NATURAL RESOURCES

Marine Vegetation along the Snohomish County shoreline

Final report to Snohomish County

IAA 93-103581

02/10/2023

PSEMP
PUGET SOUND ECOSYSTEM MONITORING PROGRAM

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
HILARY S. FRANZ | COMMISSIONER OF PUBLIC LANDS

DNR monitors abundance and depth distribution of native seagrasses to determine status and trends in greater Puget Sound through the Submerged Vegetation Monitoring Program (SVMP) (https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-eelgrass-monitoring).

The Submerged Vegetation Monitoring Program is a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (https://sites.google.com/a/psemp.org/psemp/home).

Cover Photo: Screenshots from the towed underwater video footage collected as part of IAA 93-103581

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The Nearshore Habitat Program is grateful to Snohomish County for providing funding for DNR to expand seagrass and macroalgae monitoring in their area of interest. The following document is the final report for IAA 93-103581 between DNR and Snohomish County.

The primary authors for this report are Bart Christiaen, Lisa Ferrier, and Lauren Johnson. Melissa Sanchez, Emily Smith, and Hayley Turner played a critical role in the video data collection and post-processing for the work summarized in this report.

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http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-publications

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Contents

Executive summary

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of State-Owned Aquatic Lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of native seagrasses, eelgrass (*Zostera marina*) and surfgrass (*Phyllospadix* spp.), important components of nearshore ecosystems in greater Puget Sound. DNR monitors area and depth distribution of native seagrasses to determine status and trends in greater Puget Sound through the Submerged Vegetation Monitoring Program (SVMP). Sound-wide monitoring was initiated in 2000. The monitoring results are used by DNR for the management of State-Owned Aquatic Lands, and by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound.

In 2022, DNR and Snohomish County signed IAA 93-103581. The goal of this agreement was to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp, and other macroalgae) at 24 sites along the shoreline of Snohomish County. Surveys spanned the shoreline between Warm Beach and Hermosa Point, and the shoreline of Gedney Island using methods developed for DNR's monitoring programs. This project completes a 3-year effort to comprehensively survey of the entire shoreline of Snohomish County (see also IAA 93-100931 and IAA 93-102327). This effort supplements existing and planned future sampling by DNR, and significantly increases the certainty in local estimates of eelgrass area and depth distribution over existing data from the SVMP. It also serves as a baseline classification of other marine vegetation types.

Key findings:

1. Eelgrass and other marine vegetation abundance at the 24 sites sampled for IAA 93-103581

   - In total, there were 88 +/- 3 ha of eelgrass in the study area (n = 24 sites). This corresponds to almost 10% of the area covered by eelgrass in Snohomish County (912 +/- 67 ha), approximately 13% of all eelgrass along the shoreline of King County (680+/- 9 ha), and less than 0.5% of all eelgrass in greater Puget Sound (22,102 +/- 1,074 ha). Approximately 20% of the area between the mean high water line and -6.1 m relative to MLLW at these 24 sites was covered by eelgrass. Non-native seagrass (*Zostera japonica*) was sparse in the study area.
   - There were approximately 99 ha of green algae, 61 ha of other red/brown algae, and 47 ha of understory kelp in the study area (n = 24). Green algae were most prevalent in the intertidal, above the shallow edge of eelgrass beds. Other red/brown algae were often found below the deep edge, and intermixed with understory kelp. We detected trace amounts of the invasive algae *Sargassum muticum* (less than 0.5 ha).
   - Eelgrass was usually found in dense patches with high percent cover. Green algae, and other red and brown algae were usually found at low percent cover. Understory kelp was more or less evenly distributed.

2. Depth distribution at 24 sites sampled for IAA 93-103581.

    - Eelgrass was found between 0.6 and -12 m, with a median depth of -1.3 m (MLLW). The majority of observations occurred between 0 and -4 m (MLLW).

    - Green algae, other red and brown algae, and understory kelp were found down to -15 m (MLLW), the maximum depth of the surveys. The majority of these algae occurred at shallower depths (median depths of -0.7, -6.4, and -4.0 m respectively). *Sargassum muticum* was found as deep as -4.2 m, with a median depth of -3.4 m (MLLW).

3. Eelgrass and other marine vegetation along the entire shoreline of Snohomish County

    - Based on data collected from 2019 to 2022, there was approximately 912 (+/- 67) ha of eelgrass along the shoreline of Snohomish County (n = 62 sites). The largest expanses of eelgrass occurred on sand flats near the Snohomish River delta and Port Susan. These account for over 60% of eelgrass in the study area.

    - There were approximately168 ha of understory kelp in the study area (n = 58 sites). Understory kelp was found at 46 of the 58 sites analyzed for different marine vegetation types, and was mostly comprised of prostrate kelp. Stipitate kelp was only found at one location (swh1017). The largest understory kelp beds were found along Hat Island and the stretch of shoreline between Edmonds and Mukilteo. Understory kelp was also abundant near the mouth of Tulalip Bay.

    - There was a clear spatial gradient in the deep edge of eelgrass beds, with eelgrass generally growing to deeper depths in the area between Edmonds and Mukilteo as compared to the eelgrass beds near Port Susan and the Snohomish Estuary. The spatial pattern for understory kelp was less clear. Some of the deepest understory kelp beds were found near Edmonds and along the shoreline of Hat Island. Some of the shallower understory kelp beds were located in Possession Sound and North of Tulalip Bay.

4. Long-term change in eelgrass area along the shoreline of Snohomish County

    - A comparison between data collected by DNR from 2019 to 2022 with a county-wide side survey of eelgrass beds based on data from 1999-2007 suggests that total eelgrass area was very similar between both surveys (912 +/- 67 ha between 2019 and 2022 vs. approximately 907 ha between 1999 and 2007).

    - There appears to be a lot of variability in the footprint of eelgrass beds when comparing the datasets, which is likely a real pattern in local increases and declines, but could also be due to the difference in survey methods.

    - A site-level comparison suggests that eelgrass beds have increased in area and depth at several sites between Port Susan and Tulalip Bay. Some of these site level increases correspond with known increases based on data collected by the SVMP (for example: swh1625).

1 Introduction

1.1 Eelgrass and kelp in greater Puget Sound

Seagrass and kelp beds are important components of nearshore habitats in greater Puget Sound. These plants and algae provide critical habitat for a wide array of marine life, such as rockfish, forage fish, and salmonids.

Eelgrass (*Zostera marina*) is the predominant species of seagrass in Washington State (Christiaen et al. 2022a). Like other seagrasses, it is a flowering plant that grows submerged in marine environments. Eelgrass is typically found on sandy and muddy substrates in the lower intertidal and shallow subtidal along beaches and tide flats (Mumford 2007). Individual eelgrass shoots grow along a horizontal rhizome that is shallowly rooted in the sediment. These rhizomes grow along and across each other, and form an intricate 'mat' that protects the underlying sediment from wave action and erosion (Fonseca and Cahalan 1992). The dense canopy of vertical leaves slows water currents and promotes the settling of particles, which can improve water clarity and allow for light to penetrate deeper into the water column (Koch et al. 2006, Bos et al. 2007, de Boer 2007). Eelgrass and its epiphytes have a high primary productivity, and produce large amounts of organic matter. This organic matter fuels the detrital food web, both locally and on nearby beaches, and affects biogeochemical cycles of carbon, nitrogen, sulfur, and oxygen (Mateo et al. 2006, Romero et al. 2006). Because of their high primary productivity and the relatively low decomposition rates of organic matter in marine sediments, eelgrass beds are significant sinks of 'blue carbon' (Mcleod et al. 2011, Rohr et al. 2018).

The combination of a high structural complexity and the availability of food sources make eelgrass beds a productive habitat that supports high biodiversity. Eelgrass beds tends to have rich communities of invertebrates (Heck et al. 1995), and offer both food and refuge from predation to a wide range of organisms, including forage fish and juvenile salmonids (Semmens et al. 2008, Rubin et al. 2018, Kennedy et al. 2018). They also function as spawning and nursery habitats for commercially important crustaceans and fish species, such as Dungeness crab and Pacific herring (Stevens and Armstrong 1984, Pentilla 2007). Eelgrass beds are limited by light availability, and respond quickly to changes in water clarity (Thom et al. 2008). They can be outcompeted for light by phytoplankton, epiphytes, and macroalgae when nutrient loads are high (Burkholder et al. 2007, Schmidt et al. 2012). They can also be damaged by aquaculture, dredging, construction, and recreational boating in nearshore habitats (Hemminga and Duarte 2000, Unsworth et al. 2017). Because of their habitat value and their sensitivity to human activities, eelgrass beds are often used as an indicator for the health of coastal ecosystems.

Washington State contains 22 species of kelp (Gabrielson & Lindstrom, 2018), making it one of the most diverse kelp floras in the world. Kelp are large brown algae, belonging to the order Laminariales. These algae are often split into 3 categories based on their morphology: floating kelp, prostrate kelp, and stipitate kelp. There are 2 species of floating kelp in Washington State: bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*). These species have floats that enable the photosynthetic blades to remain near the surface of the water column to obtain maximum light. Stipitate kelp, such as *Pterygophora californica*, have rigid stipes that raise them from the bottom. Prostrate kelps tend to have short stipes and form a canopy near the bottom. These species are able to grow at lower light levels, but are typically intolerant of desiccation. Examples in Puget Sound are *Agarum* spp. and *Costaria costata*. Prostrate kelp and stipitate kelp are often referred to as understory kelp (Mumford 2007).

Kelp species need solid substrate for attachment, and tend to be the dominant vegetation along rocky shorelines. In Puget Sound, kelp often attach on boulders, cobble or even gravelly substrates (Mumford 2007). Kelp beds have a high primary productivity, and provide large amounts of carbon to marine food webs, either as detritus, particulate or dissolved organic matter (Krumhansl & Scheibling, 2012, Olson et al. 2022). Organic matter from kelp and other algae can be exported over long distances and contributes to carbon sequestration in deep sea sediments (Krause-Jensen & Duarte, 2016). Kelp beds also provide physical structure in nearshore environments, which benefits a wide range of organisms including juvenile rockfish and juvenile salmon (Wernberg et al. 2019). In addition, kelp beds provide important refugia microhabitats for a large number of often-specialized organisms. Several data sources have documented the declines of bull kelp beds in South and Central Puget Sound. For example, a recent study by Berry et al. (2021) shows that the current extent of bull kelp in South Puget Sound is 63% lower than the earliest baseline in 1878. Trends in understory kelp are not well understood because there is limited data on these important but potentially vulnerable habitats.

1.2 Eelgrass and kelp monitoring at DNR

DNR manages 2.6 million acres of State-Owned Aquatic Lands for the benefit of current and future citizens of Washington. DNR's stewardship responsibilities include protection of native seagrass species and kelp. The Nearshore Habitat Program at DNR (DNR-NHP) focuses on long-term monitoring of these habitats, and informs management decisions by providing information on status and trends. DNR-NHP monitoring of eelgrass and kelp is part of a collaborative research effort called the Puget Sound Ecosystem Monitoring Program, associated with the Puget Sound Partnership. Monitoring results are used to measure the eelgrass indicators and the upcoming kelp indicator for the Beaches and Marine Vegetation Vital Sign.

DNR-NHP surveys native seagrass species through the Submerged Vegetation Monitoring Program (SVMP). This monitoring program started in 2000, and uses towed underwater videography to estimate the area and depth distribution of native seagrass species in greater Puget Sound based on a probabilistic sample design. Collaborations with local governments and Tribes are a major component of the SVMP. Between 2014 and 2021, DNR sampled large parts of Kitsap County, the entire shoreline of King County, and a substantial portion of the shoreline of Snohomish County in collaboration with the

Suquamish Tribe (Christiaen et al. 2018, Christiaen et al. 2021), the City of Bainbridge Island (Christiaen et al. 2017), King County (Christiaen et al. 2020a), and Snohomish County (Christiaen et al. 2020b, Christiaen et al. 2022b).

Kelp monitoring is another DNR-NHP area of focus. DNR-NHP has conducted annual aerial surveys of floating kelp canopy along the outer coast and the Strait of Juan de Fuca since 1989. Two species of floating kelp are monitored: bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*). Starting in 2011, surveys were expanded to include several of DNR's Aquatic Reserves, which have been surveyed annually. Kelp is also monitored by DNR-NHP using kayak surveys, vessel based surveys, and drone surveys. Recently, DNR-NHP completed comprehensive surveys of floating kelp along the shorelines of South and Central Puget Sound (2017 and 2019 respectively). Both surveys were vessel-based, and recorded floating kelp presence along the -6 m (MLLW) subtidal bathymetry line, with a minimum threshold of a single individual (Berry et al. 2021). In 2021, DNR completed a demonstration project on how aerial imaging platforms could potentially enhance the existing kayak-based bull kelp canopy monitoring program conducted by Marine Resource Committees (MRC's) throughout greater Puget Sound (Berry & Cowdrey, 2021).

More recently, DNR-NHP began utilizing video footage from the SVMP, collected under modified protocols, to assess the distribution of understory kelp in greater Puget Sound. This effort started in 2018, with footage collected for projects with King County and Snohomish County (Christiaen et al. 2020a, Christiaen et al. 2020b, Christiaen et al. 2022b). This report summarizes understory kelp distribution along the entire shoreline of Snohomish County, based on data collected from 2020 to 2022.

1.3 IAA 93-103581 between Snohomish County and DNR

On July 7 2022, Snohomish County signed an agreement with DNR to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp and other green and red/brown algae) at 24 sites in Snohomish County (including the shoreline between Warm Beach and Hermosa Point, and the shoreline of Gedney Island). This project completes a countywide survey that was initiated in 2020. Previous contracts were IAA 93-100931 and IAA 93-102327.

This report summarizes area and depth distribution of eelgrass, understory kelp and other marine vegetation for all sites sampled as part of IAA 93-103581. It also contains a summary of eelgrass beds at 62 sites sampled by DNR between 2019 and 2022 along the shoreline of Snohomish County, a summary of other marine vegetation types at 58 of the 62 sites sampled, and a change analysis comparing the eelgrass results of the recent surveys with a previous county-wide eelgrass survey compiled from several studies conducted between 1999 and 2007. In addition, we included a measure of the relative abundance of several classes of common, easily distinguished echinoderms in intertidal and shallow subtidal habitats at all sites sampled.

Note that the methods used did not allow for surveying floating kelp. The bull kelp beds in the study area are mapped by the Snohomish County MRC (Snohomish Marine Resources Committee (snocomrc.org)).

All data collected under this agreement will be archived at DNR's headquarters in Olympia, Washington, and made available to the general public. Eelgrass data will be made accessible through an online data viewer on DNR's website and a downloadable distribution dataset. Other data will be made available on request. These resources are available at the following webpages:

https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science

https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/puget-sound-eelgrass-monitoring-data-viewer

http://data-wadnr.opendata.arcgis.com

2 Methods

Field sampling was conducted using methods developed for DNR's Submerged Vegetation Monitoring Program (Christiaen et al. 2022a). The SVMP is a regional monitoring program, initiated in 2000, designed to provide information on both status and trends in native seagrass area in greater Puget Sound. This program uses towed underwater videography as the main data collection methodology to provide reliable estimates of eelgrass area for subtidal seagrass beds in places where airborne remote sensing cannot detect the deep edge of the bed. Video data is collected along transects that are oriented perpendicular to shore and span the area where native seagrasses (mainly eelgrass, *Zostera marina*) grow at a site. The video is later reviewed and each transect segment of nominal one-meter length (and one-meter width) is classified with respect to the presence of *Zostera marina* and *Zostera japonica*. For the purpose of this study, the methods have been adapted to capture additional vegetation types, including understory kelp, red/brown algae and green algae. Kelp and macroalgae survey methods were based on the towed videography portion of recent studies that evaluated the effects of dam removal along the Elwha nearshore (Rubin et al. 2017). Areas with floating kelp beds were either skipped, sampled early in the season, or sampled at very high tides to avoid damage to this habitat.

2.1 Study area description

We report on data collected at 24 sites along the shoreline of Snohomish County in 2022: 9 sites around Hat Island, and 15 sites located between Port Susan and Tulalip Bay. We summarize data on eelgrass at 62 sites surveyed by DNR between 2019 and 2022 along the shoreline of Snohomish County, and compare these data to an earlier regional survey of eelgrass collected by side-scan sonar and aerial imagery between 1999 and 2007 (Bailey et al. 2007). We also compiled all available data on other marine vegetation types and invertebrates in the study area (at 58 of the 62 sites surveyed between 2019 and 2022).

2.2 Field sampling

Field sampling for IAA 93-103581 was conducted in September 2022 from the 11 m (36-ft) research vessel, the *R/V* Brendan D II, operated by Marine Resources Consultants (Figure 1). The equipment used for sampling is listed in Table 1. During sampling, the vessel deploys a weighted towfish with an underwater video camera mounted in a downward-looking orientation (Figure 2). The towfish is deployed directly off the stern of the vessel using a cargo boom and winch. During transect sampling, an MRC technician adjusts the position of the towfish using the hydraulic winch to fly the camera above the substrate. Parallel lasers mounted 10 cm apart on the towfish provide a scaling reference in the video image. A 500-watt underwater light provides illumination when needed.

Survey equipment simultaneously records the position, depth and time of day. Time and position data are acquired using a differential global positioning system (DGPS) with ability to utilize satellite based augmentation services (SBAS). The antenna is located on top of the cargo boom directly above the towfish and camera, ensuring that the position data reflect the geographic location of the camera (Figure 2). Depth is measured using a Garmin Fishfinder 250 and a BioSonics MX habitat echo sounder (Table 1). Both are linked to the differential global positioning system (DGPS) so that collected depth data is location and time specific.

A laptop computer equipped with a video overlay controller and data logger software integrates the DGPS data, user supplied transect information (transect number and site code), and the video signal at one second intervals. Video images with overlain DGPS data and transect information are simultaneously recorded on DVDs, and digital video recorders. Date, time, position, and transect information are stored on the computer at one second intervals. A real-time plotting system integrates National Marine Electronic Association 0132 standard sentences produced by the DGPS, two depth sounders, and a user-controlled toggle switch to indicate presence of marine vegetation.

Table 1: **Equipment on the R/V Brandon D II**

Equipment	Manufacturer/Model
Differential GPS Unit	Hemisphere VS330 with Satellite Based Augmentation System (SBAS, sub-meter accuracy)
Echosounders	Primary: BioSonics Mx Habitat Echosounder Secondary: Garmin Fishfinder 250, 200 KHz 11° single-beam transducer
Underwater Camera	Ocean Systems Deep Blue SD (downward facing) Ocean Systems Deep Blue HD (forward facing)
Underwater Light	Deep Sea Power and Light Led SeaLite
Lasers	Deep Sea Power & Light (10 cm spread, red)
DVD Recorder	Sony RDR-GX7 + Intuitive Circuits TimeFrame Video Overlay Controller
Image Recording	3 Atomos Ninja 2 Digital Video Recorders, ProRes format + VideoLogix Proteus II Video Overlay Controller
Computer systems	Rugged laptop with Microsoft Office and Hypack Max hydrographic software (capable of accepting ESRI ArcGIS files). HP 4480 Color printer
Camera	Nikon Coolpix waterproof camera

Figure 1: All data were collected from the *R/V* Brendan D II, using towed underwater videography and depth sounding instrumentation.

Figure 2: The *R/V* Brendan D II is equipped with a weighted towfish that contains an underwater video camera mounted in a downward looking orientation, dual lasers for scaling reference, and underwater lights for night work (A). The towfish is deployed directly beneath the DGPS antenna attached to the A-frame cargo boom, ensuring accurate geographic location of the camera (B).

