NATURAL RESOURCES

Marine Vegetation in the southern Salish Sea

Final report to the SeaDoc Society

A17-0568-S012

02/01/2023

PSEMP
Puget Sound Ecosystem Monitoring Program

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

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

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

Cover Photo: Understory kelp and surfgrass near Tongue Point, WA. Photo credit: Bart Christiaen

Marine Vegetation in the southern Salish Sea

Final report to the SeaDoc Society

A17-0568-S012

02/01/2023

Bart Christiaen
Helen Berry
Lisa Ferrier
Pete Dowty
Jeff Gaeckle
Lauren Johnson
Melissa Sanchez
Tyler Cowdrey

Nearshore Habitat Program
Aquatic Resources Division

Puget Sound Ecosystem Monitoring Program

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

Acknowledgements

The Nearshore Habitat Program is part of the Washington State Department of Natural Resources' (DNR) Aquatic Resources Division, the steward for State Owned Aquatic Lands. The Nearshore Habitat Program monitors and evaluates the status and trends of marine vegetation for DNR and the Puget Sound Partnership.

The Nearshore Habitat Program is grateful to the SeaDoc Society for providing funding to expand classification of previously collected underwater video footage for understory kelp and other marine vegetation types. The following document is the final deliverable for agreement A17-0568-S012.

The primary authors for this report are Bart Christiaen, Helen Berry, Lisa Ferrier, Pete Dowty and Jeff Gaeckle. Lauren Johnson and Melissa Sanchez played a critical role in the video data collection and post-processing for the work summarized in this report. Tyler Cowdrey provided GIS support.

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

Washington State Department of Natural Resources
Aquatic Resources Division
1111 Washington St. SE
Olympia, WA 98504-7027
www.dnr.wa.gov

Copies of this report may be obtained from:

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

This report should be cited as:

Christiaen B., H. Berry, L. Ferrier, P. Dowty, J. Gaeckle, L. Johnson, M. Sanchez and T. Cowdrey. 2023. Marine Vegetation in the southern Salish Sea. Final report to the SeaDoc Society. A17-0568-S012. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, WA.

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 and algae, important components of nearshore ecosystems in the southern Salish Sea.

Since 2000, DNR has monitored abundance and depth distribution of native seagrasses to determine status and trends in the southern Salish Sea 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 a Vital Sign indicator to track progress in the restoration and recovery of Puget Sound.

DNR has monitored canopy-forming kelp along the outer coast and the Strait of Juan de Fuca since 1989. Over time, DNR has expanded the scope of its floating kelp monitoring program, and now uses a variety of methods to monitor floating kelp throughout the southern Salish Sea. DNR is also leading development of a new 'floating kelp canopy area indicator' for the Puget Sound Partnership Vital Signs.

In October 2021, DNR entered into a research agreement with the Regents of the University of California (A17-0568-S012) following a grant proposal to the SeaDoc Society. The goal of this agreement is to use the towed underwater video footage from the SVMP to construct a baseline of the spatial and depth distribution of understory kelp and other subtidal vegetation throughout the southern Salish Sea. This broad-scale assessment informs our understanding of habitat abundance and distribution, and provides context for higher resolution dive studies. It addresses three major themes in The Puget Sound Kelp Conservation and Recovery Plan (Calloway et al. 2020): to describe kelp distribution and trends; to fill knowledge gaps related to understory kelp; and to promote awareness and engagement. This report is the final deliverable for Research Agreement A17-0568-S012. It also includes data collected for a different project (grant no. F20AP12280-00 from the Pacific Marine and Estuarine Fish Habitat Partnership, awarded by the US Department of Fish and Wildlife).

This report is a first step towards a comprehensive assessment of marine vegetation in the southern Salish Sea. It represents exploratory work into a research topic with major knowledge and methodological gaps. Methods for sampling and analysis are still under development. The study area for this report is limited to 'fringe habitat' along the shoreline of the southern Salish Sea. It does not cover river deltas and large tide flats. This spatial limitation excludes areas with predominantly eelgrass and green algae, as understory kelp tends to be sparse at those locations. Sampling also excludes area with floating kelp beds, in order to avoid towfish entanglement. This likely leads to an underestimate of understory kelp and other red and brown algae.

Despite these limitations, this project substantially enhances our understanding of regional patterns in vegetation abundance and depth distribution, and provides valuable information for the management of nearshore habitats in the southern Salish Sea.

Key findings:

- Marine vegetation was ubiquitous. Approximately ~ 60% of the nearshore area (from +1 m to -15 m, MLLW) along fringing shorelines had marine vegetation present. The predominant vegetation types in fringe habitat in the southern Salish Sea were understory kelp and other red-brown algae.
- We estimate that there were between 20,032 - 23,923 ha of understory kelp in the study area (95% confidence interval, cover class > 1), which suggests that there is as least as much understory kelp as eelgrass in the region[1]. Note that our understory kelp estimates are an underestimate because we were not able to survey in areas with dense floating kelp canopies, which often contain abundant understory kelp.
- The majority of understory kelp were prostrate kelp species. Stipitate kelps such as *Pterygophora californica* were predominantly found along the Strait of Juan de Fuca and the San Juan Islands.
- There was a clear North to South pattern in the dominant vegetation type. Along shorelines in the Strait of Juan de Fuca and the San Juan Islands, understory kelp and other species of red and brown algae were most abundant. In contrast, there was an increasing gradient toward dominance of seagrass and green algae moving south.
- Green algae were the predominant vegetation type in the Central Basin of Puget Sound. We estimate that there was at least 2.5x more area covered by green algae than by seagrass in this basin. Note that this estimate represents a 'snapshot' in time, during the summer field season, when green algae blooms are most likely to occur.
- There was a clear pattern in % cover between the vegetation types. Green algae and other red-brown algae were most abundant in the lower cover classes. Seagrass occurred more frequently in high cover classes. Understory kelp occurrence was evenly distributed among cover classes.
- There was also a clear difference in depth distribution between marine vegetation types. Seagrass and medium-to-high cover green algae occurred most frequently at depth shallower than -5 m (MLLW). High percent cover understory kelp had the highest frequency of occurrence between -3 and -7 m (MLLW), while medium and low percent cover understory kelp were more often found at deeper depths. Other red-brown algae were found throughout the entire depth range, but occurred most frequently in the low to medium percent cover classes. Red-brown algae were the dominant vegetation at greater depths.
- The non-native algae *Sargassum muticum* was found at 48% of sites analyzed for this project. Where present, it was mostly found at shallow depths (< -5 m, MLLW). Area estimates for Sargassum were typically low (mostly less than 1 ha where present). Our area estimates may be an underestimate, as Sargassum tends to reach its maximum biomass earlier in the growing season.

[1] Based on the most recent soundwide analysis, there is approximately 22,100 ha of eelgrass in the southern Salish Sea (tide flats and river deltas included) (Christiaen et al. 2022).

1 Introduction

1.1 Marine vegetation in the southern Salish Sea

The northeast Pacific is a region with extremely high abundance and diversity of nearshore marine vegetation, encompassing more than 600 species of algae and several species of seagrass (Hurd et al 2014, Gabrielson & Lindstrom, 2018). These plants and algae form a contiguous seascape, that is linked through exchange of dissolved organic carbon, detrital matter, and movement of fauna across habitat borders (Chalifour et al. 2019, Olson et al. 2019). They provide critical biogenic habitat to a wide range of vertebrates and invertebrates, including Dungeness crab, forage fish, rockfish, and salmonids (Stevens and Armstrong 1984, Johnson et al. 2003, Hayden-Spear 2006, Pentilla 2007, Rubin et al. 2018, Shaffer et al. 2020). Marine vegetation tends to have high primary productivity, and produces large amounts of organic matter, either as detritus, particulate or dissolved organic matter. Some of this organic matter is exported to adjacent habitats and fuels secondary production in communities ranging from tens of meters to hundreds of kilometers from the source of production (Heck et al. 2008, Krumhansl & Scheibling 2012). Organic matter from seagrasses and macroalgae also contributes to carbon sequestration, both locally and in deep sea marine sediments (Krause-Jensen & Duarte 2016, Duarte & Krause-Jensen 2017).

Marine vegetation responds strongly to environmental conditions including light, temperature, salinity, substrate, water motion, depth and nutrient availability (Hurd et al. 2014). These factors determine the abundance and spatial distribution of marine vegetation throughout the southern Salish Sea. Changes in environmental conditions can alter competitive interactions and lead to changes in dominant vegetation types. Seagrasses are sensitive to light limitation and can be outcompeted by phytoplankton, epiphytes and macroalgae when nutrient loads are high (Burkholder et al. 2007, Schmidt et al. 2012). Kelps are primarily cool-water species, and respond negatively to increasing water temperatures and changes in water quality (Moy & Christie 2012, Wernberg et al. 2016, Filbee-Dexter & Wernberg 2018).

1.2 Marine vegetation monitoring in the southern Salish Sea

Because of the importance and sensitivity of marine vegetation, scientists and managers need information about its distribution and abundance to inform research and management. The Nearshore Habitat Program at DNR (DNR-NHP) focusses on long-term monitoring of eelgrass beds and floating kelp in Washington State. 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 seagrass in the southern Salish Sea. The Puget Sound Partnership uses these data as an indicator for the health of Puget Sound. DNR-NHP has conducted annual aerial surveys of floating kelp canopies along the outer coast and the Strait of Juan de Fuca since 1989. Starting in 2011, these surveys include DNR's Aquatic Reserves, which have also been surveyed annually. In recent years, DNR-NHP has expanded the scope of its floating kelp monitoring program, and now uses a variety of methods to monitor floating kelp throughout the southern Salish Sea. DNR-NHP is also leading development of a new 'floating kelp canopy area indicator' for the Puget Sound Partnership Vital Signs (Raymond et al. 2022).

While there is substantial data on seagrass and floating kelp, there is limited information on the distribution and areal extent of other marine vegetation types in the southern Salish Sea. The lack of data is particularly concerning for understory kelp. 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. Data from multiple sources document long-term declines in the canopy cover of floating kelp (*Nereocystis luetkeana*) in South and Central Puget Sound (Berry et al. 2021). Concerns also exist about potential losses to other kelp species, yet trends are unknown due to data gaps. Within the southern reaches of the Salish Sea understory kelp are far more abundant than floating kelp and losses could be detrimental to the ecosystem. Another data gap is the lack of recent information on the spread of the invasive *Sargassum muticum*. Sargassum has the ability to quickly spread, and reduces the abundance of native algae, such as understory kelp, through shading. This species is also less palatable to invertebrates (Britton-Simmons 2004).

Up to now, the Washington State ShoreZone Inventory constitutes the only comprehensive dataset in our region. While ShoreZone has been invaluable in addressing diverse science and management questions, it is limited to an approximate description of the presence of vegetation types within line features that represent stretches of shoreline. The aerial observation method severely limits subtidal observations, and provides no information on depth distribution. The ShoreZone inventory is also dated; field data collection occurred between 1994 and 2000 (Berry et al. 2001).

Data syntheses, such as the recent PMEP State of the Knowledge of Nearshore Habitat Use Report (Bizzarro et al. 2022), are another important source of marine vegetation information. These products integrate data collected with distinct methodologies across different temporal and spatial scales. They are limited by the available survey data.

1.3 A17-0568-S012 Between DNR and the SeaDoc Society

In October 2021, DNR received a grant from the SeaDoc Society (Agreement A17-0568-S012) to fill the gap in knowledge for understory kelp and other marine vegetation types by reclassifying towed underwater video footage from DNR's Submerged Vegetation Monitoring Program. The goal of this agreement is to use the towed underwater video footage from the SVMP to construct a baseline of the spatial and depth distribution of understory kelp and other subtidal vegetation throughout the southern Salish Sea. This broad-scale assessment informs our understanding of habitat abundance and distribution, and provides context for higher resolution dive studies.

As part of this project, we have reclassified footage from 80 randomly selected sites in the 'fringe' stratum in the southern Salish Sea. This report combines these data with similar data for an additional 43 randomly selected sites analyzed as part of a separately funded project: grant no. F20AP12280-00 from the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP), awarded by the US Department of Fish and Wildlife.

We explore regional patterns in marine vegetation such as seagrass, understory kelp, green algae, other red-brown alga, and the invasive *Sargassum muticum*, and generate regional estimates of the total area covered by these different marine vegetation types in 'fringe habitat' along the shoreline of the southern Salish Sea.

