Marine Vegetation along the Snohomish County shoreline between Edmonds and Everett

Final report to Snohomish County

IAA 93-102327

02/11/2022

PSEMP
Puget Sound Ecosystem Monitoring Program

Washington State Department of
Natural Resources
Hilary S. Franz | Commissioner of Public Lands

NATURAL RESOURCES

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 of towed underwater footage collected as part of IAA 93-102327 between Snohomish County and DNR

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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 93-102327 between DNR and Snohomish County.

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

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Copies of this report may be obtained from:

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

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Contents

Executive summary **1**

1 Introduction **3**
1.1 Eelgrass and kelp in greater Puget Sound 3
1.2 Eelgrass and kelp monitoring at DNR 4
1.3 IAA 93-102327 between Snohomish County and DNR 5

2 Methods **6**
2.1 Study area description 6
2.2 Field sampling 6
2.3 Site and sample polygons 9
2.4 Video processing 9
2.5 Data analysis 11
2.5.1 Eelgrass area estimates 11
2.5.2 Eelgrass depth distribution 11
2.5.3 Trends in eelgrass area 12
2.5.4 Other marine vegetation: area and depth distribution 12

3 Results **13**
3.1 Overview of sample effort 13
3.1.1 SVMP sample effort 13
3.2 Seagrass 15
3.2.1 Seagrass species 15
3.2.2 Eelgrass area 17
3.2.3 Eelgrass depth distribution 18
3.2.4 Trends in eelgrass area 21
3.3 Other marine vegetation types 23
3.4 Echinoderms in the shallow subtidal 31

4 Discussion **35**
4.1 Eelgrass, kelp, and other macroalgae 35
4.2 Echinoderms in the shallow subtidal 37
4.3 Data use and availability 38

5 References **39**

6 Appendix 1 ..... **45**

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, such as eelgrass (*Zostera marina*) and surfgrass (*Phyllospadix spp.*), important components of nearshore ecosystems in greater Puget Sound. 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). Soundwide 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 as one of 25 Vital Signs to track progress in the restoration and recovery of Puget Sound.

In 2021, Snohomish County signed an agreement with DNR to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp and other macroalgae) at 22 sites along the shoreline of Snohomish County, between Edmonds and Everett, using methods developed for DNR's monitoring programs. Four additional sites were surveyed for eelgrass in 2019 and 2020. 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 for classification of other marine vegetation types.

Key findings:

1. The intertidal and shallow subtidal were colonized by a variety of marine vegetation types, which often displayed different zonation at individual sites.

    - In total, there was 198.3 +/- 3.7 ha of eelgrass in the study area (n = 26). This corresponds to half of the area covered by eelgrass near the Snohomish Delta (386 +/- 42 ha), 31% of all eelgrass along the shorelines of King County (680+/- 9 ha), and less than 1% of all eelgrass in greater Puget Sound (22,102 +/- 1,074 ha). Approximately 34% of the area between the mean high water line and -6.1m relative to MLLW was covered by eelgrass. The non-native seagrass *Zostera japonica* was sparse in the study area.

    - There was approximately 279.3 ha of green algae, 104.2 ha of other red/brown algae, and 85.6 ha of understory kelp in the study area (n = 22). 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 also detected approximately 2.7 ha of the invasive algae *Sargassum muticum*.

    - Eelgrass was usually found in dense patches with high % cover. Green algae, and other red/brown algae were usually found in low cover classes. Understory kelp was more or less evenly distributed over the different cover classes.

2. The depth distribution of marine vegetation was similar to other sites in the Central Basin of Puget Sound.
    - Eelgrass was found between 0.8 and -15 m (MLLW). The majority of observations occurred between 0 and -5 m (MLLW).
    - *Z. japonica* was found between 0.8 and -0.1 m, and had a median depth of 0.2 m (MLLW).
    - Green algae, other red-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 of -1.7, -6.8, and -3.6 m respectively). *Sargassum* was found down to -8.5 m, with a median depth of -1.1 m (MLLW).

3. We were able to assess change in eelgrass area at 8 out of the 26 sites in the study area. At 7 of these sites, there was no significant trend in eelgrass area over time. At one site (swh1649) there was a small increase over time between 2005 and 2019.

1 Introduction

1.1 Eelgrass and kelp in greater Puget Sound

Seagrass and kelp are the foundation for diverse and productive nearshore ecosystems in greater Puget Sound. They provide critical habitat for a wide array of marine life, such as rockfish, forage fish and salmon.

Seagrasses are flowering plants that grow and reproduce submerged in marine and estuarine environments. They mostly pollinate by hydrophilly (releasing pollen in the current, which is subsequently captured by different flowers), although there is some recent evidence that invertebrate fauna may play a role as well (Ackerman 2006, van Tussenbroek et al. 2016). Seagrass beds are among the most productive habitats in the biosphere (Duarte & Chiscano 1999). They fuel the local food web through production of detritus, are subject to herbivory, and export large quantities of biomass to adjacent systems (Heck et al. 2008). Seagrasses anchor the sediment through their roots and rhizomes and locally improve water quality by limiting sediment resuspension, limiting algae blooms, and removing harmful bacteria (de Boer 2007, Lamb et al. 2017, Inaba et al. 2017, Jacobs-Palmer et al. 2020, Reusch et al. 2021). Seagrass beds are also known to be efficient long-term carbon sinks, because of their high productivity and the relatively low decomposition rates of organic matter in marine sediments (Mcleod et al. 2011).

There are 6 species of seagrass in Washington State: *Zostera marina*, *Zostera japonica*, *Phyllospadix serrularus*, *Phyllospadix scouleri*, *Phyllospadix torreii*, & *Ruppia maritima*. Eelgrass (*Z. marina*) is by far to most abundant seagrass species in greater Puget Sound. Eelgrass is usually found on soft substrates, such as sand and mud. It tends to grow in relatively shallow environments, and is often limited by light availability. Eelgrass responds quickly to anthropogenic stressors such as reductions in water quality due to excessive input of nutrients and organic matter (Burkholder et al. 2007). Other stressors include physical damage from trawling and recreational boating, shading and siltation from dredge and fill operations, construction projects in the marine environment, and eelgrass wasting disease (Hemminga and Duarte 2000, Graham et al. 2021). Because of its sensitivity & importance to the ecosystem, eelgrass is often used as indicator for the health of shallow marine ecosystems (Dennison et al. 1993, Short and Burdick 1996, Lee et al. 2004, Kenworthy et al. 2006, Orth et al. 2006).

Kelp are large brown algae, belonging to the order Laminariales. Washington State is home to 22 species of kelp (Gabrielson & Lindstrom, 2018), making it one of the most diverse kelp floras in the world. Kelp are found throughout greater Puget Sound, but grow mostly in areas with hard substrates (Mumford 2007). These algae provide a wide range of ecosystem services. Kelp 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). They 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. Kelp sporophytes are organized into three types based on morphology: prostrate kelp, stipitate kelp and floating kelp (Mumford 2007). Floating kelp species are often visible at the water surface and are relatively easy to survey. Prostrate and stipitate kelp are considered understory kelp, and are usually not visible from the water surface. Despite their importance, there is limited information on their spatial and depth distribution. In Puget Sound, available data from multiple sources document long-term declines in the canopy cover of bull kelp (*Nereocystis luetkeana*). A recent study by Berry et al. 2021 documented that the current extent of bull kelp in south Puget Sound was 63% lower than the earliest baseline in 1878, with individual sub-basins showing a loss of up to 96%. Concerns also exist about potential losses to other kelp species, yet trends are unknown due to data gaps.

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) focusses on long-term monitoring of these habitats, and informs management decisions by providing information on status and trends. DNR-NHP is one component of a collaborative research effort called the Puget Sound Ecosystem Monitoring Program, formed by 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 2020, DNR has sampled large parts of Kitsap County, the entire shoreline of King County, and a substantial portion of the shoreline of Snohomish County as parts of collaborations 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).

Kelp monitoring is another focus area. 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 integrifolia*). Starting in 2011, these methods were expanded to include DNR's Aquatic Reserves, which have also been surveyed annually. Kelp is also monitored 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 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).

DNR-NHP uses footage from the SVMP to assess the distribution of understory kelp in greater Puget Sound. This effort started in 2019, with footage collected for projects with King County and Snohomish County (Christiaen et al. 2020a, Christiaen et al. 2020b). We are currently expanding this effort to include 120 randomly selected sites in greater Puget Sound. This project is being funded by external grants from the Pacific Marine and Estuarine Fish Habitat Partnership, and the SeaDoc Society.

1.3 IAA 93-102327 between Snohomish County and DNR

On July 12th 2021, Snohomish County signed an agreement with DNR to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp and other macroalgae) at 22 sites along the Snohomish County shoreline, between Edmonds and Everett, using methods developed for DNR's monitoring programs. This report summarizes area and depth distribution of eelgrass, understory kelp and other marine vegetation throughout the study area. 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 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. 2019). 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 valuable habitat.

2.1 Study area description

This report covers the intertidal and shallow subtidal habitats along the shoreline of Snohomish County, between Edmonds to Everett. We divided this area into 26 individual sample sites, labeled according to the SVMP dataset. Thirteen of the site codes start with cps (Central Puget Sound), and 13 of the site codes start with swh (Saratoga Whidbey Basin). Each are followed by 4 numbers. The location of the individual sites is noted on the site maps in the results section. All sites were sampled to a depth of -15m (relative to MLLW). Twenty-two sites were sampled in 2021 as part of this contract (IAA 93-102327). The remaining sites have been sampled in either 2019 (swh1649) or 2020 (cps1663, swh1646, swh1653).

2.2 Field sampling

Field sampling was conducted in June and August 2021 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 boom winch. During transect sampling, an MRC technician adjusts the position of the towfish using a 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 presence/absence of marine vegetation, 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. 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 D/V hard drives. 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 11o 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 26 sample sites based on the statistical framework of DNR's Submerged Vegetation Monitoring Program. All sites belong to the fringe stratum, 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 other vegetation types 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. At all sites sampled in 2021, STR transects were newly established. At the 4 sites sampled in 2019 and 2020, STR transects were a repeat of a previous sample.

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. The non-native *Z. japonica* was classified as well, but these data were not included in the calculation of eelgrass area and depth distribution[1].
- **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*, 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 the site. The

[1] *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.

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 separately, and assigned to one time stamp. Taxonomic categories were chosen to capture the greatest degree of taxonomic detail that is regularly distinguishable on towed underwater imagery[2]. 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.

[2] 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 5 cm 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 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)[3].

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

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

We estimate site seagrass area $\hat{X}$ by multiplying the 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 2.5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 97.5^{th} 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 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:

---

[3] 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 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 Trends in eelgrass area

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 SRS or STR, and if they were new draw samples or repeats. 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 comparing presence/absence of eelgrass among both years.

2.5.4 Other marine vegetation: area and depth distribution

For each type of marine vegetation, we calculated the number of observations in each cover class per site, and divided those by the total number of frames 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).

3 Results

3.1 Overview of sample effort

3.1.1 SVMP sample effort

Field work was completed in 8 days: one day at the start of June, and 7 days mid-August. During this period of time, we surveyed 223 transects over 22 different sites, and collected approximately 26 hours of footage for this project (Table 3). Most transects[4] were selected using stratified random sampling (STR), and were oriented perpendicular to shore. At the majority of sites (n = 20), transects span most of the intertidal and shallow subtidal (+1 to -15m, MLLW). However, at two locations, there were major obstacles that did not permit us to survey the entire site:

- Cps1664 is the location of the Edmonds Underwater Park. This scuba park covers approximately 11 ha and is not accessible to boats (due to safety reasons). We sampled 10 stratified random transects up to -15m (MLLW), but were not able to survey most of the intertidal.
- At cps1665, most of the shoreline is taken up by Edmonds Marina. Here, we sampled 10 stratified random transects outside of the marina breakwater, but did not survey inside of the marina.

The total length of all stratified random transects sampled was more than 37.1 km. Eelgrass was present at approximately 17.6 km of transects sampled. Most of the 22 sites sampled were relatively small. The largest site was cps1667, with a macroalgae sample polygon area of 51.4 ha. The smallest sites[5] was swh1650, with a macroalgae sample polygon area of 9.3 ha. Although we only sampled 22 sites as part of IAA 93_102327, we included eelgrass data for 26 sites. The 4 additional sites are swh1649 (sampled in 2019), swh1646, swh1653, and cps1663 (sampled in 2020). These sites are scheduled to be analyzed for macroalgae cover in 2022.

[4] In total there were 221 STR transects, 1 recon transect (a meander along the edges of swh1644 and swh16450) and one transect that was abandoned partway through due to an obstacle.
[5] Note that the macroalgae sample polygon at cps1665 was only 6.2 ha, as most of this site was obstructed by the Edmonds underwater Park.