2.3 Site and sample polygons

The study area is divided into 24 sites based on the statistical framework of DNR's Submerged Vegetation Monitoring Program. All sites belong to the fringe frame, which means that they represent potential habitat along a narrow band parallel to the shoreline. Each site polygon is bounded by the -6.1 m MLLW bathymetry contour and the ordinary high water mark as described in the SVMP methods (Dowty et al. 2019). Sites are 1000m long, as measured along the -6.1m contour on the deep edge. In addition to the site polygons, we also delineated sample polygons:

- For eelgrass these sample polygons span the entire length of the site and encompass all the eelgrass at that location.
- For other marine vegetation types, the sample polygons span the entire length of the site, and extend to a depth of -15m relative to MLLW.

At each site, underwater videography was used to sample the presence of eelgrass and macroalgae along transects in a modified line-intercept technique (Norris et al. 1997). Video transects are oriented perpendicular to shore, and extend beyond the shallow and deep edges of the sample polygons. Sites are divided in 10 sections of similar length (strata). Transects were selected based on a stratified random (STR) approach with 1 randomly selected transect per stratum[1].

2.4 Video processing

- **Eelgrass (*Z. marina*)**: we classified presence/absence of eelgrass at one second intervals, based on observation of rooted shoots within the field of view (video sampling resolution of nominally 1 m^2). All eelgrass presence and absence classification results were recorded with corresponding spatial information. The fractional cover of eelgrass along transects was used to calculate site eelgrass area. The depth at which eelgrass grows along each transect was used to estimate maximum and minimum depth of eelgrass relative to Mean Lower Low Water (MLLW) at each site. Non-native seagrass, *Z. japonica*, was classified as well, but these data were not included in the calculation of eelgrass area and depth distribution[2].
- **Other marine vegetation**: at one video frame every 5 seconds, we estimated a cover class for 9 broad vegetation types (all vegetation, all kelp, prostrate kelp, stipitate kelp, floating kelp, *Sargassum muticum*, other red/brown algae, green algae, seagrass), using a modified Braun-Blanquet scale (similar to Rubin et al. 2017). The fractional cover of each combination of vegetation class and cover class was used to calculate an area estimate at

[1] In previous years, DNR has surveyed some sites in the study area based on a simple random sample of transects (perpendicular to shore) within the areas where eelgrass occurred at these sites. This is referred to as simple random sampling (SRS) in this report.

[2] *Z. japonica* typically grows at higher tidal elevations than *Z. marina*, and is often too shallow for the research vessel. We are not able to provide a good area estimate of this non-native seagrass based on our sample techniques.

the site. The depth at which a vegetation type grows was used to estimate maximum and minimum depth relative to MLLW at each site.

- **Depth:** All measured depths were corrected to the MLLW datum by adding the transducer offset, subtracting the predicted tidal height for the site and adding the tide prediction error (calculated using measured tide data from the National Oceanic and Atmospheric Administration website http://co-ops.nos.noaa.gov/data_res.html). The final corrected depth data were merged with eelgrass data and spatial information into a site database so the eelgrass observations had associated date/time, position and depth measurements corrected to MLLW datum.

- **Echinoderms:** We estimated the relative abundance of several classes of common, easily distinguished echinoderms at each site by tallying all observations along transects (Table 2). Each individual was counted and assigned to one time-stamp[3]. Taxonomic categories were chosen to capture the greatest degree of taxonomic detail that is regularly distinguishable on towed underwater imagery[4]. Some confusion among species undoubtedly occurred, associated with image clarity. Juvenile individuals were likely missed due to their small size. Individuals not visible from above the sea floor were also missed, often because they were obscured by vegetation or in crevices.

Table 2: Echinoderms classified based on towed underwater imagery. Taxonomy according to Kozloff (1996).

Common name	Taxonomic name
Red urchin	*Strongylocentrotus franciscanus*
Purple urchin	*Strongylocentrotus purpuratus*
Green urchin	*Strongylocentrotus droebachiensis*
Leather star	*Dermasterias imbricata*
Ochre star	*Pisaster ochraceus*
Giant pink star	*Pisaster brevispinus*
Mottled star	*Evasterias troschelii*
Sunflower star	*Pycnopodia helianthoides*
Blood star	*Henricia leviuscula*
Striped sun star	*Solaster stimpsoni*
Morning sun star	*Solaster dawsoni*
Spiny red star	*Hippasteria phyrgiana*
Vermillion star	*Mediaster aequalis*
Rainbow star	*Orthasteria koehleri*
Slime star	*Pteraster tesselatus*
Sea cucumber	*Cucumaria sp.*
	Parastichopus sp.

[3] At low densities, each individual was counted separately and assigned to one time-stamp. At high densities it is possible double-counting occurred

[4] Towed imagery is generally able to detect conspicuously visible sea stars; that is, stars that are not obscured from above by vegetation or substrate that are 10cm and larger in diameter, and that are clearly contrasted in color/form from their surrounding substrate

2.5 Data analysis

Data was analyzed with ArcGIS and R (R Core Team 2018). We used several R-packages, including "broom" (Robinson and Hayes 2018), "dplyr" (Wickam et al. 2018), "ggplot2" (Wickam 2016), "tidyr" (Wickam and Henry 2018), and "weights" (Pasek et al. 2018).

2.5.1 Eelgrass area estimates

We estimate the mean percentage seagrass cover within the site-sample polygon $\hat{\hat{p}}$ using a ratio estimator of the form (1), where l_i is the vegetated length of transect i, and L_i is the total length of transect i at a site with m transects. The ratio has an approximate variance of (2), with $\bar{L}$ the average length of transects the site (Cochran 1977)[5].

$$\hat{\hat{p}} = \frac{\sum_{i=1}^{m} l_i}{\sum_{i=1}^{m} L_i} \qquad (1)$$

$$Var_{\hat{\hat{p}}} = \frac{\sum_{i=1}^{m} \left(l_i - \hat{\hat{p}} L_i\right)^2}{(m-1)\, m \bar{L}^2} \qquad (2)$$

We estimate site seagrass area $\hat{X}$ by multiplying the mean percentage cover with the size of the sample polygon E (3). We then estimate the associated variance as (4).

$$\hat{X} = E\,\hat{\hat{p}} \qquad (3)$$

$$Var_{\hat{X}} = E^2 Var_{\hat{\hat{p}}} \qquad (4)$$

The amount of eelgrass in the entire study area is then calculated as the sum of the individual site estimates, and the variance around this estimate is the sum of the variance estimates for the individual sites.

2.5.2 Eelgrass depth distribution

Eelgrass depth characteristics for each site were estimated using descriptive statistics (i.e., the 2.5th, 10th, 25th, 50th, 75th, 90th, and 97.5th percentile) for all eelgrass observations along all STR transects at a site.

To calculate a depth distribution, eelgrass observations were binned according to their depth relative to MLLW in 0.5 m bins. The number of eelgrass observations in each depth bin was divided by the total number of eelgrass observations at the site. This fraction was multiplied by the estimated eelgrass area at the site to estimate the area of eelgrass in each depth bin at the site. We used the following formula to estimate eelgrass area in each depth bin at each site:

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[5] This formula may overestimate actual variance for stratified random samples and systematic samples, and is thus a conservative estimator of variance for these sampling schemes (McGarvey et al. 2016).

$$a_{jk} = A_j \frac{c_{jk}}{\sum_{k=1}^{n} c_{jk}} \qquad (5)$$

Where a_{jk} is eelgrass area in each histogram bin (k) at site (j), c_{jk} is the count of eelgrass observations per bin, and A_j is estimated eelgrass area at site j. Per-bin area estimates from sites were combined into a depth distribution for the entire study area.

2.5.3 Other marine vegetation: area and depth distribution

For each type of marine vegetation, we calculated the number of observations of vegetation in each cover class per site, and divided those by the total number of data points classified for marine vegetation at each site (5 second intervals). These fractions were then multiplied by the area of the sample polygon to get a rough area estimate at each site (without an associated estimate of uncertainty).

To summarize depth data characteristics, we calculated descriptive statistics (i.e., the 2.5th, 10th, 25th, 50th, 75th, 90th, and 97.5th percentile) for all marine vegetation observations at a site (regardless of cover class). The depth distribution was calculated similar to eelgrass (see Section 2.5.2).

2.5.4 Trends in eelgrass area (DNR data)

At sites with more than 2 years of data, we used inverse variance weighted regression to assess trends over time. We used all site samples, regardless if they were collected by simple random sampling (SRS) or stratified random sampling (STR), and if they were surveys of newly selected transects or repeat surveys of previously selected transects. At sites with repeat transects, we visualized the patterns of gain and loss along individual transects by associating nearest points along paired transects in ArcGIS, and compared presence/absence of eelgrass among both years. We then used pairwise t-tests of the mean change in the vegetated fraction of transects to assess change between repeat samples (the exact years of the repeat samples varies depending on the site).

2.5.5 Trends in eelgrass area (comparison with historical baseline)

We compared our recent surveys of eelgrass (2019-2022) with a historical baseline of eelgrass beds along the shoreline of Snohomish County[6], compiled from several studies conducted between 1999 and 2007 (Bailey et al. 2007). These studies include the 2003 Snohomish County Intertidal Habitat Survey (mostly based on aerial imagery), the 1999 King County Nearshore Habitat Mapping Project (side scan sonar, south of Picnic point), a 2004 pre-construction survey near Point Wells (side scan sonar, dive surveys, and underwater video), a 2004 survey along the port of Everett Rail/barge transfer facility, DNR towed underwater video footage collected between 2000 and 2006, and a 2007 deep edge meander and side scan sonar study along the entire shoreline of Snohomish County. Because of the differences in

[6] This dataset consists of vegetated polygons attributed by species.

methodology, there is some uncertainty associated with comparing these surveys. As such, we can only assess large scale patterns.

Data were analyzed in different ways:

- We clipped the 1999-2007 Snohomish County polygon layer (Bailey et al. 2007) to the 2019-2022 survey extent, and summed the area of the polygons labeled *Zostera marina*, *Zostera sp*. or *Zostera spp*. (while excluding polygons with *Z. japonica*) and compared area estimates region-wide and at the level of individual sites. Given the differences in methods and the uncertainty around the change estimates, we labeled sites as increasing or declining if there was a twofold increase or decline in eelgrass area.
- We overlaid the 2019-2022 transect data over the 1999-2007 eelgrass polygons and visually assessed differences in the location of eelgrass beds at each site.
- We calculated the mean (and standard error) of the deepest observations at each transect (2019-2022) as well as the mean (and standard error) of the deep edge observations from the 2007 deep edge meander, and compared these values for each site with eelgrass present.

3 Results

3.1 Overview of the 2022 surveys

3.1.1 SVMP sample effort

Field work was completed in 8 days: one day at the start of June and 7 days in mid-September. During this period of time, we surveyed 234 transects over 24 different sites (Table 3). All transects were selected using stratified random sampling (STR) and were oriented perpendicular to shore. At majority of sites (n=23), transects span most of the intertidal and the shallow subtidal (+1 to -15m, MLLW). At one location (swh1014) the presence of a floating kelp bed did not permit us to survey the entire site. We also detected floating kelp at swh1015 and along one transect at swh1013 (all these sites are on the southern side of Hat Island).

The total length of all transects sampled was approximately 40.2 km. Eelgrass was present at over 10.4 km of transects sampled. Most of the 24 sites sampled were relatively small. The three largest sites were swh1014, swh1610, and swh1015 with a macroalgae sample polygon areas that were 96.6, 58.5, and 55.5 ha. The smallest sites were swh1614 and swh1617 with macroalgae sample polygon areas of 8.8 and 8.5 ha.

3.1.2 Seagrass species

We detected 2 species of seagrass in the study area: *Zostera marina* and the non-native *Zostera japonica* (Figure 3). *Z. marina* is by far the most abundant species: it was found at 198 out of 234 transects sampled in 2022 (Table 3). *Z. japonica* was found at only 4 transects, all located on Hat Island. It was mostly found above mean lower low water at these locations. Note that in 2019, we found a substantial amount of *Z. japonica* at flats22 and flats23 in Port Susan. At these sites, there was very little overlap between the species.

With video analysis, there is a potential for misidentification between very small *Z. marina* and *Z. japonica*, especially when the water is turbid. However, we did take grab samples at the Hat Island sites, so we have confirmed the results from video analysis. The presence of *Z. japonica* beds at Port Susan (2019 data) has been confirmed based on other data sources (Kaldy and Mochon-Collura 2015).

Figure 3: Example of *Z. marina* in Snohomish County. The left image is a screenshot of the towed underwater videography showing a dense stand of *Z. marina*. The image on the right is a screenshot of a *Z. marina* shoot surrounded by *Z. japonica* in Port Susan.

Table 3: Overview of sites sampled as part of DNR 93-103581, start date, end date, the # of transects sampled and the number of transects with *Z. marina* present

site code	start date	end date	Transects sampled	Transects with Zm
swh1011	9/23/2022	9/23/2022	10	7
swh1012	9/23/2022	9/23/2022	10	10
swh1013	9/16/2022	9/16/2022	10	6
swh1014	6/7/2022	6/7/2022	9	9
swh1015	9/14/2022	9/16/2022	10	10
swh1016	9/15/2022	9/15/2022	10	9
swh1017	9/15/2022	9/15/2022	10	10
swh1018	9/15/2022	9/15/2022	10	8
swh1019	9/23/2022	9/23/2022	10	9
swh1610	9/22/2022	9/22/2022	10	8
swh1611	9/21/2022	9/21/2022	10	10
swh1612	9/21/2022	9/21/2022	10	10
swh1613	9/21/2022	9/21/2022	10	8
swh1614	9/21/2022	9/21/2022	10	7
swh1615	9/20/2022	9/20/2022	10	10
swh1616	9/20/2022	9/20/2022	10	7
swh1617	9/20/2022	9/20/2022	10	0
swh1618	9/20/2022	9/20/2022	10	10
swh1619	9/20/2022	9/20/2022	10	7
swh1620	9/19/2022	9/19/2022	10	9
swh1621	9/19/2022	9/19/2022	10	10
swh1622	9/19/2022	9/19/2022	10	9
swh2877	9/22/2022	9/22/2022	5	5
swh2878	9/19/2022	9/19/2022	10	10

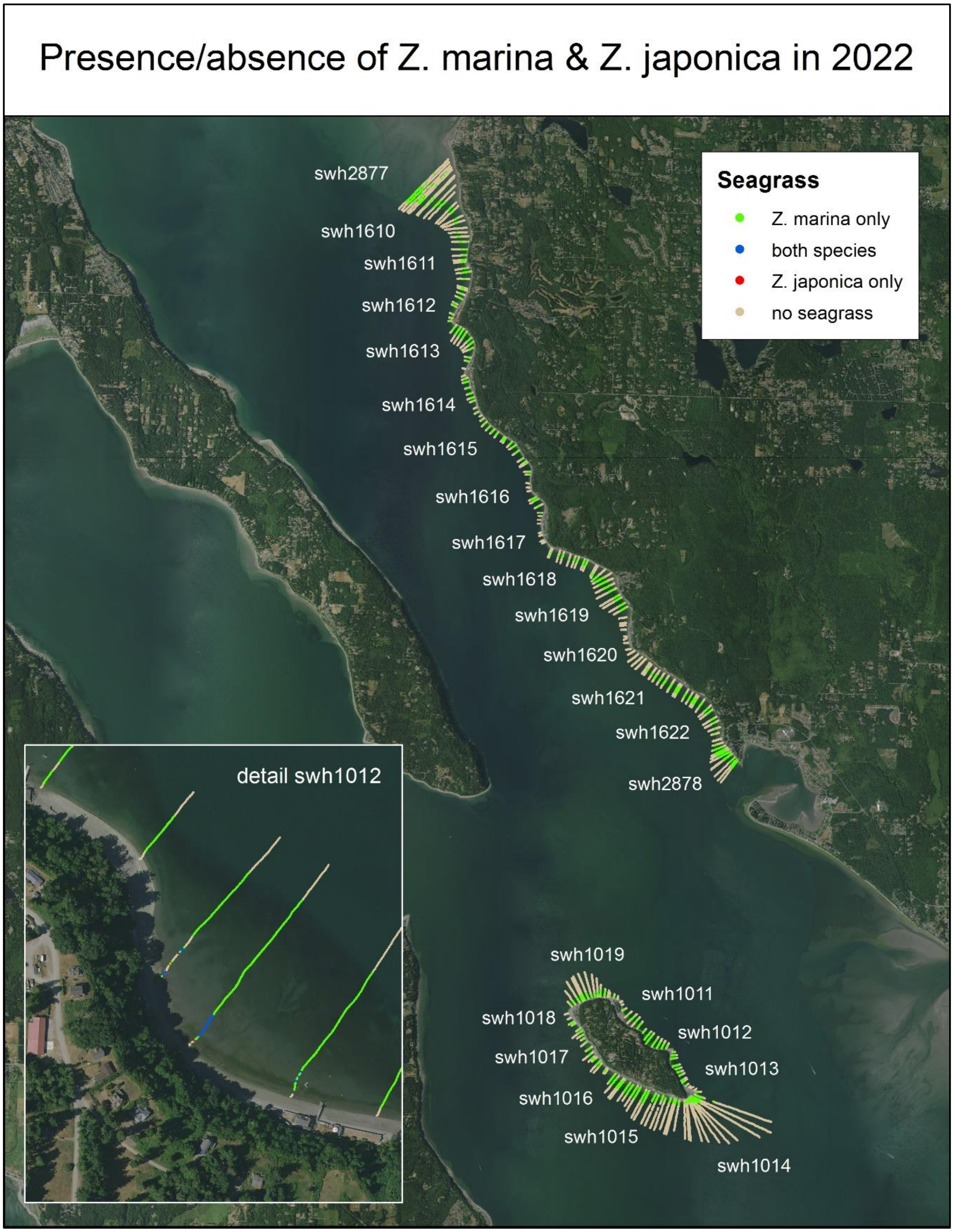

Figure 4: Presence of *Z. marina* and *Z. japonica* along transects sampled in 2022. *Z. japonica* is limited to shallow intertidal portions of a few transects along Hat Island.

3.1.3 *Eelgrass area*

There was an estimated total of 88 +/- 3 ha of eelgrass estimated at the 24 sample sites. This corresponds to almost 10% of the total area of eelgrass along the shoreline of Snohomish County (912 ha, see section 3.2), approximately 13% of all eelgrass along the shorelines of King County (680 ha, Christiaen et al. 2020a), and less than 0.5% of all eelgrass in greater Puget Sound (22,102 +/- 1,074 ha, based on a 3-year rolling average from 2018 to 2020).

Figure 4 and Table 4 show the size of eelgrass beds at individual sites. The largest eelgrass beds were found at swh1016 (11.0 ha) and swh1012 (8.7 ha). The smallest eelgrass beds were found at swh1014 (1.4 ha) and swh1614 (1.5 ha). There was 1 site without eelgrass present (swh1620), and one site with trace eelgrass [7](swh1617), an occurrence too small to calculate a valid area estimate.