This report is a first step towards a comprehensive assessment of marine vegetation in the southern Salish Sea. It represents exploratory work into a research topic with major knowledge gaps. Methods for sampling and analysis are still under development.

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 is available on request, but will be made available through an online data viewer in the near future. 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

2.1 Overview

This project leverages underwater video footage from DNR's eelgrass monitoring program (SVMP) to assess the distribution of understory kelp and other marine vegetation in the southern Salish Sea (also referred to as 'greater Puget Sound'). The study area of the SVMP is the marine waters of Washington State east of Cape Flattery, which includes the U.S. portions of the Strait of Juan de Fuca and the southern Strait of Georgia, Hood Canal, Puget Sound proper and several other smaller basins[2].

The SVMP has defined a probabilistic sampling and extrapolation framework throughout the southern Salish Sea (Dowty et al. 2022, Christiaen et al. 2022). All nearshore areas are divided into 2,467 sample sites, spread over two sampling frames. The majority of sites fall within the fringe frame (n=2,393), which encompasses narrow shorelines that are common in this fjord-estuary complex. Fringe sites comprise 1000 m sections of shoreline (measured along the -6 m bathymetry line). The flats frame (n=74) includes embayments, tide flats, river deltas, and other features that are best represented as areal sample units.

Each year, DNR surveys ~120 sites using a modified line-intercept technique (Norris et al. 1997). At each site, we tow an underwater video camera along a number of randomly selected transects oriented perpendicular to shore. To generate area estimates for marine vegetation, we multiply the mean fractions of transects covered by marine vegetation (weighted by transect length) by the area of a sample polygon.

Since 2016, most sites are sampled with on average 10 stratified random transects that are oriented perpendicular to shore, and encompass the entire depth range of seagrass at the site. Since 2018, transects at fringe sites were sampled from the mid intertidal to 15 m below MLLW (the range of most marine vegetation in this region). The sample polygon spans the entire alongshore length of the site and the same depth range as the transects sampled.

For this project, we reclassified towed underwater video footage from 80 randomly selected fringe sites sampled in 2020 and 2021. An additional 43 random sites sampled in 2019 were analyzed as part of a separately funded project (grant no. F20AP12280-00 from the Pacific Marine and Estuarine Fish Habitat Partnership, awarded by the US Department of Fish and Wildlife).

[2] The southernmost part of South Puget Sound is excluded from the SVMP, as eelgrass rarely occurs in this area.

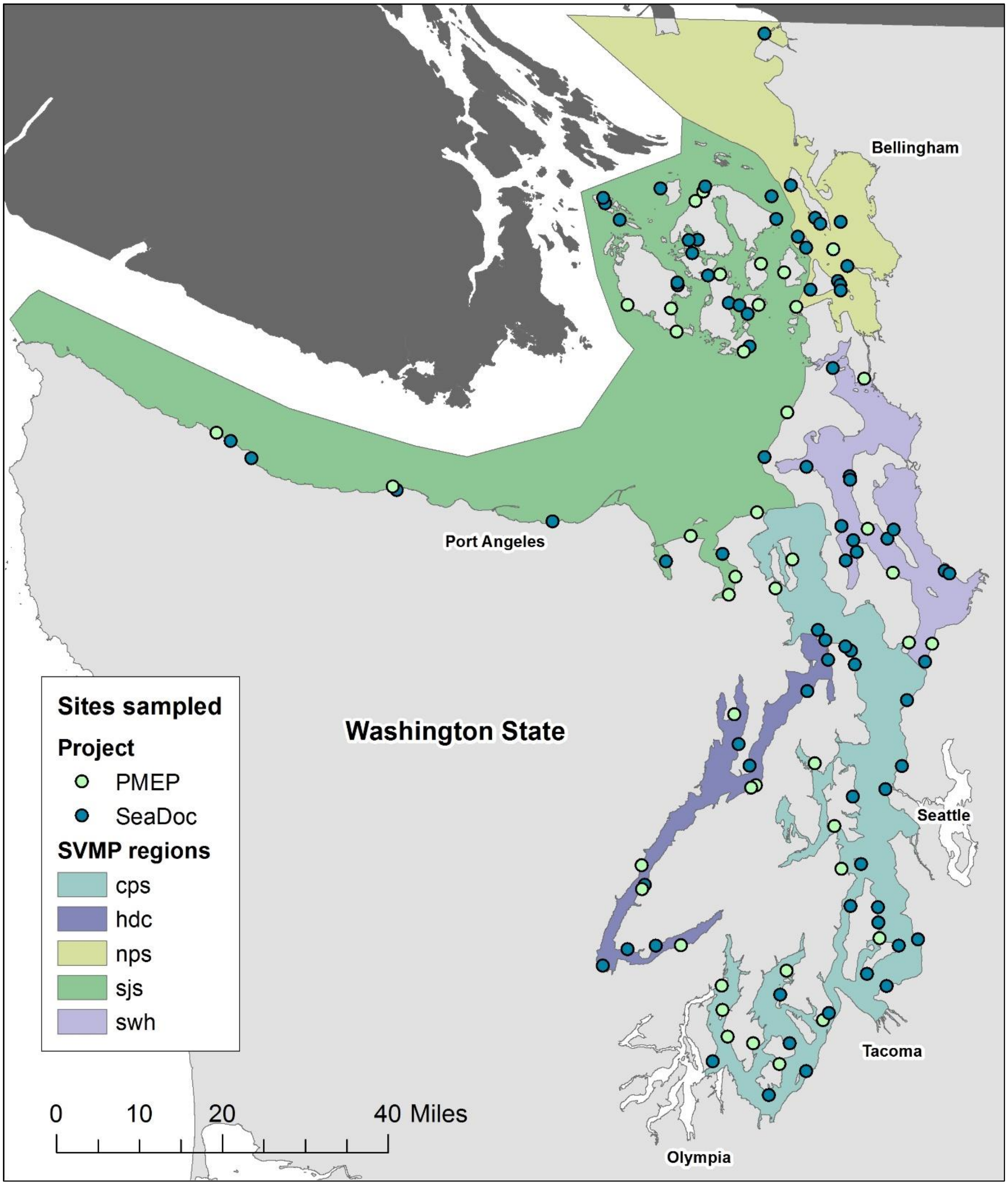

Figure 1: Study area of the SVMP and sites reanalyzed as part of the SeaDoc project (A17-0568-S012) and the PMEP project (F20AP12280-00). The SVMP regions include: Central Puget Sound (cps), Hood Canal (hdc), North Puget Sound (nps), San Juan Islands and the Strait (sjs), and the Saratoga Whidbey Basin (swh) (Christiaen et al. 2022).

In total, these sites represent ~120 km of shoreline, sampled with one transect every 100 m. The study area and the sites sampled for both projects are shown on Figure 1. We use these data to assess the spatial and depth distribution of understory kelp and other marine vegetation (see section 2.3).

We have excluded the flats habitat from this study because these sites have not been surveyed to -15 m (MLLW). This spatial limitation likely has minor effects on estimates for understory kelp, which tends to be sparse on large tide flats and in river deltas. It does have an impact on results for seagrass and green algae as these vegetation types predominate in flats habitat. Another important detail is that we cannot sample in dense floating kelp beds, in order to avoid damaging this vulnerable habitat. The majority of sites with dense floating kelp are located in the Strait of Juan de Fuca and the San Juan Islands. At some sites in these locations, transects begin at the outer edge of floating kelp beds.

2.2 Field sampling

The SVMP uses towed underwater video to generate estimates of area and depth distribution of different types of marine vegetation. Field sampling occurs between May and October, from an 11 m (36 ft.) research vessel, the *R/V* Brendan D II, operated by Marine Resources Consultants (Figure 2). Sampling requires a suite of specialized equipment to capture depth and location labeled video (Table 1). During sampling, the vessel deploys a weighted towfish with an underwater video camera mounted in a downward-looking orientation (Figure 3). The towfish is deployed directly off the stern of the vessel using a cargo boom and winch. During transect sampling, an MRC technician adjusts the position of the towfish using the hydraulic winch to fly the camera above the substrate. Parallel lasers mounted 10 cm apart on the towfish provide a scaling reference in the video image. A 500 Watt underwater light provides illumination when needed.

Survey equipment simultaneously records the 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 3). 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.

Figure 2: All data were collected from the *R/V* Brendan D II, using towed underwater videography and depth sounding instrumentation.

Figure 3: 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).

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

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

2.3 Data processing

For the purpose of estimating understory kelp and other marine vegetation, we reclassified the video footage at 123 randomly selected fringe sites sampled in 2019, 2020 and 2021 based on methods from Rubin et al. (2017). 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 at one video frame every 5 seconds (Figure 4). Note that the floating kelp category has limited use. During sampling, we actively avoid floating kelp canopies to avoid damaging this vulnerable habitat. The floating kelp category is mainly used to note the presence of juvenile sporophytes of bull kelp in the understory canopy. The 'all kelp' category is a proxy for the entire understory kelp canopy in the frame, and includes prostrate kelps, stipitate kelp and juvenile sporophytes of floating kelp. The other red-brown category summarizes all red algae as well as brown algae that are not kelp. There is some overlap between the understory kelp and other red-brown algae categories, as it is sometimes difficult to distinguish between prostrate kelps and acid kelp (*Desmarestia ligulata*) based on towed underwater videography. However, at the vast majority of frames, we were able to correctly distinguish between these groups.

To estimate the percent cover in an individual video frame, we overlaid a 2 by 3 grid on top of the video footage, and recorded each vegetation type as one of 8 cover classes (Figure 5): absent (class 0), less than 5% cover (class 1), between 5 and 16% cover (class 2), between 16 and 33% cover (class 3), between 33 and 66% cover (class 4), between 66 and 85% cover (class 5) between 85 and 95% cover (class 6) and over 95% cover (class 7). Note that different vegetation types can overlap (for example red algae epiphytes on seagrass), so the sum of all vegetation types does not necessarily add up to 100%.

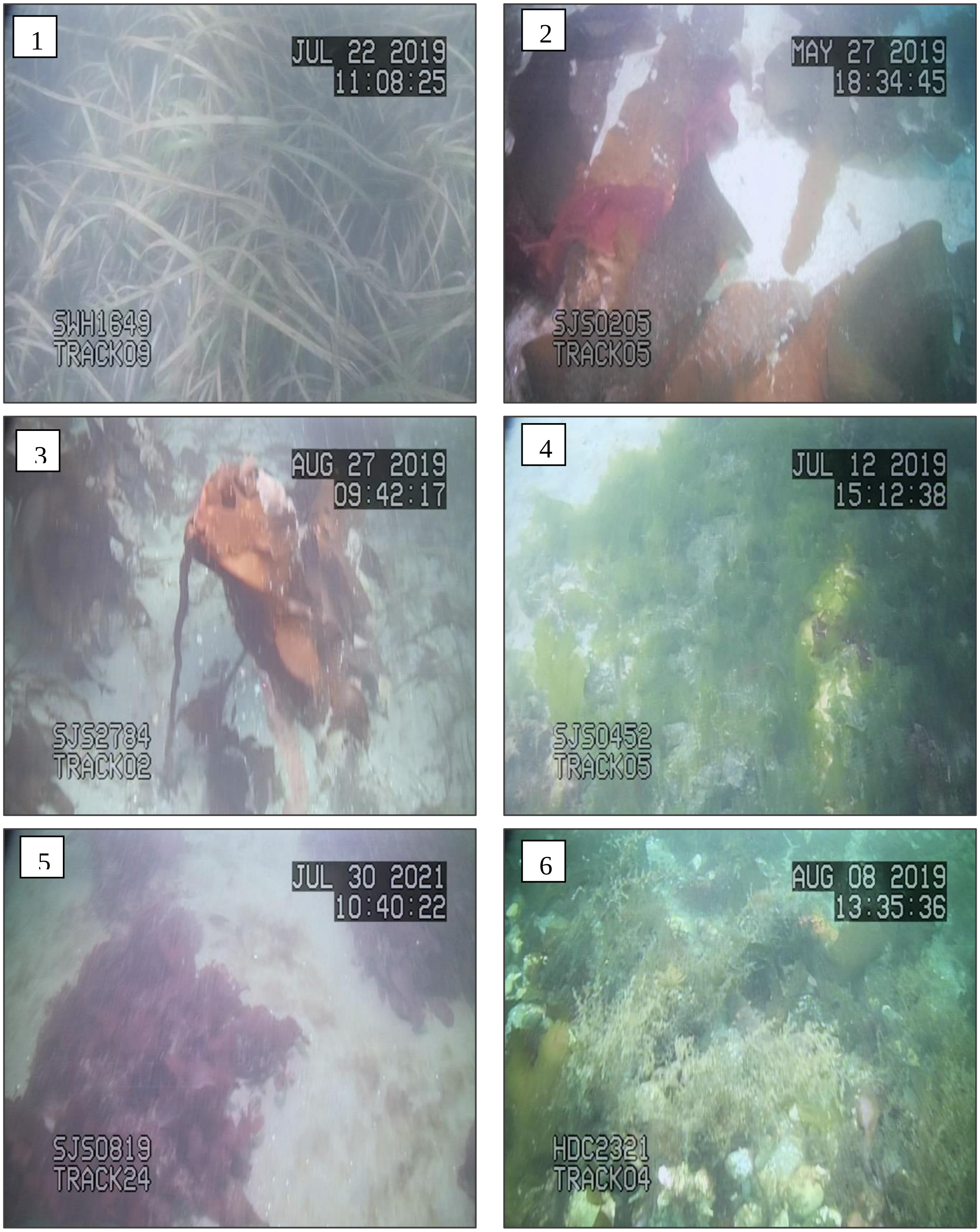

Figure 4: Different vegetation types in greater Puget Sound: (1) seagrass (eelgrass, *Z. marina*), (2) prostrate kelp & other red-brown algae, (3) stipitate kelp (*Pterygophora californica*), (4) green algae (*Ulva sp.*), (5) other red-brown algae, (6) *Sargassum muticum*.

