ecologically, economically, and culturally important species that is facing global declines. This pilot project investigated if declines in Bull Kelp in the Saturna Island Interim Sanctuary Zone could be attributed to increased herbivory by sea urchins, and/or thermal stress caused by increased ocean temperatures. In areas where sea urchins were excluded, bull kelp was more abundant and in areas where sea urchins were not excluded, heavy grazing was observed. Throughout the summer 2023 study period, sea surface temperature did not exceed bull kelp's adult or gametophyte thermal tolerance. Restoration of this site should include methods to reduce sea urchin herbivory, while carefully considering cultural and ecological implications.

Keywords: macroalgae; Sea Urchin; Bull Kelp; Kelp restoration; Herbivore exclusion

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Research for this project was conducted on the overlapping territories of the original stewards of the lands and waters of the Southern Gulf Islands, the W̱SÁNEĆ First Nations, the Hul'quimi'num Treaty Group First Nations and the Stz'uminus, Semiahmoo, and Tsawwassen Nations. This project was developed and completed on the unceded traditional territories of the Kwikwetlem, Musqueam, Squamish, and Tsleil-Waututh Nations.

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Most importantly, thank you to the Sea, for always keeping me afloat.

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List of Acronyms

ISZ	Interim Sanctuary Zone
SCUBA	Self-Contained Underwater Breathing Apparatus
SIMRES	Saturna Island Marine Research and Education Society
SRKW	Southern Resident killer whale
SSWD	Sea Star Wasting Disease

Glossary

Anthropogenic	Environmental change caused or influenced directly or indirectly by humans.
Exclosure	An area in which unwanted animals (or other intruders) are excluded by fencing or other means.
Extirpated	Locally or regionally extinct.
Gonad	The primary reproductive gland, or sexual organ, that produces reproductive cells, or gametes. Often, in males the gonads are called testes; the gonads in females are called ovaries.
Hysteresis	(In Ecology) When the pathway of recovery of an ecosystem differs from its pathway of degradation.
Macroalgae	Macroscopic, multicellular marine algae often referred to as seaweed. The term includes some types of Rhodophyta (red), Phaeophyta (brown) and Chlorophyta (green) macroalgae.

Chapter 1.

Introduction

Kelp is a macroalgae that grows in coastal ecosystems, primarily in water below 20°C (Supratya et al. 2020). The Salish Sea is a hotspot of kelp diversity (Hollarsmith et al. 2022) with 21 identified species of kelp (Hollarsmith et al. 2022). Bull kelp (*Nereocystis luetkeana*) has a central role in coastal-ecosystem function in the Salish Sea as it is the primary canopy forming kelp (Hollarsmith et al. 2022). Kelp grows in dense groupings underwater and forms three-dimensional habitat similar to terrestrial forests (Teagle et al. 2017). Kelp forests provide a number of ecosystem services to humans and marine life, including carbon sequestration, primary production, cultural importance, and marine habitat (Eger et al. 2022), but there are recent trends that suggest kelp forests are in decline. Coastal marine ecosystems are being impacted and altered by anthropogenic disturbances (Eger et al. 2022). Fishing, climate change, introduction of invasive species, and declines in high trophic level species are altering trophic cascades in coastal ecosystems (Hollarsmith et al. 2022).

Local observations on Saturna Island by the Saturna Island Marine Research and Education Society (SIMRES) indicate a loss of kelp in the Saturna Island Interim Sanctuary Zone (ISZ). Saturna Island is part of the Southern Gulf Islands Archipelago in British Columbia, Canada. The ISZ is a marine protected area, established to protect the endangered Southern Resident killer whales (SRKW) (*Orcinus orca*) (Fig. 1). This kelp loss appears to be localized to the ISZ as citizen science bull kelp mapping indicates there are healthy kelp populations elsewhere along the Saturna Island coastline (Marine Data BC 2022). The reasons for the localized kelp loss are currently unknown.

Removal of keystone species from an ecosystem may lead to an imbalance that has the potential to drive a productive system into unproductive hysteresis. In kelp

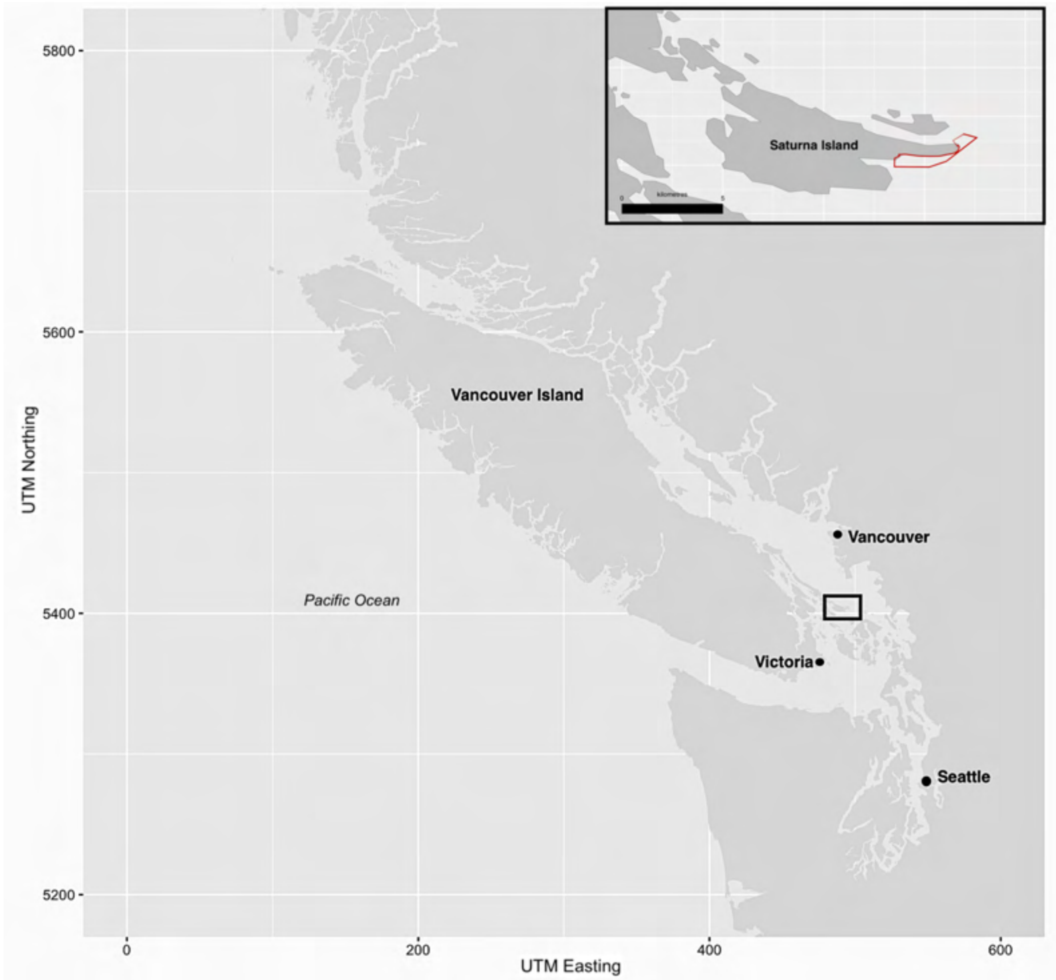

Figure 1. Saturna Island, British Columbia and surrounding landmarks for reference. Saturna Island Interim Sanctuary Zone is outlined in red.

