N A T U R A L   R E S O U R C E S

Eelgrass abundance and depth distribution in King County

Final report to King County
DNR IAA 93-097520

July 14, 2020

Puget Sound Ecosystem Monitoring Program

Washington State Department of Natural Resources

The Nearshore Habitat Program supports the Washington State Department of Natural Resources' stewardship responsibilities for state-owned aquatic lands. It is also a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (https://www.psp.wa.gov/PSEMP-overview.php).

Cover Photo: *Zostera marina* in the shallow subtidal, Photo by DNR

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Nearshore Habitat Program
Aquatic Resources Division

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The principal authors of this report include Bart Christiaen, Jeff Gaeckle, 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 continue to play 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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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*), an important nearshore habitat in greater Puget Sound. DNR monitors the status and trends of native seagrass throughout greater Puget Sound using underwater videography.

This report synthesizes results from eelgrass surveys conducted under an interagency agreement between DNR and the King County Department of Natural Resources and Parks, Wastewater Treatment Division (IAA 93-097520). This effort supplements existing and planned future sampling by DNR's Submerged Vegetation Monitoring Program (SVMP), and significantly improves our understanding of eelgrass area and depth distribution in Central Puget Sound. In addition, these surveys establish a baseline for future studies to document trends in eelgrass distribution on both local and regional spatial scales.

Key Findings:

- In 2017 and 2018, DNR conducted a comprehensive survey of eelgrass along the King County shoreline. Eelgrass was present at 137 out of 152 sites sampled. Eelgrass was absent or sparse along the southwestern shoreline of Vashon Island, inner Quartermaster Harbor, and the inner portion of Elliott Bay.

- The non-native *Zostera japonica* was widespread in the southern part of the study area. *Zostera japonica* was present at 52 out of 152 sites sampled. This non-native seagrass was mostly found in association with native eelgrass beds. *Zostera japonica* occurred at only one location where native eelgrass was absent.

- There was approximately 680 ha of eelgrass along the shoreline of King County. This is roughly 21% of the current best estimate for total eelgrass area in Central and South Puget Sound.

- While eelgrass was widespread, individual eelgrass beds were relatively small. The median size of King County eelgrass beds was 3.42 ha per 1000 m section of shoreline. The largest eelgrass beds were found along Magnolia Bluff near Discovery Park (37.6 ± 2.4 ha, 23.7 ± 1.9 ha, and 18.9 ± 0.9 ha respectively).

- Approximately 95% of all eelgrass along the shoreline of the King County grew between 0.2 and -4.45 m relative to Mean Lower Low Water (MLLW). The median depth was approximately -1.39 m (MLLW). Overall, the depth distribution of eelgrass in King County was very similar to other sites in Central Puget Sound, but more restricted as compared to the San Juan Islands and the Strait of Juan de Fuca.

- Multiple gradients in eelgrass depth distribution were evident throughout the study area. Eelgrass beds grew less deep in the southern part of King County, and inside Quartermaster Harbor. These patterns likely reflect spatial gradients in water clarity.

- At 29 out of 152 sites sampled, we were able to assess change in eelgrass area over time based on previous data from the SVMP (collected between 2000 and 2018). In total there were 7 sites with declines, 3 with increases and 19 sites without a significant trend over time. The declines were mostly centered on the southern part of the study area. We identified three areas with declines: the northern section of Colvos Passage, Dumas Bay, and the inner part of Quartermaster Harbor.

- A comparison of the current depth distribution with data from dive surveys from 1962-63 shows similar depth ranges over time. Historical data suggests that eelgrass has persisted along the shoreline of the central channel, but confirms the long-term loss of eelgrass in inner Quartermaster Harbor.

1 Introduction

Eelgrass (*Zostera marina*) is a flowering plant that grows submerged in marine and estuarine environments. Eelgrass provides a wide range of important eosystem services. These plants have a high primary productivity and create valuable habitat for a wide variety of organisms, ranging from small invertebrates to waterfowl and commercially important fish species. In Puget Sound, eelgrass provides spawning grounds for Pacific herring (*Clupea harengus pallasi*), out-migrating corridors for juvenile salmon (*Oncorhynchus* spp.) (Phillips 1984, Simenstad 1994), and important feeding and foraging habitats for waterbirds such as the black brant (*Branta bernicla*) (Wilson and Atkinson 1995) and great blue heron (*Ardea herodias*) (Butler 1995). In addition, eelgrass provides valued hunting grounds and ceremonial foods for Native Americans and First Nation People in the Pacific Northwest (Suttles 1951, Felger and Moser 1973, Kuhnlein and Turner 1991, Wyllie-Echeverria and Ackerman 2003). Because of its extensive root and rhizome system, eelgrass can stabilize the sediment, reduce erosion and improve water clarity by limiting resuspension (de Boer 2007). Recent studies suggest that eelgrass can potentially mitigate some effects of ocean acidification, and that algicidal bacteria on eelgrass leaves may influence the abundance of harmful algae in nearshore environments (Hendriks 2014, and Inaba et al. 2017, Jacobs-Palmer et al. 2020).

Eelgrass is usually found on soft substrates, such as sand and mud. It tends to grow in relatively shallow environments, and is often limited by light availability. Eelgrass responds quickly to anthropogenic stressors such as physical disturbance, and reductions in water quality due to excessive input of nutrients and organic matter. When subjected to high nutrient loads, seagrasses such as eelgrass can be light limited by phytoplankton, macro algae and epiphytes (Burkholder et al. 2007). High concentrations of organic matter in the sediment often lead to increased concentrations of sulfide in the pore water, which negatively impacts eelgrass growth when concentrations exceed the plants ability to oxidize sulfide in the rhizosphere (Holmer et al. 2005, Holmer et al. 2001). Dredging, construction, and recreational boating and anchoring in nearshore habitats can either physically damage eelgrass or negatively impact eelgrass through shading and siltation (Hemminga and Duarte 2000)

Because of its wide distribution and sensitivity to human disturbance, eelgrass is an effective indicator of habitat condition (Dennison et al. 1993, Short and Burdick 1996, Lee et al. 2004, Kenworthy et al. 2006, Orth et al. 2006). Since 2000, the Nearshore Habitat Program at the Washington State Department of Natural Resources (DNR) has collected annual data on the status of eelgrass throughout Puget Sound as part of the Submerged Vegetation Monitoring

Program (SVMP). The SVMP is one component of the broader Puget Sound Ecosystem Monitoring Program (PSEMP), a multi-agency monitoring program coordinated by the Puget Sound Partnership. The monitoring data are used to characterize the status of native seagrass and is one of 25 vital signs used by the Puget Sound Partnership to track progress in the restoration and recovery of Puget Sound (PSP 2019).

The SVMP estimates soundwide eelgrass area (and associated uncertainty) by sampling a limited number of sites throughout the entire greater Puget Sound, according to a statistical design. The soundwide study is complemented by targeted studies aimed at surveying entire stretches of shoreline in greater detail. Previously, DNR has completed detailed surveys of eelgrass along the Kitsap Peninsula, Bainbridge Island, and the shoreline of Bellingham Bay.

In 2018, King County entered into an agreement with DNR to conduct a comprehensive survey of nearshore habitat along the entire shoreline of King County, using methods standardized by the SVMP, and use this information to guide eelgrass restoration (IAA 93-097520). This project results from a settlement agreement between King County and the Department of Ecology to resolve the appeal by King County of the Notice of Penalty with the Pollution Control Hearings in case No. 17-086: King County Wastewater Treatment Division v. Washington Department of Ecology. This report is the deliverable for Task 5 (Final report – habitat survey).

2 Methods

Field sampling for this project was conducted using the methods of DNR's Submerged Vegetation Monitoring Program (SVMP). The SVMP is a regional monitoring program, initiated in 2000, designed to provide information on 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*.

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

2.1 Study area description

Our study area encompasses the entire shoreline of King County, excluding a short section of heavily modified shoreline along the industrialized Port of Seattle. The study area was split into 7 different zones (Figure 1): North Shore (NS), Elliott Bay (ELB), Mid Shore (MS), South Shore (SS), Eastern Vashon (EV), Quartermaster Harbor (QM), and Colvos Passage (CO). We further divided the area into 154 potential sample sites. Sites are labeled according to the SVMP dataset. Each code starts with 3 letters (cps, which stands for Central Puget Sound), followed by 4 numbers. The sole exception are the tidal flats, which are coded as "flats" followed by 2 numbers. Figure 1 shows an overview of the study area, divided into the 7 zones. The maps in Appendix 2 relate the site code with the location of sites.

DNR surveyed 1691 underwater video transects at 152 sites in the King County study area: 61 sites were sampled using funds from DNR in 2017 and 2018 (Quartermaster Harbor, part of Vashon Island, and south of Des Moines to the King – Pierce County line), and 91 sites were sampled in 2018 as part of Task 2 - field sampling (Figure 1). The 2 remaining sites were sampled in 2019 but have not yet been analyzed at the time of writing this report. The total extent of King County shoreline sampled in 2017 and 2018 is 160 km. The un-sampled portion of shoreline measures 5.57 km (Port of Seattle and 2 sites sampled in 2019).

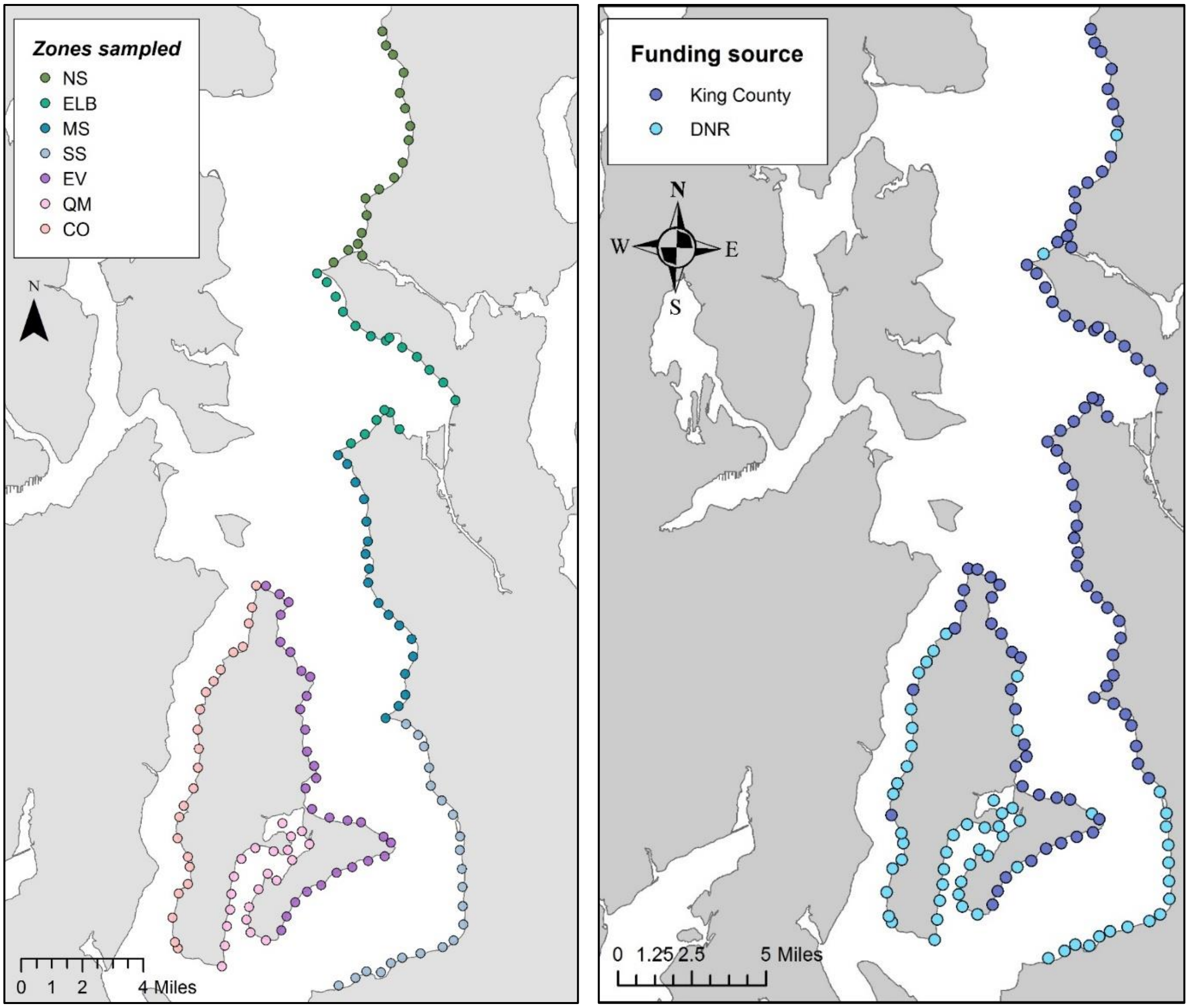

Figure 1: Left: Overview of the King County Study Area. Zones are indicated by different colors. **Right:** Funding source. Sites sampled with DNR funds are indicated in light blue, sites sampled with King County funds are indicated in dark blue.

2.2 Site definition and stratification

Sample sites were delineated according to methods from the SVMP (Dowty et al. 2019). Sites belong to one of two sample frames: flats and fringe sites.

- The flats category includes embayments, tide flats and river deltas, potential habitat that is best represented by areal sample units. The potential eelgrass habitat for each flats site is calculated as the area between the shoreline and the -6.1 m depth contour. There is only one flats site in the King County study area: flats33 (inner Quartermaster Harbor). Segment lengths for flats sites vary depending on embayment size.
- The fringe category contains potential habitat along a narrow band parallel to the shoreline, and is well represented by linear sample units. Sites are bound by the -6.1 m MLLW bathymetry contour and the ordinary high water mark. Fringe sites usually measure 1000 m in length along the -6.1 m contour. Fringe sites are further divided into

narrow and wide categories. A threshold width of 305 m is used to differentiate narrow (<305 m) and wide sites (>305 m). Along the shoreline of King County, there are 14 wide fringe sites and 139 narrow fringe sites.

2.3 Field sampling

At each site sampled, we recorded continuous underwater video along several line transects using a modification of the methods of Norris et al. (1997). Transects were oriented perpendicular to shore and spanned the entire width of a sample polygon.

- For sites sampled before 2016, sample polygons encompassed all eelgrass but did not necessarily span the entire length of a site. Transects were selected by new draw simple random sampling (SRS) within the sample polygon (Figure 2).
- At sites sampled in 2016 and later, the sample polygon typically spanned the entire length of the site, regardless of the eelgrass distribution. Transects were selected by Stratified Random Sampling with one transect per stratum – STR[1] (Figure 2).
- Sites within the King County study area that are part of the new 3-panel design of the SVMP (Christiaen et al. 2019) have been sampled with both STR and SRS transects between 2016 and 2018. The SRS transects are an exact repeat of previously sampled transects.

Sampling took place during relatively high tides so the research vessel was more likely to reach the shallow extent of native eelgrass (*Z. marina*). Transects did not always extend to the shallow edge of *Z. japonica* and do not necessarily represent the entire spatial extent of this non-native seagrass. The general target is to survey a minimum of 10 stratified random transects per site, but this number varies depending on previously observed variance and tidal conditions. In 2017 transects extended to just below the deep edge of eelgrass beds. In 2018, all transects were sampled to -15 m relative to MLLW (the range of most marine macrophytes in this region).

In 2017 and 2018, we sampled 152 out of 154 potential sample sites in the King County study area: 130 sites were sampled with STR only, 1 site was sampled with SRS only, 19 sites were sampled with both SRS and STR, and at 2 sites in Elliott Bay (cps1698 and cps1699) we sampled using ad-hoc transects because of the high number of navigational hazards. Eight sites were sampled in both 2017 and 2018. At 29 sites, we were able to repeat previously sampled transects (up to 15 years prior, depending on the site). These repeat transects were used as input for a change analysis.

[1] STR transects are selected by dividing the site along the centerline in segments of equal length, and then selecting a random transect perpendicular to shore in each of these segments

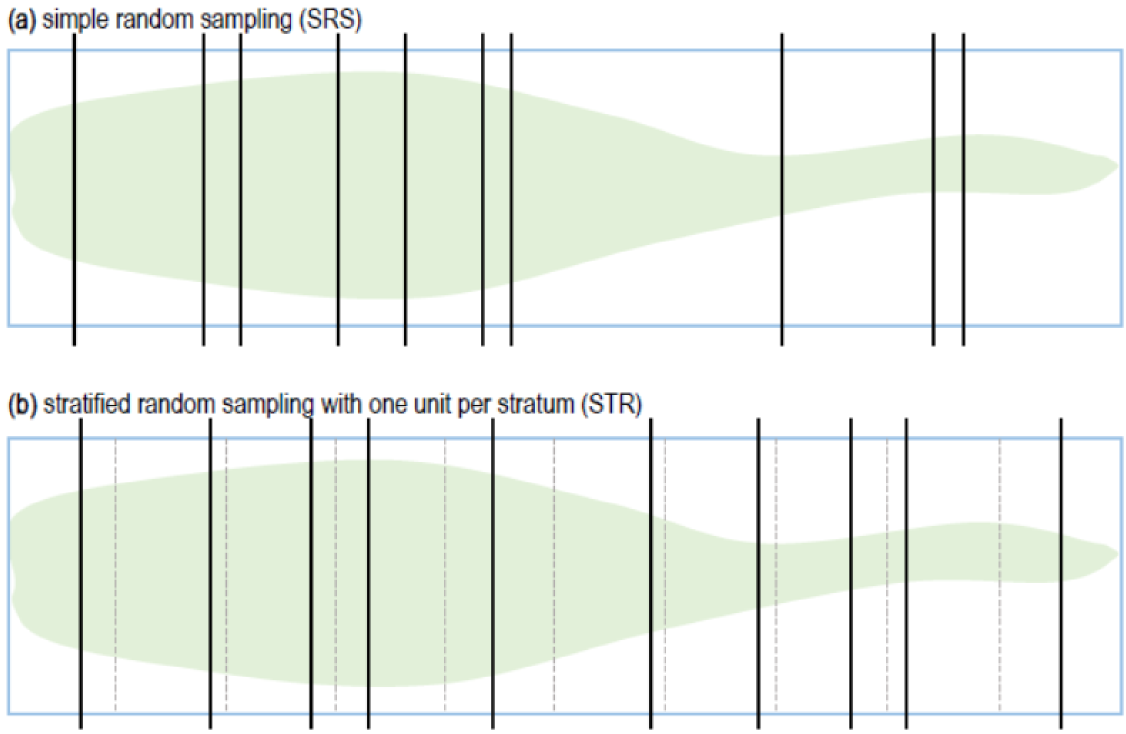

Figure 2: Different transect selection methods at the site level: (a) Simple random sampling, (b) stratified random sampling with one unit per stratum (Source: Dowty 2017).

Field sampling was conducted from an 11 m (36-ft) research vessel, the *R/V* Brendan D II, operated by Marine Resources Consultants (MRC). A DNR scientist was on board the vessel to guide the data collection. The *R/V* Brendan D II was equipped with all the necessary instruments for data collection (Table 1). Transects were surveyed using an underwater video camera mounted in a downward-looking orientation on a weighted towfish, which was deployed directly off the stern of the vessel using a cargo boom and boom winch. During transect sampling, an MRC technician adjusted the height of the towfish using a hydraulic winch to fly the camera above the eelgrass canopy. Parallel lasers mounted 10 cm apart provided a scaling reference in the video image. A 500 watt underwater light provided illumination when needed.

Survey equipment simultaneously recorded eelgrass presence/absence, position, depth and time of day. Time and position data were acquired using a differential global positioning system (DGPS) with ability to utilize satellite based augmentation services (SBAS). The antenna was located on the top of the cargo boom, directly above the towfish and camera, ensuring that the position data reflected the geographic location of the camera (Figure 3). Depth was measured using a Garmin Fishfinder 250 and a BioSonics MX habitat echo sounder. Both were linked to the differential global positioning system so that collected depth data was location and time specific.

A laptop computer equipped with a video overlay controller and data logger software integrated the DGPS data, user supplied transect information (transect number and site code), and the video signal at one second intervals. Video images with overlaid DGPS data and transect information were simultaneously recorded on DVDs, and D/V hard drives. Date, time, position, and transect information were stored on the computer at one second intervals. A real-time plotting system integrated National Marine Electronic Association 0132 standard sentences produced by the DGPS, two depth sounders, and a user-controlled toggle switch to indicate eelgrass presence/absence.

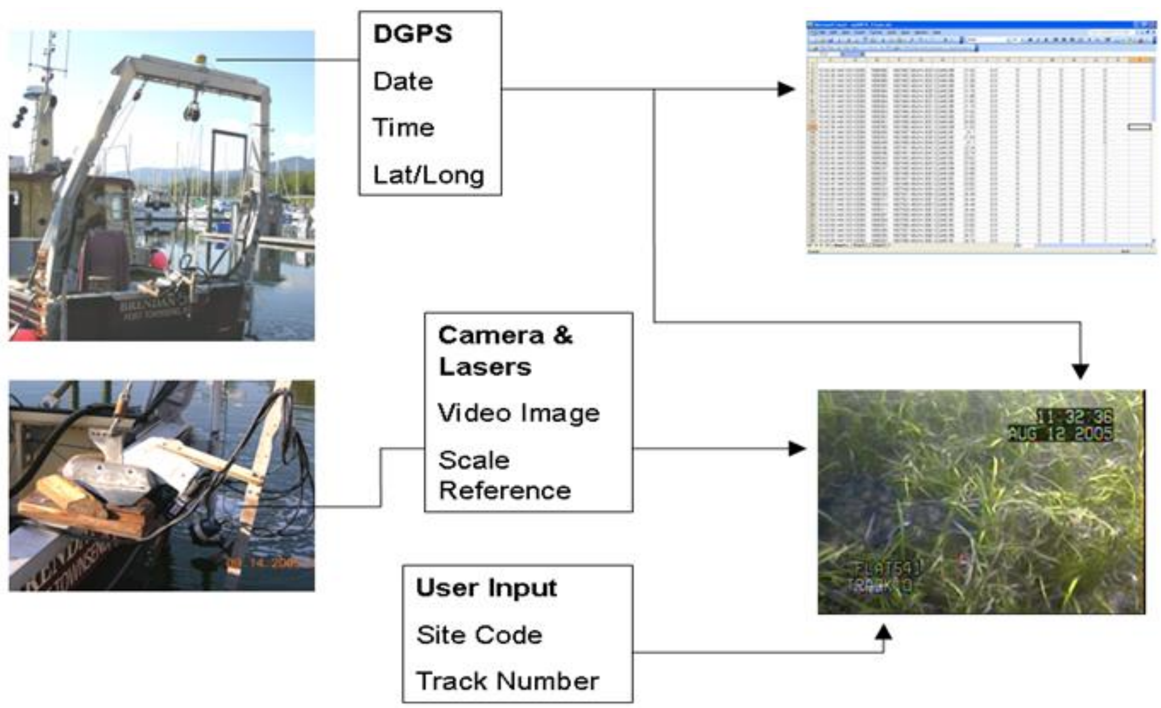

Figure 3: Overview of equipment used, and the data stream during sampling. The underwater video camera "flies" over the seabed while positioned beneath the DGPS antenna. Date and time are stamped on the video images.

Table 1: Equipment and software used to collect underwater video and depth data

Equipment	Manufacturer/Model
Differential GPS	Hemisphere VS330 with Satellite Based Augmentation System (SBAS, sub-meter accuracy)
Depth Sounders	Primary: BioSonics Mx Habitat Echosounder Secondary: Garmin Fishfinder 250, 200 KHz single-beam transducer with temperature sensor
Underwater Cameras	Ocean Systems Deep Blue SD (downward facing) Ocean Systems Deep Blue HD (forward facing)
Lasers	Deep Sea Power & Light (10 cm spread, red)
Underwater Light	Deep Sea Power & Light RiteLite (500 watt)
Navigation Software	Hypack Max
DVD Recorder	Sony RDR-GX7 + Intuitive Circuits TimeFrame Video Overlay Controller
Image recording	3 Atomos Ninja 2 Digital Video Recorder, 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

2.4 Post processing

We classified underwater video footage for the presence/absence of native (*Z. marina*) and non-native (*Z. japonica*) eelgrass at 1 second intervals. This results in a classification with a nominal 1 m^2 resolution[2]. Variations in density and percent cover within each 1 m^2 unit were not captured. Video quality was recorded for each 1 m^2 unit as good or poor. Video quality was recorded as poor when the vegetation could not be classified due to high turbidity or very low light conditions. Eelgrass was only labeled 'present' when the video processor had reasonable certainty that there was at least one rooted plant within the video frame. If a plant was visible but appeared to be rooted to either side of the 1 m-wide belt it was not considered. In practice, the video processors often made a subjective determination on whether a plant was rooted within the classification area, particularly when poor water clarity obscured the substrate.

[2] The dimension of each classified unit in the along-track direction is determined by boat speed which is variable but generally in the range of 0.5 – 1.3 m s^{-1}. The video processors use the recorded laser beams as a scale reference. The width of the transect that is classified is nominally 1 m wide in the cross-track dimension but this is approximate and depends on camera height above the sediment surface.

The fractional presence of eelgrass along transects was used to calculate site eelgrass area. The depth at which eelgrass grew along each transect was used to estimate the depth distribution of eelgrass relative to Mean Lower Low Water (MLLW) at each site. 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). These final corrected depth data were merged with eelgrass data and spatial information into a site database so that all eelgrass observations had associated date/time, position and depth measurements corrected to the MLLW datum.

2.5 Depth distribution

Eelgrass depth characteristics for each site were estimated using descriptive statistics (i.e., the 1st, 2.5th, 5th, 10th, 25th, 50th, 75th, 90th, 95th, 97.5th and 99th percentile) for all eelgrass observations along SRS and STR transects. For each site with eelgrass present, we represented the depth distribution with a histogram of depths of all sample points where eelgrass was detected at the site (Appendix 3).

The regional depth distribution of eelgrass was calculated as follows. For each site, 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:

$$a_{jk} = A_j \frac{c_{jk}}{\sum_{k=1}^{n} c_{jk}}$$

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.

2.6 Area calculation

Eelgrass area at each site was calculated using ArcGIS software and the site database file in the following sequential steps:

1. Calculate the area within the sample polygon;
2. Calculate the fraction of eelgrass along each random line transect within the sample polygon;
3. Calculate the mean fraction and associated variance[3], weighed by transect length;

[3] We calculate variance for stratified random samples using the textbook variance estimator. 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).

4. Estimate the overall eelgrass area and variance at the site by extrapolating the mean fraction along random transects over the sample polygon area.

Because we comprehensively surveyed the study area, we estimated the total eelgrass area per zone by adding all the site eelgrass area estimates. Uncertainty was estimated using the methods employed for the core stratum in the area calculations for the SVMP. For more information on the statistical framework and the sample methods in general, see Berry et al. (2003) and Dowty et al. (2019).

2.7 Trend analysis

Thirty-one sites in the study area were previously sampled by the SVMP. Out of these sites there were 23 sites with more than 2 years of data. At these locations we assessed change in eelgrass area over time using a linear regression analysis. We report results using an alpha of 0.01. At 29 sites, we sampled the same transects at more than one occasion. At these sites we calculated the difference in vegetated length at each transect between the most recent and earliest sample event, and used a paired t-test to assess change over time at each site. We report results using an alpha of 0.01. Note that for different sites, there is a different time interval between the earliest and latest sample event. We classified trends as short-, medium- and long term based on the time interval (1-3 years, 4-9 years, over 10 years). The results from these statistical tests were used in a consensus analysis. Any potential trends were confirmed by assessing change in spatial distribution using ArcGIS. Sites with total loss were always classified as declining. Sites with potential misidentification between *Z. marina* and *Z. japonica* were labeled not changing until further ground-truthing at these locations (see Appendix 4).

2.8 Historical trend analysis

We used maps from Thom and Hallum (1990) to compare current extent of eelgrass beds to historical data. These maps are based on 4 data sources[4] (Figure 4):

- dive surveys by Ron Phillips, Seattle Pacific College (1962-1963)
- surveys by the Washington Department of Fisheries (1975-1989)
- personal observations by Ron Thom (1974-1989)
- data from the Coastal Zone Atlas (1977)

The first 3 sources are based on surveys, and are accurate but not comprehensive. They cover only a portion of the King County shoreline, and cannot be used to assess changes in eelgrass distribution outside the footprint of the original surveys. The Coastal Zone Atlas was based on interpretation of aerial photographs taken in 1973-1974. These data were ground-truthed in 1977 to verify the presence of eelgrass. However, only meadows that extend in the intertidal zone were accurately represented. In addition, there appear to be locations where the presence of eelgrass may have been confused with green macroalgae. As a result data from the Coastal Zone Atlas are believed to contain inaccuracies, and should be interpreted with care.

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[4] Thom and Hallum (1990) describe other data sources but these are not relevant along the shoreline of King County

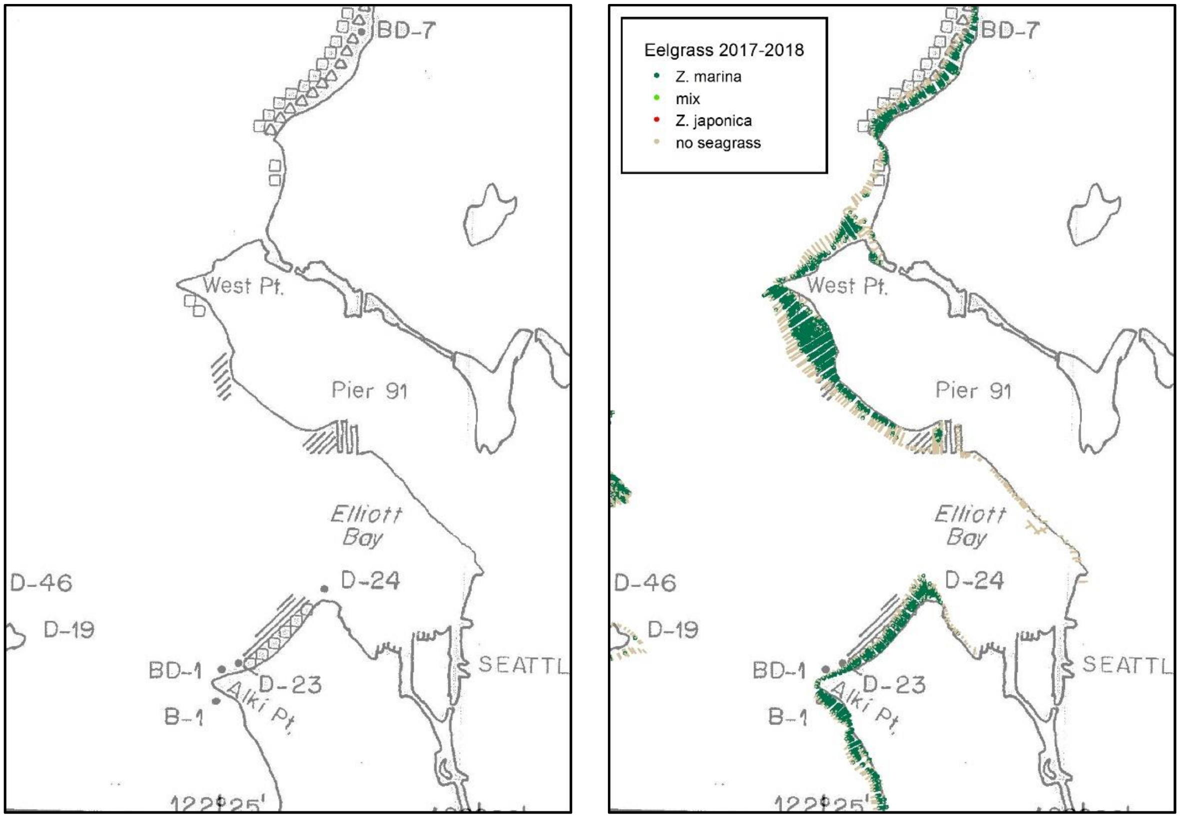
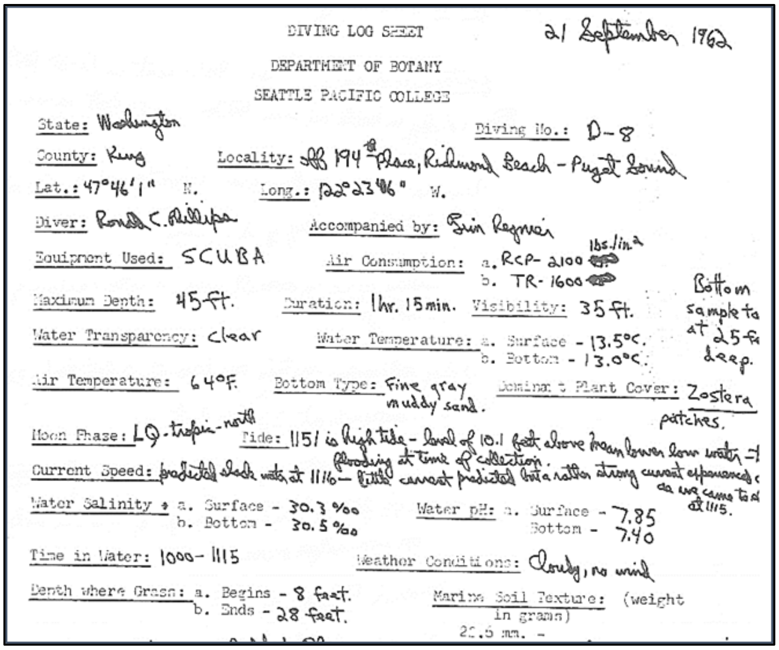


Figure 4: Comparison of maps from Thom and Hallum (1990) with current eelgrass surveys. The codes on the historical maps refer to dive surveys from Ron Phillips (1962-1963), the triangles are surveys by the Washington Department of Fisheries (1975-1989), the hashed lines are personal observations by Ron Thom (1974-1989), and the squares are data from the Coastal Zone Atlas (1977). Presence of eelgrass during the 2017-18 surveys is marked in green (right).

We georeferenced maps from Thom and Hallum, overlaid these maps with data from our recent study, and assessed the persistence of previously surveyed eelgrass beds over time. We excluded data from the Coastal Zone Atlas because of its low accuracy. We also reviewed the original dive logs of Ron Phillips to identify the precise location of these dive surveys[5]. We calculated summary statistics of eelgrass depth data for all transects within a 200m radius of the estimated dive locations, and compared the current depth distribution of eelgrass with depth observations described in the dive logs from 1962 and 1963 (Figure 5). All depth observations from dive surveys were transformed to depth relative to MLLW based on the timing of the dive and the tidal stage at the location/time of the dives.

[5] For some of the surveys, we have high confidence about the precise location, for others there is some uncertainty due to the coarse scale of the maps and unclear description in the dive logs.



DIVING LOG SHEET 21 September 1962

DEPARTMENT OF BOTANY

SEATTLE PACIFIC COLLEGE

State: Washington Diving No.: D-8

County: King Locality: off 194th Place, Richmond Beach - Puget Sound

Lat.: 47°46'1" N. Long.: 122°23'46" W.

Diver: Ronald C. Phillips Accompanied by: Erin Regnier

Equipment Used: SCUBA Air Consumption: a. RCP- 2100 lbs./in.² b. TR- 1600

Maximum Depth: 45 ft. Duration: 1hr. 15 min. Visibility: 35 ft. Bottom sample taken at 25 ft deep.

Water Transparency: clear Water Temperature: a. Surface - 13.5°C. b. Bottom - 13.0°C.

Air Temperature: 64°F. Bottom Type: Fine gray muddy sand. Dominant Plant Cover: Zostera patches.

Moon Phase: LQ - tropic - north Tide: 1151 is high tide - level of 10.1 feet above mean lower low water - flooding at time of collection.

Current Speed: predicted slack water at 1116 - little current predicted but a rather strong current experienced as we came to at 1115.

Water Salinity: a. Surface - 30.3 ‰ b. Bottom - 30.5 ‰ Water pH: a. Surface - 7.85 Bottom - 7.40

Time in Water: 1000 - 1115 Weather Conditions: Cloudy, no wind

Depth where Grass: a. Begins - 8 feet. b. Ends - 28 feet. Marine Soil Texture: (weight in grams)

2?.5 mm. -

Figure 5: Example of a dive log from 21 September 1962. Location: off 194th Place, Richmond Beach (indicated by the red arrow). The green dot represents the estimated location of the dive. We selected all 2017-2018 transects within a 200m range from the estimated dive location (red circle) and calculated local summary statistics for eelgrass depth based on these transects.

2.9 Case study: eelgrass north of Shilshole Bay Marina

In 1999, the Pacific Northwest National Laboratory conducted a large survey of aquatic habitats along the shorelines of King County and Snohomish County between Shilshole Bay Marina and Picnic Point, slightly north of Edmonds (Woodruff et al. 2001). In total, 22 km of shoreline were mapped from approximately +1 m to -30m relative to MLLW, using a combination of side scan sonar and towed underwater videography. Data were processed to generate GIS layers of different habitats types, including eelgrass and floating kelp.

We overlaid the current survey data with the polygons from the 1999 PNNL surveys, and compared the presence/absence of eelgrass for each point along the transects with the corresponding value from the polygons generated by side scan sonar in 1999. We estimated change in eelgrass cover for the 13 SVMP sites along this section of shoreline by calculating the percentage of total observations where eelgrass was present/absent in both surveys, and the percentage of observations where there was apparent loss or gain. While there were differences in the survey methods[6], we were able to assess large scale patterns spatial variability over this period of time (Figure 6).

