NATURAL RESOURCES

# Eelgrass, kelp and other macro-algae near the Snohomish delta

## Final report to Snohomish County

IAA 93-100931

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*12/31/2020*





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 of towed underwater footage collected as part of IAA 93-100931 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 93-100931 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.

The Nearshore Habitat Program would like to give special recognition to Ian Fraser and Jim Norris of Marine Resources Consultants who played a significant role in the success of the project. Marine Resources Consultants showed great dedication and logged many hours of sea time collecting data for the project.

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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

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 2020, Snohomish County signed an agreement with DNR to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp and other macroalgae) at 10 sites along the Snohomish estuary, from Hermosa Point (North of Tulalip Bay) down to Port Gardner, using methods developed for DNR's monitoring programs. 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 pilot project for classification of other marine vegetation types, based on footage collected for the SVMP.

## Key findings:

1. Marine vegetation in the study area was dominated by eelgrass and green algae, which is expected for intertidal and shallow subtidal estuarine habitats dominated by sandy substrates.
    - In total, there was 386 +/- 42 ha of eelgrass in the study area. This corresponds to 9.5 % of all eelgrass in the Saratoga Whidbey Basin (approximately 4,082 +/- 301 ha), and 1.7 % of all eelgrass in greater Puget Sound (22,259 +/- 1090 ha). The non-native seagrass *Zostera japonica* was sparse in the study area.
    - There was approximately 236 ha of green algae, 181 ha of other red/brown algae, and 6.6 ha of understory kelp in the study area. Green algae were most prevalent in the intertidal, above the shallow edge of eelgrass beds. Other red/brown algae mostly occurred as low cover epiphytes on eelgrass leaves. Understory kelp was limited to a small area near Hermosa Point.
    - Eelgrass was usually found in dense patches with high % cover. Green algae, understory kelp and other red/brown algae were usually found in low cover classes.
2. The depth distribution of marine vegetation was similar to other sites in the Saratoga Whidbey basin, but more restricted in maximum depth as compared to Central Puget Sound.
    - Eelgrass was found between 0.9 and -4.2 m (MLLW). The majority of observations occurred between 0 and -2 m (MLLW).

- *Z. japonica* was found between 1.2 and -0.9 m, and had a median depth of 0.7 m (MLLW).
- Green algae and understory kelp were found to -15 m (MLLW), the maximum depth of the surveys. The majority of these algae occurred at shallower depths (median of -0.3 and -2.9 m respectively). Other red/brown algae were found down to -8.1 m, with a median depth of -1.2 m (MLLW).

3. We were able to assess change in eelgrass area at 6 out of the 10 sites sampled. Eelgrass area has increased over time at 3 sites along the shoreline between Mission Beach and Priest Point. Eelgrass has declined in Tulalip Bay and in the center of the Snohomish delta. The declines in Tulalip Bay are part of a longer-term trend. Declines at the center of the Snohomish delta may be due to natural variability at this highly dynamic site. Both locations are a priority for future monitoring.

# 1 Introduction

## 1.1 Eelgrass and kelp in greater Puget Sound

Greater Puget Sound is home to 5 species of seagrass, and several hundred species of macroalgae, which includes at least 17 species of kelp (Calloway et al. 2020). These plants and algae serve as critical habitat for a wide variety of organisms, including several fish species that are listed as endangered or threatened under the Federal Endangered Species Act.

Eelgrass (*Zostera marina*) is by far the most abundant seagrass in greater Puget Sound. It is found in each of the 5 regions of the Sound, but it is absent/scarce in South Puget Sound, Liberty Bay and Dyes Inlet. Eelgrass mostly grows in the intertidal and shallow subtidal in muddy to sandy substrates and low to moderately high-energy environments. The majority of eelgrass in greater Puget Sound is found between 0 and -4m relative to mean lower low water (MLLW), but it has been documented as shallow as 1.4m and as deep as -12.5m (Christiaen et al. 2019).

The term kelp refers to a group of large brown macroalgae in the order *Laminariales*. These algae are found throughout greater Puget Sound, and are often the dominant vegetation in intertidal and subtidal habitats with solid substrate (Mumford 2007). Kelp sporophytes are organized into three types based on morphology: prostrate kelp, stipitate kelp, and floating kelp. Prostrate kelp, such as *Costaria costata* or *Saccharina latissima*, lack a rigid stipe, and create a canopy close to the substrate. Stipitate kelp, such as *Pterygophora californica*, are raised off the bottom by a rigid stipe, and form a mid-story canopy. Prostrate and stipitate kelp are considered understory kelp, and are usually not visible from the water surface. There is limited information on their spatial and depth distribution, but they are considered to be more abundant than floating kelp in Puget Sound (Calloway et al. 2020). Floating kelp have evolved floats that allow them to create thick canopies near the water surface. Bull kelp (*Nereocystis luetkeana*) is the predominant floating kelp species in the Salish Sea.

Eelgrass and kelp are ranked among the most productive habitats in the biosphere (Costanza et al. 1997, Mann 1973). They produce large amounts of carbon that fuel both local and distant foodwebs (Duarte et al. 2005, Heck et al. 2008, Krause-Jensen & Duarte 2016, Krumhansel et al. 2012, Olsen et al. 2019), and create a structurally complex habitat that provides refuge from predation (Semmens et al. 2008). Eelgrass and kelp support high biodiversity and are important habitats for forage fish and juveniles of commercially important fish species, including salmonids and endangered rockfish (Murphy et al. 2000, Johnson et al. 2003, Unsworth et al. 2019, Shaffer et al. 2020).

Eelgrass and kelp are sensitive to anthropogenic stressors, including climate change (Smale 2019, Wilson & Lotze 2019), physical disturbance (Unsworth et al. 2017, Norderhaug et al. 2020), and eutrophication (Burkholder et al. 2007, Filbee-Dexter and Wernberg 2018). As such they are often seen as indicators of habitat condition. Both eelgrass and kelp are included in the Puget Sound Partnership's revised 2020 list of vital sign indicators for tracking the recovery and restoration of Puget Sound.

## 1.2 Eelgrass and kelp monitoring at DNR

As part of its stewardship responsibility, DNR's Nearshore Habitat Program monitors nearshore vegetation and other indicators of habitat health along Puget Sound's shorelines. Research focuses on seagrass and kelp, and includes:

- Annual monitoring of the native seagrass population (*Zostera marina* and *Phyllospadix spp.*) through the Submerged Vegetation Monitoring Program (SVMP). This program started in 2000 and is ongoing.
- 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*).
- Monitoring of bull kelp populations in Central and South Puget Sound.

Monitoring data are used by diverse organizations including government, academia, tribes and non-governmental groups to better understand eelgrass and kelp distribution, assess change over time, and inform management actions.

Local partnerships play a key role in DNR's monitoring efforts, and allow for detailed surveys in in areas of management concern. Previous examples include collaborations with the Suquamish Tribe (Christiaen et al. 2018), the City of Bainbridge Island (Christiaen et al. 2017), and King County (Christiaen et al. 2020).

## 1.3 IAA 93-100931 between Snohomish County and DNR

The successful conservation and restoration of critical fish habitat relies on having accurate information on the distribution of marine vegetation, such as eelgrass and kelp. The shorelines of Water Resource Inventory Area 7 (WRIA7) are important migration habitat routes for salmonids, yet detailed information on marine vegetation in the Snohomish estuary is lacking.

On July 7th 2020, Snohomish County signed an agreement with DNR to conduct a comprehensive survey of marine vegetation (eelgrass, understory kelp and other macroalgae) at 10 sites along the Snohomish estuary, from Hermosa Point (north of Tulalip Bay) down to Port Gardner, using methods developed for DNR's monitoring programs. This report summarizes area and depth distribution of eelgrass, kelp and other marine vegetation throughout the study area.

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 of both the 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).

## 2.1 Study area description

This report covers the intertidal and shallow subtidal habitats along the shoreline of the Snohomish estuary, from Hermosa Point (north of Tulalip Bay) to Harborview Park, south of Port Gardner (excluding the harbor area). We divided this area into 10 individual sample sites, labeled according to the SVMP dataset. Six of the site codes start with 3 letters (swh, which stands for Saratoga Whidbey Basin), followed by 4 numbers. The 4 tidal flats are coded as "flats" followed by 2 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).

## 2.2 Field sampling

Field sampling was conducted in July and August 2020 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<br>Secondary: Garmin Fishfinder 250, 200 KHz 11o single-beam transducer |
| **Underwater Camera** | Ocean Systems Deep Blue SD (downward facing)<br>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

Prior to field sampling, a site polygon was defined for each site, 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). Fringe sites are 1000 m along the -6.1 m contour on the deep edge. Segment lengths vary for flats sites (e.g., depending on embayment size). In addition, we 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 5 sites, the 2020 transects were repeats of a previously established STR sample[1]. At the other sites, STR transects were newly established. Six sites were also previously sampled with a simple random sample (SRS)[2]. At 3 sites these SRS transects had been resampled in previous years.

## 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[3].
- **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

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[1] Note that the year of the initial STR sample varies among sites. Flats25 and flats27 were initially sampled with STR transects in 2014, flats26 was initially sampled with STR in 2016, swh1626 was initially sampled with STR in 2017, and swh1625 was initially sampled with STR in 2018.

[2] For SRS samples, we first delineated a sample polygon that encompassed all eelgrass at a site, based on reconnaissance prior to sampling. We then established a random sample of transects throughout this sample polygon. Transects were always oriented perpendicular to shore. For more details, see Dowty et al. (2019).

[3] *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 are estimate of this non-native seagrass based on our sample techniques.

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 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[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* |
| **Sea cucumber.** | *Cucumaria sp.* |
| | *Parastichopus sp.* |

[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 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)[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 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 0.25 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:

[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 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 during nine field days in July & August 2020. During this time, our research vessel collected approximately 42 hours of towed underwater video footage along 124 transects, spread over 10 sites (Table 3). The vast majority of these transects were perpendicular to shore, and selected using stratified random sampling (STR). A few transects consist of meanders along the shallow edge of seagrass beds at locations of interest (predominantly at flats27, near the N end of Jetty Island).

The total length of all transects sampled was over 78.6 km. Eelgrass was present at over 20.3 km of transects sampled. The largest sites in terms of sample effort were flats26, flats27 and flats28 (in front of the Snohomish delta). These sites account for 78.1% of total transect length (61.4 km) and 70.7 % of video footage collected (almost 30 hours). Swh1639, swh1640 and swh1641 (south of Everett) were among the smallest sites in terms of total transect length (3.5 km) and hours of footage collected (approximately 3 hours total).

**Table 3:** Overview of sites sampled as part of DNR 93-100931

| site code | date_start | date_end | transects | Footage (hh:mm) |
|---|---|---|---|---|
| **flats25** | 8/3/2020 | 8/3/2020 | 10 | 02:52 |
| **flats26** | 7/30/2020 | 7/31/2020 | 10 | 07:54 |
| **flats27** | 7/28/2020 | 7/29/2020 | 14 | 14:50 |
| **flats28** | 7/27/2020 | 7/28/2020 | 19 | 06:58 |
| **swh1625** | 7/31/2020 | 7/31/2020 | 17 | 02:43 |
| **swh1626** | 7/20/2020 | 7/20/2020 | 12 | 02:37 |
| **swh1639** | 7/24/2020 | 7/24/2020 | 14 | 01:14 |
| **swh1640** | 7/24/2020 | 7/24/2020 | 10 | 00:51 |
| **swh1641** | 8/4/2020 | 8/4/2020 | 10 | 00:52 |
| **swh2879** | 8/3/2020 | 8/3/2020 | 10 | 01:07 |

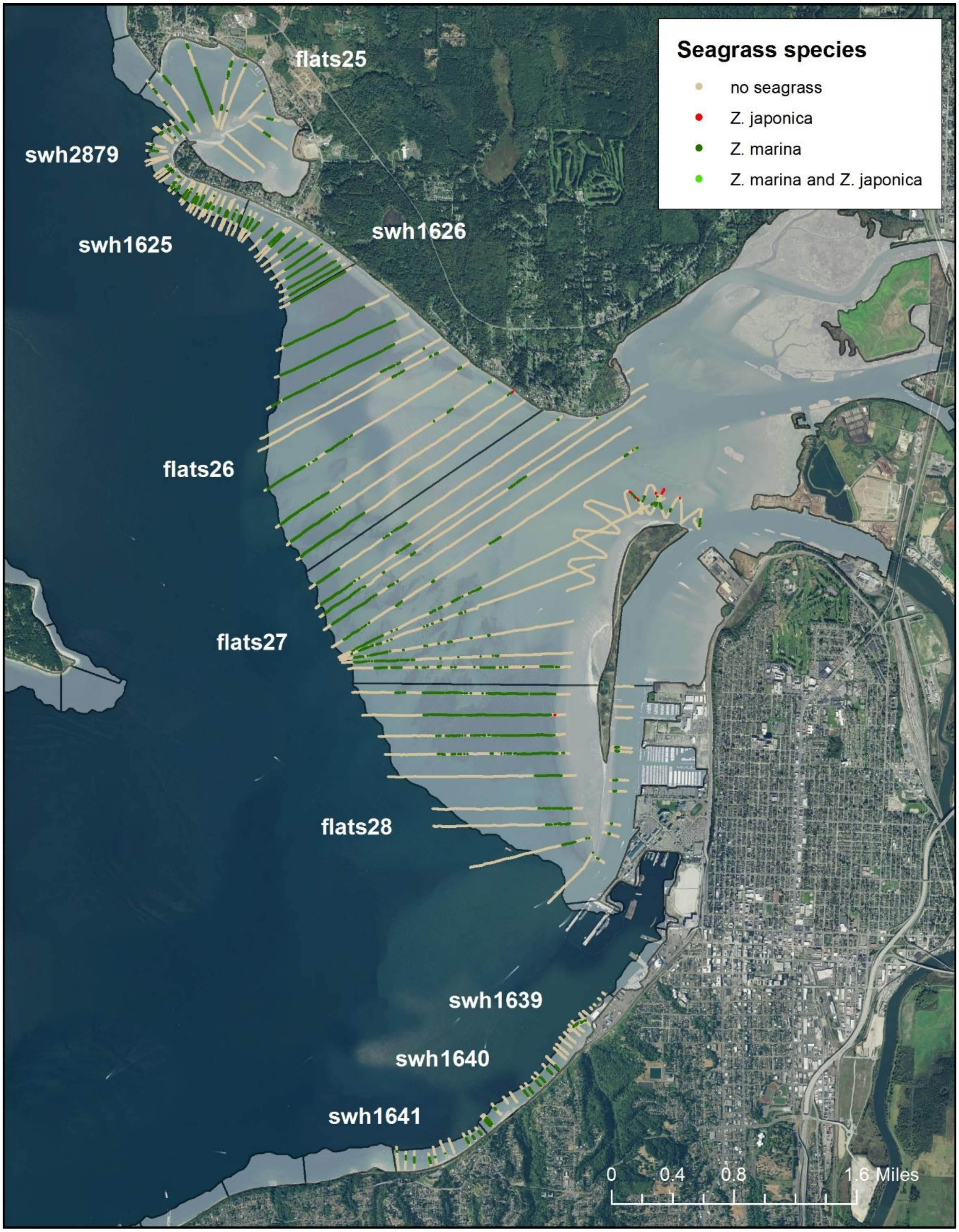


**Figure 3**: *Z. marina* and *Z. japonica* in the study area, visualized on underwater imagery transects that span from the low intertidal to -15 m (MLLW). Site polygons are shown in tan, bounded by the -6.1 m MLLW bathymetry contour and the ordinary high water mark. Fringe sites are 1000 m along the -6.1 m contour on the deep edge. Segment lengths vary for flats sites (e.g., depending on embayment size). Site polygons are used for large area identification of habitat throughout greater Puget Sound, observations outside of site polygons are included in site statistics.