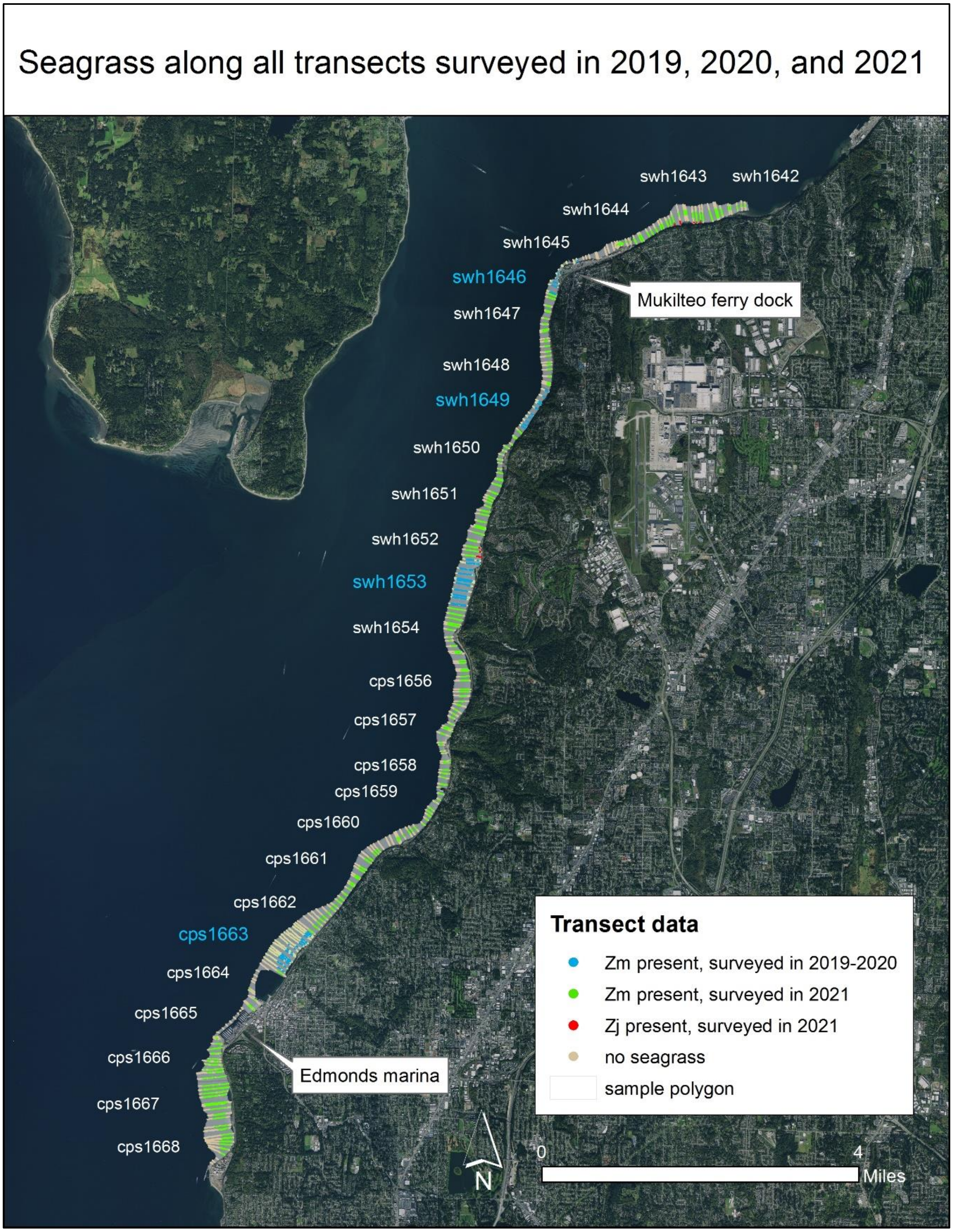

Figure 3: *Z. marina* and *Z. japonica* in the study area, visualized on underwater imagery transects that span from the low intertidal to -15 m (MLLW). Sample polygons, shown in grey, are used in combination with the transect data to estimate eelgrass area at individual sites.

Table 3: Overview of sites sampled as part of DNR 93-102927. In total we collected over 26 hours of footage at 223 transects over 22 different sites (calculated as the sum of all usable video per track, rounded to the nearest 5 second interval).

site code	date_start	date_end	transects	Footage (hh:mm:ss)
cps1656	16 Aug 2021	17 Aug 2021	10	01:27:45
cps1657	17 Aug 2021	17 Aug 2021	10	01:06:35
cps1658	17 Aug 2021	17 Aug 2021	10	00:47:40
cps1659	17 Aug 2021	17 Aug 2021	10	00:43:45
cps1660	18 Aug 2021	18 Aug 2021	10	01:11:40
cps1661	18 Aug 2021	18 Aug 2021	10	01:05:40
cps1662	18 Aug 2021	18 Aug 2021	10	01:25:05
cps1664*	2 June 2021	16 Aug 2021	11	00:57:25
cps1665*	20 Aug 2021	20 Aug 2021	10	00:18:50
cps1666	19 Aug 2021	20 Aug 2021	10	01:37:05
cps1667	19 Aug 2021	19 Aug 2021	10	02:37:45
cps1668	19 Aug 2021	19 Aug 2021	10	01:49:40
swh1642	14 Aug 2021	14 Aug 2021	10	01:26:10
swh1643	14 Aug 2021	14 Aug 2021	10	01:29:30
swh1644	14 Aug 2021	15 Aug 2021	12	01:20:45
swh1645	15 Aug 2021	15 Aug 2021	10	00:36:55
swh1647	15 Aug 2021	15 Aug 2021	10	00:51:10
swh1648	15 Aug 2021	15 Aug 2021	10	00:59:45
swh1650	15 Aug 2021	15 Aug 2021	10	00:28:30
swh1651	16 Aug 2021	16 Aug 2021	10	00:59:20
swh1652	16 Aug 2021	16 Aug 2021	10	01:31:40
swh1654	16 Aug 2021	16 Aug 2021	10	01:19:20

3.2 Seagrass

3.2.1 Seagrass species

We detected two species of seagrass in the study area: *Z. marina* (eelgrass) and the non-native *Z. japonica* (Figure 4). *Z. marina* was by far the most abundant species in the study area, and was found at all 22 sites sampled[6]. The 4 additional sites sampled in 2019 and 2020 also had eelgrass present (Figure 3). The non-native *Z. japonica* was found at 2 sites only: swh1643 and swh1652. At both locations this species was found shallower than -0.1m (MLLW), and generally higher up in the intertidal than *Z. marina*. There was little overlap between both species. Note that these data may underestimate the presence of *Z. japonica*, as it can fairly high up in the intertidal, potentially outside the reach of our survey vessel. There is also a potential for misidentification between very small *Z. marina* and *Z. japonica*, especially when the water is turbid. Nevertheless, the limited presence in our data suggests that *Z. japonica* is not very abundant in the study area.

[6] Note that there were only a few scattered eelgrass shoots present at swh1645. This site was classified as 'trace', and does have an area estimate of 0 ha.

This pattern is very similar to other sites in the Central Basin of Puget Sound. A previous study of 378 sites along the shorelines of King County and Kitsap County found that *Z. marina* was present along most of the shorelines of the Central Basin (Christiaen et al. 2021). *Z. japonica* was also commonly found, but was mostly absent along the northern part of King County (adjacent to the study area for the current project).

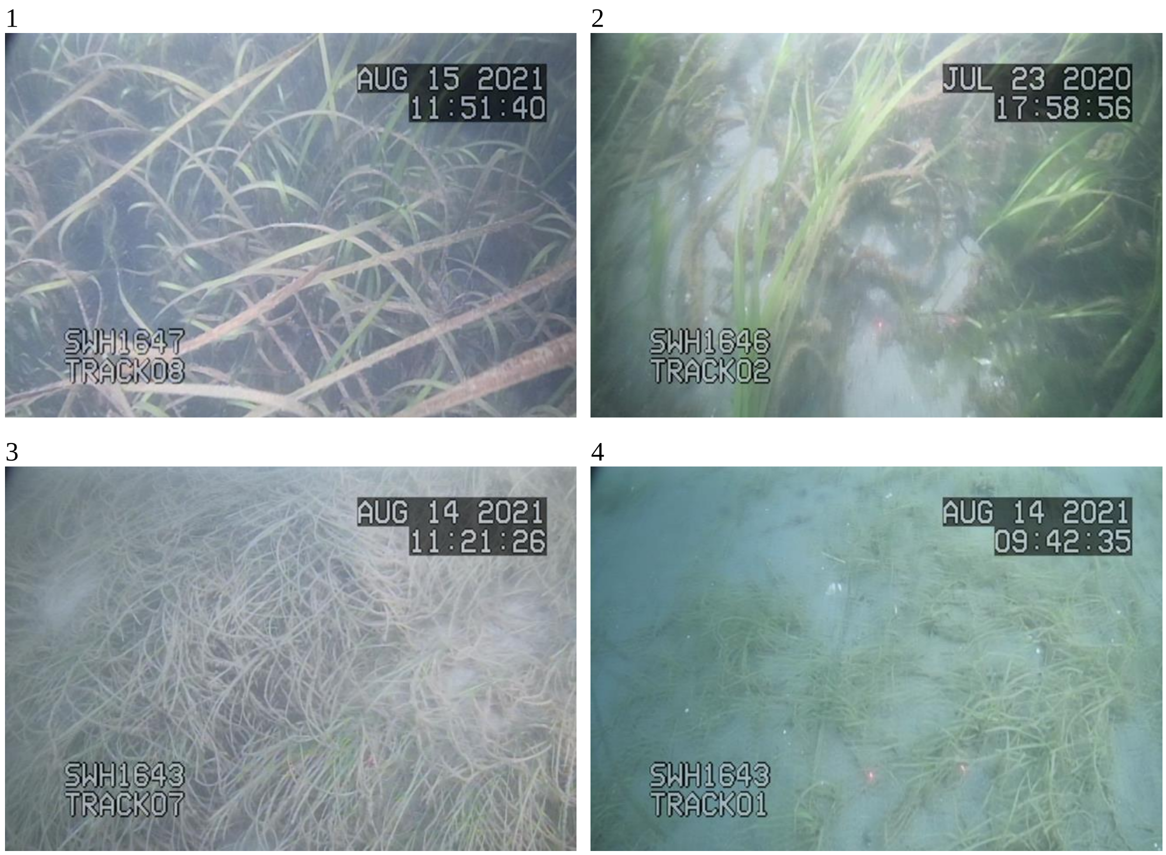

Figure 4: Screen captures of towed underwater footage at swh1647, swh1646, and swh1643. Photos 1 and 2 show *Z. marina*, and photos 3 & 4 are *Z. japonica*. The laser dots in images 2 and 4 are 10 cm apart. These images illustrate the size difference of two different seagrass species.

3.2.2 Eelgrass area

There was a total of 198.3 +/- 3.7 ha of eelgrass at the 26 sites along the shoreline of Snohomish County between Edmonds and Everett. This corresponds to half of the area covered by eelgrass near the Snohomish Delta (386 +/- 42 ha), 31% of all eelgrass along the shorelines of King County (680+/- 9 ha), and less than 1% of all eelgrass in greater Puget Sound (22,102 +/- 1,074 ha, based on a 3-year rolling average from 2018 to 2020).

Figure 5 and Table 4 show the size of eelgrass beds at individual sites. The largest eelgrass beds were found at cps1667 and swh1653 (24.11 +/- 1.04 ha and 17.47 +/- 1.57 ha respectively). This was expected, as these are the two sites with the most available substrate between +1 and -15m (MLLW). The smallest eelgrass beds were located at cps1665 and swh1645 (0.76 +/- 0.49 ha, and trace respectively)[7]. Both sites are heavily impacted by human development. Cps1665 is the location of the Edmonds Marina, which takes up most of the shallow subtidal. Swh1645 was the location of an old US Air Force fueling station that included a 1,360 foot fueling pier on 3900 creosote-treated timber pilings. This site has been rehabilitated and is now the location of the new Mukilteo ferry terminal.