All observations were recorded with their corresponding spatial and depth data. 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 end result is a geodatabase with all observations and their associated date/time, position and depth measurements corrected to MLLW datum. This data was used to generate area estimates for each combination of site, vegetation type and cover class, by multiplying the area of the sample polygon with the fraction of observations with vegetation per vegetation type and cover class at the site.

Cover classes

- Absent (0)
- < 5% (1)
- 5-15% (2)
- 16-32% (3)
- 33-66% (4)
- 67-85% (5)
- 86-95% (6)
- >95% (7)

Figure 5: Screenshot of the grid overlaid on towed underwater video footage to estimate the percent cover of different vegetation types in towed underwater videography. The 8 cover classes with the corresponding percent of the frame covered by vegetation are listed on the right. Here, the frame is dominated by prostrate kelp (cover class 7), with a small presence of other red-brown algae (cover class 1).

2.4 Analysis

Data was analyzed with ArcGIS Pro and R. We used several R-packages, including “broom” (Robinson and Hayes 2018), “dplyr” (Wickam et al. 2018), “ggplot2” (Wickam 2016), and “tidyr” (Wickam and Henry 2018).

2.4.1 Site area estimates

For each vegetation type, we estimate the area of vegetation with cover class i at site j by multiplying the area of a sample polygon (Aj) with the ratio of all data points with vegetation in cover class i at site j (p_{ij}) over the total amount data points sampled at the site (q_j).

$$\hat{X}_{ij} = \text{Aj}\ \frac{p_{ij}}{q_j} \qquad (1)$$

Site area estimates are used to generate regional estimates of vegetation cover, as well as depth distributions for particular vegetation types. They can also be used to make a 'vegetation fingerprint' of each site.

2.4.2 Site depth distribution

To calculate a depth distribution, observations were binned according to their depth relative to MLLW in 2 m bins. We also simplified the cover class into low (less than 15% cover), medium (15 to 66% cover) or high (66 to 100% cover). For each vegetation type, we divided the number of observations with vegetation per depth bin k & cover class i by the total number of points sampled at the site j. This ratio was multiplied by the area of the sample polygon to estimate the vegetated area per cover class and depth bin at the site:

$$\hat{X}_{ijk} = Aj\ \frac{p_{ijk}}{q_j} \qquad (2)$$

Where $\hat{X}_{ijk}$ is the vegetated area in depth bin k for cover class i at site j, and Aj is the area of the sample polygon at the site. We then calculate the total area sampled in each depth bin by multiplying the area of the sample polygon with the ratio of the number of points per depth bin over the total number of data points sampled at the site:

$$\hat{D}_{jk} = Aj\ \frac{q_{kj}}{q_j} \qquad (3)$$

Where $\hat{D}_{jk}$ is the area in depth bin (k) at site j, Aj is the area of the sample polygon, q_{kj} is he number of data points sampled in depth bin k at site j, and qj is to total number of data points at the site j. We then calculate the fraction of vegetated area with cover class i relative to the total area per 2 m depth bins at the site as:

$$\hat{Y}_{ijk} = \frac{\hat{X}_{ijk}}{\hat{D}_{kj}} \qquad (4)$$

2.4.3 Regional depth distribution

To calculate regional depth distributions for different vegetation types, we sum the vegetated area per depth bin for all sites sampled (n) in the region, and divide this value by the sum of the total sampled area per depth bin for all sites sampled (n):

$$\hat{Y}_{ik} = \frac{\sum_{j=1}^{n} \hat{X}_{ijk}}{\sum_{j=1}^{n} \hat{D}_{jk}} \qquad (5)$$

Where $\hat{Y}_{ik}$ is an estimate of the fraction of vegetated area at cover class i in depth bin k, relative to the total area in depth bin k throughout the region.

2.4.4 Regional area estimates

To generate regional area estimates for the different vegetation types, as well as associated uncertainty, we estimate the vegetated area in discrete depth bins, and extrapolate these values over the entire 'area within these depth bins' in the fringe stratum of the SVMP. This method is different from the original statistical framework of the SVMP, were site area estimates in the fringe stratum are extrapolated based on the length of the stratum (Dowty et al. 2022).

Here, we use an extrapolation that is area based, derived from the formulas for the flats stratum of the SVMP. This method assumes that we have a reasonable accurate bathymetry dataset that spans the entire study area. We are using the CoNED topobathymetric models of Puget Sound and the Strait of Juan de Fuca, published by USGS (OCM Partners 2023a, OCM Partners 2023b).

2.4.4.1 Total substrate area per 2m depth bins in the fringe stratum of the SVMP

To calculate the total available substrate per depth bin, we first transformed the CoNED topobathymetric models from NAVD88 vertical datum to depth relative to MLLW. We used VDatum (NOAA) to generate a transformation raster file with spatial reference *NAD 83 UTM Zone 10N*. Then each set of individual bathymetry tiles was converted to MLLW with the above transformation files using a custom ArcPy Python script run using PyCharm. Finally, following confirmation that the above workflow generated a continuous and accurate data set, bathymetry tiles were projected using another ArcPy Python script, which used the Project Raster tool to project each tile into *NAD 1983 HARN StatePlane Washington South FIPS 4602*, and also applied an LZW compression to each tile.

Using the zonal histogram tool in ArcGIS Pro, we calculated the total area of substrate between +1 and -15 m relative to MLLW in the fringe stratum of the SVMP, split over 2 m depth bins, for each of 5 sub-regions in the southern Salish Sea (Figure 1). These values are listed in Table 2. Based on these data, we estimate that there is approximately 84,250 ha of available substrate between +1 and -15 m in the fringe stratum of the SVMP.

Table 2: Total substrate area (ha) between +1 and -15m relative to MLLW in the fringe stratum of the SVMP, split over 2m depth bins, for 5 sub-regions in the southern Salish Sea.

region	-15 to -13 m	-13 to -11 m	-11 to -9 m	-9 to -7 m	-7 to -5 m	-5 to -3 m	-3 to -1 m	-1 to +1 m
cps	2577	2603	2551	2479	2429	2577	3056	6985
hdc	602	670	765	723	600	600	831	2503
nps	2615	2534	1998	1876	1291	973	805	1413
sjs	4117	4453	4352	4061	3393	3030	3252	3816
swh	747	733	752	731	728	782	910	2343

2.4.4.2 *Calculating regional estimates of vegetated area*

To generate regional estimates of vegetated area, we first calculate for each vegetation type the total area with more than 5% cover (cover class i > 1) per depth bin k for all (n) sites sampled in each of the 5 sub-regions of the southern Salish Sea:

$$\hat{X}_k = \sum_{i=2}^{7}\sum_{j=1}^{n}\hat{X}_{ijk} \quad (6)$$

We then estimate the total sampled area per depth bin k for all (n) sites sampled in each of the 5 sub-regions of the southern Salish Sea as:

$$\widehat{D}_k = \sum_{j=1}^{n}\widehat{D}_{jk} \quad (7)$$

To estimate the total vegetated area per depth bin k in each of the sub-regions, we calculate the ratio of $\hat{X}_k$ over $\widehat{D}_k$, and then multiply this ratio by the total substrate area per depth bin in the fringe stratum for each sub-region, derived from the CoNED topobathymetric models (Table 2) as:

$$\hat{B}_k = \left[\frac{\hat{X}_k}{\widehat{D}_k}\right] Z_k \quad (9)$$

The total vegetated area per region in the fringe stratum (between +1 and 15 m MLLW) is calculated as the sum of all area estimates per depth bin;

$$\hat{B} = \sum_{k}^{m}\hat{B}_k \quad (10)$$

We can estimate the variance for this modified area estimator using the following formulas:

$$\widehat{Var}(\hat{B}) = \sum_{k}^{m}\widehat{Var}(\hat{B}_k) \quad (11)$$

with $$\widehat{Var}(\hat{B}_k) = (N)^2\left(1-\frac{n}{N}\right)\frac{\sum_{j=1}^{n}(\hat{X}_{jk}-\hat{D}_{jk}\hat{R})}{n(n-1)} \quad (12)$$

and $$\hat{R} = \frac{\hat{X}_k}{\hat{D}_k} \quad (13)$$

Where:

- $\hat{B}_k$ is the estimate of regional vegetated area in depth bin k (k = 1,…,m),
- Z_k is the total substrate area for depth bin k in the sub-region (derived from CoNED),
- N is the total number of fringe sites in the sub-region,
- n is the number of sites sampled in the sub-region,
- $\hat{X}_{jk}$ is the vegetated area at depth bin k for site j (cover class i > 1),
- $\widehat{D}_{jk}$ is the total area at depth bin k for site j.

Note that formulas 11, 12 and 13 are a simplified version of the area extrapolations for the SVMP flats stratum. The original formula for variance of regional area estimates has two components: one term for the variance contribution due to differences in area estimates between the sites, and one term for the contribution of variance at the site level. Here we use only the first term of that equation. Note that in the original framework of the SVMP, this term accounts for the majority of uncertainty around our regional area estimates.

2.4.5 Environmental factors associated with nearshore vegetation distribution and abundance

For the purpose of comparing environmental conditions and vegetation patterns over a large spatial area, we broadly characterized each SVMP region using existing datasets, including:

- The total extent of fringe habitat between +1 m and -15 m (MLLW), derived by CoNED bathymetry data (OCM Partners 2023a, OCM Partners 2023b).
- The dominant wetland system, derived from Cowardin (1979) and refined by Dethier (1990) for Washington State. This summary classification synthesizes multiple environmental characteristics, including salinity, circulation and water movement, into two categories (marine, estuarine). The marine system encompasses areas not appreciably diluted by freshwater while the estuarine system captures waters that are semi-enclosed by land with partial access to the ocean[3].
- The relative abundance of substrate types – derived from the WA State ShoreZone Inventory (Berry et al. 2001). We ranked the substrate classes per region in order of relative abundance.
- Summer temperature variation and nutrient drawdown, which is a summary assessment of the degree of summer temperature increases and water column nutrient drawdown, assessed using data from the Salish Sea Model.

Table 3: Characterization of conditions in 5 sub-regions of the southern Salish Sea

region	CPS	HDC	NPS	SJS	SWH
Nearshore area (ha) For fringe habitat	25,257 ha	7,294 ha	13,505 ha	30,474 ha	7,726 ha
Dominant Wetland System	Estuarine	Estuarine	Estuarine	Marine	Estuarine
Relative abundance of substrate types (top 3)	Sand/mud/fines, gravel and sand, man-made	Sand/mud/fines, gravel and sand, gravel,	Sand/mud/fines, gravel and sand, man-made,	rock, gravel and sand, rock/gravel/sand	Sand/mud/fines, gravel and sand, man-made
Summer temperature elevation and nutrient drawdown	moderate	high	high	low	high

[3] As noted in Dethier (1990), many areas in the Puget Trough are transitional, with surface salinities that are generally high (>25 ppt) yet lower than ocean water. Areas with extensive turbulent mixing and strong tidal flow, such as the San Juan Islands and the Strait of Juan de Fuca, are considered marine.