## 3.2 Seagrass

### 3.2.1 Seagrass species near the Snohomish estuary

We detected two species of seagrass near the Snohomish estuary: *Z. marina* (eelgrass) and the non-native *Z. japonica* (dwarf eelgrass). *Z. marina* was by far the most abundant seagrass species, and was found at all 10 sites sampled (Figure 3). The largest eelgrass beds were located on the western side of Jetty Island (flats28) and along Mission Beach (swh1625 and flats26). A third species, *Ruppia maritima*, may be present further up in the estuary, but was not detected during our surveys.

The non-native *Z. japonica* was only found at 3 locations: near Priest Point (flats26), at the northern edge of Jetty Island (flats27), and on the western side of Jetty Island (flats28). *Z. japonica* usually grows at higher tidal elevations than *Z. marina*, and is often too shallow for the sample vessel (Figure 4). As such, our data are conservative estimates for the presence/absence of *Z. japonica.* However, the limited presence in our data suggests that *Z. japonica* is not very abundant in the study area.

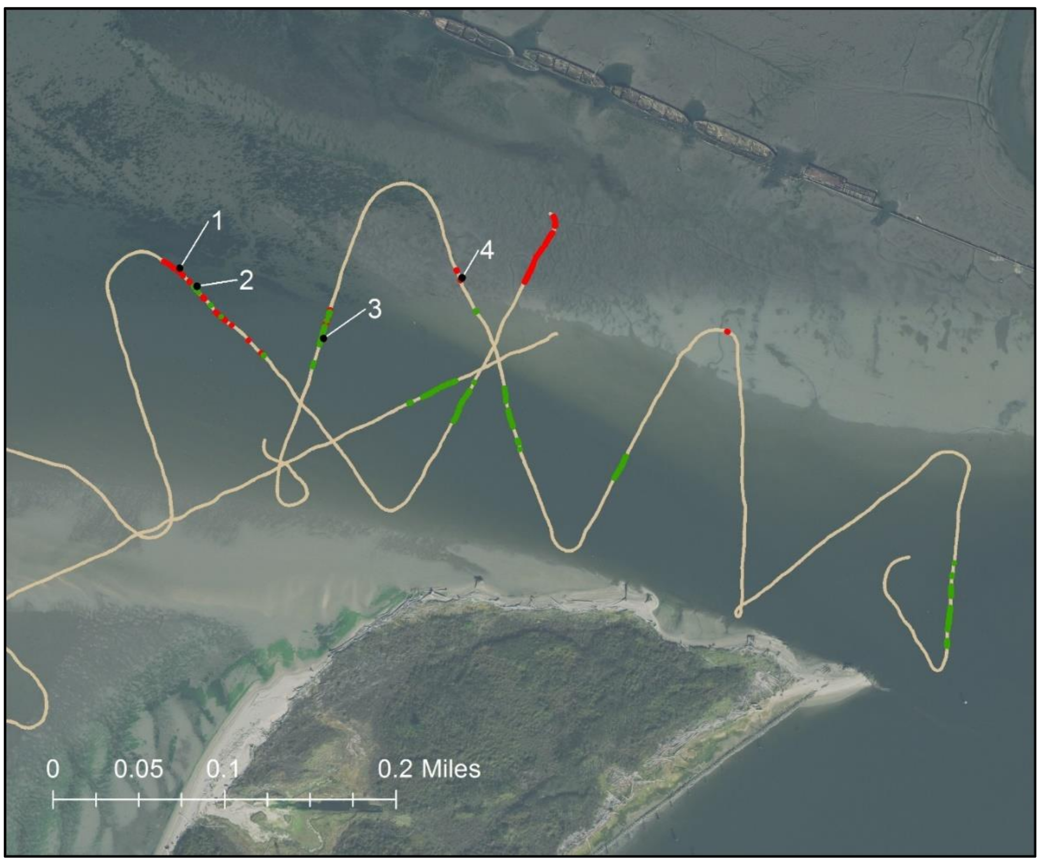


**Figure 4:** *Zostera marina* (green) and *Zostera japonica* (red) at the northern edge of Jetty Island, classified along meandering towed underwater imagery transects. Numbers indicate the locations of screenshots with the different seagrass species found in the study area (Figure 5).

DNR classifies presence/absence of *Z. marina* and *Z. japonica* from video imagery (Figure 5). Typically, the image quality is sufficient to distinguish between both species as their appearance differs in the video data. The non-native *Z. japonica* is typically a lot smaller than *Z. marina* (leaf length from 10-30 cm as compared to 10 cm - 1.5m in greater Puget Sound). Both species also have different depth distributions. *Z. japonica* is limited to the intertidal, while *Z. marina* grows between +1.4 and -12.5 m in greater Puget Sound.

At some locations it can be difficult to distinguish between the species based on video data alone. This usually occurs in shallow areas where *Z. japonica* grows interspersed with relatively small *Z. marina*. At these locations, we take grab samples to confirm species identity based on other characteristics, such as the morphology of the leaf sheath and the root system. Near the Snohomish estuary, there were few locations where both species co-occurred.

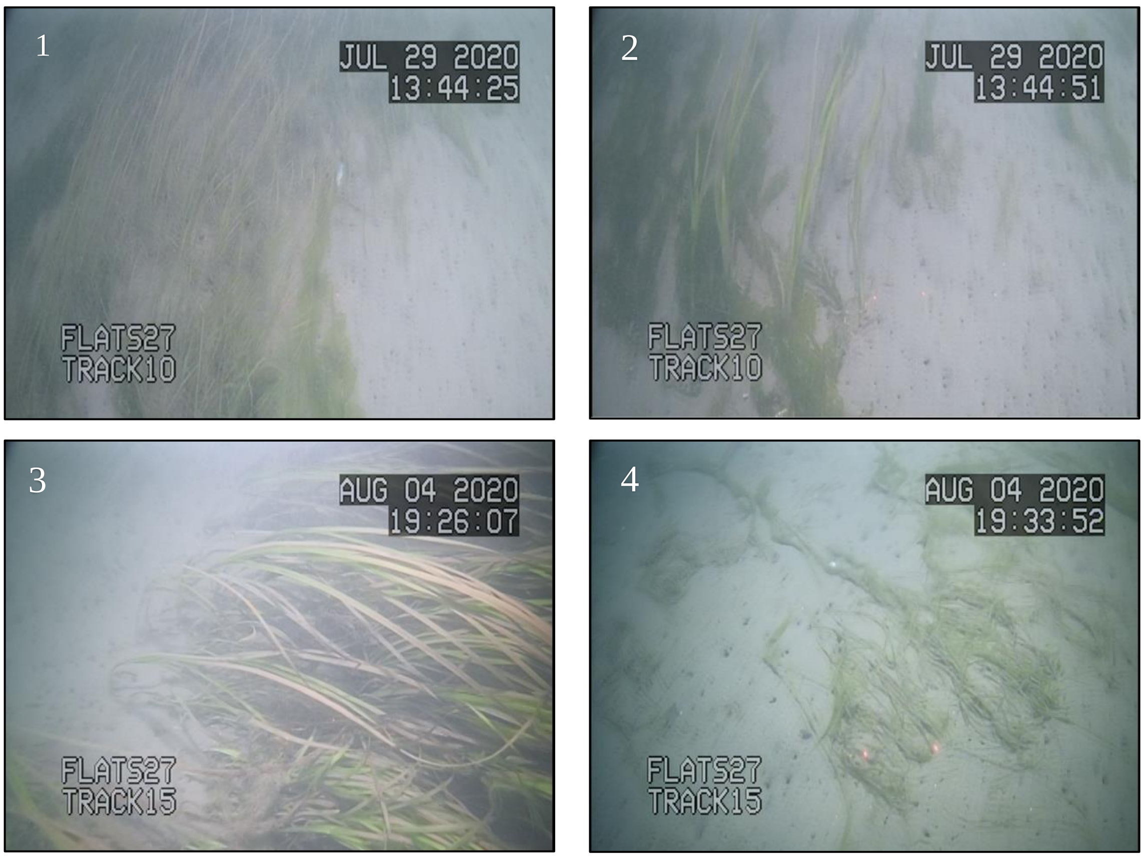


**Figure 5:** Screenshots of towed underwater footage along transects near Jetty Island. These images illustrate the variability in appearance of the different seagrass species. Photos 1 and 4 are *Zostera japonica,* photos 2 and 3 are *Zostera marina*. The two red dots in the center of the screenshots are parallel laser lights, spaced 10cm apart. These provide a frame of reference for the size of the different seagrass species.

## 3.2.2 Eelgrass area

In total, there was 386 +/- 42 ha of eelgrass throughout the study area in summer 2020. This corresponds to 9.5 % of all eelgrass in the Saratoga Whidbey Basin (approximately 4,082 +/- 301 ha), and 1.7 % of all eelgrass in greater Puget Sound (22,259 +/- 1090 ha)[6].

The largest eelgrass beds were found at flats26 (159 +/- 32 ha), flats27 (76 ha +/- 7 ha), and flats28 (90 +/- 14 ha). This is not surprising, as these are the 3 largest sites sampled. Figure 6 shows the eelgrass sample polygons, shaded by eelgrass area (1) and the fraction of the polygon covered by eelgrass (2). Sites swh1626, and flats28 and swh1640 had the largest eelgrass beds relative the size of the area sampled for eelgrass (Table 4).

Based on visual assessment, the eelgrass bed at flats27 appeared to be more fragmented as compared to the other sites (Figure 3). This is likely the most dynamic site given its location near the river delta. The largest contiguous eelgrass beds were located in flats28 (west of Jetty Island), swh1626, and northern part of flats26 (Mission Beach).

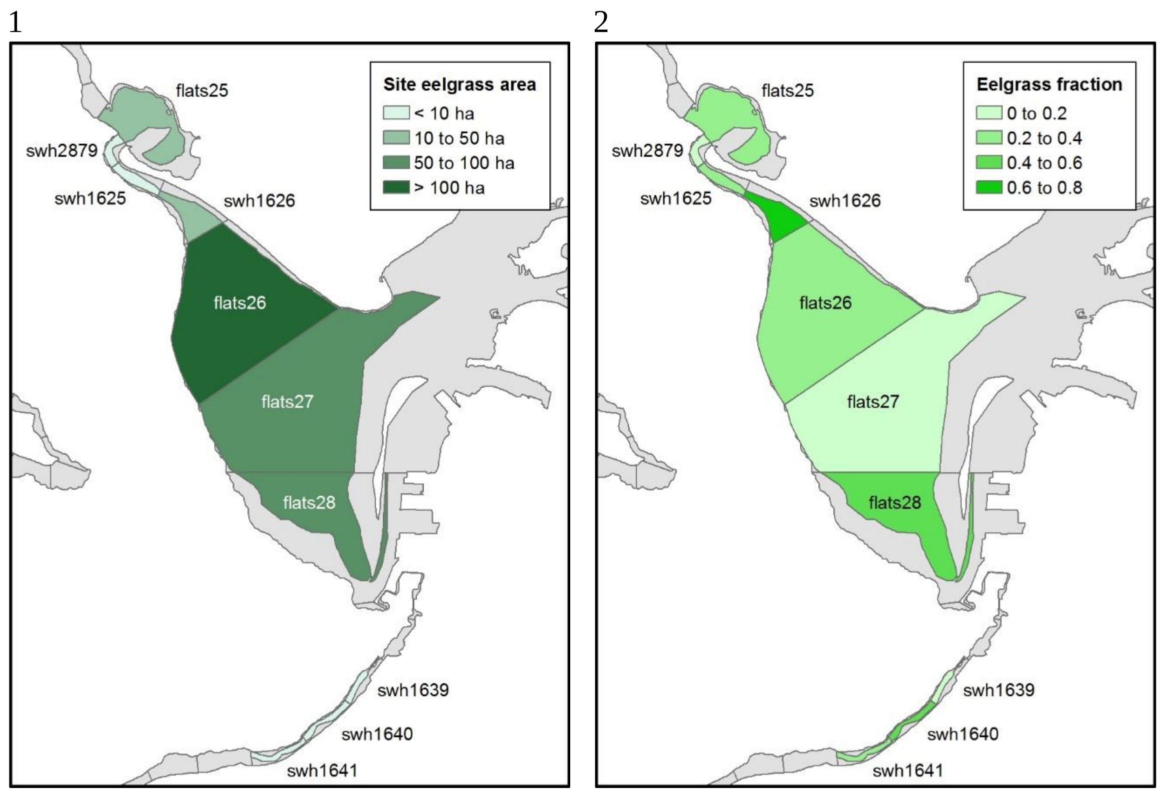


**Figure 6:** Map of the eelgrass sample polygons for each site sampled. 1. Eelgrass area estimates (hectares) 2. Fraction of the sample polygon covered with eelgrass, which serves as a proxy for the relative abundance of eelgrass within the sample polygon.