forests, an increase in herbivore abundance increases kelp grazing, and causes a decrease in kelp abundance (Burt et al. 2018, O'Brien & Scheibling 2016). In kelp forests of the Pacific Northwest, sea urchins are a primary kelp grazer (Watson and Estes 2011). There are two species of sea urchins that have been observed in the Saturna Island ISZ: Red Sea Urchins (*Mesocentrotus franciscanus*) and Green Sea Urchins (*Strongylocentrotus droebachiensis*). These species have different physiology and life histories (Rogers-Bennet and Okamoto 2020, Scheibling and Hatcher 2013). Red sea urchins are on average 89 mm in diameter (California Department of Fish and Wildlife 2020), and green sea urchins are on average 55 mm in diameter (Fisheries and Oceans Canada 2016). Red sea urchins live in excess of 100 years and green sea urchins live approximately 25 years (Rogers-Bennet and Okamoto 2020, Scheibling and Hatcher 2013). They share the same predators, which, in British Columbia, are primarily Sunflower Sea Stars (*Pycnopodia helianthoides*) and Sea Otters (*Enhydra lutris*) (Burt et al. 2018).

A key urchin predator, the Sunflower Sea Star, has recently experienced a mass mortality along the Pacific coast of North America, including the Salish Sea, due to Sea Star Wasting Disease (SSWD) that began in 2013 (Montecino-Latorre et al., 2016). Another key urchin predator, Sea Otters, were historically extirpated in British Columbia and populations have not returned to the Gulf Islands (The Gulf Islands Guide 2013). The absence of predators is contributing to uncontrolled populations of sea urchins, which may provide an explanation for the loss of kelp.

Another possible explanation for declining kelp abundance is thermal stress caused by increasing water temperatures primarily due to climate change, and marine heat waves, such as "The Blob". The Blob was a patch of abnormally warm water that started in Alaska in 2013 and moved through the Pacific Northwest as far as Mexico by the end of 2016 (Wagner 2020). Kelp is a cold water macroalgae that is found at temperate, Arctic and sub-Antarctic latitudes (United Nations Environment Programme 2023). Water temperature plays a role in nutrient availability and regulates the physiology of kelp (Steneck et al. 2002, Adey & Steneck 2001).

These possible drivers of change, absence of predators, and thermal stress, do not provide an explanation for why the kelp loss is only observed in localized areas, or how to restore productive kelp forests. This project investigated the role of sea urchin herbivory and thermal stress in relation to kelp loss and was conducted in the Saturna Island ISZ.

The ISZ is a marine protected area that was created in 2019 as a refuge for whales in Boundary Pass, and to protect the traditional feeding grounds of SRKW (Burnham et al. 2021). Kelp forests provide nursery habitat for juvenile salmonids and forage fish, including Pacific herring (*Clupea pallasii*). Juvenile forage fish support upper trophic predators like adult salmon, seals, and sea lions, which are all residents of kelp forests.

One of the key diet components in the Salish Sea for SRKW is Chinook salmon (*Oncorhynchus tshawytscha*) (Shaffer et al. 2020). Loss of kelp forests in the ISZ results in loss of shelter, habitat, and prey for the salmon that are a food source for SRKW. This results in a decline in salmon and subsequent negative implications for this struggling population of killer whale. Maintaining healthy productive kelp forests in the ISZ is vital to the rehabilitation of this clan of whales, all lower trophic-level species in this food web, and the other marine species who reside there. Maintaining a diverse community in the ISZ benefits its trophic resilience to resident species and transient species who use this habitat temporarily for foraging and refuge.

The purpose of this project was to investigate the mechanism of bull kelp decline and, bull kelp distribution, in the Saturna Island ISZ. This project investigated the relationship between kelp and sea urchins, and measured water temperature to investigate thermal stress. This project installed flexible fence exclosures to determine if they are effective at excluding sea urchins and if the macroalgae inside the flexible fence differs from that in a control. Sharma et al. (2021) has provided evidence that flexible fences 30 cm in height are effective at excluding sea urchins, this study tested 30 cm, and 10 cm to evaluate the effectiveness of alternate heights of fencing for excluding urchins and protecting kelp.

This project has contributed and continues to contribute to an effective approach to restore healthy kelp populations in the ISZ in partnership with SIMRES. Educating Saturna Island community members about the benefits of healthy kelp populations to humans and marine life and sharing research goals and findings was an important component of this project.

This project answered the following questions:

Is bull kelp abundance higher when sea urchins are excluded?

Do 10 cm flexible fence sea urchin exclosures retain bull kelp and reduce sea urchin herbivory?

Is sea surface temperature in the summer leading to bull kelp thermal stress in the Saturna Island Interim Sanctuary Zone?

Are there any sea urchin predators in the Saturna Island Interim Sanctuary Zone?

Chapter 2.

Methods

2.1 Study Region and Site Selection

The decreased abundance of kelp surrounding Saturna Island is localized to regions in the ISZ along the shoreline of Boundary Pass. All research occurred in the ISZ. The shoreline of the ISZ is dubbed “Cliffside” by Saturna Island residents. The terrain consists of treacherous sandstone cliffs that makes access challenging (Figure A1). This area of the Salish Sea has strong tidal currents close to shore and is part of an international shipping route with cargo shipping traffic. Accessibility and safety were large considerations in site selection. Access to the shoreline was granted by a private residence with a staircase and ladder down to the ISZ shoreline.

2.2 Sea Urchin Exclosures

Sea Urchin Exclosure sites were selected in proximity to the staircase access point, and in areas of refuge from strong tidal currents to allow for ease of sampling and monitoring.

2.2.1 Sea Urchin Exclosure Instillation

Flexible fencing urchin exclosures were modified from those developed by Sharma et al. (2021) by using alternate heights, a different shape, and larger mesh size. Alternate heights were used to test a shorter minimum height than Sharma et al (2021), the shape used in this study was determined as most effective for instillation, and a larger mesh size was used due to availability of materials and sea urchin size. Exclosures were installed at three replicate locations along the shoreline of the ISZ, in Boundary Pass, on June 5 and 6, 2023. To account for random spatial variability, 3 replicate sites were selected (Figure 2). Each of the three sites contained the following 3 treatments: an exclosure with mesh net fence of 30 cm height, an exclosure with mesh net of 10 cm height, and a control of no exclosure mesh net. Treatments were randomly placed on each site in a complete randomized block experimental design.

Exclosures were custom made with 2 cm nylon mesh net fence, a galvanized steel chain along the bottom and marine floats along the top (Figure 3, 4). This mesh size was chosen as it is smaller than the average size of both red and green sea urchins. A 50 cm net was also originally installed at each site but it was removed to prevent bycatch as it was found early in its deployment to have the potential to function as a gillnet.

Sea urchin exclosures were installed using a concrete drill to drill into the sandstone and the chain was secured to the substrate with 9.53 mm expansion bolts. This installation was required to ensure that exclosures were not carried away in the strong tidal currents of Boundary Pass. Once installed, they remained until the end of the study period. Use of the concrete drill limited placement to sites that could be drilled just above the low tide line clear of saltwater to prevent corrosion and damage of equipment. To allow for maximum depth, exclosures were installed during a negative tide. Three attachment points were drilled per exclosure and the exclosure was installed in the shape of an equilateral triangle, each of the three sides was 80 cm in length. The flexible fences were installed so that the base chain was flush with the seabed (i.e., no gaps present) so that urchins could not enter from underneath. Similar to Sharma et al. (2021), treatments in each site were at least 1 m apart to ensure that urchins could freely move around and between the exclosures and did not impede the urchin movement across the site. Post installation, all sea urchins within the netted area were removed.