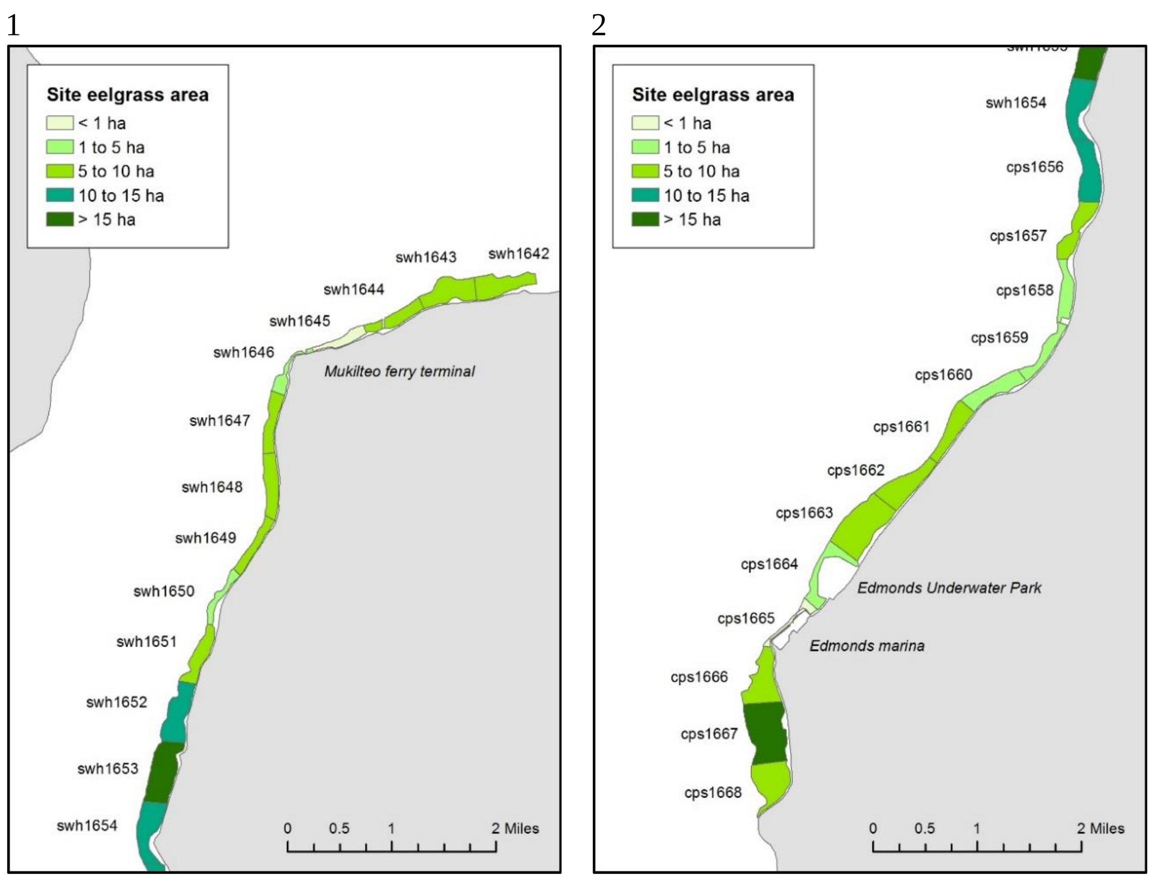

Figure 5: Map of eelgrass polygons, colored by eelgrass area estimates (in ha).

[7] Our estimates of eelgrass area at cps1664 are an underestimate, since we could not survey the area covered by the Edmonds Underwater Park.

Table 4: Eelgrass area (veg) and corresponding standard error (se), as well as the characteristics of the 'site sample' (number of transects n, sample selection, and sample repeat).

site code	year	sample selection	n	fraction	sample poly (ha)	veg (ha)	veg se (ha)
cps1656	2021	STR	10	0.5348	19.98	10.68	0.52
cps1657	2021	STR	10	0.3841	17.09	6.56	0.43
cps1658	2021	STR	10	0.4064	11.75	4.78	0.75
cps1659	2021	STR	10	0.3856	10.73	4.14	0.51
cps1660	2021	STR	10	0.2809	11.41	3.2	0.74
cps1661	2021	STR	10	0.6217	13.79	8.57	0.15
cps1662	2021	STR	10	0.5227	14.36	7.51	0.31
cps1663	2020	STR	14	0.288	21.68	6.24	0.69
cps1664	2021	STR	11	0.0743	14.48	1.08	0.63
cps1665	2021	STR	10	0.1598	4.73	0.76	0.49
cps1666	2021	STR	10	0.3029	27.29	8.27	1.04
cps1667	2021	STR	10	0.5397	44.68	24.11	1.04
cps1668	2021	STR	10	0.5552	16.81	9.33	0.54
swh1642	2021	STR	10	0.6138	15.74	9.66	0.92
swh1643	2021	STR	10	0.5481	18.22	9.99	1.3
swh1644	2021	STR	10	0.5271	12.81	6.75	1.11
swh1645	2021	STR	10	trace			
swh1646	2020	STR	11	0.5088	6.72	3.42	0.65
swh1647	2021	STR	10	0.622	11.71	7.28	0.67
swh1648	2021	STR	10	0.4469	11.47	5.12	0.59
swh1649	2019	STR	10	0.8182	7.53	6.16	0.23
swh1650	2021	STR	10	0.4081	6.63	2.71	0.54
swh1651	2021	STR	10	0.623	15.25	9.5	0.32
swh1652	2021	STR	10	0.5693	23.07	13.14	0.43
swh1653	2020	STR	11	0.5493	31.81	17.47	1.57
swh1654	2021	STR	10	0.544	21.76	11.84	0.68

3.2.3 Eelgrass depth distribution

Table 5 and Figure 6 show the depth distribution of eelgrass at individual sites based on our observations. Eelgrass was found between 0.8 and -15 m (MLLW) but the majority of observations occurred between 0 and -5m. The deepest observations were at cps1664 and cps1666, where some scattered shoots were found to depths down to -15m. However, the deep edge of the eelgrass bed at these locations (calculated as the 2.5th percentile of all depth observations at the site) did not extend deeper than -5.1 and -8.4m) respectively.

The median depth of eelgrass at individual sites ranged from -0.6 to -2.9m. The shallowest observations were found at cps1666 (0.8m) and swh1653 (0.7m). 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 swh1646 (2.8m) and largest at cps1666 (8.6m). At most sites the depth range was between 3 and 5m (Table 5).

Figure 7 shows the depth distribution and the cumulative depth distribution of eelgrass for the 26 sites in the study area. We classified eelgrass as either intertidal or subtidal based on a boundary at -1 m (MLLW), which is a biologically relevant estimate of extreme low tide depth in the Puget Sound region (Hannam et al. 2015). When comparing to this boundary, approximately 66% of all eelgrass in the study area grew in the subtidal, while 34% grew in the intertidal. This is similar to eelgrass along the shoreline of King County, and for greater Puget Sound as a whole (where 64% of all eelgrass is subtidal and 62% of all eelgrass is subtidal respectively). Overall, 95% of all eelgrass was found between -4.9 and -0.1m (MLLW). Approximately half of all eelgrass grew shallower than -1.4m (MLLW), and less than 1% of all eelgrass was found deeper than -5.3m (MLLW).

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. Data is from the most recent year a site was sampled (either 2019, 2020, or 2021).

site code	maxd	q025	q10	q25	q50	q75	q90	q975	mind	range	n
cps1656	-5.3	-4.4	-3.7	-2.6	-1.4	-0.7	-0.4	-0.3	-0.1	4.1	1844
cps1657	-5.5	-5.0	-4.4	-3.6	-2.5	-1.5	-0.9	-0.6	0.2	4.4	1165
cps1658	-5.2	-4.7	-3.6	-2.4	-1.5	-0.8	-0.5	-0.3	0.1	4.4	797
cps1659	-5.6	-4.7	-3.6	-2.7	-1.8	-1.2	-0.9	-0.6	-0.1	4.1	715
cps1660	-5.0	-4.6	-4.1	-3.5	-2.7	-1.9	-1.4	-1.1	-0.5	3.5	615
cps1661	-5.9	-5.1	-4.5	-3.6	-2.3	-1.3	-0.9	-0.7	-0.2	4.4	1574
cps1662	-5.7	-4.6	-4.0	-3.4	-2.3	-1.4	-0.9	-0.7	-0.4	3.9	1334
cps1664	-14.5	-5.1	-4.1	-3.2	-2.2	-1.6	-1.2	-0.1	-0.1	4.9	187
cps1665	-5.2	-4.7	-3.7	-2.9	-2.0	-1.3	-0.3	-0.1	-0.1	4.6	135
cps1666	-15.0	-8.4	-2.7	-1.4	-1.2	-0.7	-0.3	0.2	0.8	8.6	1529
cps1667	-6.1	-5.1	-3.9	-2.0	-1.3	-0.9	-0.7	-0.5	0.2	4.6	4267
cps1668	-6.7	-4.9	-3.7	-3.0	-2.1	-1.4	-1.0	-0.6	-0.3	4.3	1717
swh1642	-3.9	-3.3	-2.5	-1.5	-0.7	-0.4	-0.2	0.0	0.2	3.2	1865
swh1643	-4.3	-3.4	-2.8	-1.9	-1.0	-0.5	-0.3	-0.1	0.0	3.3	1932
swh1644	-4.6	-3.4	-2.6	-1.8	-1.1	-0.6	-0.2	0.0	0.1	3.4	1623
swh1645					-1.5					-	1
swh1647	-4.8	-3.9	-3.1	-2.0	-1.7	-1.4	-1.2	-1.0	-0.5	2.9	1417
swh1648	-4.6	-4.0	-3.4	-2.7	-1.9	-1.4	-1.1	-0.9	-0.6	3.1	849
swh1650	-4.6	-3.6	-2.5	-1.7	-0.9	-0.3	0.1	0.4	0.5	3.9	522
swh1651	-6.3	-3.7	-2.8	-1.7	-0.7	-0.4	-0.1	0.1	0.3	3.8	1767
swh1652	-4.9	-4.0	-3.1	-1.9	-0.9	-0.5	-0.3	0.0	0.4	4.0	2387
swh1654	-6.0	-4.0	-2.9	-1.8	-1.2	-0.7	-0.5	-0.1	0.1	3.9	1950
cps1663	-6.2	-5.7	-5.3	-4.8	-2.9	-1.7	-1.0	-0.5	-0.3	5.3	1311
swh1646	-4.3	-3.3	-2.1	-1.7	-1.5	-1.2	-0.8	-0.5	-0.3	2.8	788
swh1649	-4.6	-3.7	-2.8	-1.7	-0.7	-0.2	0.1	0.3	0.5	3.9	1222
swh1653	-5.9	-4.7	-3.1	-1.4	-0.6	-0.4	-0.2	-0.1	0.7	4.6	2928

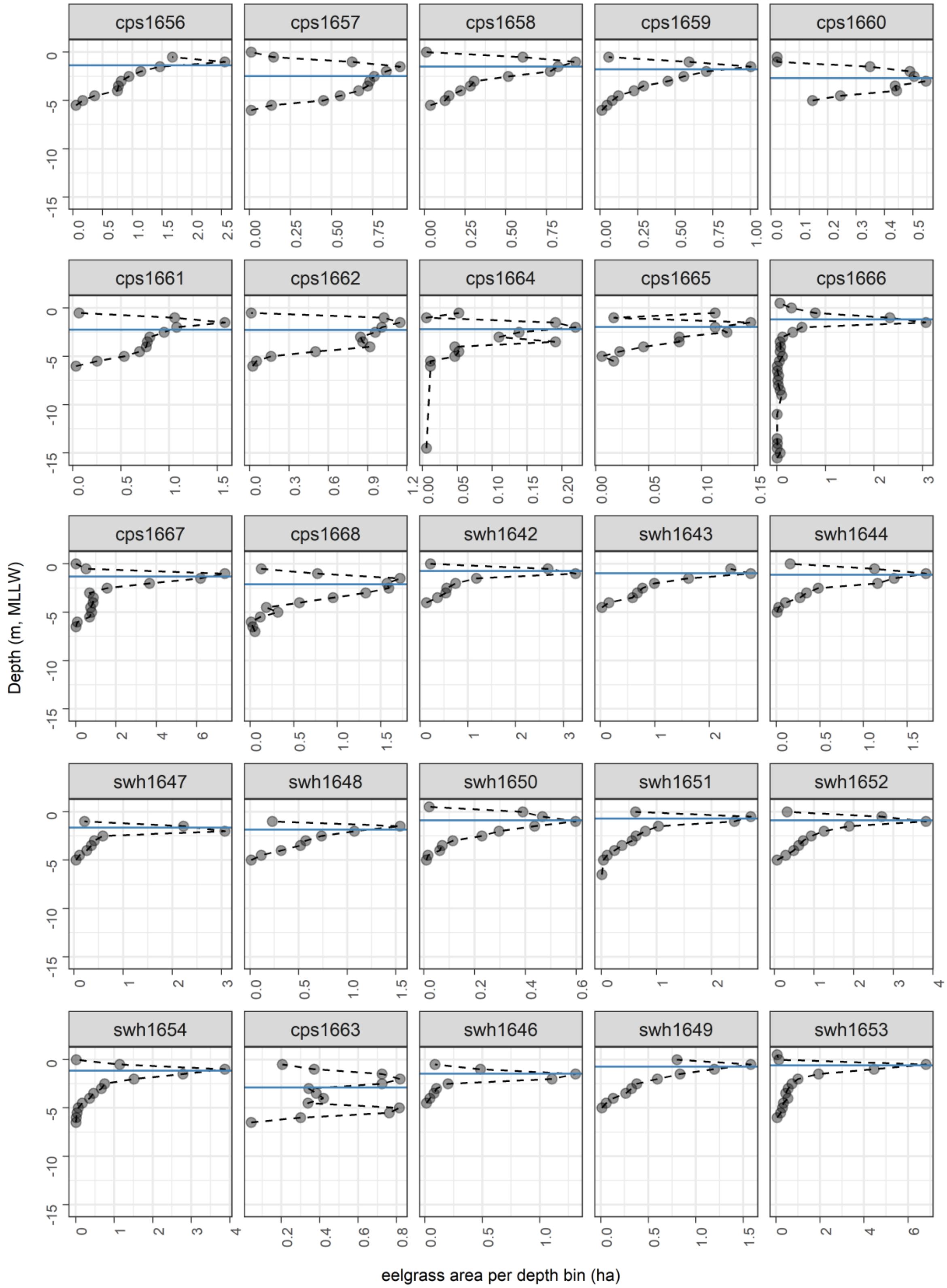

Figure 6: Eelgrass depth distributions at individual sites (as area in ha per 0.5m depth bins). Plots are based on data from the most recent year a site was sampled (either 2019, 2020, or 2021). Swh1645 is not included as this site only has trace eelgrass present. Blue lines indicate the median depth of eelgrass per site.