[6] Source: Christiaen et al. (2021) – Puget Sound Seagrass Monitoring Report, Monitoring Year 2018-2019 – in prep.

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

| site code | date start | sample selection | sample repeat | n | fraction | sample poly (ha) | veg (ha) | veg s.e. (ha) |
|---|---|---|---|---|---|---|---|---|
| **flats25** | 3-Aug-20 | STR | repeat | 10 | 0.201 | 102.95 | 20.69 | 8.35 |
| **flats26** | 30-Jul-20 | STR | repeat | 10 | 0.32 | 496.34 | 158.77 | 38.32 |
| **flats27** | 28-Jul-20 | STR | repeat | 12 | 0.119 | 635.43 | 75.77 | 6.71 |
| **flats28** | 27-Jul-20 | STR | mixed | 19 | 0.444 | 203.25 | 90.14 | 14.04 |
| **swh1625** | 31-Jul-20 | STR | repeat | 17 | 0.217 | 14.95 | 3.25 | 0.35 |
| **swh1626** | 20-Jul-20 | STR | mixed | 12 | 0.752 | 38.25 | 28.76 | 1.41 |
| **swh1639** | 24-Jul-20 | STR | new | 14 | 0.041 | 7.53 | 0.31 | 0.13 |
| **swh1640** | 24-Jul-20 | STR | new | 10 | 0.495 | 10.06 | 4.97 | 0.77 |
| **swh1641** | 4-Aug-20 | STR | new | 10 | 0.22 | 9.91 | 2.18 | 0.69 |
| **swh2879** | 3-Aug-20 | STR | new | 10 | 0.127 | 8.81 | 1.12 | 0.3 |

### *3.2.3 Eelgrass depth distribution*

Table 5 and Figure 7 show the depth distribution of eelgrass at individual sites based on our observations. Eelgrass was found between 0.9 and -4.2 m (MLLW), but the majority of observations occurred between 0 and -2 m (MLLW). Eelgrass grew deepest at swh1640, and was found at the shallowest depths at flats27, swh1626 and swh1641. The median depth for all eelgrass observations at a site was usually around -1 m (MLLW). We calculated the depth range as the difference between the 2.5$^{th}$ percentile and 97.5$^{th}$ 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 swh1625 and swh1626 (1.3 and 1.4 m respectively), and largest at swh1639 (3.2m). These values are similar to other sites in the Saratoga Whidbey Basin, but are relatively small as compared to sites in Central Puget Sound (Christiaen et al. 2021 – in prep).

Figure 8 shows the depth distribution and cumulative depth distribution based on all observations of eelgrass in each of the 10 sites. Approximately half of the eelgrass in the study area grew shallower than -1.2 m relative to MLLW. 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[7] (Hannam et al. 2015). When comparing to this boundary, approximately 69.5% of all eelgrass in the study area grew in the subtidal, while 30.5% grew in the intertidal. This is similar to other sites in greater Puget Sound, where approximately 62% of all eelgrass occurs in the subtidal (Hannam et al. 2015). The non-native seagrass *Z. japonica* was not commonly found in the study area and had a different depth distribution as compared to *Z. marina*. It usually grew shallower than *Z. marina*, and was limited to the intertidal habitats.

[7] Note that this is different from the Extreme Low Tide Line as estimated by the federal government.

**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.

| site code | maxd | q025 | q10 | q25 | q50 | q75 | q90 | q975 | mind | range | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **flats25** | -3.3 | -3.0 | -2.9 | -2.2 | -1.2 | -0.9 | -0.7 | -0.5 | -0.2 | 2.5 | 1632 |
| **flats26** | -2.9 | -1.9 | -1.5 | -1.2 | -1.0 | -0.6 | -0.5 | -0.4 | -0.1 | 1.6 | 8567 |
| **flats27** | -2.8 | -2.1 | -1.7 | -1.4 | -1.2 | -1.0 | -0.6 | -0.4 | 0.9 | 1.7 | 5298 |
| **flats28** | -3.0 | -2.1 | -1.8 | -1.6 | -1.4 | -1.2 | -1.0 | -0.6 | 0.3 | 1.5 | 5798 |
| **swh1625** | -2.4 | -2.0 | -1.7 | -1.5 | -1.3 | -1.2 | -1.0 | -0.7 | -0.2 | 1.3 | 1191 |
| **swh1626** | -2.6 | -1.9 | -1.6 | -1.5 | -1.2 | -1.0 | -0.7 | -0.5 | 0.8 | 1.4 | 4378 |
| **swh1639** | -3.1 | -2.9 | -2.4 | -2.0 | -1.4 | -0.9 | 0.2 | 0.3 | 0.3 | 3.2 | 97 |
| **swh1640** | -4.2 | -2.9 | -2.3 | -1.5 | -0.9 | -0.6 | -0.4 | -0.2 | 0.0 | 2.7 | 940 |
| **swh1641** | -3.1 | -2.5 | -2.0 | -1.5 | -0.9 | -0.8 | -0.6 | -0.3 | 0.8 | 2.2 | 373 |
| **swh2879** | -2.8 | -2.2 | -1.4 | -1.0 | -0.9 | -0.7 | -0.6 | -0.4 | 0.0 | 1.8 | 313 |

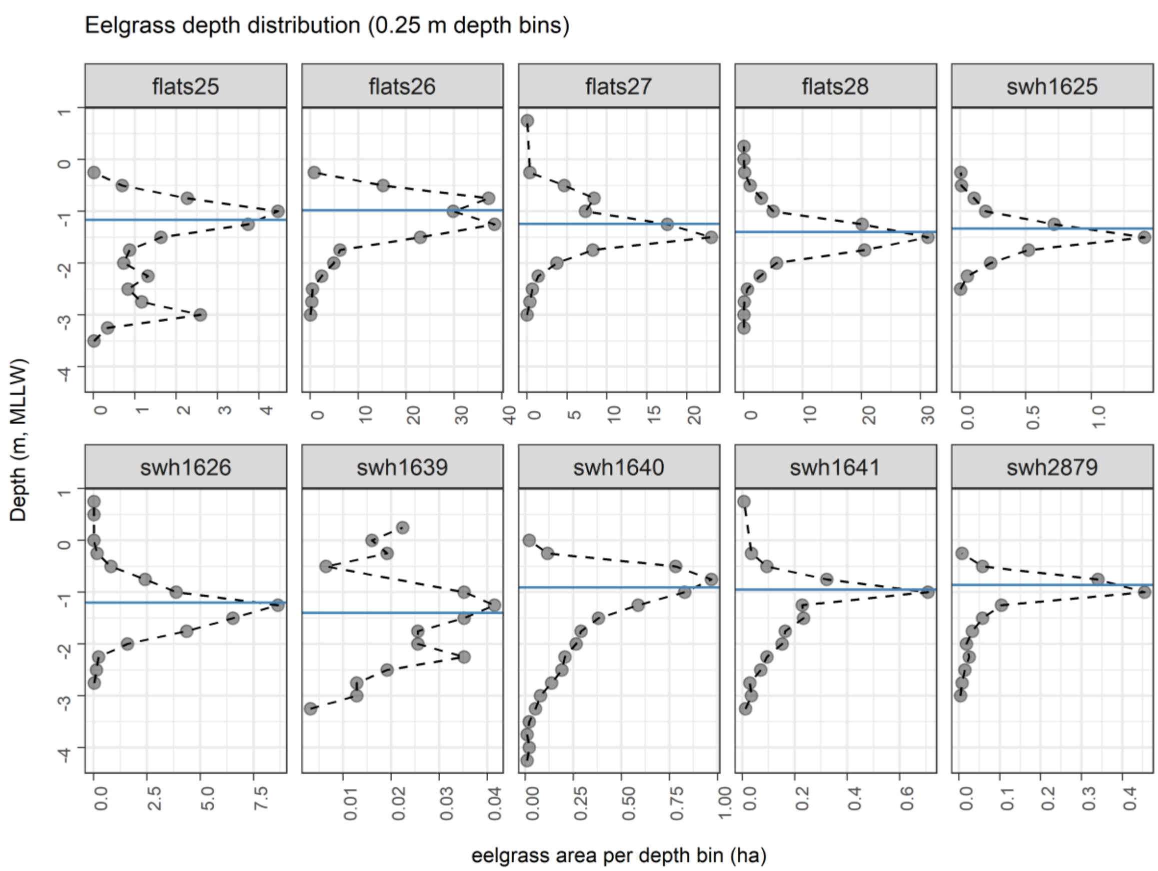


**Figure 7:** Depth distribution of eelgrass at individual sites, calculated as the amount of eelgrass (ha) per 0.25m depth bin at each of the sites. The blue line represents the median depth of all eelgrass observations at the site.

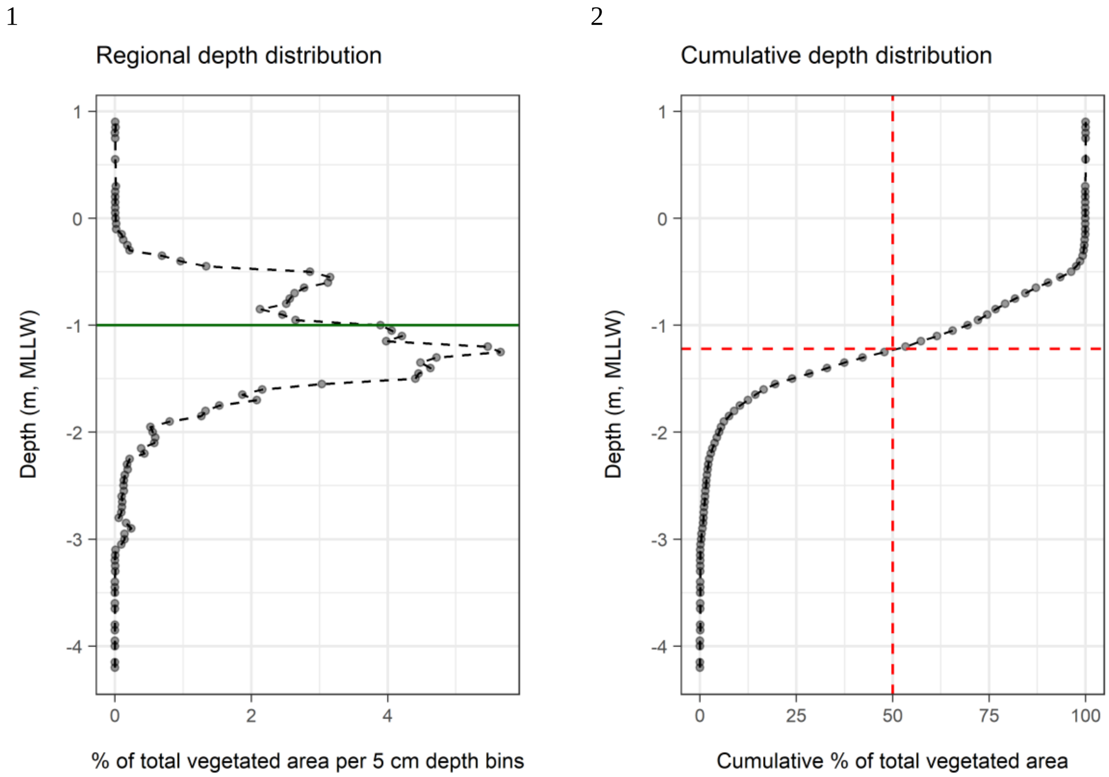


**Figure 8:** (1) Regional depth distribution and (2) cumulative depth distribution for all sites sampled near the Snohomish estuary, calculated as % of total eelgrass area per 5 cm depth bins. The green line on the left plot indicates the boundary between intertidal and subtidal habitat (Hannam et al. 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*

Six out of the 10 sites were previously sampled by DNR's eelgrass monitoring program. At these locations, we were able to assess change in eelgrass area over time. 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 transects sampled in 2020 with an earlier year (the exact year of the repeat sample varies depending on the site)[8].

Figure 9 and Figure 10 show the results of both analyses. On the left hand side are maps that indicate where eelgrass appeared (green), disappeared (red), and was persistent over time (blue) along repeat transects. The plots on the right hand side show site eelgrass area estimates (ha) over time.

[8] In early years, transects were usually selected as a new draw simple random sample (new draw SRS). At some locations, one of these simple random samples was resampled in a later year (repeat SRS). More recently, transects were selected as stratified random samples. These stratified random samples were resampled in 2020 (repeat STR). In some years (2016, 2017 & 2018) sites were sampled with both SRS and STR.

At 3 out of 6 sites eelgrass increased over time (Figure 9):

- At **swh1625**, the pairwise comparison of STR transects shows that the eelgrass expanded considerably between 2018 and 2020 (Figure 9.1). The eelgrass area estimate more than doubled during this period of time (from 1.53 +/- 0.28 in 2018 to 3.25 +/- 0.35 ha in 2020)[9]. Both the scatterplot and the pairwise comparison of SRS transects (2004-2018) indicate that eelgrass remained relatively stable before 2018.
- Eelgrass beds at **swh1626** show a similar pattern, but less pronounced. The pairwise comparison of STR transects shows an increase between 2017 and 2020 (Figure 9.3). 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 0.64 ha/year between 2010 and 2020 (adj.r.squared = 0.618, p = 0.007).
- At **flats26** eelgrass did not change much between 2016 and 2020 (Figure 9.5). However, the pairwise comparison of SRS transects did suggest an increase between 2009 and 2016. The linear regression indicates that eelgrass area increased on average by 3.8 ha/year between 2004 and 2020 (adj.r.squared = 0.417, p = 0.036).