2.2.2 Sea Urchin Exclosure Sampling

Sampling of each exclosure took place weekly, on the day of the lowest tide of the week, to minimize required dive depth. Sampling was done by snorkeling and free diving.

For each treatment, macroalgae was measured by number of stipes of each species. Stipes that had no leaf matter or had been cropped and identification was not possible were recorded as non-intact stipes. For all sampling, video footage of each exclosure and snorkel survey was recorded using a GoPro Hero 11.

Figure 2. **Red points represent the three sites with sea urchin exclosures installed on Saturna Island, British Columbia in Boundary Pass in the Saturna Island Interim Sanctuary Zone in 2023.**

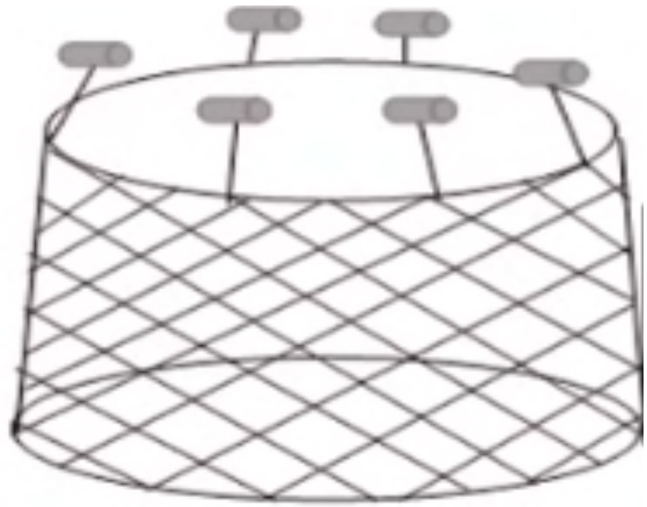

Figure 3. **Modified from Sharma et al. (2021), an illustration of flexible fence exclosures with nylon net walls, marine floats along the top to hold up the walls, and not illustrated, a chain along the bottom to weigh the structure flush with the seabed.**

Figure 4. **Underwater photograph of a flexible fence sea urchin exclosure installed in 2023 in the Saturna Island Interim Sanctuary Zone, British Columbia.**

Photo Credit: Rachel Fairfield Checko

If any intact species were unknown, they were identified after the dive using Lamb and Hanby 2005 and GoPro video footage. If there were sea urchins inside of the flexible fence at the time of sampling, they were identified, counted, recorded, and removed. Removal prevented them from grazing all flora within the exclosure and made sure they were not counted again the following week should they not have been able to get out on their own from the week before.

2.2.3 Snorkel Surveys on Exclosure Sites

A systematic snorkel survey was also conducted at each site each week and species richness and abundance was recorded for all invertebrates and vertebrates within a 5 m diameter of the flexible fences to survey for urchin predators (Figure 5). These snorkel surveys were recorded using a GoPro Hero 11.

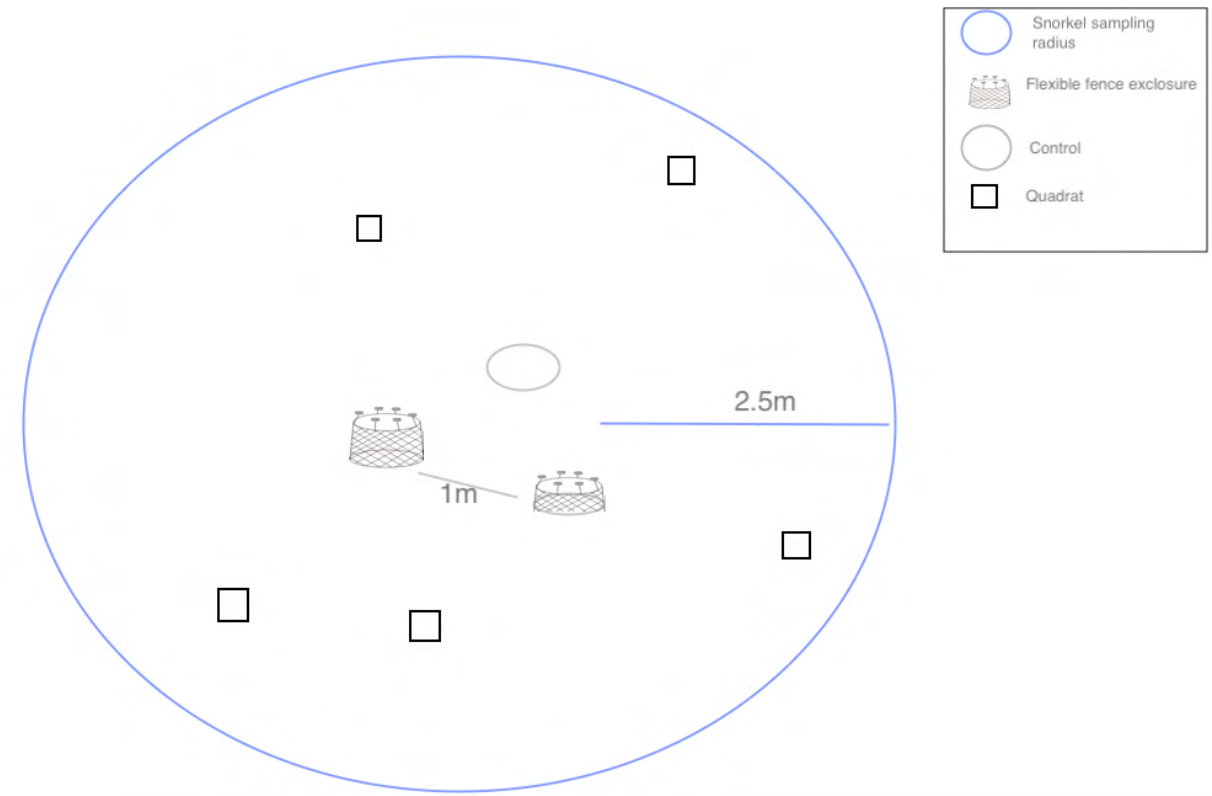

Figure 5. Schematic of one site with flexible fence sea urchin exclosures, urchin density quadrat sampling, and 5m systematic snorkel survey radius. This set up was repeated for a total of 3 sites.

2.2.4 Sea Urchin Density on Exclosure Sites

At each exclosure site, monthly measurements of sea urchin density were taken. A 50 cm^2 quadrat (squares in Figure 5) made of PVC pipe was randomly placed on the seabed and the number of red and green sea urchins inside the quadrat were counted (Figure 5, 6). This size of quadrat was chosen for ease of maneuvering under the water while free diving, opposed to the universal 1 m^2. Due to the size of the quadrat, individuals partially in the quadrat were included in the count. This was repeated five times per site each month.