Table 4: eelgrass area (veg) and corresponding standard error (se) at sites sampled in 2022.

site_code	year	fraction	sample poly (ha)	veg (ha)	veg se (ha)	n
swh1011	2022	0.4527	9.88	4.47	0.63	10
swh1012	2022	0.7379	11.76	8.68	0.59	10
swh1013	2022	0.258	7.14	1.84	0.38	10
swh1014	2022	0.1832	7.62	1.39	0.34	9
swh1015	2022	0.3339	14.44	4.82	0.74	10
swh1016	2022	0.5074	21.57	10.95	0.57	10
swh1017	2022	0.1959	8.23	1.61	0.26	10
swh1018	2022	0.3034	7.61	2.31	0.58	10
swh1019	2022	0.3575	8.64	3.09	0.65	10
swh1610	2022	0.0771	41.9	3.23	1.15	10
swh1611	2022	0.2296	15.95	3.66	0.9	10
swh1612	2022	0.373	8.43	3.14	0.67	10
swh1613	2022	0.475	9.97	4.73	0.65	10
swh1614	2022	0.2234	6.49	1.45	0.55	10
swh1615	2022	0.4841	7.14	3.46	0.51	10
swh1616	2022	0.2675	7.68	2.05	0.66	10
swh1617	2022	trace	trace	trace	trace	trace
swh1618	2022	0.1905	18.75	3.57	1.09	10
swh1619	2022	0.3364	21.15	7.12	0.69	10
swh1620	2022	0	0	0	0	0
swh1621	2022	0.1103	19.1	2.11	0.43	10
swh1622	2022	0.3286	16.12	5.3	1	10
swh2877	2022	0.0534	28.4	1.52	0.5	5
swh2878	2022	0.4793	15.38	7.37	0.73	10

[7] Presence confirmed at quantities too low to reliably characterize using our methods.

3.1.4 Eelgrass depth distribution

Table 5 and Figure 5 show the depth distribution of eelgrass at individual sites based on our observations. Eelgrass was found between 0.6 and -12 m (MLLW) but the majority of observations occurred between 0 and -4 m. The deepest observation was at swh1614 and swh1618, where some scattered shoots were found at depths down to -12 m and -9.4 m respectively. However, the deep edge of the eelgrass beds at these location (calculated as the 2.5th percentile of all depth observations at the site) did not extend deeper than -3 m and -7.6 m. The median depth of eelgrass at individual sites ranged from -0.75 to -2.0 m. The shallowest observations were found at swh1011 (0.6 m) and swh1012 (0.3 m). We calculated the depth range as the difference between the 2.5th percentile and 97.5th percentile of all eelgrass depth observations at a site. This value represents the width of the depth band where 95% of all eelgrass grows at a site. The depth range was smallest at swh1610 (1.1 m) and largest at cps1618 (7.0 m). At most sites the depth range was between 1.5 and 4.5 m (Table 5).

Table 5: Eelgrass depth distribution (m, MLLW) at each site sampled; q025 is the 2.5th percentile of all eelgrass depth observations at a site, q10 is the 10th percentile of all eelgrass depth observations, etc. The range is calculated as the difference between the 2.5th and 97.5th percentiles. MinD and maxD are the shallowest and deepest observations of eelgrass at a site, and n is the total number of eelgrass observations. Swh1617 is not included as this site only has trace eelgrass present. Eelgrass was absent at swh1620.

site_code	maxD	q025	q05	q10	q25	q50	q75	q90	q95	q975	minD	range	n
swh1011	-5.35	-4.42	-3.98	-3.11	-1.40	-0.91	-0.66	-0.43	-0.09	0.09	0.57	4.51	803
swh1012	-5.76	-4.57	-4.01	-2.93	-1.29	-0.77	-0.36	-0.05	0.12	0.24	0.35	4.81	1638
swh1013	-5.10	-4.41	-4.04	-3.73	-2.38	-1.61	-1.01	-0.68	-0.56	-0.46	-0.23	3.95	366
swh1014	-2.77	-2.64	-2.58	-2.51	-2.25	-1.25	-0.90	-0.65	-0.56	-0.49	-0.34	2.16	586
swh1015	-4.88	-4.68	-4.36	-3.96	-3.02	-1.34	-0.78	-0.41	-0.23	-0.10	0.29	4.58	949
swh1016	-5.42	-4.67	-4.55	-4.30	-3.64	-1.76	-0.80	-0.45	-0.15	-0.05	0.34	4.63	2081
swh1017	-3.59	-3.08	-2.89	-2.38	-1.63	-1.04	-0.66	-0.50	-0.42	-0.32	-0.23	2.76	336
swh1018	-5.26	-4.47	-4.06	-3.52	-2.57	-1.69	-1.14	-0.73	-0.55	-0.45	-0.19	4.01	462
swh1019	-5.93	-4.86	-4.61	-4.24	-3.11	-1.72	-1.09	-0.75	-0.61	-0.54	-0.29	4.32	771
swh1610	-2.54	-1.79	-1.67	-1.54	-1.26	-1.07	-0.92	-0.77	-0.73	-0.71	-0.58	1.08	557
swh1611	-3.30	-2.04	-1.94	-1.77	-1.46	-1.11	-0.76	-0.42	-0.29	-0.23	-0.10	1.81	616
swh1612	-5.32	-3.23	-2.99	-2.57	-2.01	-1.45	-1.01	-0.75	-0.55	-0.18	0.07	3.06	601
swh1613	-4.30	-3.33	-3.11	-2.79	-2.21	-1.56	-1.04	-0.67	-0.54	-0.42	-0.26	2.91	783
swh1614	-11.58	-3.02	-2.72	-2.40	-1.93	-1.71	-1.18	-0.88	-0.71	-0.58	-0.39	2.44	245
swh1615	-5.21	-4.01	-3.58	-3.15	-2.61	-1.99	-1.51	-1.18	-1.02	-0.92	-0.65	3.09	573
swh1616	-4.17	-3.42	-3.27	-2.96	-2.28	-1.73	-1.24	-0.89	-0.73	-0.66	-0.49	2.77	322
swh1618	-9.36	-7.58	-5.79	-3.05	-2.20	-1.56	-1.26	-1.03	-0.83	-0.59	-0.33	6.99	599
swh1619	-3.45	-3.06	-2.80	-2.54	-1.99	-1.47	-1.07	-0.78	-0.67	-0.52	-0.23	2.54	1250
swh1621	-2.82	-2.44	-2.32	-2.14	-1.77	-1.43	-1.21	-1.04	-0.98	-0.92	-0.73	1.53	380
swh1622	-3.33	-2.66	-2.52	-2.27	-1.76	-1.20	-0.94	-0.74	-0.68	-0.63	-0.47	2.03	873
swh2877	-3.28	-1.56	-1.25	-1.04	-0.95	-0.76	-0.62	-0.48	-0.40	-0.27	0.07	1.30	460
swh2878	-3.28	-2.62	-2.49	-2.29	-1.82	-1.39	-0.98	-0.62	-0.44	-0.30	0.15	2.33	2380

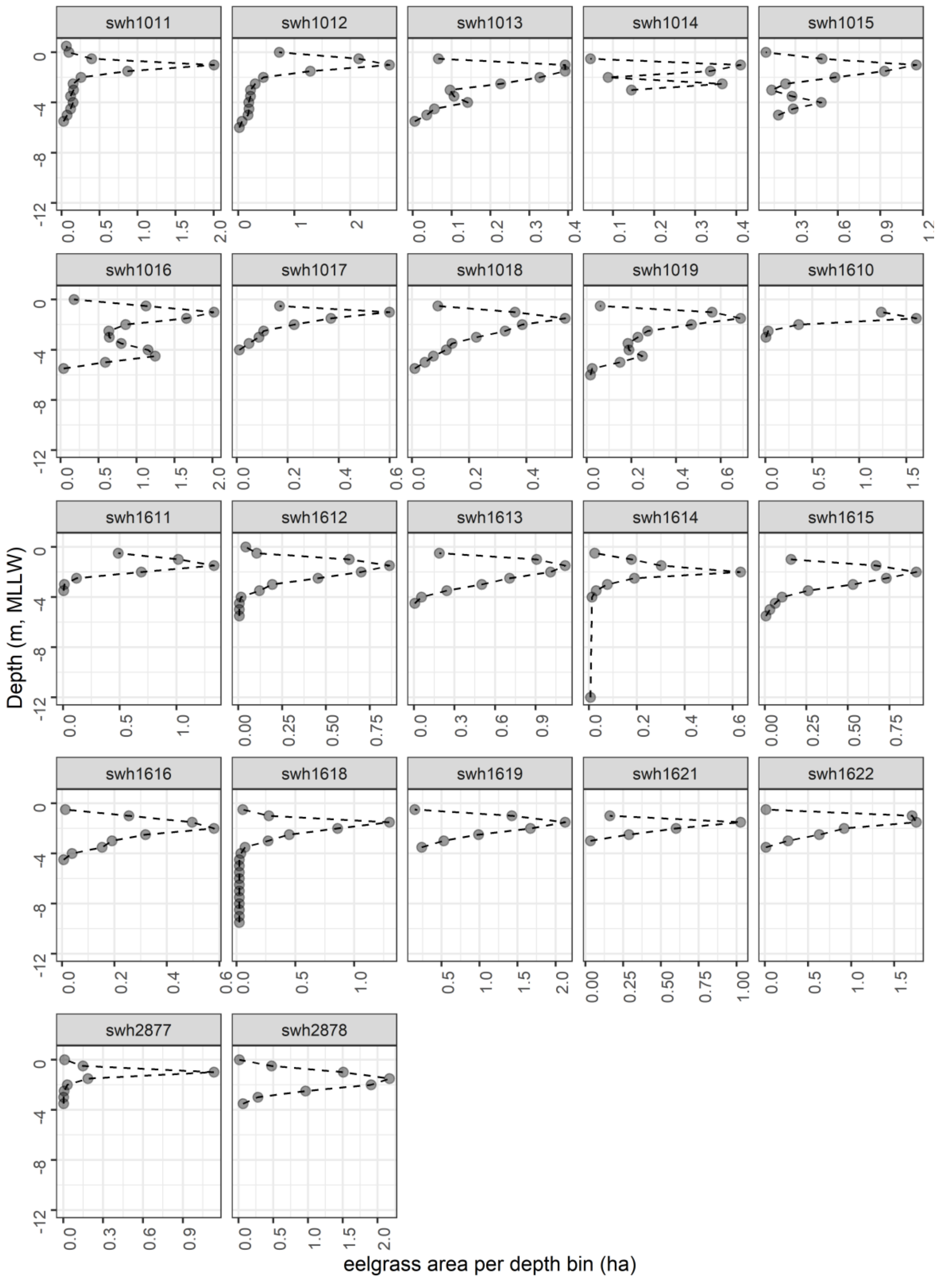

Figure 5: Eelgrass depth distributions at individual sites (as area in ha per 0.5 m depth bins). Swh1617 is not included as this site only has trace eelgrass present. Eelgrass was absent at swh1620.

3.1.5 Other marine vegetation types

We estimated a cover class for several broad vegetation types (all vegetation, all kelp, prostrate kelp, stipitate kelp, *Sargassum muticum*, other red/brown algae, green algae, seagrass) at one frame every 5 seconds using modified Braun-Blanquet vegetation cover categories, for each transect surveyed as part of IAA 93-103581 (Figure 6). Seagrass, green algae, understory kelp, and other red/brown algae were widespread in the study area, while *Sargassum muticum* was rather sparse (Figure 7, Figure 8, Figure 9, Figure 10, Figure 11). Floating kelp was present at some locations, in particular at swh1014 and swh1015 along Hat Island. We did not estimate area for floating kelp based on our footage, partly because we actively avoided sampling in floating kelp beds so as not to damage to this sensitive habitat.

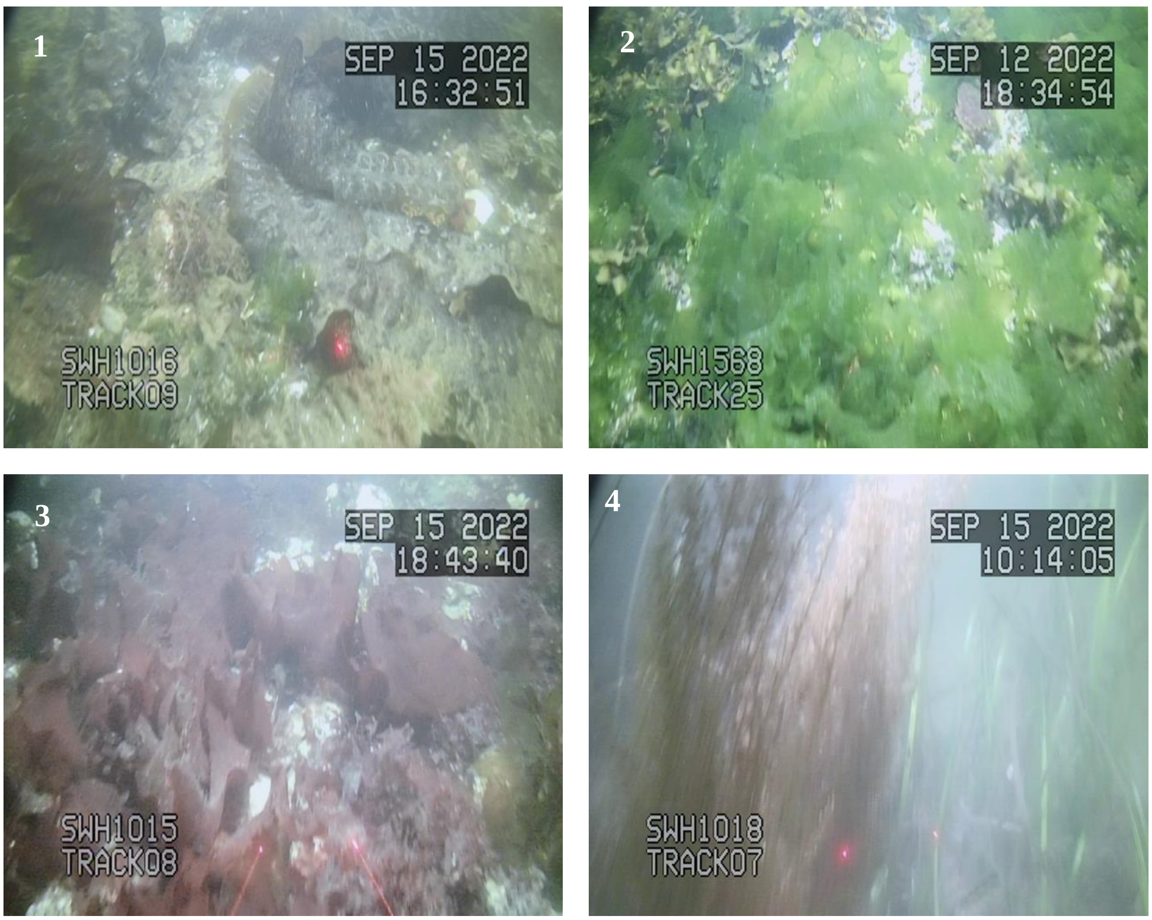

Figure 6: Different groups of macroalgae in the study area: understory kelp (1), green algae (2), other red/brown algae (3), and *Sargassum muticum* (4).

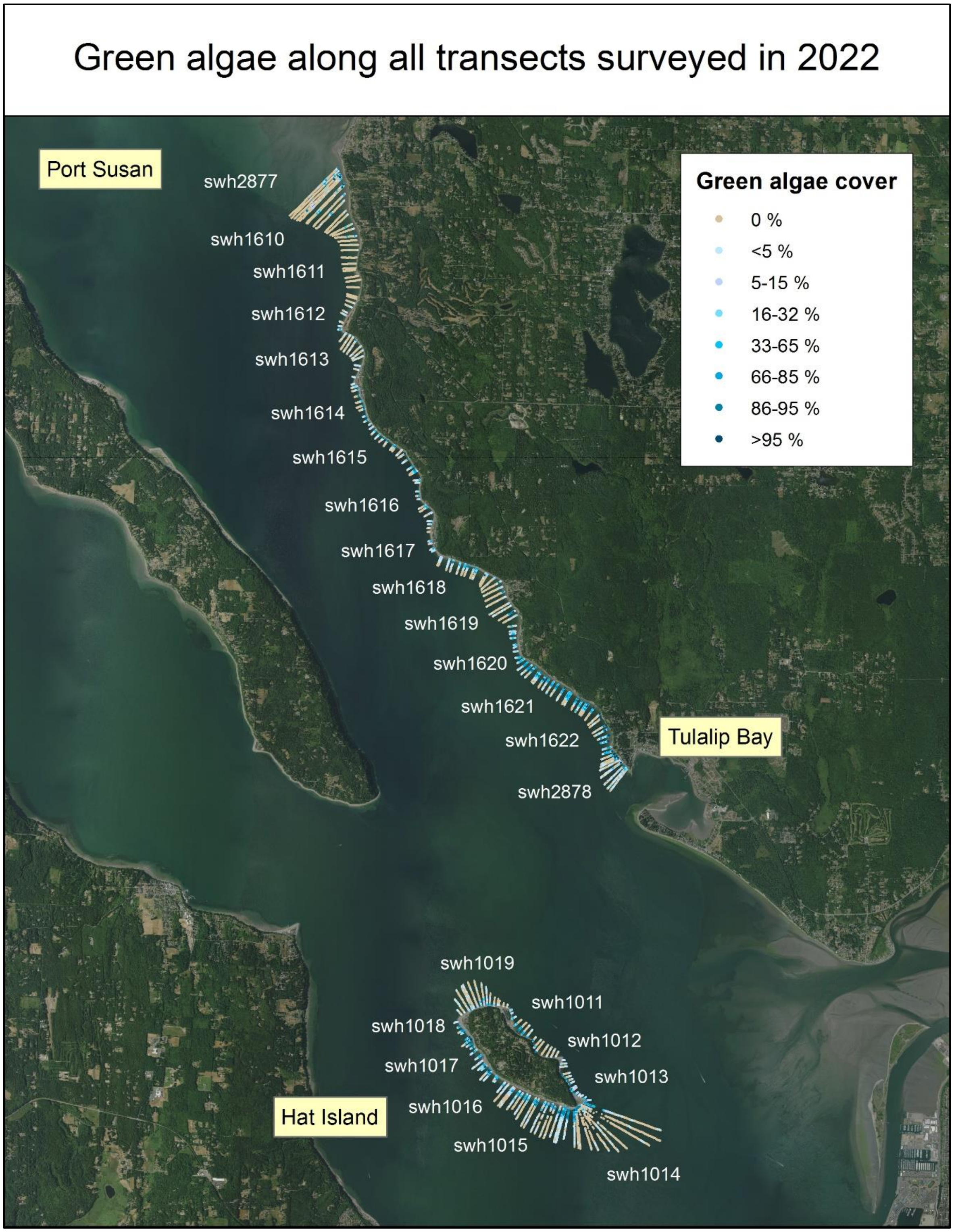

Figure 7: Percent (%) green algae cover at one frame every five seconds along all transects surveyed in 2022