At the remaining 3 sites, eelgrass either declined or remained stable over time (Figure 10):

- Eelgrass beds at **flats25** lost on average 1.15 ha per year between 2006 and 2020 (adj.r.squared = 0.903, p = 0.008). 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 (Figure 10.1).
- **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 (Figure 10.3). Site eelgrass area declined by nearly 50% at this location (from 139.7 +/- 19.3 ha in 2014 to 75.8 +/- 6.7 ha in 2020). Note that this is a very dynamic site, given its location in front of the Snohomish delta.
- There was no significant trend in eelgrass area between 2000 and 2020 at **flats28** (adj.r.squared = 0.012, p = 0.348). At this site, we do not have a repeat sample of previous years. However, some transects did overlap with SRS transects sampled in 2011 (Figure 10.5). This partial comparison suggests possible loss between 2011 and 2020.

[9] There is a big difference between the SRS sample and the STR sample in 2018. The discrepancy is due to the patchy nature of the eelgrass bed in 2018. At sites with small, patchy eelgrass beds (less than 1 ha) our area estimates are not as accurate. Both were valid samples, and were retained for the regression analysis. However, the outcome was rejected because the data violates the assumptions for linear regression.

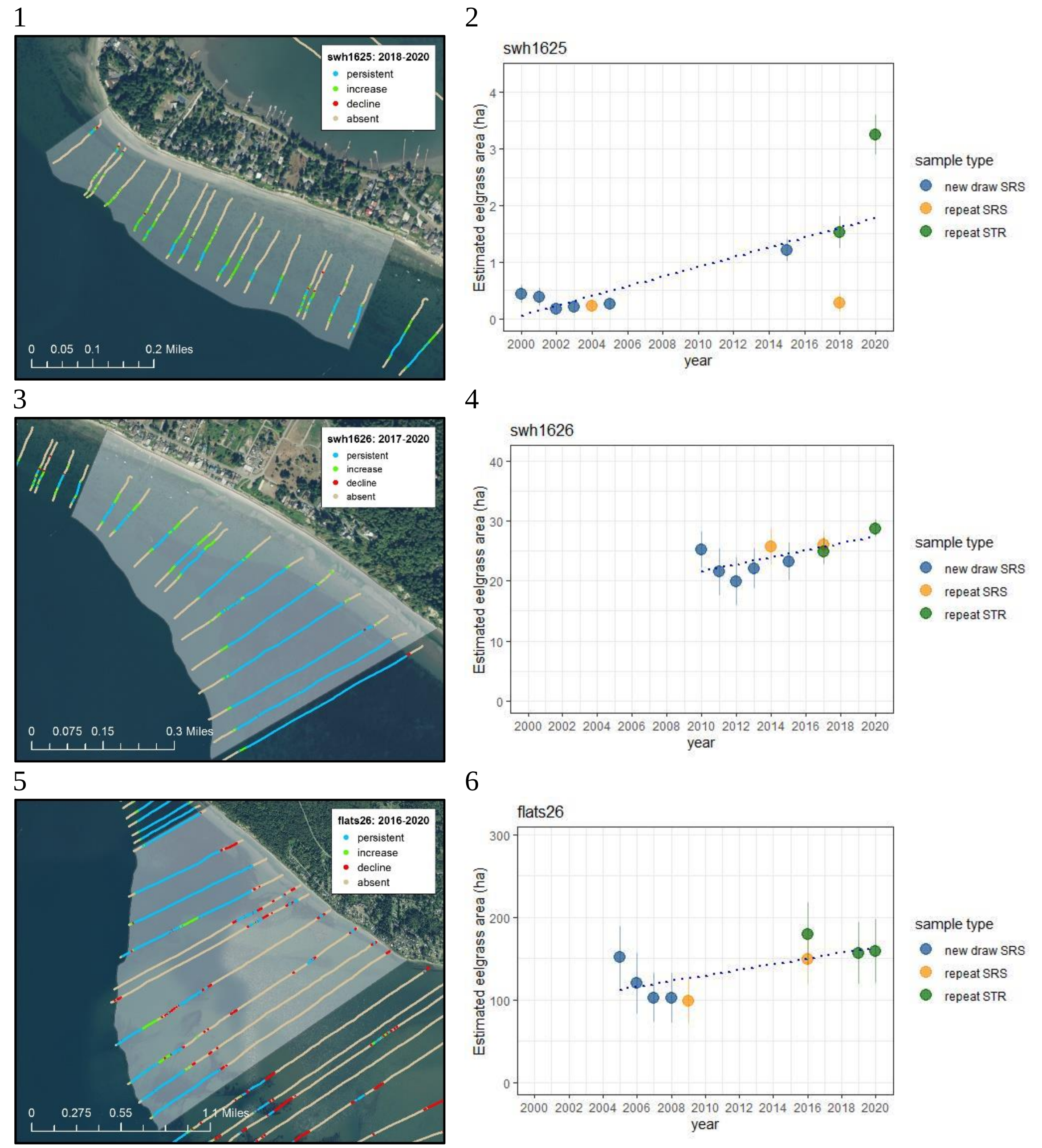


**Figure 9**: Change in eelgrass area over time at swh1625, swh1626 and flats26. The maps on the left side (1, 3, and 5) show where eelgrass appeared (green), disappeared (red), and was persistent over time (blue) along transects that were resampled over time. The years of the paired transect analysis are indicated on the map legends. The plots on the right show linear regression of all site samples over time. The different colors show the type of sample (new draw SRS, SRS repeat, or STR repeat). Error bars indicate standard error. The regression line is indicated in dark blue.

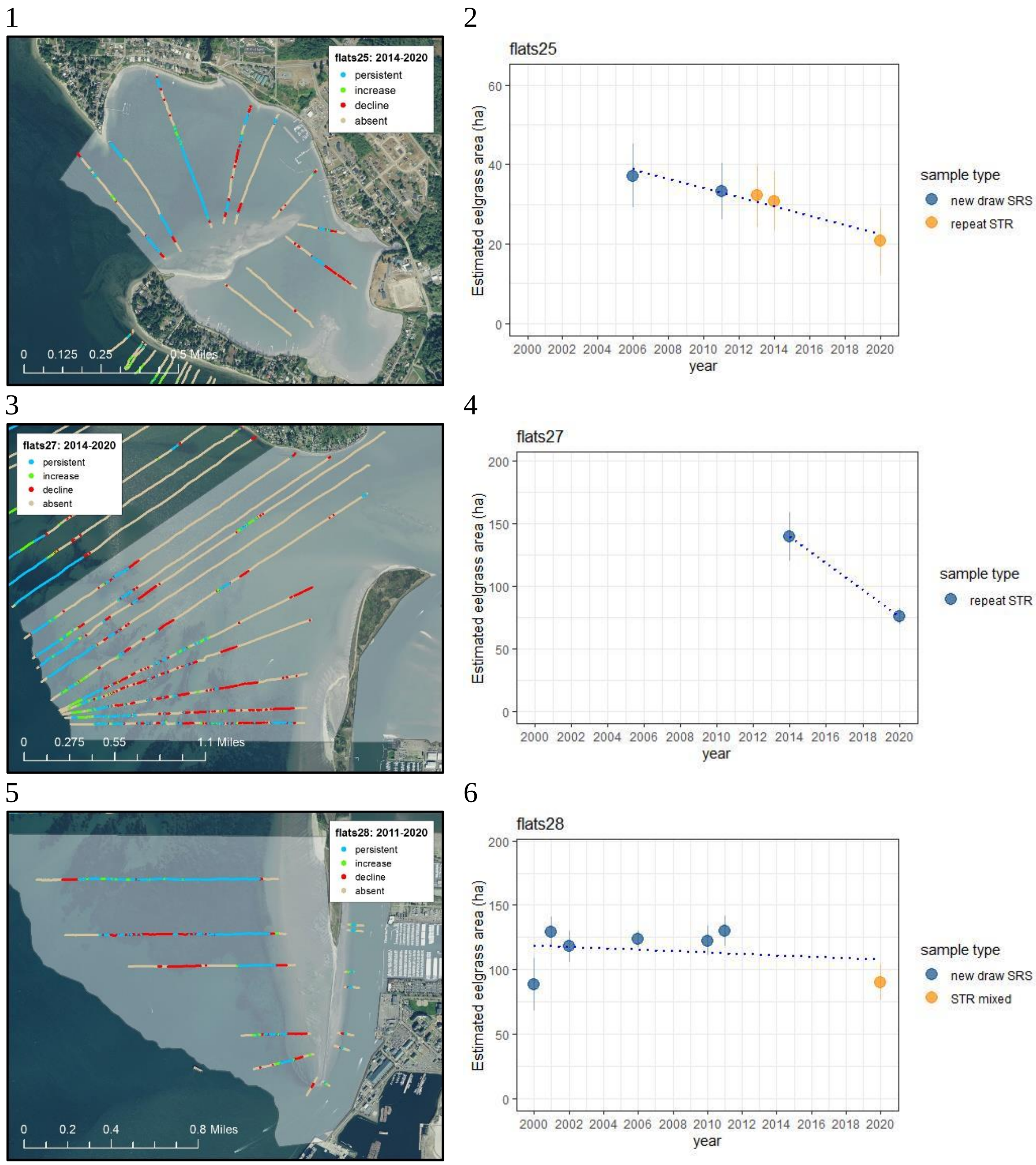


**Figure 10:** Change in eelgrass area over time at flats25, flats27 and flats28. The maps on the left side (1, 3, and 5) show where eelgrass appeared (green), disappeared (red), and was persistent over time (blue) along transects that were resampled over time. The years of the paired transect analysis are indicated on the map legends. The plots on the right show linear regression of all site samples over time. Sample types include new draw SRS, repeat SRS and repeat STR. Flats27 was only sampled twice, so analysis was limited to the pairwise comparison for this location.

## 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 93-100931. We only found seagrass, green algae, prostrate kelp, and other red/brown algae in the study area (Figure 11). Stipitate kelp, floating kelp, and *Sargassum* were not detected. Seagrass was the most widely distributed vegetation type (Figure 12). When it was detected, it was typically present in a high cover class. Frames with low % cover for seagrass were usually found at the edges of seagrass beds, or at locations where seagrass beds were fragmented (such as flats28). Green algae were present at all sites sampled (Figure 13). The largest accumulations of green algae were found in the intertidal, usually shoreward of the shallow edge of seagrass beds. Prostrate kelp was predominantly found near Hermosa Point, at the mouth of Tulalip Bay (Figure 14). Flats25 and swh2879 were the only sites with a significant presence. Other red/brown algae were often present in relatively low cover, with the highest abundance between Mission Beach and Priest Point (Figure 15). The majority of red algae were found as epiphytes growing on seagrass.

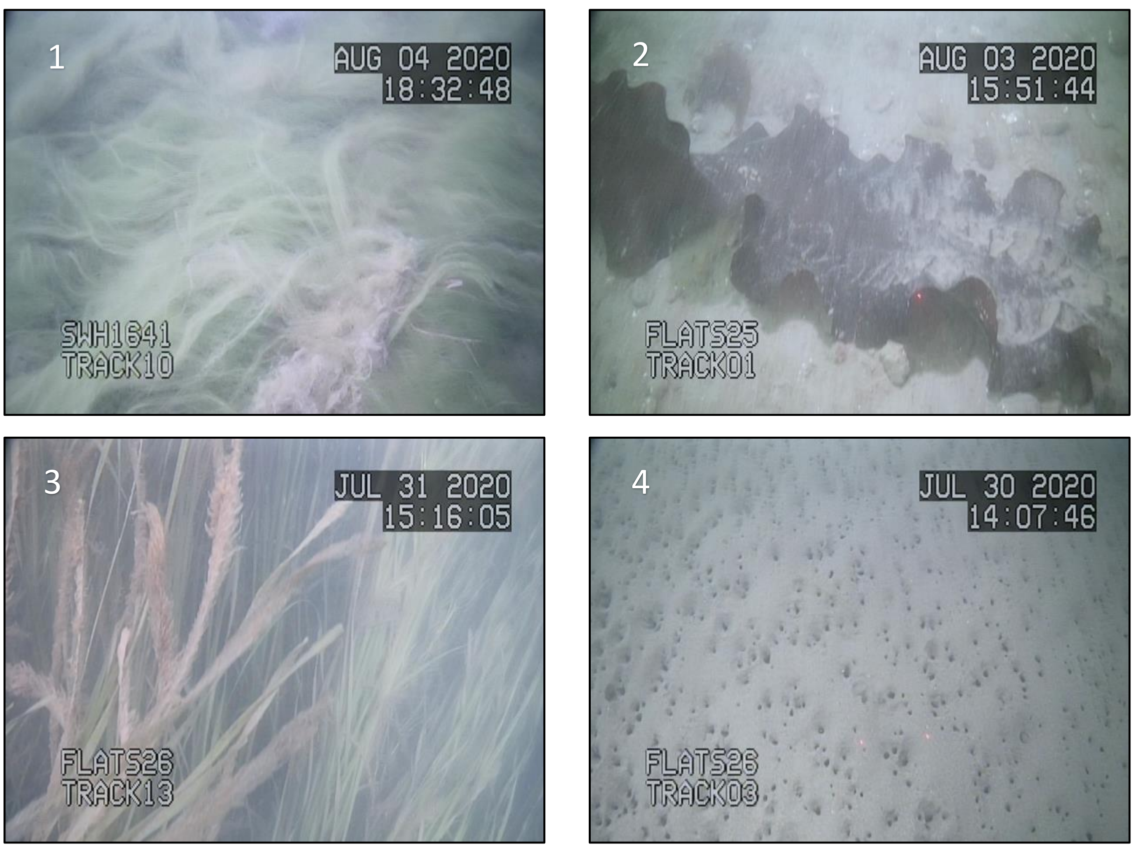


**Figure 11**: (1) Filamentous green algae at swh1641 (2) Prostrate kelp at flats25. (3) Red algae on seagrass leaves at flats26. (4) Signs of burrowing shrimp in the sediment at flats26.