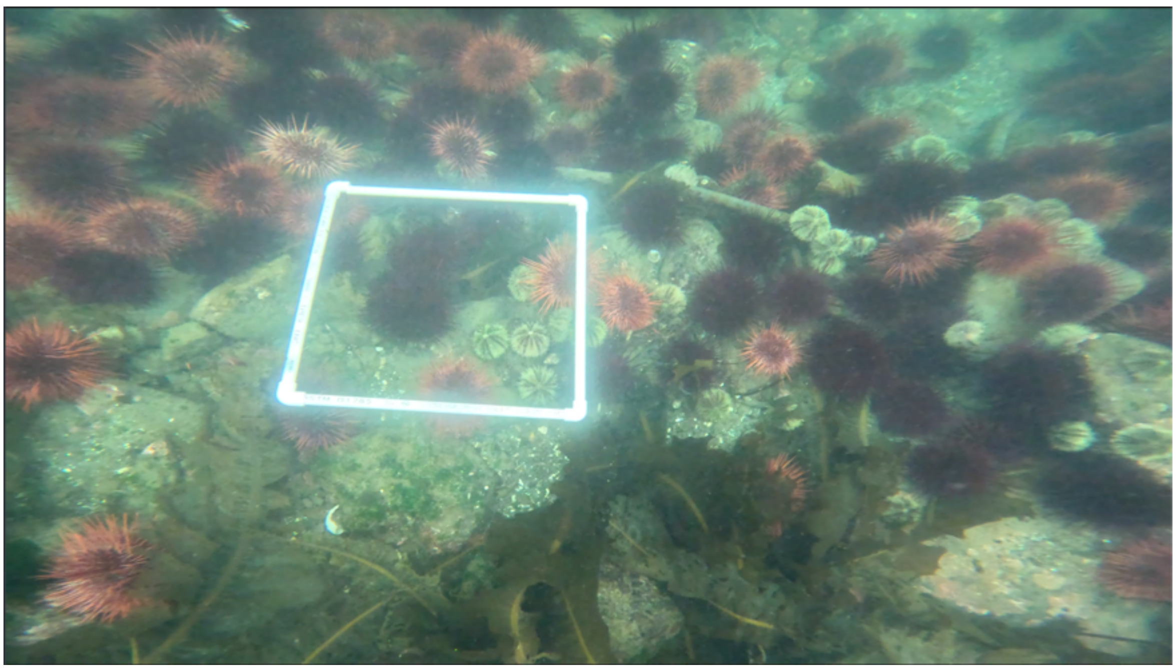

Figure 6. Underwater photo of a single 50 cm^2 quadrat used to count urchin density in the Saturna Island Interim Sanctuary Zone, British Columbia in 2023.
Photo Credit: Rachel Fairfield Checko

2.2.5 Sea Urchin Exclosure Sites Water Temperature

To determine if water temperature was affecting kelp abundance, water temperature was collected at each of the three sites on the same day as the exclosure sampling. Water temperature plays a role in nutrient availability and regulates the physiology of kelp (Steneck et al. 2002, Adey and Steneck 2001). Water temperature was taken using a Hanna HI98129 Combo unit. The same unit was used throughout the study period and was calibrated for other water parameters as per the manual once per week on the day of sampling.

2.3 Interim Sanctuary Zone Urchin and Kelp Sampling

In addition to sea urchin exclosures in a localized area of the ISZ, this project created a baseline map of sea urchin and kelp density of the entire ISZ coastline in August 2023.

2.3.1 Sea Urchin Density

Sea urchin density was measured at 15 sites along the length (approximately 3 km) of accessible ISZ coastline at approximate 100m to 200 m intervals. These methods used the same 50 cm^2 PVC pipes to measure urchin density as described in Section 2.2. At each of the 15 sites, sea urchin density was measured in four quadrat samples. Four samples were taken instead of five (as described in Section 2.2) for efficiency in areas with high currents.

Approximately, 600 m of coastline (6 sampling sites) in the middle of the ISZ was inaccessible to reach by foot and currents did not allow for snorkel sampling. In this 600 m area, in 100m to 200 m intervals, a GoPro was deployed on a 1 m pole mount from a kayak and video of the underwater environment of the site was recorded for approximately 10 seconds. There was a total of 15 sampling sites along the ISZ coast, 9 of which were sampled via snorkel and 6 of which were sampled via GoPro (Figure 7).

Figure 7. **15 sites along the Saturna Island Interim sanctuary Zone coastline in British Columbia where sea urchin density sampling occurred in August of 2023.**

2.3.2 Kelp Mapping

In addition to sea urchin density, canopy kelp sampling was conducted along approximately 2.5 km of the eastern-most section of the ISZ coastline. This sampling was conducted to determine spatial distribution and estimated abundance of bull kelp within the ISZ. Bull kelp mapping has been ongoing for over 10 years at Saturna Island by the Mayne Island Conservancy Society; however, the ISZ has not been included in this mapping. In 2023, bull kelp in the ISZ was mapped as per the Mayne Island Conservancy Society methods. Complete mapping methods can be found in the Mayne Island Conservancy Society Manual (Fretwell and Boyer 2010). These methods involve using a GPS and data sheets to delineate the following features: kelp beds, lines of kelp, and single individuals (also referred to as bulbs or points). These three features are classified as follows, from the Mayne Island Conservancy Manual:

Polygons represent kelp beds greater than 5 m in both length and width. The edge of the bed was defined as the point at which the distance between kelp bulbs becomes greater than 8 m. Along the contours of the Polygon edge, waypoints are recorded every 4 m to 6 m.

In some cases, kelp may form continuous strips along the shoreline, or appear to form a line. When less than 5 m in width these strips are recorded as ‘Lines’, and a series of a waypoints are taken at intervals of 4 m to 6 m. A separation of greater than 8 m between bulbs marks the end of the current Line and the beginning of a new Feature.

Single bulbs or small clusters less than 5 m in diameter are marked as ‘Points’, by recording a single waypoint at the center. Solitary bulbs or small clusters will be considered on their own feature when they are separated from other bulbs by more than 8 m. When there are multiple bulbs within a ‘Point Feature’, the number of bulbs was recorded on a data sheet. Due to time limitations and inclement weather, the western-most 400m (approximately) of the ISZ coastline was not mapped for bull kelp in 2023.

2.4 Site Reconnaissance

In May 2023, deep self-contained underwater breathing apparatus (SCUBA) transect surveys of the ISZ were completed by a consulting company, Dynamic Ocean. The SCUBA surveys were conducted at deeper depths than the systematic snorkel surveys to help determine this deeper zone's urchin density and predator picture. This was an important method to include as the snorkels were limited to those sea urchins and predators seen from the surface and shallow free dives, whereas SCUBA transects covered deeper habitat along the ISZ region of interest.

2.5 Data Analysis

To determine if there was a difference in the number of bull kelp stipes and the number of sea urchins within the different height exclosures across all 3 sites throughout the sampling period, a generalized linear mixed model was performed in RStudio. This model used a Poisson distribution to account for the urchin and bull kelp stipe data being count data. This is a common distribution used to analyze count data and is appropriate for integer values greater than or equal to zero. This model accounted for the randomization of the blocked study design by incorporating a random effect of site into the generalized linear model. This model accounted for autocorrelation of measuring the same response over time by incorporating a penalized quasi-likelihood (PQL) term that accounts for any correlation between kelp counts at the same location between weekly time intervals (i.e., a repeated measure design). The PQL model allows for fixed effects such as the exclosure treatment and water temperature, and random effects such as block (site replication).