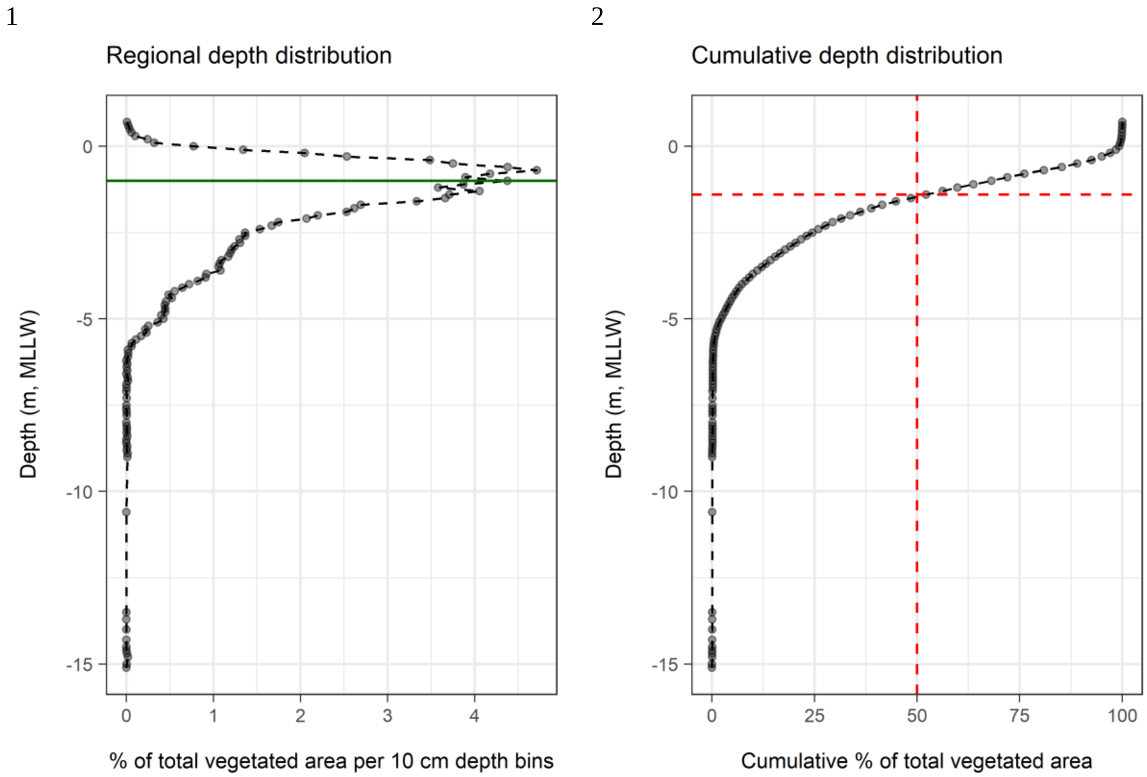

Figure 7: (1) Regional depth distribution and (2) cumulative depth distribution for all 26 sites in the study area calculated as % of total eelgrass area per 10 cm depth bins. The green line on the left plot indicates the boundary between intertidal and subtidal habitat (Hannam et al. 2015). The dashed red lines on the right side plot show the mean eelgrass depth in the region.

3.2.4 Trends in eelgrass area

Nine out of the 26 sites in the study area were previously sampled by DNR. At 8 of these sites, we were able to assess change in eelgrass area over time (Figure 8). At one location (swh1645) eelgrass has always been classified as 'trace'. These assessments were based on two methods:

- linear regressions of site eelgrass area estimates over time (which includes all samples taken at a site);
- pairwise comparisons of sets transects that have been resampled over time (indicated in black on Figure 8)

At only one of the sites sampled, eelgrass area increased over time: at swh1649 a pairwise test indicated that eelgrass significantly increased between 2016 and 2019 (p = 0.002). The linear regression indicates that eelgrass area increased on average by 0.07 ha/year between 2005 and 2019 (adj.r.squared = 0.835, p = 0.001). This increase is very small. At the 7 remaining sites there was no consistent trend over time. There was some variability, which may be due to either sampling artefacts or short-term change in eelgrass beds at these locations.

Note that there is an apparent increase in eelgrass area at swh1653 on Figure 8. However, the linear regression did not show a significant increase over time, and visual assessment of the transect data suggests that lower values in 2012 and 2013 may be due to the high patchiness of the eelgrass bed at this location

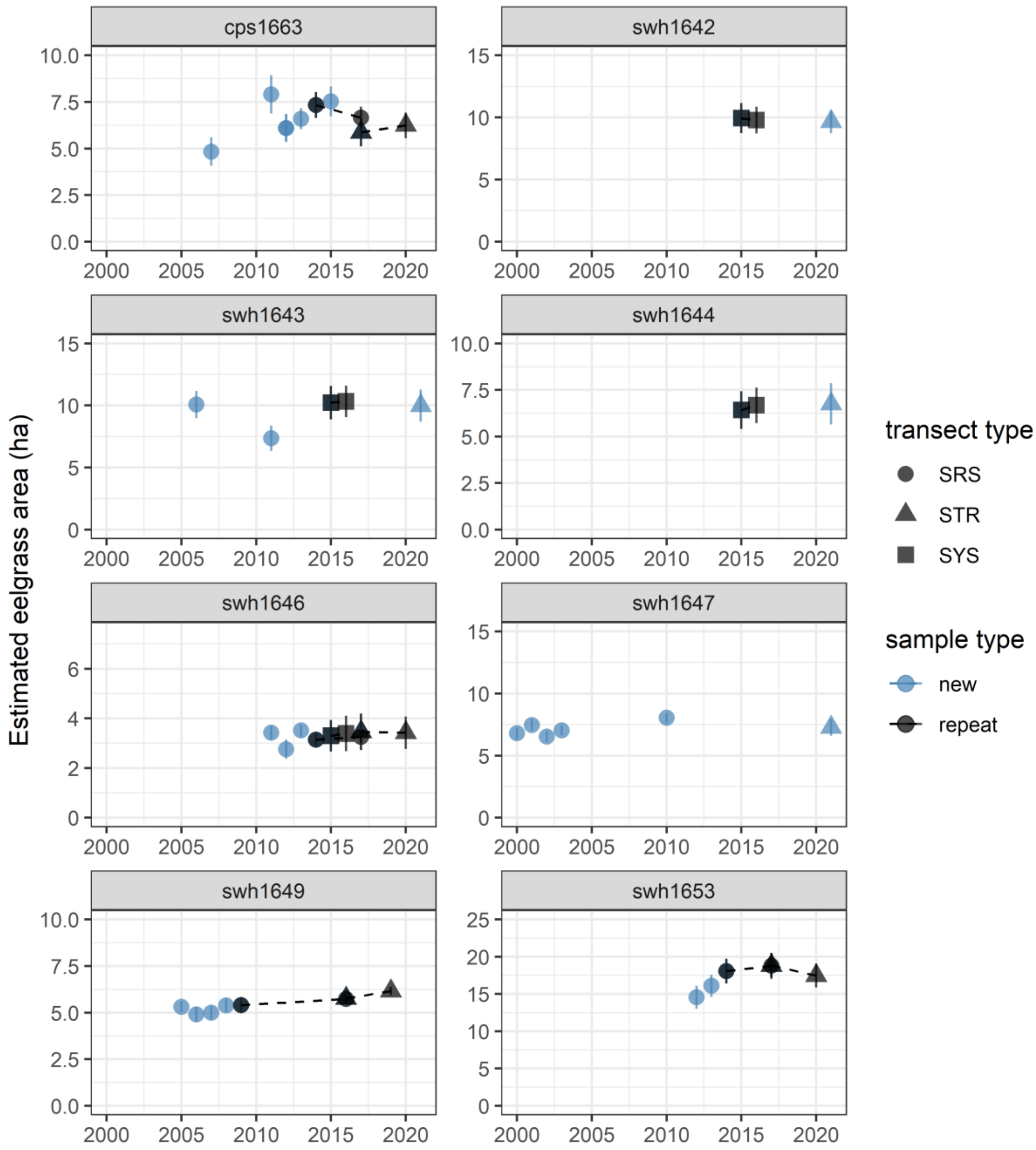

Figure 8: Trends in eelgrass area at 8 sites that were previously sampled by DNR. Blue color indicates that transects were a new draw random sample, while black indicates samples where transects were repeats. The shape of individual symbols indicates the transect type (simple random sample, stratified random sample, or systematic).

3.3 Other marine vegetation types

We estimated a cover class for several broad vegetation types (all vegetation, all kelp, prostrate kelp, stipitate kelp, floating kelp, *Sargassum*, other red-brown algae, green algae, seagrass) at one frame every 5 seconds using modified Braun-Blanquet vegetation cover categories, for each transect sampled as part of IAA 93-102327. At the time of writing this report, we have not yet reviewed the footage collected in 2019 and 2020 at swh1646, swh1649, swh1653, cps1663. These sites will be analyzed for other marine vegetation types in 2022.

We documented the presence of prostrate kelp, seagrass, green algae, other red/brown algae, and *Sargassum* in the study area (Figure 9). Stipitate kelp and floating kelp were not present in our footage, partly because we actively avoided sampling in floating kelp beds to avoid damaging to this sensitive habitat.

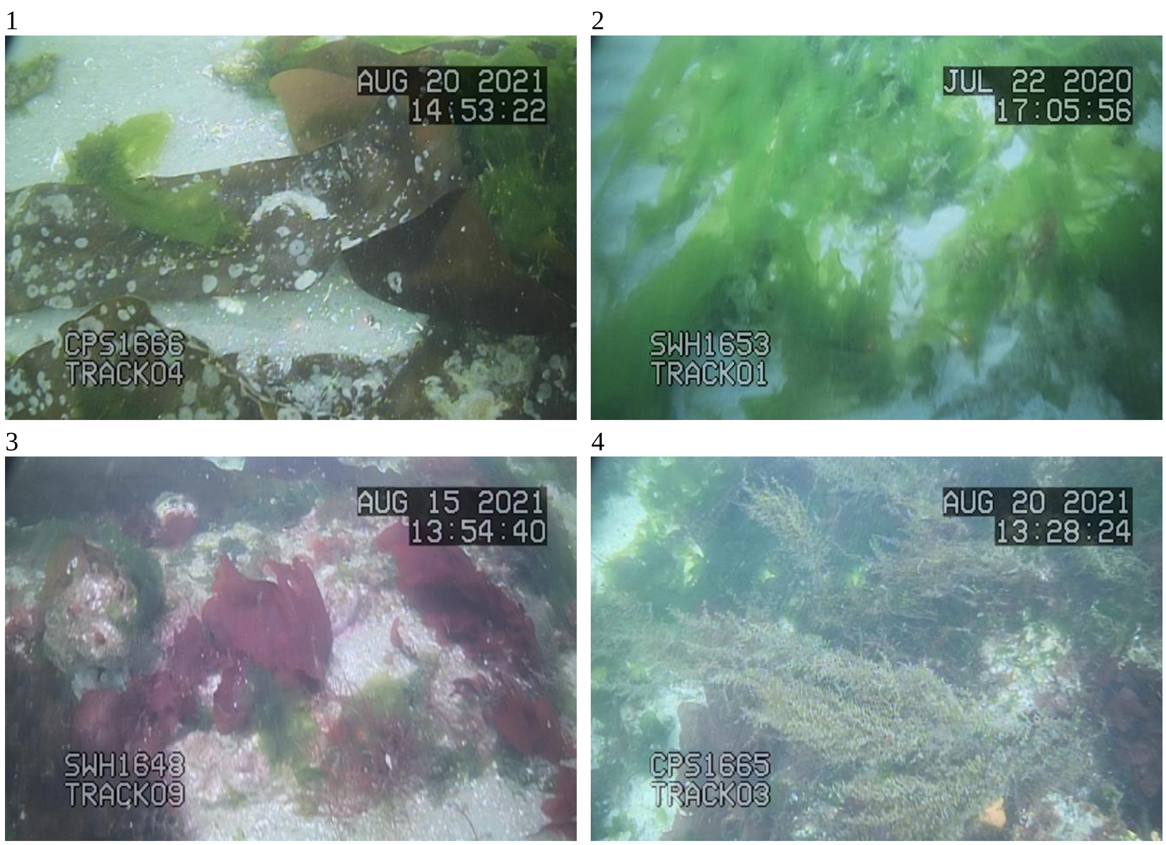

Figure 9: different groups of macroalgae in the study area: understory kelp (1), green algae (2), other red/brown algae (3), and Sargassum (4).