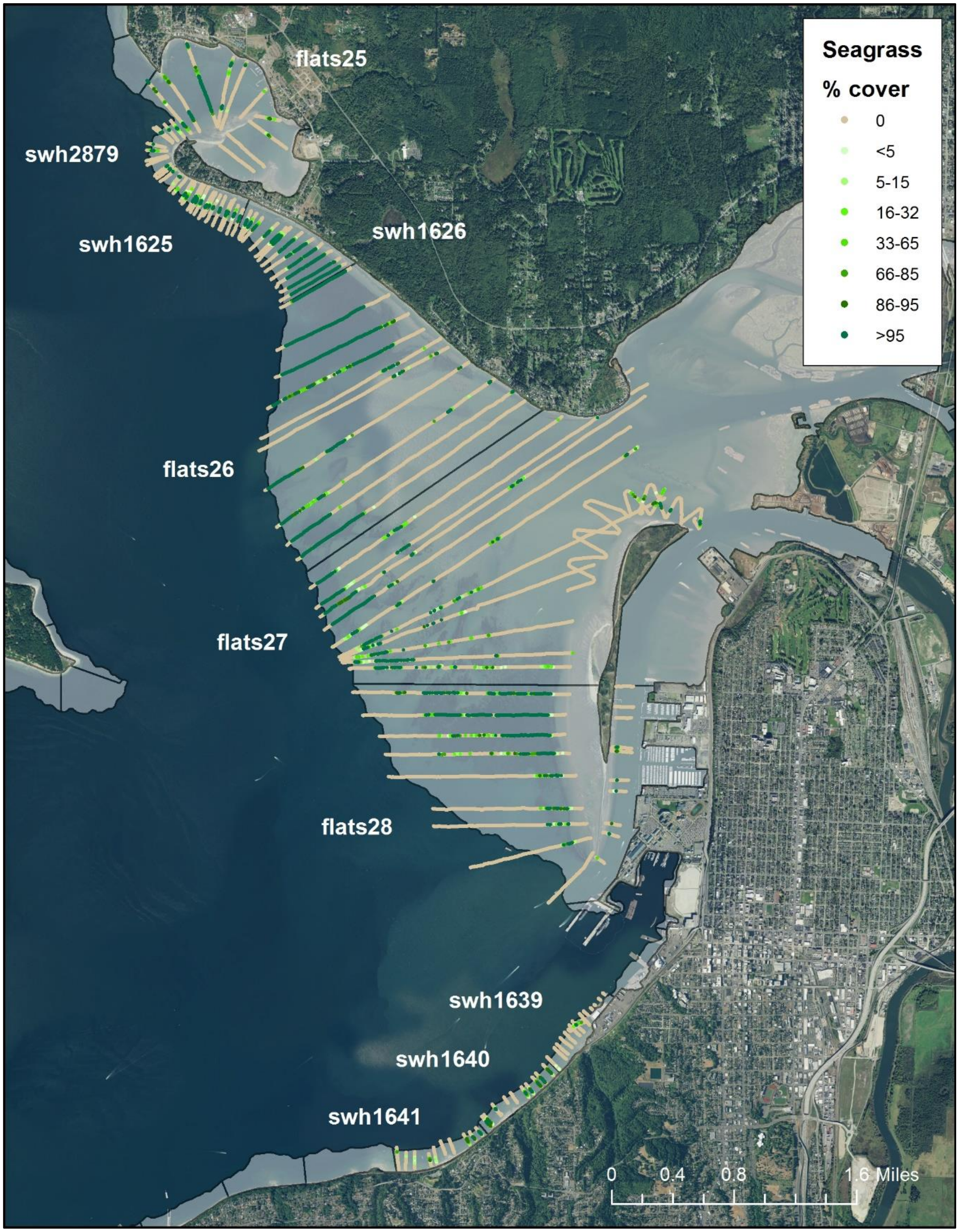


**Figure 12:** % seagrass cover at one frame every five seconds along all transects sampled in 2020.

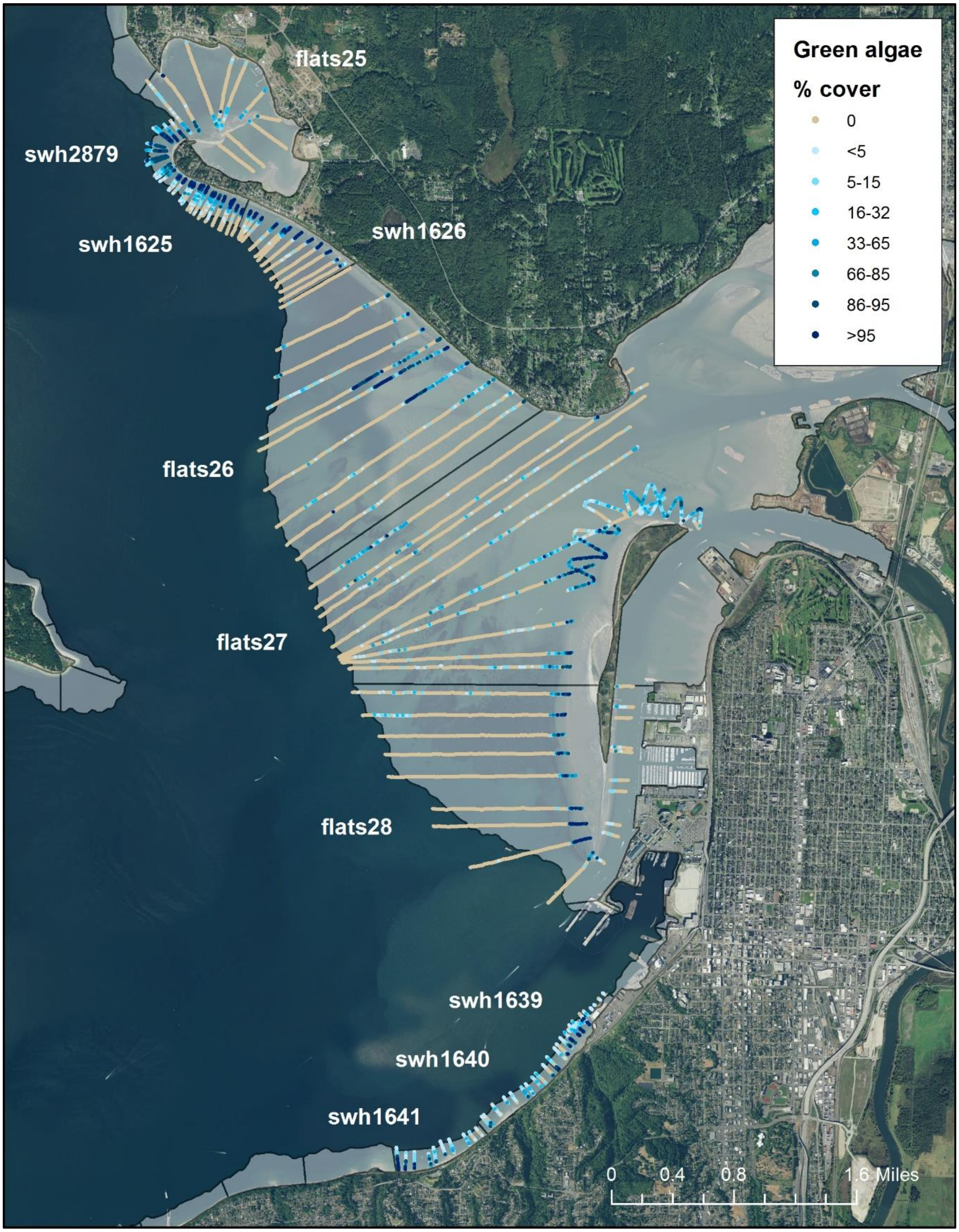


**Figure 13:** % green algae cover at one frame every five seconds along all transects sampled in 2020

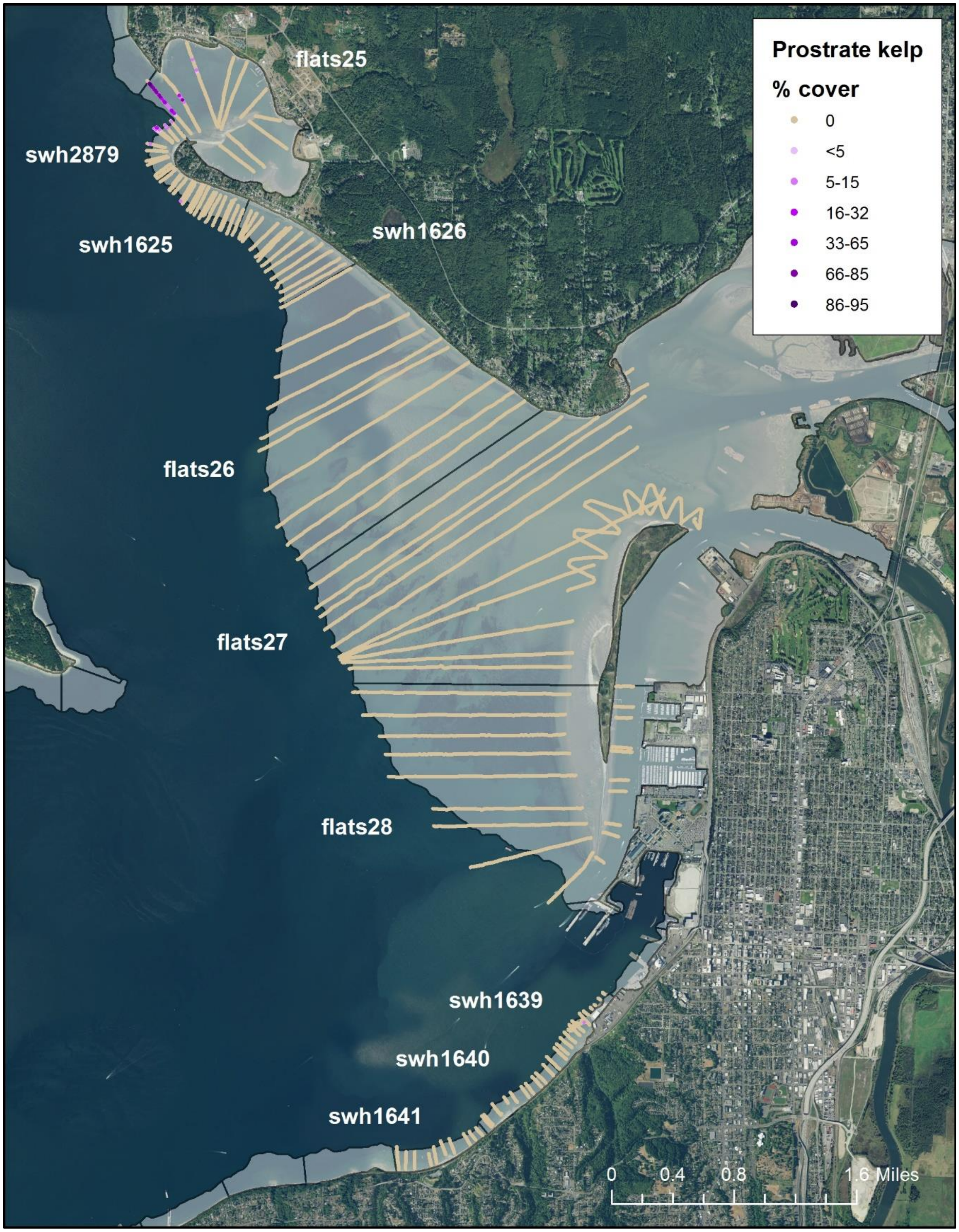


**Figure 14:** % prostrate kelp cover at one frame every five seconds along all transects sampled in 2020

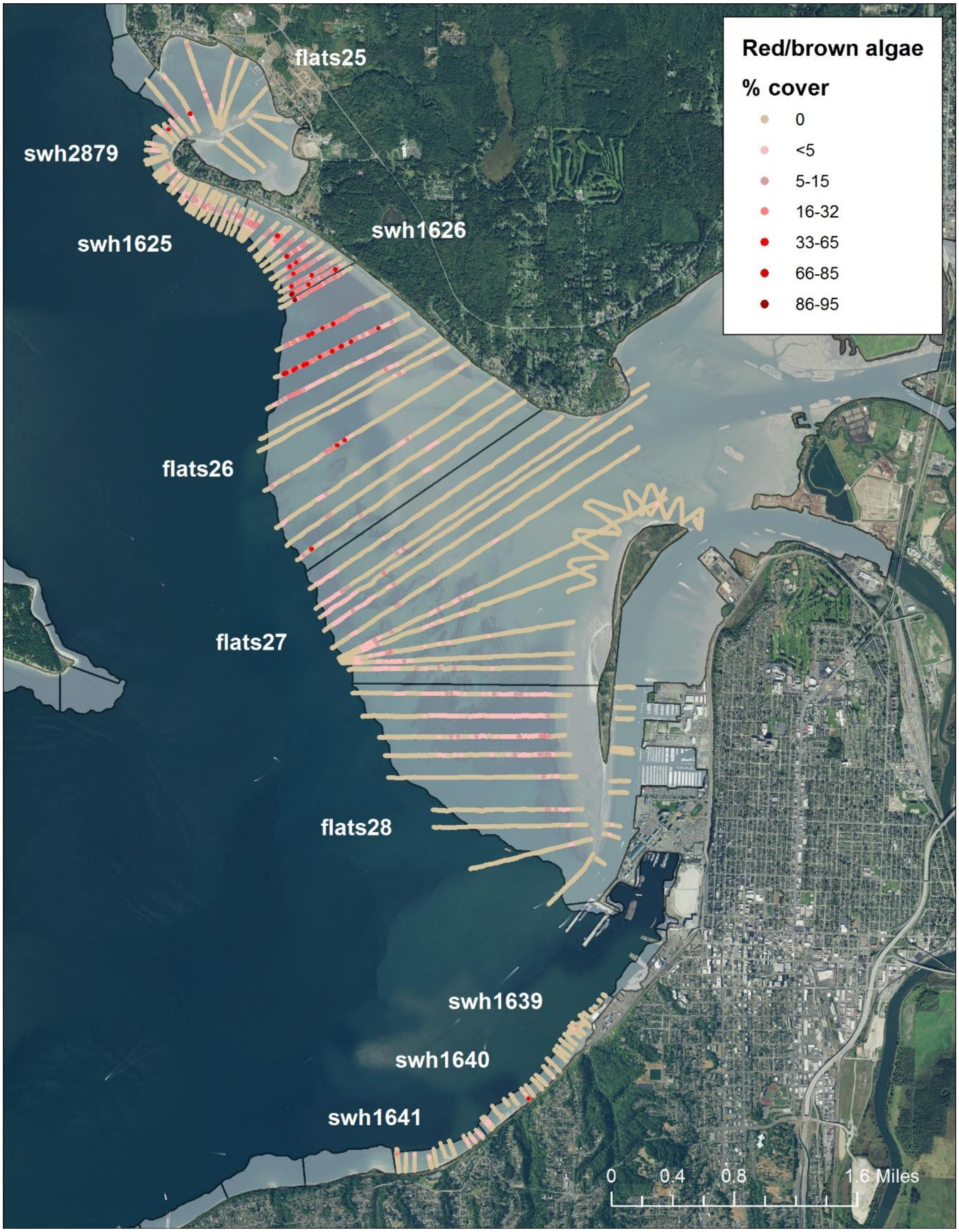


**Figure 15:** % other red/brown algae cover at one frame every five seconds along all transects sampled in 2020

Figure 16 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 404 ha of seagrass, 236 ha of green algae, 6.6 ha of prostrate kelp, and 181 ha of other red/brown algae present in the study area (Table 8, Appendix 1). Almost 70 % of all seagrass was classified as high cover (> 85 % cover). Other red/brown algae showed an opposite pattern: over 92 % of this vegetation type was classified as low cover (< 15 % cover). For green algae and prostrate kelp the pattern was less pronounced, but again the majority of observations were in the lower cover classes.

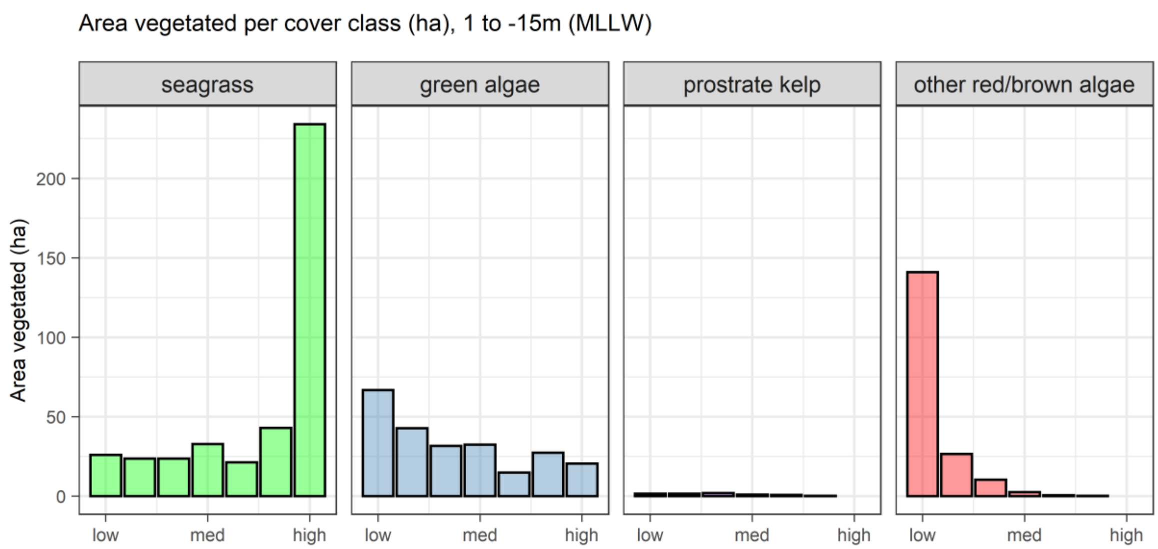


**Figure 16:** Vegetated area per vegetation type and cover class in the Snohomish delta nearshore study area.

Figure 17 and Table 6 show 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 -4 m (MLLW), which is partly due to the availability of substrate in each depth bin. There are differences between the vegetation types. Seagrass is found between 0.9 and -4.2 m (MLLW)[10], the median depth was -1.2 m. Green algae was found throughout the entire surveyed depth range (from 1.2 to -15.2 m, MLLW). However, most green algae were found at shallower depths than eelgrass (median depth = -0.3 m, MLLW).

[10] Note: Because of the lower number of classified frames, we calculated the depth distribution for the different vegetation types in 1 m depth bins. For a more accurate representation of the eelgrass depth distribution, see Figure 8.

Prostrate kelp was found between -0.4 and -15 m (MLLW). Most prostrate kelp grew at deeper depths as compared to the other vegetation types (median depth of -2.9 m, MLLW). Other red/brown algae were found between 0.7 and -8.1 m (MLLW), with a median depth of -1.2 m (MLLW).