A second generalized linear mixed model was created to determine if there was a difference in the number of non-intact kelp stipes, as a proxy for urchin grazing, within the exclosures and the controls across all 3 sites over the sampling period. This model was a difference model that investigated the difference in the response from the beginning and end of the season. It also used a Poisson distribution and incorporated a random effect of site into the model.

Sea urchin density of the 6 sites that were inaccessible for quadrat sampling were analysed using the collected GoPro video footage. This video footage was processed using a video of a snorkel deployed quadrat, recorded with the same GoPro, and ImageJ software. This software was used to measure the pixel length of the quadrat and superimpose an artificial quadrat matching pixel size, to videos without a quadrat, to estimate the number of urchins within a quadrat when true quadrat sampling was not achievable. These 6 sites use only one estimated count with no replicates. In addition, to account for depth, the number of pixels of one green sea urchin diameter was measured using ImageJ software and applied to green urchins in the videos, this assumes that green urchins along the ISZ coast are all approximately the same size.

Data collected in May by Dynamic Ocean SCUBA divers was reviewed to determine if sea urchin predators were detected, and where along the ISZ coastline sea urchins were detected during deeper dives than done in this study.

Bull kelp mapping data was converted into shapefiles and uploaded to QGIS on top of an OpenMap base map to visualize kelp along the ISZ coast. Results of kelp mapping were analysed to determine approximate percentages of the ISZ coast of each kelp feature, and the predominant feature of the ISZ coastline. This was achieved using the "measure" tool in QGIS software, to measure small sections, totaling the length of the entire coastline, and categorize each section as one of the following: lines, bulbs, or beds of kelp, no kelp, or insufficient data. New measurements began when a feature ended on the map. The distances of each measurement were totaled for each feature and divided by the total distance to determine the percentage for each feature.

Chapter 3.

Results

3.1 Sea Urchin Exclosures

3.1.1 Sea Urchin Exclosure Sampling

The data analysis indicated that there was significantly more bull kelp within the 30 cm exclosures (1.03, p=0.01), and the 10 cm exclosures (0.92, p=0.02) compared to the controls (0.32). Results from this model indicated that taller fences had more bull kelp stipes than a shorter fence, or the control.

The data analysis indicated that exclosure fencing significantly decreased negative effects on kelp count ($p < 0.001$) compared to the control category. There was significantly more non-intact bull kelp stipes within the controls at the end of the study period, compared to the beginning, than both 10 cm and 30 cm exclosure treatments (p=0.006) (Figure 8).

There was no significant difference in the number of green sea urchins within the control and the exclosures at the three sites (p>0.05), despite there being significant improvement in bull kelp survival with urchin exclosures.

3.1.2 Sea Urchin Exclosure Sites Snorkel Surveys

No sea urchin predators were observed in the species inventory, exclosure, and systematic snorkel surveys. Similarly, there were no sea urchin predators observed by the Dynamic Ocean scuba dive surveys (Figure 9) within the ISZ in May of 2023 (Burdett-Coutts 2023).

Throughout the study period, multiple sun stars were observed, Morning Sun Stars (*Solaster dawsoni*) and Striped Sun Stars (*Solaster stimpsoni*) but no Sunflower Sea Stars. Morning and Striped Sun Stars do not predate on sea urchins. Throughout the summer, during systematic snorkel surveys, there were three occasions when sea star wasting disease was observed on single individual sea stars within the ISZ.

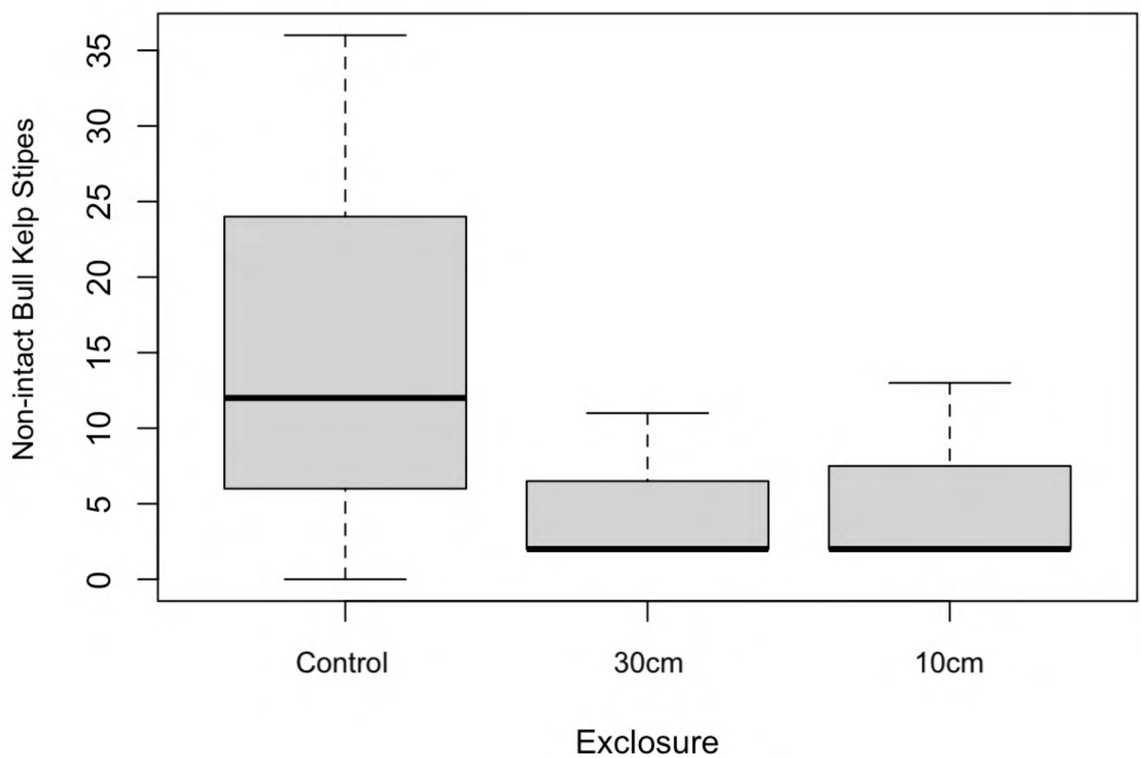

Figure 8. Non-intact kelp stipes in each treatment of sea urchin exclosure in the Saturna Island Interim Sanctuary Zone June through August 2023. Boxes represent the interquartile range (IQR), solid black lines within the IQR represent the median, and whiskers represent the range of data.

Figure 9. **Red points represent 5 dive sites where SCUBA dives were completed by Dynamic Ocean in May 2023 for a pilot study of sea urchins and biodiversity in the Saturna Island Interim Sanctuary Zone, British Columbia.**

3.1.3 Sea Urchin Exclosure Sites Urchin Density

Results of monthly urchin density measurements at each exclosure site, and weekly systematic snorkel surveys indicated that urchins were present at each exclosure site throughout the study period. On average, monthly mean urchin densities were similar amongst exclosure sites (Figure 10) with all sites predominated by green urchin abundance. There were on average 14 green sea urchins per 50 cm^2 at each site each month. Sampling at exclosure site 2 was affected by poor visibility in July and is an anomaly with 3.5 green sea urchins per 50 cm^2. Red sea urchins were less abundant and averaged 0.1 individuals per 50 cm^2. Red urchins were most seen on site 2.