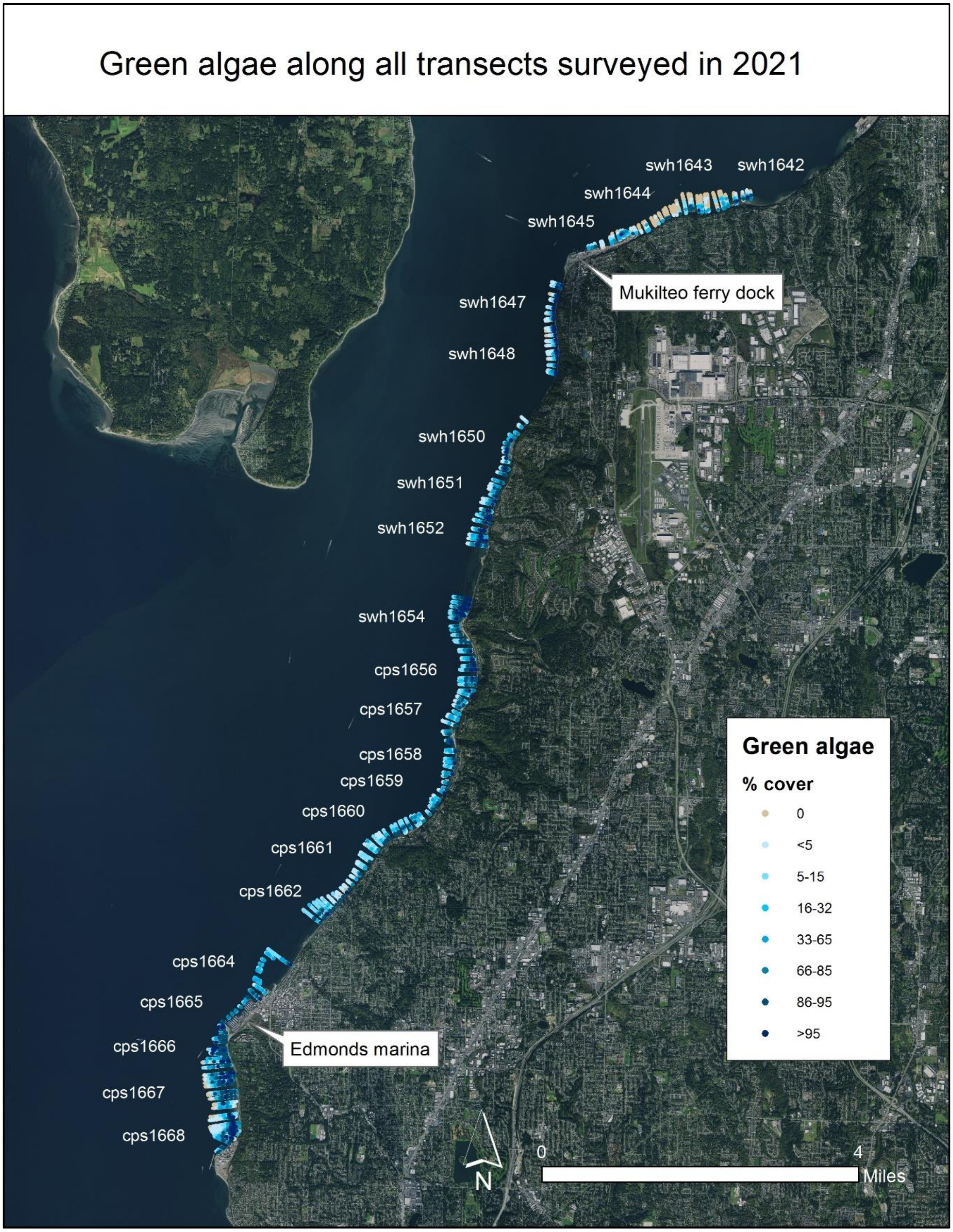

Figure 10: % green algae cover at one frame every five seconds along all transects surveyed in 2021

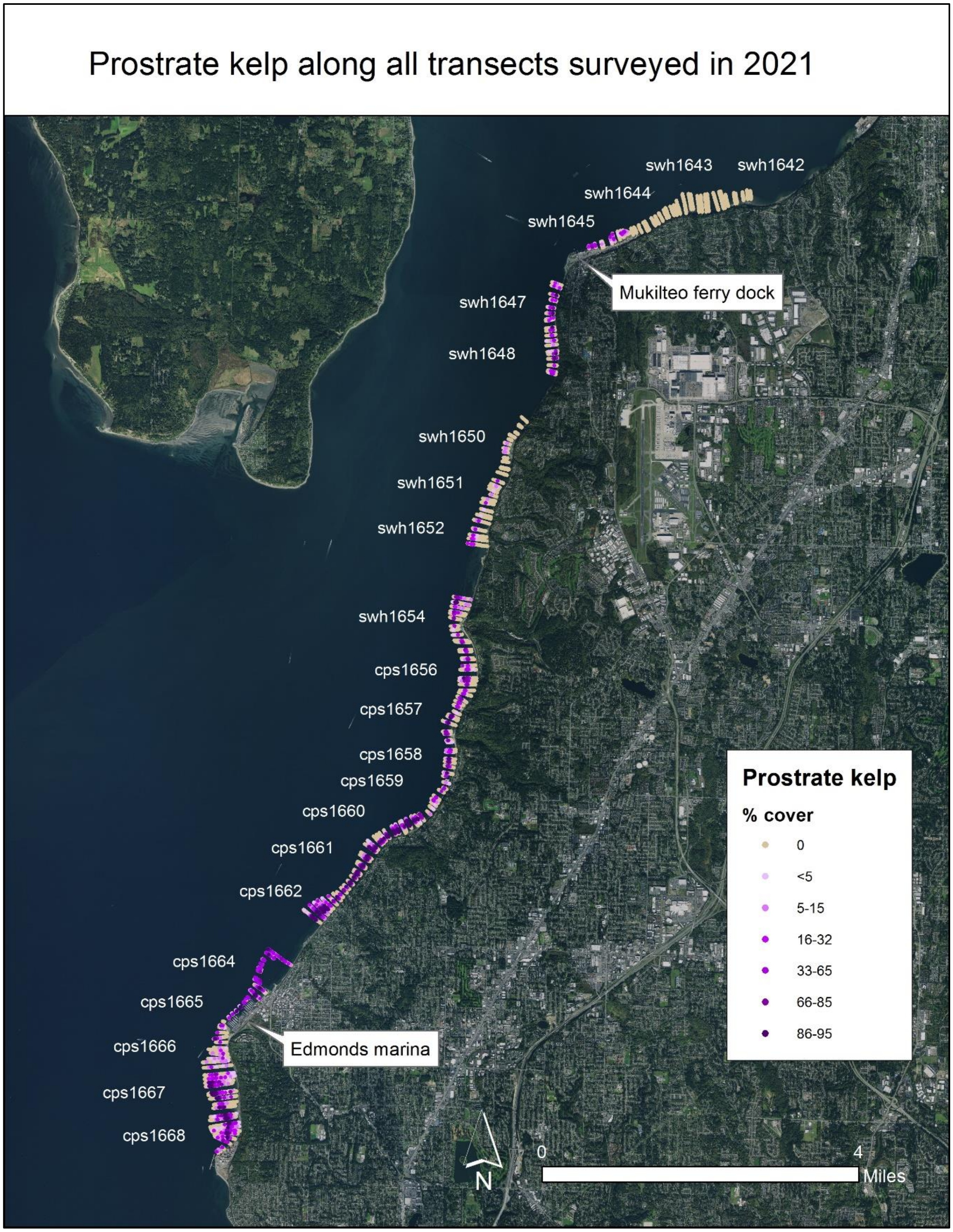

Figure 11: % prostrate kelp cover at one frame every five seconds along all transects surveyed in 2021

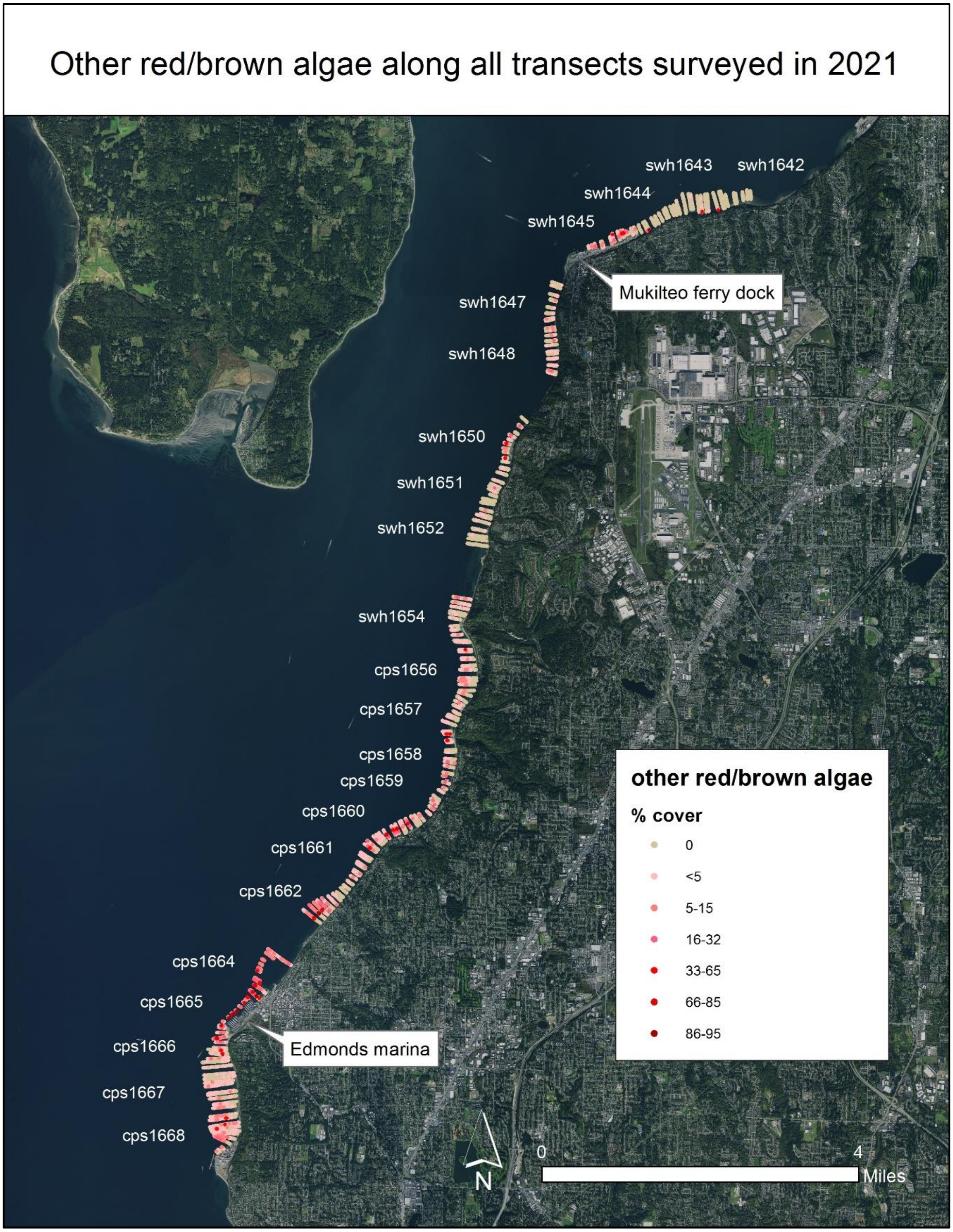

Figure 12: % other red/brown algae cover at one frame every five seconds along all transects surveyed in 2021