**Table 6:** depth distribution of different vegetation types in the study area (m, MLLW); q025 is the 2.5th percentile of all vegetated depth observations at a site, q10 is the 10th percentile of all vegetated 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 a vegetation type at a site, and n is the total number of observations (note: frames classified at 5 second intervals).

| vegetation type | maxd | q025 | q10 | q25 | q50 | q75 | q90 | q975 | mind | range | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| seagrass | -4.2 | -2.3 | -1.8 | -1.5 | -1.2 | -0.9 | -0.6 | -0.4 | 0.9 | 1.9 | 6032 |
| green algae | -15.2 | -12.3 | -2.1 | -0.7 | -0.3 | 0.2 | 0.6 | 0.9 | 1.2 | 13.2 | 4854 |
| prostrate kelp | -15.0 | -10.0 | -8.9 | -4.8 | -2.9 | -2.6 | -2.2 | -2.1 | -0.4 | 7.9 | 127 |
| red/brown algae | -8.1 | -2.0 | -1.6 | -1.4 | -1.2 | -0.7 | -0.9 | -0.5 | 0.7 | 1.5 | 2711 |

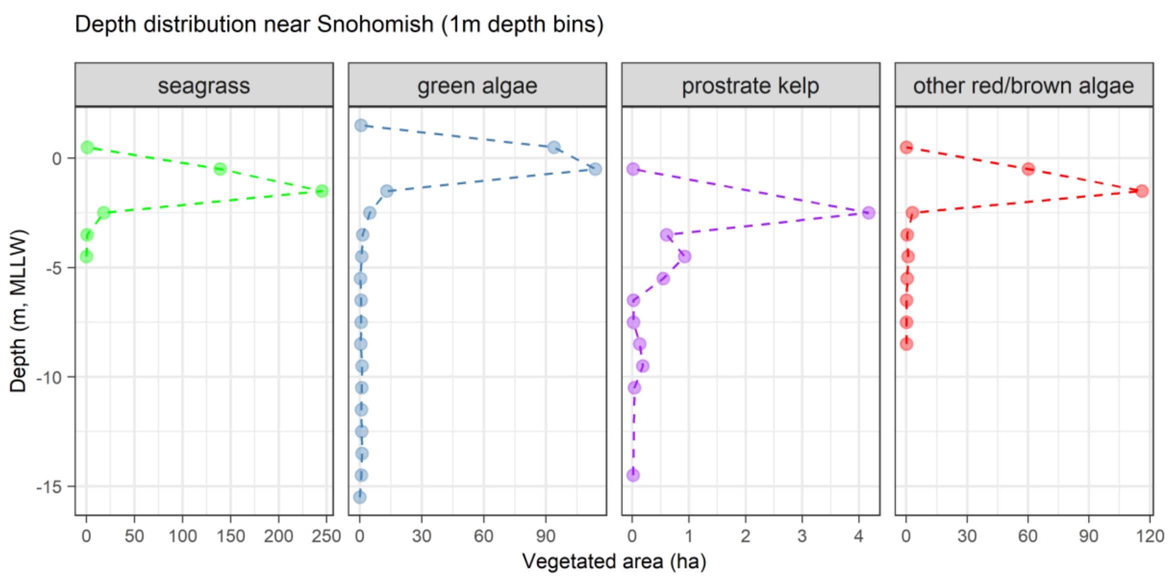


**Figure 17:** Depth distribution of seagrass, green algae, prostrate kelp and other red/brown algae, calculated as the vegetated area (ha) per 1 m depth bins in the study area.

## 3.4 Echinoderms near the Snohomish delta

We analyzed towed underwater video footage to assess the relative abundance of common, easily distinguished echinoderms at each site, 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*) 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. Only five classes were detected along the video survey transects: undifferentiated stars, giant pink stars, mottled sea stars, and the two types of sea cucumbers.

The mottled sea star (*Evasterias troschelli*, Figure 18.1) was most commonly found (n = 131). The giant pink star (*Pisaster brevispinus*, Figure 18.2) was less abundant (n = 14). There were also 93 seastars that we were not able to identify based on imagery detail (undifferentiated stars), and 5 sea cucumbers (4 *cucumaria sp.* and 1 *Parastichopus sp*.). Echinoderms were most abudant at flats25, swh2879, swh1625, swh1626, swh1639, swh1640, and swh1641. At these locations, they were commonly found below the deep edge of eelgrass beds. At flats25, echoniderms were mostly limited to the mouth of the bay. They did not occur south of the sandbar. There were few echinoderms at flats26, flats27, and flats28. If present they were mostly found at the deep edge of the study area (Figure 19).

The mottled seastars were found between -0.7 and -16m, with a median depth of -3.3 m relative to MLLW. Giant pink stars occurred slightly deeper. They were found between -2.4 and -14.1 m, with a median depth of -9.7m relative to MLLW. Undifferentiated stars were found between -1.4 and -15.1 m, with a median depth of -3.3 m relative to MLLW.