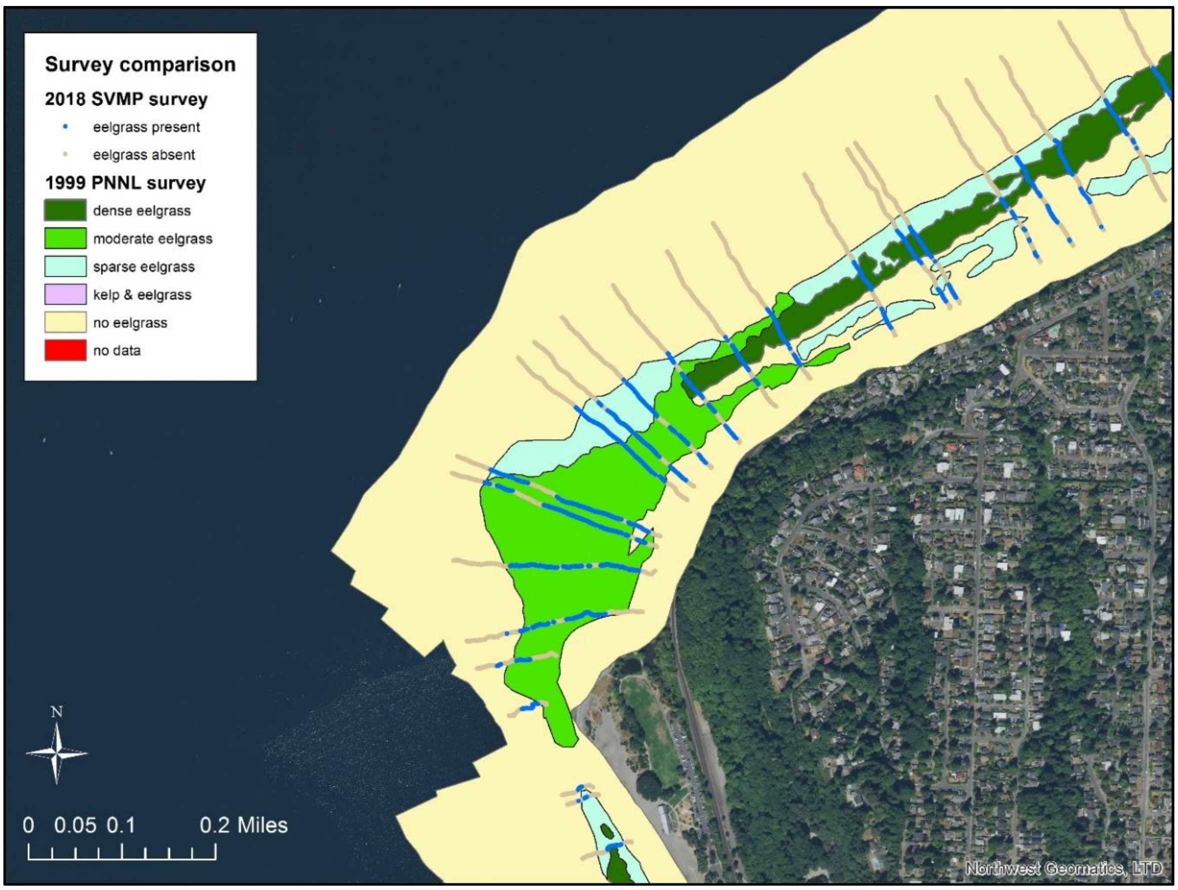


Figure 6: SVMP transect data overlaid on GIS polygons depicting sparse, moderate and dense eelgrass beds based on the 1999 PNNL survey along the King County shoreline near Golden Gardens Park.

[6] We did not compare the towed underwater survey data (~ presence/absence per m^2) with the actual side scan data, which have a theoretical pixel size of 6 cm x 30 cm, but with the eelgrass polygons that were a summary result of the 1999 surveys. There will be discrepancies between the data due to these methodological considerations, but the comparison should allow for detecting large differences in spatial extent.

3 Results

3.1 Seagrass species in King County

There are two species of seagrass in King County: native eelgrass (*Z. marina)* and non-native dwarf eelgrass (*Z. japonica*) (Figure 7). Both species prefer sandy and muddy substrates. Eelgrass is found between +1.4 m and -12.5 m relative to MLLW in greater Puget Sound. It is morphologically very plastic: its leaves can vary from 10-20 cm to well over 1.5 m long depending on the depth and location in greater Puget Sound. The non-native *Z. japonica* typically grows shallower than eelgrass. It is much smaller and has a different morphology of the leaf sheath and root system. It can be difficult to distinguish the species based on size alone because their size ranges overlap. DNR classifies presence/absence of *Z. japonica* from video observations, but at sites where we suspect this species to be present, we usually take a number of grab samples to confirm our observations based on the morphology of the leaf sheath.

Figure 7: A small patch of non-native *Z. japonica*, surrounded by the native *Z. marina*. *Z. japonica* is usually smaller than *Z. marina*, but at some locations it is difficult to differentiate between both species based on size. Other defining characteristics include the morphology of the leaf sheath and the root system.

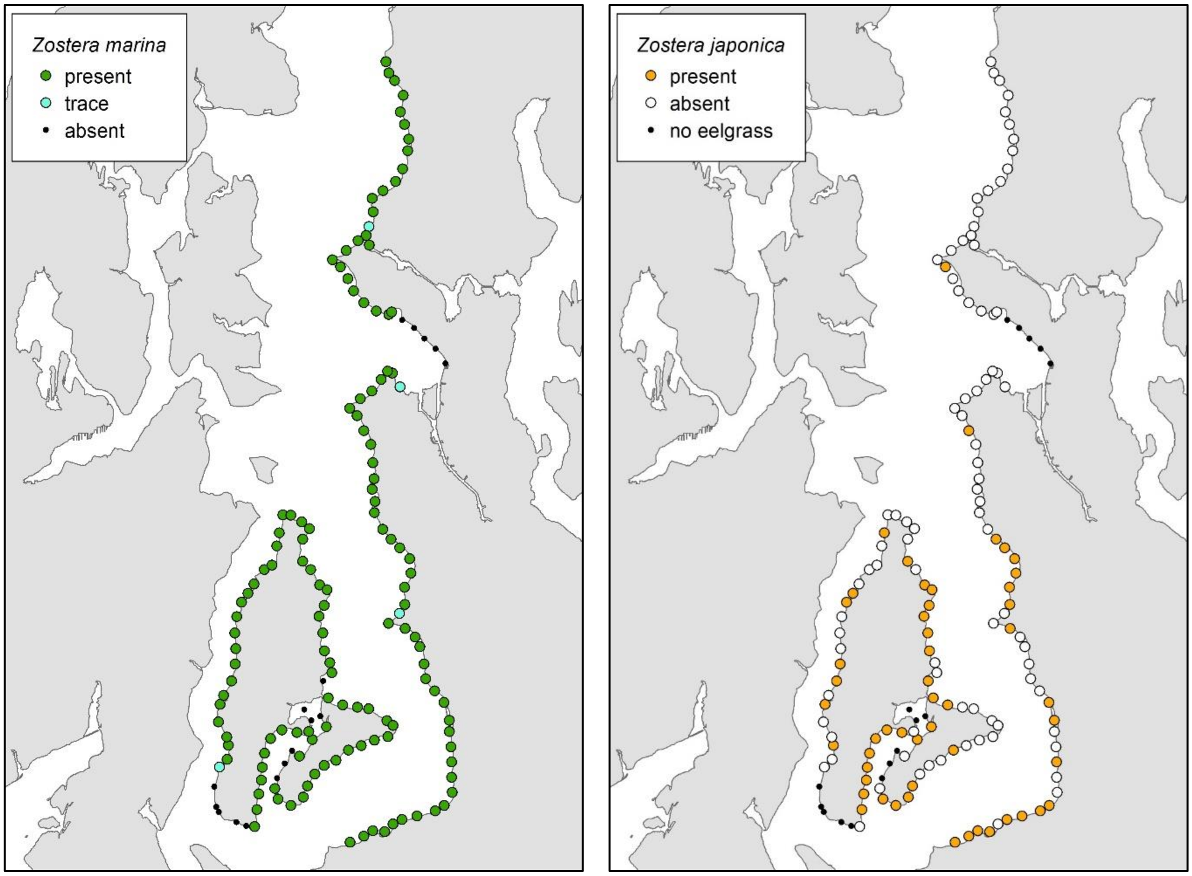


Figure 8: Left: Distribution of *Z. marina* in King County. Sites without eelgrass are indicated in black. Sites with eelgrass are in green. **Right:** Distribution of *Z. japonica*. Sites without eelgrass are indicated in black. Sites without *Z. japonica* are in white, and sites with *Z. japonica* are yellow.

Out of the 152 sites sampled along the shoreline of King County, there were 137 sites with eelgrass and 15 sites where eelgrass was absent (Figure 8). At four sites, eelgrass was too sparse to derive an estimate of eelgrass area or depth distribution. These sites have been designated as trace. Native eelgrass (*Z. marina*) was widespread along the entire shoreline of King County, but it did not grow along the heavily modified shorelines of Elliott Bay. Eelgrass did also not occur along the inner parts of Quartermaster Harbor, which is probably related to poor water clarity. Finally, eelgrass was missing from some sites on the southern tip of Vashon Island.

We detected the non-native *Z. japonica* at 52 sites along the King County shoreline. *Z. japonica* grew at higher tidal elevations than *Z. marina*, and was often too shallow for the sample vessel. As such, our data are conservative estimates for the presence/absence of *Z. japonica*. Nevertheless, the data suggests that *Z. japonica* was common in the southern part of the study area. *Z. japonica* was most prevalent on Vashon Island, and on the mainland south of Fauntleroy Cove (Figure 8 and Figure 9). We found very little *Z. japonica* north of Fauntleroy Cove. *Z. japonica* mostly occurred at sites where *Z. marina* was present in the study area. This suggests that both species have very similar requirements in terms of habitat and substrate. While it was not possible to provide an accurate estimate of *Z. japonica* area due to sampling restrictions, the maps in Appendix 2 indicate that *Z. marina* was far more abundant than *Z. japonica* at sites where both species were present.

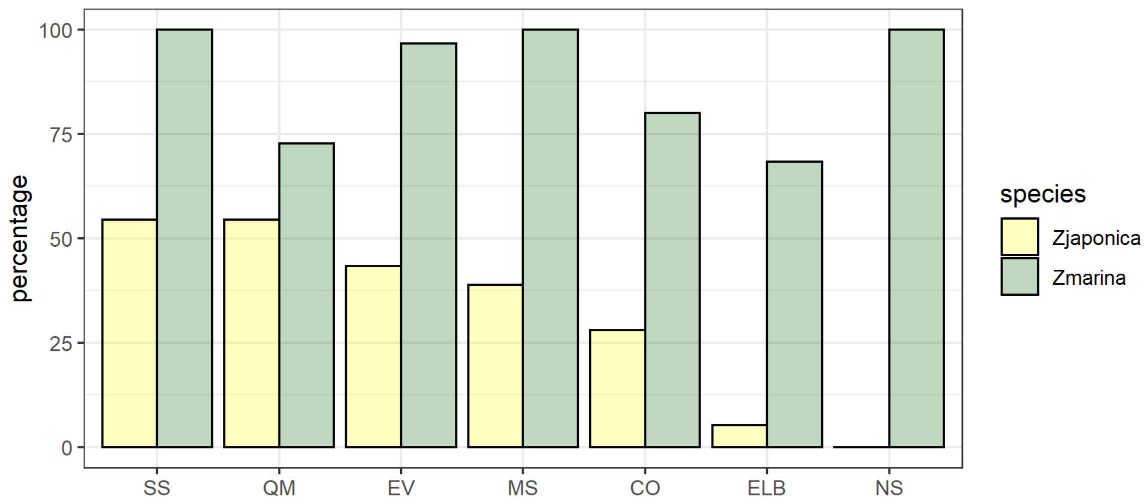


Figure 9: Percentage of all sites with *Z. marina* and *Z. japonica* in the different zones of King County (see Figure 1).

3.2 Area estimates of eelgrass beds in King County

The eelgrass beds along the shoreline of King County were relatively small (Figure 13). This is to be expected, as most of these beds grew on relatively narrow fringes of shoreline. Out of the 137 sites with eelgrass, 20 sites had less than 1 ha of eelgrass present, 62 sites had between 1 and 5 ha of eelgrass present, 45 sites had between 5 and 10 ha present, 8 sites had between 10 and 15 ha present, and only 3 sites had eelgrass beds larger than 15 ha. As such, the distribution of eelgrass area in King County was skewed (Figure 10). The sites with the largest eelgrass beds were cps1688, cps1689, and cps 1690 with 23.7 ± 1.9 ha, 37.6 ± 2.4 ha, and 18.9 ± 0.9 ha respectively. Overall, sites in the northern part of the study area had larger eelgrass beds as compared to sites in the southern part of the study area. The median size of eelgrass beds in King County was approximately 3.42 ha (range 0.001 – 37.56 ha). This is very similar to fringe sites throughout greater Puget Sound (median size 3.5 ha, range 0.001 – 75 ha). Based on the site estimates, there was approximately 680 ha of eelgrass on the shores of King County (as compared to ~23,000 ha in the entire greater Puget Sound area).

We divided the King County Study Area into 7 zones (Figure 1) and estimated total eelgrass area in each of these zones based on the current sample of 152 sites (Figure 11). Given that we sampled the vast majority of sites within the study area, the degree of uncertainty associated with the estimates is relatively small, which is represented by the standard error in Figure 11. The mainland (North Shore, Elliott Bay, Mid Shore, and South Shore) and the eastern part of Vashon Island had the greatest eelgrass area.

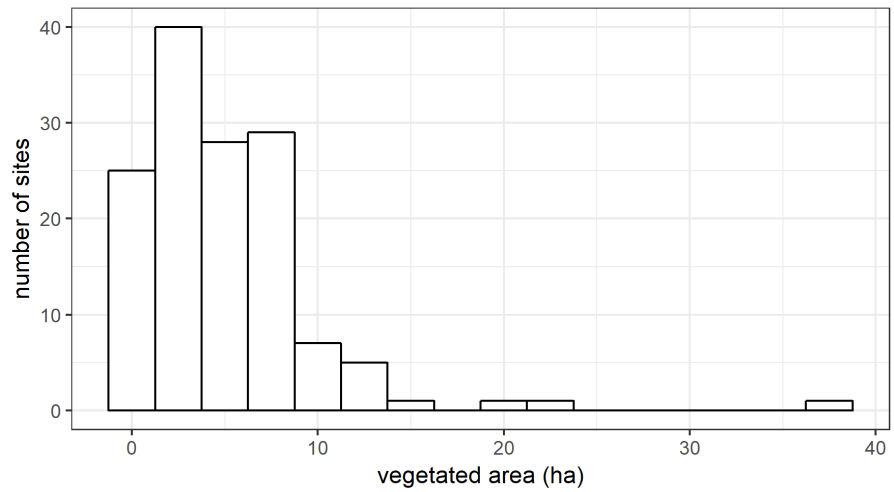


Figure 10: The size distribution of eelgrass beds at sites in the King County Study Area (ha). The majority of eelgrass beds in the study area were relatively small (< 10 ha).

Eelgrass was less abundant along the Colvos Passage and in Quartermaster Harbor. Eelgrass was absent in the inner parts of Quartermaster and along the industrialized sections of Elliott Bay. Given that there is much less available substrate along the Colvos Passage than in Quartermaster Harbor, the relative abundance of eelgrass was much higher along the Colvos Passage than in Quartermaster Harbor (Figure 12).

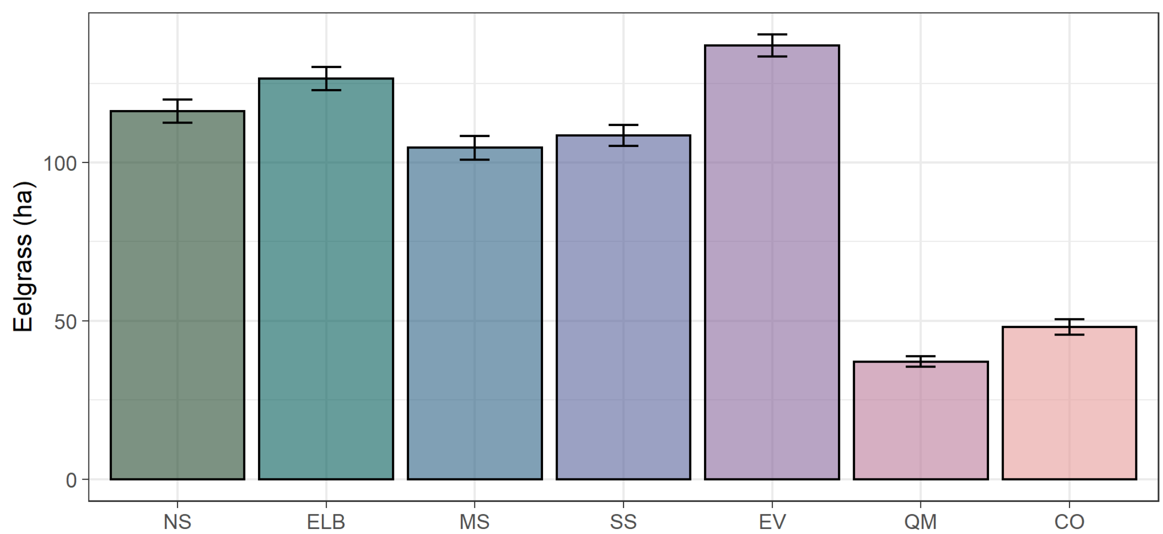


Figure 11: Estimates of total eelgrass area (ha) in 7 zones of the King County Study Area. The error bars are standard error.

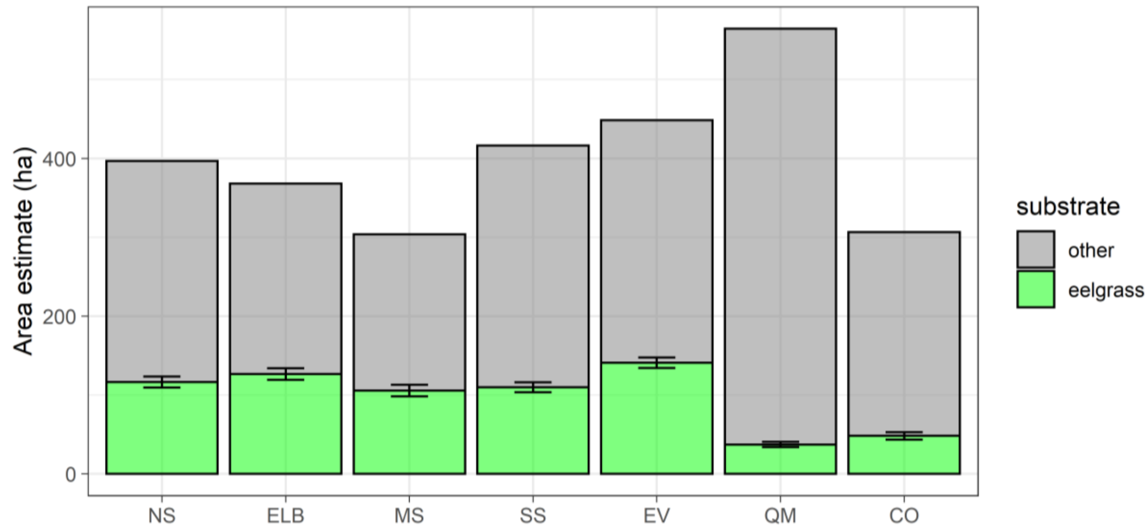


Figure 12: Estimates of total eelgrass area (ha) relative to total available substrate in each of the 7 zones, calculated as the sum of the areas of all SVMP site polygons per zone. The SVMP site polygons stretch from the high water mark to -6.1 m (MLLW).

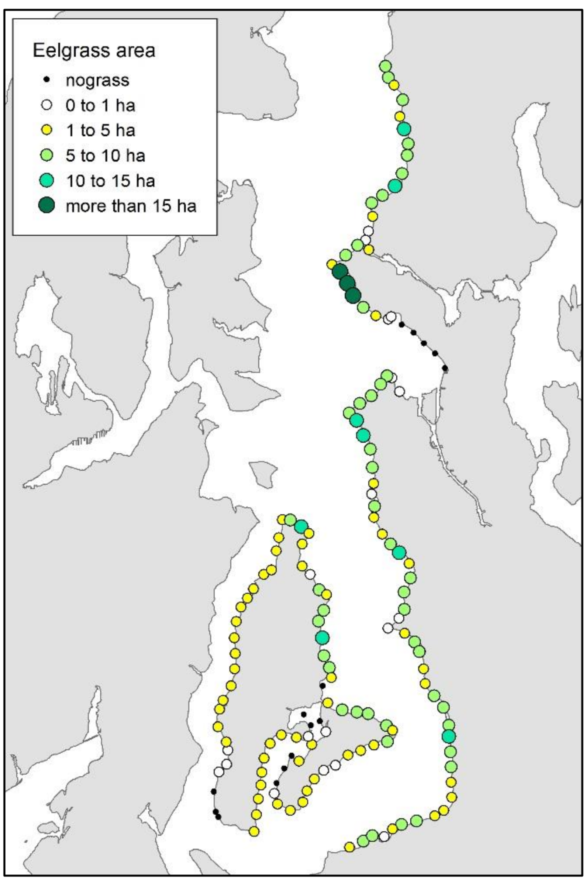


Figure 13: Size of eelgrass beds in King County. Darker green colors indicate sites with larger eelgrass beds.

3.3 Depth range of eelgrass beds in King County

Table 4 in Appendix 1 summarizes the depth distribution of eelgrass at individual sites based on our observations. Sites cps1125, cps1682, cps1720 and cps1742 were excluded because we had insufficient data to generate a depth distribution ('trace' eelgrass). Eelgrass grew between -13.3 and 1.14 m relative to MLLW. However, there were only a few observations of individual shoots deeper than -10 m in the entire study area. At the majority of sites, the deepest eelgrass observations were shallower than -8 m relative to MLLW (Figure 14). While the deepest observation conveys some information of the distribution of eelgrass at a site, it is generally not representative of the deep edge of eelgrass beds at a location. Instead, we calculated the deep edge of eelgrass beds as the 2.5^{th} percentile of eelgrass depth observations at individual sites (q025 in Table 4). These values were generally between -5.16 and -0.62 m relative to MLLW (Figure 14).

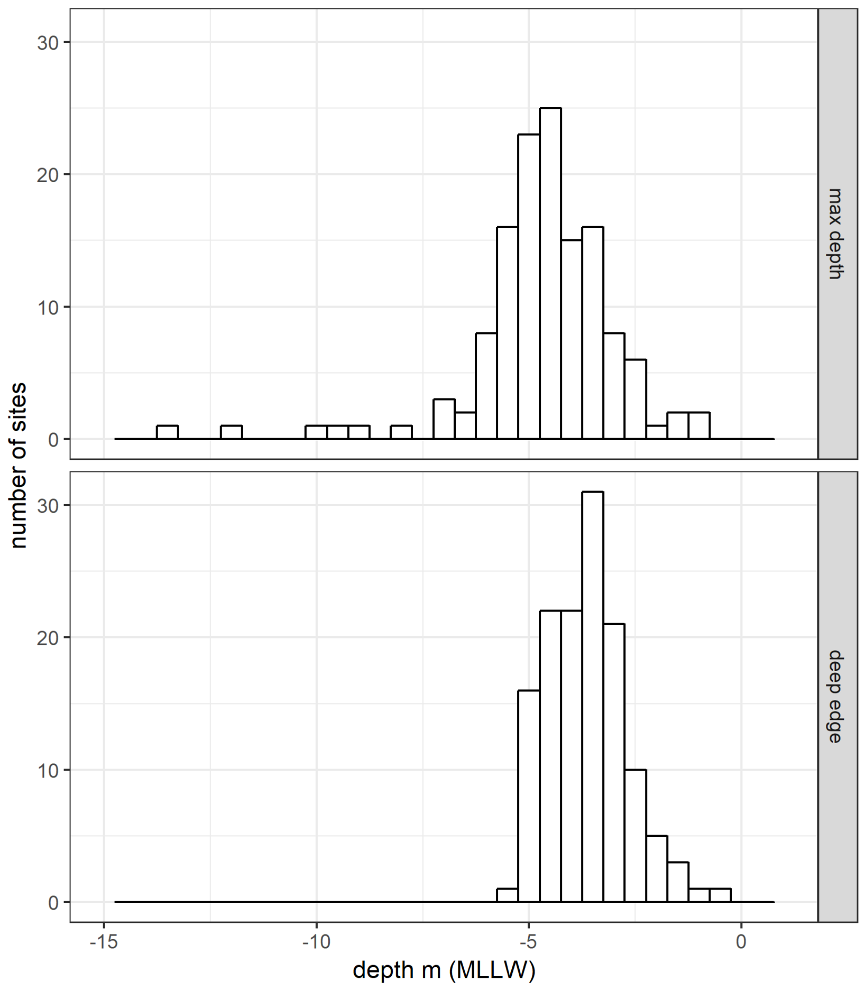


Figure 14: Distribution of deepest eelgrass observation at sites (top), and the deep edge calculated as the 2.5^{th} percentile of all eelgrass depth observations at each site (bottom).

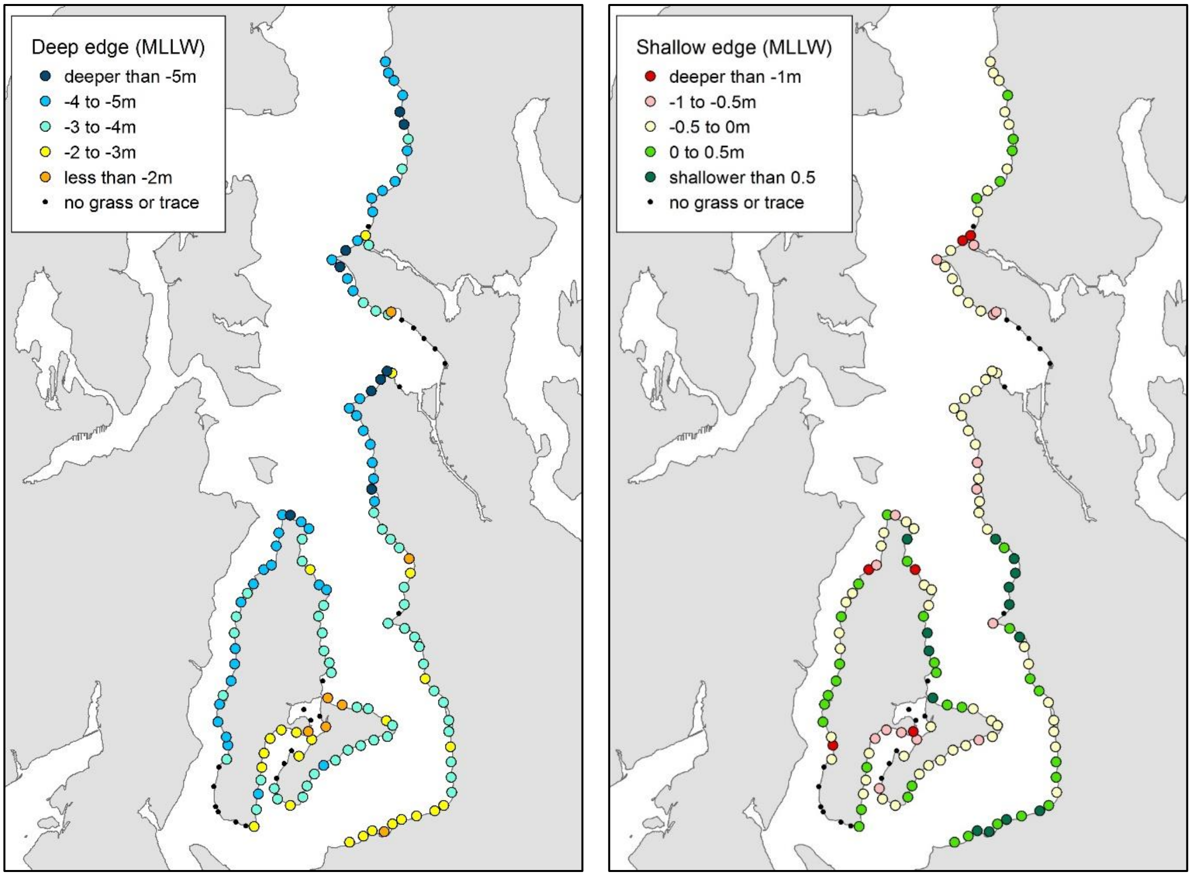


Figure 15: Left: Deep edge of eelgrass beds at sites along the shoreline of King County. Sites without eelgrass are indicated in black. The deep edge is calculated as the 2.5th percentile of all eelgrass depth observations at individual sites. **Right:** Shallow edge of eelgrass beds at sites along the shoreline of King County. Sites without eelgrass are indicated in black. The shallow edge is calculated as the 97.5th percentile of all eelgrass depth observations at individual sites.

Figure 15 shows the spatial distribution of the deep edge of eelgrass beds along King County. There was a clear spatial gradient from north to south. The deep edge of eelgrass beds was shallower south of Fauntleroy Cove, and especially between Poverty Bay and Dash Point. There was also a spatial gradient in maximum depth from the mouth to the inner portion of Quartermaster Harbor. The spatial distribution of the shallow edge showed a different pattern. Eelgrass beds grew further up in the intertidal between Poverty Bay and Dash Point and immediately north of Three Tree Point. There was a spatial gradient inside Quartermaster Harbor as well. Inside Quartermaster Harbor, the shallow edge of eelgrass beds did not grow as far in the intertidal as compared to eelgrass at the mouth of this inlet (Figure 15).

There appeared to be a spatial correlation between the presence of *Z. japonica* and the shallow edge of *Z. marina* beds. At locations with Z. *japonica*, native eelgrass beds grew further up in the intertidal (Figure 16).

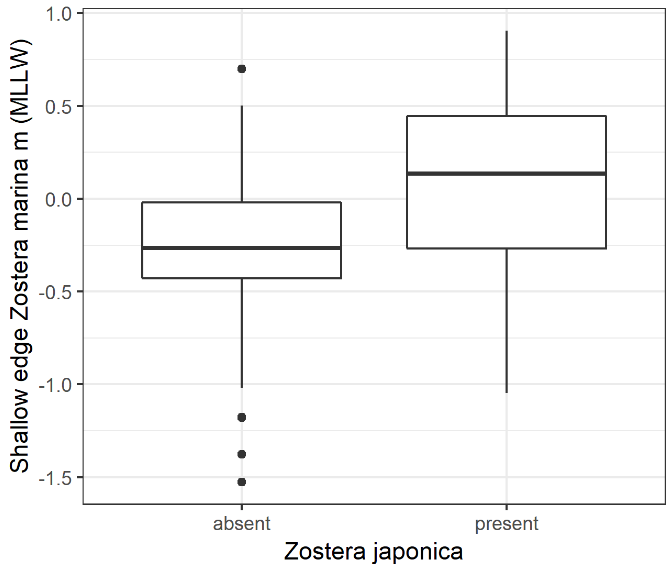


Figure 16: Comparison of the shallow edge of *Z. marina* at locations where *Z. japonica* is present vs. locations where *Z. japonica* is absent.

Figure 17 shows the depth range where eelgrass grew, calculated as the difference between the 2.5th and the 97.5th percentile for each site in King County, ordered by zone. Eelgrass depth range was mostly determined by the deep edge. Similar to Figure 15 there was high variability in the depth range and the deep edge among individual sites.

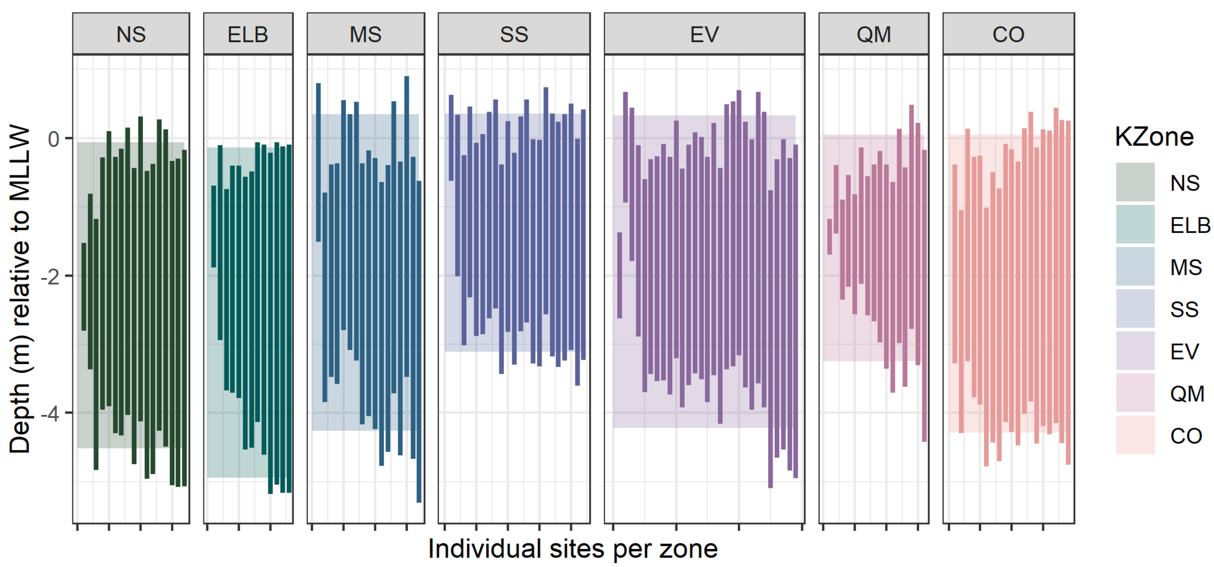


Figure 17: Deep edge, shallow edge and depth range for all sites with eelgrass, ordered by depth range within each zone. The transparent box indicates the overall shallow edge, deep edge and depth range for each of the 7 zones with eelgrass present, calculated as the 2.5th and 97.5th percentile of eelgrass area per 10 cm depth bins for each zone.

Eelgrass grew deepest at sites north of Brace Point (North Shore, Elliott Bay, and Mid Shore) and along the Colvos Passage (Figure 15 and Figure 17). Some eelgrass beds with deep edges also occurred on the northeastern side of Vashon Island. South Shore and Quartermaster Harbor usually had eelgrass beds with smaller depth ranges. This was mostly due to the shallower maximum depth of eelgrass at these locations. The transparent boxes in Figure 17 indicate overall shallow and deep edge per zone, calculated as the 2.5th and 97.5th percentile of eelgrass area per 10 cm depth bins for each zone. The overall depth range was largest in North Shore and Elliott Bay, and narrowest in Quartermaster Harbor and South Shore (Figure 17 and Figure 18).

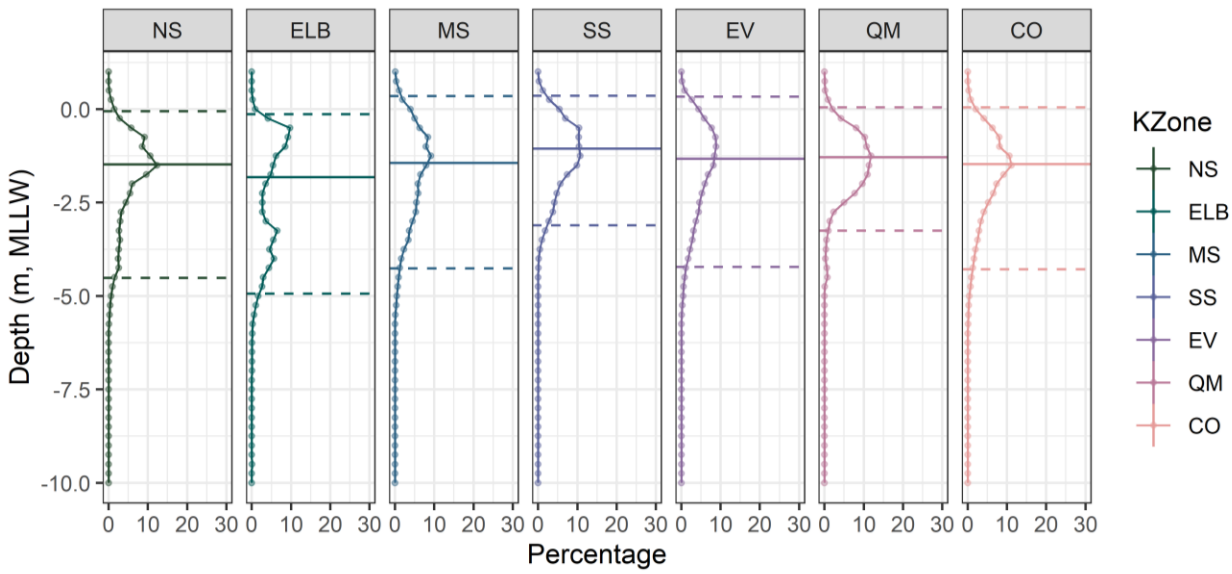


Figure 18: Depth distribution of eelgrass at each zone in King County.

Figure 19 shows the depth distribution and cumulative depth distribution based on all observations of eelgrass in each of the 7 zones. Approximately 95% of all eelgrass in the study area grew between 0.2 and -4.45 m (MLLW), but the optimal depth range for eelgrass was more restricted. Approximately half of the eelgrass in the study area grew shallower than -1.39 m relative to MLLW (Figure 19). 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 64% of all eelgrass in the study area grew in the subtidal, while 36% 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 common in the study area and had a different depth distribution as compared to *Z. marina*. It usually grew shallower, and was able to thrive in the intertidal habitats.