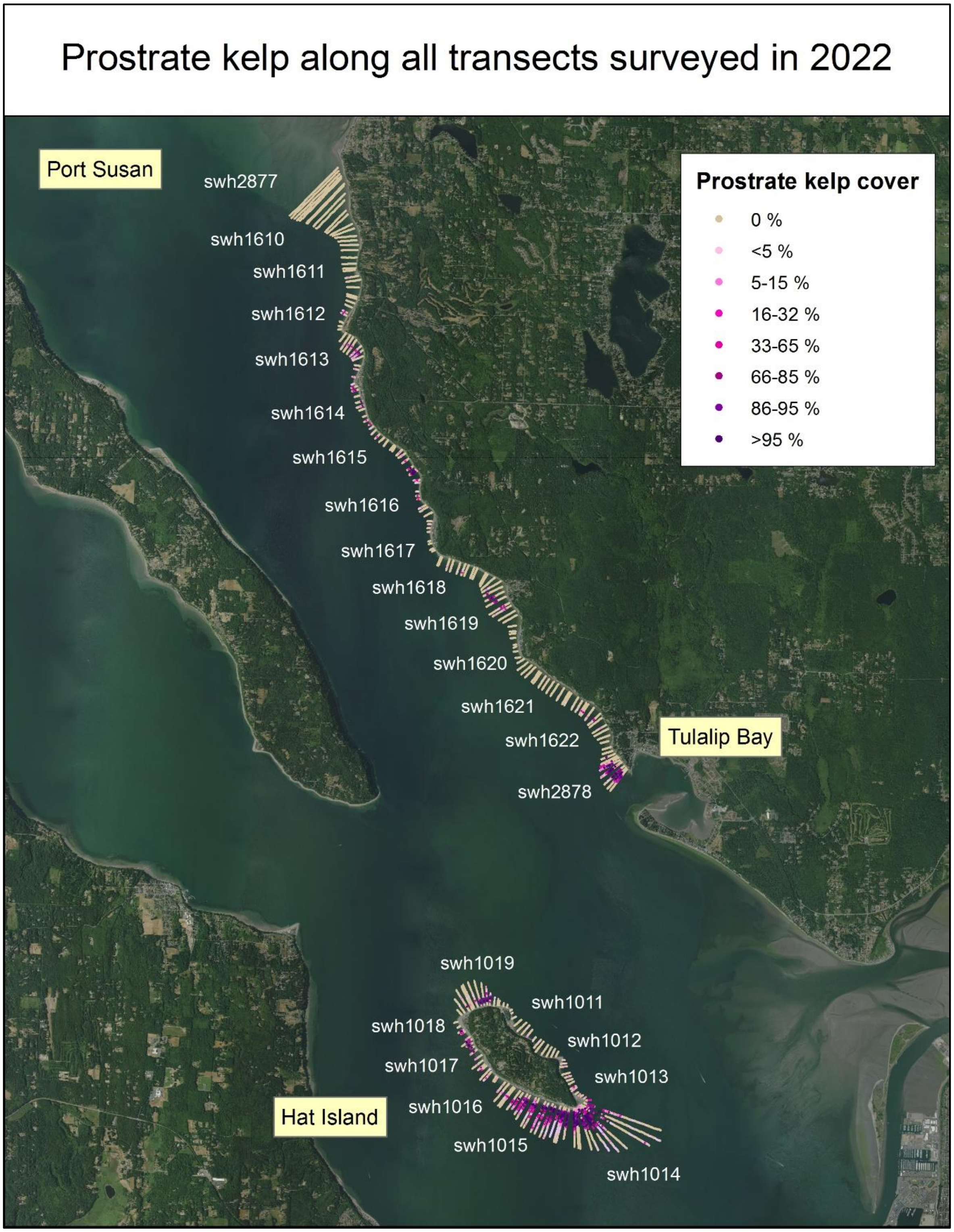

Figure 8: Percent (%) prostrate kelp cover at one frame every five seconds along all transects surveyed in 2022

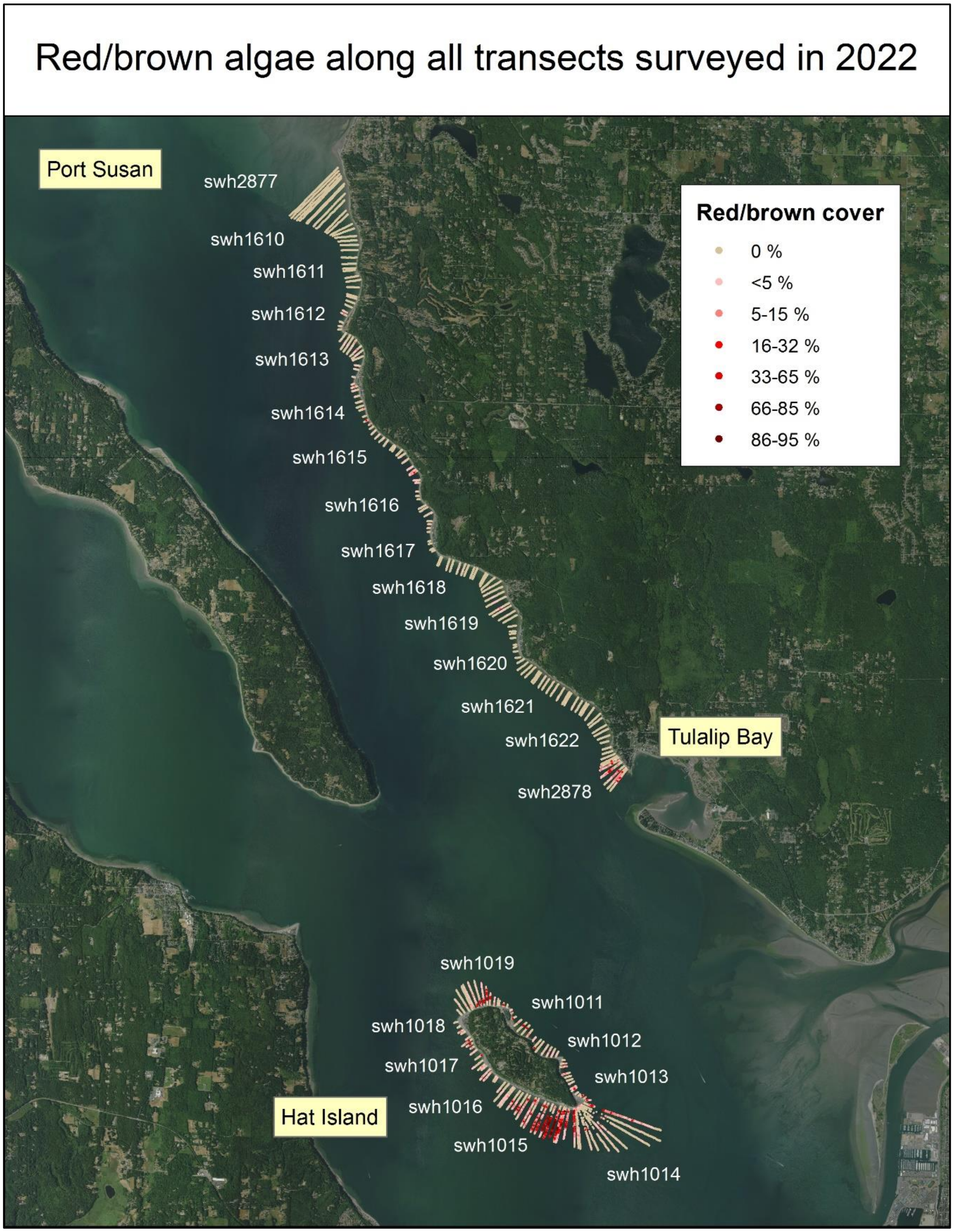

Figure 9: Percent (%) other red/brown algae cover at one frame every five seconds along all transects surveyed in 2022

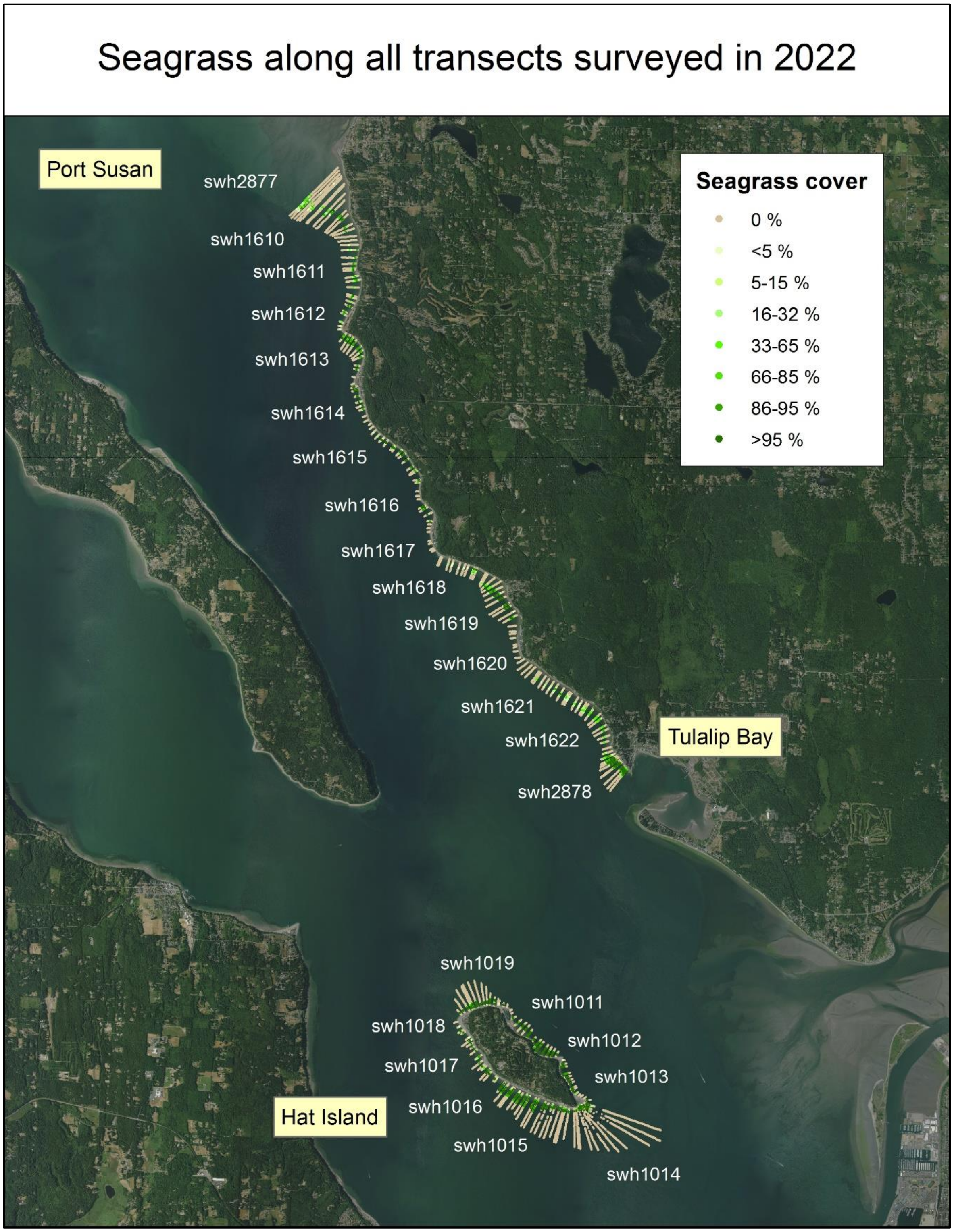

Figure 10: Percent (%) seagrass cover at one frame every five seconds along all transects surveyed in 2022. This figure differs from Figure 4Figure 4 which shows presence/absence of different seagrass species at one second intervals.

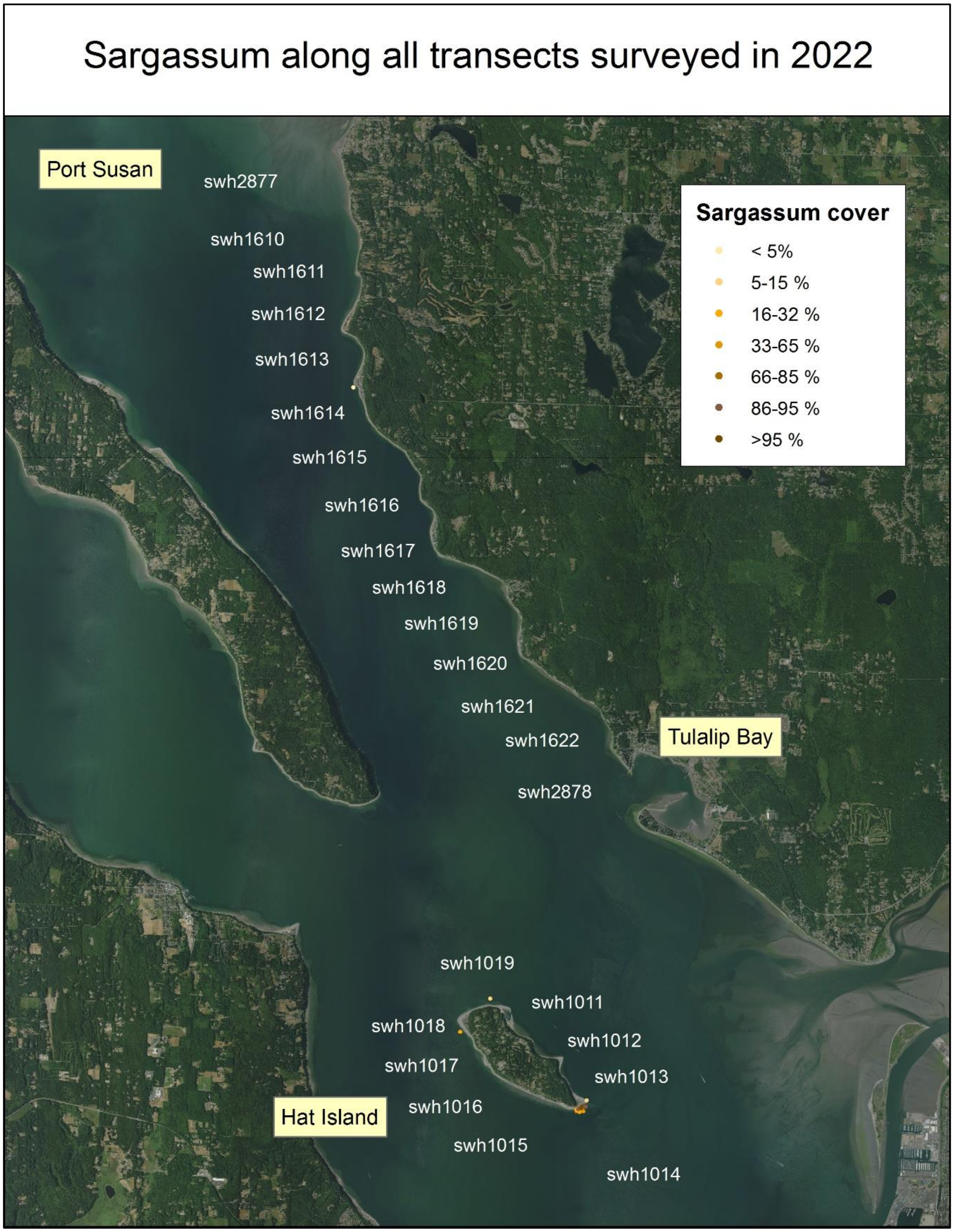

Figure 11: Percent (%) *Sargassum muticum* cover at one frame every five seconds along all transects surveyed in 2022. Transect points without *Sargassum muticum* are left out to highlight the locations where it occurs.

Figure 12 shows the total vegetated area per vegetation type and cover class for all vegetation, seagrass, green algae, understory kelp, other red/brown algae and *Sargassum muticum*. These estimates were calculated from one frame at every 5 seconds and are considered less precise than the eelgrass area estimates in section 3.1.3. We did not have enough resolution to calculate an uncertainty estimate for each cover class and each vegetation type. Despite these shortcomings, they are a good representation of the relative abundance of each vegetation type in the study area.

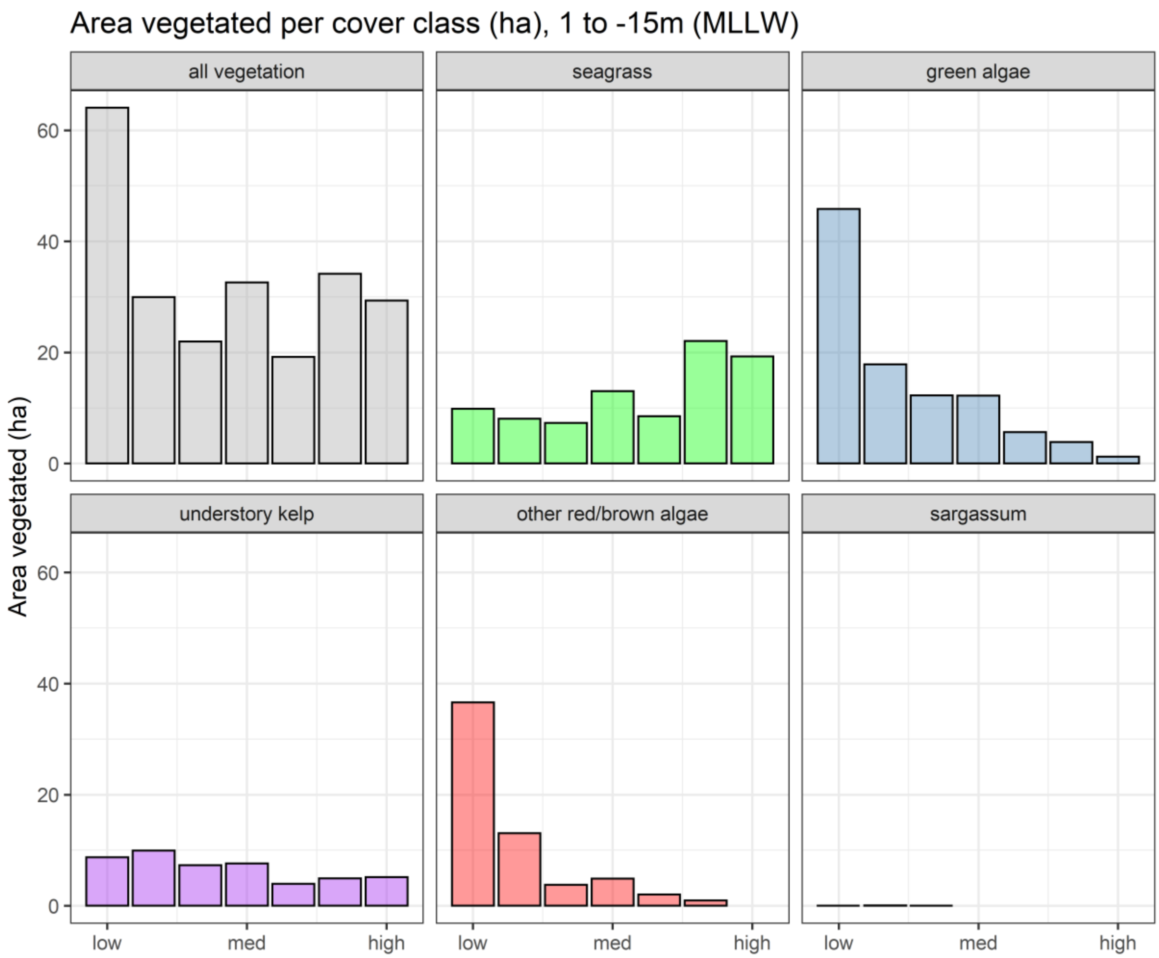

Figure 12: Vegetated area per cover class and per vegetation type at 24 sites sampled for DNR 93-103581.

Seagrass and green algae were the predominant vegetation types in the study area (88 ha and 99 ha respectively). These vegetation types were found at most sites sampled in 2022 (Figure 7 and Figure 10). However, most of green algae were present in lower cover classes, while most of the seagrass was found in medium to high cover classes. This pattern is consistent with other sites along the shoreline of Snohomish County. Other red/brown algae were also commonly found, but mostly present in the lower cover classes (approximately 61 ha, Figure 9).