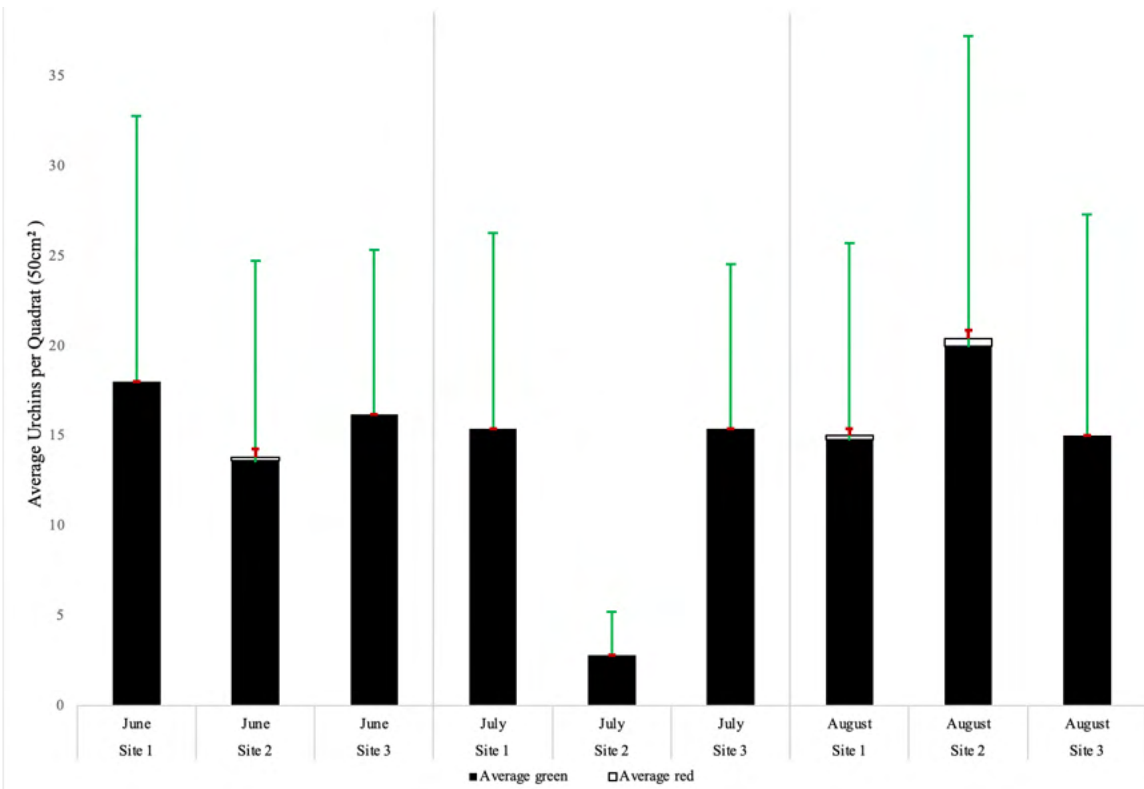

Figure 10. Average red and green sea urchins per quadrat per month at each sea urchin exclosure site in the Saturna Island Interim Sanctuary Zone. Error bars reflect upper 95% confidence interval (CI), green error bars represent the upper 95% CI for green urchins at that site and month, and red represents upper 95% CI for red urchins at that site and month.

3.1.4 Sea Urchin Exclosure Sites Water Temperature

There was no significant difference in temperature among the exclosure sites ($p>0.05$). Water temperature measurements taken throughout the summer at each exclosure site each week ranged from a minimum of 11.3 degrees Celsius to a maximum of 14.5 degrees Celsius and was 12 degrees Celsius on average. This range is within the ideal growing and maintenance conditions for bull kelp adult stage and gametophytes (Hotz 2021, Weigel et al. 2023).

3.2 Interim Sanctuary Zone Urchin and Kelp Sampling

3.2.1 Sea Urchin Density

Along the ISZ coastline, urchin density within the 15 sites varied widely. For example, some quadrats of the same site (Site 1) had 0 green urchins, while another quadrat for that same site contained 46 green urchins. This indicates large spatial variation of urchin aggregates. All sites that had sea urchins present had a higher abundance of green sea urchins compared to red sea urchins (Figures 11). Site 3 had a higher quantity of red urchins than all other sites (Figure 12). In contrast to the findings of this study, Dynamic Ocean did not find a higher abundance of red urchins at this site 3 compared to other sites.

The coastline sampling indicated that urchin density was variable along the coast and decreased abruptly to 0 closer to the West end of the ISZ. No urchins were visible from snorkel surveys or GoPro recordings from a kayak at low tide from site 12 westward until the end of the ISZ at site 15. Dynamic Ocean SCUBA surveys found urchins at all 5 of their dive sites along the coastline of the ISZ, including one site on the western end of the ISZ (Figure 13), dubbed “Fiddlers Cove”, that was south of the snorkel and kayak surveys. Dynamic Ocean recorded red urchins at this site, and no green urchins. Moving eastward from Fiddler’s cove, the other Dynamic Ocean dive sites were situated closest to site 10, 4, and 3 of this study’s urchin density sampling, with an additional site further east than was possible for this study (Figure 13). Similarly to the findings of this study, Dynamic Ocean found red and green urchins at all of these sites, with a higher abundance of green than red.

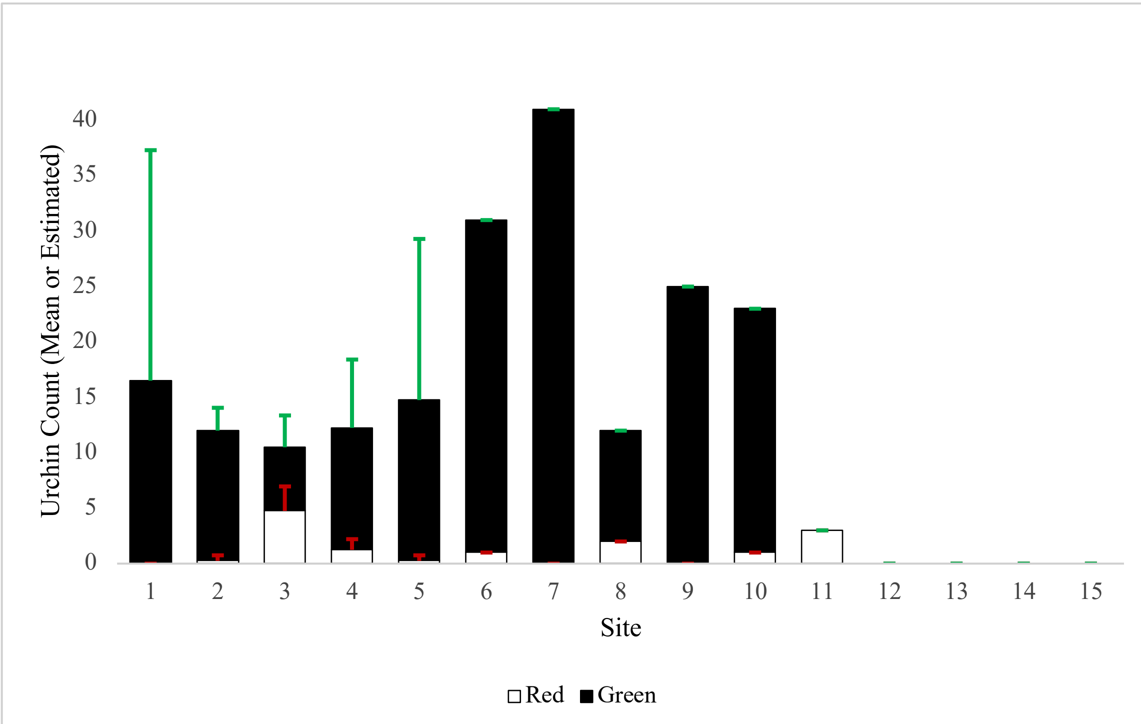

Figure 11. **Mean Sea Urchin Density of 4 quadrat samples taken in 15 sites along the Saturna Island Interim Sanctuary Zone coastline. Sites 6 through 11 are estimated from a single 0.5m^2 area calculated using video footage and ImageJ software. Error bars reflect upper 95% confidence interval (CI), green error bars represent the upper 95% CI for green urchins at that site, and red represents upper 95% CI for red urchins at that site.**