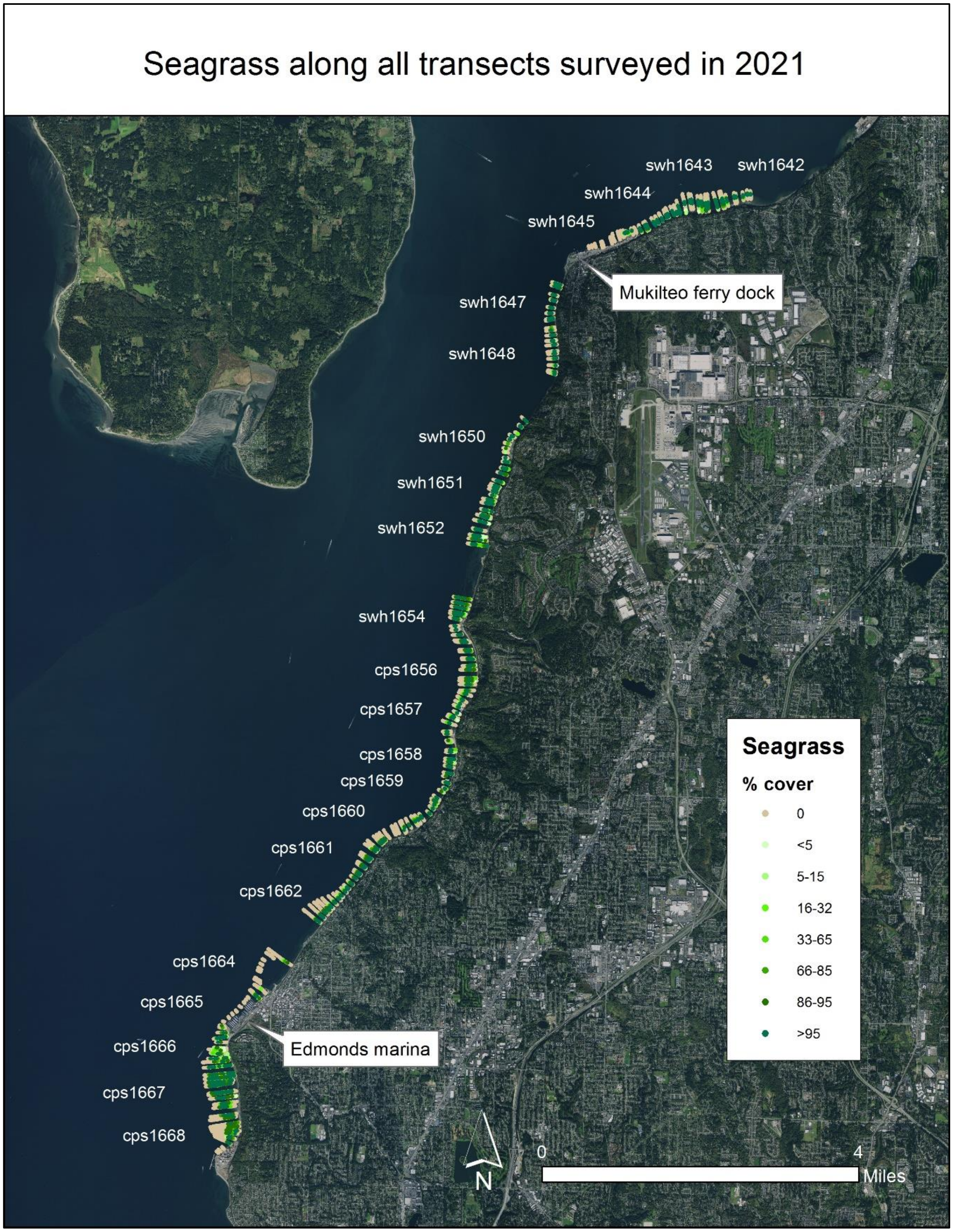

Figure 13: % seagrass cover at one frame every five seconds along all transects surveyed in 2021.

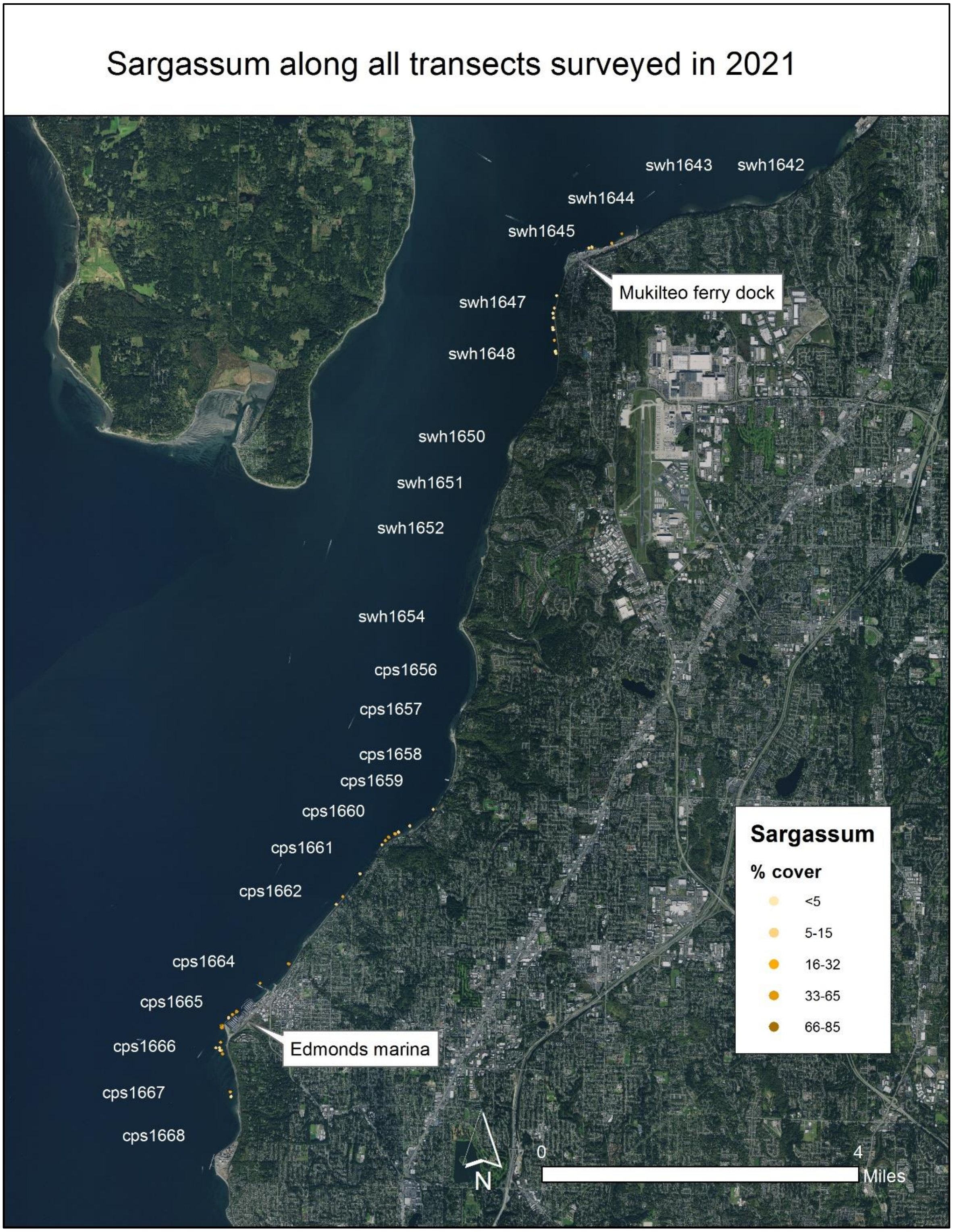

Figure 14: % sargassum cover at one frame every five seconds along all transects surveyed in 2021.

Seagrass, understory kelp and green algae were common in the study area (Figure 10, Figure 11, and Figure 13). Seagrass and green algae were found at all 22 sites sampled, and understory kelp was present at all sites except swh1642 and swh1643. Other red/brown algae were also commonly found, but mostly present in the lower cover classes (Figure 12). We found several locations where the non-native algae *Sargassum muticum* was present, but this species tended to be rare (Figure 14). Figure 15 shows the total vegetated area per vegetation type and cover class. These estimates were calculated from one frame at every 5 seconds and are considered less precise than the eelgrass area estimates in section 3.2.2. 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.

According to this lower resolution estimate, there was a total of 164.7 ha of seagrass[8], 279.3 ha of green algae, 85.6 ha of prostrate kelp, 104.2 ha of other red/brown algae, and 2.7 ha of *Sargassum* present in the study area (Table 6, Appendix 1). More than 57 % of all seagrass was classified as high cover (> 85 % cover). Green algae and other red/brown algae showed an opposite pattern: approximately 59 % of green algae and 94% of other red/brown algae type were classified as low cover (< 15 % cover). Understory kelp was more or less evenly distributed over the different cover classes.

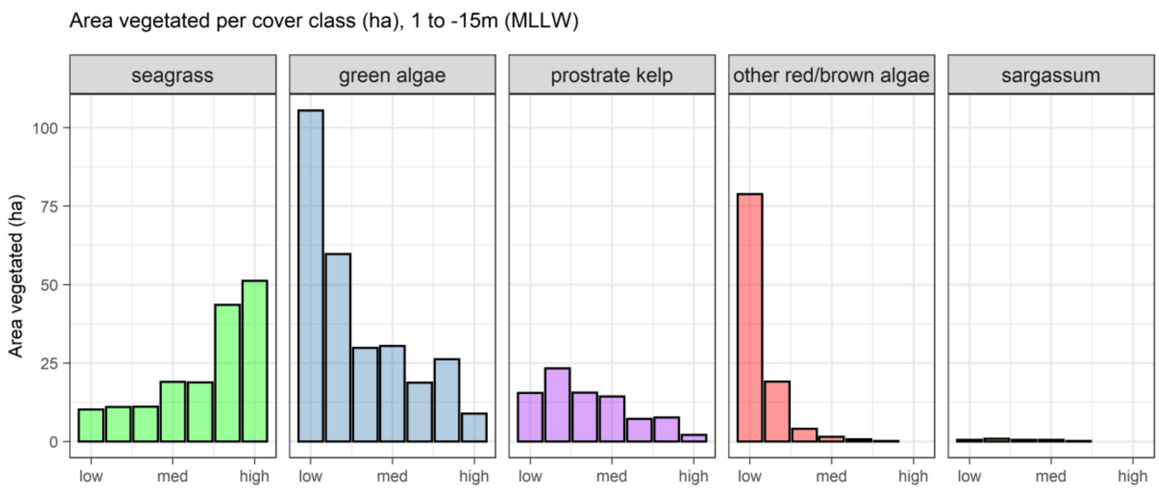

Figure 15: Vegetated area per vegetation type and cover class at 22 sites sampled for DNR 93-102327

Figure 16 shows the depth distribution for each vegetation type in the study area, calculated as the vegetated area (ha) per one 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, *Sargassum* and green algae were most abundant at relatively shallow depths (median depth of -1.4, -1.1, and -1.7m respectively). Understory kelp was usually found a

[8] Note that this estimate is for 22 sites, while the estimate in section 3.2.2 includes 4 additional sites sampled in 2019 and 2020.

little deeper (median depth of -3.6m), and other red-brown algae were common through the entire depth range (with a median depth of 6.8m). These general patterns in depth distribution are often visible at the level of individual sites. At several sites there is a clear spatial pattern in the different marine vegetation types, which may be due to the bathymetry, differences in substrate, or competitive interactions between the different vegetation types (Figure 17).

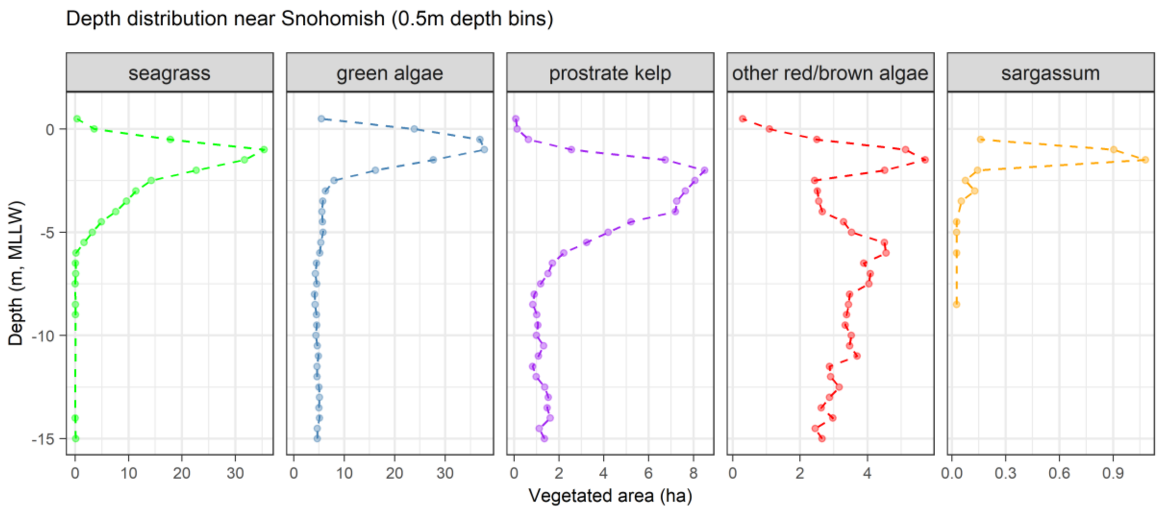

Figure 16: Depth distribution of seagrass, green algae, prostrate kelp and other red/brown algae, calculated as the vegetated area (ha) per 1 m depth bins in the study area.