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

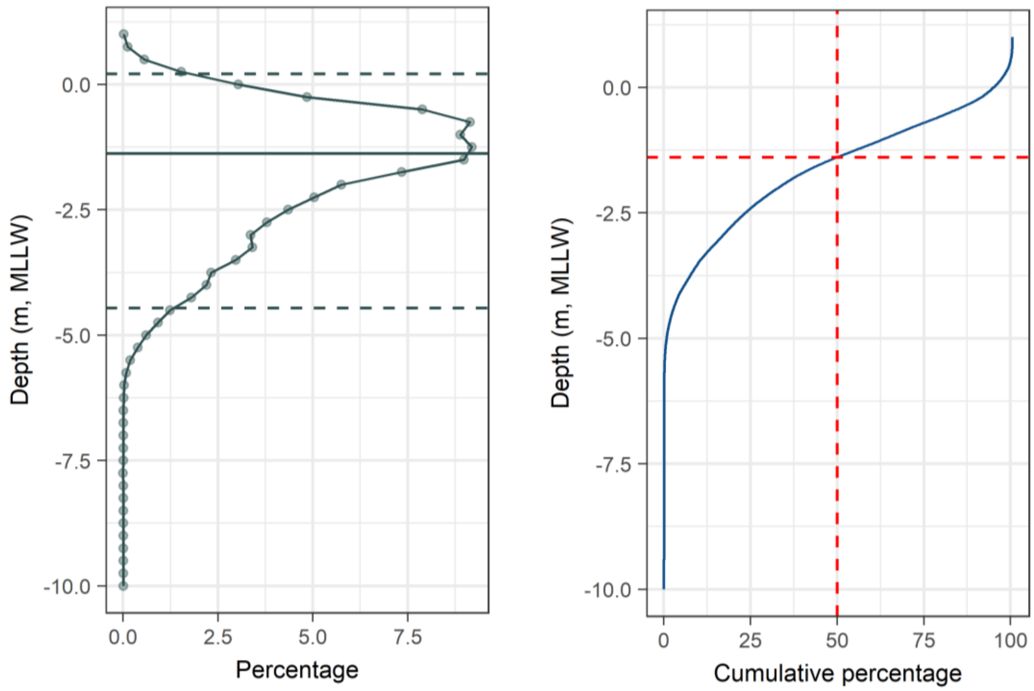


Figure 19: Depth distribution and cumulative depth distribution of eelgrass for the entire King County Study Area. The median depth for eelgrass was -1.39 m (MLLW).

Figure 20 compares the eelgrass depth range (the width of the band where eelgrass occurred) between different size classes of eelgrass beds. At sites with small eelgrass beds there was high variability in depth range. This variability became progressively smaller with increasing size of eelgrass beds. The median depth range tended to be larger at sites with large eelgrass beds.

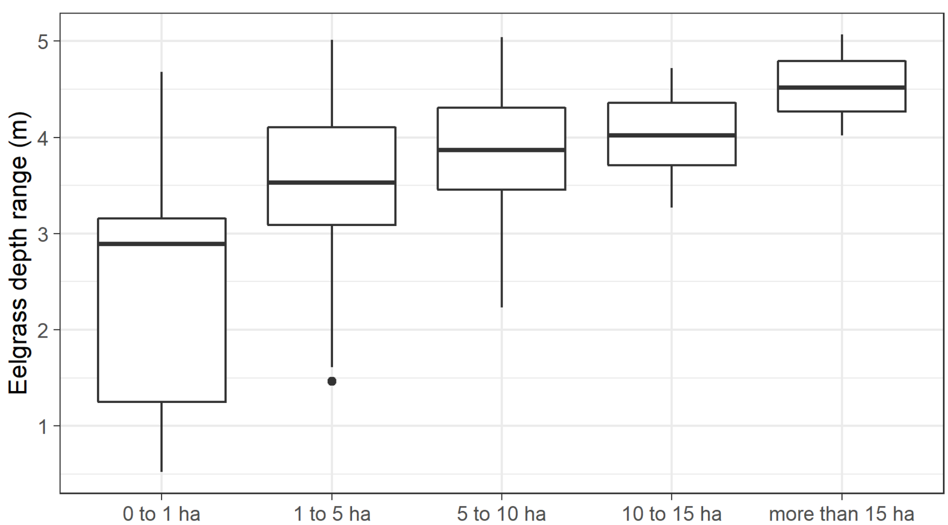


Figure 20: Depth range (m) vs. eelgrass area (ha) for all sites in King County.

3.4 Trends in eelgrass area

A. Regression analysis

Thirty-one sites along the King County shoreline have been sampled more than once between 2000 and 2018 by DNR. Out of this number, 23 sites were sampled more than twice. At these sites we tested for trends in site eelgrass area using a linear regression analysis (alpha = 0.01). We included all available information (including instances where sites were sampled with both SRS and STR). Note that most estimates were based on new draw SRS, which introduces some uncertainty to the trend analysis. At 3 sites eelgrass increased (cps1118, cps1164, and cps1676), at 3 sites there were declines (core005, cps1686, and flats33), and at 15 sites there was no linear trend over time (Figure 21 and Appendix 4).

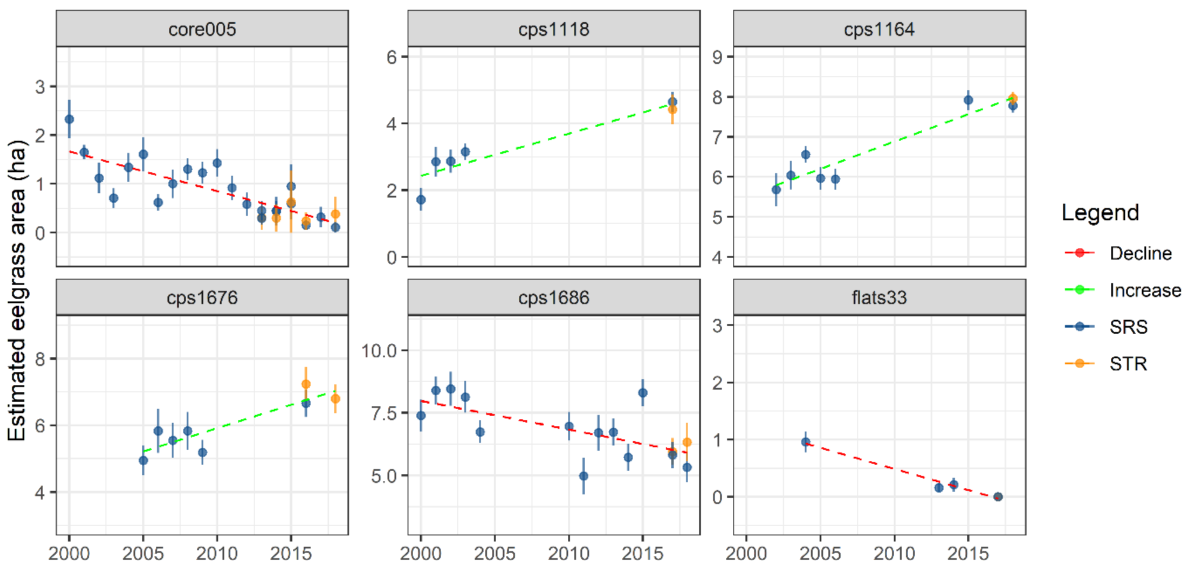


Figure 21: Increases and declines in eelgrass area based on regression analysis (alpha = 0.01) at sites along King County that were sampled for more than 2 years. Error bars represent standard error. The colors of the trend line indicate increases (green) or declines (red).

B. Paired transect comparison

At 29 sites, we resampled previously established transects, and compared the vegetated length in 2016, 2017 or 2018 with values from the previous sample. The time interval in between these sample events varied among sites. At 5 sites there was between 1 and 3 years between sample events, at 13 sites there was between 4 and 9 years between resampling, and at 11 sites the time between resampling was more than 10 years. We plotted the change in vegetated length per site (Figure 22) and tested if the mean change in vegetated length was different from zero using a paired t-test (alpha = 0.01). At 7 out of 29 sites eelgrass declined, at 4 sites there were increases, and at 18 sites there was no change over time.

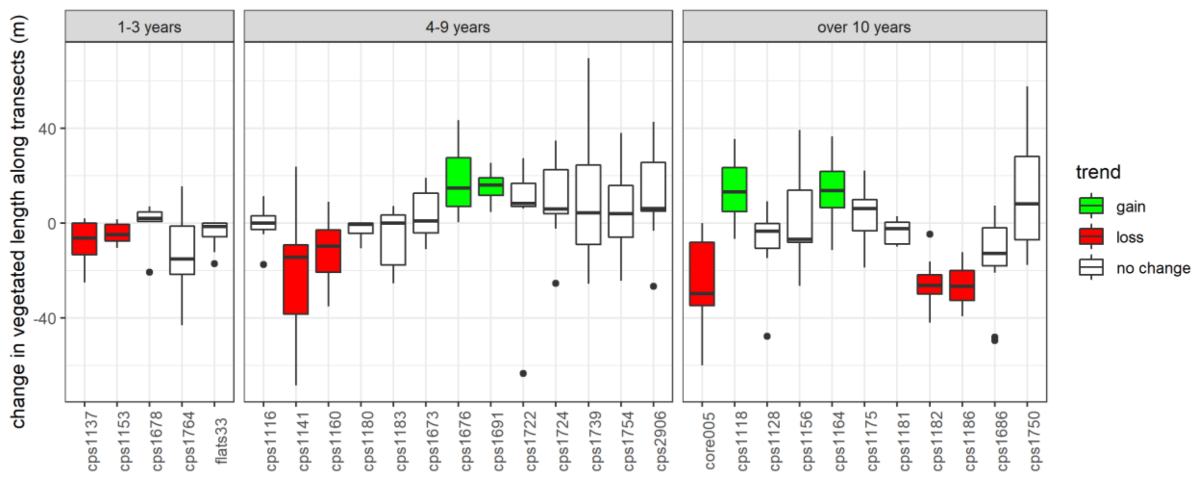


Figure 22: Boxplots of change in vegetated length along transects that were resampled over time, analyzed using paired t-tests (alpha = 0.01). Sites with increases in eelgrass length are indicated in green and sites with declines are marked in red.

C. <u>Consensus analysis</u>

The regression and paired transect analyses highlight different aspects of changes in eelgrass distribution. The regressions are based on all area estimates at a site. These analyses are less precise but they use all available information and encompass the entire time series at each site. Paired transect analyses are more precise since they compare changes in cover at the transect level, but they are limited to 2 years from the entire time series. To determine overall trends in eelgrass area at each site, we combined results from the regression and paired transect analyses, and confirmed any potential trends based on visual assessment of the change in spatial distribution over time in ArcGIS (see Table 5 in Appendix 4). Sites with potential misidentification between *Z. marina* and *Z. japoni*ca (cps1153, cps1160, cps1764, and cps2906) were labeled as not changing, regardless of the outcome of regression and paired transect analyses. Sites where eelgrass completely disappeared were labeled as declining (cps1180 and flats33).

Based on this consensus analysis, there were 7 sites with declines, 3 sites with increases, 19 sites without a trend, and 2 sites where there was not enough data for analysis. Sites with declines were all located in the southern part of the study area (Figure 23). Four out of six sites sampled in inner Quartermaster Harbor were declining (flats33, cps1180, cps1182, and cps 1186). The remaining two also showed signs eelgrass loss, but these declines were only significant at an alpha of 0.05. Other sites with notable declines included Dumas Bay (core005) and two sites in the northern part of Colvos Passage (cps1137 and cps1141). Sites with increases were more evenly spread across the study area (cps1118, cps1164, and cps1676).

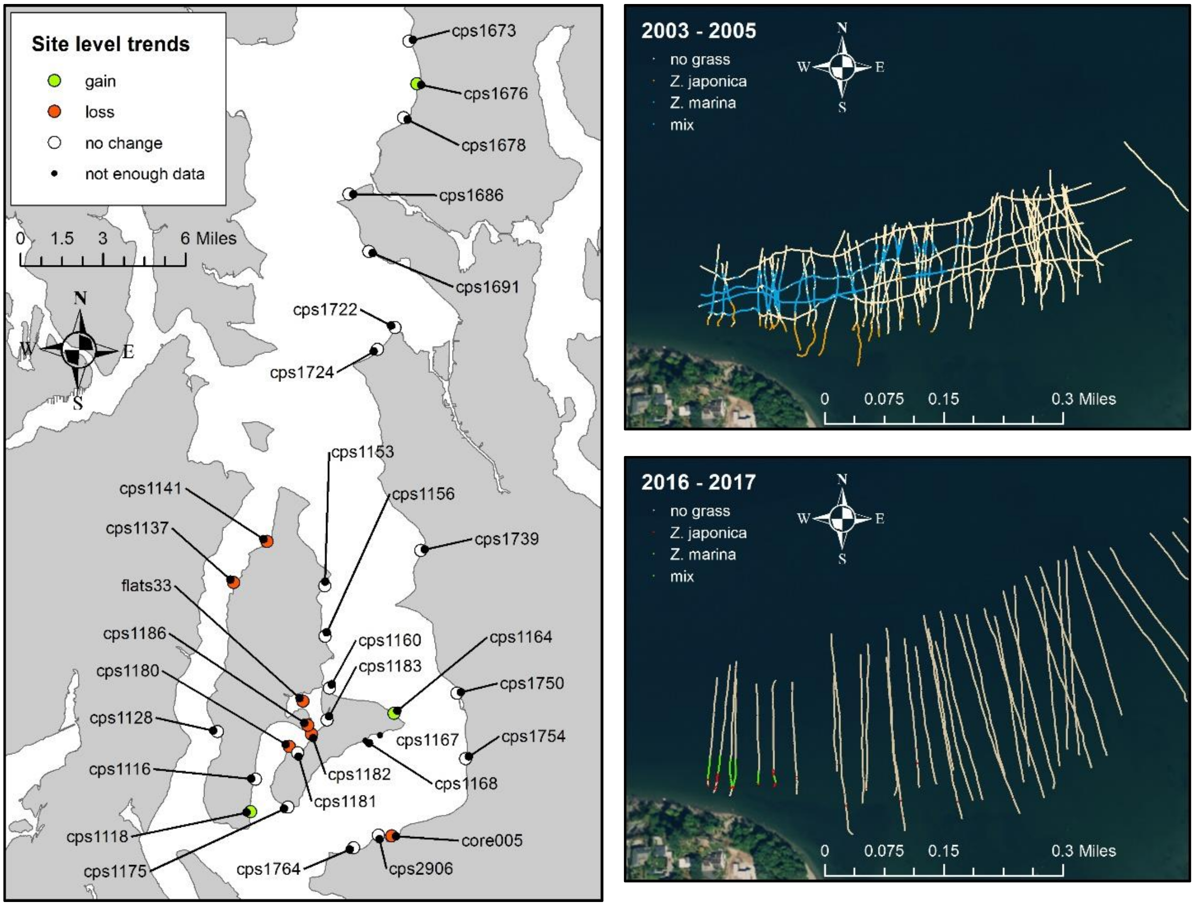


Figure 23 left: Results from the consensus analysis. **Right:** Eelgrass loss at Dumas Bay (core005) between 2003 and 2017.

3.5 Historical trends

We used maps from Thom and Hallum (1990) to compare historical extent of eelgrass beds to the current surveys. For this analysis we excluded data from the Coastal Zone Atlas (1977) because of known accuracy issues. This limits the assessment to 55 out of the 152 sites sampled in 2017 and 2018. Because of the nature of the historical data, we only report on persistence/loss at the site scale (1000 m sections of shoreline). At the vast majority of these sites, eelgrass was present in both the historical and current data. However, there are 3 sites with total loss of eelgrass relative to data from Thom and Hallum (1990). These sites are all located inside Quartermaster Harbor (Figure 24).

For a second analysis, we focused on the oldest data source from Thom and Hallum (1990): the dive surveys from 1962-1963. During this period of time, R. Phillips conducted over 100 dive surveys to assess the regional distribution of eelgrass in Puget Sound. Fourteen of his original dive surveys fall within the King County study area. At one of these sites, eelgrass was absent in both 1962-63 and 2017-18, at two locations there was a complete loss over time, and at 11 locations eelgrass persisted (Figure 24).

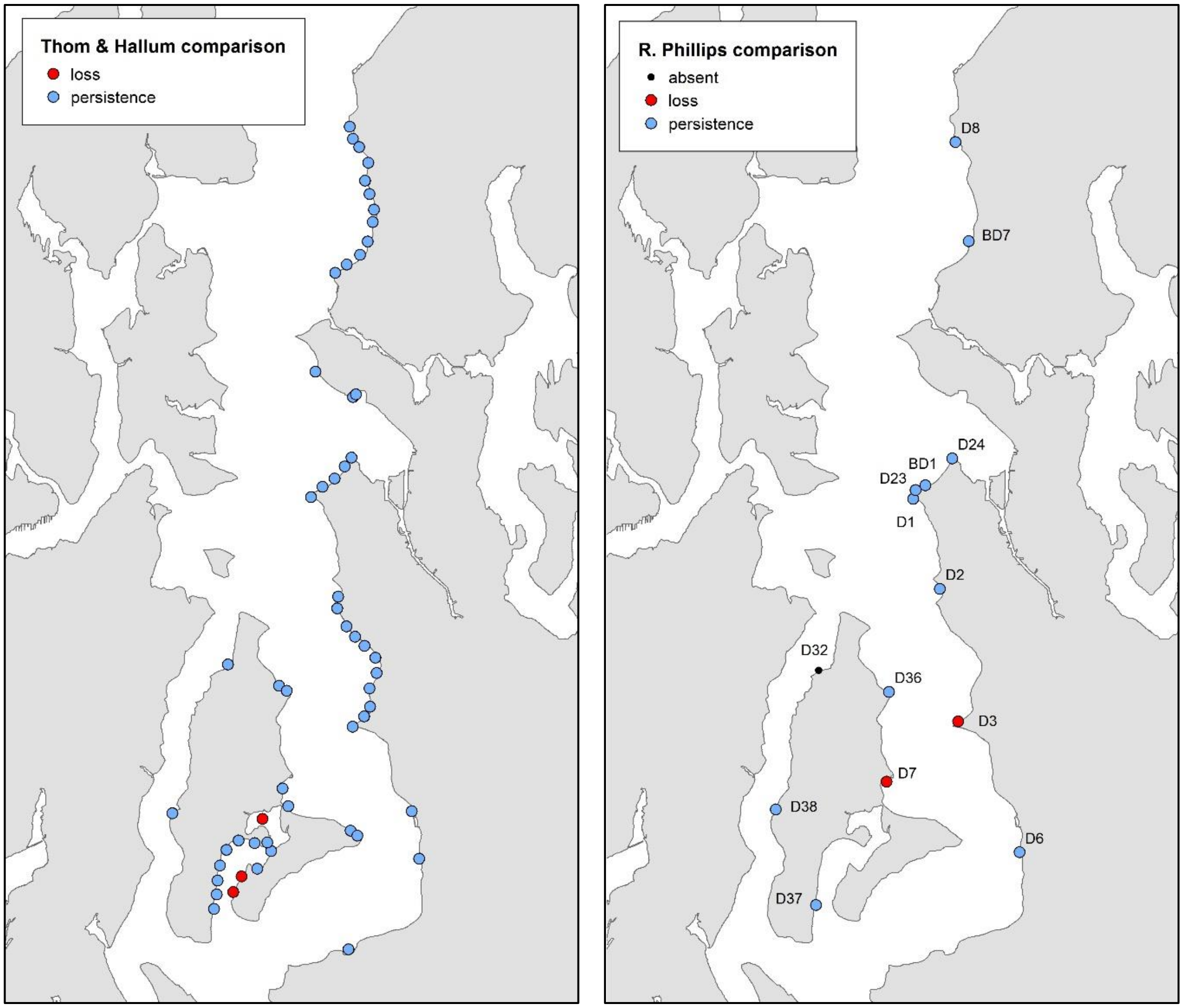


Figure 24: Left: Site level comparison between data from the 2017-18 surveys in King County and maps of the historical distribution of eelgrass in the study area (Thom & Hallum 1990). **Right:** Comparison at sub-site scale between data from the 2017-18 surveys in King County and dive surveys by R. Phillips (1962-63). Sites where eelgrass was present in both time periods are indicated in blue. Sites with total loss are indicated in red.

At one of the sites with losses (D7; right panel Figure 24) there used to be a substantial eelgrass bed present according to the descriptions in the dive logs. Based on our survey data, there is currently no eelgrass left at this location. At a second site with losses (D3), there was a narrow band of eelgrass near MLLW. During our surveys, we found no evidence of eelgrass at transects in a 200 m radius around the original dive location. Figure 25 shows the shallow and deep edge at each dive location in 1962-63 and 2017-2018. At the majority of sites, there were no big changes in depth distribution. Sites where the depth distribution has changed are BD1, D2, and D36. At two of these sites, there is some uncertainty on the original depth distribution. R. Phillips surveyed D36 using a snorkel instead of scuba. The dive log also mentions very poor visibility (less than 2 feet). As such, it is very likely that he underestimated the deep edge of the eelgrass bed during his survey.

At D2, the original dive log states that the eelgrass bed started at -2.1 m (MLLW). However, the log also notes that there were small plants present at -0.5 m, (MLLW). Currently, there is a continuous eelgrass bed between -0.2 and -3.75 m (MLLW) at this location. On average, there was less than 0.25 m difference in the depth of the shallow edge when comparing the two time periods at all 14 dive locations (-0.24 ± 0.92 m). For the deep edge, there was on average less than 0.4 m difference (-0.39 ± 1.79 m).

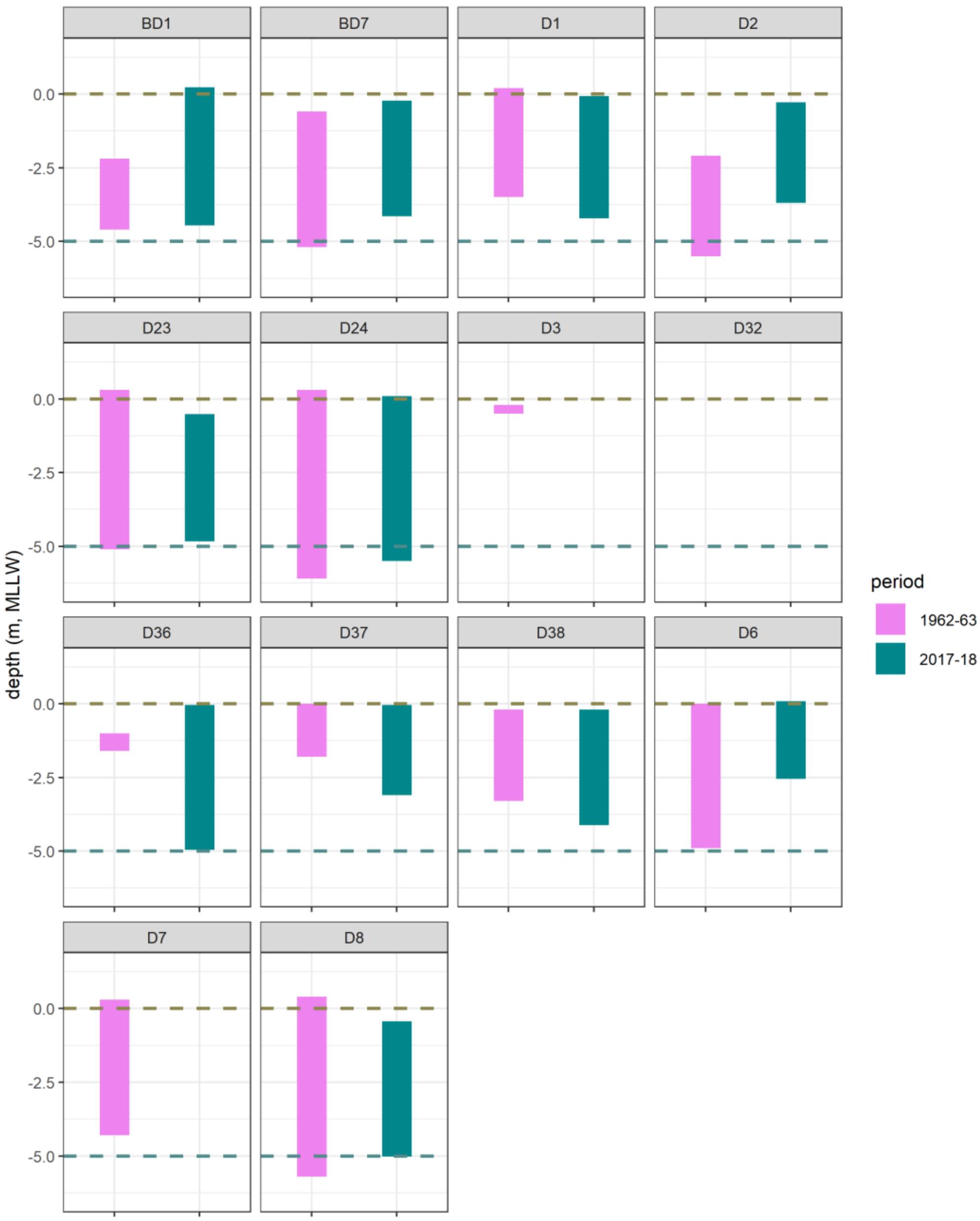


Figure 25: Depth range of eelgrass beds (m) during dive surveys by Ron Phillips (1962-63) vs. depth range derived from all 2017-18 transects in a 200 m radius around the original dive location (calculated as the 1st and 99th percentiles of eelgrass depth observations). All depth information has been transformed to depth (m) relative to MLLW.

3.6 Case study: eelgrass north of Shilshole Bay Marina

In 1999, PNNL conducted a comprehensive survey of nearshore habitat along the shoreline of King County and Snohomish County between Picnic Point and Shilshole Bay Marina, using a combination of side scan sonar and towed underwater video (Woodruff et al. 2001). Figures 27, 28, 29 and 30 show the transect point feature data from the 2017-2018 survey overlaid on the polygons from 1999, at locations where there was overlap between both surveys. In general, the recent eelgrass observations line up well with the 1999 polygons. Parts of 2017-2018 transects that crossed polygons marked as 'dense eelgrass' by PNNL were almost always vegetated. For polygons marked as 'moderate eelgrass' or 'sparse eelgrass', there were several locations with apparent loss. There were also several transects with eelgrass outside the previously mapped polygons from 1999, which could be perceived as gains.

We calculated the percentage of observations where eelgrass was present during both surveys (persistent), where it was absent in both surveys, where there was apparent gain, and where there appeared to be losses for 13 sites along the northern shoreline of King County (Figure 26). There is some uncertainty around these estimates because of the differences in methodology between the surveys. As such, we can only assess large scale patterns. At most locations, potential gains offset the apparent losses. At one site, cps1669, the spatial pattern and extent of the apparent losses suggest an actual decline in eelgrass cover (Figure 27).

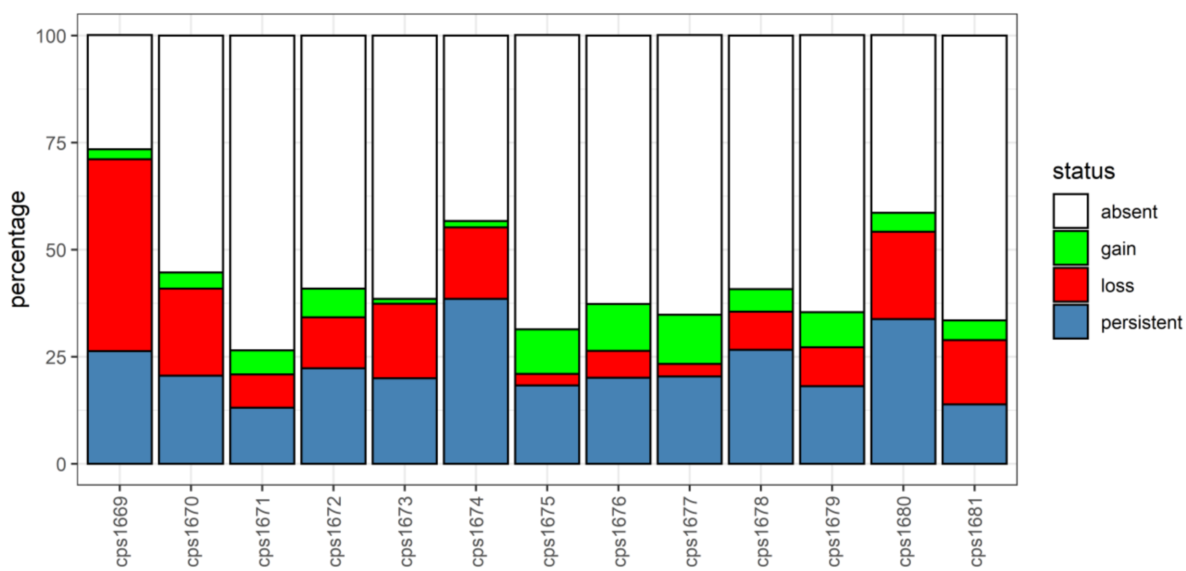


Figure 26: Percentage of total observations where eelgrass was absent, persistent, gained or lost, based on a comparison of a 1999 survey by PNNL and the current survey by DNR at 13 sites along the northern shoreline of King County.

Figure 27: 2017-2018 transect point features overlaid on eelgrass polygons from the 1999 PNNL survey. Blue color on the transect lines indicates that eelgrass was present in 2017-2018. Polygons with different shades of green and blue indicate sparse, moderate or dense eelgrass cover in 1999. From Point Wells to Innis Arden Reserve Park.

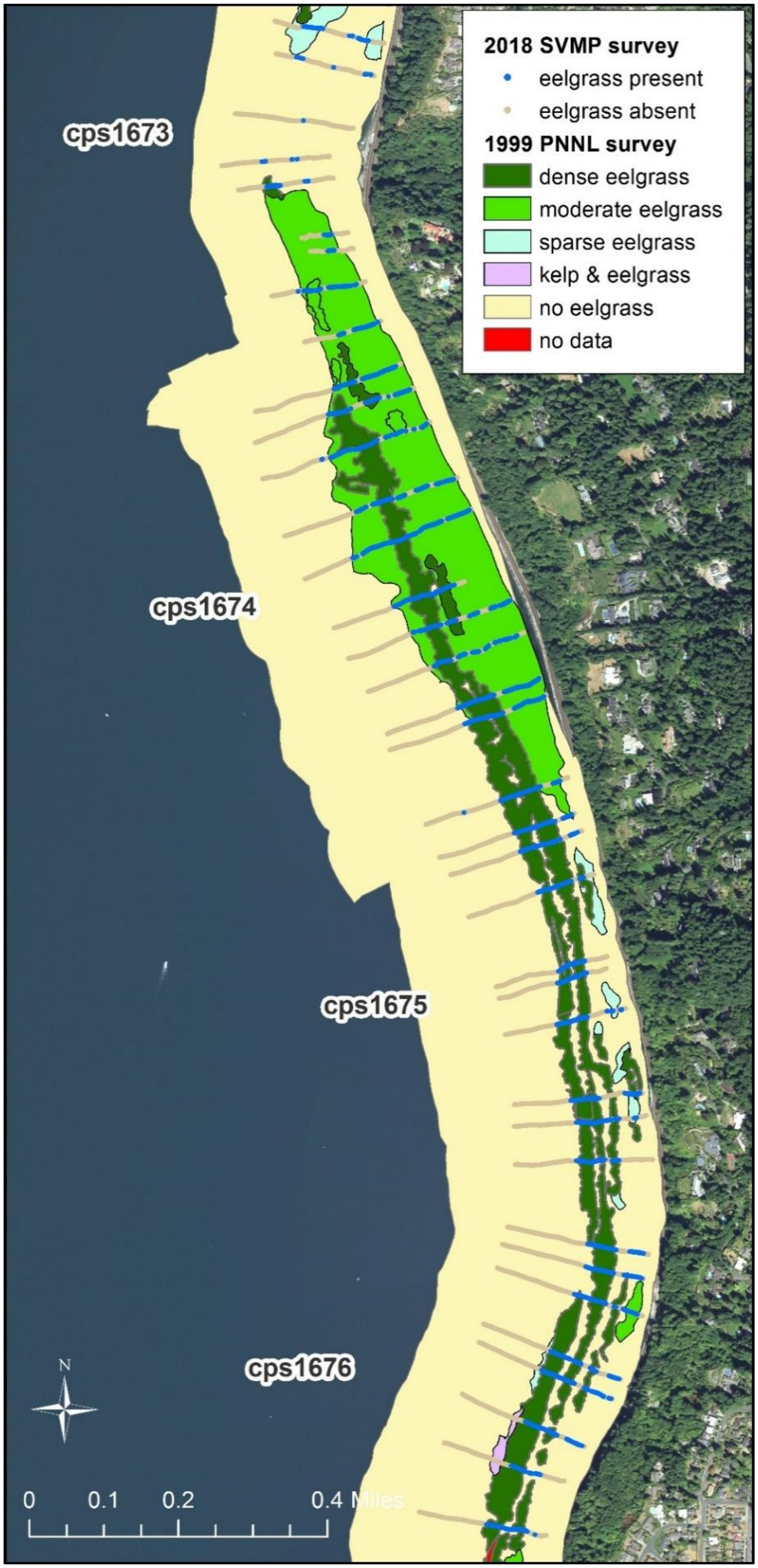


Figure 28: 2017-2018 transect point features overlaid on eelgrass polygons from the 1999 PNNL survey. Blue color on the transect lines indicates that eelgrass was present in 2017-2018. Polygons with different shades of green and blue indicate sparse, moderate or dense eelgrass cover in 1999. From Boeing Creek to Broadview.

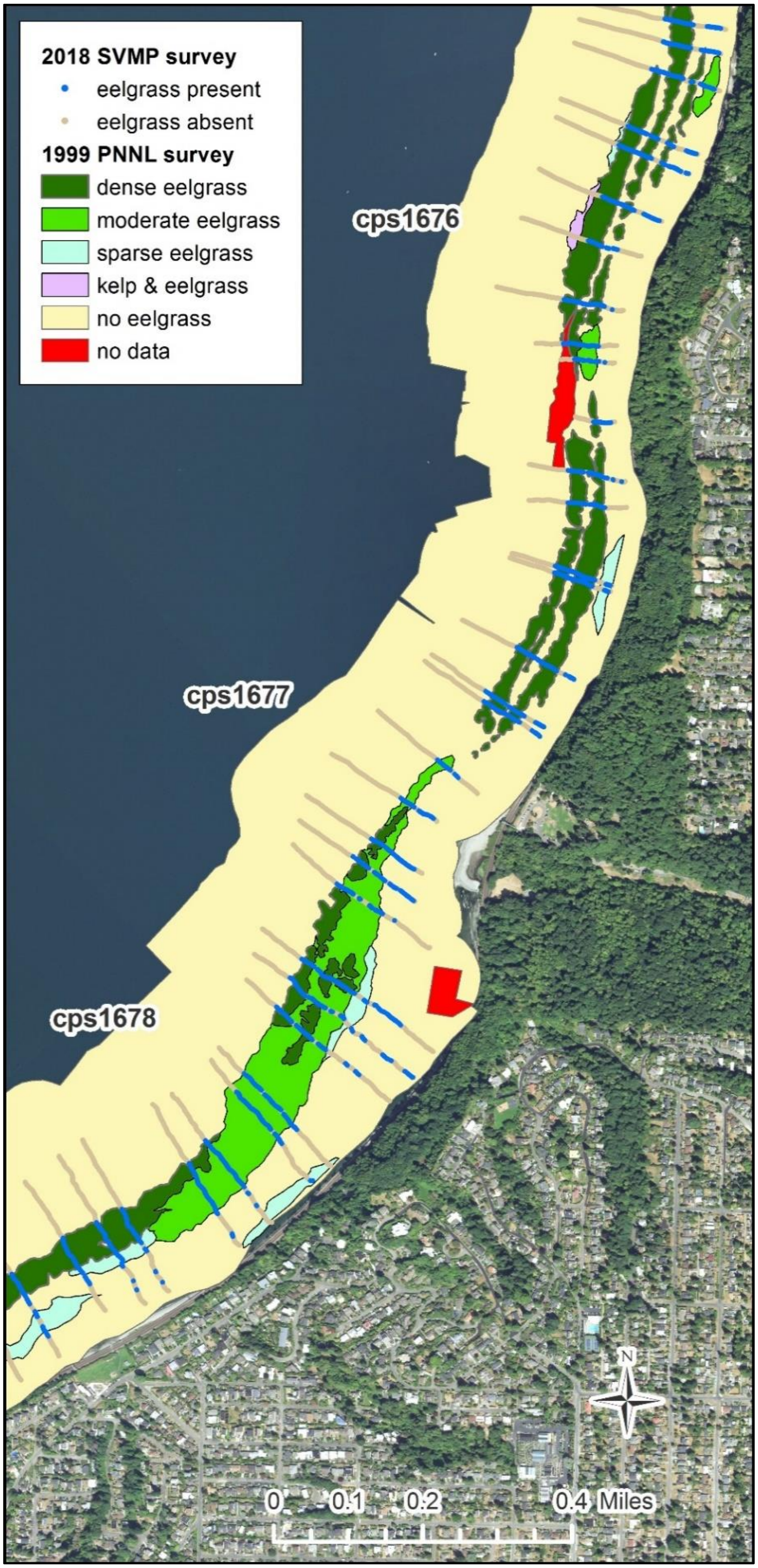


Figure 29: 2017-2018 transect point features overlaid on eelgrass polygons from the 1999 PNNL survey. Blue color on the transect lines indicates that eelgrass was present in 2017-2018. Polygons with different shades of green and blue indicate sparse, moderate or dense eelgrass cover in 1999. Vicinity of Carkeek Park.