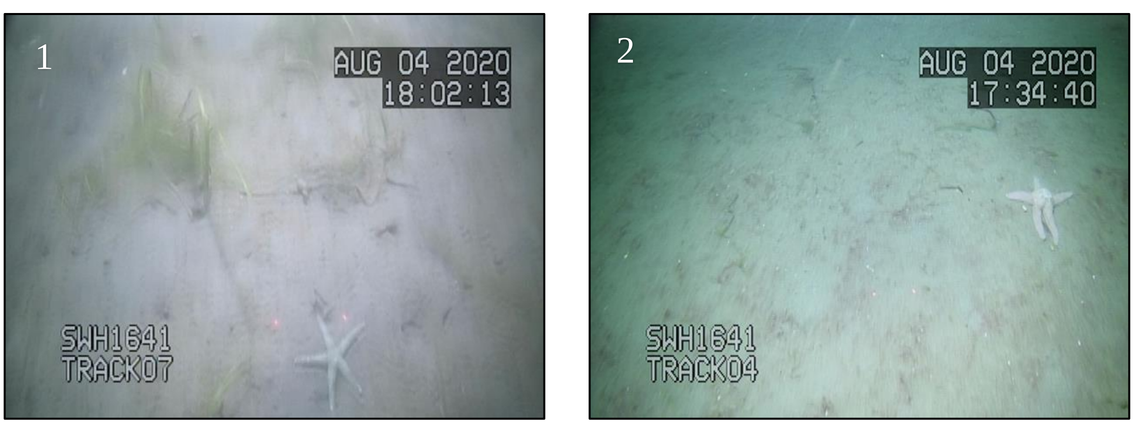


**Figure 18:** 1. Mottled sea star (*Evasterias troschelii*); 2. Giant pink star (*Pisaster brevispinus*)

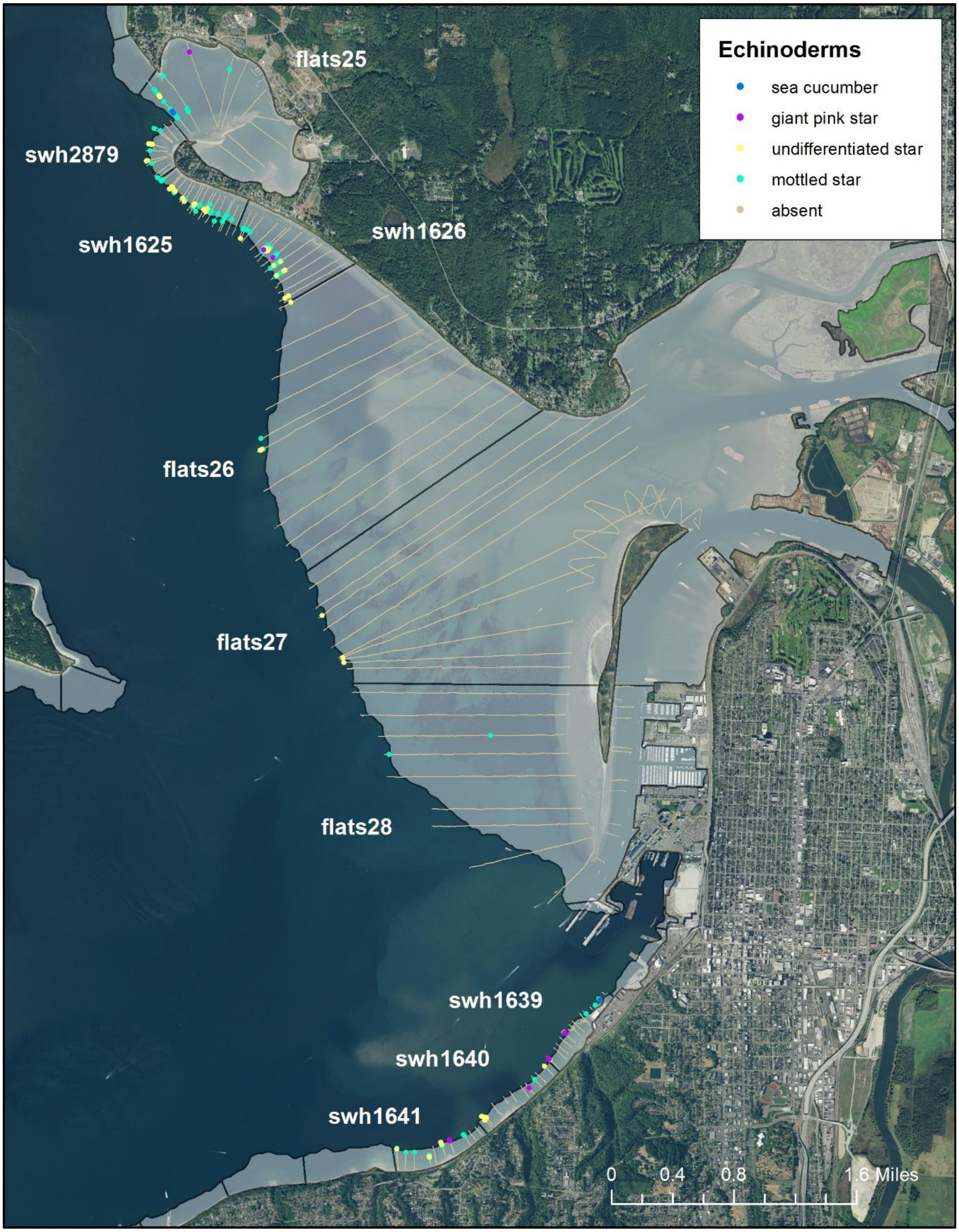


**Figure 19:** Occurrence of different species/groups of echinoderms near the Snohomish delta

**Table 7:** Total number of echinoderms between 1 and -15m relative to MLLW at each site in the study area.

| site code | undefined sea star | giant pink star | mottled sea star | sea cucumber |
|---|---|---|---|---|
| flats25 | 2 | 1 | 21 | 4 |
| flats26 | 4 | 0 | 4 | 0 |
| flats27 | 3 | 0 | 0 | 0 |
| flats28 | 0 | 0 | 2 | 0 |
| swh1625 | 26 | 0 | 35 | 0 |
| swh1626 | 19 | 2 | 38 | 0 |
| swh1639 | 5 | 8 | 5 | 1 |
| swh1640 | 7 | 1 | 2 | 0 |
| swh1641 | 10 | 2 | 13 | 0 |
| swh2879 | 17 | 0 | 11 | 0 |

# 4 Discussion

The successful conservation and restoration of critical fish habitat requires detailed knowledge on the distribution of marine vegetation, such as eelgrass and understory kelp. Currently, this information is lacking for large parts of Puget Sound, in particular for understory kelp.

Over the last decade, there has been increasing appreciation that coastal biogenic habitats, such as eelgrass meadows and kelp forests, exist as components of a functionally connected 'seascape' (Bostrom et al. 2011). Individual components support a different composition and biomass of fish species, but they are linked through exchanges 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, Zuercher and Galloway 2019). If one component of a seascape becomes degraded, it is likely to affect neighboring habitats as well.

Complexity and connectivity are important features of diverse and productive nearshore ecosystems (Bostrom et al. 2011). It is important to consider multiple habitat types for the management these ecosystems (Chalifour et al. 2019). This project represents an effort to survey different marine vegetation types by modifying an existing monitoring program for eelgrass in Puget Sound.

## 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 10 sites near the Snohomish estuary. Marine vegetation in the study area was dominated by eelgrass and green algae, which is expected for intertidal and shallow subtidal estuarine habitats, dominated by sandy substrates (Dethier 1990). Stipitate kelp, floating kelp, or *Sargassum* were not observed.

### *4.1.1 Eelgrass*

Eelgrass beds provide important habitat to a wide range of vertebrate and invertebrate species, spawning substrate for Pacific herring, and nursery habitat for commercially important and endangered fish species such as rockfish and salmonids. Juvenile chinook and chum salmon make extensive use of nearshore and estuarine environments during their early marine rearing phase (Duffy et al. 2005). These species are often found in high abundances in eelgrass beds at the outer edge of river deltas during their outmigration period (Hodgson et al. 2016, Rubin et al. 2018). Kennedy et al. (2018) found that eelgrass beds can provide important forage habitat for juvenile Chum and Chinook. Other studies have highlighted the importance of eelgrass as refuge from predation (Semmens et al. 2008).

Eelgrass was the most abundant marine vegetation type near the Snohomish estuary during summer 2020. In total there was 386 +/- 42 ha of eelgrass throughout the study area. This corresponds to 9.5 % of all eelgrass in the Saratoga Whidbey Basin, and 1.7 % of all eelgrass in greater Puget Sound. The 3 sites that comprise the delta flat (flats26, 27 and 28) had approximately 325 ha of eelgrass. The depth distribution of eelgrass was similar to other sites in the Saratoga Whidbey basin, but more limited as compared to for example Central Puget Sound. This is likely due to turbidity from the river outflow.

Six out of 10 sites were previously sampled by DNR. At 3 of these sites eelgrass area increased over time (swh1625, swh1626, and flats26), at two sites there was a decline (flats25 and flats27), and at one site no trend was detected (flats28). The decline at flats25 was gradual and most pronounced in the inner parts of the bay. At flats27, eelgrass declined by roughly 50% between 2014 and 2020 (~ 70 ha loss). This decline was most pronounced at the shallow edge of the bed. This site is likely dynamic, given its location in front of the river mouth. Other sites in front of river deltas have experienced high variability in eelgrass cover over time. A recent avulsion of the N fork of the Skagit River has carved a series of channels through the delta flat, and caused a significant loss of eelgrass in Skagit Bay (Christiaen et al. 2021 – in prep). Eelgrass beds at the mouth of the Skokomish River and the Nisqually River delta have shown both marked increases and large declines during the last 20 year (Christiaen et al. 2019).

The declines in eelgrass area at flats25 and flats27 are somewhat concerning given their location. 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, which also provide suitable spawning substrate. In addition, the Port Susan herring stock is known to deposit significant spawn on rock and gravel (Sandell et al. 2019). Eelgrass losses at flats27 was quite substantial, based on the paired transect analysis (Figure 10.3). Eelgrass on river deltas may be particularly important for juvenile salmon, as it is the first eelgrass that is encountered during outmigration (Rubin et al. 2018). This site needs to be resampled in future years, to assess if these declines persist or if they are part of natural variability at this location.

### *4.1.2 Green algae*

Green algae blooms are often associated with eutrophication, and can have negative impacts on eelgrass and other biota in nearshore habitats (Burkholder et al. 2007). They have a superior ability to sequester nutrients, and are able to outcompete other marine vegetation when nitrogen limitation is lifted (Valiela et al. 1997). There is limited information on the extent, or history of green algae blooms in Puget Sound, but anecdotal evidence suggests that localized eutrophic conditions do occur in nearshore habitats (Thom et al. 1988). Thick accumulations of green algae on the beach have caused odor related complaints near Fauntleroy Cove and Dumas Bay (Thom 1985, Nelson et al. 2011), and large mats of green algae have been documented at several locations in Puget Sound by DNR's Submerged Vegetation Monitoring Program and the Department of Ecology's Eyes over Puget Sound (ECY Publication No.20-03-070).

We estimate that there was approximately 236 ha of green algae in the study area in summer 2020. Approximately 48 ha had a high % cover (>85 %), 79 ha had medium cover, and 109 ha had a low % cover of green algae (< 15%). At the largest sites, eelgrass was more abundant than green algae. However, at some of the smaller sites green algae were the most abundant vegetation type (Table 8, Appendix 1). Green algae was present throughout the entire depth range that was sampled (~ +1 to -15 m MLLW), but the majority was found between 0.6 and -2.1m (MLLW). The highest abundance of green algae occurred in the shallow intertidal, above the shallow edge of eelgrass beds. A large fraction of these green algae likely occur as drift algae.

In general there was little overlap between green algae and other marine vegetation types, such as eelgrass, prostrate kelp or other red/brown algae. Where there was overlap, green algae were usually present in a lower cover class. Three potential sites of concern were swh1639, swh1641, and swh2879. Here the area covered by green algae was far greater than the area covered by any other vegetation type. At these locations, green algae cover may have a negative impact on the eelgrass bed, as high biomass of green algae is often associated with lower shoot density in eelgrass beds (Nelson and Lee 2001, Burkholder et al. 2007). However, green algae are highly seasonal (Nelson et al. 2003), and more dynamic than for example eelgrass beds. Our data are a snapshot of one point in time. More information is needed to assess if green algae blooms are a recurring phenomenon at these locations.

### *4.1.3 Understory kelp*

Kelp beds are an important, but often overlooked, habitat type in greater Puget Sound. Similar to eelgrass, they support high biodiversity and are important habitat for juveniles of several commercially important or forage fish species (Johnson et al. 2003, Shaffer et al. 2020). Kelp beds are important nursery habitat for juvenile rockfish species (Matthews 1989, Hayden-Spear 2006). They also improve the nursery function of other nearshore habitat types. Olsen 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. Understory kelp beds are a common feature of nearshore habitats in our region. Based on the ShoreZone survey (Berry et al. 2001), they occur along 31% of the shoreline of Washington State, as compared to 11% for floating kelp. Despite their importance and relative abundance, understory kelp beds are not actively monitored in greater Puget Sound.

Understory kelp was relatively sparse in the study area. In total we detected 6.6 ha of prostrate kelp (predominantly *Saccharina sp*.) at the mouth of Tulalip Bay. Approximately half of this kelp occurred as low cover (<15%), while the remainder was predominantly present as medium cover (between 15 and 85%). The limited spatial extent of kelp was expected, as kelp is generally sparse in nearshore delta environments (Dethier 1990). Kelp prefers to grow on rock or coarse substrate in relatively exposed environments (Mumford

2007). The subtidal parts of the study area consist mainly of sandy substrate. Prostrate kelp was found through most of the depth range sampled, but it did not occur as shallow as the other vegetation types (-0.4 to -15m, MLLW).

### *4.1.4 Other red/brown algae*

Other red/brown algae were abundant in the study area, but they mostly occurred as relatively low % cover epiphytes on seagrass leaves. This was expected, as red and brown algae are not common on sandy sediments (Dethier 1990). We estimate that there were approximately 181 ha of red/brown algae in the study area during summer 2020. The highest amounts were found at swh1626, flats26, flats27, and flats28 (the sites with the largest eelgrass beds). The highest % cover was found at swh1626 and flats26. High epiphyte loads can reduce the light penetration in eelgrass beds, and contribute to eelgrass declines under eutrophic conditions (Brush & Nixon 2002, Burkholder et al. 2007). However, they are an essential component of seagrass ecosystems, and often contribute significantly to the high primary productivity of seagrass beds (Phillips 1984, Thom 1990). A large number seagrass associated organisms graze on epiphytic algae, including amphipods, gastropods, shrimp and small fish. These grazers play a key role in controlling epiphytic biomass on seagrass leaves, and are an importance source of prey for higher order consumers (Heck and Valentine 2006). A high abundance but relative low % cover of epiphytes is expected in a healthy eelgrass bed.

## 4.2 Echinoderms near the Snohomish Estuary

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). Infected sea stars developed large lesions, and subsequently lost one or several arms before dying. This epidemic, called sea star wasting disease, was caused by a virus but has been linked to the unusual warm waters during this period of time (Eisenlord et al. 2016, Miner et al. 2018).

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 15 classes of echinoderms along each transect. Only 5 classes were detected in the study area: undifferentiated stars, giant pink stars (*Pisaster brevispinus*), mottled sea stars (*Evasterias troschelii)*, and two types of sea cucumbers (*Cucumaria sp.* and *Parastichopus sp.).*

In total, we found 131 mottled stars, 14 giant pink stars, 93 undifferentiated stars and 5 sea cucumbers along 78.6 km of sampled transects. We were not able to detect small individuals and sea stars inside dense vegetation or under surfaces, so these numbers are conservative estimates. Sea stars were mostly found at the edges of the study area, away from the delta flat, which may be due to avoidance of low salinities.

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. Giant pink stars and mottled sea stars are common in Puget Sound. Both 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. 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).

Montechino_Latorre et al. (2016) found the largest impacts of sea star wasting disease in greater Puget Sound occurred in sunflower stars (*Pycnopodia helianthoides*), giant pink stars, striped sun stars (*Solaster stimpsoni*), morning sun stars (*Solaster dawsoni*) and rainbow stars (*Orthasterias koehleri*). The epidemic only had a moderate impact on populations of mottled sea stars, subtidal ochre stars (*Pisaster ochraceus*) and blood stars (*Henricia leviscula*). This corresponds to the relative abundance of species found near the Snohomish estuary. Mottled stars were almost 10 times as abundant as giant pink stars, and sensitive species that also occur on sandy substrates (such as sunflower stars) were not detected. These findings suggest that towed underwater videography may be a useful tool for large area monitoring of shallow subtidal sea star populations.