Understory kelp was less common in the study area (approximately 47 ha overall), and it was mostly concentrated at two locations: the southern part of Hat Island (swh1015 and swh1016 with 22 and 6.6 ha respectively) and immediately North of Tulalip Bay (swh2878 with 5.5 ha, Figure 8). Note that we did not quantify understory kelp at swh1014. We do not have a good record of understory kelp at this location, as we tried to avoid the bull kelp bed at this site. However, our incomplete data record suggests that there is a substantial amount of understory kelp and other red/brown algae at this location. We found several locations where the non-native algae *Sargassum muticum* was present, but this species tended to be rare (Figure 11). This could be in part because we have sampled relatively late in the season (September 2022)

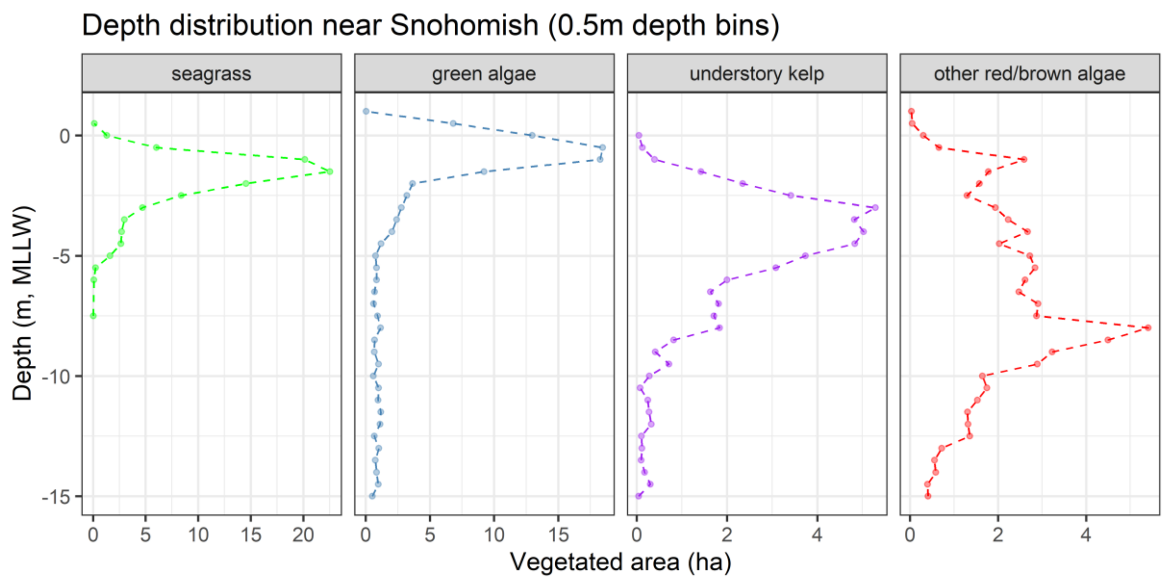

Figure 13: Depth distribution of seagrass, green algae, prostrate kelp and other red/brown algae, calculated as the vegetated area (ha) per 0.5 m depth bins in the study area.

Figure 13 shows the depth distribution for each vegetation type in the study area, calculated as the vegetated area (ha) in 0.5-meter depth bins. The majority of vegetated area for each vegetation type occurs between +1 and -5 m (MLLW), which is partly due to the availability of substrate in each depth bin. However, there are differences in depth distribution among the marine vegetation types. Seagrass and green algae tend to occur shallower than understory kelp and other red/brown algae. We did not calculate the depth distribution for *Sargassum muticum* as there were only a few shallow observations.

3.1.6 Echinoderms in the shallow subtidal

We analyzed towed underwater video footage to assess the relative abundance of common, easily distinguished echinoderms at each site (Figure 14), including purple urchins (*Strongylocentrotus purpuratus*), green urchins (*S. droebachiensis*), red urchins (*S. franciscanus*), leather stars (*Dermasterias imbricata*), ochre stars (*Pisaster ochraceus*), giant pink stars (*P. brevispinus*), mottled stars (*Evasterias troschelii*), sunflower stars (*Pycnopodia helianthoides*), blood stars (*Henricia leviuscula*), striped sun stars (*Solaster *stimpsoni), morning sun stars (S. dawsoni*), spiny red stars (*Hippasteria phyrgiana*), vermillion stars (*Mediaster aequalis*), slime stars (*Pteraster tesselatus*), rainbow stars (*Orthasteria koehleri*), and sea cucumbers (*Cucumaria sp.* and *Parastichopus sp.*). We followed the taxonomy from Kozloff (1996), and used a category named "undifferentiated stars" (undiff stars) to represent stars that were observed on video but where we were not able to identify the species. Taxonomic categories were chosen to capture the greatest degree of taxonomic detail that is regularly distinguishable on towed underwater imagery. Some confusion among species associated with image clarity undoubtedly occurred. Juvenile individuals were likely missed due to their small size. Individuals not visible from above the sea floor were also missed, often because they were obscured by vegetation or in crevices.

Figure 14: Examples of different echinoderms in our underwater footage. 1. Giant pink star (*Pisaster brevispinus*), 2. Mottled star (*Evasterias troschelii*), 3. Sunflower star (*Pycnopodia helianthoides*), 4. Sea cucumber (*Parastichopus sp.*)

Figure 15: Occurrence of different species/groups of echinoderms along the shoreline of Snohomish County between Port Susan and Tulalip Bay, and including Hat Island, surveyed in 2022. No urchins, blood stars, spiny red stars, morning sun stars, or vermilion stars were observed.

From the 2022 survey footage, we counted a total of 5,323 individuals, spread over 10 classes of echinoderms: undifferentiated stars, mottled stars, giant pink stars, rainbow stars, ochre stars, sunflower stars, slime stars, striped sun stars, and two types of sea cucumbers (Figure 15 and Figure 16). The most abundant categories were undifferentiated stars (n = 4,188), mottled stars (n = 937), giant pink stars (n =143), rainbow stars (n = 15), ochre stars (n = 8), and sea cucumbers (n = 22). The least abundant categories were sunflower stars (n = 5), striped sun stars (n = 4), and slime stars (n = 1).

The sites with the highest counts of echinoderms were located around Hat Island, as well as just north of Tulalip Bay (swh2878). The sites with the most diverse species of echinoderms were also located around Hat Island. The site with the highest abundance and diversity of echinoderms was swh1015, located on the southern end of Hat Island. There were eight species categories observed at this location: mottled stars (n = 622), giant pink stars (n = 15), ochre stars (n = 5), rainbow stars (n = 9), striped sun stars (n = 4), *Parastichopus sp*. (n = 4), *Cucumaria sp*., (n = 18) and undiff stars (n = 2,168). Only two sites in the study area had no invertebrates observed and those were located on the north side of the study area closest to Port Susan (swh2877 and swh1610).

Mottled stars and undiff stars were found in both high and low densities at sites throughout the study area. The highest amount of mottled stars and undiff stars were seen at swh1015 (mottled = 622, undiff = 2,168), swh1016 (mottled = 49, undiff = 610), and swh2878 (mottled = 112, undiff = 245). Giant pink stars were only observed at sites around Hat Island, except for one site, swh2878, located just north of Tulalip Bay. The site with the highest count of giant pink stars was swh1019 (n = 58), on the north side of Hat Island. Most of the ochre stars were found on the south end of Hat Island at swh1015 (n = 5) and swh1013 (n = 1), with one ochre star found along the mainland shoreline at the site swh1616. Rainbow stars were found in similar areas to ochre stars, most of them at several sites along Hat Island (n = 13), and there were rainbow stars found further north at the site swh1615 (n = 2). There were five sunflower stars observed, three on the north end of Hat Island (swh1011 and swh1018), and two were along the shoreline north of Tulalip Bay (swh1619). The sunflower stars were all relatively large in size. Four striped sun stars were found on transects close to each other on the south end of Hat Island (swh1015). One slime star was observed on the north end of Hat Island (swh1019). Both sea cucumber species were observed on the south end of Hat Island (swh1015). *Parastichopus sp*. (n = 4) occurred at deeper depths than *Cucumaria sp*. (n =18). *Cucumaria sp*. were mostly found clustered together on transects. Invertebrates were found across all depths along transects in and outside of vegetation.

There were no green, red, or purple urchins observed in the study area in 2022. There were no vermillion stars, blood stars, morning sun stars, or spiny red stars observed in the study area in 2022.

When dense aggregations of stars occur, the undiff star category is heavily utilized and there is a strong possibility we are double-counting stars, meaning we are counting the same star twice over multiple time stamps. The undiff star category is used when video or habitat conditions make it too challenging to identify the species of a star.

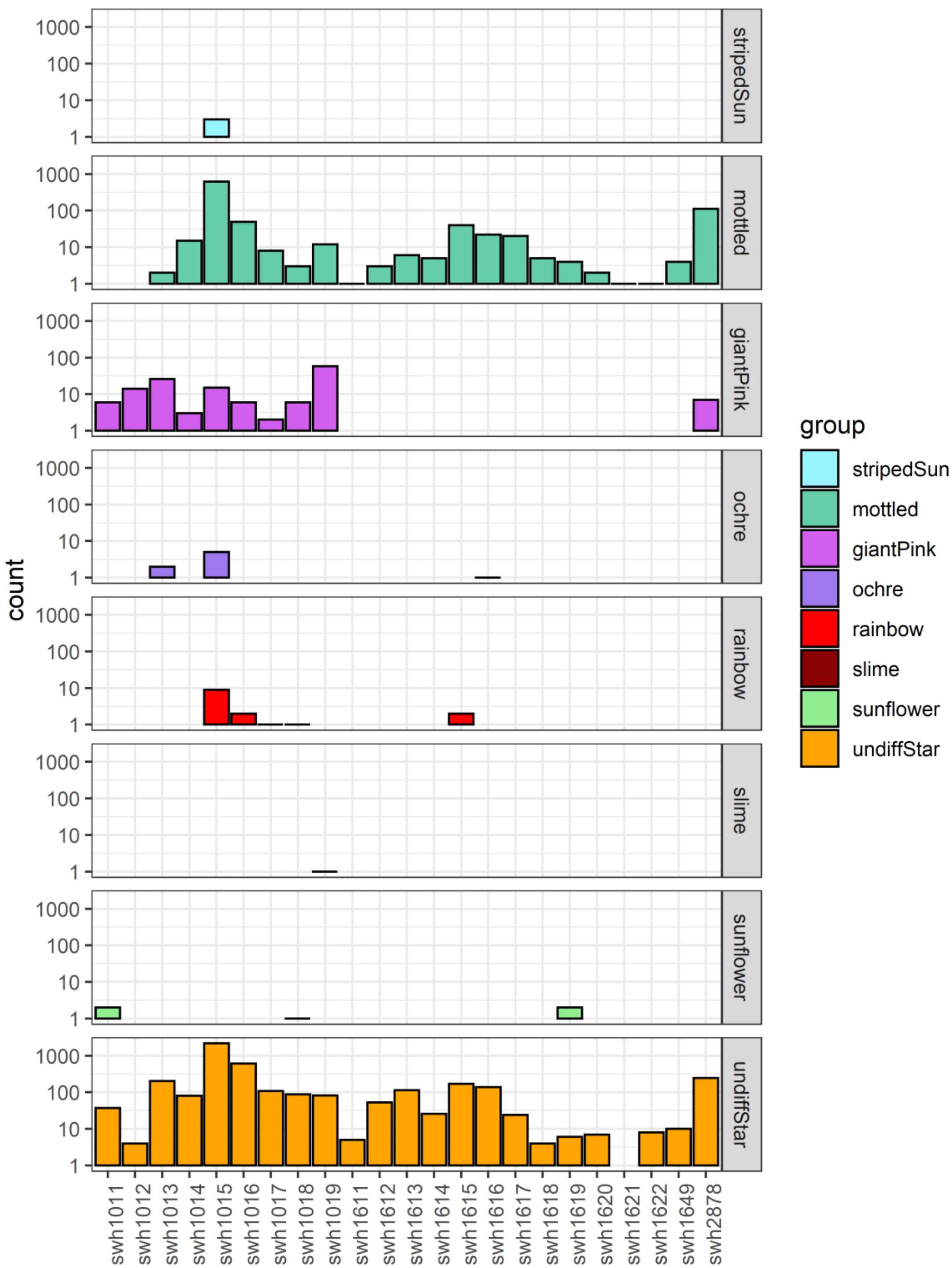

Figure 16: Abundance of easily distinguishable sea stars at 24 sites sampled in 2022 along the shoreline of Snohomish County. Y-axis is logarithmic scale.

3.2 Eelgrass, understory kelp, and invertebrates along Snohomish County (2019-2022)

3.2.1 Eelgrass and understory kelp along Snohomish County

Based on data collected between 2019 and 2022, there was approximately 912 (+/- 67) ha of eelgrass along the shoreline of Snohomish County. The largest expanses of eelgrass occurred on sand flats near the Snohomish River delta and Port Susan (Figure 17). These accounted for over 60% of eelgrass in the study area. Approximately 22% of all eelgrass grew along the stretch of shoreline between Edmonds and Mukilteo. Here, there were several locations where eelgrass beds were relatively large as compared to the total amount of available habitat at the site. The shoreline between Port Susan and Tulalip Bay and the shoreline of Hat Island were characterized by relatively small eelgrass beds (with the exception of swh1016 and swh1012 on Hat Island).

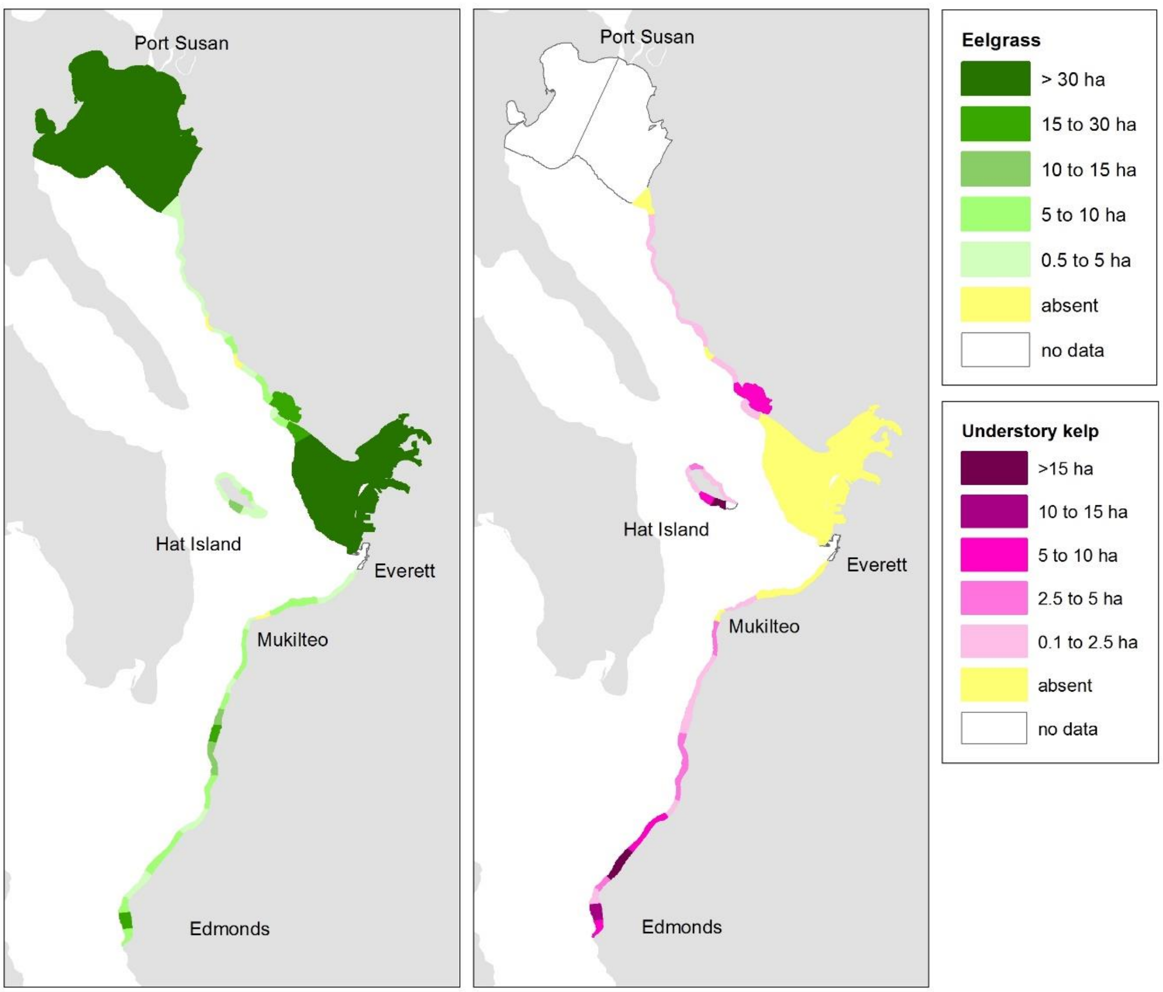

Figure 17: Overview of eelgrass and understory kelp along the shoreline of Snohomish County, sampled between 2019 and 2022.

The spatial distribution of understory kelp along the shoreline of Snohomish County was very different as compared to the distribution of eelgrass. In total, we found approximately 168 ha of understory kelp in the study area. Understory kelp was found at 46 out of the 58 sites that were analyzed for different types of marine vegetation. It was mostly comprised of prostrate kelp. Stipitate kelp was only found at one location (swh1017). Understory kelp was not found on the sand flats near the Snohomish Delta. While we have not classified the Port Susan sites (flats22 and flats23) for different types of marine vegetation, visual assessment of the footage from these sites suggests that understory kelp was mostly absent here as well. The largest understory kelp beds were found along Hat Island and the stretch of shoreline between Edmonds and Mukilteo. Understory kelp was also abundant near the mouth of Tulalip Bay (Figure 17).