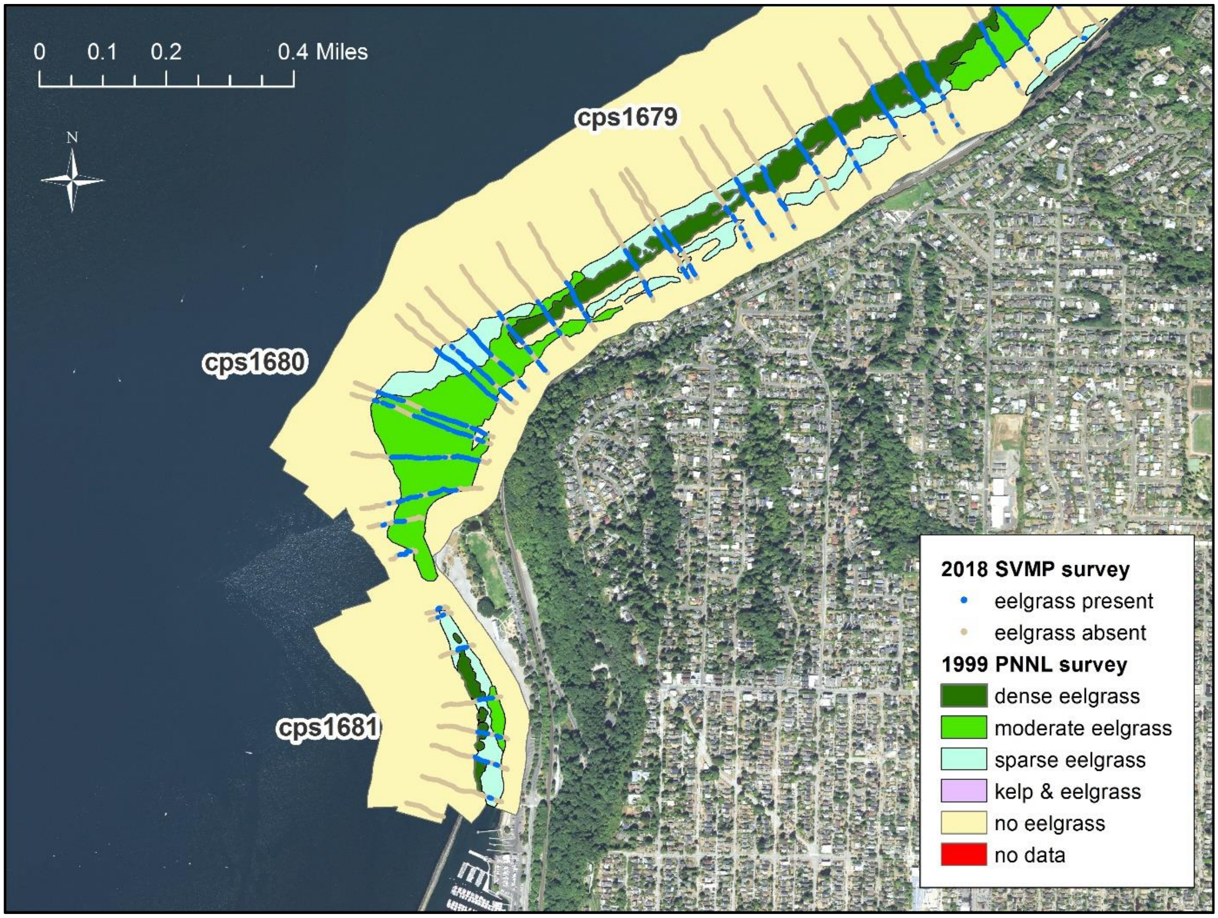


Figure 30: 2017-2018 transect point features overlaid on eelgrass polygons from the 1999 PNNL survey. Blue color on the transect lines indicates that eelgrass was present in 2017-2018. Polygons with different shades of green and blue indicate sparse, moderate or dense eelgrass cover in 1999. Vicinity of Golden Gardens Park.

4 Discussion

4.1 Importance of eelgrass monitoring

Eelgrass is an important but vulnerable component of nearshore ecosystems in Puget Sound. Seagrasses, such as eelgrass, can be damaged by a wide range of human actions, such as dredging, anchoring, construction of overwater structures, and the excessive input of nutrients and organic matter from coastal watersheds. They are often used as a bio-indicator of ecosystem health – both globally and within Puget Sound (Krause-Jensen et al. 2005, Orth et al. 2006, Mumford 2007). Large scale surveys, such as the 2017-18 survey in King County, provide information on the spatial variability of eelgrass beds and form a high resolution baseline for assessing future change. In combination with data from other monitoring programs, these surveys provide insight on effects of potential stressors and the spatial extent of human disturbance.

4.2 Spatial patterns in eelgrass area

Based on the site area estimates, we estimate that there was approximately 680 ha of eelgrass along the shorelines of King County in 2017-2018. This is roughly 21% of the current best estimate for eelgrass area in Central Puget Sound, and less than 3% of all eelgrass in greater Puget Sound (Christiaen et al. 2016). The size distribution of individual eelgrass beds is skewed towards smaller bed sizes, which is partly due to the amount of available substrate. The majority of eelgrass in the study area grows along narrow fringes of intertidal and subtidal land along the shoreline. This is very similar to other eelgrass habitat in Central Puget Sound, where more than 90% of eelgrass grows on fringe sites. It contrasts with the soundwide distribution pattern, where approximately 50% of eelgrass grows on tidal flats.

Small seagrass beds at fringe sites may provide different ecosystem services than contiguous seagrass beds growing on large flats sites. Large contiguous seagrass beds tend to have more stable nekton communities over time, as they provide enough habitat to sustain a wide variety of species (Hensgen et al. 2014), while smaller seagrass beds on fringe sites are important for habitat connectivity. Small narrow seagrass beds also tend to be more dynamic than larger beds, as they are more vulnerable to disturbance from hydrodynamic forces (Koch 2001, Greve and Krause-Jensen 2005), and have a lower ability to recruit new shoots through both sexual and asexual reproduction (Greve and Krause-Jensen 2005).

There is a regional pattern in the size of eelgrass beds throughout the study area. Most eelgrass grows along the central channel of Central Puget Sound (North Shore, Elliott Bay, Mid Shore, South Shore and East Vashon). The largest eelgrass beds are found on wide shelves near Discovery Park in Elliott Bay. The zones with the lowest amount of eelgrass are the shorelines of Colvos Passage and Quartermaster Harbor. Along Colvos Passage, eelgrass beds are likely limited by the amount of suitable substrate in the intertidal and lower subtidal. The subtidal areas are relatively steep and the substrate quickly reaches a depth where light is limiting for eelgrass growth. Quartermaster Harbor has a relatively large amount of available substrate, as compared to the area covered by eelgrass. This suggests that environmental conditions in parts of Quartermaster Harbor are currently not conducive to eelgrass growth.

4.3 Spatial patterns in eelgrass depth distribution

The majority of eelgrass in King County is found between 0 and -4.5 m relative to MLLW, but eelgrass has been documented as shallow as +1.1m and as deep as -13.3 m (MLLW). The optimal depth range for eelgrass appears to be between 0 and -2.5 m (MLLW), as these are the depth bins with the highest percentage of eelgrass present in the eelgrass depth distribution for each of the zones. At only five sites eelgrass grew deeper than -8.5 m (cps1669, cps1674, cps1681, cps1688, and cps1723), and at those locations very few plants extended to this depth. Overall, the depth distribution of eelgrass in the King County study area is very similar to other sites in Central Puget Sound, but more restricted as compared to the San Juan Islands and the Strait of Juan de Fuca (Hannam et al. 2015).

Approximately 64% of all eelgrass grew in the subtidal (deeper than -1 m, MLLW), and roughly 50.7% of eelgrass grew deeper than the Extreme Low Tide Line[8]. This is very similar to greater Puget Sound as a whole, where approximately 62% of all eelgrass grows in the subtidal (Hannam et al. 2015) and 50% grows deeper than the Extreme Low Tide Line. The depth distribution of eelgrass has implications for the protection of this vulnerable plant. The Extreme Low Tide Line forms the boundary between tidelands and bedlands for a large part of Puget Sound. Virtually all bedlands in Washington are owned by the State, while only 29% of Washington State's tidelands remain in public ownership (Ivey 2014). This suggests that a large proportion of eelgrass occurs on state owned aquatic lands, which emphasizes the importance of continued stewardship activities by DNR.

Throughout the study area, there were a number of spatial gradients in depth distribution. Eelgrass tended to grow to deeper extents in the northern parts of the study area and along Colvos Passage. It did not grow as deep in the southern section of the central channel. There also was a clear gradient in maximum depth throughout Quartermaster Harbor. Seagrasses have relatively high light requirements because they support a large biomass of roots and rhizomes in relation to their size (Hemminga at al. 1998, Lee et al. 2007). In the Pacific Northwest, eelgrass requires on average 3 mol quanta m^{-2} day^{-1} for long-term survival (Thom et al. 2008). The maximum depth to which they grow is in part determined by the amount of

[8] For the purpose of designating ownership boundaries, the federal government defined the Extreme Low Tide line (ELT) as the line below which it might be reasonably expected that the tide would not ebb. In the Puget Sound area of Washington State this line is estimated by the federal government to be a point in elevation 4.5 ± 0.5 feet below the datum plane of MLLW (Ivey 2014).

light that filters through the water column, as well as the level of overgrowth by epiphytes and macroalgae (Dennison 1987). The 'shallower' deep edge of eelgrass beds along the shoreline of Federal Way (from Dash Point to Redondo Beach), could be caused by the Puyallup river plume, which is laden with sediment and highly turbid. The spatial patterns in the deep edge within Quartermaster Harbor are also suggestive of a gradient in water clarity. However, there are a number of confounding variables, such as a gradient in water temperature during summer, differences in flushing rates, and potential differences in the condition of the substrate, which can impact the maximum depth of eelgrass at this location.

4.4 Trends in eelgrass area

Based on the consensus analysis, we were able to assess change in eelgrass area over time at 29 sites sampled previously by the SVMP (between 2000 and 2018). In total there were 7 sites with declines, 3 with increases and 19 sites without a clear trend over time. The declines were mostly centered on the southern end of the study area. We identified three areas with declines: the inner part of Quartermaster Harbor, Dumas Bay, and the northern part of Colvos Passage. Potential stressors at these locations include lower water clarity, bioturbation, green algae blooms and eelgrass wasting disease. At this point we have not determined the exact cause for the declines.

A comparison with PNNL survey data suggests that the footprint of eelgrass beds in the northern part of the study area did not substantially change over the last 20 years. There appears to be net gain / net loss in eelgrass at some locations, but it is difficult to assess if these changes are real or an artifact of the analysis. Potential gains were often located near the shallow edge of eelgrass beds. It is possible that these areas were missed by the side scan survey, because of the shallow depth and/or the smaller size of intertidal eelgrass plants (Phillips 1972). Apparent declines were most pronounced in an areas that were previously classified as having low (0-10 % cover) or moderate eelgrass cover (10-50% cover). These apparent declines could be an artifact from comparing presence /absence data at 1 second intervals (SVMP) with polygons that represent patchy eelgrass beds (PNNL). At one site, cps1669, the spatial pattern and extent of potential losses suggest an actual decline in eelgrass cover.

When comparing our current surveys with historical observations, eelgrass persists along the central channel of Puget Sound. The dive surveys by R. Phillips indicate that the width of the band where eelgrass occurs did not substantially change over time. However, there are several sites with long term declines located inside Quartermaster Harbor, which further supports the notion that this is an area where eelgrass is vulnerable. Quartermaster Harbor is a relatively small, semi-enclosed system, with longer water residence times in the inner portion of the embayment (Albertson 2013). Declines in eelgrass cover have also been documented in other inlets and embayments in greater Puget Sound (Christiaen et al. 2019). Localized eelgrass losses, such as in Quartermaster Harbor, may have implications for fauna associated with eelgrass beds. For example, the Quartermaster Harbor herring stock has declined over time, and is now considered to be in critical condition. No spawn was detected in 2016, and no herring spawn has been detected in the inner harbor in recent years, which could be due to the extensive shoreline modification by human activities (Sandell et al. 2019).

4.5 Potential restoration sites

Based on the survey, we identified a number of candidate areas for restoration (Figure 31). Eelgrass was absent from these locations, yet conditions may be sufficient for eelgrass growth based on substrate availability and nearby eelgrass populations. The candidate areas include places with historical loss (inner Quartermaster Harbor, Dumas Bay), and suspected dispersal limitation (pocket beaches in Elliott Bay). We also considered future potential habitat use. Eelgrass beds in Quartermaster Harbor and Elliott Bay have been used as spawning substrate for local herring stock (Sandell et al. 2019), and eelgrass near the mouth of the Duwamish River could potentially provide out-migrating corridors for juvenile salmon. Environmental monitoring data will be collected in 2020 to further assess site suitability for eelgrass transplantation in these general areas (corresponding site codes are listed in Table 2).

4.6 Zostera japonica in King County

The non-native seagrass *Z. japonica* was detected at 52 out of 152 sites. This species was more prevalent southern part of the study area. *Z. japonica* grew higher in the intertidal as compared to *Z. marina*, and at most sites in the study area there was little overlap in the depth distribution of both species. This suggests that there was little competition, and that *Z. japonica* did not have negative effects on *Z. marina* in areas where both species co-occurred (Shafer et al. 2014, Harrison 1982, Hahn 2003). On the contrary, *Z. marina* beds often extended farther into the intertidal when *Z. japonica* was present at a site. There are several possible explanations for this. *Z. japonica* may be facilitating *Z. marina* colonization by increasing water retention on the beach at low tides. However, this may also be a case of mistaken identity. At several locations, it was difficult to distinguish between both species in the video feed, so there is some uncertainty about our identification. Additional ground-truthing is needed to confirm the spatial extent of *Z. japonica*.

4.7 Data use and availability

As a result of a series of interagency agreements between DNR, the City of Bainbridge Island, the Suquamish Tribe, and King County, the shoreline of the central basin has become one of the most extensively sampled areas for eelgrass status in greater Puget Sound. Surveying large, contiguous stretches of shoreline has generated detailed estimates of eelgrass area and depth distribution for the entire shoreline of King County. These data provide a highly precise large area profile of the current extent of both eelgrass (*Z. marina*) and the non-native *Z. japonica*. It can serve as a baseline for future studies on trends in eelgrass area and depth distribution.

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

All data presented in this report will be available online in the next distribution dataset of DNR's Submerged Vegetation Monitoring Program (scheduled for 2020). For more information, visit http://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science

Table 2: General restoration areas and corresponding SVMP site codes

General restoration areas	Site codes
Quartermaster Harbor	cps1178
	cps1179
	cps1182
	cps1183
Dumas Bay	core005
Pocket Beaches at Myrtle Edwards Park	cps1696
	cps1697
Pocket beaches at Seacrest, Jack Block and Joe Block Park	cps1719
	cps1720

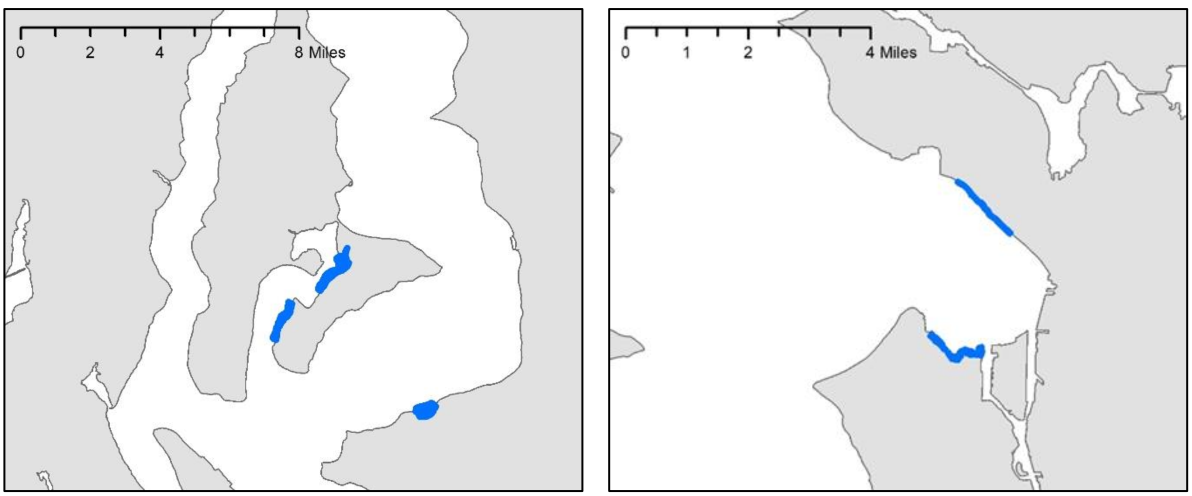


Figure 31: General restoration areas. **Left:** Quartermaster Harbor and Dumas Bay. **Right:** Pocket beaches in Elliott Bay

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6 Appendix 1: Summary Tables

Table 3: Eelgrass area at all 152 sites sampled along the King County shoreline as part of IAA 93-097520

site_code	zone	type	date	# transects	fraction vegetated	eelgrass area (ha)	standard error (ha)
core005	SS	SRS	18-Jul-17	11	0.0561	0.32	0.21
core005	SS	SRS	10-Aug-18	11	0.0224	0.11	0.11
core005	SS	STR	10-Aug-18	10	0.033	0.38	0.36
cps1116	QM	SRS	2-Jun-17	11	0.3277	1.97	0.55
cps1116	QM	STR	2-Jun-17	12	0.3219	1.94	0.51
cps1117	QM	STR	1-Jun-17	11	0.2251	2.2	0.52
cps1118	QM	SRS	2-Jun-17	15	0.6601	4.65	0.3
cps1118	QM	STR	2-Jun-17	17	0.6269	4.42	0.44
cps1119	QM	STR	1-Jun-17	10	0.4268	2.4	0.57
cps1122	CO	STR	24-Aug-18	10	0	0	0
cps1123	CO	STR	24-Aug-18	10	0	0	0
cps1124	CO	STR	22-Aug-18	10	0	0	0
cps1125	CO	STR	24-Aug-18	10	0.0023	0.01	0.01
cps1126	CO	STR	24-Aug-18	10	0.1174	0.63	0.21
cps1127	CO	STR	18-Oct-18	10	0.0592	0.67	0.66
cps1128	CO	SRS	3-Aug-18	18	0.4066	2.67	0.28
cps1128	CO	STR	3-Aug-18	15	0.3792	2.49	0.39
cps1129	CO	STR	12-Oct-18	10	0.3076	1.09	0.24
cps1130	CO	STR	17-Oct-18	10	0.5414	4.64	0.49
cps1131	CO	STR	17-Oct-18	10	0.4151	2.97	0.45
cps1132	CO	STR	17-Oct-18	10	0.3069	2.69	0.59
cps1133	CO	STR	17-Oct-18	10	0.3476	2.29	0.56
cps1134	CO	STR	16-Oct-18	10	0.2822	1.48	0.43
cps1135	CO	STR	16-Oct-18	10	0.4329	2	0.5
cps1136	CO	STR	12-Oct-18	10	0.5757	2.57	0.13
cps1137	CO	SRS	28-Jul-17	17	0.5406	3.83	0.4
cps1137	CO	STR	28-Jul-17	14	0.4661	3.31	0.51
cps1138	CO	STR	16-Oct-18	10	0.4327	4.36	0.85
cps1139	CO	STR	16-Oct-18	10	0.4514	3.54	0.7
cps1140	CO	STR	16-Oct-18	10	0.1463	1.05	0.52
cps1141	CO	STR	15-Oct-18	15	0.3154	2.89	0.71
cps1142	CO	STR	15-Oct-18	10	0.4022	4.32	0.98
cps1143	CO	STR	15-Oct-18	10	0.3777	2.64	0.52

site_code	zone	type	date	# transects	fraction vegetated	eelgrass area (ha)	standard error (ha)
cps1144	CO	STR	12-Oct-18	10	0.3467	2.35	0.5
cps1145	EV	STR	13-Sep-18	8	0.3275	5.8	1.62
cps1146	EV	STR	13-Sep-18	10	0.7183	11.64	0.26
cps1147	EV	STR	13-Sep-18	10	0.4882	3.48	0.68
cps1148	EV	STR	12-Oct-18	10	0.416	2.74	0.65
cps1149	EV	STR	12-Oct-18	10	0.3322	3.41	0.58
cps1150	EV	STR	7-Sep-18	10	0.0545	0.35	0.22
cps1151	EV	STR	7-Sep-18	10	0.5434	6.42	0.7
cps1152	EV	STR	7-Sep-18	10	0.6536	4.91	0.51
cps1153	EV	SRS	17-Jul-17	14	0.5843	6	0.47
cps1153	EV	STR	17-Jul-17	11	0.5667	5.82	0.53
cps1154	EV	STR	5-Sep-18	10	0.346	6.76	1.33
cps1155	EV	STR	5-Sep-18	10	0.5569	12.03	0.81
cps1156	EV	SRS	1-Aug-18	14	0.6544	6.71	0.49
cps1156	EV	STR	1-Aug-18	15	0.6077	6.85	0.65
cps1157	EV	STR	5-Sep-18	10	0.5931	6.83	0.66
cps1158	EV	STR	30-Aug-18	10	0.3254	2.59	0.81
cps1159	EV	STR	30-Aug-18	10	0	0	0
cps1160	EV	STR	27-Aug-18	15	0.3489	3.79	0.58
cps1161	EV	STR	28-Aug-18	10	0.373	5.17	0.63
cps1162	EV	STR	29-Aug-18	10	0.6405	8.52	0.32
cps1163	EV	STR	29-Aug-18	10	0.552	6.83	0.56
cps1164	EV	SRS	2-Aug-18	20	0.7995	7.78	0.17
cps1164	EV	STR	2-Aug-18	15	0.8182	7.96	0.16
cps1165	EV	STR	28-Aug-18	10	0.5359	4.03	0.38
cps1166	EV	STR	28-Aug-18	10	0.6367	6.66	0.27
cps1167	EV	STR	23-Aug-18	12	0.1984	1.1	0.51
cps1168	EV	STR	23-Aug-18	10	0.2371	1.24	0.32
cps1169	EV	STR	23-Aug-18	10	0.4168	2.39	0.27
cps1170	EV	STR	23-Aug-18	10	0.1255	0.55	0.34
cps1171	EV	STR	22-Aug-18	10	0.192	0.96	0.39
cps1172	EV	STR	21-Aug-18	10	0.277	1.51	0.43
cps1173	EV	STR	21-Aug-18	10	0.4356	3.37	0.37
cps1174	EV	STR	21-Aug-18	10	0.4497	3.37	0.59
cps1175	QM	SRS	29-May-17	14	0.5509	4.34	0.36
cps1175	QM	STR	29-May-17	10	0.4795	3.78	0.49
cps1175	QM	SRS	2-Aug-18	18	0.593	4.39	0.24
cps1175	QM	STR	2-Aug-18	15	0.5412	4	0.3
cps1176	QM	STR	29-May-17	10	0.3206	3	0.62
cps1177	QM	STR	29-May-17	10	0.2307	0.82	0.47
cps1178	QM	STR	29-May-17	10	0	0	0
cps1179	QM	STR	29-May-17	10	0	0	0
cps1180	QM	SRS	30-May-17	12	0	0	0
cps1180	QM	STR	30-May-17	10	0	0	0
cps1181	QM	SRS	30-May-17	11	0.512	1.09	0.18
cps1181	QM	STR	30-May-17	10	0.3027	1.12	0.45
cps1182	QM	SRS	30-May-17	10	0.3676	2.29	0.26
cps1182	QM	STR	30-May-17	10	0.4099	2.55	0.21
cps1183	QM	SRS	30-May-17	10	0.0358	0.06	0.02
cps1183	QM	STR	30-May-17	10	0.0084	0.09	0.09
cps1186	QM	SRS	31-May-17	11	0.072	0.05	0.01

site_code	zone	type	date	# transects	fraction vegetated	eelgrass area (ha)	standard error (ha)
cps1186	QM	STR	31-May-17	11	0.0141	0.04	0.04
cps1187	QM	STR	31-May-17	10	0.3811	4.41	0.33
cps1188	QM	STR	31-May-17	10	0.3553	4.73	0.58
cps1189	QM	STR	1-Jun-17	10	0.2613	1.99	0.56
cps1190	QM	STR	1-Jun-17	10	0.3211	1.71	0.31
cps1191	QM	STR	1-Jun-17	10	0.3269	1.74	0.31
cps1669	NS	STR	5-Oct-18	8	0.3358	6.98	0.45
cps1670	NS	STR	8-Oct-18	10	0.4324	6.49	0.49
cps1671	NS	STR	8-Oct-18	10	0.3803	4.37	0.39
cps1672	NS	STR	9-Oct-18	10	0.4869	7.26	1.01
cps1673	NS	STR	9-Oct-18	10	0.2679	3.93	1.07
cps1674	NS	STR	10-Oct-18	10	0.6254	13.07	1.01
cps1675	NS	STR	10-Oct-18	10	0.5192	8.42	0.33
cps1676	NS	STR	11-Oct-18	10	0.5166	6.8	0.43
cps1677	NS	STR	11-Oct-18	10	0.5123	8.9	0.66
cps1678	NS	SRS	10-Aug-17	11	0.4603	13.75	0.48
cps1678	NS	STR	10-Aug-17	10	0.4288	12.81	0.98
cps1678	NS	STR	3-Oct-18	10	0.4309	12.58	0.73
cps1679	NS	STR	3-Oct-18	10	0.4056	8.5	0.6
cps1680	NS	STR	2-Oct-18	10	0.5046	9.56	0.73
cps1681	NS	STR	2-Oct-18	10	0.2677	1.77	0.53
cps1682	NS	STR	2-Oct-18	10	0.0021	0.01	0.01
cps1683	NS	STR	2-Oct-18	8	0.0341	0.18	0.16
cps1684	NS	STR	1-Oct-18	9	0.2048	1.75	0.82
cps1685	NS	STR	1-Oct-18	10	0.3533	9.29	2.34
cps1686	NS	SRS	9-Aug-17	12	0.4261	5.81	0.52
cps1686	NS	STR	9-Aug-17	10	0.4362	5.95	0.54
cps1686	NS	SRS	31-Jul-18	11	0.4069	5.32	0.59
cps1686	NS	STR	31-Jul-18	10	0.4839	6.33	0.76
cps1687	ELB	STR	28-Sep-18	10	0.259	3.44	0.73
cps1688	ELB	STR	27-Sep-18	10	0.4812	23.69	1.91
cps1689	ELB	STR	24-Sep-18	10	0.5073	37.56	2.44
cps1690	ELB	STR	21-Sep-18	10	0.5556	18.93	0.86
cps1691	ELB	STR	21-Sep-18	10	0.4061	6.78	1.15
cps1692	ELB	STR	18-Sep-18	12	0.216	2.38	0.91
cps1693	ELB	STR	18-Sep-18	7	0.0954	0.54	0.36
cps1694	ELB	STR	18-Sep-18	10	0	0.0001	0
cps1695	ELB	STR	17-Sep-18	10	0	0	0
cps1696	ELB	STR	17-Sep-18	10	0	0	0
cps1697	ELB	STR	17-Sep-18	10	0	0	0
cps1698	ELB	SUBJ	17-Sep-18	7	0	0	0
cps1699	ELB	SUBJ	17-Sep-18	5	0	0	0
cps1720	ELB	STR	20-Sep-18	8	0.0011	0	0
cps1721	ELB	STR	20-Sep-18	10	0.1813	0.7	0.39
cps1722	ELB	STR	9-Aug-17	10	0.6977	9.17	0.37
cps1722	ELB	STR	20-Sep-18	10	0.6755	8.88	0.49
cps1723	ELB	STR	25-Sep-18	10	0.444	9.07	0.66
cps1724	ELB	STR	9-Aug-17	10	0.4859	7.66	0.72
cps1724	ELB	STR	25-Sep-18	10	0.5009	7.9	0.7
cps1725	ELB	STR	26-Sep-18	10	0.5461	6.48	0.33
cps1726	MS	STR	26-Sep-18	10	0.6188	7.02	0.83

site_code	zone	type	date	# transects	fraction vegetated	eelgrass area (ha)	standard error (ha)
cps1727	MS	STR	12-Sep-18	10	0.6313	12.58	0.84
cps1728	MS	STR	12-Sep-18	10	0.4308	10.11	1.43
cps1729	MS	STR	12-Sep-18	10	0.3984	7.29	0.93
cps1730	MS	STR	14-Sep-18	10	0.5229	6.59	1.37
cps1731	MS	STR	14-Sep-18	10	0.3012	2.49	0.88
cps1732	MS	STR	27-Sep-18	10	0.1009	0.85	0.34
cps1733	MS	STR	11-Sep-18	10	0.5282	8.51	1.53
cps1734	MS	STR	11-Sep-18	10	0.5788	4.26	0.44
cps1735	MS	STR	11-Sep-18	10	0.5382	4.26	0.38
cps1736	MS	STR	10-Sep-18	10	0.5245	6.41	0.66
cps1737	MS	STR	10-Sep-18	10	0.5673	11.75	0.82
cps1738	MS	STR	6-Sep-18	10	0.1018	1.43	0.54
cps1739	MS	STR	17-Jul-17	10	0.4176	6.49	0.9
cps1739	MS	STR	6-Sep-18	10	0.3881	6.03	0.86
cps1740	MS	STR	6-Sep-18	10	0.5589	6.9	0.96
cps1741	MS	STR	4-Sep-18	10	0.4955	7.34	1.18
cps1742	MS	STR	4-Sep-18	10	0.0023	0.02	0.01
cps1743	MS	STR	4-Sep-18	10	0.1886	0.82	0.17
cps1744	SS	STR	4-Sep-18	10	0.5335	4.46	0.48
cps1745	SS	STR	31-Aug-18	10	0.4498	7.97	1.3
cps1746	SS	STR	31-Aug-18	10	0.5298	5.14	0.58
cps1747	SS	STR	30-Aug-18	10	0.5353	3.12	0.17
cps1748	SS	STR	30-Aug-18	10	0.5331	3.05	0.3
cps1749	SS	STR	29-Aug-18	10	0.5987	6.36	0.48
cps1750	SS	SRS	2-Aug-18	11	0.6218	6.03	0.54
cps1750	SS	STR	2-Aug-18	10	0.523	5.71	0.71
cps1751	SS	STR	19-Oct-18	10	0.5185	7.37	0.67
cps1752	SS	STR	19-Oct-18	10	0.3961	10.59	1.02
cps1753	SS	STR	24-Oct-18	10	0.4306	5.14	0.33
cps1754	SS	STR	24-Oct-18	10	0.3589	5.61	1.26
cps1755	SS	STR	24-Oct-18	10	0.1912	1.67	0.87
cps1756	SS	STR	23-Oct-18	10	0.3784	3.06	0.47
cps1757	SS	STR	23-Oct-18	10	0.235	2.79	0.92
cps1758	SS	STR	22-Oct-18	10	0.4899	4.8	0.69
cps1759	SS	STR	22-Oct-18	10	0.5545	5.43	0.14
cps1760	SS	STR	22-Oct-18	10	0.6582	7.76	0.48
cps1763	SS	STR	18-Oct-18	10	0.3557	5.51	0.45
cps1764	SS	SRS	18-Jul-17	13	0.2394	4.03	0.46
cps1764	SS	STR	18-Jul-17	10	0.2336	3.94	0.53
cps2886	QM	STR	31-May-17	10	0	0	0
cps2887	QM	STR	30-May-17	10	0	0	0
cps2906	SS	SRS	18-Jul-17	10	0.4265	3.76	0.49
cps2906	SS	SRS	10-Aug-18	10	0.6135	5.41	0.44
cps2907	SS	STR	18-Oct-18	10	0.4392	3.29	0.98
flats33	QM	SRS	27-Jul-17	21	0	0	0
flats33	QM	STR	27-Jul-17	19	0	0	0

Table 4: Eelgrass depth distribution (m, MLLW) at 134 out of 137 vegetated sites in the King County study area. Sites cps1125, cps1682, cps1720 and cps1742 are not included, since we have insufficient data to generate a depth distribution (trace eelgrass).

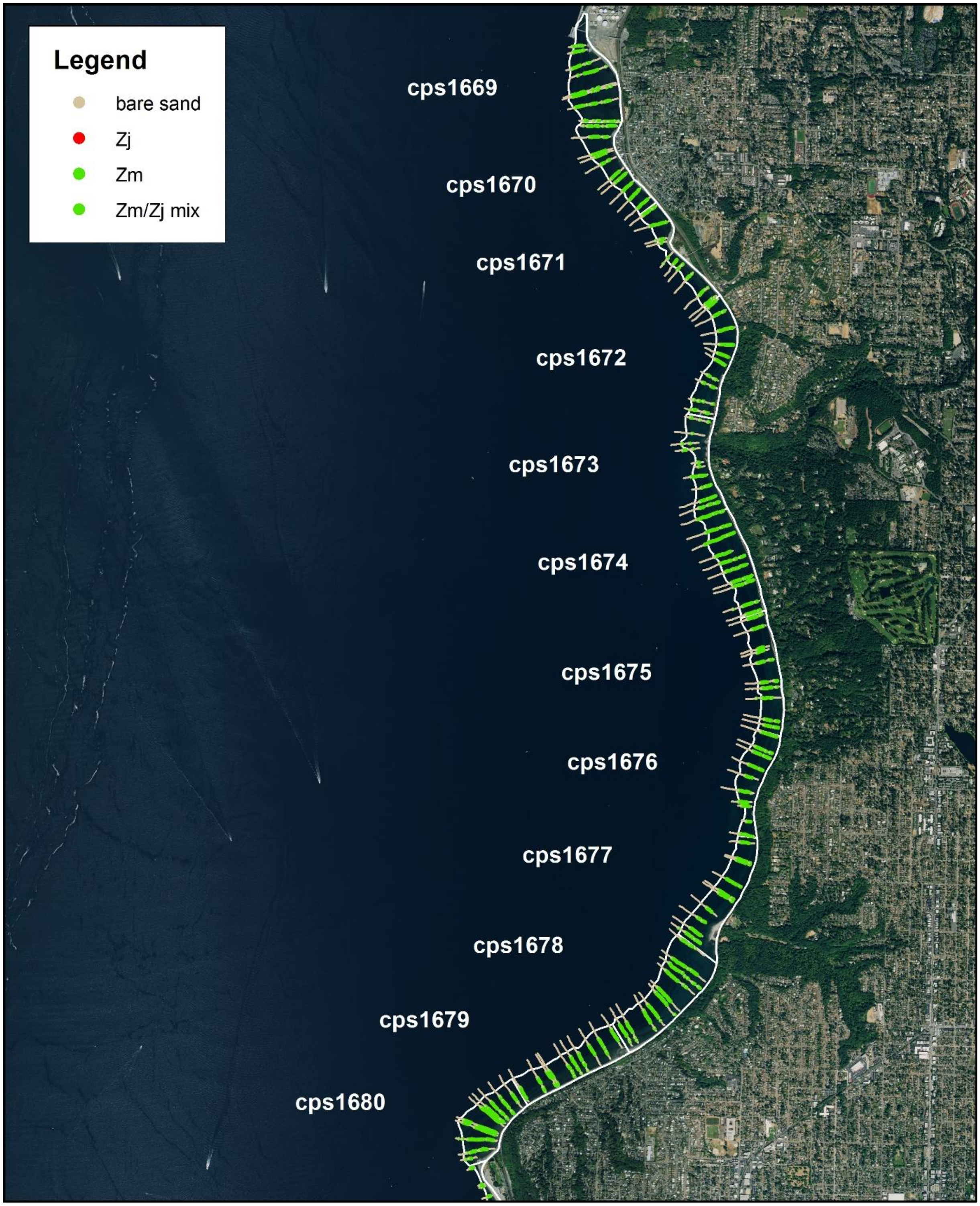
site_code	maxd	q01	q025	q05	q10	q25	q50	q75	q90	q95	q975	q99	mind	range	n
core005	-1.2	-0.7	-0.6	-0.6	-0.5	-0.2	0.1	0.4	0.5	0.6	0.6	0.6	0.7	1.3	144
cps1116	-4.3	-3.8	-3.4	-2.6	-2.2	-1.6	-1.1	-0.7	-0.6	-0.4	-0.4	-0.3	-0.2	3.0	250
cps1117	-4.5	-4.5	-4.4	-4.3	-4.3	-2.1	-1.1	-0.5	-0.3	-0.2	-0.2	-0.1	0.0	4.3	422
cps1118	-4.6	-3.8	-3.3	-2.7	-2.1	-1.3	-0.6	-0.3	0.0	0.1	0.2	0.3	0.4	3.5	784
cps1119	-4.5	-3.2	-2.8	-2.3	-1.6	-0.7	-0.4	0.0	0.3	0.5	0.5	0.5	0.6	3.3	411
cps1126	-3.7	-3.5	-3.3	-3.1	-2.8	-1.9	-1.2	-0.8	-0.5	-0.4	-0.4	-0.3	-0.3	2.9	142
cps1127	-4.6	-4.5	-4.3	-3.9	-3.4	-2.5	-2.0	-1.7	-1.4	-1.1	-1.0	-0.9	-0.5	3.2	151
cps1128	-5.7	-4.9	-4.4	-4.1	-3.5	-2.3	-1.4	-0.8	-0.4	-0.2	-0.1	-0.1	0.0	4.3	998
cps1129	-4.8	-4.4	-4.2	-3.8	-3.1	-1.8	-1.0	-0.6	-0.2	-0.1	0.1	0.1	0.2	4.3	226
cps1130	-4.4	-4.2	-4.0	-3.7	-3.4	-2.6	-1.7	-0.8	-0.5	-0.1	0.1	0.4	0.6	4.2	805
cps1131	-4.6	-4.2	-3.8	-3.4	-3.0	-2.0	-1.2	-0.4	0.0	0.3	0.4	0.5	0.5	4.2	554
cps1132	-5.0	-4.8	-4.4	-4.0	-3.5	-2.6	-1.5	-0.8	-0.2	0.0	0.3	0.5	0.6	4.7	493
cps1133	-5.9	-5.1	-4.3	-3.6	-3.0	-1.9	-1.1	-0.5	-0.1	0.0	0.1	0.1	0.2	4.4	410
cps1134	-4.9	-4.6	-4.1	-3.7	-2.8	-1.7	-1.1	-0.6	-0.3	-0.2	-0.1	0.0	0.0	4.0	291
cps1135	-4.5	-4.2	-3.9	-3.5	-2.9	-2.3	-1.8	-0.9	-0.4	-0.3	-0.3	-0.2	0.1	3.6	478
cps1136	-4.0	-3.8	-3.2	-2.8	-2.2	-1.4	-0.8	-0.3	0.0	0.1	0.1	0.2	0.2	3.4	458
cps1137	-6.5	-5.1	-4.3	-3.7	-3.0	-2.2	-1.5	-0.8	-0.5	-0.3	-0.2	-0.1	0.0	4.1	819
cps1138	-4.7	-4.3	-3.8	-3.4	-2.9	-2.2	-1.6	-1.0	-0.5	-0.4	-0.3	-0.2	0.2	3.5	891
cps1139	-5.2	-4.4	-4.1	-3.9	-3.4	-2.4	-1.6	-1.1	-0.4	0.0	0.4	0.7	0.9	4.6	809
cps1140	-5.1	-5.0	-4.8	-4.6	-4.3	-3.3	-1.9	-1.3	-1.1	-1.1	-1.0	-0.9	-0.8	3.8	247
cps1141	-5.6	-5.1	-4.7	-4.2	-3.4	-2.4	-1.7	-1.2	-0.9	-0.8	-0.7	-0.7	-0.6	4.0	820
cps1142	-5.7	-5.0	-4.5	-3.8	-3.2	-2.4	-1.6	-1.2	-0.8	-0.5	-0.3	-0.2	0.1	4.1	880
cps1143	-5.5	-5.0	-4.4	-3.6	-2.8	-1.7	-1.2	-0.9	-0.6	-0.5	-0.5	-0.5	-0.3	3.9	556
cps1144	-5.3	-5.0	-4.8	-4.4	-3.9	-3.2	-2.0	-1.1	-0.1	0.1	0.3	0.3	0.4	5.0	508
cps1145	-5.7	-5.3	-5.1	-5.0	-4.5	-3.8	-3.0	-2.3	-1.5	-1.1	-0.8	-0.3	0.4	4.3	1719
cps1146	-5.7	-4.9	-4.7	-4.4	-4.0	-3.3	-2.5	-1.5	-0.7	-0.4	-0.3	-0.2	0.0	4.3	2738
cps1147	-6.8	-5.1	-4.8	-4.7	-4.3	-3.6	-2.6	-1.4	-0.6	-0.4	-0.3	-0.2	0.0	4.5	920
cps1148	-5.0	-3.3	-3.2	-2.9	-2.5	-1.8	-1.0	-0.2	0.4	0.6	0.7	0.9	1.0	3.9	518
cps1149	-4.6	-4.3	-3.9	-3.0	-2.0	-1.3	-0.7	-0.2	0.1	0.2	0.4	0.5	0.7	4.3	638
cps1150	-2.7	-2.6	-2.6	-2.6	-2.5	-2.3	-1.8	-1.6	-1.5	-1.4	-1.4	-1.4	-1.3	1.2	77
cps1151	-5.4	-4.9	-4.5	-4.3	-3.9	-2.9	-1.5	-0.7	-0.4	-0.2	0.0	0.1	0.3	4.5	1353
cps1152	-5.6	-5.2	-4.9	-4.7	-4.3	-3.5	-2.5	-1.2	-0.6	-0.3	-0.1	0.1	0.4	4.9	1075
cps1153	-4.8	-4.2	-4.0	-3.6	-3.1	-2.4	-1.8	-1.0	-0.4	-0.2	0.0	0.1	0.3	3.9	1345
cps1154	-4.1	-3.7	-3.4	-3.1	-2.8	-2.2	-1.2	-0.5	-0.2	0.0	0.1	0.2	0.4	3.5	1443
cps1155	-4.4	-3.7	-3.3	-2.9	-2.4	-1.5	-0.7	0.0	0.3	0.5	0.5	0.6	0.7	3.9	2612
cps1156	-4.4	-3.8	-3.6	-3.2	-2.6	-1.5	-0.9	-0.3	0.2	0.5	0.7	0.8	0.9	4.2	2263
cps1157	-4.8	-3.9	-3.6	-3.4	-3.1	-2.3	-1.1	-0.5	-0.1	0.1	0.2	0.4	0.8	3.9	1522
cps1158	-4.5	-3.7	-3.4	-3.0	-2.5	-2.0	-1.2	-0.3	0.0	0.3	0.5	0.5	0.6	3.9	689
cps1160	-1.2	-1.1	-0.9	-0.8	-0.5	-0.1	0.2	0.4	0.5	0.6	0.7	0.7	0.8	1.6	611
cps1161	-2.3	-1.9	-1.8	-1.6	-1.4	-1.0	-0.1	0.2	0.3	0.4	0.4	0.5	1.0	2.2	1018
cps1162	-3.9	-3.4	-3.2	-2.9	-2.6	-2.0	-1.1	-0.3	0.0	0.2	0.3	0.5	0.8	3.5	1789
cps1163	-4.0	-3.8	-3.6	-3.4	-3.0	-2.3	-1.5	-0.6	-0.3	-0.2	-0.1	0.1	0.9	3.5	1486
cps1164	-4.2	-3.2	-2.9	-2.6	-2.2	-1.7	-1.3	-0.8	-0.6	-0.4	-0.1	0.0	0.3	2.8	3107
cps1165	-4.3	-3.8	-3.5	-3.2	-2.6	-1.9	-1.4	-0.7	-0.4	-0.3	-0.1	0.0	0.3	3.4	910
cps1166	-4.4	-3.9	-3.7	-3.5	-3.1	-2.6	-1.7	-1.0	-0.5	-0.4	-0.3	-0.1	0.2	3.5	1388
cps1167	-4.3	-3.9	-3.7	-3.2	-2.6	-1.8	-1.1	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	3.1	286
cps1168	-4.3	-3.8	-3.4	-2.9	-2.3	-1.3	-0.8	-0.5	-0.4	-0.3	-0.3	-0.2	-0.2	3.1	270