Figure 12. Top: Underwater photo taken at urchin density site 3 in the Saturna Island Interim Sanctuary Zone, British Columbia, representing a site with high red urchin density. Bottom: Underwater photo taken at Site 7 in the Saturna Island Interim Sanctuary Zone, British Columbia, representing a green urchin dominated site

Photo credits: Rachel Fairfield Checko 2023

3.2.2 Kelp Mapping

Along the ISZ coastline, bull kelp density varied from no kelp, bulbs, lines, and small beds (polygons) (Figure 14). Predominantly in 2023, the coastline was comprised of sections with no kelp. In 2023, at least 41% of the ISZ coastline had no bull kelp and there were multiple stretches of 100m or more where there was no bull kelp. There was bull kelp present along at least 43% of the coastline. Sections of the coastline that had bull kelp present was comprised of 22% lines, 15% bulbs, and 6% beds. The largest mapped bed within the ISZ is located at East Point, the eastern most point of the Saturna Island shoreline. 16% of the coastline was not mapped due to time constraints.

Figure 13. **Flexible Fence and Sea Urchin Density sampling sites, May Dynamic Ocean Dive sites, and August Kelp mapping results of this project conducted in the Saturna Island Interim Sanctuary Zone, British Columbia, in 2023.**

Figure 14. **Results of Bull Kelp Mapping of the Saturna Island Interim Sanctuary Zone coastline in British Columbia in 2023. Green points represent single bulbs, black lines represented lines of kelp, and orange polygons represent kelp beds. Kelp mapping done in accordance with Mayne Island Conservancy Manual (Fretwell and Boyer 2010).**

Chapter 4.

Discussion

The findings of this study provide evidence that sea urchins may be the cause of declining bull kelp populations in the Saturna ISZ. The finding that there was no significant difference in the number of sea urchins within the control and exclosures is not a result of there being a large urchin density within the exclosures and the control. Rather, there were very low to no urchins within all treatments throughout the study period. This can be explained because exclosures excluded urchins and prevented them from grazing kelp within, as determined by there being significantly more bull kelp within the exclosures than outside. In the control, all macroalgae was grazed within 2 (sites 2 and 3) - 4 (site 1) weeks after implementation and bull kelp does not regenerate throughout the summer so, once it had been grazed, urchins had no reason to remain in the control areas.

Additionally, results of monthly sea urchin density measurements at each exclosure site, and weekly systematic snorkel surveys indicated that urchins were present at each exclosure site throughout the study period. Further, there were significantly more non-intact kelp stipes in the controls than within the exclosures. These non-intact stipes are likely the result of grazing, as sea urchin grazing was observed many times throughout the study period. Water temperature measurements indicated that in the summer of 2023, thermal stress was likely not affecting the ability of bull kelp to persist in the ISZ as the range remained within the ideal growing and maintenance conditions for bull kelp (Hotz 2021).

The cause of red sea urchin abundance in the ISZ coastline sampling site 3 is unknown. Among all sampled sites along the ISZ coastline, this site had more red urchins (Figure 12). It is possible that water temperature or quality at this site differs from the rest of the ISZ coastline, as temperature measurements were not recorded for the entire ISZ coastline. However, this site aligns closest with exclosure site 2 and water temperature here did not significantly differ from other exclosure sites that were not predominated by red urchins. There was also no visible difference in kelp abundance at this site, which is highlighted by the kayak kelp mapping (Figure 14). It is possible that Boundary Pass tidal currents are causing this aggregate; however, it is not known how this might be affecting red urchins differently than green urchins. This site is within a relatively shallow bay during low tide, opposed to an underwater cliff that is the common landscape of other sites. It is possible that this shallow site that is marginally protected from Boundary Pass currents might be preferable habitat for red urchins, who may be more susceptible to be impacted by currents than green urchins due to their larger size and taller spines, resting higher in the water column. Dynamic Ocean did not find substantially higher abundance of red urchins than green urchins at this site, indicating that this anomaly and large aggregate may be limited to shallower water and not representative of the entire underwater region of interest. Given the lower densities of red urchins at all other sites along the ISZ, it is likely that this species is not responsible for the decimation of kelp. This finding aligns with other studies in the Salish Sea that found that there was no change in red urchin populations before and after “The Blob” and SSWD events of 2013 (Schultz et al. 2016).

Bull kelp mapping and sea urchin density measurements of the ISZ in 2023 formed a baseline that can be monitored in the coming years if mapping and urchin sampling continues annually. Continued mapping and monitoring in this area will allow for long-term trends to be accounted for. This is an important component when working with kelp forests, as they are continuously changing mosaics that respond to large- and small-scale environmental events (Dayton et al. 1984, Dayton et al. 1992). Continued urchin density monitoring will also help to overcome the challenges of the large-scale within site variation of urchin density that occurred in 2023 surveying.

Results of 2023 bull kelp mapping indicated that there are expansive healthy bull kelp beds elsewhere around the island, including on the northern side of the peninsula that the ISZ is located to the south of. One explanation for this could be substrate type. At the eastern most point of Saturna Island, there is a beach, known as Shell Beach. This beach is located on the north side of Saturna’s eastern peninsula and is adjacent to the

ISZ in a waterway called Tumbo Channel. Tumbo Channel has sandy substrate, with sandstone reefs. This is a large contrast to the substrate of the ISZ which is comprised entirely of sandstone and underwater cliffs. Sea urchins prefer rocky substrate due to their methods of locomotion, that become challenged in soft substrate (Laur et al. 1986). It is possible that sea urchins have not colonized this part of Saturna Island, as they are avoiding the sand, and as a result, bull kelp populations remain abundant. However, research indicates that when starved, urchins will eventually cross a sandy substrate to reach a food source (Laur et al. 1986). This highlights the urgency to reduce sea urchin populations within the ISZ, to not only retain and restore kelp populations there, but also to maintain healthy populations elsewhere surrounding the island.

Sea urchin herbivory in the ISZ may pose a challenge to restore this site as sea urchin life history is unique in that they can remain alive even in the extended absence of food. Sea urchins have the ability to reduce their metabolic rate, by reducing nutrient and energy requirements of their gonads (Spindel et al. 2020). This results in very low energy requirements for the animal and allows them to remain alive once all macroalgae in their environment has been grazed (Spindel et al. 2020). Even in this state, sea urchins will continue to eat macroalgae as it grows and attempts to reestablish, resulting in barren environments that can persist for decades (Filbee-Dexter and Sheibling 2014, Spindel et al 2020). As a result, for kelp to re-establish, sea urchin density must decrease well below the density that caused the initial shift to barrens (Filbee-Dexter and Sheibling 2014). Once macroalgae is depleted or abolished, a cascade effect often occurs and most other life also disappears in that area.