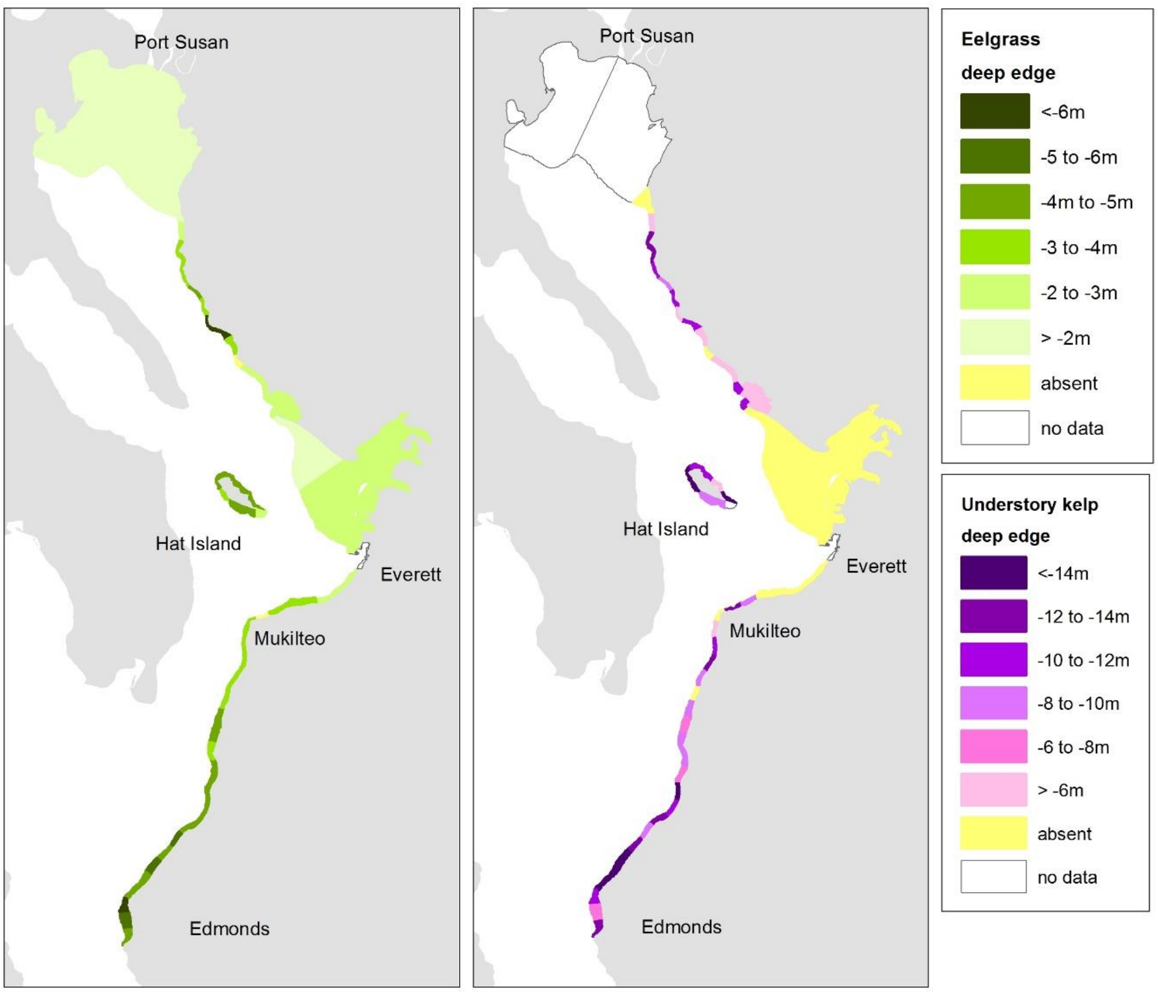

Figure 18: Deep edge of eelgrass and understory kelp beds along the shoreline of Snohomish County, sampled between 2019 and 2022 (calculated as the 2.5th percentile of all depth observations along these sites).

The depth distributions of eelgrass and understory kelp were very different, with understory kelp growing to deeper maximum depths (Figure 13). The deep edges of understory kelp beds were consistently deeper than those of eelgrass beds at sites in Snohomish County (Figure 18).

There was a clear spatial gradient in the deep edge of eelgrass beds, with eelgrass growing to deeper depths in the area between Edmonds and Mukilteo as compared to the eelgrass beds near Port Susan and the Snohomish Estuary. There were some exceptions to this general pattern. Eelgrass grew relatively deep along the shorelines of Hat Island, and at a few sites south of Kayak Point (swh1615 and swh1618). The spatial pattern for understory kelp was less clear. Some of the deepest understory kelp beds were found near Edmonds and along the shoreline of Hat Island. Some of the shallower understory kelp beds were located in Possession Sound and North of Tulalip Bay. Note that we did not calculate depth distribution for swh1611, swh1617, swh1621, and swh1625 (which are all sites with extremely low presence of understory kelp).

3.2.2 Change in eelgrass area & depth distribution

3.2.2.1 Long-term trends in eelgrass area at sites sampled on multiple occasions by DNR

Sixteen out of the 62 sites sampled have been visited more than once by DNR. At 15 of these sites, we were able to assess change in eelgrass area over time (Figure 19). At one location (swh1645) eelgrass has always been classified as 'trace' (Christiaen et al. 2022). These assessments were based on two methods:

- Trend analysis conducted with linear regressions of site eelgrass area estimates over time (which includes all samples taken at a site);
- pairwise comparisons of sets of transects that have been resampled over time

Figure 19 shows the eelgrass area estimates over time at the sites with trend analysis (in ha). Here, years with repeat transect analysis are indicated in black. Years that were sampled with new draw random samples are indicated in blue. At four of the 15 sites eelgrass area increased over time:

- At swh1625, the pairwise comparison of STR transects shows that the eelgrass expanded considerably between 2018 and 2021 (Figure 19). Eelgrass area increased fourfold during this period of time (from 1.53 +/- 0.28 in 2018 to 6.84 +/- 0.38 ha in 2021). Both the scatterplot and the pairwise comparison of SRS transects (2004-2018) indicate that eelgrass remained relatively stable before 2018.
- Swh1626 has a similar pattern, but less pronounced. The pairwise comparison of STR transects shows an increase between 2017 and 2020. A pairwise comparison of SRS transects suggests that eelgrass area did not change much between 2014 and 2017. The linear regression indicates that eelgrass area increased on average by 0.6 ha/year between 2010 and 2020.
- At flats26 eelgrass did not change much between 2016 and 2020. However, the pairwise comparison of SRS transects did suggest an increase between 2009 and 2016. The linear regression model reflects an increasing trend in eelgrass area of 4.1 ha/year between 2005 and 2020
- At swh1649 the pairwise comparisons indicate that eelgrass continuously increased between 2009 and 2022). The linear regression indicates that eelgrass area increased on average by 0.09 ha/year between 2005 and 2022

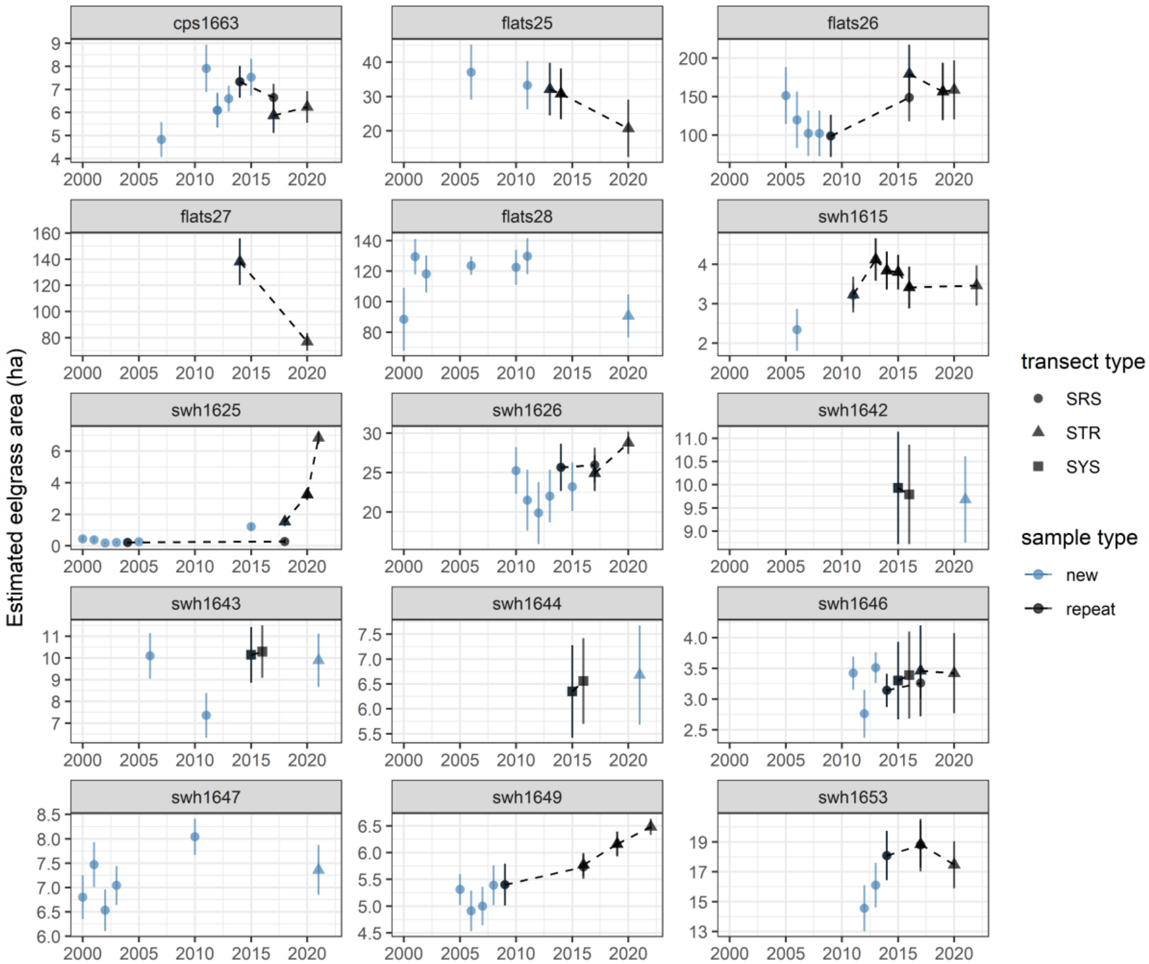

Figure 19: Eelgrass area over time at 15 sites that have been sampled repeatedly by DNR between 2000 and 2022. Symbols indicate if transects were selected by simple random sampling (SRS), Stratified random sampling (STR) or systematic sampling (SYS). The color indicates if transects were resampled over time.

At two of the 15 sites eelgrass area declined over time:

- Eelgrass beds at flats25 lost on average 1.14 ha per year between 2006 and 2020. Losses were most pronounced in the inner parts of the embayment. The pairwise comparison of STR transects between 2014 and 2020 confirms this pattern of loss.
- Flats27 was sampled twice, using the same set of STR transects. The pairwise comparison shows a clear loss of eelgrass in the shallow parts of the bed between 2014 and 2020. Site eelgrass area declined by nearly 50% at this location (from 138.1 +/- 17.9 ha in 2014 to 76.8 +/- 6.8 ha in 2020). Note that this is a very dynamic site, given its location in front of the Snohomish delta.

Note that there is a lot of variability in eelgrass area at other sites, such as cps1663, swh1615, swh1647, swh1653, and flats28. However, at none of these sites, there was enough evidence for a trend in eelgrass area over time.

3.2.2.2 A regional comparison of current eelgrass surveys (2019-2022) to a historical baseline based on aerial imagery and side scan sonar (1999-2007).

We compared our recent surveys of eelgrass (2019-2022) with a historical baseline of eelgrass along the shoreline of Snohomish County, compiled from several studies conducted between 1999 and 2007 (Bailey et al. 2007). These studies include the 2003 Snohomish County Intertidal Habitat Survey (mostly based on aerial imagery), the 1999 King County Nearshore Habitat Mapping Project (side scan sonar, south of Picnic point), a 2004 pre-construction survey near Point Wells (side scan sonar, dive surveys, and underwater video), a 2004 survey along the Port of Everett rail/barge transfer facility, DNR towed underwater video footage collected between 2000 and 2006, and a 2007 deep edge meander and side scan sonar study along the entire shoreline of Snohomish County. Because of the differences in methodology between the surveys, there is some uncertainty associated with this comparison. As such, we can only assess large scale patterns. Data were analyzed in different ways.

First we compared eelgrass area estimates from 2019 to 2022 with the area of the polygons from the 1999-2007 surveys. We excluded polygons labeled as *Z. japonica*. The regional estimates of total eelgrass area are indistinguishable between both surveys: the 1999-2007 surveys detected approximately 907 ha with eelgrass present[8], while the current DNR surveys estimate 912 +/- 67 ha of eelgrass between 2019 and 2022.

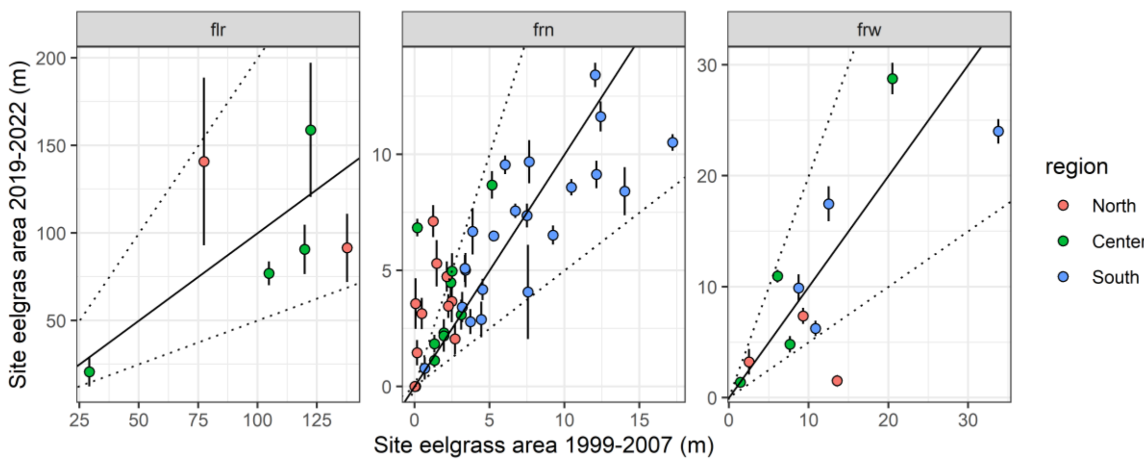

Figure 20: Eelgrass area estimates from recent surveys compared to the area of the 1999-2007 polygons, summarized at the level of individual sites. The 3 panes show data for sand flats (flr), narrow fringe (frn) and wide fringe (frw) sites. The fill color of the dots indicates where sites where located (North, Center or South). Black lines indicate a 1:1 ratio. Dotted lines indicate a two-fold increase/decline in eelgrass area.

Figure 20 shows a comparison of eelgrass area at the level of individual SVMP sites. The black line shows a 1:1 ratio, and the dotted lines indicate a 2x increase or decline in eelgrass area. Sites were binned according to their location. We split the area in 3 sub-regions: North (which encompasses all sites between Tulalip Bay and Port Susan), Center

[8] Our historical baseline estimate differs slightly from the values documented by Bailey et al. (2007), who estimated the total area of eelgrass as 1099.3 ha. The reason is two-fold: (1) we clipped the historical survey to the exact boundaries of the SVMP sites, which exclude some of the polygons in Port Susan, and (2) we excluded polygons listed as *Z. japonica* from the overall area estimate.

(which encompasses the sites near the Snohomish delta as well as Hat Island), and South (all the sites between Edmonds and Mukilteo).

The majority of sites fall within the area enclosed by the 2x increase and 2x decline lines on the plots. However, there are a few sites where eelgrass beds increased or declined by over a factor two[9]. These are mostly located in the northern part of the study area (indicated in red).

- Sites with suspected increases in eelgrass area in the northern part of the study area include swh1612, swh1613, swh1614, swh1618, swh1619, swh1621, and swh1622. Sites with suspected increases in the center region include swh1017 (Hat Island) and swh1625. The largest site level increases are at swh1619 (from 1.24 ha to 7.12 +/- 0.69 ha) and swh1625 (from 0.19 to 6.84 +/- 0.38 ha).
- There is only one site with a clear decline: swh2877. Here eelgrass area declined from 13.8 ha to 1.52 +/- 0.5 ha in 2022.).

Figure 21: 2019-2022 transect point features overlaid on eelgrass polygons from the 1999-2007 surveys. Blue color on the transect lines indicates that eelgrass was present in 2019-2022. Red indicates the presence of *Zostera japonica*. Polygons with different shades of green and pink indicate the presence of eelgrass and the non-native *Zostera japonica* in 1999-2007.

[9] Due to the difference in methodology between both surveys, we considered a site to be increasing or declining if the area of eelgrass beds changed by more than a factor 2

Additionally, we overlaid the current survey data with the polygons from the baseline to visually compare the presence/absence of eelgrass along transects collected between 2019 and 2022 with the corresponding eelgrass polygons from 1999-2007. Here we only show a few examples.

Figure 21 shows the area south of Port Susan (left) and the area immediately south of Tulalip Bay (right). This figure illustrates that there used to be a substantial eelgrass bed at relatively shallow depth at swh2877. The 2019-2022 found only scattered shoots inside the footprint of the original survey, but some apparent gain at the deep edges of this site. At swh1610, swh1611 and swh1612 we noted substantial gains at the deep edge of the site. At swh1625 and on the border with swh1626, there is a clear gain of eelgrass as compared to the 1999-2007 baseline.

Figure 22: 2019-2022 transect point features overlaid on eelgrass polygons from the 1999-2007 surveys. Blue color on the transect lines indicates that eelgrass was present in 2019-2022. Red indicates the presence of *Zostera japonica*. Polygons with different shades of green and pink indicate the presence of eelgrass and the non-native *Zostera japonica* in 1999-2007.

Figure 22 shows the shoreline of Hat Island. At most sites the historical baseline corresponds relatively well to the 2022 eelgrass survey data. However there are some discrepancies. There is an apparent increase in eelgrass at swh1017 and on the border with swh1018, as well as an apparent gain at the shallow edge of swh1016.

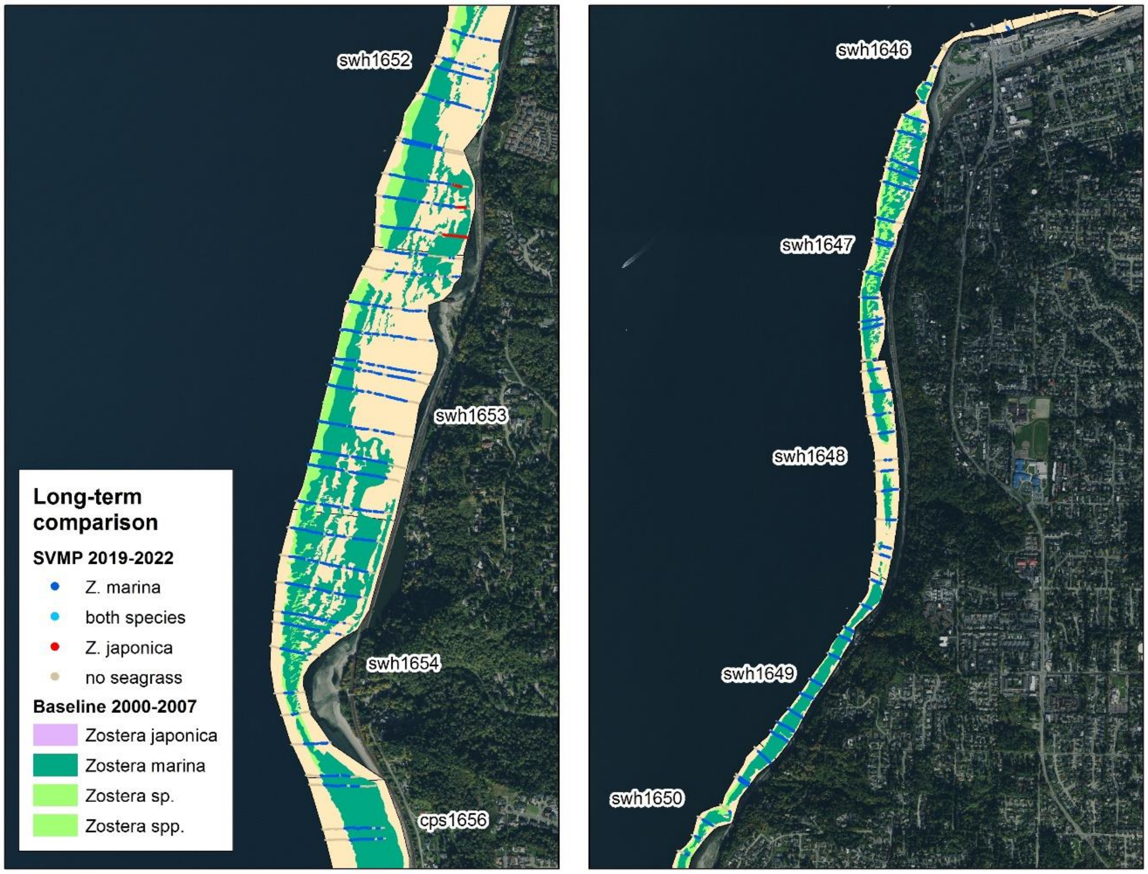

Figure 23: 2019-2022 transect point features overlaid on eelgrass polygons from the 1999-2007 surveys. Blue color on the transect lines indicates that eelgrass was present in 2019-2022. Red indicates the presence of *Zostera japonica*. Polygons with different shades of green and pink indicate the presence of eelgrass and the non-native *Zostera japonica* in 1999-2007.