site_code	maxd	q01	q025	q05	q10	q25	q50	q75	q90	q95	q975	q99	mind	range	n
cps1169	-4.2	-3.9	-3.5	-3.1	-2.4	-1.6	-1.1	-0.6	-0.4	-0.3	-0.3	-0.2	-0.1	3.3	483
cps1170	-4.2	-4.1	-3.9	-3.5	-2.9	-2.0	-1.4	-1.0	-0.6	-0.5	-0.4	-0.4	-0.4	3.5	111
cps1171	-4.8	-4.4	-4.2	-3.9	-3.3	-2.1	-1.4	-1.0	-0.6	-0.5	-0.4	-0.4	-0.4	3.7	228
cps1172	-4.5	-4.0	-3.8	-3.5	-3.0	-2.0	-1.2	-0.9	-0.5	-0.4	-0.3	-0.2	-0.2	3.6	309
cps1173	-4.2	-3.8	-3.5	-3.1	-2.8	-1.9	-1.2	-0.6	-0.3	-0.1	0.2	0.3	0.4	3.7	704
cps1174	-4.8	-3.9	-3.5	-3.2	-2.4	-1.6	-1.0	-0.7	-0.3	-0.2	0.0	0.1	0.3	3.5	758
cps1175	-3.4	-3.1	-3.0	-2.7	-2.3	-1.7	-1.1	-0.6	-0.4	-0.3	-0.2	-0.1	0.0	2.8	1617
cps1176	-4.1	-3.9	-3.6	-3.3	-3.0	-2.3	-1.8	-1.0	-0.6	-0.5	-0.4	-0.4	-0.3	3.2	423
cps1177	-4.0	-3.9	-3.7	-3.5	-3.0	-2.0	-1.6	-1.5	-1.4	-1.0	-0.6	-0.5	-0.4	3.1	92
cps1181	-2.3	-2.2	-2.1	-2.0	-1.9	-1.6	-1.2	-0.8	-0.4	-0.2	-0.1	1.0	1.0	2.0	231
cps1182	-2.7	-2.2	-2.2	-2.1	-2.0	-1.7	-1.4	-1.2	-0.9	-0.6	-0.5	-0.4	-0.3	1.6	351
cps1183	-1.4	-1.4	-1.4	-1.4	-1.3	-1.2	-1.1	-0.7	-0.6	-0.5	-0.4	-0.4	-0.3	1.0	28
cps1186	-1.7	-1.7	-1.7	-1.7	-1.6	-1.5	-1.4	-1.3	-1.3	-1.2	-1.2	-1.2	-1.1	0.5	30
cps1187	-3.0	-2.8	-2.6	-2.4	-2.2	-1.8	-1.4	-1.0	-0.7	-0.6	-0.6	-0.5	-0.4	2.0	460
cps1188	-3.0	-2.8	-2.6	-2.5	-2.4	-2.1	-1.8	-1.4	-1.0	-0.9	-0.8	-0.7	-0.7	1.7	439
cps1189	-2.5	-2.4	-2.4	-2.3	-2.2	-2.0	-1.6	-1.3	-1.1	-1.0	-0.9	-0.8	-0.8	1.5	218
cps1190	-2.8	-2.8	-2.7	-2.6	-2.4	-1.9	-1.3	-0.8	-0.6	-0.5	-0.4	-0.3	-0.2	2.3	193
cps1191	-3.3	-3.2	-3.0	-2.7	-2.3	-1.4	-0.8	-0.5	-0.2	0.0	0.1	0.2	0.2	3.1	224
cps1669	-10.1	-5.4	-5.0	-4.7	-2.9	-2.2	-1.7	-1.2	-0.8	-0.7	-0.5	-0.4	0.0	4.5	1502
cps1670	-5.2	-5.0	-4.7	-4.3	-3.5	-2.0	-1.5	-1.0	-0.7	-0.5	-0.4	-0.4	0.0	4.3	1389
cps1671	-4.7	-4.6	-4.3	-3.9	-3.3	-2.4	-1.7	-1.1	-0.5	-0.4	-0.3	-0.2	0.1	4.0	866
cps1672	-4.8	-4.5	-4.3	-4.0	-3.6	-2.6	-1.4	-0.6	-0.3	0.1	0.3	0.4	0.6	4.5	1365
cps1673	-7.2	-5.7	-5.1	-4.5	-3.6	-1.8	-1.1	-0.8	-0.6	-0.5	-0.3	0.2	0.3	4.8	866
cps1674	-9.7	-6.1	-5.1	-4.5	-4.1	-3.2	-1.3	-0.7	-0.5	-0.4	-0.3	-0.2	0.0	4.7	2668
cps1675	-4.3	-4.1	-3.9	-3.6	-3.2	-2.0	-1.3	-0.9	-0.3	-0.1	0.1	0.3	0.5	4.0	1511
cps1676	-5.1	-4.4	-4.1	-3.9	-3.4	-2.2	-1.4	-1.0	-0.2	0.0	0.3	0.5	0.7	4.4	1361
cps1677	-4.8	-4.3	-4.0	-3.6	-3.2	-2.0	-1.3	-1.1	-0.7	-0.4	-0.3	-0.2	0.0	3.7	1556
cps1678	-4.6	-4.3	-4.0	-3.8	-3.3	-2.1	-1.4	-0.8	-0.5	-0.1	0.2	0.3	0.4	4.2	2363
cps1679	-4.9	-4.6	-4.3	-4.2	-3.9	-3.0	-1.7	-0.8	-0.6	-0.4	-0.2	0.0	0.2	4.2	1819
cps1680	-5.1	-4.6	-4.5	-4.2	-3.8	-2.3	-1.2	-0.5	-0.1	0.0	0.1	0.2	0.5	4.6	2638
cps1681	-9.1	-5.1	-4.9	-4.5	-3.7	-2.2	-1.3	-0.8	-0.5	-0.4	-0.4	-0.3	-0.1	4.5	467
cps1683	-2.9	-2.9	-2.8	-2.6	-2.3	-2.1	-1.9	-1.8	-1.7	-1.6	-1.5	-1.5	-1.4	1.3	43
cps1684	-4.4	-3.6	-3.4	-3.3	-3.0	-2.7	-2.0	-1.6	-1.0	-0.9	-0.8	-0.7	-0.6	2.6	841
cps1685	-5.9	-5.2	-4.8	-4.4	-3.9	-2.8	-1.9	-1.5	-1.3	-1.2	-1.2	-0.6	-0.1	3.7	1915
cps1686	-5.9	-5.5	-5.1	-4.7	-4.1	-2.6	-1.6	-0.9	-0.4	-0.2	-0.2	-0.1	0.1	4.9	1338
cps1687	-6.2	-4.7	-4.5	-4.3	-3.6	-3.1	-2.4	-1.6	-1.2	-1.0	-0.6	-0.3	-0.1	4.0	951
cps1688	-13.3	-5.4	-5.2	-5.0	-4.8	-4.4	-3.9	-2.5	-0.6	-0.3	-0.1	0.0	0.4	5.1	4698
cps1689	-6.4	-5.3	-4.6	-4.2	-4.0	-3.4	-2.7	-0.6	-0.4	-0.2	-0.1	0.1	0.4	4.5	7857
cps1690	-5.6	-4.9	-4.5	-3.8	-3.1	-1.8	-1.3	-0.9	-0.7	-0.6	-0.5	-0.3	-0.1	4.0	4201
cps1691	-5.6	-4.1	-3.8	-3.6	-3.3	-2.6	-1.8	-1.3	-0.9	-0.6	-0.4	-0.3	-0.1	3.4	1467
cps1692	-8.2	-3.8	-3.7	-3.5	-3.2	-2.4	-1.7	-1.2	-0.7	-0.5	-0.4	-0.3	-0.2	3.3	658
cps1693	-5.0	-3.8	-3.7	-3.5	-3.3	-2.8	-1.5	-1.0	-0.8	-0.8	-0.7	-0.7	-0.7	2.9	733
cps1694	-2.9	-2.3	-1.9	-1.7	-1.4	-0.9	-0.9	-0.8	-0.8	-0.7	-0.7	-0.6	-0.6	1.2	94
cps1721	-3.6	-3.3	-2.9	-2.7	-2.3	-1.7	-1.0	-0.5	-0.2	-0.1	-0.1	-0.1	0.0	2.8	149
cps1722	-5.8	-5.5	-5.2	-4.9	-4.4	-3.7	-2.7	-1.5	-0.8	-0.5	-0.2	0.1	0.3	5.0	2890
cps1723	-12.2	-8.5	-5.2	-4.5	-3.5	-2.0	-0.7	-0.4	-0.3	-0.2	-0.1	0.0	0.3	5.0	2132
cps1724	-5.8	-5.3	-5.0	-4.0	-2.9	-1.6	-0.6	-0.3	-0.2	-0.1	-0.1	0.0	0.4	5.0	1681
cps1725	-4.9	-4.4	-4.1	-3.9	-3.4	-2.6	-1.5	-0.7	-0.3	-0.2	-0.1	0.2	0.3	4.1	1397
cps1726	-5.1	-4.4	-4.1	-3.7	-3.4	-2.8	-2.1	-1.3	-0.8	-0.5	-0.2	-0.1	0.1	3.9	1730
cps1727	-6.0	-4.7	-4.2	-3.8	-3.3	-2.6	-1.4	-0.8	-0.6	-0.5	-0.4	-0.2	0.3	3.8	2869
cps1728	-5.4	-5.0	-4.7	-4.4	-4.0	-3.3	-2.5	-1.3	-0.6	-0.4	-0.3	0.0	0.2	4.4	2194

site_code	maxd	q01	q025	q05	q10	q25	q50	q75	q90	q95	q975	q99	mind	range	n
cps1729	-5.4	-4.9	-4.6	-4.4	-3.9	-3.0	-2.2	-1.4	-0.8	-0.5	-0.3	-0.2	0.1	4.3	1522
cps1730	-5.4	-5.0	-4.8	-4.4	-3.8	-3.0	-2.2	-1.5	-1.1	-0.9	-0.6	-0.1	0.0	4.1	1433
cps1731	-6.0	-4.7	-4.2	-3.7	-3.5	-2.6	-1.6	-0.7	-0.4	-0.4	-0.3	-0.2	-0.2	3.9	551
cps1732	-5.5	-5.4	-5.3	-5.2	-5.0	-4.4	-3.4	-2.4	-1.6	-1.3	-0.6	-0.5	-0.5	4.7	202
cps1733	-5.7	-5.0	-4.6	-4.1	-3.7	-2.8	-1.9	-1.2	-0.8	-0.5	-0.4	-0.3	0.0	4.2	1927
cps1734	-6.8	-4.1	-3.5	-2.9	-2.4	-1.6	-1.2	-1.0	-0.6	-0.5	-0.4	-0.3	-0.2	3.1	1008
cps1735	-5.0	-4.1	-3.6	-3.0	-2.2	-1.5	-1.1	-0.7	-0.5	-0.4	-0.4	-0.3	-0.2	3.2	1015
cps1736	-4.1	-3.7	-3.5	-3.2	-2.8	-2.1	-0.9	0.0	0.5	0.8	0.9	1.0	1.1	4.4	1390
cps1737	-3.9	-3.4	-3.1	-2.8	-2.6	-1.8	-0.7	0.0	0.2	0.3	0.3	0.5	0.7	3.4	2629
cps1738	-1.8	-1.6	-1.5	-1.4	-1.1	-0.9	-0.6	0.0	0.5	0.7	0.8	0.9	0.9	2.3	307
cps1739	-3.7	-3.2	-2.8	-2.5	-2.1	-1.6	-1.1	-0.6	-0.1	0.4	0.6	0.7	0.9	3.4	1217
cps1740	-5.2	-4.0	-3.7	-3.4	-2.7	-1.8	-0.9	-0.5	0.0	0.3	0.5	0.7	0.8	4.2	1560
cps1741	-4.3	-3.6	-3.2	-3.0	-2.4	-1.3	-0.5	0.0	0.3	0.4	0.5	0.6	0.7	3.8	1640
cps1743	-5.1	-4.1	-3.8	-3.4	-3.0	-2.2	-1.6	-1.3	-0.9	-0.8	-0.8	-0.8	-0.7	3.1	203
cps1744	-4.1	-3.5	-3.3	-3.1	-2.6	-1.9	-0.9	-0.4	0.0	0.1	0.2	0.3	0.5	3.6	890
cps1745	-4.9	-3.4	-3.1	-2.8	-2.5	-1.9	-0.9	-0.3	0.1	0.2	0.5	0.7	0.8	3.6	1621
cps1746	-3.3	-3.1	-3.0	-2.9	-2.7	-2.1	-1.1	-0.8	-0.6	-0.4	-0.2	-0.1	0.1	2.8	1186
cps1747	-3.7	-3.5	-3.3	-3.1	-2.8	-1.9	-1.0	-0.5	-0.2	-0.1	0.0	0.0	0.1	3.3	671
cps1748	-3.5	-3.2	-2.9	-2.4	-1.8	-1.2	-0.7	-0.4	-0.2	-0.1	0.1	0.2	0.5	2.9	744
cps1749	-3.7	-3.4	-3.2	-3.1	-2.7	-1.9	-0.8	-0.4	0.1	0.3	0.4	0.6	0.8	3.6	1456
cps1750	-4.0	-3.7	-3.4	-3.2	-2.9	-2.1	-1.4	-0.8	-0.5	-0.5	-0.4	-0.3	0.0	3.1	1578
cps1751	-4.2	-3.9	-3.6	-3.2	-2.6	-1.4	-0.9	-0.4	-0.3	-0.1	0.0	0.1	0.2	3.6	1472
cps1752	-4.3	-3.5	-3.3	-3.1	-2.7	-1.8	-1.3	-0.8	-0.4	-0.2	0.0	0.1	0.8	3.3	2093
cps1753	-3.7	-3.1	-2.9	-2.7	-2.6	-2.1	-1.3	-0.9	-0.5	-0.3	-0.1	0.1	0.2	2.8	998
cps1754	-4.3	-3.5	-3.2	-3.0	-2.8	-2.2	-1.2	-0.5	-0.2	0.1	0.4	0.5	1.0	3.5	1082
cps1755	-3.5	-3.3	-3.2	-3.1	-2.9	-2.1	-1.2	-0.5	0.0	0.3	0.3	0.4	0.5	3.6	314
cps1756	-3.7	-3.5	-3.3	-3.1	-2.8	-2.1	-1.5	-1.0	-0.6	-0.4	-0.2	0.0	0.1	3.1	596
cps1757	-3.6	-2.8	-2.6	-2.5	-2.3	-1.8	-1.3	-0.5	0.1	0.3	0.4	0.4	0.5	3.0	555
cps1758	-3.4	-2.9	-2.7	-2.4	-2.2	-1.6	-1.0	-0.3	0.2	0.4	0.6	0.7	0.9	3.3	972
cps1759	-3.3	-2.9	-2.8	-2.6	-2.4	-1.9	-1.2	-0.5	0.0	0.2	0.3	0.4	0.5	3.1	1045
cps1760	-3.4	-2.7	-2.5	-2.2	-1.9	-1.5	-0.9	-0.3	0.3	0.5	0.6	0.7	0.8	3.0	1648
cps1763	-3.2	-2.7	-2.3	-1.8	-1.4	-0.8	-0.3	0.1	0.3	0.4	0.5	0.6	0.6	2.8	1008
cps1764	-2.4	-2.2	-2.0	-1.8	-1.7	-1.4	-0.9	-0.5	-0.1	0.0	0.3	0.6	0.9	2.4	725
cps2906	-3.2	-2.8	-2.6	-2.4	-2.1	-1.6	-1.0	-0.1	0.3	0.6	0.7	0.8	1.0	3.3	1965
cps2907	-3.2	-3.0	-2.8	-2.4	-2.0	-1.4	-1.1	-0.5	-0.1	0.1	0.2	0.3	0.4	3.1	1143

7 Appendix 2: Overview Maps

The following pages contain a series of maps with the location of each transect sampled along the shoreline of King County in 2017 and 2018. Eelgrass observations (including mixed beds with *Zostera japonica*) are indicated in green, locations with only *Zostera japonica* are indicated in red, and bare sediment is indicated in light brown. The contours of the site polygons are indicated in white, and are labeled with the corresponding SVMP site code.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Zm
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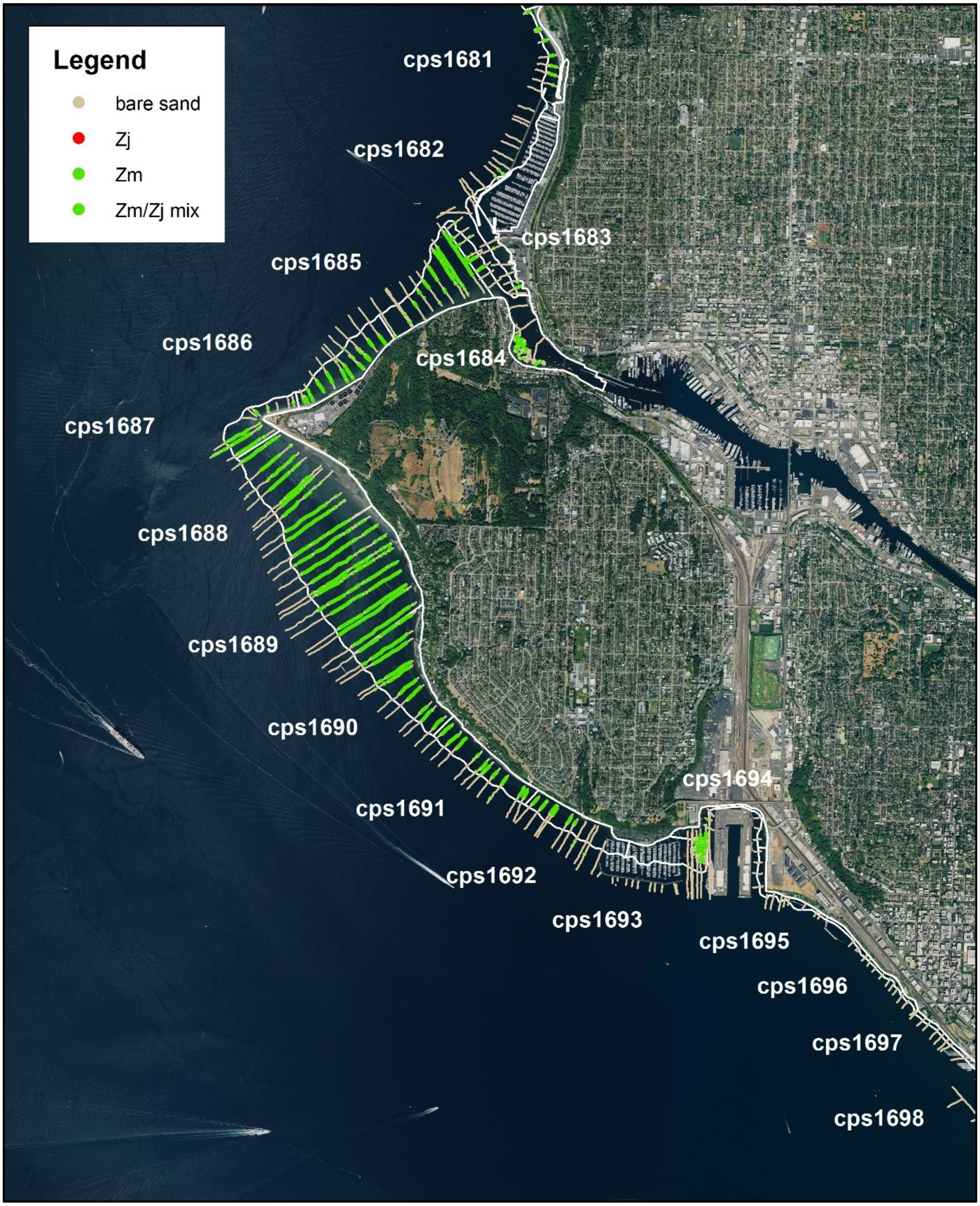
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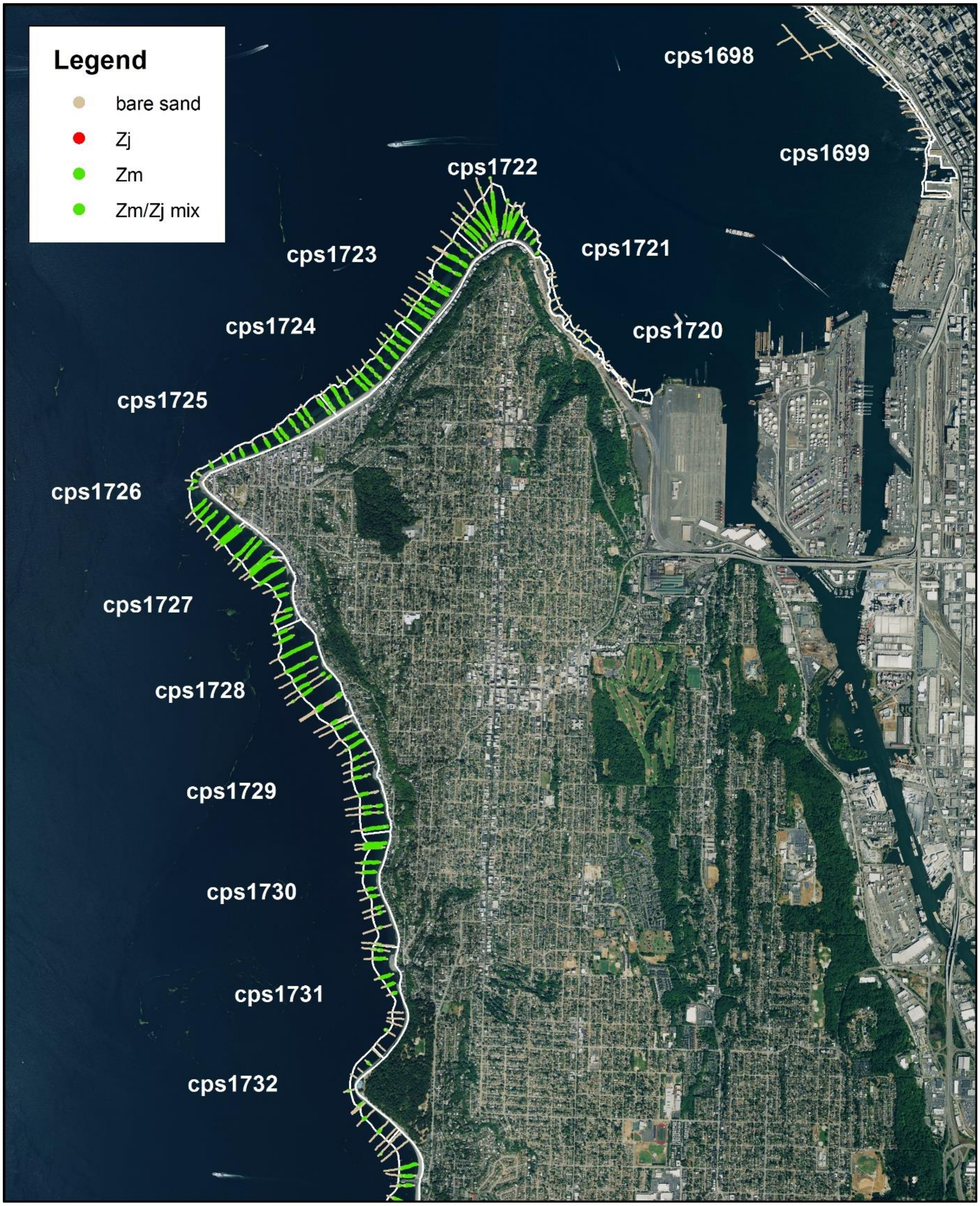
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Zm
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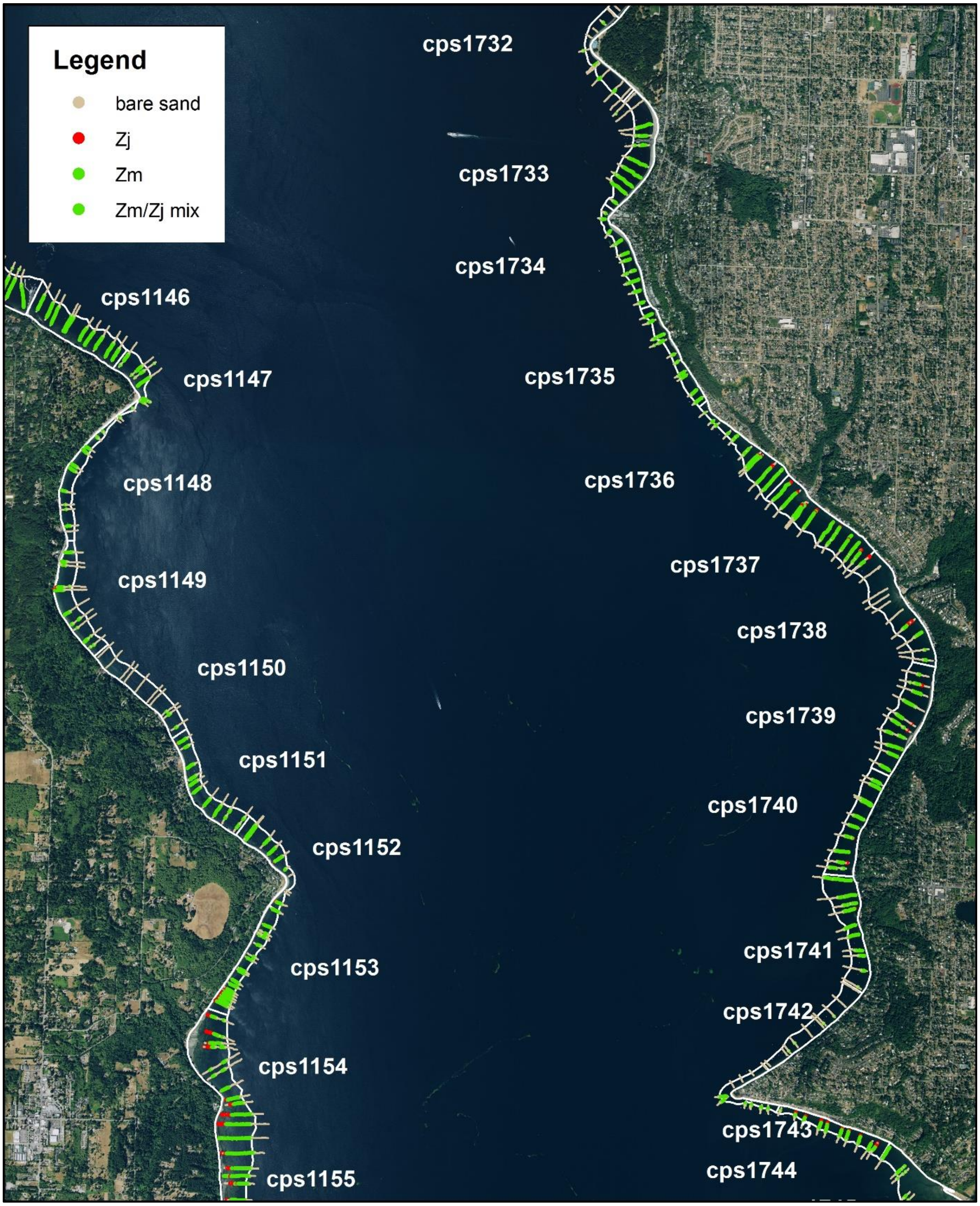
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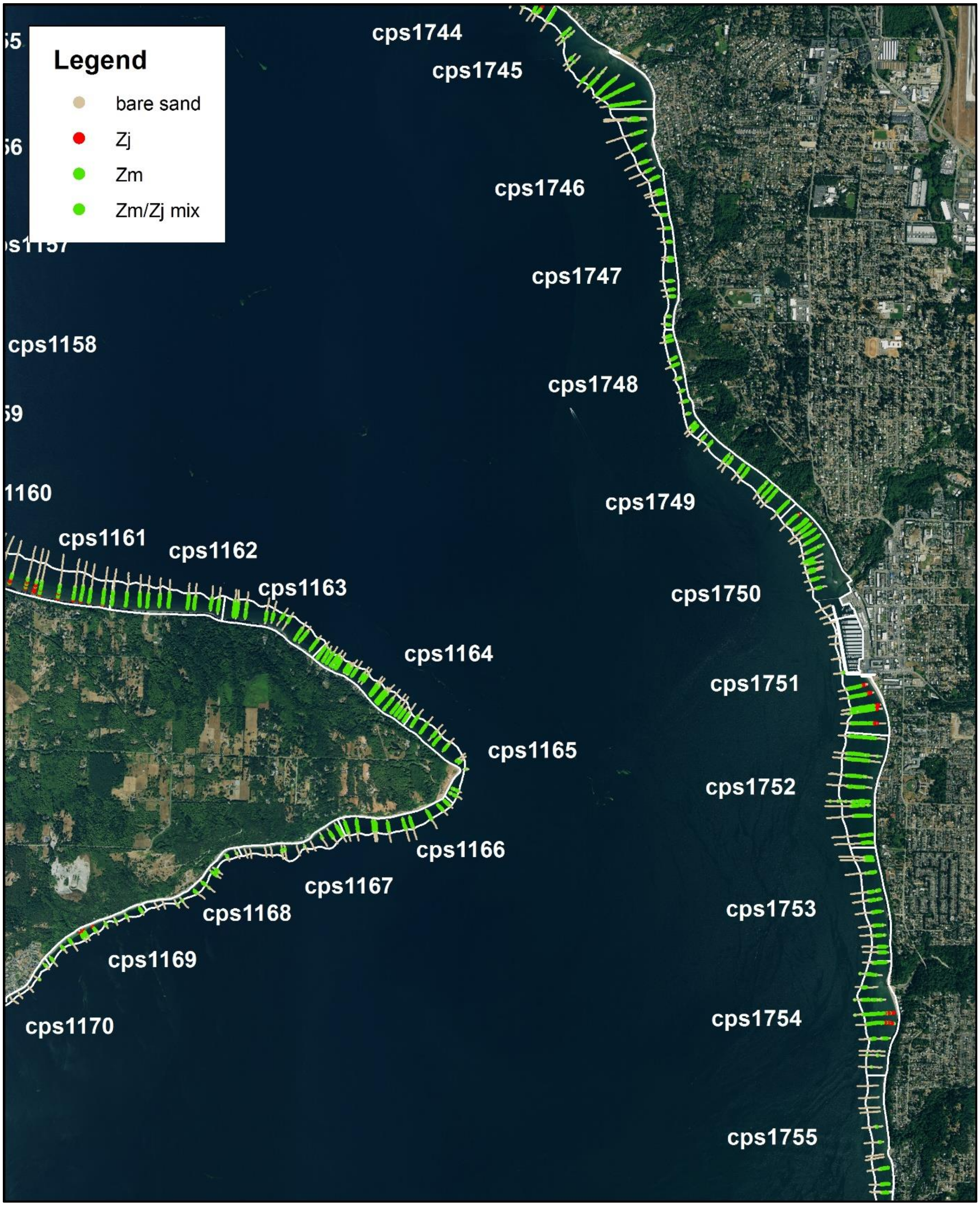
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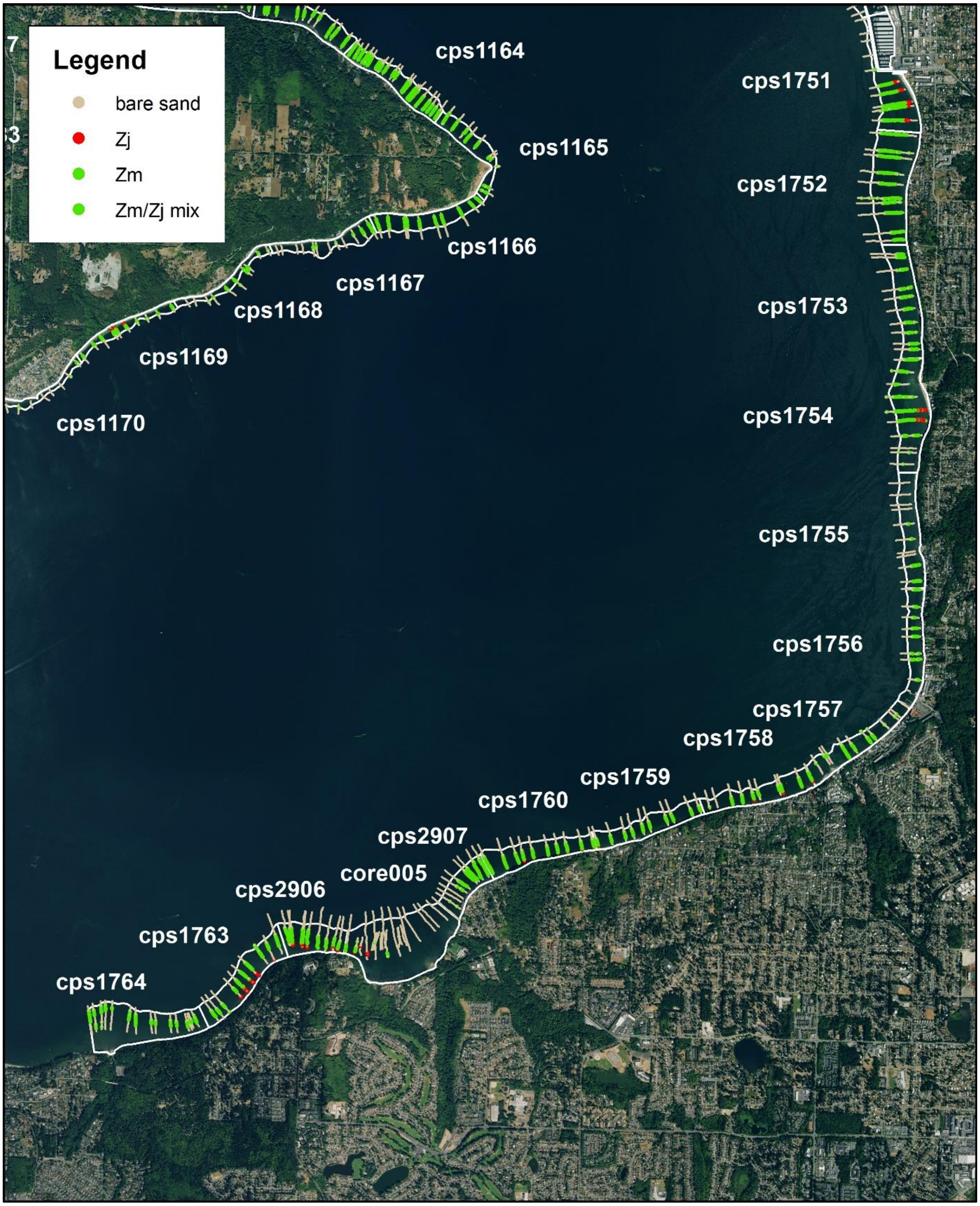
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Zm/Zj mix
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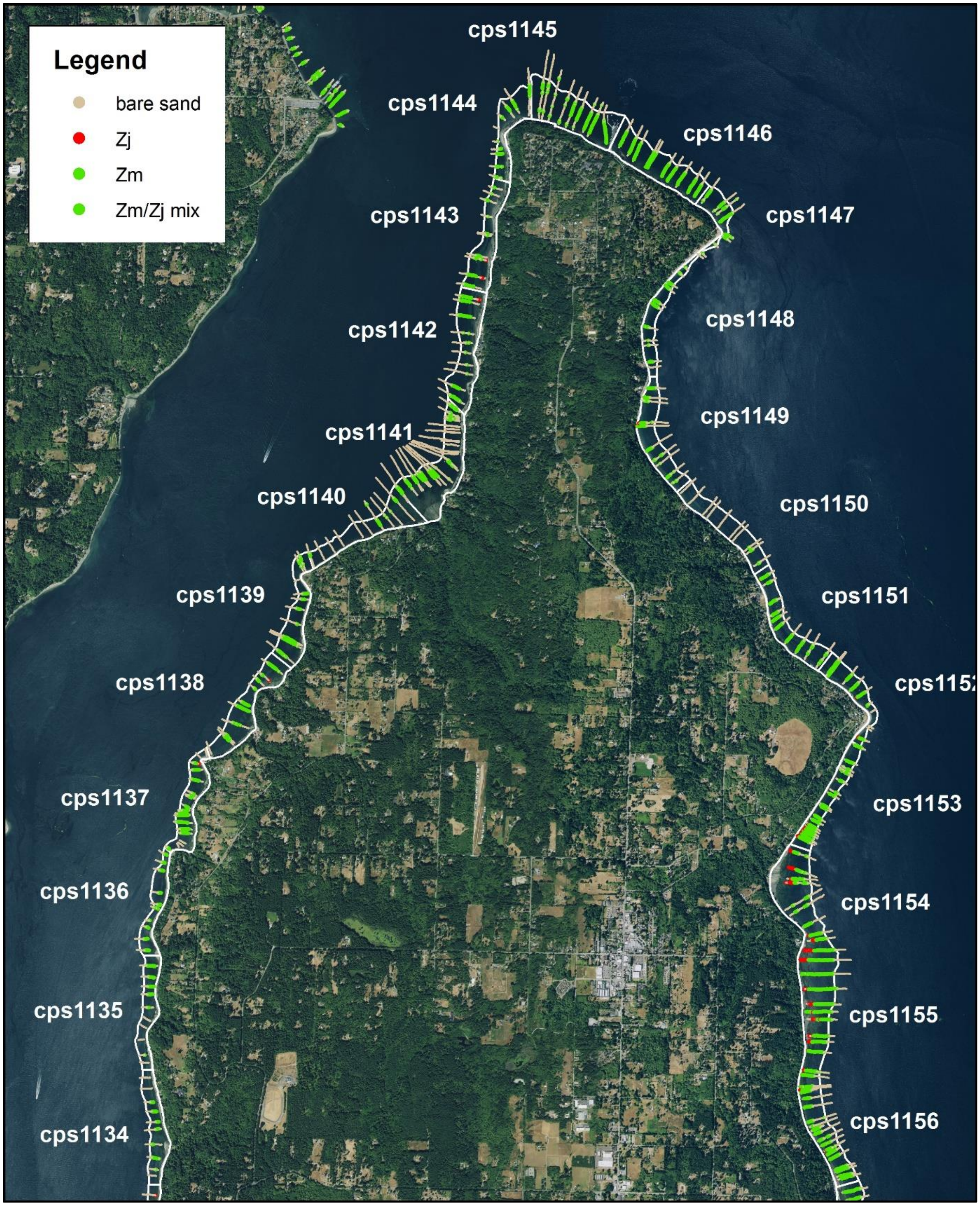
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Zm
Zm/Zj mix
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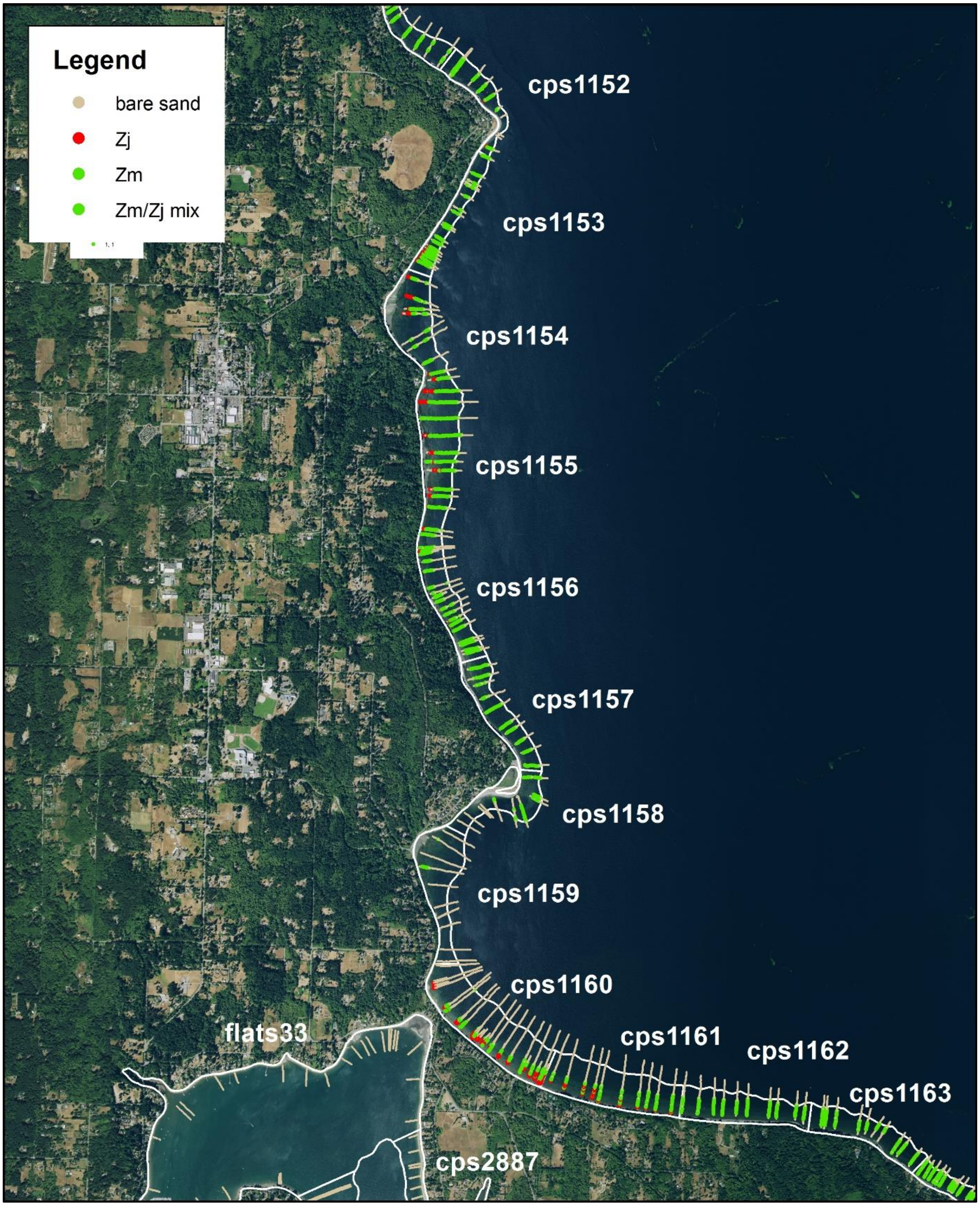
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Zm
Zm/Zj mix
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cps1159
cps1160
cps1161
cps1162
cps1163
flats33
cps2887