## 4.3 Data use and availability

This project has generated a large area profile for eelgrass, understory kelp, and other vegetation types at 10 sites along the Snohomish estuary, from Hermosa Point (North of Tulalip Bay) down to Port Gardner. 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 (scheduled for 2021). 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

# 5 References


- Berry H.D., J.R. Harper, T.F. Mumford Jr., B.E.  Bookheim, A.T. Sewell, L.J. Tamayo. 2001. The Washington State ShoreZone Inventory User's Manual. Olympia, WA: DNR Nearshore Habitat Program.
- Bostrom C., S.J. Pittman, C. Simenstad, R.T. Kneib. 2011. Seascape ecology of coastal biogenic habitats: advances, gaps, and challenges. Marine Ecology Progress Series 427: 187-190.
- Brush M.J., S.W.Nixon. 2002. Dirct measurments of light attenuation by epiphytes on eelgrass *Zostera marina*. Marine Ecology Progress Series 238: 73-79
- Burkholder J.M., D.A. Tomasko, B.W. Touchette. 2007. Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology 350:46-72
- Calloway M., D. Oster, H. Berry, T. Mumford, N. Naar, B. Peabody, L. Hart, D. Tonnes, S. Copps, J. Selleck, B. Allen, and J. Toft. 2020. Puget Sound kelp conservation and recovery plan. Prepared for NOAA-NMFS, Seattle, WA. 52 pages plus appendices. Available at: https://nwstraits.org/our-work/kelp/.
- Chalifour L., D.C. Scott, M. MacDuffee, J.C. Iacarella, T.G. Martin, J.K. Baum. 2019. Habitat use by juvenile salmon, other migratory fish, and resident fish species underscores the importance of estuarine habitat mosaics. Marine Ecology Progress Series 625: 145-162.
- Christiaen B., J. Gaeckle, L. Ferrier. 2017. Eelgrass abundance and depth distribution on Bainbridge Island. Final report to the City of Bainbridge Island, DNR IAA 16-239. Nearshore Habitat Program, Washington Department of Natural Resources, Aquatic Resources Division, Olympia WA.
- Christiaen B., J. Gaeckle, L. Ferrier. 2018. Eelgrass abundance and depth distribution in East Kitsap. Final report to the Suquamish Tribe, DNR IAA 15-17 Amendment 1. Nearshore Habitat Program, Washington Department of Natural Resources, Aquatic Resources Division, Olympia WA.
- Christiaen B., L. Ferrier, P. Dowty, J. Gaeckle, H. Berry (2019). Puget Sound Seagrass Monitoring Report: Monitoring Year 2016 - 2017. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, WA.

- Christiaen B., J. Gaeckle, L. Ferrier. 2020. Eelgrass abundance and depth distribution in King County. Final Report to King County. DNR IAA 93-097520. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, WA
- Christiaen B., L. Ferrier, P. Dowty, J. Gaeckle, H. Berry (2021). Puget Sound Seagrass Monitoring Report: Monitoring Year 2018 - 2019. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, WA. – in preparation
- Cochran WG. 1977. Sampling Techniques. John Wiley and Sons, New York
- Costanza R., R. Arge, R. de Groot, S. Farber, M. Grasso, B. Hannum, K. Limburg, S. Naeem. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.
- Dethier M.N. 1990. A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Dept. Natural Resources. 56 pp. Olympia, Wash.
- Dowty P., L. Ferrier, B. Christiaen, J. Gaeckle, H. Berry. 2019. Submerged Vegetation Monitoring Program: 2000-2017 Geospatial Database User Manual. Washington Department of Natural Resources. Olympia, WA.
- Duarte C.M., J.J. Middelburg, N. Caraco. 2005. Major role of marine vegetation on the oceanic carbon cycle. Biogeosciences 2: 1-8
- Duffy E.J., D.A. Beauchamp, R.M. Buckley. 2005. Early marine life history of juvenile Pacific salmon in two regions of Puget Sound. Estuarine, Coastal and Shelf Science 64(1): 94-107
- ECY Publication No.20-03-070. 2020. Eyes over Puget Sound. 2019 in review. https://apps.ecology.wa.gov/publications/documents/2003070.pdf
- Eisenlord M.E., M.L. Groner, R.M. Yoshioka, J. Elliott, J. Maynard, S. Fradkin, M. Turner, K. Pyne, N. Rivlin, R. van Hooidonk, C.D. Harvell. 2016. Ochre star mortality during the 2014 wasting disease epizootic: role of population size structure and temperature. Philosophical Transactions of the Royal Society London 371: 20150212.
- Filbee-Dexter K., T. Wernberg. 2018. Rise of turfs: A new battlefront for globally declining kelp forests. BioScience. 13 pages.
- Hannam M.P., P. Dowty, B. Christiaen, H. Berry, L. Ferrier, J. Gaeckle, J. Stowe, E. Sutton. 2015. Depth Distribution of Eelgrass in Greater Puget Sound. Nearshore Habitat Program, Washington Department of Natural Resources, Olympia, WA
- Hayden-Spear J. 2006. Nearshore habitat associations of young-of-year copper (*Sebastes caurinus*) and quillback (*S. maliger*) rockfish in the San Juan Channel, Washington. Master of Science Dissertation, University of Washington, Seattle, WA. 38 pages.
- Heck K.L., J.F. Valentine. 2006. Plant-herbivore interactions in seagrass meadows. Journal of Experimental Marine Biology and Ecology 330: 420-436
- Heck K.L., T.J.B. Carruthers, C.M. Duarte, A.R. Hughes, G. Kendrick, R.J. Orth, and S.W. Williams. 2008. Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers. Ecosystems 11:1198−1210

- Hodgson S., C.S. Ellings, S.P. Rubin, M.C. Hayes, W. Duval, E.E. Grossman. 2016. 2010-2015 Juvenile Fish Ecology in the Nisqually River Delta and Nisqually Reach Aquatic Reserve. Nisqually Indian Tribe Department of Natural Resources. Salmon Recovery Program Technical Report No. 2016-1
- Hyndes G.A., P.S. Lavery, C. Doropoulos. 2012 Dual processes for cross-boundary subsidies: incorporation of nutrients from reef-derived kelp into a seagrass ecosystem. Marine Ecology Progress Series 445:97-107. https://doi.org/10.3354/meps09367
- Johnson S.W., L. Murphy, D.J. Csepp, P.M. Harris, J.F. Thedinga. 2003. A survey of fish assemblages in eelgrass and kelp habitats in southeastern Alaska. U.S. Dpartment of Commerce, NOAA Technical Memo. NMFS-AFSC-139, 39p
- Kennedy L.A., F. Juanes, R. El-Sabaawi. 2018. Eelgrass as valuable nearshore foraging habitat for juvenile Pacific salmon in the early marine period. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 10: 190-203
- Klinkenberg B. (Editor). 2019. E-Fauna BC: Electronic Atlas of the Fauna of British Columbia [efauna.bc.ca]. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver.
- Kozloff E.N. 1996. Marine Invertebrates of the Pacific Northwest. University of Washington Press
- Krause-Jensen D., C. M. Duarte. 2016. Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience. Volume 9, pages 737 to 743.
- Krumhansl K. A., R. E. Sheibling. 2012. Production and fate of kelp detritus. Marine ecology progress series 467, pages 281 to 302.
- Mann K. H. 1973. Seaweeds: Their productivity and strategy for growth. Science, 182, 975–981. https://doi.org/10.1126/science.182.4116.975
- Matthews K.R. 1990. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. Fishery Bulletin. Volume 88, pages 223-239.
- McGarvey R., P. Burch, J.M. Matthews. 2016. Precision of systematic and random sampling in clustered populations: habitat patches and aggregating organisms. Ecological Applications 26(1):233-248.
- Miner C.M., J.L.Burnaford, R.F. Ambrose, L. Antrim, H. Bohlmann, C.A. Blanchette, J.M. Engle, S.C. Fradkin, R. Gaddam, C.D.G. Harley, B.G. Miner, S.N. Murray, J.R. Smith, S.G. Whitaker, P.T. Raimondi. 2018. Large-scale impacts of sea star wasting disease (SSWD) on intertidal sea stars and implications for recovery. PLoS ONE 13(3): e0192870. https://doi.org/10.1371/journal.pone.0192870
- Montecino-Latorre D., M.E. Eisenlord, M. Turner, R. Yoshioka, C.D. Harvell, C.V. Pattengill-Semmens, J.D. Nichols, J.K. Gaydos. 2016. Devastating transboundary impacts of Sea Star Wasting Disease on subtidal asteroids. PLoS ONE 11: e0163190. https://doi.org/10.1371/journal.pone.0163190

- Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.
- Murphy M. L., S. W. Johnson, D. J. Csepp. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bullulletin 7:11-21.
- Nelson T.A., A. Lee. 2001. A manipulative experiment demonstrates that blooms of the macroalga *Ulvaria obscura* can reduce eelgrass shoot density. Aquatic Botany 71: 149-154.
- Nelson T.A., A.V. Nelson, M. Tjoelker. 2003. Seasonal and spatial patterns of 'green tides' (Ulvoid macroalgae blooms) and related water quality parameters in the coastal waters of Washington State, USA. Botanica marina 46: 263-275.
- Norderhaug K.M., K. Filbee-Dexter, C. Freitas, S.R. Birkeley, L. Christensen, I. Mellerud, J. Thormar, T. van Son, F. Moy, M. Vazques Alonso, H. Steen. 2020. Ecosystem-level effects of large-scale disturbance in kelp forests. Marine Ecology Progress Series 656: 163-180.
- Norris J.G., S. Wyllie-Echeverria, T. Mumford, A. Bailey, T. Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquatic Botany 58:269-287
- Olson A. M., M. Hessing-Lewis, D. Haggarty, F. Juanes. 2019. Nearshore seascape connectivity enhances seagrass meadow nursery function. Ecological Applications. Volume 29(5), e01897.
- Pasek J., A. Tahk A, G. Cutler, M. Schwemmle. 2018. weights: Weighting and Weighted Statistics. R package version 1.0. https://CRAN.R-project.org/package=weights
- Phillips RC (1984). The ecology of eelgrass meadows in the Pacific Northwest: a community profile. U. S. Fish and Wildlife Service FSW/OBS-84/24. 85pp. Available online: http://www.nwrc.gov/library.html
- R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.
- Robinson D., A. Hayes. 2018. broom: Convert Statistical Analysis Objects into Tidy Tibbles. R package version 0.5.1. https://CRAN.R-project.org/package=broom
- Rubin S.P., I.M. Miller, M.M. Foley, H.D. Berry, J.J. Duda, B. Hudson., N.E. Elder, M.M. Beirne, J.A. Warrick, M.L. McHenry, A.W. Stevens, E.F. Eidam, A.S. Ogston, G. Gelfenbaum, R. Pedersen. 2017. Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. PLoS ONE 12(12): e0187742. https://doi.org/10.1371/journal.pone.0187742
- Rubin S.P., M.C. Hayes, E.E. Grossman. 2018. Juvenile Chinook salmon and forage fish use of eelgrass habitats in a diked and channelized Puget Sound river delta. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 10: 435-451

- Sandell T., A. Lindquist, P. Dionne, D. Lowry. 2019. 2016 Washington State Herring Stock Status Report. Washington Department of Fish and Wildlife. Fish Pogram, Fish management Division. Fish Program Technical Report No. FPT 19-07.
- Semmens B.X. 2008. Acoustically derived fine-scale behaviors of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) associated with intertidal benthic habitats in an estuary. Canadian Journal of Fisheries and Aquatic Sciences 65(9): 2053-2062
- Shaffer A.J., S.H. Munsch, J.R. Cordell. 2020. Kelp forest zooplankton, forage fishes, and juvenile salmonids of the northeast Pacific nearshore. Marine and Coastal Fisheries. Volume 12(4), 4-20.
- Smale, D. A. 2019. Impacts of ocean warming on kelp forest ecosystems. New Phytologist.
- Thom R.M. 1985. An oceanographic analysis of odorous beach conditions in Fauntleroy Cove, West Seattle. Fisheries Research Institute, WH-10. University of Washington, Seattle.
- Thom R.M., A.E. Copping, R.G. Albright. 1988. Nearshore primary productivity in central Puget Sound: a case for nutrient limitation in the nearshore systems of Puget Sound. Proceedings of the first annual meeting on Puget Sound research, Volume 2. Puget Sound Water Quality Authority, Seattle, Washington.
- Thom, R.M., 1990. Spatial and temporal patterns in plant standing stock and primary production in a temperate seagrass system. Botanica Marina 33: 497–510
- Unsworth R.K.F., B. Williams, B.L. Jones, L.C. Cullen-Unsworth. 2017. "Rocking the Boat: Damage to Eelgrass by Swinging Boat Moorings." Frontiers in Plant Science 8: 1309.
- Unsworth R.K.F., L.M. Nordlund, L.C. Cullen-Unsworth. 2019. Seagrass meadows support global fisheries production. Conservation Letters 12: e12566
- Valiela I., J. McClelland, J. Hauxwell, P.J. Behr, D. Hersh, K. Foreman. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. Limnol. Oceanogr. 42: 1105–1118.
- Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.
- Wickham H., R. François, L. Henry, K. Müller. 2018. dplyr: A Grammar of Data Manipulation. R package version 0.7.8. https://CRAN.R-project.org/package=dplyr
- Wickham H., L. Henry. 2018. tidyr: Easily Tidy Data with 'spread()' and 'gather()' Functions. R package version 0.8.2. https://CRAN.R-project.org/package=tidyr
- Wilson K.L., Lotze H.K. 2019. Climate change projections reveal range shifts of eelgrass Zostera marina in the Northwest Atlantic. Marine Ecology Progress Series 620:47-62. https://doi.org/10.3354/meps12973
- Zuercher R., A.W.E. Galloway. 2019. Coastal marine ecosystem connectivity: pelagic ocean to kelp forest subsidies. Ecosphere 10(2): e02602

# 6 Appendix 1

**Table 8:** 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 | green algae | other red/brown algae | prostrate kelp |
|---|---|---|---|---|---|
| **flats25** | 35.6 | 22.2 | 9.5 | 5.6 | 6.2 |
| **flats26** | 220.9 | 163.2 | 56.5 | 75.7 | 0.0 |
| **flats27** | 154.9 | 79.8 | 83.0 | 30.9 | 0.0 |
| **flats28** | 136.0 | 98.6 | 39.3 | 48.1 | 0.0 |
| **swh1625** | 13.0 | 3.9 | 9.7 | 1.9 | 0.0 |
| **swh1626** | 35.3 | 27.5 | 9.4 | 17.2 | 0.0 |
| **swh1639** | 5.0 | 0.3 | 4.9 | 0.0 | 0.0 |
| **swh1640** | 7.9 | 4.9 | 4.3 | 0.3 | 0.0 |
| **swh1641** | 10.0 | 2.2 | 8.7 | 0.8 | 0.0 |
| **swh2879** | 11.9 | 1.3 | 10.8 | 0.6 | 0.4 |