Figure 23 shows a few stretches of shoreline between Edmonds and Mukilteo (South region). Here, there appears to be less variability in the location and size of eelgrass beds when comparing the 2019-2022 surveys with the 1999-2007 baseline. However, there are some locations with differences. For example, at swh1653 there is a large section with apparent gains along the shallow edge, while at swh1652 an area that was originally classified as eelgrass is currently covered by a *Z. japonica* bed.

There appears to be a lot of variability in the footprint of eelgrass beds when comparing the datasets, which likely reflects real pattern in local increases and declines, but could also be impacted by the difference in sample methods.

3.2.2.3 *A regional comparison of deep edge of eelgrass beds between current surveys (2019-2022) and data collected in 2007.*

We compared depth data from the 2019-2022 eelgrass surveys to a deep-edge meander along the entire shoreline of Snohomish County, collected in 2007 (Bailey et al. 2007). In order to do so, we calculated the average and standard error of the deepest observations along each transect per SVMP site, and plotted these measures relative to the average and standard error of the deep edge data from the 2007 survey (Figure 24). This figure shows a very similar pattern to the comparison of eelgrass area estimates from both surveys.

In the South and Center regions of Snohomish County, sites cluster around the 1:1 line, indicating that there was no systematic change in the deep edge of eelgrass beds at these locations. There are 3 exceptions to this general pattern: cps1664 (- 6.6 m in 2007 vs. - 4.6 m in 2021), cps1666 (- 3.2 m in 2007 vs. - 5.8 m in 2021), and swh1625 (- 0.6 m in 2007 and - 2.6 m in 2021). At cps1664, the discrepancy may be due to the fact that this site was partially obstructed, and only partially sampled in both 2007 and 2021 (Edmonds Underwater Park). At cps1666, there was a lot of variability in the deep edge (which is reflected in the large size of the error bars). The difference at swh1625 reflects the increase in eelgrass at this location.

In the North region, all sites fall below the line, indicating that eelgrass beds occurred at greater maximum depths between 2019 and 2022. This corresponds with the large number of suspected eelgrass area increases in this region.

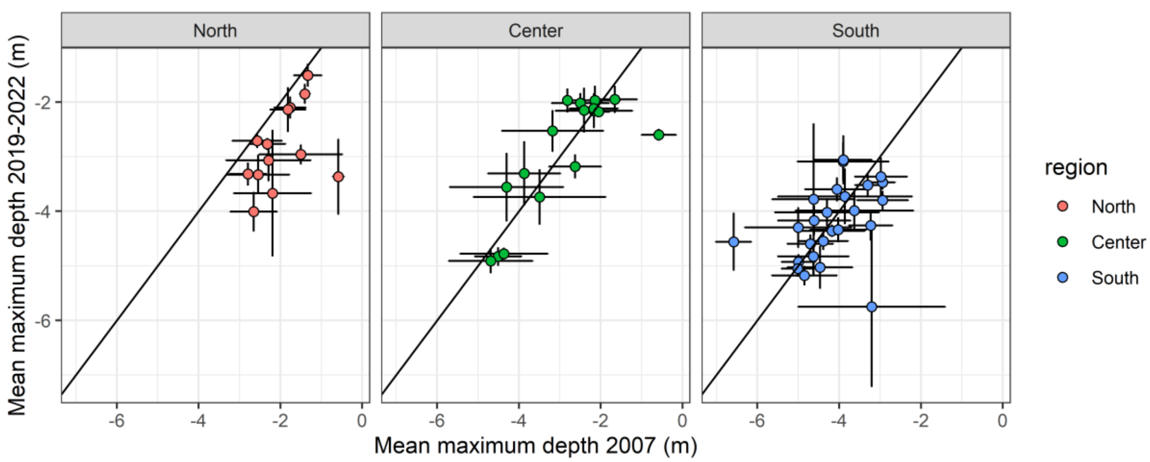

Figure 24: Average of the deepest eelgrass observations along individual transects (2019-2022) or along the deep edge meander (2007) at individual SVMP sites. Error bars are standard error. The fill color of the dots indicates where sites were located (North, Center or South). Black lines indicate a 1:1 ratio.

3.2.3 Echinoderms in the shallow subtidal along Snohomish County

From the 2020, 2021, and 2022 survey footage, we counted a total of 5,961 individuals, spread over 11 classes of echinoderms: undifferentiated stars, mottled stars, giant pink stars, rainbow stars, ochre stars, sunflower stars, leather stars, slime stars, striped sun stars, and two types of sea cucumbers (Figure 25 and Figure 26). The most abundant categories were undifferentiated stars (n = 4,406), mottled stars (n = 1,222), giant pink stars (n =210), ochre stars (n = 21), rainbow stars (n = 17), and sea cucumbers (n = 66). The least abundant categories were sunflower stars (n = 9), leather stars (n = 4), striped sun stars (n = 4), and slime stars (n = 2).

The site with the highest count of echinoderms was swh1015 (n = 2,845), located on the south end of Hat Island, surveyed in 2022. This was also the site highest species richness, with eight species categories observed: mottled stars (n = 622), giant pink stars (n = 15), ochre stars (n = 5), rainbow stars (n = 9), striped sun stars (n = 4), *Parastichopus sp*. (n = 4), *Cucumaria sp*., (n = 18) and undiff stars (n = 2,169). The site with the second highest species richness was swh1648, surveyed in 2021. At this location we counted six groups of echinoderms: mottled stars (n = 29), *Cucumaria sp*. (n = 7), *Parastichopus sp*. (n = 6), ochre stars (n = 3), rainbow stars (n = 2), and undiff stars (n =3).

Mottled stars occurred at sites over the entire region of the study area and in all three years of surveys sampled between 2020 and 2022 (Figure 27). We documented 44 sites with mottled stars. At most of these sites, mottled stars were present in relatively low densities. Twenty-two sites had five or less stars per 1000m of transect, and fourteen sites had 5-20 stars recorded per 1000m of transect. We recorded eight sites with more than 20 stars per 1000m of transect. Sites with the highest densities were swh1015 located off the south end of Hat Island (with 377 mottled stars per 1000m of transect), swh1645 located next to the Mukilteo ferry ramp (with 82 mottled stars per 1000m of transect) and swh1615 between Tulalip Bay and Port Susan (with 56 mottled stars per 1000m of transect).

Giant pink stars occurred at nineteen sites sampled between 2020 and 2022 (Figure 27). These sites were all located in the central region of the study area, including around Hat Island, between Mukilteo and Everett, and near Tulalip Bay. No giant pink stars were observed north of site swh2878 (on the north side of Tulalip Bay), or south of site swh1645 (next to the Mukilteo ferry dock). The sites with the highest densities of giant pink stars were swh1019 and swh1013, located on the north and east side of Hat Island (with 44 and 31 giant pink stars per 1000m of transect respectively). There were 4 sites with a density of 10 - 20 giant pink stars per 1000m of transect. One of these sites was swh1012 (located on the east side of Hat Island), and the other three were swh1645, swh1644 and swh1643 (located between Mukilteo and Everett). All other sites had less than 10 giant pink stars per 1000m of transect.

Figure 25: Occurrence of different species/groups of echinoderms along the shoreline of Snohomish County between Port Susan and Everett at sites surveyed in 2020, 2021 and 2022

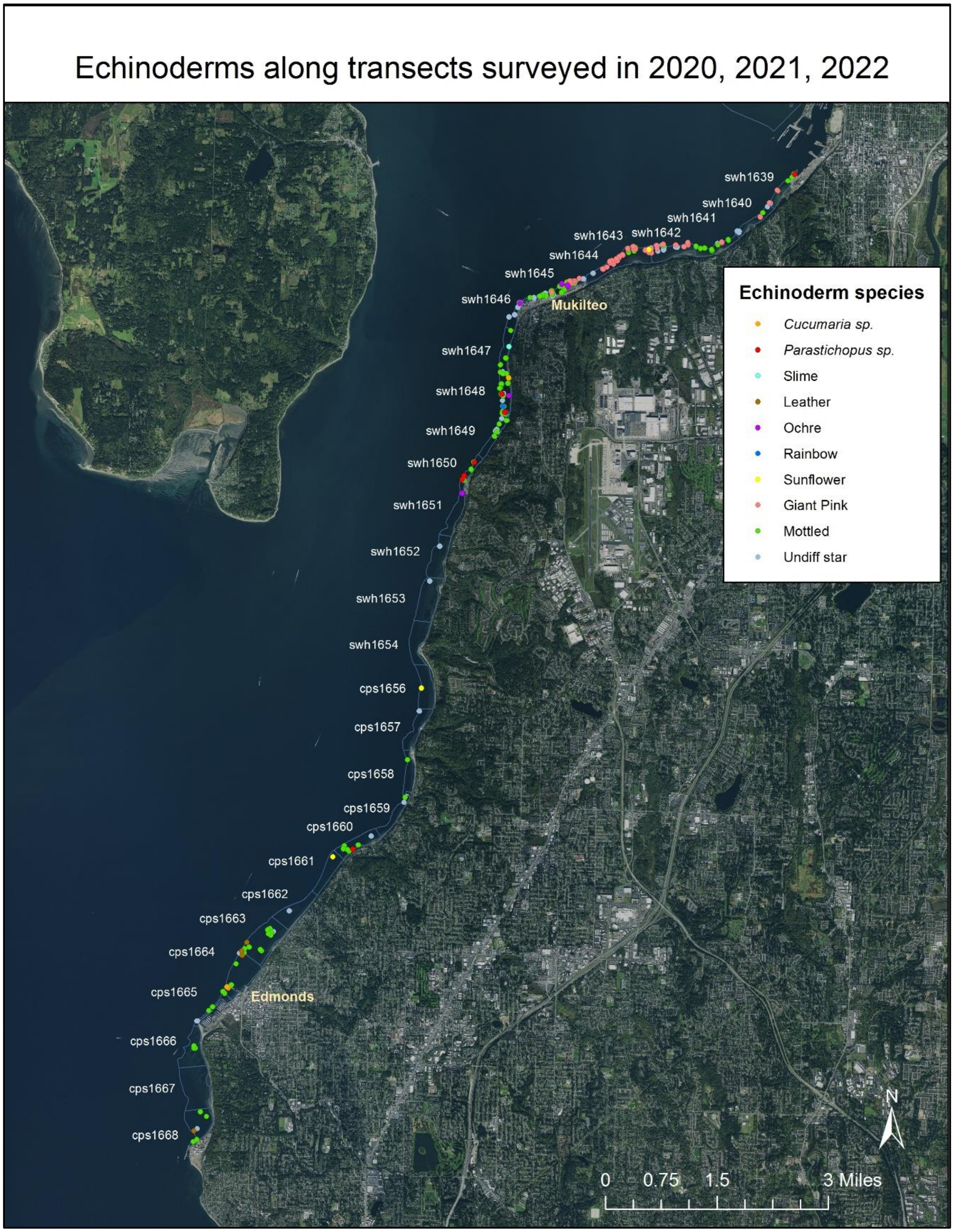

Figure 26: Occurrence of different species/groups of echinoderms along the shoreline of Snohomish County between Edmonds and Everett at sites surveyed in 2020, 2021 and 2022.

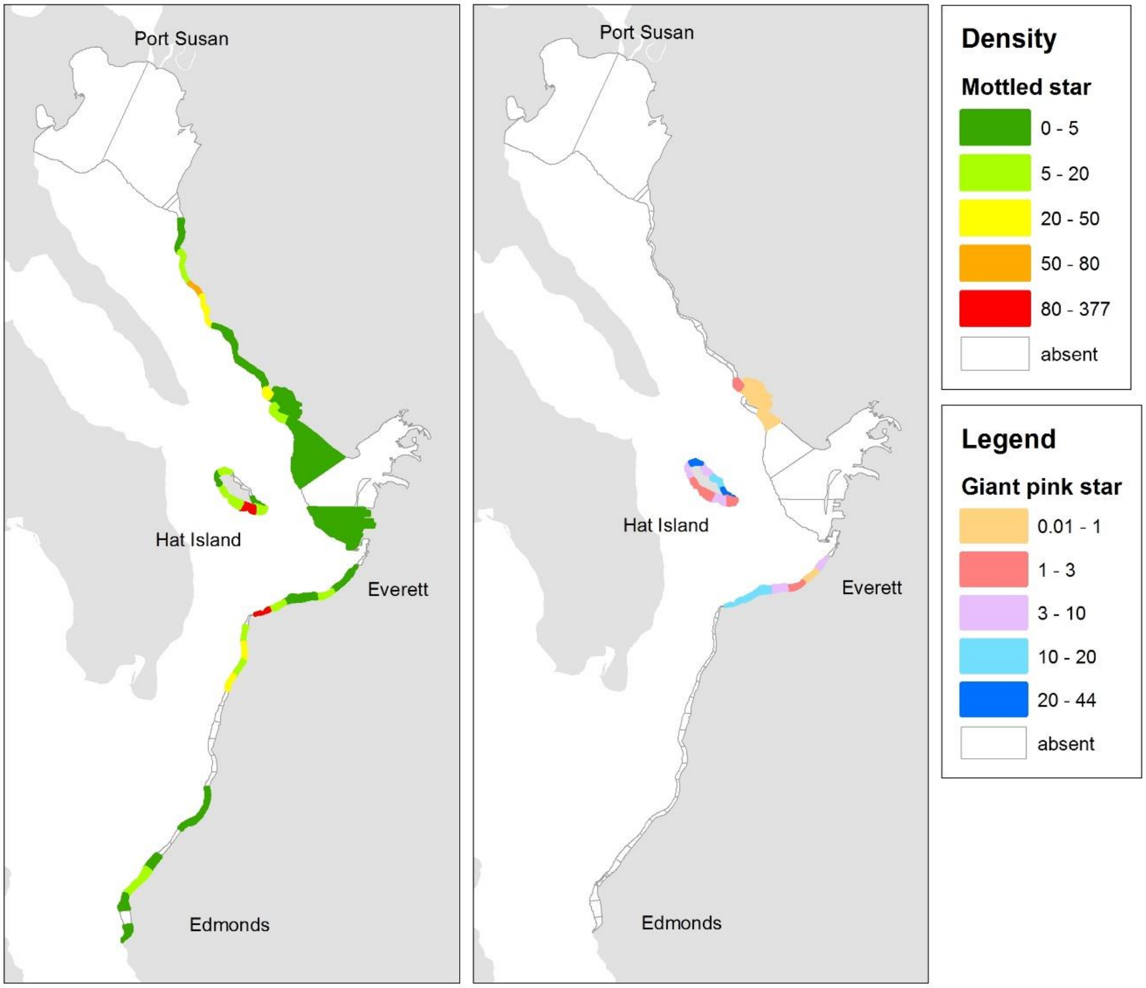

Figure 27: Density of mottled stars and pink stars at sites surveyed in 2020, 2021, and 2022. Densities represent the number of stars per 1000m of transect at the site (calculated by dividing the count of stars at a site by transect lengths).

Ochre stars occurred at seven sites throughout the study area, and were observed in all three years of surveys. Ochre stars occurred at sites near Mukilteo (swh1650, swh1648, swh1646, swh1645), at sites on the south end of Hat Island (swh1013 and swh1015), and at one site further north in the study area between Tulalip Bay and Port Susan (swh1616). The site with the most ochre stars observed was swh1645 (n = 6), surveyed in 2021.

Rainbow stars were observed at six sites throughout the study area, and often in close proximity to sites with ochre stars. Rainbow stars were observed in the survey years of 2021 and 2022, but the 2020 video footage did not include the rainbow star category. Rainbow stars occurred at sites on the south and west side of Hat Island (swh1015, swh1016, swh1017, and swh1018), at one site further north between Tulalip Bay and Port Susan (swh1615), and at one site near Mukilteo (swh1648). The site with the most rainbow stars was swh1015 (n = 9), surveyed in 2022.

Sunflower stars occurred at seven sites, scattered over the entire study area in low densities, and they occurred in all three survey years. Sunflower stars occurred at two sites on the north end of Hat Island (swh1011 and swh1018), at site between Tulalip Bay and

Port Susan (swh1619), at a site between Mukilteo and Everett (swh1643), at a two sites between Mukilteo and Edmonds (cps1656 and cps1661), and at the site in Tulalip Bay (flats25). All the sites with sunflower star occurrences only had one sunflower star counted, except for sites swh1011 and swh1619, which had two sunflower stars each, and both sites were surveyed in 2022.

We classified the towed underwater video footage for 2 groups of sea cucumbers: *Cucumaria sp*. and *Parastichopus sp*. *Cucumaria sp*. occurred at four sites: a site on Hat Island (swh1015), a site near Edmonds (cps1664), a site near Mukilteo (swh1648), as well as Tulalip Bay (flats25). The site with the most *Cucumaria sp*. counted was swh1015 (n = 18), sampled in 2022. *Parastichopus sp*. was found at five sites: on Hat Island (swh1015), two sites near Mukilteo (swh1648 and swh1650), a site between Mukilteo and Edmonds (cps1660), and a site near Everett (swh1639). The site with the highest count of *Parastichopus sp*. was swh1650 (n = 9), surveyed in 2021.

The least common echinoderms in our dataset were leather stars, striped sun stars and slime stars. Leather stars occurred at only three sites located in southern region of the study area, close to Edmonds. There were two leather stars observed at cps1663, one leather star observed at cps1664, and one leather star observed at cps1668 (the furthest site south in the study area). Four striped sun stars were observed at the same site, swh1015, on the south end of Hat Island and was surveyed in 2022. There were two slime star occurrences. One slime star was observed at a site near Mukilteo in 2021 (swh1647), and the other slime star was observed at a site on the north end of Hat Island in 2022 (swh1019).

There were no green, red, or purple urchins found in the study area between 2020 and 2022. There were no vermillion stars, blood stars, morning sun stars, or spiny red stars found in the study area between 2020 and 2022.

4 Discussion

4.1 Eelgrass and understory kelp

Seagrass and kelp are the foundation for the diverse and productive nearshore ecosystems in greater Puget Sound. These species are very different, both in life cycle and preferred substrate (Mumford 2007), yet they are linked through exchange of dissolved organic carbon, detrital matter, and movement of fauna across habitat borders (Heck et al. 2008, Hyndes et al. 2012, Chalifour et al. 2019). Together with other macroalgae, they form a contiguous seascape that supports a rich community of organisms, ranging from small invertebrates to commercially important or forage fish species (Johnson et al. 2003, Rubin et al. 2018, Wernberg et al. 2019, Shaffer et al. 2020). Eelgrass and kelp have a high primary productivity, and provide structural complexity to nearshore ecosystems, offering both plentiful resources as well as refuge from predation (Semmens 2008). Eelgrass beds function as spawning and nursery habitats for Dungeness crab and Pacific herring (Stevens and Armstrong 1984, Pentilla 2007), while kelp beds act as nursery habitat for juvenile rockfish (Matthews 1990, Hayden-Spear 2006). Kelp and eelgrass also provide important microhabitats for a large number of specialized organisms, such as epiphytes and endophytes (Mumford 2007).