Legend
bare sand
Zj
Zm
Zm/Zj mix
cps1743
cps1744
cps1745
cps1746
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cps1156
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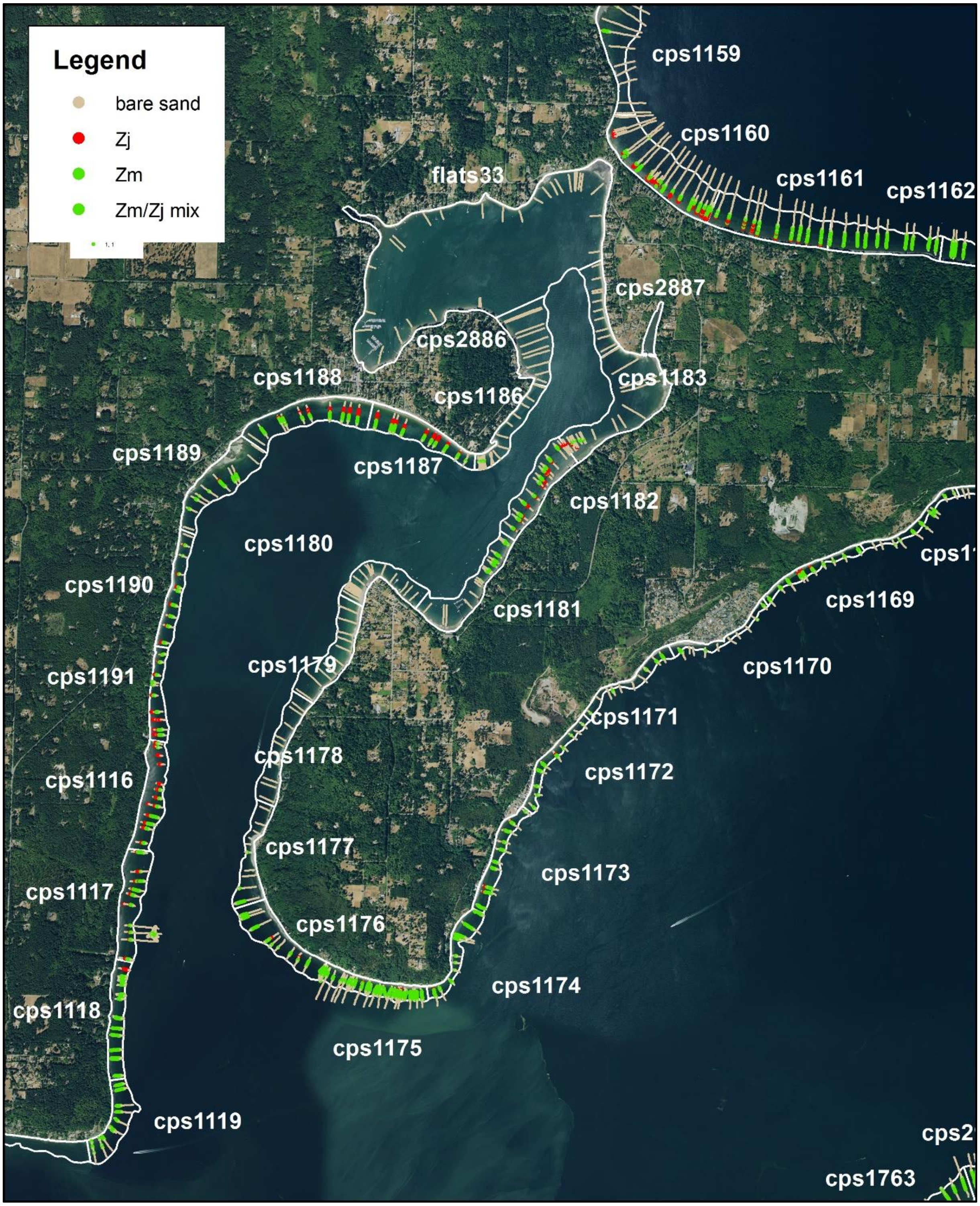
cps1158
cps1159
cps1160
cps1161
cps1162
cps1163
cps1164
cps1165
cps1166
cps1167
cps1168
cps1169
cps1170
cps1171
cps1172
flats33
cps2887
cps2886
cps1183
cps1186
cps1187
cps1182
cps1181



Legend
bare sand
Zj
Zm
Zm/Zj mix
cps1159
cps1160
cps1161
cps1162
flats33
cps2887
cps2886
cps1188
cps1186
cps1183
cps1189
cps1187
cps1182
cps1180
cps1190
cps1181
cps1169
cps1179
cps1170
cps1191
cps1171
cps1178
cps1172
cps1116
cps1177
cps1173
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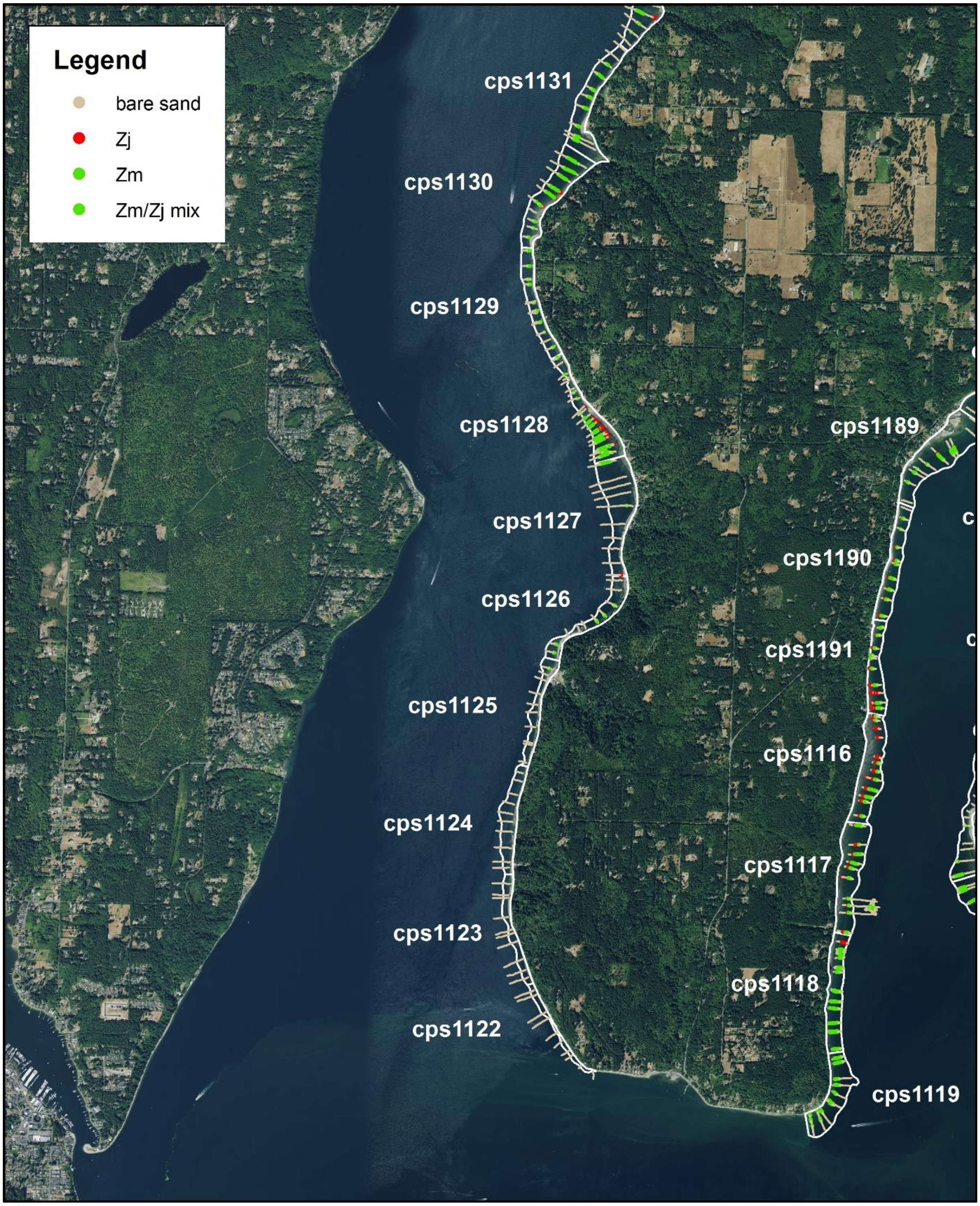
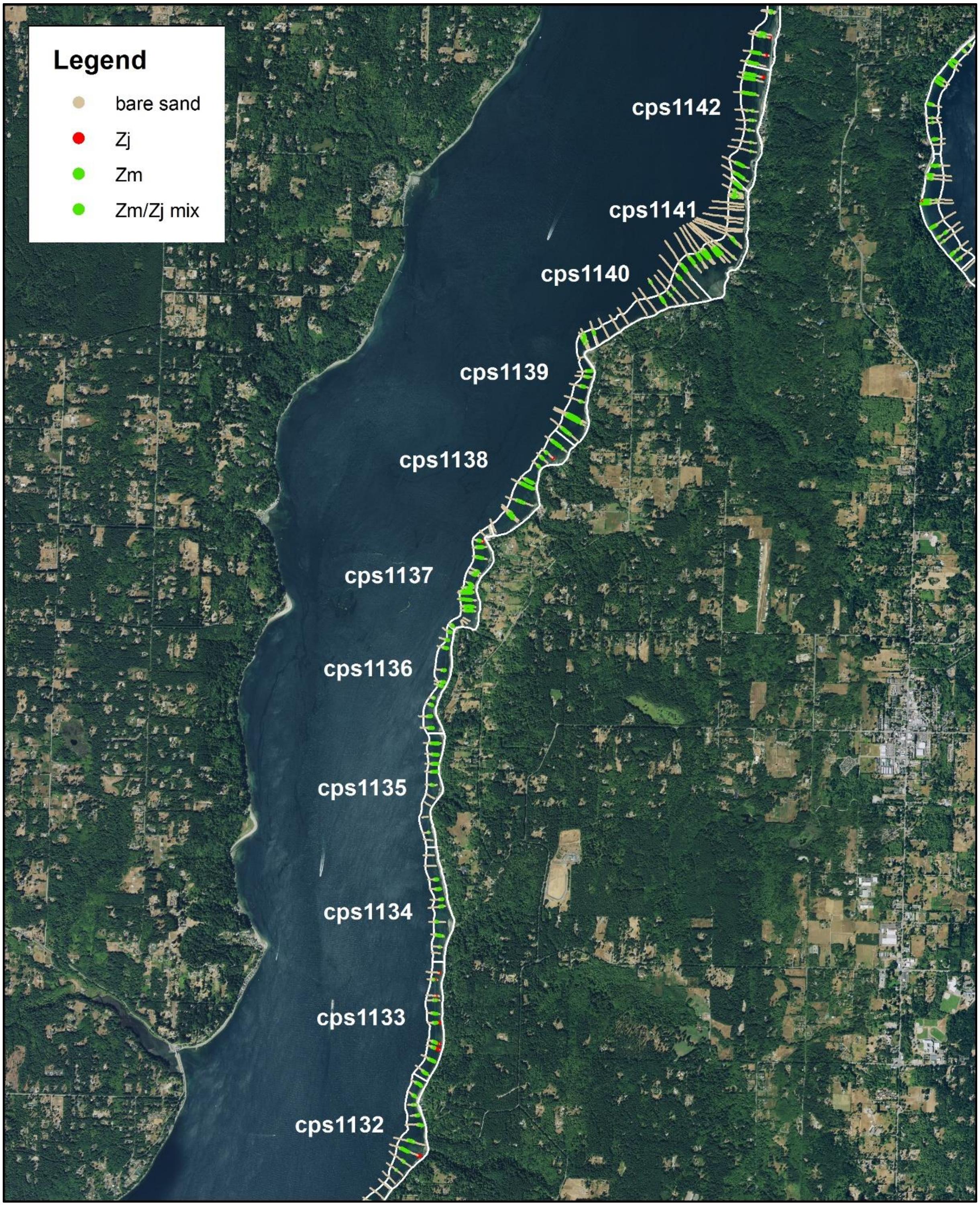
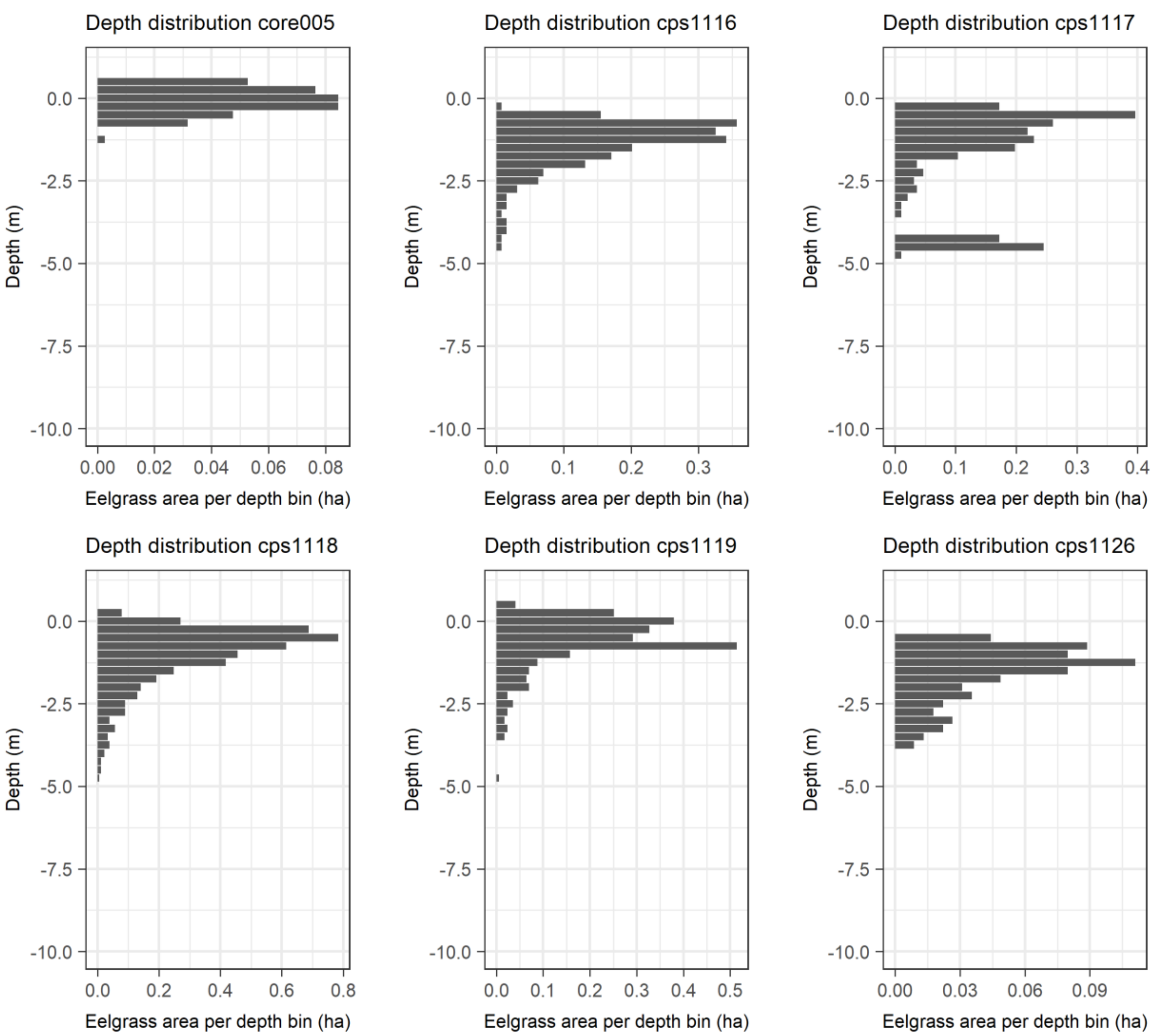
cps1118
cps1175
cps1119
cps1763

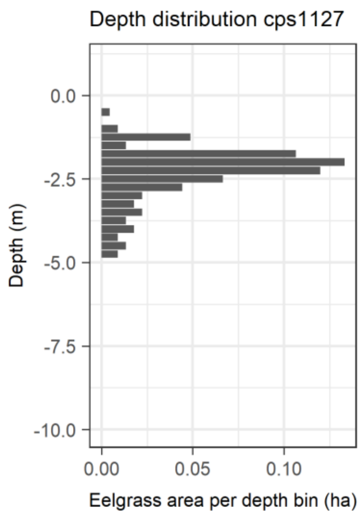

Legend
bare sand
Zj
Zm
Zm/Zj mix
cps1131
cps1130
cps1129
cps1128
cps1127
cps1126
cps1125
cps1124
cps1123
cps1122
cps1189
cps1190
cps1191
cps1116
cps1117
cps1118
cps1119

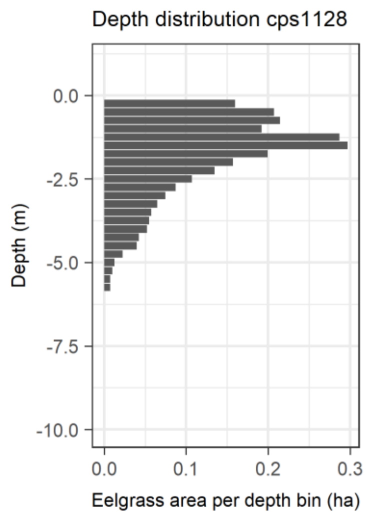

Legend
bare sand
Zj
Zm
Zm/Zj mix
cps1142
cps1141
cps1140
cps1139
cps1138
cps1137
cps1136
cps1135
cps1134
cps1133
cps1132

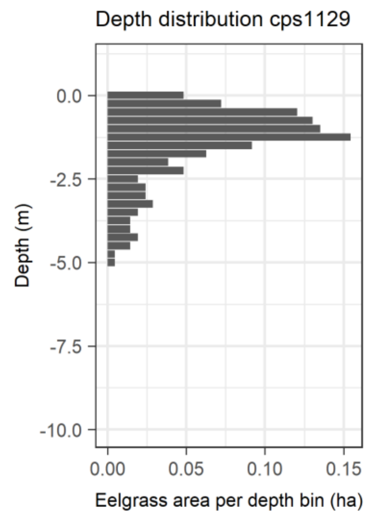
8 Appendix 3: Depth distribution

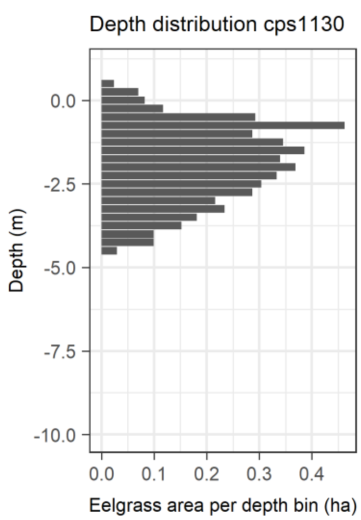
Depth distribution at individual sites (horizontal bars represent eelgrass area at 25cm depth bins). Note that we have limited the y-axis to -10 m (MLLW), given that there are only a few sites with a couple of plants deeper than -10 m in the entire study area.

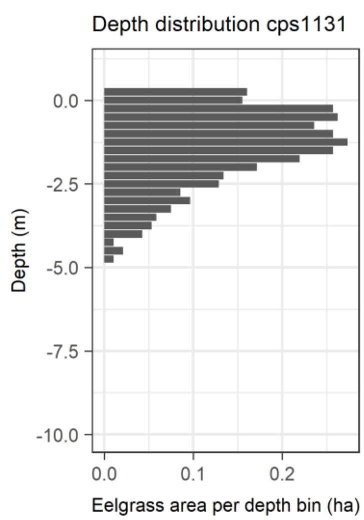


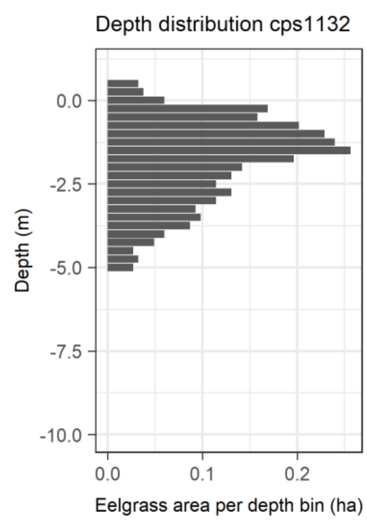

Depth distribution cps1127
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00
0.05
0.10
Eelgrass area per depth bin (ha)

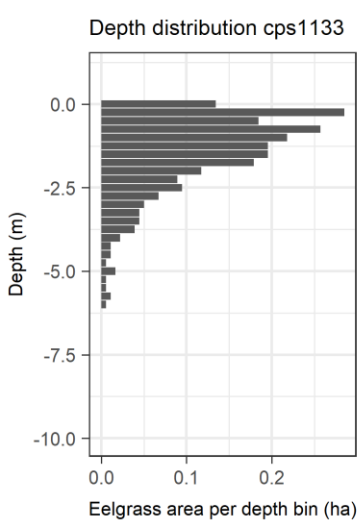

Depth distribution cps1128
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.1
0.2
0.3
Eelgrass area per depth bin (ha)

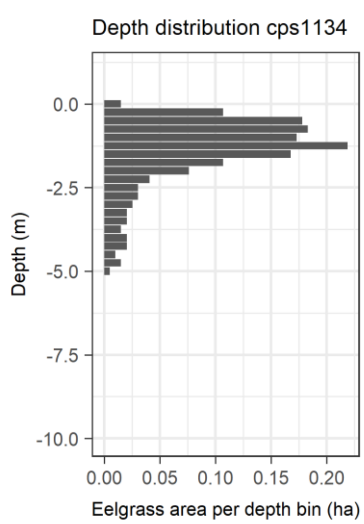

Depth distribution cps1129
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00
0.05
0.10
0.15
Eelgrass area per depth bin (ha)

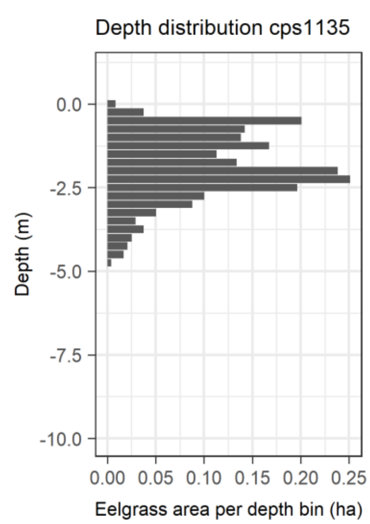

Depth distribution cps1130
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.1
0.2
0.3
0.4
Eelgrass area per depth bin (ha)

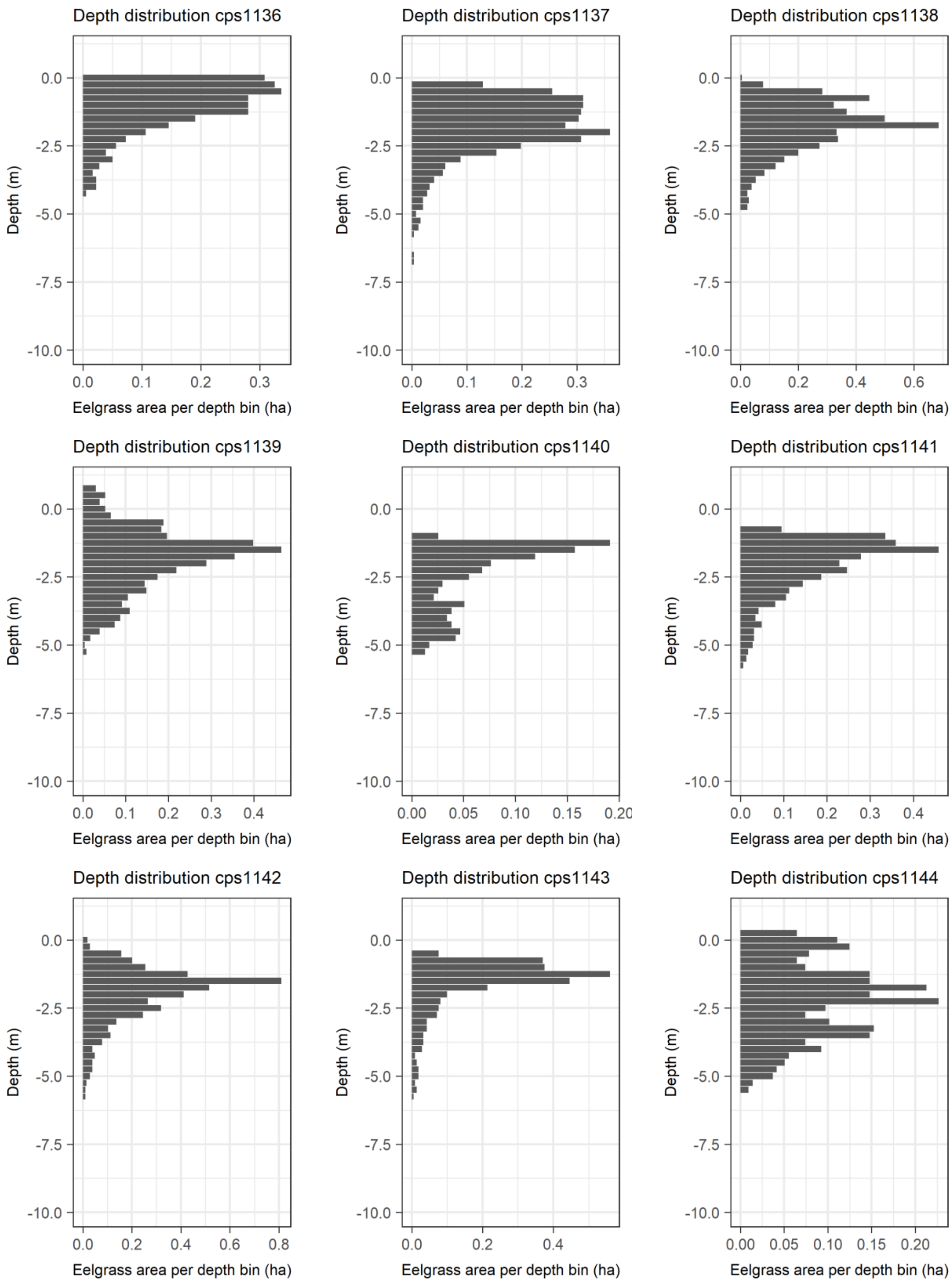

Depth distribution cps1131
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.1
0.2
Eelgrass area per depth bin (ha)

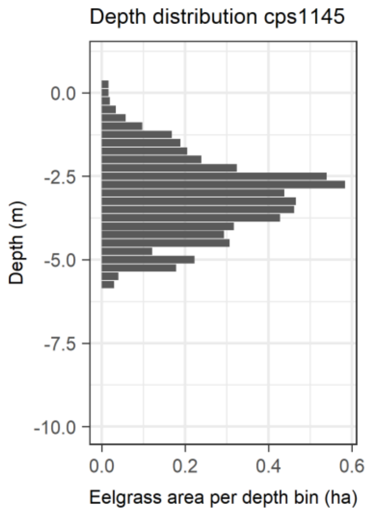

Depth distribution cps1132
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.1
0.2
Eelgrass area per depth bin (ha)