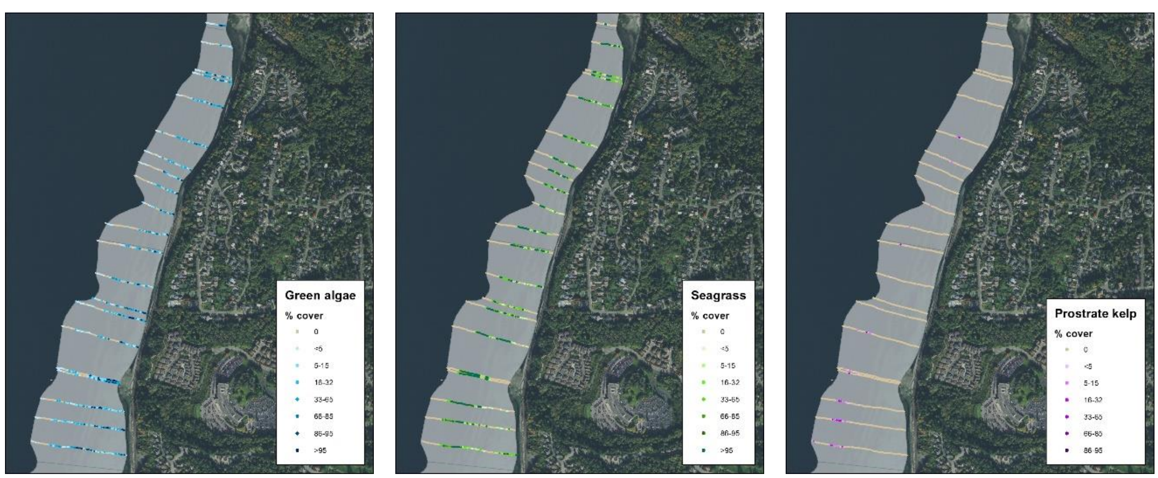

Figure 17: Different marine vegetation types as swh1651 and swh1652. There is a clear spatial pattern in where the different vegetation types are found. Green algae were most abundant in the shallow, seagrass is most abundant below the green algae band, and understory kelp is found below the deep edge of the seagrass bed at these locations.

3.4 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 18), 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*), sun stars (*Solaster stimpsoni* and *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). Taxonomic categories were chosen to capture the greatest degree of taxonomic detail that is regularly distinguishable on towed underwater imagery. 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.

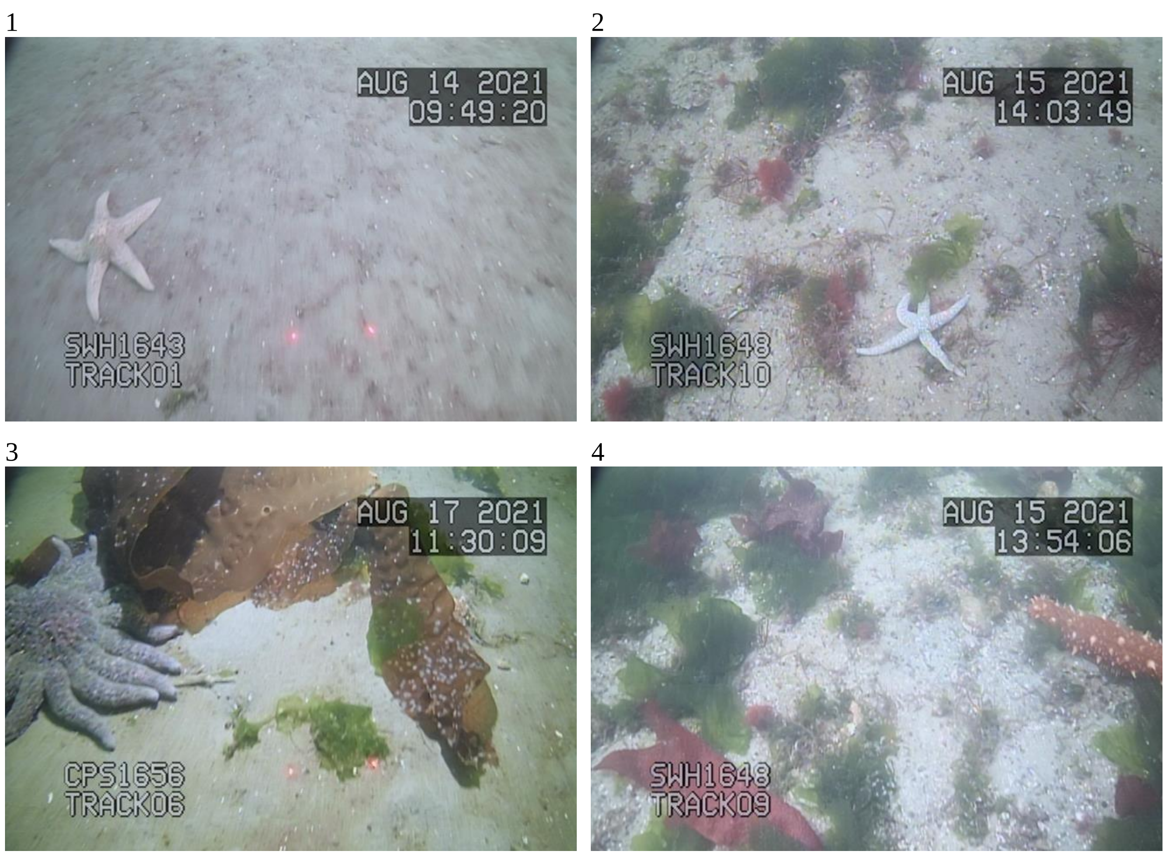

Figure 18: Examples of different invertebrates in our underwater footage. 1. giant pink star (*Pisaster brevispinus*), 2. mottled star (*Evasterias troschelii*), 3. Sunflower star (*Pycnopodia helianthoides*), 4. Sea cucumber (*Parastichopus sp.*)

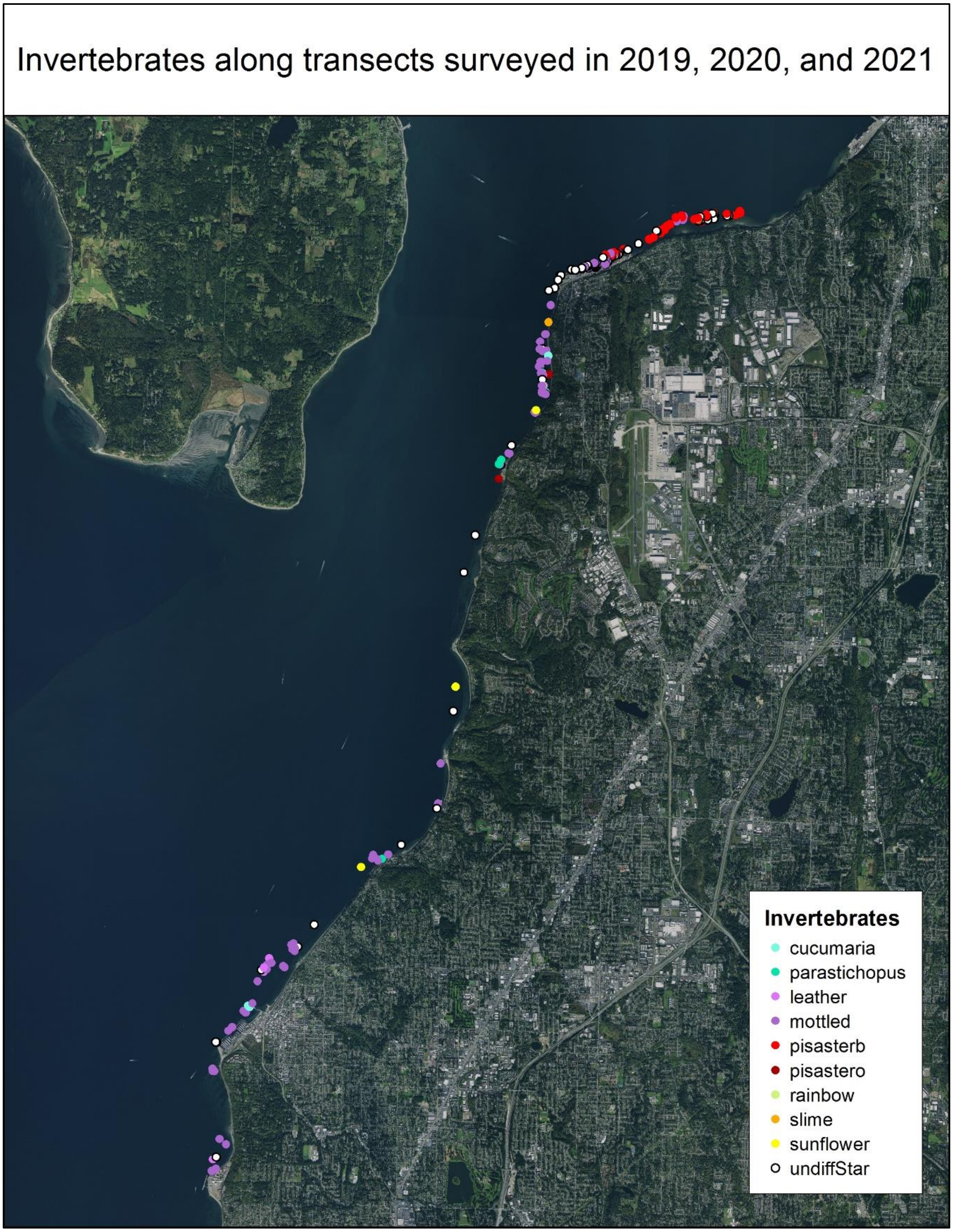

Figure 19: Occurrence of different species/groups of echinoderms along the shoreline of Snohomish County between Edmonds and Everett.

We counted a total of 395 individuals, spread over 10 classes of invertebrates in the footage: undifferentiated stars, sunflower stars, slime stars, rainbow stars, giant pink stars, ochre stars, mottled sea stars, leather stars, and the two types of sea cucumbers (Figure 19 and Figure 20). The most abundant categories were mottled seastars (n = 154), undifferentiated stars (n = 125), giant pink stars (n = 53), sea cucumbers (n = 39), and ochre stars (n = 13). Leather stars, rainbow stars, slime stars and sunflower stars were rare (n <5 for each species).

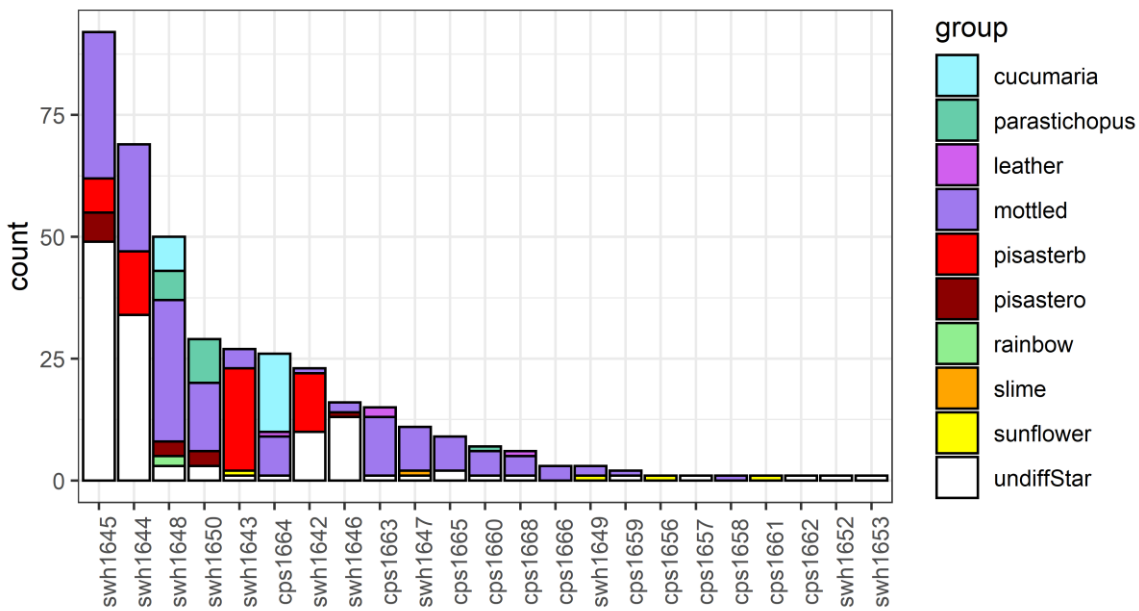

Figure 20: relative abundance of common, easily distinguished echinoderms in the intertidal and shallow subtidal shorelines of Snohomish County (between Edmonds and Everett).

The sites with the highest counts of invertebrates were swh1645 (n = 92), swh1644 (n = 69), and swh1648 (n = 50). These sites are all located in the northern part of the study area. Note that swh1645, the site with the highest relative abundance of invertebrates, was the former site of a 1360ft long fueling pier.

There appears to be a spatial pattern in where species occur. While mottled stars were found throughout the study area, giant pink stars were mostly found in the northern part of the study area. This is also where we found the highest number of undifferentiated stars.

There was no clear pattern in depth distribution. Invertebrates occurred throughout the entire depth range that was sampled at these sites. Mottled stars and undifferentiated stars were slightly more abundant between 0 and -5m (MLLW), while giant pink stars were mostly found between -5 and -15m (Figure 21).