3 Results

3.1 Site area estimates

We estimated a cover class for several broad vegetation types (all vegetation, all kelp, prostrate kelp, floating kelp, stipitate kelp, Sargassum, other red-brown algae, green algae, and seagrass) at one frame every 5 seconds using modified Braun-Blanquet vegetation cover categories, at 1443 transects spread over 123 sites sampled in 2019, 2020 and 2021. A small number of transects were removed from analysis because of large gaps due to obstacles (such as floating kelp) or the inability to classify the footage due to low water clarity. In total, we used data from 1427 transects with a total of 121,347 data points for analysis.

For each site, we calculated the vegetated area per cover class for each of the vegetation types, with a focus on all vegetation, all (understory) kelp, other red-brown algae, green algae, seagrass and Sargassum. Values for individual sites are listed in Appendix 1, Table 5). We used these estimates to generate a 'vegetation fingerprint' at each of the 123 sites analyzed for this project. Figure 6 shows an example output of one of the sites: cps1686, located near immediately North of the West Point sewage treatment plant in the Central Basin of Puget Sound. On this figure, the y-axis shows estimates of vegetated area for 6 vegetation types while the x-axis represents 7 cover classes, from low (less than 5% cover) to high (>95% cover).

For each vegetation type, you can add the area estimates per cover class to estimate the total area covered by a particular vegetation type at a site. For example, at cps1686 there was 31.2 ha with vegetation present, 25.8 ha with green algae, 13.9 ha with understory kelp, 21.6 ha with other red-brown algae, 6.7 ha with seagrass and 0.6 ha with Sargassum[4].

It is not possible to add up area estimates across vegetation types, because these vegetation types often overlap. Most of the time, there are often multiple types of vegetation present in a same video frame. At the site in Figure 6, many of the frames with higher cover eelgrass or kelp had low amounts of green algae cover. As a result, there is a high area with less than 5% green algae cover, but a relatively low area with less than 5% cover for 'all vegetation'.

[4] Note that these values are the sum of all cover classes (including cover class = 1). For the regional area estimates and the site area estimates in Table 5 we excluded cover class = 1, as it represents < 5 % cover per video frame, which is not meaningful in the context of comparing vegetated area among sites.

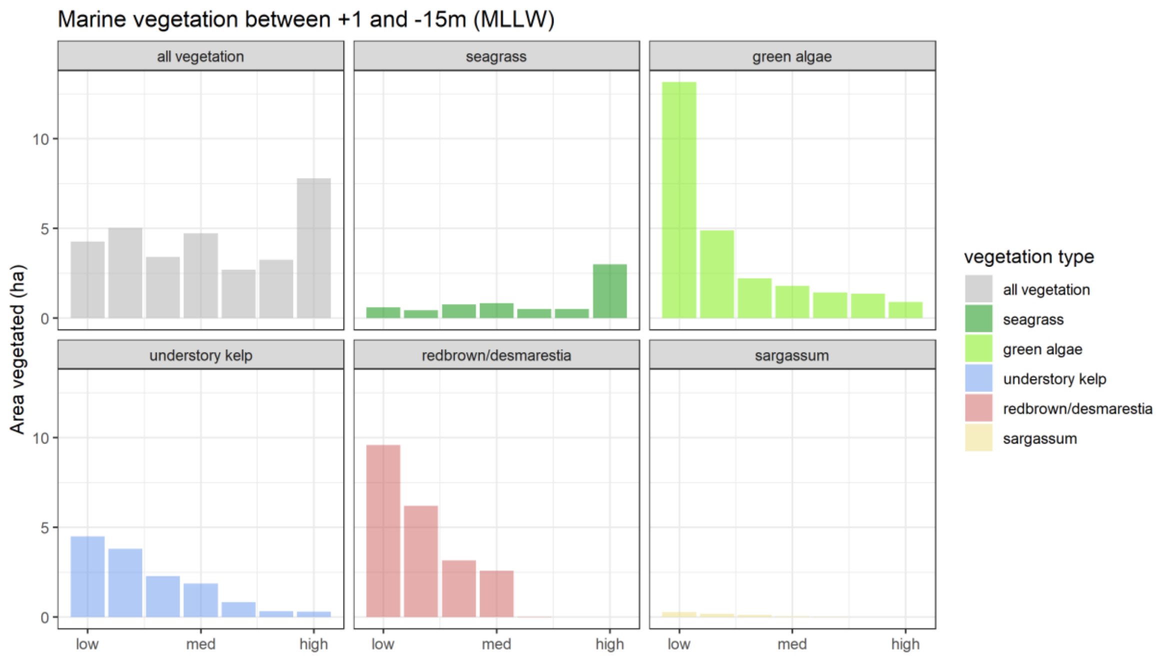

Figure 6: Example of a 'vegetation fingerprint' at a site (cps1686, sampled in 2019). The Y-axis shows estimates of vegetated area between +1 and -15m (MLLW) for 6 vegetation types, partitioned over 7 different cover classes (ordered from low to high %cover along the X-axis).

Figure 7 summarizes area estimates for all 123 sites analyzed as part of this project. This figure shows distinct patterns in vegetation cover among all sites. In general, green algae and other red-brown algae tend to be highly abundant in the study area. Both vegetation types tend to be most abundant in the lower cover classes (especially cover class 1, less than 5% cover). Seagrass and understory kelp are also abundant, but seagrass tends to occur more often in the higher cover classes, while understory kelp is more evenly spread over the different cover classes as compared to the other marine vegetation types. The non-native Sargassum was frequently found, but was often limited in aerial extent.

There are exceptions to this general pattern. For example, several sites had a relatively large area with high green algae cover. The same is true for other red-brown algae (but to a lesser degree). It is also important to note that the y-axis of Figure 7 is on a log-scale, which indicates considerable variability in the size of eelgrass and understory kelp beds among the different sites. This is partly due to differences in the amount of available substrate between +1 and -15 m (MLLW) at individual locations.

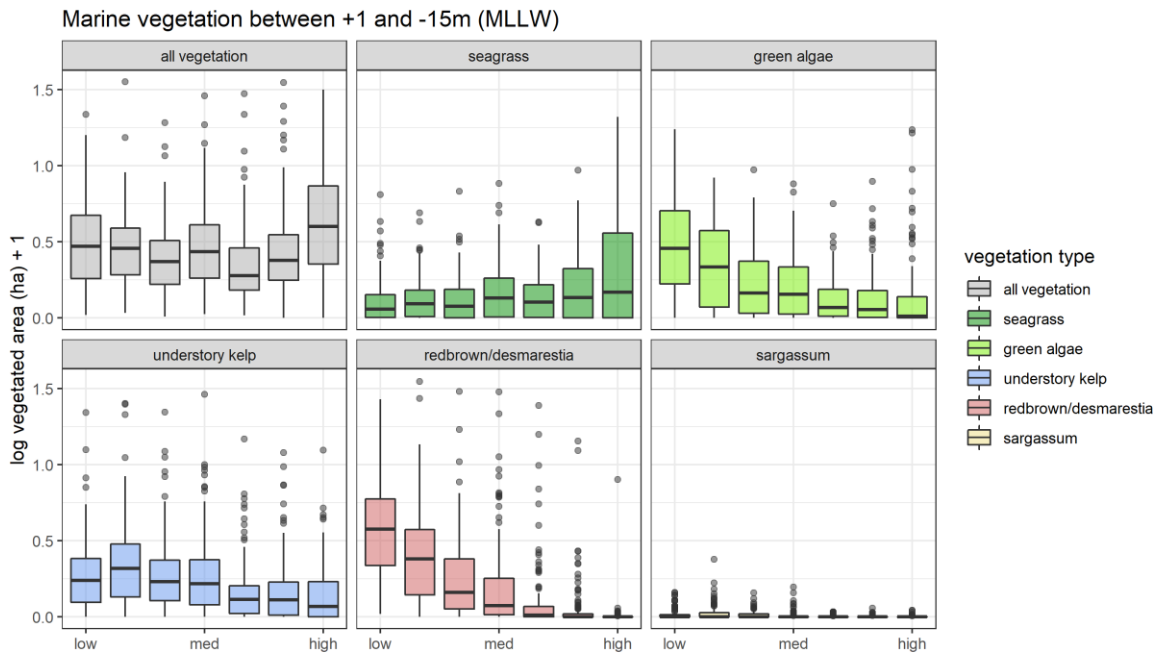

Figure 7: Boxplots of vegetated area between +1 and -15m (MLLW) for all 123 sites analyzed as part this project. Area estimates are for each vegetation type are partitioned over 7 cover classes (ordered from low to high % cover). The y-axis is log transformed to accommodate the different sizes of these sites.

3.2 Spatial patterns in marine vegetation

3.2.1 Dominant vegetation types

There was a clear spatial pattern in the dominant vegetation type among sites along a North to South gradient in the study area. Figure 8 shows the area with medium-high cover red-brown algae, understory kelp, seagrass and green algae at each site (calculated as the sum of all area with cover class 3 or higher). Sites with the highest area of red-brown algae were predominantly found along the Strait of Juan de Fuca, Admiralty Inlet, and on Guemes- and Sinclair Island. These were all sites with large areas of subtidal habitat in a depth range that is suitable for other red-brown algae. Sites with large amounts of other red-brown algae often also had large amounts of medium-high cover understory kelp. However, medium-high cover understory kelp appeared to be more abundant, especially in the San Juan Islands. The largest seagrass beds (predominantly eelgrass) were found in the Saratoga Whidbey Basin and the Northern part of Central Puget Sound. Other sites with substantial amounts of seagrass include Sinclair Island, Waldron Island and Blaine (on the border between Washington State and Canada). Green algae were most abundant in the Central Basin of Puget Sound, with large green algae beds on the east side of Bainbridge Island, near Yukon Harbor and on the east side of Vashon Island.

Figure 9 shows the ratio of the area with medium-high cover red-brown algae, understory kelp, seagrass and green algae over the total area with medium-high cover vegetation at each site (expressed as a %). This metric allows for better comparison among sites of different sizes.

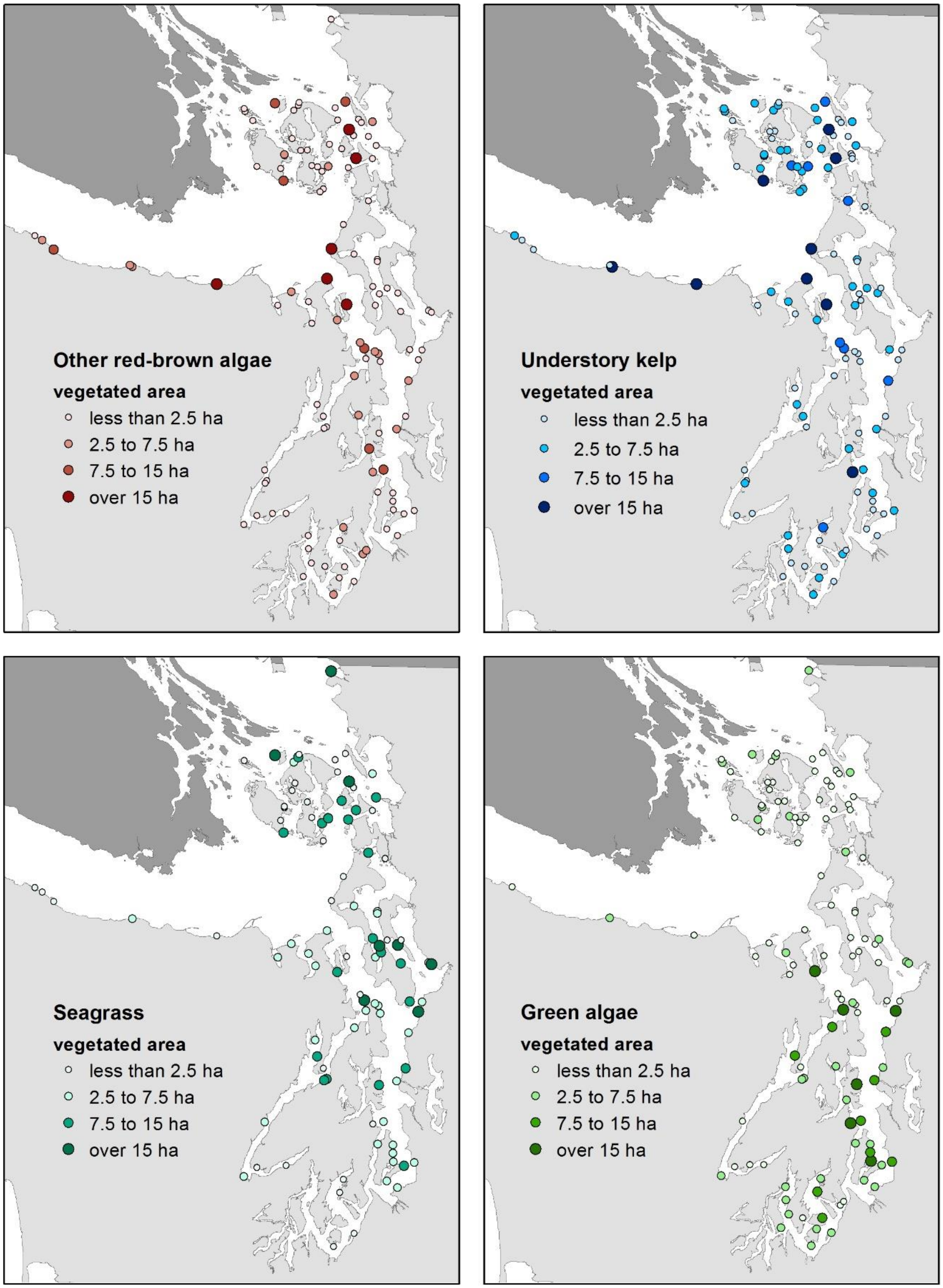

Figure 8: Area with medium-high cover red-brown algae, understory kelp, seagrass and green algae (cover class 3 and up) at each site.