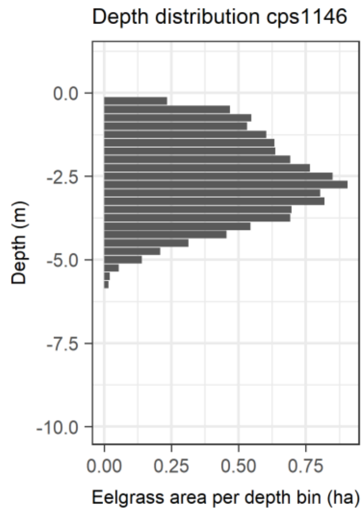

Depth distribution cps1133
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.1
0.2
Eelgrass area per depth bin (ha)

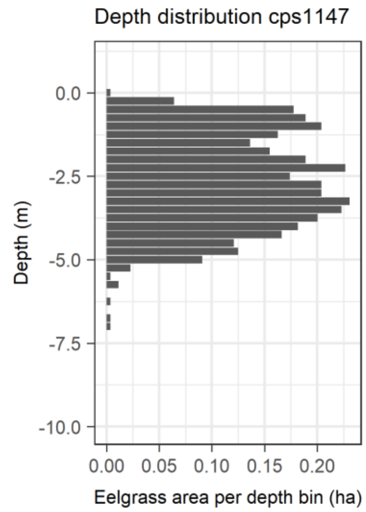

Depth distribution cps1134
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00
0.05
0.10
0.15
0.20
Eelgrass area per depth bin (ha)

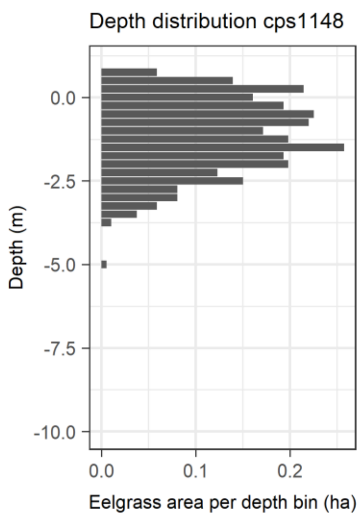

Depth distribution cps1135
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00
0.05
0.10
0.15
0.20
0.25
Eelgrass area per depth bin (ha)

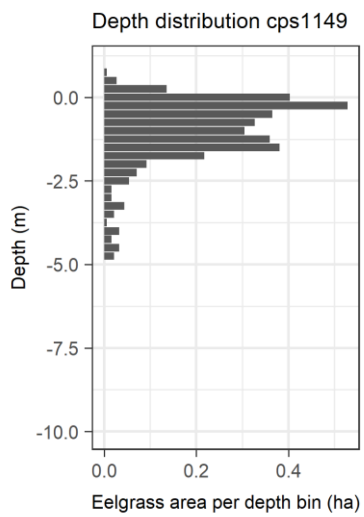

Depth distribution cps1136
Depth distribution cps1137
Depth distribution cps1138
Depth distribution cps1139
Depth distribution cps1140
Depth distribution cps1141
Depth distribution cps1142
Depth distribution cps1143
Depth distribution cps1144
Depth (m)
Eelgrass area per depth bin (ha)
0.0
-2.5
-5.0
-7.5
-10.0

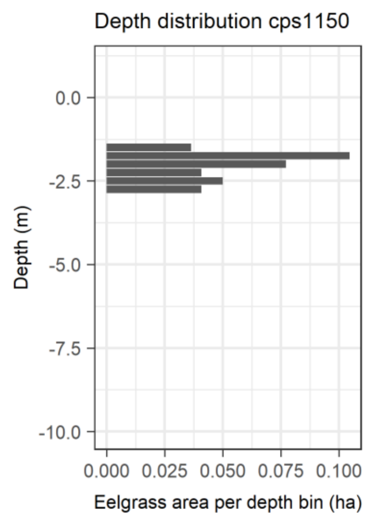

Depth distribution cps1145
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

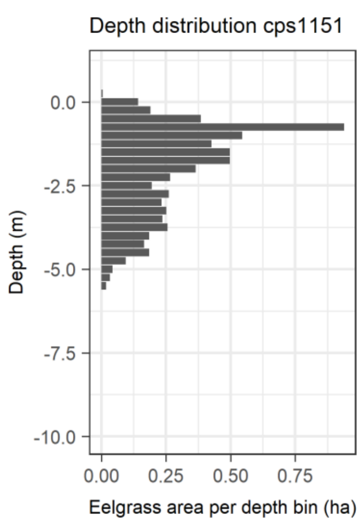

Depth distribution cps1146
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)

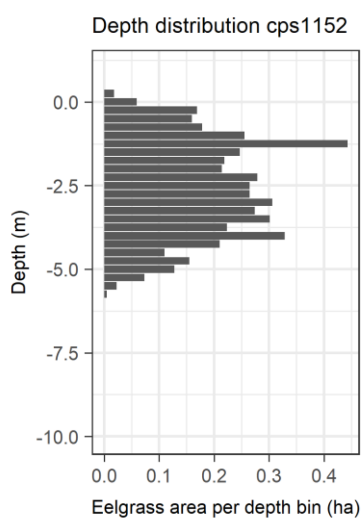

Depth distribution cps1147
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.05 0.10 0.15 0.20
Eelgrass area per depth bin (ha)

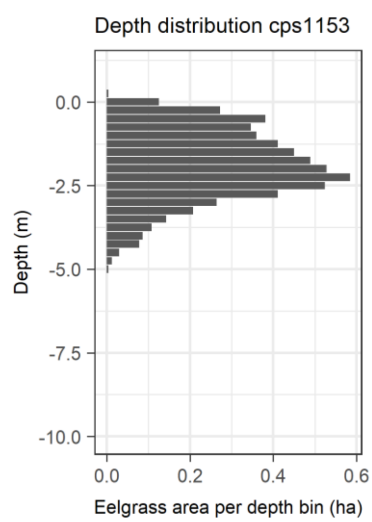

Depth distribution cps1148
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.1 0.2
Eelgrass area per depth bin (ha)

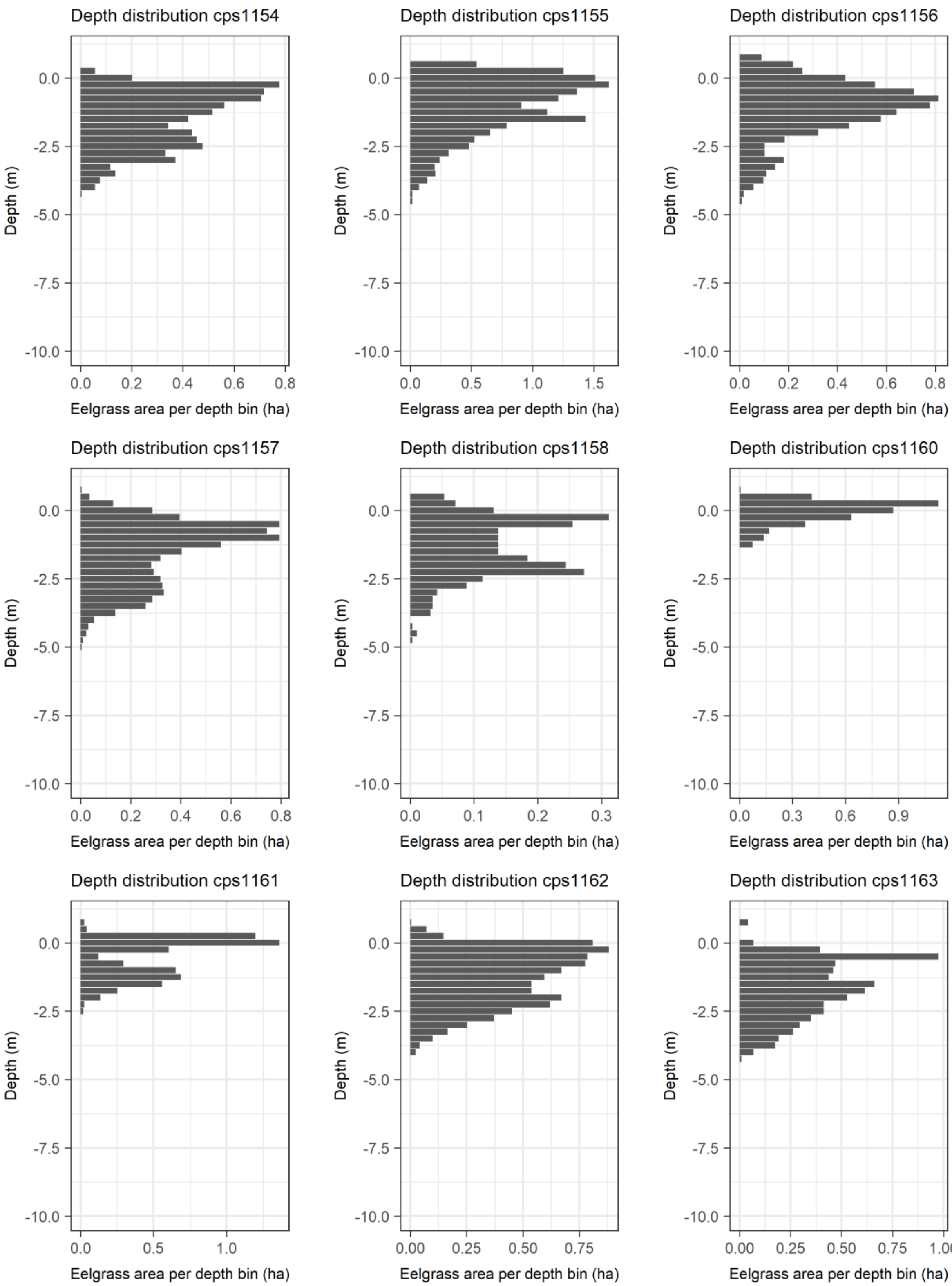

Depth distribution cps1149
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4
Eelgrass area per depth bin (ha)

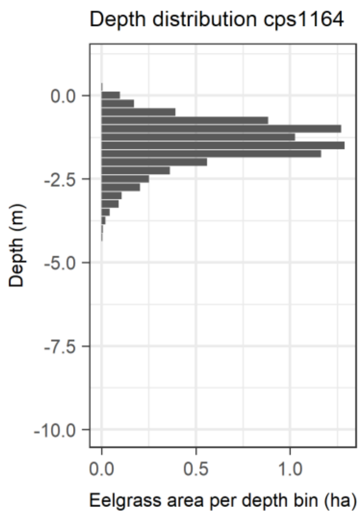

Depth distribution cps1150
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.000 0.025 0.050 0.075 0.100
Eelgrass area per depth bin (ha)

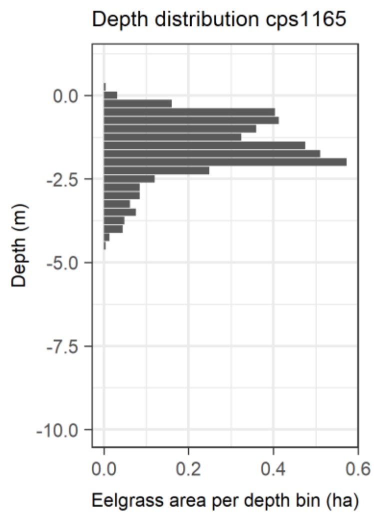

Depth distribution cps1151
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)

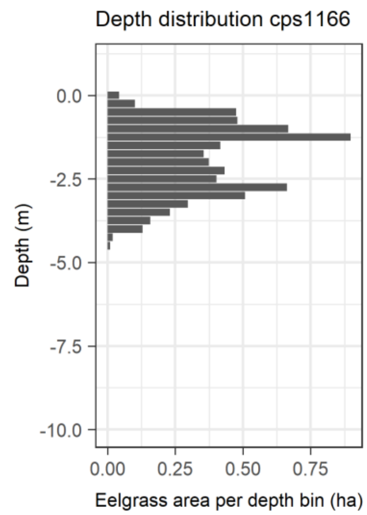

Depth distribution cps1152
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.1 0.2 0.3 0.4
Eelgrass area per depth bin (ha)

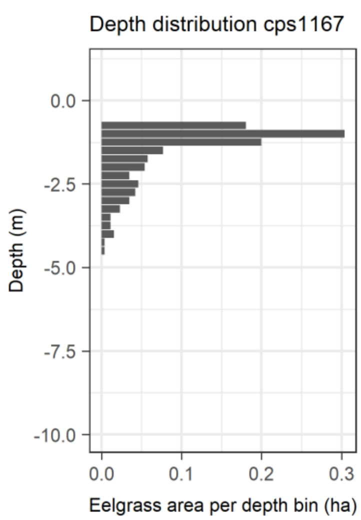

Depth distribution cps1153
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

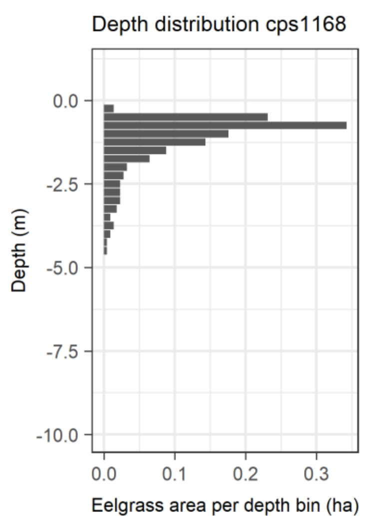

Depth distribution cps1154
Depth distribution cps1155
Depth distribution cps1156
Depth distribution cps1157
Depth distribution cps1158
Depth distribution cps1160
Depth distribution cps1161
Depth distribution cps1162
Depth distribution cps1163
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
Eelgrass area per depth bin (ha)
0.0 0.2 0.4 0.6 0.8
0.0 0.5 1.0 1.5
0.0 0.1 0.2 0.3
0.0 0.3 0.6 0.9
0.0 0.5 1.0
0.00 0.25 0.50 0.75
0.00 0.25 0.50 0.75 1.00

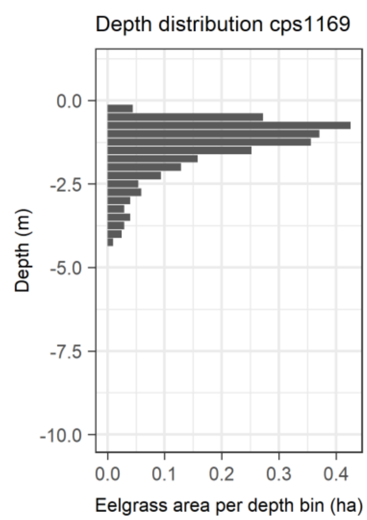

Depth distribution cps1164
Depth (m)
Eelgrass area per depth bin (ha)

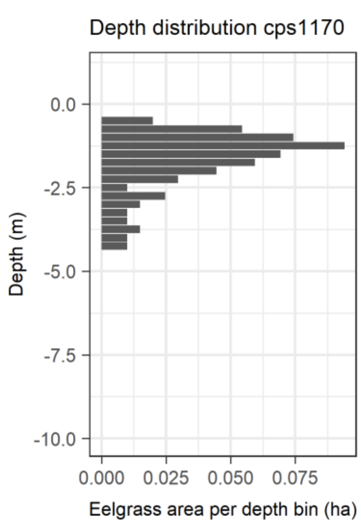

Depth distribution cps1165
Depth (m)
Eelgrass area per depth bin (ha)

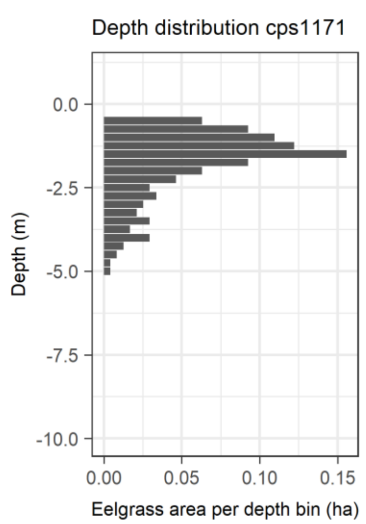

Depth distribution cps1166
Depth (m)
Eelgrass area per depth bin (ha)

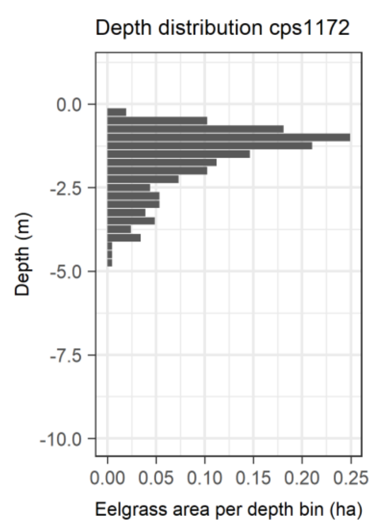

Depth distribution cps1167
Depth (m)
Eelgrass area per depth bin (ha)

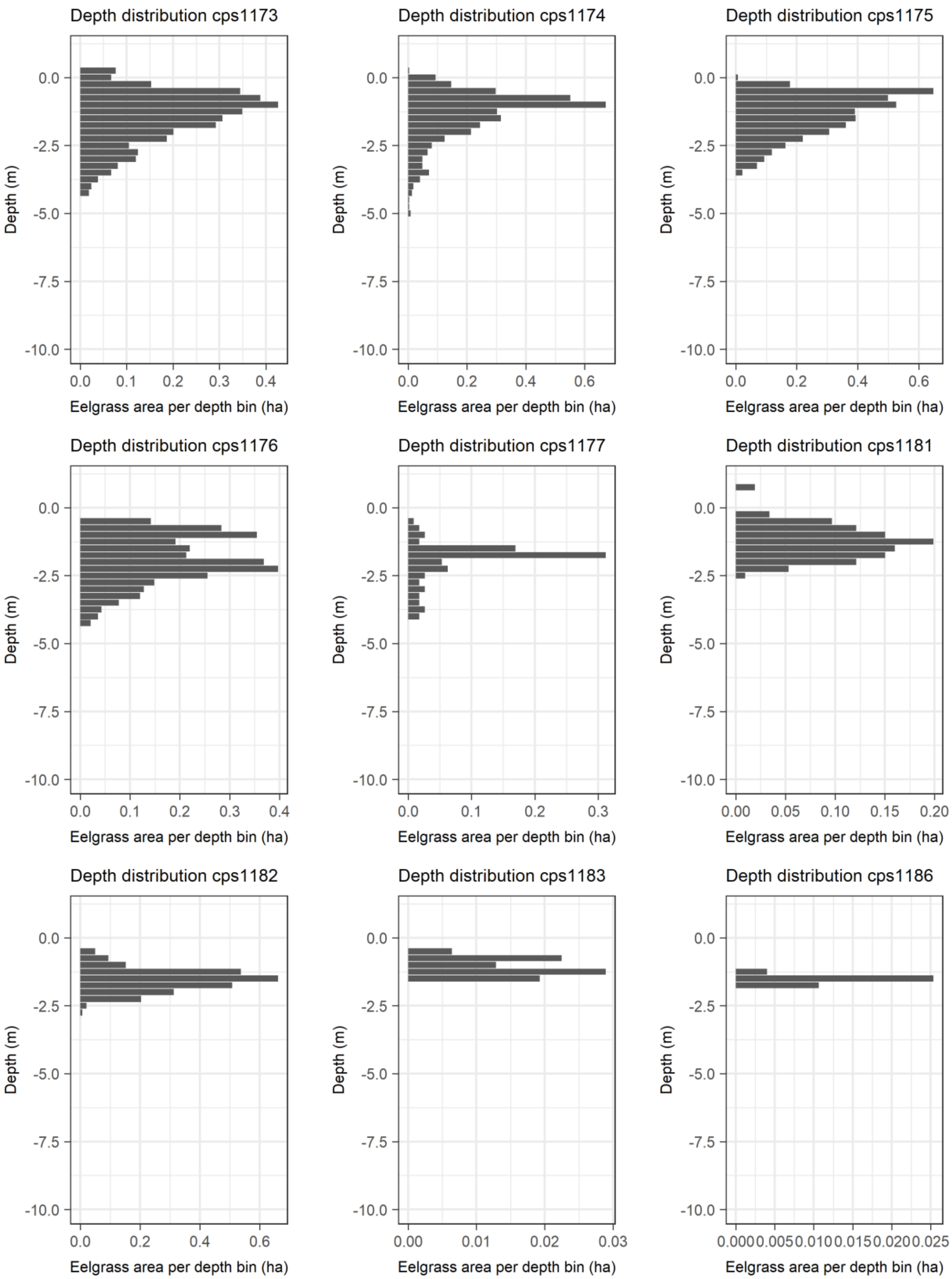

Depth distribution cps1168
Depth (m)
Eelgrass area per depth bin (ha)


Depth distribution cps1169
Depth (m)
Eelgrass area per depth bin (ha)

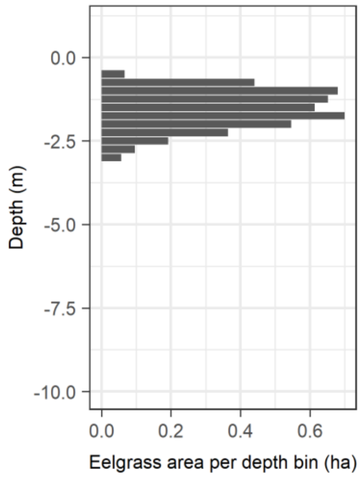

Depth distribution cps1170
Depth (m)
Eelgrass area per depth bin (ha)


Depth distribution cps1171
Depth (m)
Eelgrass area per depth bin (ha)

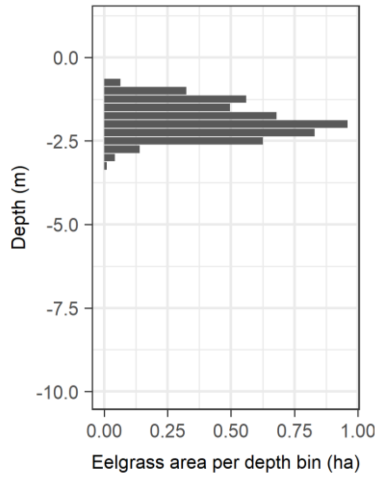

Depth distribution cps1172
Depth (m)
Eelgrass area per depth bin (ha)


Depth distribution cps1173
Depth distribution cps1174
Depth distribution cps1175
Depth distribution cps1176
Depth distribution cps1177
Depth distribution cps1181
Depth distribution cps1182
Depth distribution cps1183
Depth distribution cps1186
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
Eelgrass area per depth bin (ha)

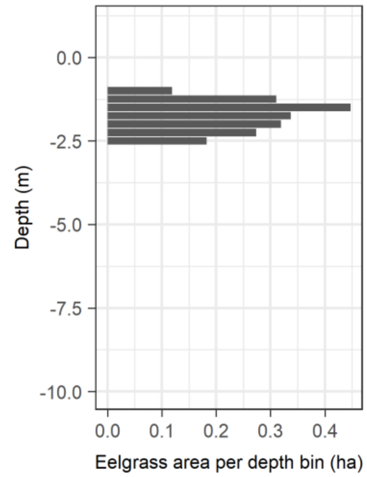
Depth distribution cps1187



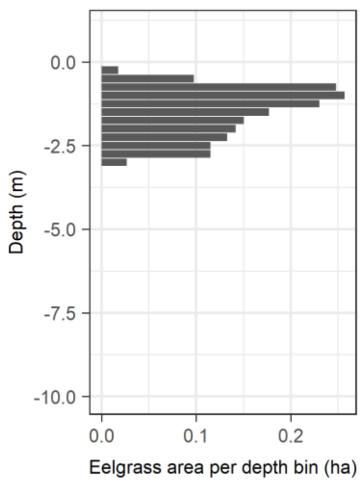
Depth distribution cps1188



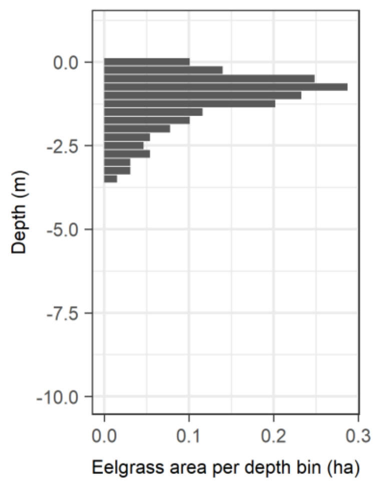
Depth distribution cps1189



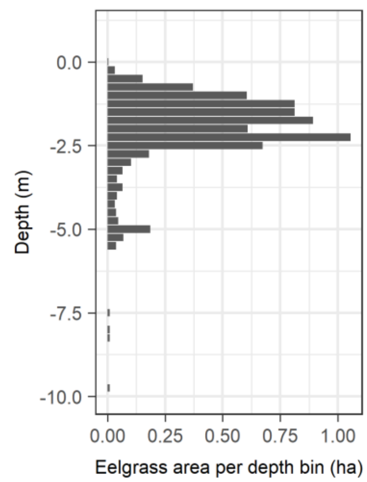
Depth distribution cps1190



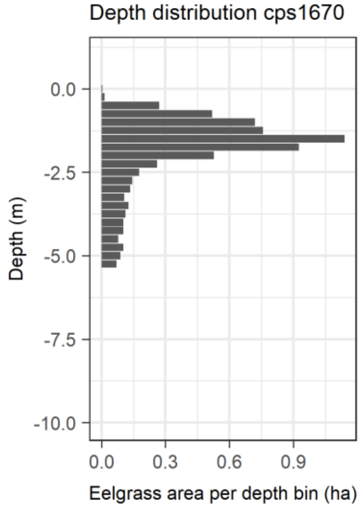
Depth distribution cps1191



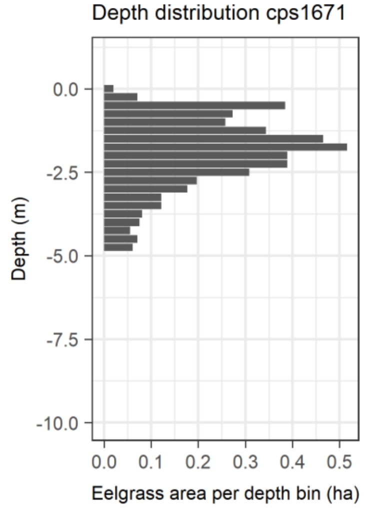
Depth distribution cps1669



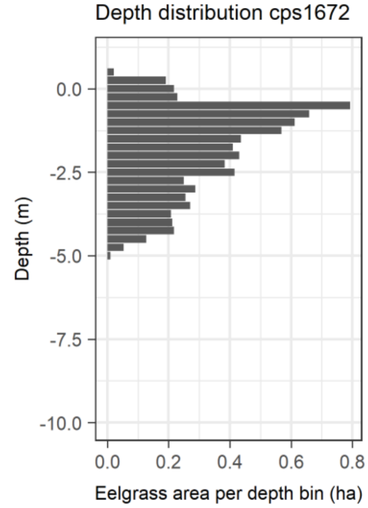
Depth distribution cps1670

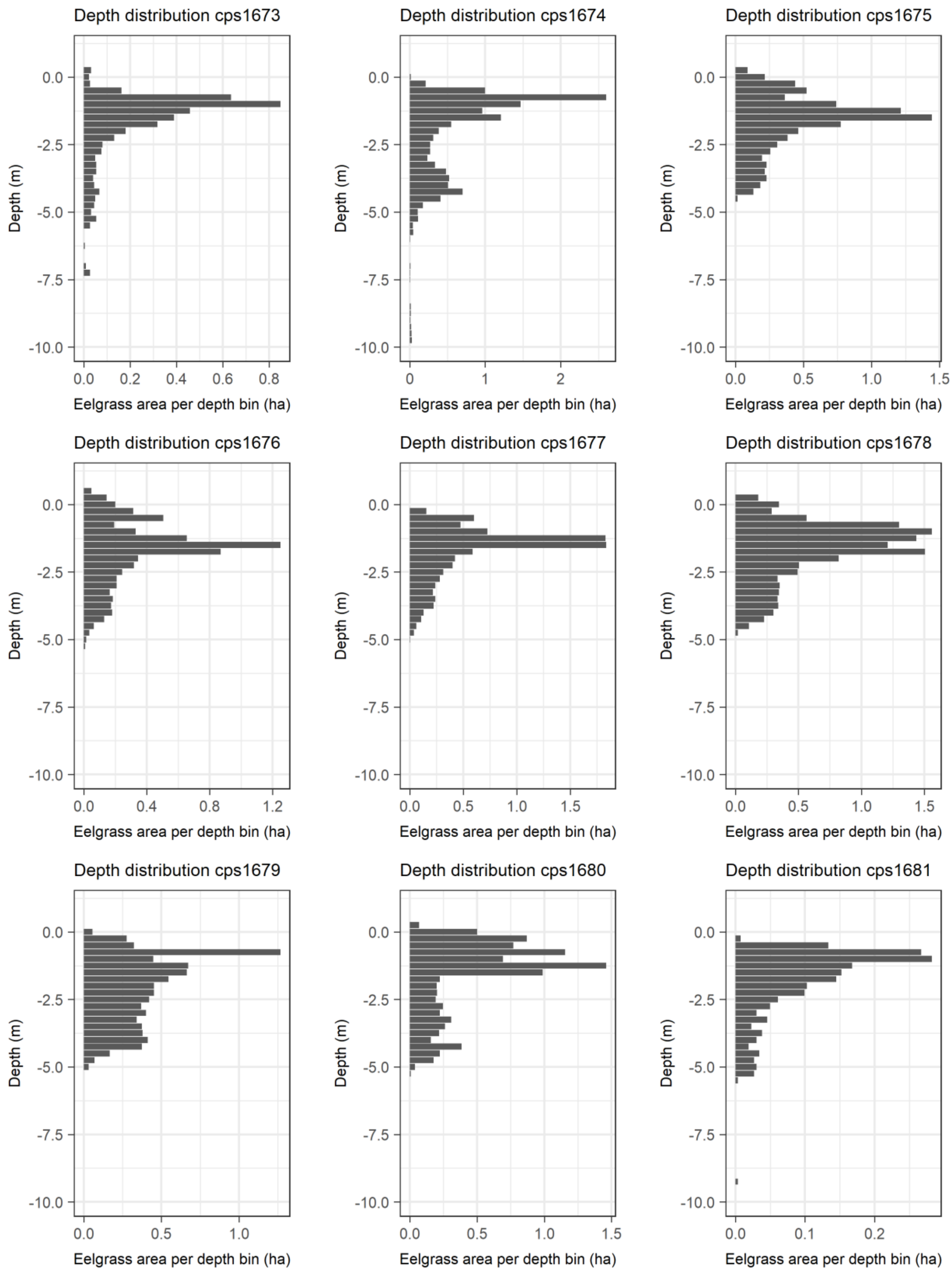


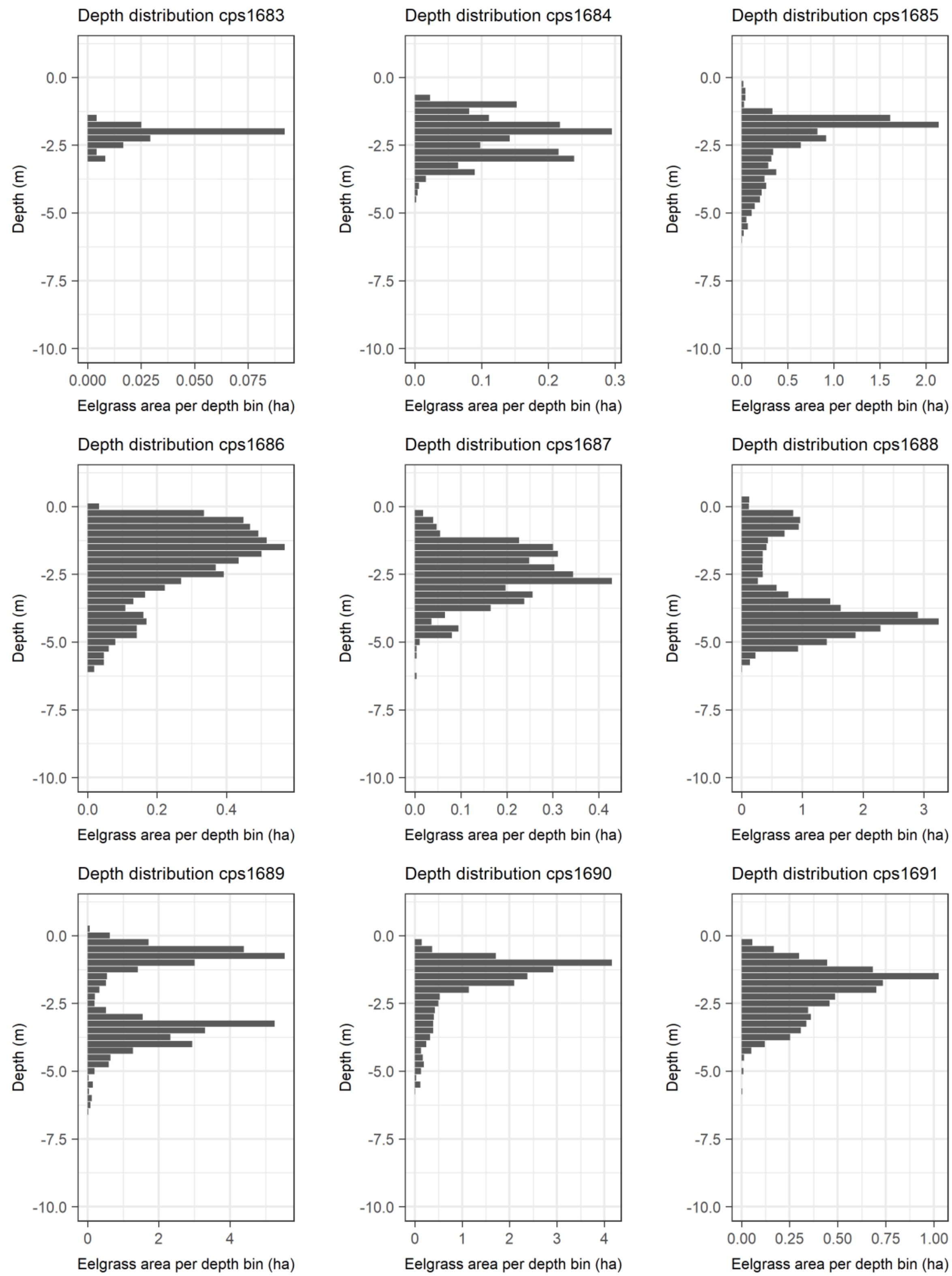
Depth distribution cps1671

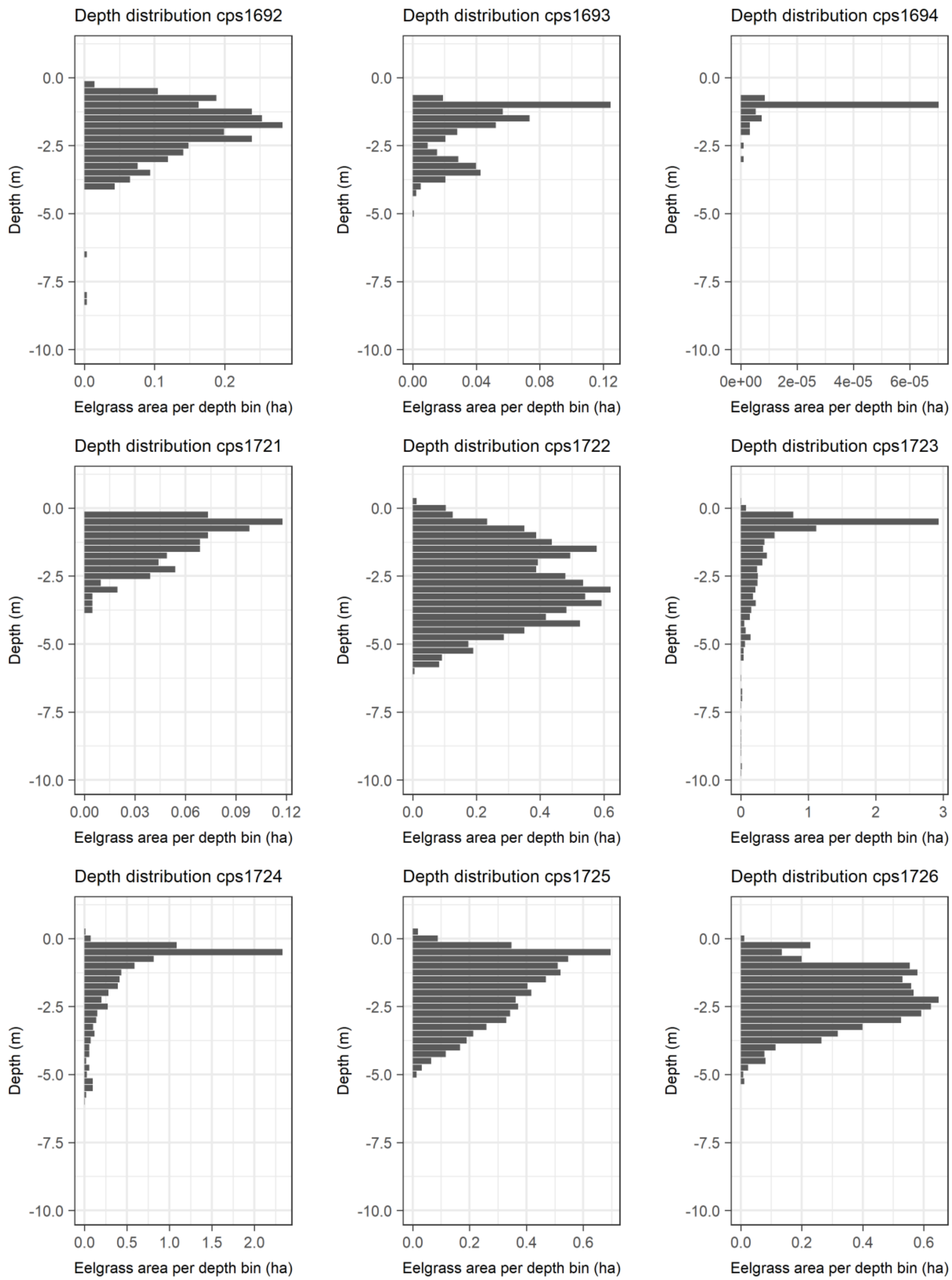


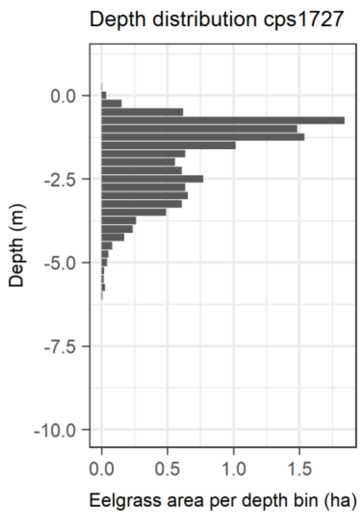
Depth distribution cps1672

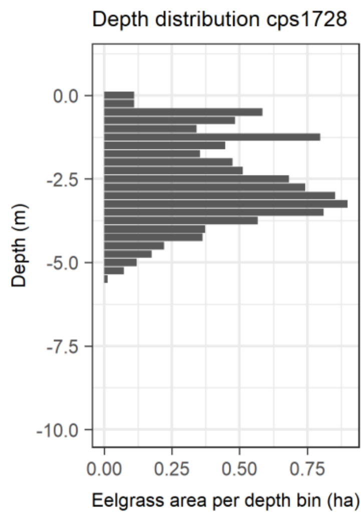


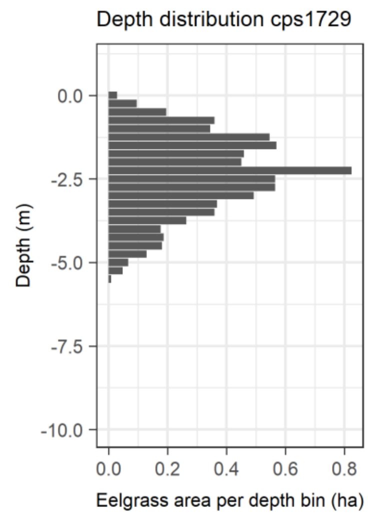

Depth distribution cps1673
Depth distribution cps1674
Depth distribution cps1675
Depth distribution cps1676
Depth distribution cps1677
Depth distribution cps1678
Depth distribution cps1679
Depth distribution cps1680
Depth distribution cps1681
Depth (m)
Eelgrass area per depth bin (ha)
0.0
-2.5
-5.0
-7.5
-10.0