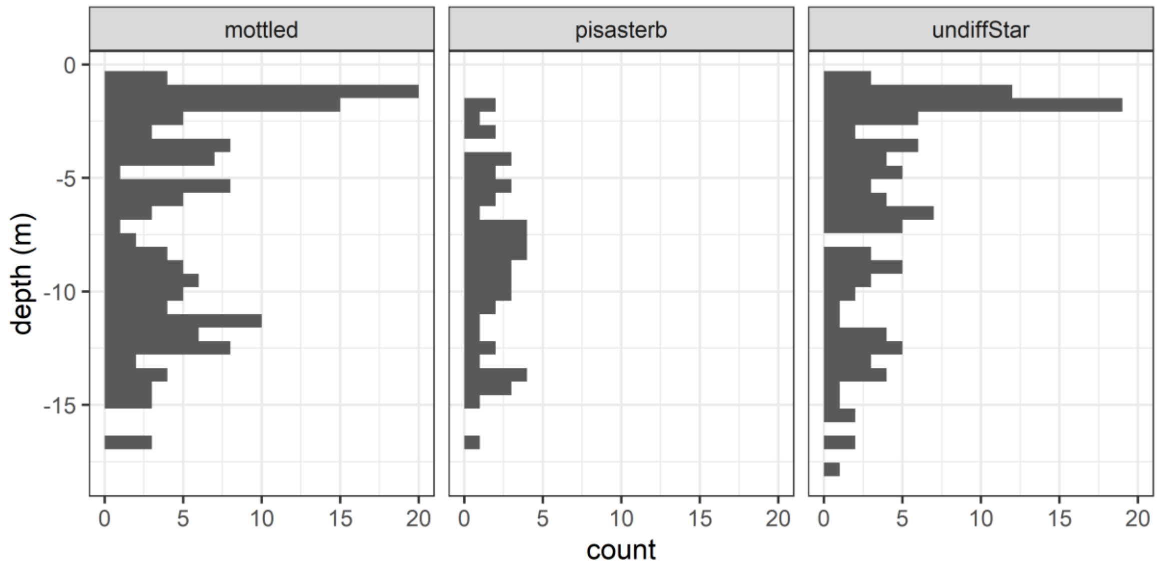

Figure 21: depth distribution of the 3 most abundant groups of invertebrates in the intertidal and shallow subtidal shorelines of Snohomish County (between Edmonds and Everett).

4 Discussion

4.1 Eelgrass, kelp, and other macroalgae

We classified towed underwater video footage for several broad vegetation types (all vegetation, all kelp, prostrate kelp, stipitate kelp, floating kelp, *Sargassum*, other red-brown algae, green algae, eelgrass) at 22 sites along the shoreline of Snohomish County between Edmonds and Everett. There was a contiguous band of vegetation along most of the shoreline in the study area, which consisted of a mix of different vegetation types, with different depth and % cover. Marine vegetation was predominantly eelgrass, green algae and understory kelp, with a substantial amount of low % cover red-brown algae. *Sargassum* was present at some locations, but stipitate kelp and floating kelp were not detected in the towed underwater video footage. Note that floating kelp is present at sites cps1663 and cps1664, and is surveyed by Snohomish County MRC[9]. At 16 sites, eelgrass was the predominant vegetation type[10], 5 sites were mostly covered by green algae, and at one site understory kelp was most abundant.

Eelgrass and understory kelp beds support a rich community of invertebrates, and provide valuable habitat for juveniles of several commercially important or forage fish species (Johnson et al. 2003, Rubin et al. 2018, Shaffer et al. 2020). This is in part due to their high structural complexity, which offers refuge from predators as well as an abundance of prey (Semmens et al. 2008). Both eelgrass and understory kelp are important habitat for juvenile chinook and chum, who make extensive use of nearshore and estuarine environments during their early marine rearing phase (Duffy et al. 2005). Kelp beds are also important nursery habitat for juvenile rockfish species (Matthews 1990, Hayden-Spear 2006), while eelgrass beds provide spawning substrate to Pacific Herring.

There was 198.3 +/- 3.7 ha of eelgrass at the 26[11] sites along the shoreline of Snohomish County between Edmonds and Everett. This corresponds to half of the area covered by eelgrass near the Snohomish Delta (386 +/- 42 ha), 31% of all eelgrass along the shorelines of King County (680+/- 9 ha), and less than 1% of all eelgrass in greater Puget Sound (22,102 +/- 1,074 ha, based on a 3-year rolling average from 2018 to 2020). Approximately 34% of the area between the mean high water line and -6.1m (MLLW) was covered by eelgrass.

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[9] Cps1663 was sampled in 2020. The footage from this site was not classified for macroalgae. The bull kelp bed at cps1664 falls within the boundaries of the Edmonds Underwater Park.

[10] calculated as the vegetation type with the largest area in the high cover classes (>66% cover)

[11] 22 sites sampled for IAA 93-102327 and 4 additional sites previously sampled in 2019 and 2020 by DNR

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 the study area sequester approximately 49 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 14200 metric tons of organic carbon in the upper 1m of the sediment[12]. Note that the carbon sequestration rates are only a fraction of the amount of carbon produced by eelgrass beds. For example, Thom (1990) estimated the annual aboveground net primary production of eelgrass beds in Padilla Bay as approximately 351 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 size of eelgrass beds at individual sites ranged from trace to 24.1 ha, with a median size of approximately 7 ha per 1000 m section of shoreline. These beds are relatively small as compared to the large expanses of eelgrass at the mouth of the Snohomish River delta (Christiaen et al. 2020b). Smaller seagrass beds provide a relatively large amount of edge habitat. These boundary zones between structurally complex vegetation and more open areas are an important microhabitat for a wide variety of organisms. Edges tend to have higher densities of bivalves, crustaceans or fish species due to elevated settlement (Carol et al. 2012) or growth rates (Bologna and Heck, 2002), but are also areas of intense predation and lower survivorship (Gorman et al. 2009, Smith et al. 2011, Mahony et al. 2018). Smaller seagrass beds may be more variable than large contiguous seagrass beds, as they are more vulnerable to disturbance from hydrodynamic forces (Koch 2001; Greve and Krause-Jensen 2005). Seagrass survival and growth rate is also related to the patchiness of the bed. Larger seagrass patches tend have lower mortality and higher growth rates due to mutual physical protection and physiological interactions among the shoots (Olesen and Sand Jensen 1994, Vidondo et al. 1997). Despite the potential for higher variability at small sites, we did not detect any significant trends in eelgrass area in 7 of the 8 sites that were assessed for change over time. Only one site (swh1649) showed a small but consistent increase in eelgrass area over time.

Understory kelp was less abundant (85.6 ha of prostrate kelp at the 22 sites sampled in 2021), but occupied a wider depth band than eelgrass (median depth of -3.8m as compared to -1.4m for eelgrass). The area covered understory kelp at individual sites generally declined towards the northern end of the study area, with understory kelp completely absent at swh1642 and swh1643. This may be due to differences in the availability of suitable substrate, or due to differences in water column characteristics between the Saratoga-Whidbey Basin and the Central Basin of Puget Sound. Eelgrass and understory kelp often occurred intermixed or adjacent each other, and are likely linked by movement of fauna across habitat borders (Heck et al. 2008, Chalifour et al. 2019). The presence of kelp near eelgrass beds could improve the nursery function of eelgrass beds. Olson et al. (2019) found that young of the year rockfish consumed higher quality prey in eelgrass beds adjacent to kelp beds, as compared to eelgrass beds adjacent to sand, and that the proximity to kelp improved rockfish recruitment within eelgrass meadows.

[12] Note that these are theoretical estimates. We have not collected data on carbon sequestration rates / organic matter storage in the study area for this project.

Green algae were the most abundant vegetation type in the study area: approximately 279 ha over the 22 sites sampled in 2021. Approximately 54 ha had a high % cover (>66 %), 30 ha had medium cover, and 195 ha had a low % cover of green algae (< 33%). Green algae was present throughout the entire depth range sampled, but was most abundant between 0 and -2.5m (MLLW). Green algae are able to outcompete other marine vegetation types when they are not nutrient limited, and large green algae blooms can be a sign of eutrophication (Valiela et al. 1997, Burkholder et al. 2007). At some locations there was significant overlap between dense green algae and other vegetation types. For example, at cps1666 and cps1667, areas of high % cover green algae were found within eelgrass beds. At these locations, green algae cover may have a negative impact on eelgrass, as high biomass of green algae is often associated with lower shoot density (Nelson and Lee 2001, Burkholder et al. 2007). Most of the time, areas with high % cover green algae were found in very shallow habitat, outside the footprint of the kelp and eelgrass beds at those locations.

There were approximately 104 ha of other red-brown algae in the study area. This marine vegetation type was abundant throughout the entire depth range sampled, but was mostly present as low % cover. Other red-brown algae tend to be the predominant vegetation type below -5 m (MLLW). Note that this vegetation type covers a highly diverse group of algae species that cannot be reliably identified through towed underwater videography. *Sargassum muticum* was first documented in Washington State in the 1950's, and is now common along at least 20% of the shorelines of greater Puget Sound based on data from the ShoreZone inventory (1994-2000). This invasive algae species has the ability to impact nearshore ecosystems, as it is known is displace native macroalgae through competition for light (Britton-Simmons 2004), and inhibit the recruitment of native kelp species (Ambrose and Nelson 1982). *Sargassum* can be less palatable to local grazers, and may receive a competitive advantage through lower grazing pressure in some regions of the world (Monteiro et al. 2009, Engelen et al. 2011). In greater Puget Sound, *Sargassum* appears to be less palatable to kelp crabs (*Pugettia producta*), but it is the preferred food source for the common herbivorous snail *Lacuna vincta* (Britton-Simmons et al. 2011). *Sargassum muticum* was the least abundant marine vegetation type in the study area. It was detected at 9 different sites, but only covered 2.7 ha in the entire study area, and was only found at very shallow depths (mostly less than -2.5m MLLW). Our data do not show any clear impact on native seagrass and other algae species in the study area.

4.2 Echinoderms in the shallow subtidal

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 counted the abundance of 17 classes of echinoderms along each transect. Ten different classes were detected in the study area: undifferentiated stars, sunflower stars (*Pycnopodia helianthoides)*, slime stars (*Pteraster tesselatus*), rainbow stars (*Orthasteria koehleri)*, giant pink stars (*Pisaster brevispinus*), ochre stars (*Pisaster ochraceus)*, mottled sea stars (*Evasterias troschelii*), leather stars (*Dermasterias imbricata)*, and the two types of sea cucumbers (*Cucumaria sp.* and *Parastichopus sp.*). We counted a total of 395 individuals along the more than 37 km of transects sampled. The most abundant categories were mottled seastars (n = 154), undifferentiated stars (n = 125), giant pink stars (n = 53), sea cucumbers (n = 39), and ochre stars (n = 13). Leather stars, rainbow stars, slime stars and sunflower stars were rare (n <5 for each 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 part of the depth range where these sea stars occur.

The 22 sites sampled in 2021 generally had a higher abundance and diversity as compared to sites sampled with the same methodology near the Snohomish River delta in 2020. The 3 most abundant categories were the same in both years (mottled stars, giant pink stars and undifferentiated stars), but 2021 we also detected a substantial number of ochre stars and sea cucumbers. Giant pink stars, mottled sea stars, and ochre stars are common in Puget Sound. These species feed on a variety of prey, including bivalves, snails, and barnacles. The giant pink star can grow up to 60 cm in diameter and is usually found on sandy or muddy substrate, from the intertidal to 128 m deep. Ochre stars have arms up to 25 cm long. They are often found in the intertidal (especially on rocky shores), but can occur up to 97m deep. Mottled stars are smaller (up to 28 cm in diameter), and are usually found on rocks, pebbles or sand, from the intertidal to 75 m deep (Klinkenberg 2019).

We only detect a few sunflower stars in the study area, as well as one rainbow star. These species were heavily impacted by the 2013-2015 epidemic of sea star wasting disease, and were expected to be rare (Montechino_Latorre et al. 2016).

4.3 Data use and availability

This project has generated a large area profile for eelgrass, understory kelp, and other vegetation types at 22 sites along the Snohomish shoreline, between Edmonds and Everett. 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 will be made 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	prostrate kelp	green algae	other red/brown algae	sargassum
cps1656	24.53	10.31	4.36	22.86	7.60	0.00
cps1657	15.74	6.58	3.77	13.74	2.38	0.00
cps1658	12.58	4.81	3.09	10.72	2.37	0.00
cps1659	10.34	4.26	2.06	7.61	2.03	0.03
cps1660	19.58	3.37	7.86	14.78	10.11	0.39
cps1661	17.68	8.41	6.76	9.17	5.89	0.03
cps1662	24.94	7.50	9.42	16.87	12.36	0.05
cps1664	17.51	1.01	11.25	16.58	12.24	0.19
cps1665	6.02	0.78	2.98	5.83	4.26	0.39
cps1666	22.06	8.62	2.08	21.44	4.70	0.42
cps1667	36.13	24.02	11.02	24.97	8.91	0.14
cps1668	27.04	8.48	7.24	19.21	14.28	0.00
swh1642	13.27	9.08	0.00	5.28	0.12	0.00
swh1643	13.61	10.94	0.00	3.59	0.23	0.00
swh1644	10.85	5.29	0.59	6.44	3.40	0.02
swh1645	7.59	0.00	2.00	6.33	3.93	0.24
swh1647	12.27	8.01	3.06	6.78	0.83	0.38
swh1648	12.42	5.04	3.08	10.55	3.13	0.39
swh1650	8.38	3.14	0.35	6.50	1.97	0.00
swh1651	12.67	9.30	0.37	10.20	0.79	0.00
swh1652	22.55	14.10	1.57	18.66	0.41	0.00
swh1654	22.37	11.69	2.70	21.15	2.31	0.00