The shoreline of Snohomish County supports approximately 912 +/- 67 ha of eelgrass and approximately 168 ha of understory kelp, which often grow in close proximity to each other. Eelgrass and understory kelp are common along the shoreline between Edmonds and Mukilteo, as well as near Hat Island and at the mouth of Tulalip Bay. At these locations understory kelp (most commonly sugar kelp or *Saccharina spp.*) grows either interspersed with eelgrass or beyond the deep edge of eelgrass beds. This is important, as the presence of understory kelp can improve the nursery function of eelgrass beds (Olson et al. 2019).

Eelgrass and kelp are not evenly distributed through the study area. The largest eelgrass beds were found near Port Susan and the Snohomish Estuary. Approximately 60% of all eelgrass in Snohomish County was found in these two areas. Eelgrass beds near river deltas are an important resource for juvenile chum and Chinook salmon in their early marine phase. These eelgrass beds provide important forage habitat for these species (Kennedy et al. 2018), which are often found in high abundance during outmigration at these locations (Hodgson et al. 2016, Rubin et al. 2018). Eelgrass beds tend to be smaller and less dense between Port Susan and Tulalip Bay. There is also a clear North to South gradient in the deep edge of eelgrass beds along the shoreline of Snohomish County. Both of these factors suggest that there may be a gradient in water clarity throughout this area, as lower light conditions are often associated with shallower maximum depths and lower shoot densities (Schmidt et al. 2012).

Eelgrass beds have relatively low carbon sequestration rates as compared to tropical seagrass species. Assuming a carbon sequestration rate of 24.8 g OC m^{-2} y^{-1} (the average rate in Pacific Northwest eelgrass habitat, Prentice et al. 2020), the eelgrass beds in Snohomish County sequester approximately 226 metric tons of organic carbon per year. Assuming a carbon stock of 7,168 g OC m^{-2} (Prentice et al. 2020), they store approximately 65,400 metric tons of organic carbon in the upper 1m of the sediment. Note that the carbon sequestration rates are only a fraction of the amount of carbon fixed by eelgrass beds. For example, Thom (1990) estimated the annual aboveground net primary production of eelgrass beds in Padilla Bay as approximately 351 g OC m^{-2} y^{-1}. The majority of net primary production in seagrass beds is either decomposed, exported to adjacent habitats, or consumed by herbivores (Duarte and Cebrian 1996).

The spatial distribution of understory kelp along the shoreline of Snohomish County is very different as compared to the distribution of eelgrass. Understory kelp was found at 46 sites in the study area, but was absent from sites near the Snohomish River delta. While we did not classify the 2019 sites in Port Susan, a quick visual inspection suggests that understory kelp was absent there as well. The limited spatial extent of kelp at these locations was expected, as kelp is generally sparse in nearshore delta environments (Dethier 1990). Understory kelp was fairly abundant north of Everett, around Hat Island and adjacent to Tulalip Bay. Most of the understory kelp consisted of prostrate kelp species. Stipitate kelp was only found at one location: swh1017 on Hat Island.

While we have not classified our video footage to the level of individual species, it appears that the majority of understory kelp in the study area is either *Saccharina groenlandica* or *Saccharina latissima*. These species are virtually indistinguishable in the field. *Saccharina spp*. are perennial kelps with a range from Alaska to central California. The sporophyte has a small, branched holdfast, short stipe and a thick, smooth brown blade, and can live for several years (2 to 4 years for *S. latissima* or sugar kelp). *Saccharina spp*. is limited to the lower intertidal and shallow subtidal, as they cannot tolerate desiccation at low tide (Klinkenberg 2020). These species are often found on mixed substrate, with the holdfast growing on shells, pebbles or cobble, or even tubeworms, which is a common occurrence along the shoreline of Snohomish County.

4.2 Change in eelgrass beds in Snohomish County

At 15 out of the 62 sample sites in the study area, we were able to assess trends in eelgrass area based on data collected with towed underwater video over multiple years. Out of these 15 sites, there were 4 sites with increases and 2 sites with declines.

Two of these sites were located on the Snohomish River delta. At flats26 eelgrass area increased by approximately 50% between 2009 and 2016. At the adjacent site, flats27, eelgrass declined by over 50% between 2014 and 2020. This decline was most pronounced along the shallow edge of the bed. Eelgrass beds near river deltas tend to be highly variable in greater Puget Sound (Christiaen et al. 2022a). These areas offer expansive habitat in the form of large gradually sloping sand flats, but are subject to a variety of stressors such as variable temperature, salinity, desiccation at low tide, burial and erosion due to wave action and river flow. Other factors could also play a role. Eelgrass beds in warmer waters tend to be less resilient than eelgrass beds in cooler waters, as higher temperatures can lower eelgrass tolerance to low-light conditions (Krumhansel et al. 2021). This could contribute to the relatively ‘shallow’ deep edge of eelgrass beds near Port Susan and at the Snohomish River Delta. It is also worth noting that the Snohomish River delta and adjacent areas in the Whidbey Basin are feeding areas for grey whales, who prey on the abundant ghost shrimp (*Neotrypaea californiensis*). This feeding activity creates shallow oblong depressions or “feeding pits” in the intertidal and shallow subtidal (Pruit & Donoghue 2016). At this point, we are not aware of any feeding activity within eelgrass beds at these locations.

In Tulalip Bay, eelgrass declined by an average 1.14 ha/year between 2006 and 2020. In recent years, Tulalip Bay was the only location with documented herring spawn for the Port Susan Herring Stock, which is currently classified as critical (Sandell et al. 2019). However, the loss of eelgrass at this location may be mitigated by the presence of understory kelp near the mouth of Tulalip Bay, which also provides suitable spawning substrate. In addition, there have been substantial increases in eelgrass area right outside Tulalip Bay at swh1625 and swh1626. The increase was particularly pronounced at swh1625. Here, eelgrass area increased fourfold between 2018 and 2021. The Port Susan herring stock is also known to deposit significant spawn on rock and gravel (Sandell et al. 2019).

We also compared eelgrass area from the current towed underwater video surveys (2019-2022) with a comprehensive baseline of eelgrass data, compiled from a series of surveys between 1999 and 2007. These surveys were conducted with a variety of methods, but were mostly based on side scan sonar and ground-truthed aerial imagery (Bailey et al. 2007). While there is some uncertainty in our change estimates, the comparison with the 2019-2022 data reveals some large-scale patterns in the data. The estimates of total eelgrass area were very similar between both surveys. Bailey et al. (2007) reported that there was approximately 1099.3 ha of eelgrass within Snohomish County. However, this estimate includes the non-native *Zostera japonica*. When you exclude *Z. japonica* from the estimates, and clip the 1999-2007 and 2019-2022 surveys to the same extent, there was approximately 906 ha of eelgrass in 1999-2007 and approximately 912 ha of eelgrass in 2019-2022. There appears to be a lot of variability over time on smaller spatial scales. When you compare site area estimates at the site level between both datasets, there are substantial changes in the footprint of eelgrass beds over time. This is likely a real pattern in local increases and declines, but could be influenced by the difference in sample methods.

Because of the uncertainty associated with these estimates, we only considered sites increasing or declining if there was a more than 2-fold increase or decline in eelgrass area over time. By this standard, there are several sites with increases and one site with a decline. Sites with increases were mostly located in the northern part of the study area (several sites between Port Susan and Tulalip Bay, one site on Hat Island, as well as swh1625 directly south of Tulalip Bay). The site with a decline is located directly south of Port Susan. This pattern is confirmed when you look at the depth data from both datasets. A comparison of maximum depths of eelgrass between 1999-2007 and 2019-2022 shows that the deep edge of eelgrass beds is consistently deeper in 2019-2022 as compared to the previous survey north of Tulalip Bay. There was no systematic pattern in deep edge in the other parts of the study area.

This pattern of large scale of regional stability but high variability on smaller spatial scales has been documented in other long-term datasets on eelgrass. The most recent report from DNR's eelgrass monitoring program shows that soundwide eelgrass area was relatively stable between 2004 and 2020, but that out of a random sample of 214 sites, approximately 40% of vegetated sites had a significant long-term trend in eelgrass area (Christiaen et al. 2022a). A recent study on 40 years of eelgrass data in the herring spawn areas in Puget Sound showed a similar result (Shelton et al. 2016).

4.3 Echinoderms in the shallow subtidal

Between 2013 and 2015, a large epidemic decimated sea star populations along the Pacific Coast of North America. Over 20 species were affected, including several subtidal species that were common in the Salish Sea (Montechino-Latorre et al. 2016). Symptoms of sea star wasting disease generally start with the appearance of lesions across the star, followed by tissue degradation and death. The pace of wasting disease can be quick, only a few days, and it can spread to other stars and be disastrous to sea star populations. As of yet, there is limited information on the long-term impact of sea star wasting disease in the Salish Sea. Here, we take advantage of our towed underwater video surveys to assess the relative abundance of different sea star species to assess the status of their populations along the shoreline of Snohomish County.

Monitoring subtidal sea star populations usually requires time-intensive dive surveys. We developed an experimental classification to assess if towed underwater video footage is a viable large area method for estimating the relative abundance of sea stars and other echinoderms in shallow subtidal habitats. We measured the abundance of eighteen classes of echinoderms along each transect sampled along the shoreline of Snohomish County between 2020 and 2022. Eleven different classes were detected in the study area. The most abundant categories of echinoderms were undifferentiated stars (n = 4,046), mottled stars (n = 1,222), giant pink stars (n = 210), sea cucumbers (n = 66), ochre stars (n = 21), and rainbow stars (n = 17). Sunflower stars (n = 9), leather stars (n = 4), striped sun stars (n =4), and slime stars (n = 2) were less commonly occurring species. We were not able to detect small individuals and sea stars inside dense vegetation or under surfaces, so these numbers are conservative estimates. It is important to note that our study area (1 to -15m MLLW) only covers a portion of the depth range where these sea stars occur. Note that we did not find any sea stars that appeared to be in the process of wasting in our video footage.

Between the three years of surveys, a few notable regional patterns emerged. One regional pattern was the low abundance of echinoderms around the Snohomish River delta and near Port Susan. Invertebrate counts were generally higher in areas with steeper shores, located further away from freshwater. Most of the echinoderm species we are documenting using our towed video footage feed on mussels, chitons, barnacles, snails, limpets, sponges, small sea cucumbers, and more. The variable salinity and the sandier and muddy substrate in areas like the Snohomish River delta and Port Susan may limit the amount of prey items available, and could be why fewer echinoderms are observed in our video in these areas. Other studies have documented that low salinity environments reduce sea star feeding rates and predation activity (Dickey et al. 2021), and that low salinity environments can limit the development and distribution of sea stars in an area (Casties et al., 2015).

Another pattern was the relative abundance of the different species observed in our surveys. The most abundant sea stars in the intertidal and shallow subtidal areas of Snohomish County were mottled sea stars and giant pink stars, both species that were among the most vulnerable to sea star wasting disease (Miner et al. 2022):

- Giant pink stars were seen only in the central region of the study area, between Mukilteo and Tulalip Bay, and around Hat Island. These stars usually prefer softer surfaces, and dig out clams in the muddy and sandy substrate, but, they also will eat barnacles on rocky substrates. It is interesting to note that the giant pink star was not observed in the more northern or southern areas of the study area. The prey items (clams) of the giant pink star overlap with the sunflower star, and, the giant pink star is occasionally eaten by sunflower stars. There are several sites (swh1018, swh1011, swh1643), where both the sunflower star and giant pink star were present.
- Mottled stars were observed throughout the entire study area and found in both low and high numbers. Mottled stars are very common throughout the Salish Sea, as this species occurs in a wide range of habitats. These stars are intertidal to subtidal, and can be found near eelgrass beds on sandy substrates, as well as in rockier habitats. Mottled sea stars primarily prey on bivalves and barnacles. Since this star is seen at various depths and is more tolerant of different habitats, it could be why we see this species in such high numbers in our video surveys compared to other echinoderm species.

Other species that were impacted by wasting disease such as sunflower stars, striped sun stars and ochre stars were relatively sparse in the study area:

- Ochre stars were only seen at a few locations. These stars live in the intertidal and prefer rockier areas where they can hide in damp crevices. This habit may be a reason why we have a harder time observing their presence on video. There have been instances where we have seen these stars on top of, or near understory kelp, as well as on sandier substrates. Their diet is mostly comprised of mussels, barnacles, and slow moving creatures. The ochre star is of high interest as it is a keystone species of the rocky intertidal in the Salish Sea. They help keep the number of mussels in these areas in balance. One site where ochre stars occurred was at site swh1645, near the Mukilteo ferry dock. The dock structure and surrounding area would provide many places for the ochre star and its food to live on.
- Sunflower stars were observed in low densities at sites spread across the region. These sea stars are voracious predators. They are fast, and they are able to live in a wide range of subtidal and intertidal habitats (sandy, muddy, rocky, and seaweed or kelp-covered substrates). They will eat anything that is in their path, including urchins, snails, clams, sea cucumbers, other sea stars, and more. In 2020, we counted only one sunflower star (flats25), in 2021 we counted three (cps1656, cps1661, and swh1643), and 2022 we counted five sunflower stars (swh1011, swh1018, and swh1619). The sunflower stars seen in footage from 2022 all appear to be large, at least around 20 cm across, which signifies they are likely a couple years old, based on an estimated growth rate of 8 cm/year in the first few years of life (Gravem et al. 2021).

- There were only a few striped sun stars observed. These stars primarily eat sea cucumbers. They are mostly found in rocky locations, but can be found in sandy and muddy areas. They range from the intertidal and subtidal depths. Striped sun stars are preyed upon by morning sun stars (*Solaster dawsoni*). The striped sun stars and morning sun stars can be difficult to distinguish from each other on video. Striped sun stars were only observed off the south end of Hat Island (swh1015), very close to where sea cucumbers were observed.

Some of the more uncommon echinoderms in our surveys included rainbow stars, leather stars and slime stars.

- Rainbow stars are able to exist both on sandy substrates, rocky substrates, and have been observed on understory kelp. They eat clams on the sandy substrates, and on rocky substrates they will eat tunicates, chitons, bivalves, and more. This species is more uncommon in the Salish Sea than the mottled star and ochre star. This species is found in the intertidal zone mostly. It is interesting that we have observed this species in the similar numbers to the ochre star. This could be due to the difficulty in distinguishing between the mottled, ochre and rainbow star species in towed underwater video footage. We observed rainbow stars at the same sites, or sites close to, ochre stars and mottled stars. This could be due to overlapping living habits, or due to misidentification.

- There were four leather stars observed, mostly in the southern region of the study area, near Edmonds. They can occur in the intertidal and at deeper depths, and prefer rocky substrates, but can be found on sandy substrates. Leather stars eat sea pens, anemones, algae, invertebrates, tunicates and other creatures. The prey items for the leather star are slightly different compared to other species observed, which could be why we only see the leather star in the southern region of the study site.

- There were only two slime stars observed in the three years of surveys. The slime stars can be challenging to identify on video, and look very similar to wrinkled stars (*Pteraster militaris*). This species is found at deeper depths, more in the subtidal range, and is found on rocky substrates. The slime star eats sponges and other small invertebrates. The slime stars that we have observed have been found at the deeper end of the transects, and these deep depths where they occur may be why we do not observe many in our videos.

Finally, we also analyzed our footage for the presence of two types of sea cucumbers: *Cucumaria sp*. and *Parastichopus sp*. We documented the presence of sea cucumbers at several sites throughout the study area. *Parastichopus sp*. is intertidal and subtidal, and exists in a range of habitats (sandy, rocky, muddy, etc.), although it prefers hard substrate and calm water. This species feeds mostly on detritus and microorganisms. *Cucumaria sp*. are similarly found in the intertidal to subtidal ranges, but unlike *Parastichopus sp*., they are more common in areas with high currents. *Cucumaria sp*. also consumes detritus and plankton. Both groups of sea cucumbers are preyed upon by sea stars. Note that *Cucumaria sp*. are relatively inconspicuous on the video footage, and hide in crevices or between rocks, with only their tentacles exposed, whereas *Parastichopus sp*. are much easier to detect. The more hidden placement of the *Cucumaria sp*. could lead us to underestimate their abundance based on video footage.

4.4 Data use and availability

This project, in combination with IAA 93-102327 and IAA 93-100931, has generated a large area profile for eelgrass, understory kelp, and other vegetation types along the entire shoreline of Snohomish County. This effort supplements existing and planned future sampling by DNR, and significantly increases the certainty in local estimates of eelgrass area and depth distribution over existing data from the Submerged Vegetation Monitoring Program. It also serves as a pilot project for classification of other marine vegetation types, based on footage collected for the SVMP.

Eelgrass and kelp abundance, distribution and depth data identify sensitive habitat areas for consideration in land-use planning. Given the recognized ecological importance of these habitats, planning should explicitly consider the location of eelgrass and kelp beds, their environmental requirements and potential habitat.

All eelgrass data presented in this report will be available online in the next distribution dataset of DNR's Submerged Vegetation Monitoring Program.
Data on other marine vegetation and sea star abundance is available on request. For more information, visit http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science

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6 Appendix 1

Table 6: Area estimates (ha) for different marine vegetation types based on classification of 1 frame every 5 seconds (low resolution). Note that there is overlap between the vegetation types (especially for seagrass and other red/brown algae). As a consequence, the area estimates for all vegetation does not correspond to the sum of the individual vegetation types at the sites.

site_code	all vegetation	seagrass	understory kelp	green algae	other red/brown algae	*Sargassum muticum*
swh1011	7.08	4.34	0.18	3.13	1.03	0.00
swh1012	9.39	8.51	0.15	1.16	1.38	0.00
swh1013	8.48	3.33	0.64	4.24	2.20	0.05
swh1015	45.41	4.40	22.00	15.72	31.18	0.00
swh1016	20.59	11.23	6.62	5.62	6.70	0.00
swh1017	8.79	1.68	0.81	6.91	2.05	0.00
swh1018	6.22	2.20	1.21	3.97	1.09	0.02
swh1019	9.81	3.57	2.76	2.33	4.90	0.02
swh1610	4.98	3.32	0.00	1.77	0.00	0.00
swh1611	3.71	3.62	0.03	0.06	0.00	0.00
swh1612	4.67	3.04	0.20	1.41	0.30	0.00
swh1613	7.45	4.10	1.25	1.75	1.23	0.03
swh1614	4.53	1.57	0.53	2.70	0.67	0.00
swh1615	7.08	3.31	1.26	2.77	1.26	0.00
swh1616	6.28	1.81	1.67	2.88	1.44	0.00
swh1617	2.83	0.03	0.06	2.72	0.11	0.00
swh1618	7.32	3.27	0.14	4.14	0.12	0.00
swh1619	12.72	6.09	2.08	3.73	1.40	0.00
swh1620	8.34	0.00	0.00	8.34	0.00	0.00
swh1621	11.97	3.35	0.09	9.78	0.17	0.00
swh1622	13.75	5.88	0.34	8.51	0.10	0.00
swh2877	2.83	1.50	0.00	1.36	0.00	0.00
swh2878	17.05	7.98	5.52	3.89	3.93	0.00