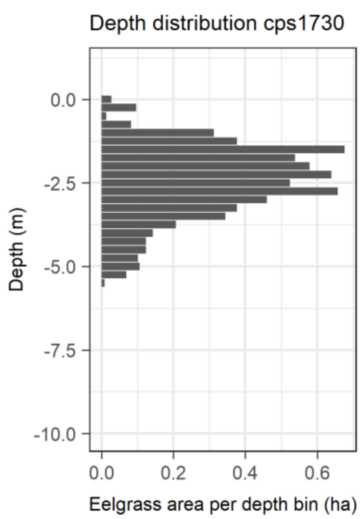

Depth distribution cps1683
Depth distribution cps1684
Depth distribution cps1685
Depth distribution cps1686
Depth distribution cps1687
Depth distribution cps1688
Depth distribution cps1689
Depth distribution cps1690
Depth distribution cps1691
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
Eelgrass area per depth bin (ha)
0.000 0.025 0.050 0.075
0.0 0.1 0.2 0.3
0.0 0.5 1.0 1.5 2.0
0.0 0.2 0.4
0.0 0.1 0.2 0.3 0.4
0 1 2 3
0 2 4
0 1 2 3 4
0.00 0.25 0.50 0.75 1.00

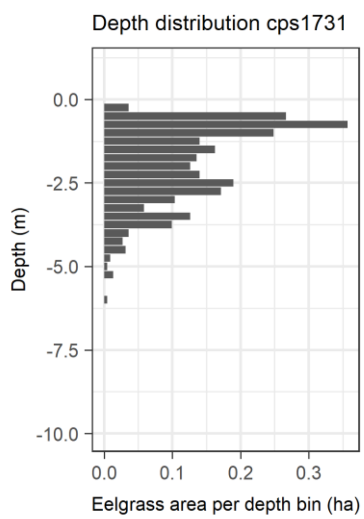

Depth distribution cps1692
Depth distribution cps1693
Depth distribution cps1694
Depth distribution cps1721
Depth distribution cps1722
Depth distribution cps1723
Depth distribution cps1724
Depth distribution cps1725
Depth distribution cps1726
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
Eelgrass area per depth bin (ha)
0.0 0.1 0.2
0.00 0.04 0.08 0.12
0e+00 2e-05 4e-05 6e-05
0.00 0.03 0.06 0.09 0.12
0.0 0.2 0.4 0.6
0 1 2 3
0.0 0.5 1.0 1.5 2.0
0.0 0.2 0.4 0.6
0.0 0.2 0.4 0.6

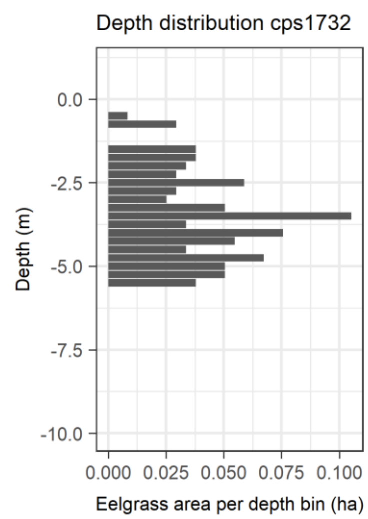

Depth distribution cps1727
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.5 1.0 1.5
Eelgrass area per depth bin (ha)

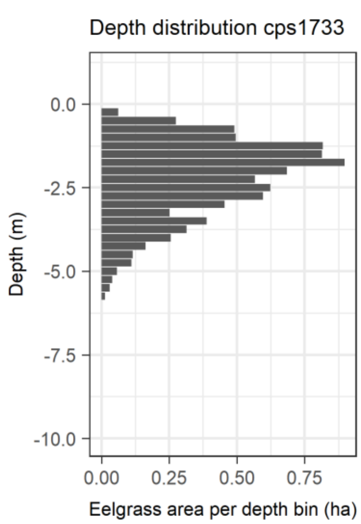

Depth distribution cps1728
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)

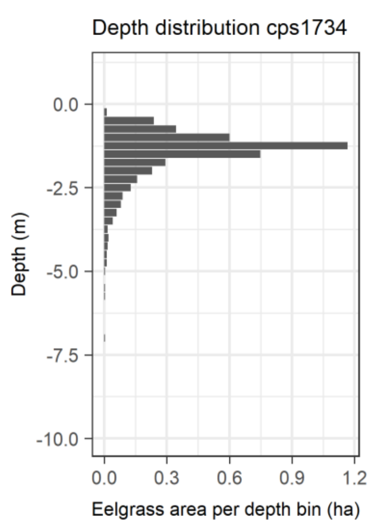

Depth distribution cps1729
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6 0.8
Eelgrass area per depth bin (ha)

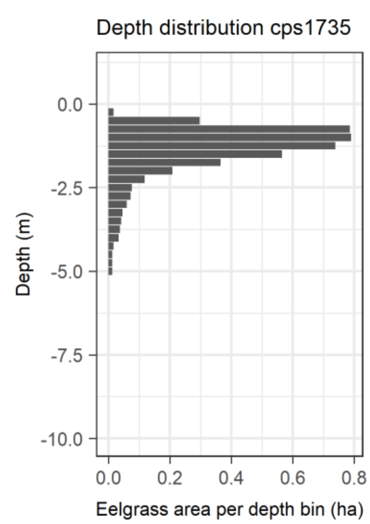

Depth distribution cps1730
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

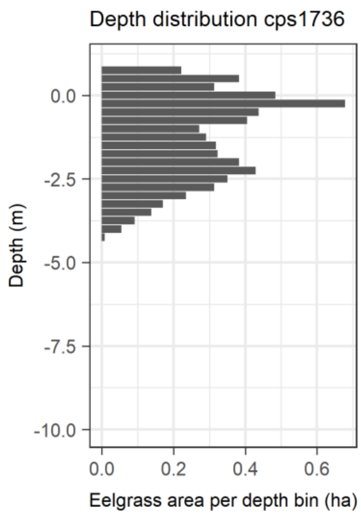

Depth distribution cps1731
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.1 0.2 0.3
Eelgrass area per depth bin (ha)

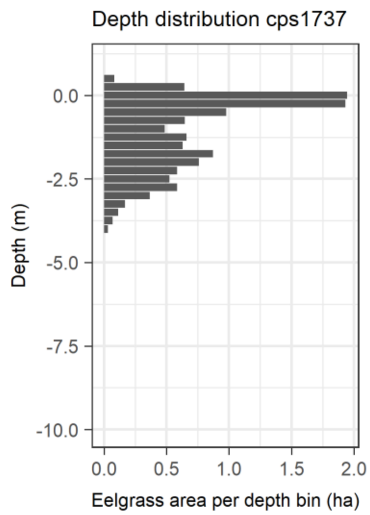

Depth distribution cps1732
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.000 0.025 0.050 0.075 0.100
Eelgrass area per depth bin (ha)

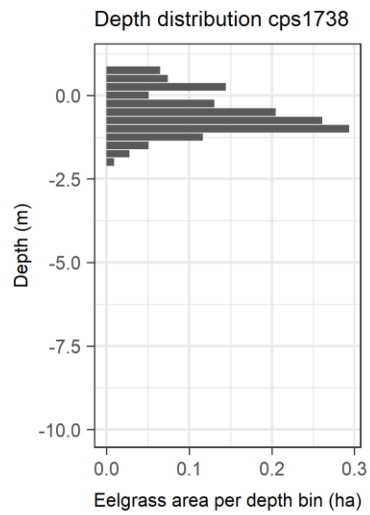

Depth distribution cps1733
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)

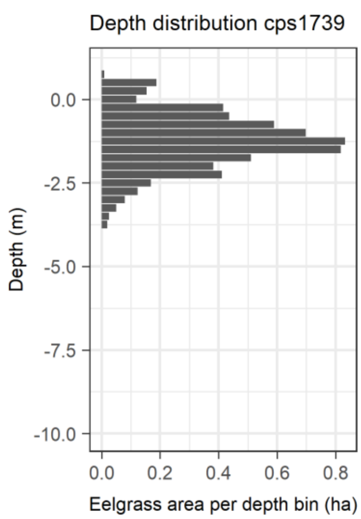

Depth distribution cps1734
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.3 0.6 0.9 1.2
Eelgrass area per depth bin (ha)

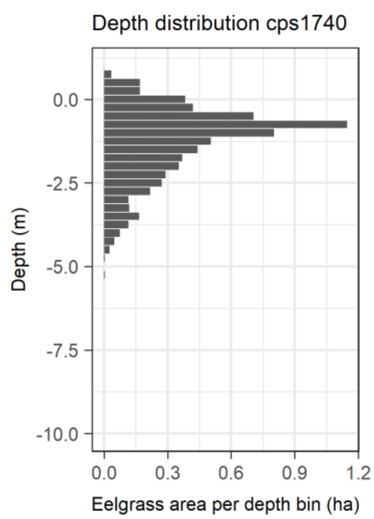

Depth distribution cps1735
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6 0.8
Eelgrass area per depth bin (ha)

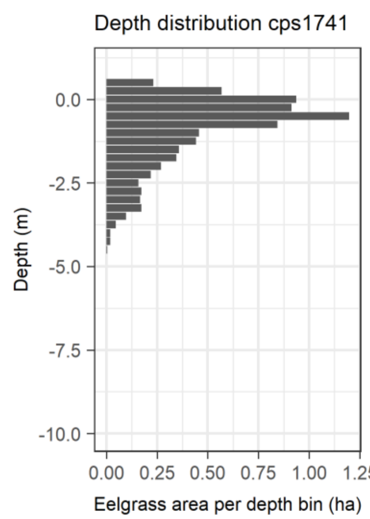

Depth distribution cps1736
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

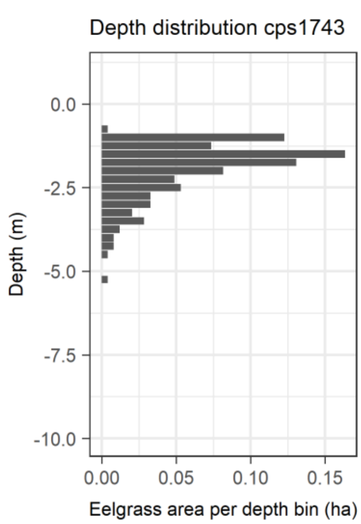

Depth distribution cps1737
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.5 1.0 1.5 2.0
Eelgrass area per depth bin (ha)

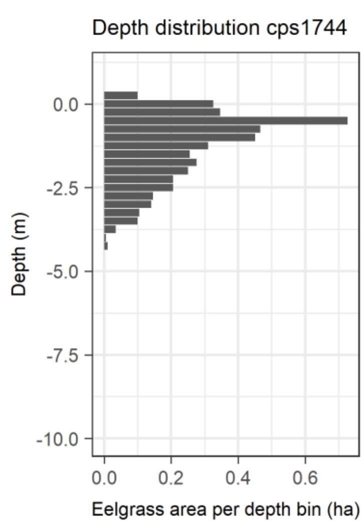

Depth distribution cps1738
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.1 0.2 0.3
Eelgrass area per depth bin (ha)

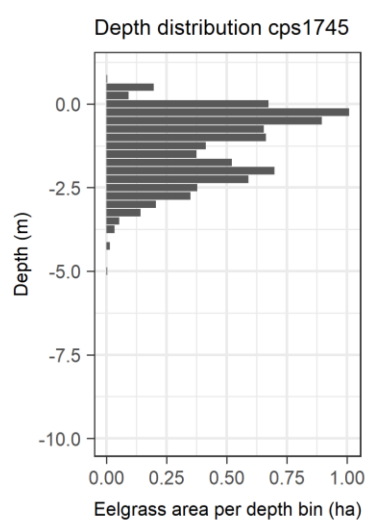

Depth distribution cps1739
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6 0.8
Eelgrass area per depth bin (ha)

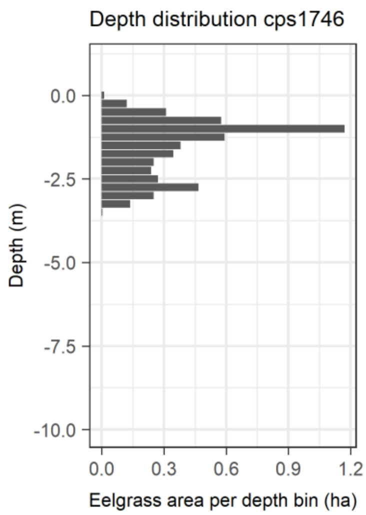

Depth distribution cps1740
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.3 0.6 0.9 1.2
Eelgrass area per depth bin (ha)

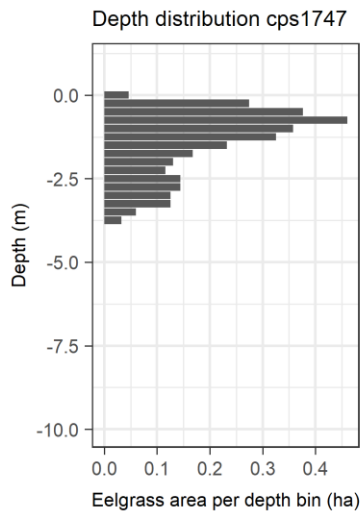

Depth distribution cps1741
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75 1.00 1.25
Eelgrass area per depth bin (ha)

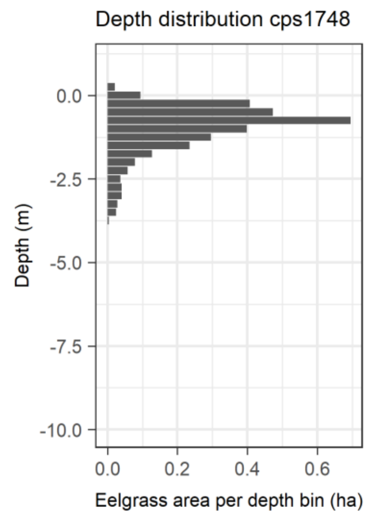

Depth distribution cps1743
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.05 0.10 0.15
Eelgrass area per depth bin (ha)

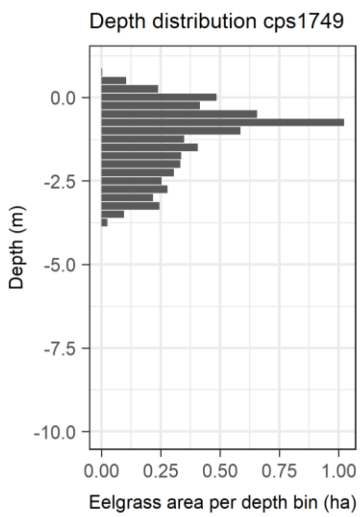

Depth distribution cps1744
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

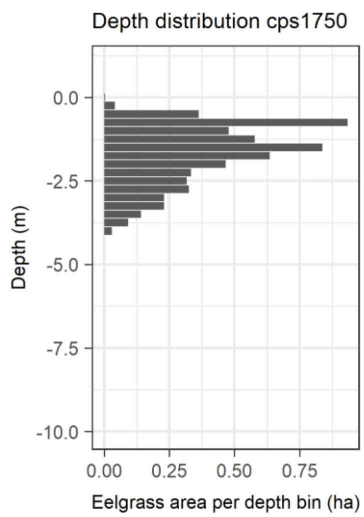

Depth distribution cps1745
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75 1.00
Eelgrass area per depth bin (ha)

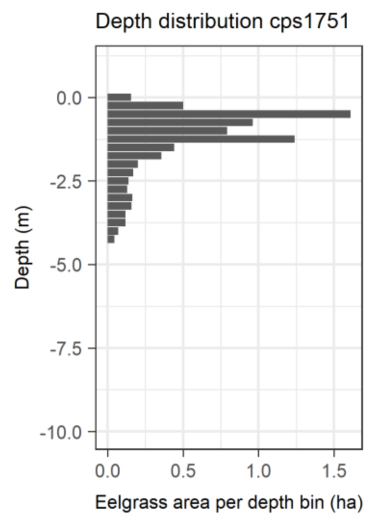

Depth distribution cps1746
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.3 0.6 0.9 1.2
Eelgrass area per depth bin (ha)

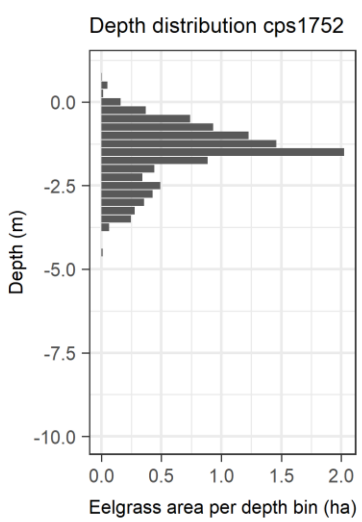

Depth distribution cps1747
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.1 0.2 0.3 0.4
Eelgrass area per depth bin (ha)

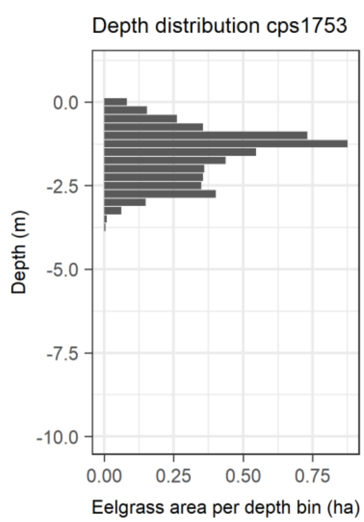

Depth distribution cps1748
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

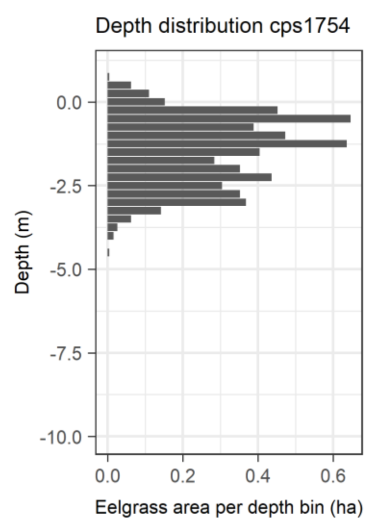

Depth distribution cps1749
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75 1.00
Eelgrass area per depth bin (ha)

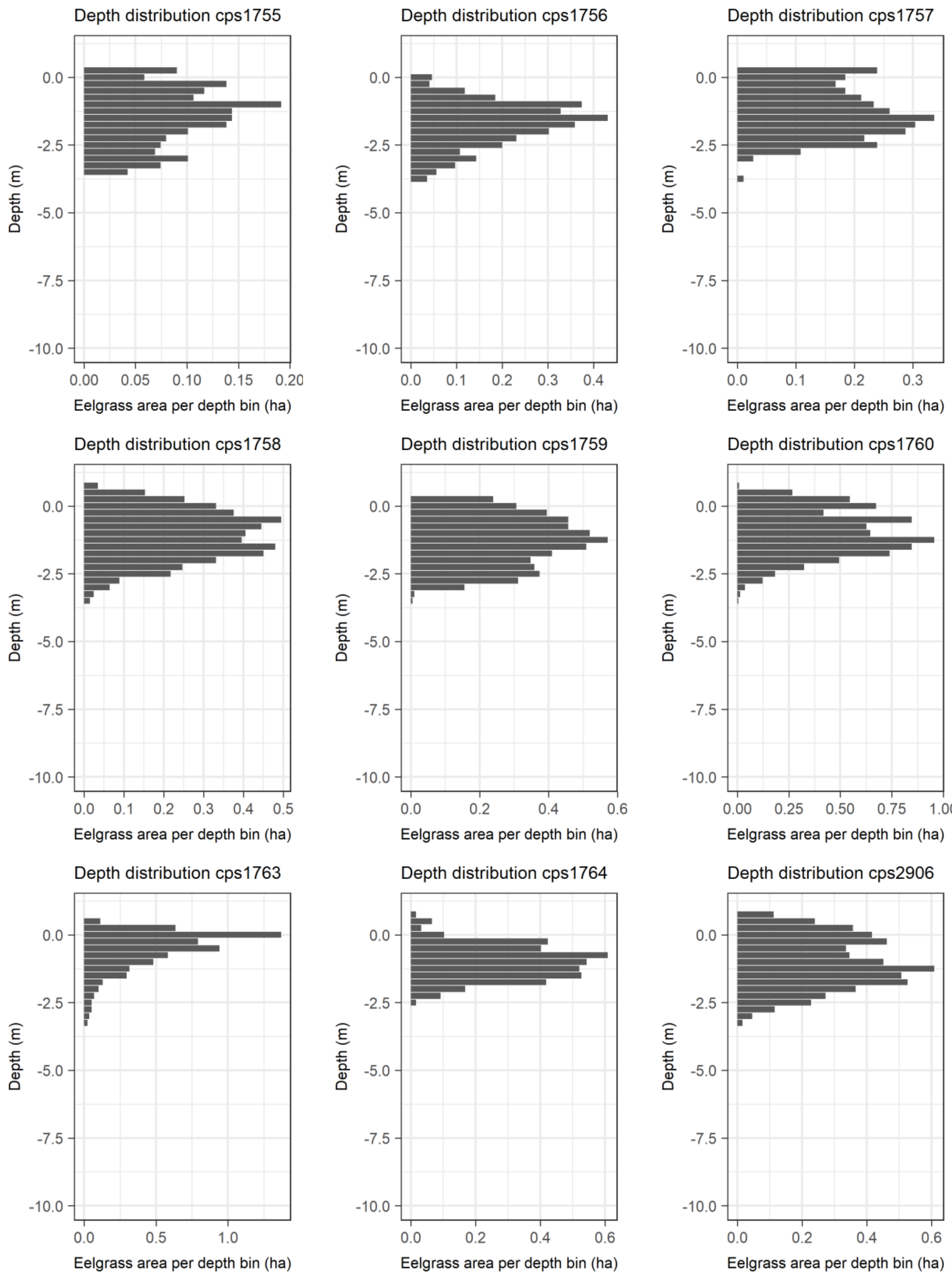

Depth distribution cps1750
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)

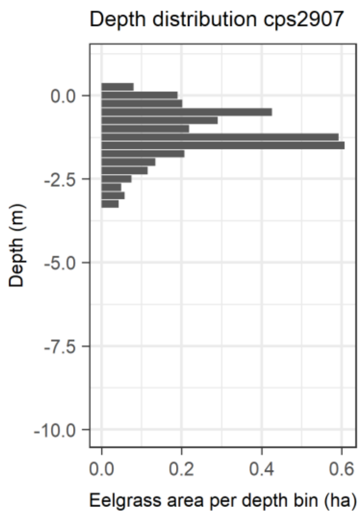

Depth distribution cps1751
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.5 1.0 1.5
Eelgrass area per depth bin (ha)


Depth distribution cps1752
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.5 1.0 1.5 2.0
Eelgrass area per depth bin (ha)


Depth distribution cps1753
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.00 0.25 0.50 0.75
Eelgrass area per depth bin (ha)


Depth distribution cps1754
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0 0.2 0.4 0.6
Eelgrass area per depth bin (ha)

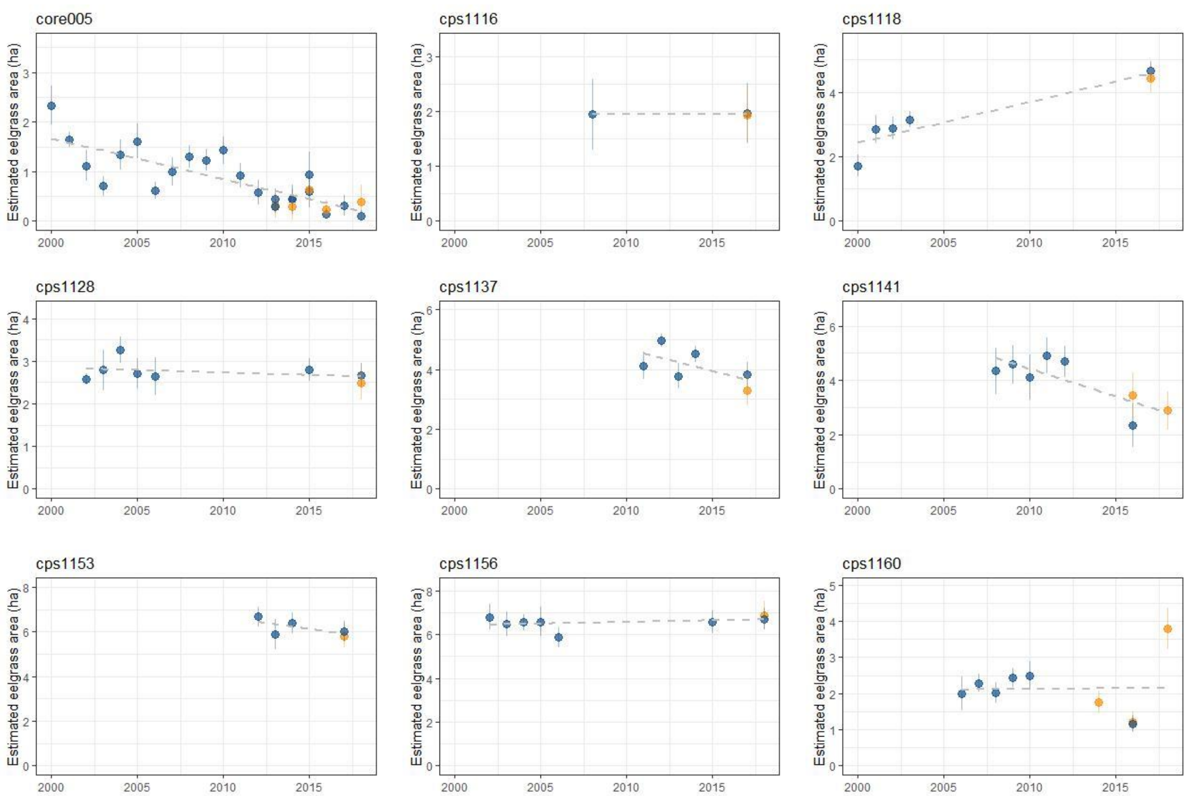

Depth distribution cps1755
Depth distribution cps1756
Depth distribution cps1757
Depth distribution cps1758
Depth distribution cps1759
Depth distribution cps1760
Depth distribution cps1763
Depth distribution cps1764
Depth distribution cps2906
Depth (m)
Eelgrass area per depth bin (ha)

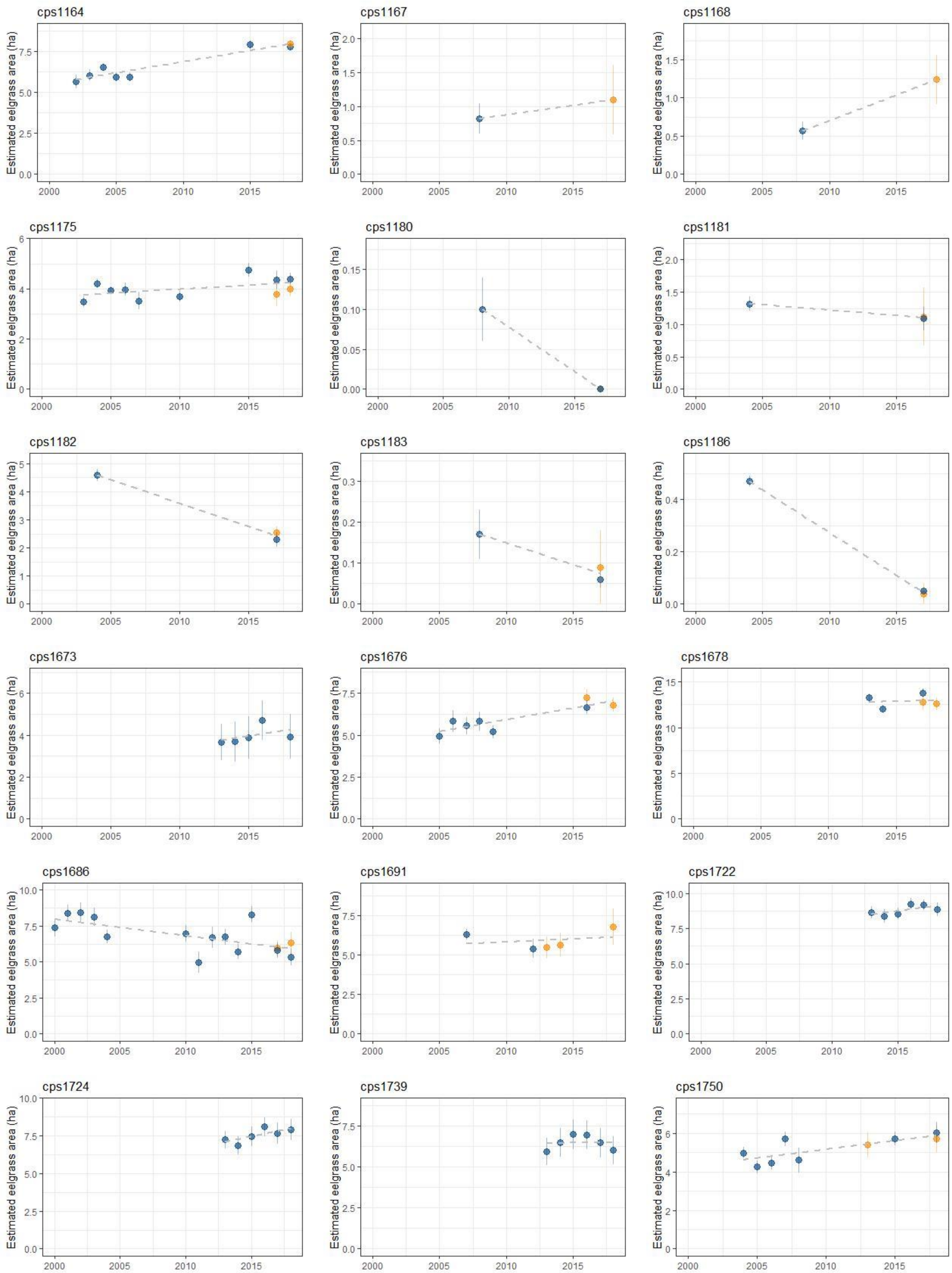


Depth distribution cps2907
Depth (m)
0.0
-2.5
-5.0
-7.5
-10.0
0.0
0.2
0.4
0.6
Eelgrass area per depth bin (ha)

9 Appendix 4: Time series data

Time series of all eelgrass area estimates at 31 sites in King County that were previously sampled by the SVMP (2000-2018). Blue symbols indicate that the area estimate is based on SRS transects, yellow symbols indicate that the area estimate is based on STR.





cps1164
cps1167
cps1168
cps1175
cps1180
cps1181
cps1182
cps1183
cps1186
cps1673
cps1676
cps1678
cps1686
cps1691
cps1722
cps1724
cps1739
cps1750
Estimated eelgrass area (ha)
2000
2005
2010
2015

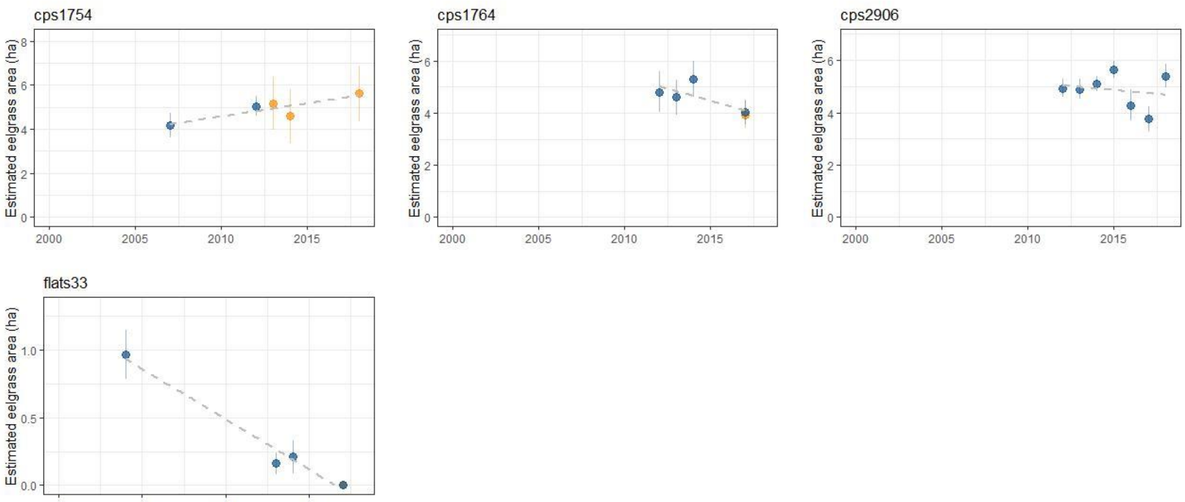

cps1754
cps1764
cps2906
flats33
Estimated eelgrass area (ha)
0
2
4
6
8
0.0
0.5
1.0
2000
2005
2010
2015

Table 5: Consensus analysis based on regressions of eelgrass area over time[9] (for sites that were sampled by DNR at more than 2 occasions), paired t-tests on repeat transects, and visual confirmation of changes in the spatial distribution of eelgrass over time using ArcGIS.

site_code	regression			paired t-test			consensus	notes
	df residual	R squared	p-value	statistic	df	p-value		
cps1118	4	0.871	0.007	4.080	14	0.001	gain	
cps1164	6	0.905	0.000	4.490	19	0.000	gain	
cps1676	6	0.789	0.003	5.240	13	0.000	gain	
core005	25	0.650	0.000	-4.280	10	0.002	loss	
cps1137	4	0.397	0.180	-3.760	16	0.002	loss	
cps1141	6	0.655	0.015	-3.330	15	0.005	loss	
cps1180	na	na	na	-2.350	11	0.038	loss	total loss
cps1182	na	na	na	-7.550	9	0.000	loss	
cps1186	na	na	na	-9.640	10	0.000	loss	
flats33	3	0.978	0.001	-1.930	7	0.095	loss	total loss
cps1167	na	na	na	na	na	na	na	sampled twice, no repeat transects
cps1168	na	na	na	na	na	na	na	sampled twice, no repeat transects
cps1116	na	na	na	-0.084	9	0.935	no change	
cps1128	6	0.119	0.403	-2.370	17	0.030	no change	
cps1153	3	0.457	0.210	-3.690	13	0.003	no change	potential misidentification
cps1156	6	0.116	0.410	0.235	13	0.818	no change	
cps1160	7	0.000	0.959	-4.530	18	0.000	no change	potential misidentification
cps1175	9	0.250	0.118	1.270	17	0.222	no change	
cps1181	na	na	na	-2.360	10	0.040	no change	
cps1183	na	na	na	-1.570	9	0.151	no change	
cps1673	3	0.202	0.448	0.851	9	0.417	no change	
cps1678	3	0.015	0.845	0.278	9	0.788	no change	
cps1686	13	0.438	0.007	-2.560	10	0.029	no change	no clear spatial pattern of change
cps1691	3	0.063	0.683	7.230	9	0.000	no change	no clear spatial pattern of change
cps1722	4	0.412	0.169	0.676	9	0.516	no change	
cps1724	4	0.574	0.081	1.810	9	0.104	no change	
cps1739	4	0.001	0.472	1.210	9	0.258	no change	
cps1750	7	0.609	0.013	1.800	10	0.102	no change	
cps1754	3	0.733	0.064	0.802	9	0.443	no change	
cps1764	3	0.563	0.144	-2.660	12	0.021	no change	potential misidentification
cps2906	5	0.040	0.669	1.860	9	0.095	no change	potential misidentification

[9] We used area estimates derived from both SRS and STR as input for the regression analysis