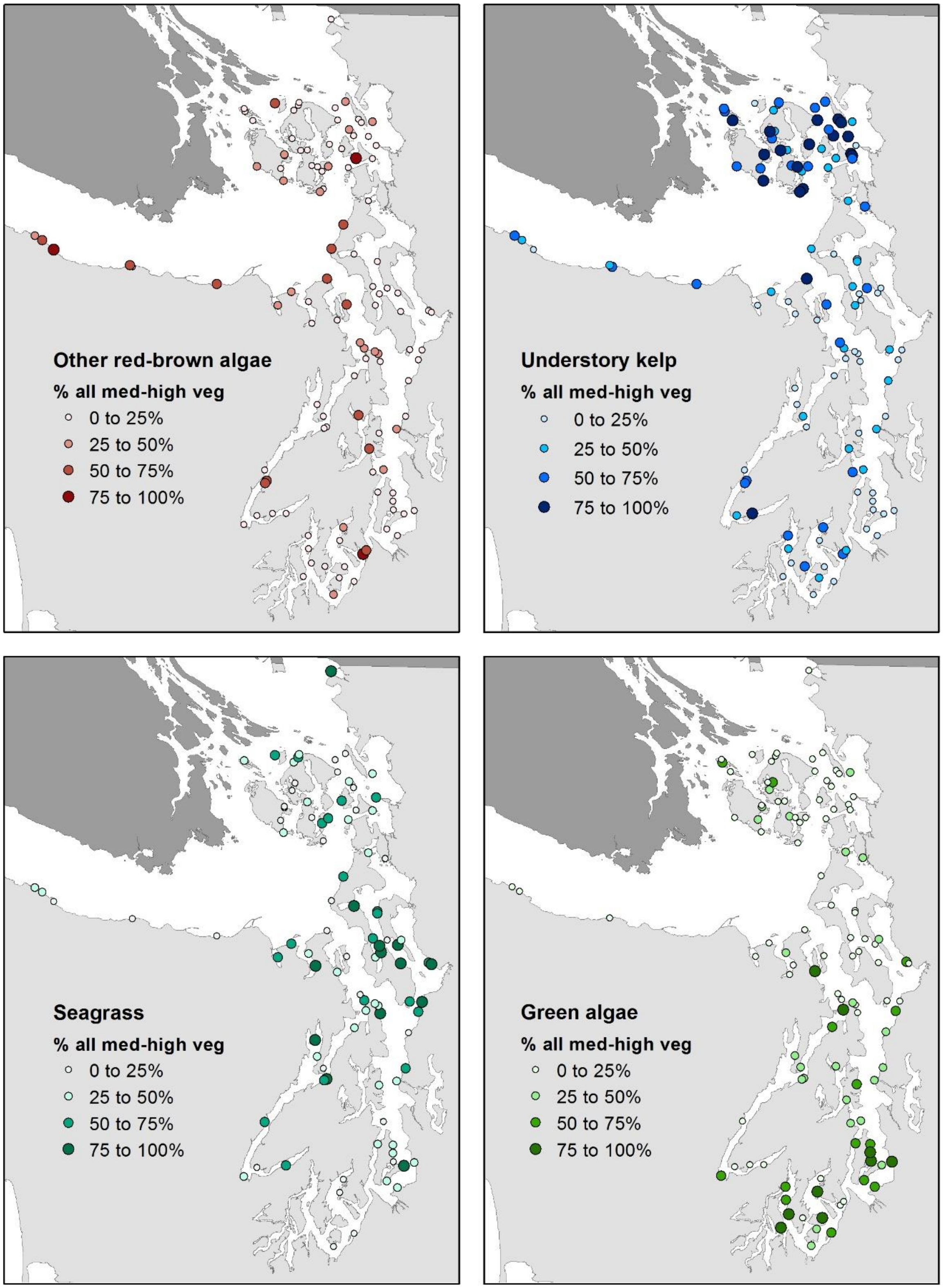

Figure 9: Ratio of area with medium-high cover red-brown algae, understory kelp, seagrass and green algae over the total area with medium-high cover vegetation (cover class 3 and up) at each site (expressed as a %).

This figure emphasizes the spatial pattern in dominant vegetation types. Understory kelp is the predominant vegetation type near the San Juan Islands. This shifts to eelgrass, and finally green algae the further South one goes into Central Puget Sound. Sites in South Puget Sound tend to have smaller amounts of medium-high cover vegetation, but the dominant vegetation tends to be green algae. Note that there are a number of sites with a relatively high percentage of understory kelp in this region. Sites with a high percentage of other red-brown algae are mostly found along the Strait of Juan de Fuca and in Admiralty Inlet. Other sites with a high percentage other red-brown algae include Guemes Island and the Tacoma Narrows, which are areas with rocky substrates and high current speeds. It is also interesting to note that sites with high area estimates for certain vegetation types do not always correspond with sites where that vegetation type represents a large percentage of the area with medium-high cover vegetation. One example is sjs0819 near Partridge Point, the western tip of Whidbey Island. This site has one of the largest area estimates of medium-high cover understory kelp. However, a large portion of the medium-high cover vegetation is located along the deeper parts of the site, and tends to be dominated by other red-brown algae.

3.2.2 Less abundant marine vegetation types

Figure 10 shows the area covered by stipitate kelp and Sargassum (summed over all cover classes). Stipitate kelp is most abundant in the Strait of Juan de Fuca and to a lesser degree in the San Juan Islands. Stipitate kelps are not common in Puget Sound proper, but were documented at locations such as the Tacoma Narrows.

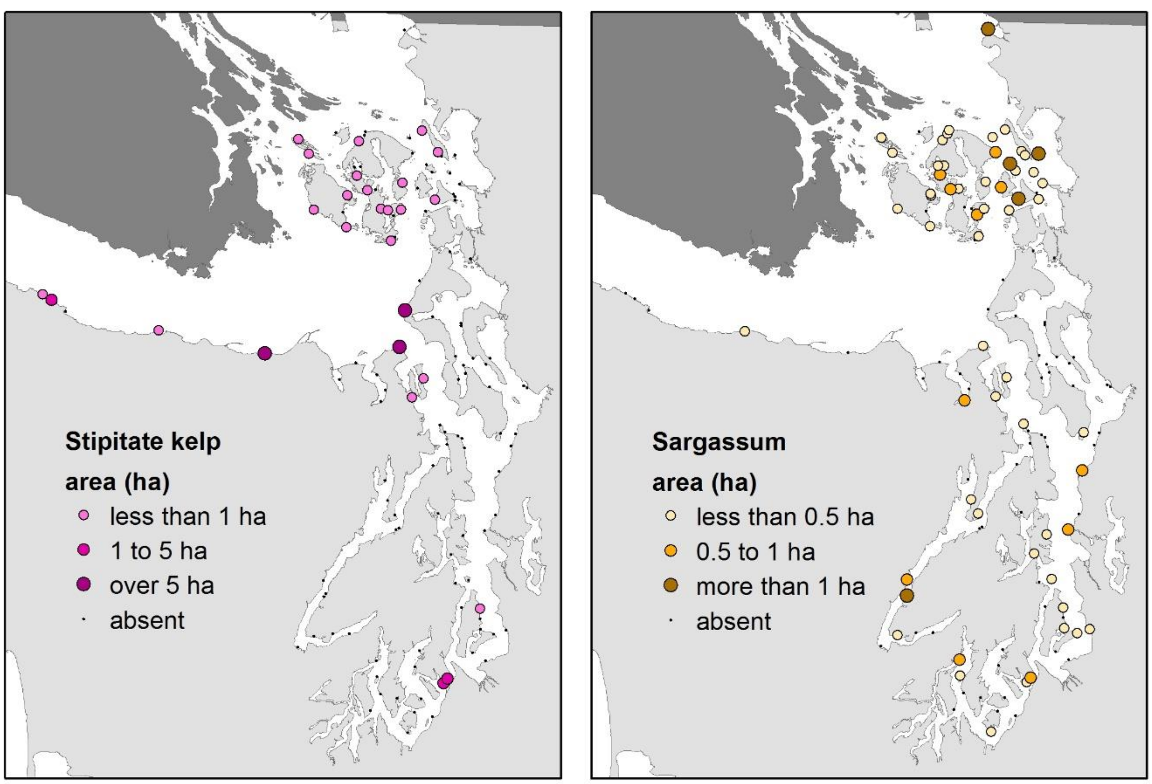

Figure 10: area covered by stipitate kelp (left) and sargassum (right) at all sites analyzed for the project. For these less abundant vegetation types, the area estimates include all cover classes > 0.

It is important to emphasize that we actively avoided floating kelp beds during sampling, in order to avoid damage to these habitats. Because floating kelp co-occurs with other species of kelp and red and brown algae, the exclusion of areas with floating kelp led to an underestimate of area for all understory kelp and other red and brown algae. The magnitude of the underestimate is expected to be considerable along the Strait of Juan de Fuca and the San Juan Islands, where floating kelp is abundant. The underestimate is expected to be smaller in the remainder of Puget Sound, where floating kelp beds commonly form narrow fringing beds.

The non-native algae *Sargassum muticum* was documented at ~ 48% of sites sampled for this project. It was found in each of the sub-regions of the southern Salish Sea, but was most frequently found in the San Juan Islands and in Central Puget Sound. Site area estimates were relatively small (less than 1 ha at the majority of sites). The highest site area estimate was ~2.9 ha (nps0654 on Guemes Island, sampled in 2021). Note that all sites were sampled between the start of May and the end of September. As such, area estimates for Sargassum could be an underestimate, particularly for sites sampled late in the season, when Sargassum tends to senesce and die back.

3.3 Patterns in depth distribution

Different vegetation types have different depth distributions (Figure 11). Marine vegetation was present throughout the entire depth range of the study area (+1 to -15 m, MLLW). In general, high cover marine vegetation is most abundant between +1 and -9 m (MLLW), while medium and low cover tends to become more common with increasing depth.

The different seagrass species (*Z. marina*, *Z. japonica* and *Phyllospadix sp*.) tend to be most abundant at relatively shallow depths, regardless of the cover class. Seagrass becomes very sparse below -7 m (MLWW), but individual shoots have been observed down to -14 m (MLLW) in the study area. While we did not ‘formally’ differentiate between the different species for this study, we did observe a clear difference in depth distribution between *Z. japonica* and *Z. marina*. At sites where both species are present, *Zostera japonica* tends to grow higher in the intertidal. There is sometimes a small band where both species coexist, but usually *Z. marina* becomes the dominant species below 0 m (MLLW).

High and medium cover green algae followed a similar pattern as seagrass, and was most common at depths shallower than -5 m (MLLW). For this study, we only count algae that appear attached to the substrate. However, it is sometimes hard to differentiate between attached and ‘free-flowing’ green algae when there is a thick layer of *Ulva* covering the substrate. This could have skewed our numbers higher. Note that green algae were very abundant in Central and South Puget Sound. If we were to calculate a depth distribution for these only these regions, the relative abundance would look very different. Low cover green algae were abundant throughout the entire depth range.