This reduction of gonads poses an additional barrier to reduce urchin populations, as there is no longer incentive to harvest. The edible and valuable portion of the sea urchin is the uni, or gonads. When the size of the gonads are reduced due to absence of nourishment, the value decreases, and the incentive to harvest declines. Harvesting sea urchins is energy and labour intensive as it is often done by hand, either during low tide or by diving. As a result, when uni is not plentiful, the costs of harvest outweigh the benefits. Additionally, due to the size, in British Columbia, red urchins are the most sought after and harvested urchin species. The findings of this report indicated some aggregates of red urchins but a higher overall density of green urchins, which may limit harvest potential. An important area of future research is to further understand the large variation in urchin aggregates that were observed throughout the coast of the ISZ. More samples are necessary to have a full grasp of urchin density across the entire underwater landscape due to the large within site spatial variability in urchin density.

The cause of large populations of sea urchins in the ISZ is likely the result of altered trophic interactions caused by the mass reduction in Sunflower Sea Stars in the Pacific Northwest, as no sunflower stars were observed throughout the study period. The observation of other sun stars and sea stars within the ISZ and study area may elude that this habitat is suitable for Sunflower Sea Stars, and they have just not reestablished since the SSWD epidemic. Initiatives in San Juan Island, Washington, part of the San Juan Archipelago, sister Islands to the Southern Gulf Islands in British Columbia, have begun a captive breeding program for Sunflower Sea Stars (Grayem et al. 2022). This initiative began after SSWD in an effort to restore the critically endangered species and create populations that are resistant to the disease (Grayem et al. 2022). The intention is to release these lab grown sea stars into the sea to reestablish the food chain and ecosystem dynamics (Grayem et al. 2022). However, the observed presence of SSWD in the Saturna Island ISZ in the summer of 2023 may prevent the reintroduction of Sunflower Sea Stars, as conditions should be optimal when releasing hand raised specimens to allow for the best chance at survival. Nonetheless, this captive breeding program provides a potential next step and hope for the future of kelp forests in the Pacific Northwest.

In Haida Gwaii, British Columbia, a similar phenomenon to the loss of kelp caused by sea urchin grazing was encountered. There, a kelp reforestation project was implemented in collaboration with the Haida Nation, federal agencies, academia, and fishing industry (Lee et al. 2021). This project aimed to reduce sea urchin grazing pressure to allow restoration of bull kelp. This project was guided by Haida values and ethics, and successfully increased bull kelp and canopy cover (Lee et al. 2021). By integrating Haida values such as respect, responsibility, interconnectedness, balance, seeking wise counsel, and giving and receiving, they could be mirrored with western ecological values such as precautionary approach, integrated management, sustainability, adaptive management, and equitable sharing (Lee et al. 2021). This integration of indigenous and western science is likely the cause of this project's success and illustrates the importance of indigenous leadership and partnership in restoration.

When considering the use of flexible fence sea urchin exclosures in the future, the result that the small and large exclosures were both significant at retaining bull kelp is important as the shorter the fence, the less effort is required to keep them clean of marine life and debris, and the cost of materials decreases. This is important for future interventions where money and people power may be limited. However, while exclosures were effective at excluding sea urchins in the study sites, it is unknown if they would be effective in areas of mass urchin populations, or if they would be effective at retaining flora in areas of urchin barrens. These exclosures are not intended to be used as a restoration technique, and it is not recommended that they are installed in large numbers, or increased sizes, as increasing the scale introduces potential for them to act as a gill net and unintentionally trap marine life.

The findings of this study provide evidence that restoration of this site should include methods to reduce sea urchin herbivory. A common method globally for reducing sea urchin herbivory is culling. In some cases, one-off sea urchin culling has been proven to be a successful short term restoration approach (Miller et al. 2023). However, as demonstrated by the many kelp restoration projects globally, long-term adaptive management is often required to maintain low populations of sea urchins, in the absence or decline of predators (Tegner & Dayton 1991, Steneck et al. 2004, Miller et al. 2023). Additionally, sea urchin is edible, and harvesting it for food is a traditional practice in the Pacific Northwest (Parks Canada Agency and Government of Canada 2019). Red urchin is an important species for many Indigenous nations within the Salish Sea not only for food but also ceremonial and social use (Rogers-Bennet and Okamoto 2020). Similarly in New Zealand, sea urchin is a treasured species to Maori people who have relied on it as a food source for centuries (Miller et al. 2023). Restoration of sea urchin barrens requiring kelp reforestation in that part of the world is focused on harvesting and using the animals whenever possible, opposed to culling (Miller et al. 2023). This careful consideration of cultural and ecological implications should be applied when considering sea urchin removal methods.

The decline in kelp that has been observed in the Saturna ISZ is a phenomenon occurring globally and spans over cross-boundary ecosystems, such as the Salish Sea, that extends through both Canada and the USA (Filbee-Dexter and Scheibling 2014). Collaboration with not only governments and research initiatives on either side of borders, but also cross boundary Indigenous Nations will be required for successful restoration. This extends beyond kelp to all marine forest inhabitants such as invertebrates, including endangered abalone, fish, such as endangered pacific salmon, and mammals, such as endangered Southern Resident killer whales.

Chapter 5.

Conclusion

5.1 Conclusion of Findings

The findings of this study provide insight into the causes of bull kelp decline in the Saturna Island ISZ. In the summer of 2023, sea surface water temperature remained within the threshold for bull kelp, indicating that thermal stress is likely not responsible for the declining bull kelp populations in the Saturna ISZ. Sea urchin exclosures were effective at reducing herbivory to kelp in the study sites. When sea urchins were excluded from small areas, less kelp was grazed, and more Bull Kelp remained throughout the summer of 2023 in these areas. When sea urchins were not excluded, kelp faced increased grazing pressure and was fully grazed from small areas within 2-4 weeks (site dependent). It is unknown if exclosures would be effective in areas of mass urchin populations, or if they would be effective at retaining flora in areas of urchin barrens.

In 2023, the coastline of the Saturna ISZ consisted of at least 41% bull kelp. At least 43% of the coast had no bull kelp. There were very few beds of bull kelp, only 6% of the ISZ coastline. Approximately 75% of the coastline had red and/or green urchins present, indicating that most kelp along the ISZ is facing grazing pressure. The findings of this study provide evidence that restoration of the Saturna Island ISZ should include methods to reduce sea urchin herbivory. These findings are integral to informing future management measures and a restoration plan for this site.

5.2 Restoration Planning and Community Education

Findings of this project are being used in collaboration with SIMRES to determine a restoration plan to restore the kelp populations surrounding Saturna Island to healthy, productive kelp forest. The purpose of this research has been presented to community members of Saturna Island in an invited “Sunset Talk’ hosted by Parks Canada. Preliminary findings and this research have been presented to residents of the

Southern Gulf Islands in an invited talk at the Southern Gulf Islands Whale Sightings Network event. This project involved contributing to a technical working group hosted by SIMRES to collaborate with kelp specialists within the Pacific Northwest to collaborate on a restoration plan for the ISZ.

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Appendix A

Figure A1. Cliffside coastline of the Saturna Island Interim Sanctuary Zone.
Photo credit: Rachel Fairfield Checko 2023