Understory kelps appeared to be more tolerant of low light levels as compared to seagrasses and green algae, and were most frequently found at deeper depths. There is a clear difference between the cover classes. High cover understory kelp had the highest frequency of occurrence between -3 and -7 m (MLLW), while medium and low% cover understory kelp were more often found at deeper depths. There was virtually no medium or high cover understory kelp below -13 m (MLLW), but low cover understory kelp was frequently found down to -15 m (MLLW). Note that there was virtually no understory kelp shallower than -1 m (MLLW).

Other red-brown algae were found throughout the entire depth range, but occurred most frequently in the low to medium cover classes. Low and medium cover other red-brown algae had the highest frequency of occurrence between -5 and -11 m (MLLW), and became the dominant vegetation type below -13 m (MLLW). High cover red-brown algae were more frequently found at deeper depths as compared to other marine vegetation types.

The non-native Sargassum was present at a large number of sites, but area estimates at individual sites were usually low. Sargassum was found most frequently at depths shallower than -5 m (MLLW), regardless of the cover class. At these depths it was more often found in low cover classes as compared to medium and high cover.

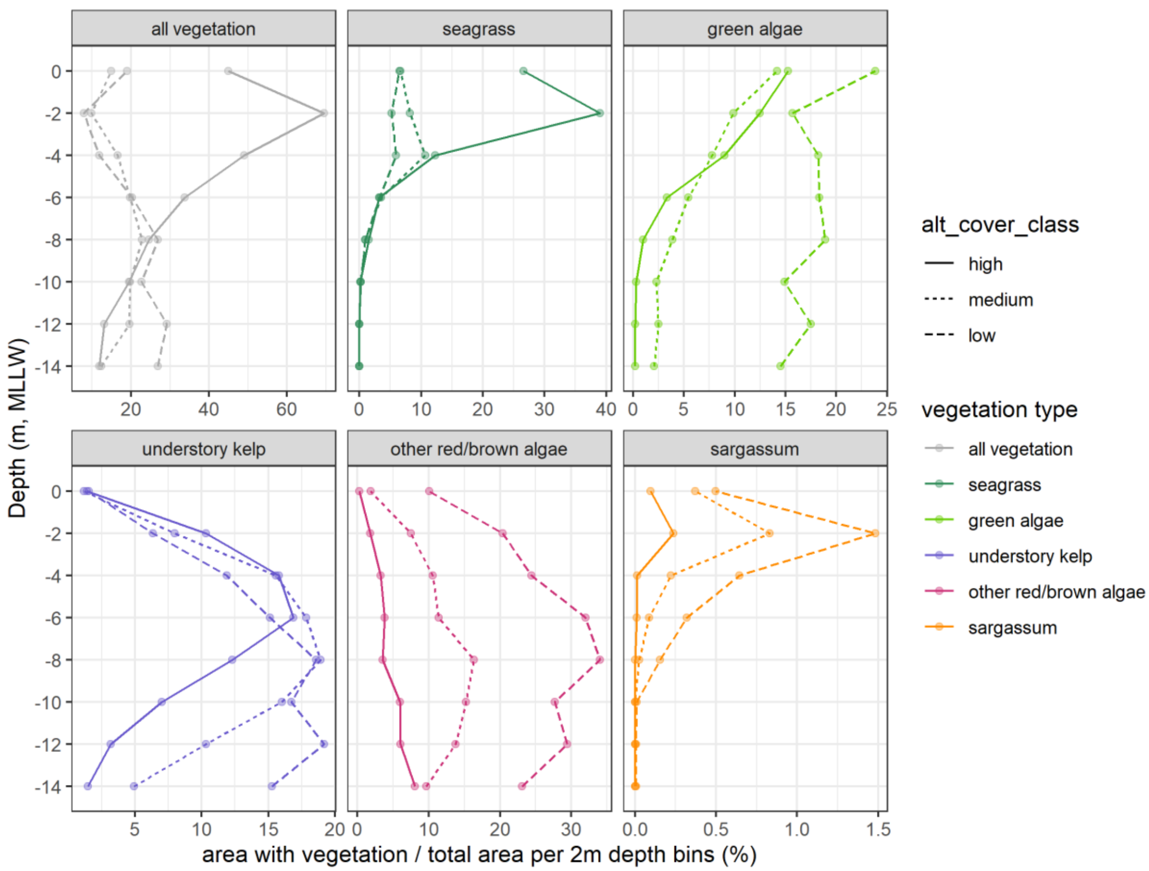

Figure 11: Depth distribution of all vegetation, seagrass, green algae, understory kelp, other red/brown algae and sargassum, calculated as the area with vegetation over the total available area per 2 m depth bins (expressed as percentage). Different line types represent low (< 15%), medium (>15% and < 66%), and high (> 66%) cover classes. The dots on each line indicate the point value summarizing area at the center of each 2 m depth bin.

3.4 Regional area estimates

Figure 8 and Figure 9 show clear spatial patterns in the dominant vegetation types throughout the southern Salish Sea. This raises the question of how much vegetated habitat there is in each of the regions of the southern Salish Sea. We extrapolated the site level estimates of vegetated area at different depths to generate regional estimates of vegetated area for 6 different groups of marine vegetation: all vegetation, seagrass, green algae, understory kelp, other red-brown algae, and Sargassum (Figure 12). Values were summed to estimate vegetated area for the entire fringe stratum of southern Salish Sea (Table 4). Note that we excluded cover class 1 (less than 5% cover) from the calculations.

According to our estimates, there was ~ 50,425 ha of marine vegetation in fringe habitat in the southern Salish Sea. This suggests that in the study area ~ 60% of available habitat had some type of marine vegetation present at cover class 2 or higher (>5% cover). The most abundant vegetation types in the study area were understory kelp (21,978 ha) and other red-brown algae (20,654 ha), followed by green algae (16,293 ha) and seagrass (12,971 ha). We only detected ~ 509 ha of Sargassum soundwide (which corresponds to 0.6% of available substrate). There is uncertainty around these measurements, as indicated by the confidence intervals in Table 4.

Note that our study area excludes large tidal flats and river deltas, which are included in the flats stratum of the SVMP. These habitats are typically dominated by seagrass and green algae. As result, our estimates of seagrass and green algae cannot be used to assess the total area covered by these vegetation types in the southern Salish Sea. The exclusion of flats also led to underestimates of understory kelp and other red-brown red algae. However, it likely captured the majority of habitat where kelp is dominant, as kelps are typically sparse on tidal flats.

The study area also excludes the most southern extent of South Puget Sound. This area has relatively low amounts of marine vegetation, mostly green algae and other red-brown algae. Excluding this area likely has a minor impact on the regional estimates for seagrass and understory kelp.

Table 4: area estimates (ha) for different vegetation types (cover class > 1) in the southern Salish Sea (SVMP fringe stratum only), the estimated 95% confidence interval, as well as the vegetated area expressed as % of all available substrate in the study area.

Vegetation type	area vegetated (ha)	95 % CI (ha)	% of available substrate
Green algae	16,293	15,047 - 17,538	19.3
Understory kelp	21,978	20,032 - 23,923	26.1
Other red-brown algae	20,654	18,649 - 22,659	24.5
Sargassum	509	411 - 607	0.6
Seagrass	12,971	11,843 - 14,100	15.4
All vegetation	50,425	48,040 - 52,810	59.8

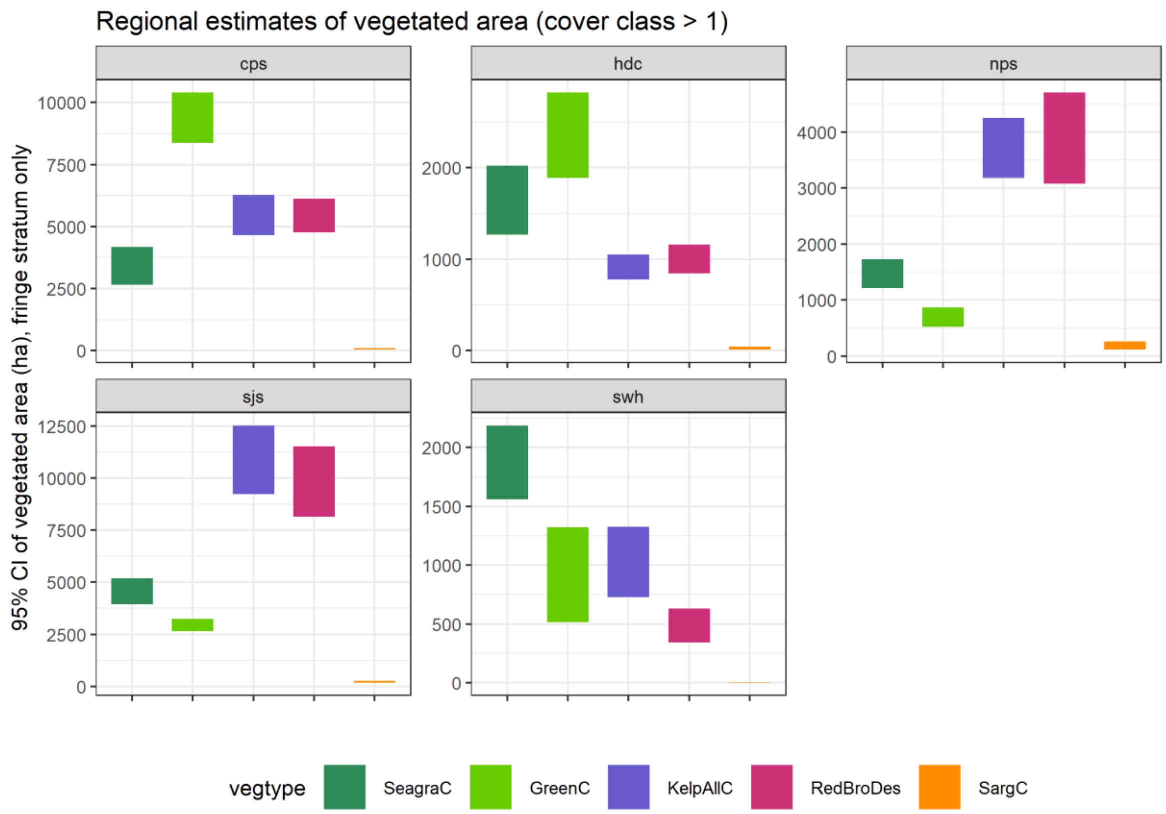

Figure 12: Regional estimates of vegetated area (cover class > 1) for 5 different groups of marine vegetation. The vertical lines represent a 95% confidence interval of vegetated area in the fringe stratum of the 5 sub-regions in greater Puget Sound.

The regional estimates of marine vegetation shown in Figure 12 confirm the patterns observed in Figure 8 and Figure 9. In Central Puget Sound (cps), green algae were the predominant marine vegetation type, followed by understory kelp and other red-brown algae. Area estimates for green algae were almost 3x higher than for seagrass in this region. Note that medium to high cover green algae were mostly found in relatively shallow habitats, and had a similar depth range as seagrass. As such there could be competition for substrate. In Hood Canal (hdc), green algae were the predominant vegetation type, closely followed by seagrass. Northern Puget Sound (nps) and the San Juan Islands and the Strait (sjs) showed a completely different pattern. These regions were dominated by understory kelp and other red-brown algae. Here, seagrass and green algae area estimates were relatively low as compared to the other vegetation types. However, absolute area covered by eelgrass was still substantial as compared to the other regions. In the Saratoga Whidbey Basin (swh) seagrass was the predominant vegetation type, followed by green algae and understory kelp. Note that Northern Puget Sound and the Saratoga Whidbey Basin are home large tide flats, dominated by seagrass and green algae. These areas contribute significantly to the regional estimates of eelgrass in the SVMP (Christiaen et al. 2022). Analyzing other marine vegetation types in flats habitat may be necessary to generate better estimates on regional scales, especially for green algae.

4 Discussion

Nearshore marine vegetation is a sensitive and critically important component of coastal ecosystems. Successful conservation and restoration of these ecosystems requires detailed information on the distribution, abundance and stressors of different marine vegetation types. In the southern Salish Sea, there exists a substantial body of knowledge on the distribution of eelgrass (*Zostera marina*) and floating kelp species such as bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*). Data on other marine vegetation types such as understory kelp are lacking.

This project fills a major information gap in our understanding of marine vegetation types in the southern Salish Sea by analyzing existing footage from a regional eelgrass monitoring program. While it is a first step towards a comprehensive assessment of marine vegetation, this project substantially enhances our understanding of regional patterns in vegetation abundance and depth distribution, and provides valuable information for the management of nearshore habitats in the southern Salish Sea.

4.1 Area estimates and comparisons with existing datasets

We estimate that nearshore marine vegetation occupied between 48,040 and 52,810 ha (95% CI), or ~ 60% of the available substrate between +1 and -15m (MLLW) in the fringe habitat in the southern Salish sea. Overall, understory kelp (20,032 - 23,923 ha) and other red-brown algae (18,649 - 22,659 ha) were the most abundant marine vegetation types, followed by green algae (15,047 - 17,538 ha) and seagrass (11,843 - 14,100 ha). Note that our regional area estimates exclude large tide flats, which are generally dominated by seagrass and green algae (Dethier 1990). As such the estimates for seagrass and green algae must be interpreted with caution. If estimates of eelgrass area on large flats from the eelgrass monitoring program are included, the total extent of eelgrass beds in the southern Salish Sea is similar to that of understory kelp and other red-brown algae (~22,100 ha, Christiaen et al. 2022).

The estimate for seagrass area in fringe habitat in the southern Salish Sea overlaps with the values estimated for the SVMP (between 8,995 and 12,695 ha, based on data from 2018-2020). This is expected as datasets are derived from the same towed underwater video footage. The slightly higher values from this project are likely due to methodological differences. The 2018-2020 SVMP estimate for fringe habitat was based on a larger sample of sites (n = 174) and was limited to native seagrasses area only. This project had a smaller sample size (n = 123) and did not distinguish between native seagrasses and the non-native seagrass *Z. japonica*.

The estimate for all marine vegetation (48,040 - 52,810 ha) is remarkably similar to the PMEP estimate of 51,501 ha aquatic vegetation beds (Bizzarro et al. 2022). This similarity between numerical estimates does not represent similar overall findings because the PMEP result is based on a different methodology, and covers a different spatial extent.

Our area estimates indicate that understory kelp is widespread in the southern Salish Sea. The Washington ShoreZone mapping effort (1994-2000) documented the presence of understory kelp along 31% of the shoreline of Washington State (Berry et al. 2001). We documented substantial presence of understory kelp at ~81% of sites sampled[5]. Note that the ShoreZone project was based on aerial imagery, and was not geared toward the detection of marine vegetation in subtidal habitats. Understory kelp is most abundant at depths below -3 m (MLLW). The difference in estimates between the current study and ShoreZone does not suggest any increase over the last 20 years.

4.2 Regional patterns in dominant vegetation types

The southern Salish Sea spans diverse environments in a network of interconnected basins that connect the ocean to a vast inland sea. Large scale oceanographic processes are commonly captured by subdividing the area based on oceanographic sub-basins, with the boundaries placed at shallow, interconnecting sills. In addition to capturing oceanographic characteristics, sub-basins generally divide the study area into regions with more similar environmental characteristics and stressors. The challenge in defining regions is to capture the most important spatial differences and to select a tractable number for sampling. This study adopts the SVMP regional delineation, which divides the southern Salish Sea into five regions to distinguish areas with distinct characteristics while also maintaining a sufficient number of samples within each region to support meaningful analyses (Figure 1).

While all vegetation types occurred throughout the study area, relative abundance varied greatly by region. There was a clear North to South pattern in the dominant vegetation types. Understory kelp and other red-brown algae were the dominant vegetation types in areas with strong marine influence, such as the Strait of Juan de Fuca and the San Juan Islands. Seagrass and green algae dominated at sites with more estuarine conditions in the Saratoga Whidbey Basin, Central Puget Sound, and Hood Canal. This result reflects the widespread understanding that brown and red algae abundance and distribution is greater in marine systems (Hurd et al. 2014). It also reflects the general pattern in substrate types in the southern Salish Sea. Kelp species need some sort of solid substrate for attachment, and tend to be the dominant vegetation along rocky shorelines, such as in the San Juan Islands and the Strait. Eelgrass (the predominant seagrass in the southern Salish Sea) prefers sandy or muddy substrates and is widespread along the shorelines of Puget Sound (Mumford et al. 2007). Northern Puget Sound appeared to be an exception – an estuarine area dominated by red and brown algae – but this result reflects the exclusion of large flats, which dominate the region and are heavily vegetated with green algae and eelgrass.

[5] Estimated as the percentage of sites sampled with over 1 ha of understory kelp at cover class 2 or higher.

The relative abundance of green algae was highest at sites furthest removed from marine influence, such as South Puget Sound. Sites in Central and South Puget Sound with a high relative abundance of medium and high cover green algae tend to have less seagrass present. This is consistent with the literature, as green algae blooms can have negative impacts on seagrass and other marine vegetation through shading and the release of toxic compounds (Nelson and Lee 2001, Burkholder et al. 2007, Van Alstyne et al. 2015). It is important to note that our data represents a ‘snapshot’ in time during the summer field season, when green algae blooms are most likely to occur. Resampling these sites will probably yield different area estimates. The regional pattern will probably persist.

The least abundant vegetation types in the study area were stipitate kelp and Sargassum. Stipitate kelps, such as *Pterygophora californica*, were most abundant in the Strait of Juan de Fuca and to a lesser degree in the San Juan Islands. They were rarely found in other regions, but were documented at locations with high currents and coarse substrates, such as the Tacoma Narrows. The non-native *Sargassum muticum* was found at 48% of sites analyzed for this project. This alga is a is a species of concern because it can outcompete native kelp and it is less palatable to grazers (Britton-Simmons 2004). It has been reported to be widely distributed, and “frequently [forming] very dense beds” (Druehl and Clarkston, 2016). Our area estimates for Sargassum were typically low (mostly less than 1 ha where present). This unexpected result could be attributed, in part, to the seasonal phenology of Sargassum, which begins growing and then dies back earlier than other algal species. Many of the vegetation surveys were conducted relatively late in the summer in order to capture peak abundance of many vegetation species.

4.3 Depth distribution of different vegetation types

Primary producers tend to grow down to a depth where enough light penetrates for photosynthesis to exceed respiration (Hurd et al. 2014). This depth depends on a range of factors, such as day length, temperature, tidal range, and water clarity. We documented 2 distinct patterns in our dataset.

There was a clear difference in depth distribution between the vegetation types. Seagrass, green algae and Sargassum were most abundant in the lower intertidal and shallow subtidal, with peak abundance at -2 m (MLLW) or shallower. In contrast, understory kelp and other red/brown algae showed greater abundance at -4 m (MLLW) and deeper. This pattern of abundance with depth is related, in part, to physiological adaptations of species of red and brown algae to lower light environments (Hurd et al. 2014).

There was also a pattern in densities for several vegetation types. High cover understory kelp predominated at intermediate depth, while low to medium cover understory kelps occurred more often at deeper depths. Medium and high cover green algae were mostly limited to shallow depths, but low cover green algae occurred throughout the entire depth range studied. Other red-brown algae showed an opposite pattern. Low and medium cover other red-brown algae were common throughout the entire depth range studied, but high cover red algae became more prevalent with increasing depths. These patterns probably reflect both difference in shade tolerance, as well as competitive interactions between the different marine vegetation types.

4.4 Methodological limitations

This project is a first step towards generating regional estimates for different marine vegetation types in the southern Salish Sea. There are some inherent limitations to the dataset, as data were collected with the goal of estimating native seagrass populations. Three key factors must be considered in applying these results across southern Salish Sea:

- Areas with floating kelp were excluded to avoid entanglement of the video towfish. Because floating kelp is always found in association with other algae, this methodological limitation results in an under-estimate of vegetation abundance and distribution.
- The estimate is limited to fringing shorelines; flats sites were excluded from the sampling frame in order to manage project costs. The exclusion of flats habitats most strongly affects the seagrass and green algae estimates. Separate sampling by the SVMP estimates that approximately half of the eelgrass in the southern Salish Sea occurs in flat sites. We do not have an estimate for green algae in flats sites.
- The southern extent of South Puget Sound is excluded from the study area. These shorelines were excluded from the eelgrass monitoring program because eelgrass is rare. Marine vegetation estimates could be improved by including these portions, which constitute the southern terminus of the Salish Sea.

Note that there were several differences in methodology as compared to the original eelgrass monitoring program. We estimated % cover of marine vegetation in one frame at 5 seconds intervals instead of presence/absence at 1 second intervals, we summarized data at the site level instead of at the transect level, we did not calculate uncertainty associated with the site level area estimates, and we used a different experimental extrapolation scheme to generate regional area estimates. Despite these differences in methodology, the regional estimates for seagrass were very similar to the values generated by the SVMP. This suggests that the values for other marine vegetation types are a good first estimate of abundance in the southern Salish Sea.

4.5 Data use and availability

This project, in combination F20AP12280-00, has generated a large area profile for eelgrass, understory kelp, and other vegetation types for fringe habitat in the southern Salish Sea. This effort significantly increases the certainty in both local and regional estimates of area and depth distribution of different marine vegetation types in the southern Salish Sea.

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 data presented in this report will be made available online. For more information, visit http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science

5 References

- Berry HD, Mumford TF, Christiaen B, Dowty P, Calloway M, Ferrier L, et al. (2021). Longterm changes in kelp forests in an inner basin of the Salish Sea. PLoS ONE 16(2): e0229703. https://doi.org/10.1371/journal.pone.0229703
- Bizzarro JJ, Selleck J, Sherman K, Drinkwin J, Hare VC, and Fox DS (2022). State of the knowledge: U.S. West Coast nearshore habitat use by fish assemblages and select invertebrates. Portland, OR: Pacific Marine & Estuarine Fish Habitat Partnership. https://www.pacificfishhabitat.org/assessment-reports/
- Britton-Simmons KH (2004). Direct and indirect effects of the introduced alga Sargassum muticum on benthic, subtidal communities of Washington State, USA. Mar Ecol Prog Ser.; 277:61–78. https://doi.org/10.3354/meps277061
- Burkholder JM, Tomasko DA, Touchette BW (2007). Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology 350:46-7
- Calloway M, Oster D, Mumford TF Jr., Berry H. (2020). Puget Sound kelp conservation and recovery plan Olympia, WA: Northwest Straits Commission. p. 52. https://nwstraits.org/ourwork/kelp/
- Chalifour L, Scott DC, MacDuffee M, Iacarella JC, Martin TG, Baum JK (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, Ferrier L, Dowty P, Gaeckle J, Berry H (2022). Puget Sound Seagrass Monitoring Report, monitoring year 2018-2020. Nearshore Habitat Program. Washington State Department of Natural Resources, Olympia, WA
- Dethier MN (1990). A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Dept. Natural Resources. Olympia, WA
- Dowty P, Ferrier L, Christiaen B, Gaeckle J, Berry H (2022). Submerged Vegetation Monitoring Program: 2000-2017 Geospatial Database User Manual. Washington Department of Natural Resources. Olympia, WA
- Druehl L, Clarkston B (2016). Pacific Seaweeds: Updated and Expanded Edition. Harbour Publishing. ISBN-10: 1550177370

- Duarte CM and Krause-Jensen D (2017). Export from Seagrass Meadows Contributes to Marine Carbon Sequestration. Frontiers in Marine Science 4:13.
- Filbee-Dexter K, Wernberg T (2018). Rise of Turfs: A New Battlefront for Globally Declining Kelp Forests. BioScience. 68(2):64–76. https://doi.org/10.1093/biosci/bix14
- Gabrielson PW, Lindstrom SC. Keys to the Seaweeds and Seagrasses of Southeast Alaska, British Columbia, Washington, and Oregon. Vancouver, British Columbia: University of British Columbia; 2018. 180 p.
- 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 KL, Carruthers TJB, Duarte CM, Hughes AR, Kendrick G, Orth RJ, Williams SW (2008). Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers. Ecosystems 11:1198−1210.
- Hurd CL, Harrison PJ, Bischof K, Lobban CS (2014). Seaweed Ecology and Physiology. 2 ed. Cambridge: Cambridge University Press.
- Johnson SW, Murphy L, Csepp DJ, Harris PM, Thedinga JF (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
- Krause-Jensen D and Duarte CM (2016). Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9, 737–742.
- Krumhansl KA, Sheibling RE (2012). Production and fate of kelp detritus. Marine ecology progress series 467, p. 281-302
- Moy FE, Christie H (2012). Large-scale shift from sugar kelp (Saccharina latissima) to ephemeral algae along the south and west coast of Norway. Marine Biology Research. 2012; 8(4):309–21. https://doi.org/10.1080/17451000.2011.63756
- Mumford TF Jr (2007). Kelp and Eelgrass in Puget Sound. Seattle, WA: Seattle District, US Army Corps of Engineers; p. 27. http://www.pugetsoundnearshore.org/technical_papers/kelp.pdf
- Nelson TA, Lee A (2001). A manipulative experiment demonstrates that blooms of the macroalga Ulvaria obscura can reduce eelgrass shoot density. Aquatic Botany 71: 149-154.
- Norris JG, Wyllie-Echeverria S, Mumford T, Bailey A, Turner T (1997). Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquatic Botany 58:269-287
- OCM Partners (2023). 2020 CoNED Topobathymetric Model of Puget Sound, Washington, 1887 to 2017, https://www.fisheries.noaa.gov/inport/item/59971.
- OCM Partners (2023): 2021 USGS CoNED Topobathymetric Model (1891 - 2016): Strait of Juan de Fuca, https://www.fisheries.noaa.gov/inport/item/65169

- Olson AM, Hessing-Lewis M, Haggarty D, Juanes F (2019). Nearshore seascape connectivity enhances seagrass meadow nursery function. Ecological Applications. Volume 29(5), e01897
- Pentilla D (2007). Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03, Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington
- Raymond WW, Berry H, D Claar D, Dowty P, Spaulding E, Christiaen B, Ferrier L, Ledbetter J, Naar N, Woodard T, Palmer-McGee C, Cowdrey T, Oster D, Shull S, Mumford T, Dethier M (2022). Floating kelp canopies: a new Vital Sign indicator in Puget Sound, Indicator Options and Visualizations.
- Robinson D and Hayes A (2018). broom: Convert Statistical Analysis Objects into Tidy Tibbles. R package version 0.5.1. https://CRAN.R-project.org/package=broom
- Rubin SP, Miller IM, Foley MM, Berry HD, Duda JJ, Hudson B, Elder NE, Beirne MM, Warrick JA, McHenry ML, Stevens AW, Eidam EF, Ogston AS, Gelfenbaum G, Pedersen R (2017). Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. PLoS ONE 12(12): e0187742
- Rubin SP, Hayes MC, Grossman EE (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
- Schmidt AL, Wysmyk JKC, Craig SE, Lotze HK (2012). Regional-scale effects of eutrophication on ecosystem structure and services of seagrass beds. Limnology Oceanography 57: 1389−1402
- Shaffer AJ, Munsch SH, Cordell JR (2020). Kelp forest zooplankton, forage fishes, and juvenile salmonids of the northeast Pacific nearshore. Marine and Coastal Fisheries. Volume 12(4), 4-20
- Stevens BG, Armstrong DA (1984). Distribution, abundance, and growth of juvenile Dungeness crabs, Cancer magister, in Grays Harbor estuary, Washington. Fishery Bulletin, 82(3), 469-483.
- Van Alstyne KL, Nelson TA, Ridgway RL (2015). Environmental chemistry and chemical ecology of ‘green tide’ seaweed blooms. Integrative and Comparative Biology 55(3): 518-532.
- Wernberg T, Bennett S, Babcock RC, de Bettignies T, Cure K, Depczynski M, et al. (2016). Climate-driven regime shift of a temperate marine ecosystem. Science 353(6295):169.
- Wickham H (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.
- Wickham H, François R, Henry L and Müller K (2018). dplyr: A Grammar of Data Manipulation. R package version 0.7.8. https://CRAN.R-project.org/package=dplyr
- Wickham H and Henry L (2018). tidyr: Easily Tidy Data with 'spread()' and 'gather()' Functions. R package version 0.8.2. https://CRAN.R-project.org/package=tidyr

6 Appendix 1

Table 5: Area estimates for green algae, understory kelp, other red-brown algae, Sargassum and seagrass at all sites reanalyzed as part of the SeaDoc project (A17-0568-S012) and the PMEP project (F20AP12280-00). Area estimates are in ha, and represent the sum of all vegetated area with cover class 2 or higher (over 5% of each frame covered by the vegetation type in question).

Site code	Green algae (ha)	Understory kelp (ha)	other red-brown algae (ha)	Sargassum (ha)	Seagrass (ha)
cps0221	7.3	1.1	1.7	0.0	0.0
cps1035	9.6	10.2	13.7	0.1	0.0
cps1069	26.4	3.5	2.5	0.0	14.9
cps1113	16.5	9.6	14.8	0.1	5.2
cps1137	8.4	1.6	1.7	0.0	3.1
cps1153	10.5	4.7	2.0	0.2	5.9
cps1156	17.3	1.2	0.6	0.0	6.1
cps1160	31.6	2.9	0.9	0.0	4.6
cps1164	7.2	2.4	1.6	0.1	8.2
cps1175	8.4	0.3	0.5	0.0	4.3
cps1194	5.6	4.4	3.8	0.0	0.0
cps1245	9.6	1.3	0.5	0.0	0.0
cps1277	4.8	4.2	6.2	0.0	2.5
cps1289	5.9	4.7	4.3	0.0	0.0
cps1663	13.4	13.9	11.7	0.6	5.9
cps1678	11.3	1.3	2.4	0.0	11.4
cps1686	12.7	9.4	12.0	0.4	6.1
cps1750	16.7	5.2	3.0	0.0	6.0
cps1764	9.5	2.6	2.5	0.0	5.9
cps1820	4.6	1.0	1.8	0.0	1.0
cps1951	6.4	6.0	2.5	0.4	0.0
cps1983	7.9	2.5	2.0	0.0	0.0
cps1999	1.6	3.4	2.6	0.0	0.0
cps2038	4.1	12.7	8.6	0.0	1.1
cps2047	11.1	0.4	1.3	0.0	0.1
cps2068	1.7	6.5	7.5	0.1	0.0

Site code	Green algae (ha)	Understory kelp (ha)	other red-brown algae (ha)	Sargassum (ha)	Seagrass (ha)
cps2070	1.2	4.1	8.6	0.4	0.0
cps2105	32.5	39.4	13.7	0.0	0.1
cps2182	5.9	0.1	5.0	0.0	0.0
cps2218	1.8	0.1	0.9	0.0	5.2
cps2221	5.3	2.1	6.1	0.0	6.6
cps2223	7.2	1.9	6.7	0.0	4.8
cps2227	3.9	18.6	13.3	0.0	17.4
cps2230	2.1	16.8	13.2	0.3	0.4
cps2552	32.8	6.1	8.7	0.1	9.6
cps2565	3.9	20.9	26.5	0.2	2.2
hdc2239	25.4	1.0	2.4	0.0	8.0
hdc2259	14.7	2.5	6.8	0.0	5.6
hdc2283	9.3	0.1	1.2	0.0	13.8
hdc2284	7.4	0.0	1.7	0.0	12.2
hdc2320	0.0	2.5	3.7	0.0	0.0
hdc2321	0.0	2.8	3.5	0.7	0.0
hdc2338	0.9	2.7	2.4	0.0	0.6
hdc2346	0.2	2.5	0.3	0.0	0.0
hdc2364	0.7	0.0	0.6	0.0	0.8
hdc2383	7.2	0.0	0.4	0.0	3.2
hdc2408	0.5	1.4	1.4	0.2	4.9
hdc2460	0.3	1.3	0.0	0.0	5.4
hdc2479	12.2	7.2	6.0	0.0	11.3
hdc2492	3.4	3.4	2.1	0.0	0.7
nps0059	0.4	2.9	0.7	0.1	0.2
nps0064	3.2	32.2	22.7	1.0	20.8
nps0522	5.4	6.0	5.9	1.3	3.4
nps0550	0.0	0.4	0.2	0.0	0.0
nps0654	3.0	49.6	77.5	2.5	11.2
nps0669	0.0	0.5	0.0	0.0	0.0
nps0670	0.0	1.1	0.0	0.0	0.0
nps0671	1.0	1.7	0.6	0.3	0.8
nps1320	4.5	0.1	0.4	1.2	18.2
nps1363	3.6	17.0	17.9	0.2	0.6
nps1373	0.1	2.6	0.7	0.2	0.0
nps1375	0.5	2.1	1.0	0.5	0.0
nps1461	2.5	5.1	0.4	0.2	9.0
sjs0001	1.6	7.4	1.1	0.5	10.5
sjs0081	1.7	2.7	0.1	0.4	0.9
sjs0099	0.9	9.1	6.3	0.8	12.3
sjs0114	1.5	13.4	10.4	0.2	9.6

Site code	Green algae (ha)	Understory kelp (ha)	other red-brown algae (ha)	Sargassum (ha)	Seagrass (ha)
sjs0133	6.0	6.8	0.5	0.0	1.0
sjs0191	0.2	2.2	1.9	0.1	0.0
sjs0205	0.1	31.7	21.7	0.0	12.3
sjs0311	1.6	5.3	4.6	0.0	1.5
sjs0318	5.3	7.7	0.1	0.0	0.0
sjs0330	1.3	4.5	1.2	0.1	2.1
sjs0351	9.3	6.3	18.6	0.0	19.7
sjs0417	2.2	1.3	0.1	0.0	0.3
sjs0427	0.8	2.0	0.1	0.1	0.0
sjs0448	3.0	4.1	2.4	0.0	3.7
sjs0452	6.4	4.8	2.7	0.0	10.8
sjs0454	1.1	2.2	0.6	0.2	1.2
sjs0473	0.3	5.1	0.4	0.6	0.9
sjs0488	0.0	2.3	0.7	0.3	0.0
sjs0526	0.1	2.2	0.3	0.3	0.0
sjs0600	2.8	4.2	2.4	0.3	2.7
sjs0617	6.4	10.1	0.8	0.0	1.5
sjs0635	0.0	6.3	0.6	0.1	1.4
sjs0639	0.0	3.8	2.2	0.0	0.0
sjs0649	0.2	4.3	0.7	0.5	0.0
sjs0682	4.9	4.1	4.2	0.1	2.0
sjs0683	0.7	6.8	5.0	0.2	0.2
sjs0695	0.5	9.0	1.6	0.0	0.0
sjs0819	0.0	44.4	82.5	0.0	1.4
sjs0829	0.0	0.0	0.3	0.0	0.4
sjs1004	0.7	0.2	2.5	0.0	2.6
sjs1492	4.1	9.0	4.1	0.4	9.9
sjs2605	0.3	28.3	24.2	0.2	7.0
sjs2622	6.6	4.2	5.3	0.0	5.4
sjs2628	0.1	0.1	0.1	0.0	4.2
sjs2632	0.1	0.0	0.2	0.6	0.0
sjs2652	0.4	4.7	6.8	0.0	5.6
sjs2695	0.2	102.0	100.8	0.0	0.5
sjs2741	6.9	29.4	15.4	0.0	5.7
sjs2742	0.2	4.6	6.2	0.0	0.0
sjs2775	0.0	1.8	13.7	0.0	2.7
sjs2781	0.0	3.3	4.0	0.0	1.9
sjs2784	0.6	4.8	4.1	0.0	2.2
swh0713	1.3	2.4	0.2	0.0	0.7
swh0848	8.8	14.0	3.4	0.0	12.0
swh0901	1.9	0.7	0.1	0.0	4.9

Site code	Green algae (ha)	Understory kelp (ha)	other red-brown algae (ha)	Sargassum (ha)	Seagrass (ha)
swh0918	0.2	7.8	3.0	0.0	12.9
swh0926	0.0	8.1	6.3	0.0	5.8
swh0940	0.8	0.7	0.0	0.0	8.3
swh0943	0.3	1.6	0.6	0.0	20.6
swh0955	0.3	0.0	0.2	0.0	12.9
swh0973	3.2	8.0	1.9	0.1	14.6
swh1556	1.6	4.6	0.4	0.0	5.8
swh1557	1.2	2.2	0.1	0.0	4.2
swh1568	2.8	6.8	2.8	0.0	0.0
swh1574	3.7	4.3	2.0	0.0	16.1
swh1593	5.2	1.5	0.6	0.0	2.4
swh1625	8.4	0.0	1.0	0.0	6.9
swh1626	7.9	0.0	7.1	0.0	25.8
swh1649	3.3	0.5	0.3	0.0	5.9
swh1653	20.8	1.6	1.2	0.0	16.8