NATURAL RESOURCES

Long-term kayak monitoring of floating kelp in Puget Sound: Results through field year 2023

May 2024

WASHINGTON STATE DEPT OF NATURAL RESOURCES

The Nearshore Habitat Program is part of the Washington State Department of Natural Resources, Aquatic Resources Division. The Nearshore Habitat Program conducts research and monitoring in support of the agency's work to ensure environmental protection of Washington's state-owned aquatic lands. (https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-program).

The Nearshore Habitat Program is also a component of the Puget Sound Ecosystem Monitoring Program (PSEMP) (https://www.psp.wa.gov/PSEMP-overview.php).

Cover photo: Salmon Beach bull kelp bed. Photo Credit: Julia Ledbetter.

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Washington State Department of Natural Resources

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The Nearshore Habitat Program is part of the Aquatic Resources Division within the Washington State Department of Natural Resources (DNR), the steward for state-owned aquatic lands. The Nearshore Habitat Program monitors and evaluates the status and trends of marine vegetation and other indicators of habitat health for DNR and the Puget Sound Partnership.

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Contents

Executive Summary

The Washington Department of Natural Resources (DNR) is the state steward of 2.6 million acres of state-owned aquatic lands, which DNR manages for the benefit of current and future citizens. As part of DNR's stewardship actions, the Nearshore Habitat Program monitors kelp and other nearshore vegetation.

Floating kelp forests provide vital habitats for many species, as well as important ecosystem services. The status of floating kelp forests in Washington State differs by region; some areas are stable, some are declining, and many areas lack sufficient data for assessment. South Puget Sound (SPS) and Central Puget Sound (CPS) constitute regions of major concern due to substantial documented losses.

The DNR Nearshore Habitat Program conducts kayak-based monitoring of floating kelp as one component of a multi-pronged approach that also includes fixed wing aircraft and unmanned aerial survey (drone) technologies. Kayak-based monitoring successfully detects narrow, low density floating kelp forests that are often missed by remote sensing. Kayak platforms are also cost-effective and allow tracking of additional parameters, such as depth distribution.

This report presents kayak-based monitoring results from 2013 through 2023. At 13 core sites, ongoing annual surveys provided long-term data for SPS and CPS to the WA State Floating Kelp Vital Sign Indicator. At seven focus sites, surveys addressed targeted scientific and management topics.

Key Findings

<u>Severe declines and total losses continued to dominate long-term trends in floating kelp at sites in South and Central Puget Sound.</u>

- Four sites experienced total loss without recovery (Brisco Point, Devil's Head, Wing Point, Point Jefferson).
- Two sites showed major declines over the past decade:
    - Squaxin Island, the innermost floating kelp bed in Puget Sound, has persisted over decades amidst losses at many other sites. However, massive losses occurred in 2022, constituting a 97% decline in bed area since 2013. Partial recovery occurred in 2023 (78% decrease relative to 2013).
    - Fox Island, near the Tacoma Narrows, experienced dramatic declines in the last 10 years. In 2023, only two kelp plants remained.

- One site showed no trend in bed area over six years (Salmon Beach). Historical data suggests that floating kelp has persisted here for the last 150 years. Cool, nutrient-rich water and strong currents in the Tacoma Narrows likely contributed to kelp resilience.
- Overall, declines continued to dominate floating kelp trends in South and Central Puget Sound, with pockets of resilience. These results support retaining the current WA State Floating Kelp Indicator status assessment for these sub-basins.

In contrast to long-term trends, stability and/or increases were common over recent years.

- Among sites with at least five years of data, the 5-year recent trends showed 2 sites decreasing, 1 site with no trend, and 4 sites with no floating kelp.
- The 3-year recent trends showed 4 sites increasing, 1 site decreasing, 4 sites with no trend, and 4 sites with no floating kelp.
- In 2023, two sites increased substantially in size. Magnolia Bluff quadrupled, from 0.6 ha in 2022 to 2.3 ha in 2023. Squaxin Island expanded to 6 times its previous size, from 0.3 ha in 2022 to 1.9 ha in 2023, which constitutes a partial recovery from long-term losses.

The depth distribution of most floating kelp forests was shallow, with notable exceptions.

- Bed depth ranged from -0.2 m to -13.8 m (MLLW) in 2023. Deeper mean maximum depths occurred closer to oceanic influence (e.g., Freshwater Bay) and in areas of intense currents and mixing (e.g., Salmon Beach). The shallowest mean maximum depths were found at Squaxin Island (-2.4 m MLLW) and Beckett Point (-2.3 m MLLW).
- At the majority of sites (10 out of 16 sites), more than 85% of the bed footprint occurred shallower than -6 m (MLLW). Freshwater Bay had the deepest proportion, with 70% of the bed footprint deeper than -6 m (MLLW).
- Mean minimum depth was less variable across sites than mean maximum depth. In 2023, it ranged from -0.7 m to -3.1 m (MLLW).

Co-locating monitoring with research and restoration provided crucial insights into floating kelp forest stressors and supported management actions.

- Collaborative research with the University of Washington identified physiological impacts to multiple floating kelp life stages associated with elevated temperatures.
- DNR’s documentation of the floating kelp losses at Squaxin Island provided evidence of the need for restoration efforts. The Squaxin Island Tribe and Puget Sound Restoration Fund initiated actions in 2023, with support from DNR.
- DNR’s monitoring informs the Statewide Kelp Forest and Eelgrass Meadow Health and Conservation Plan by providing data to guide conservation and recovery actions.

1 Introduction

1.1 Kelp Science and Management Initiatives in Puget Sound

More than 20 species of kelp, large brown algae in the family Laminariales, can be found in Puget Sound (Mumford 2007). Most of these kelp species are understory kelps, which do not reach the surface of the water. However, two species, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*), reach the surface and create large floating kelp forests. Floating kelp grows on about 11% of WA's coastline (DNR 2001), and bull kelp is more prevalent than giant kelp. Floating kelp forests are highly productive habitats that serve as refuge and foraging grounds for many ecologically and economically important species including salmon, rockfish, forage fish, and killer whales (Harvey et al. 2012, Southern Resident Orca Taskforce 2019). Floating kelp forests also provide important ecosystem services such as primary production, wave attenuation, and nutrient cycling (Smale et al. 2013). Changes in environmental conditions such as increased water temperature, pH, nutrient availability, and water clarity can impact floating kelp growth and persistence (Schiel and Foster 2015, Krumhansl et al. 2016, Hollarsmith et al. 2020).

The projected impacts of climate change and urbanization threaten floating kelp persistence and there is growing research that these stressors are playing a role in floating kelp declines worldwide (Harley et al. 2012, Wernberg et al. 2016, Rogers-Bennett and Catton 2019, Smale 2020, Tait et al. 2021). While floating kelp beds often experience high natural variability, extensive, persistent losses in floating kelp have been documented in Puget Sound's inner basins (Berry et al. 2021) and concerns exist in other parts of the region (Calloway et al. 2020, Claar et al. 2024). In 2020, a diverse group of partners in Washington State including the Northwest Straits Initiative (NW Straits), the National Oceanic and Atmospheric Administration (NOAA), Washington State Department of Natural Resources (DNR), and others published the Puget Sound Kelp Conservation and Recovery Plan (hereafter called the Kelp Plan). The Kelp Plan was developed to provide a research and management framework for coordinated actions to advance knowledge of kelp forest changes and declines and work to strengthen conservation and restoration efforts (Calloway et al. 2020).

The release of the Kelp Plan catalyzed efforts in the kelp research community to address knowledge gaps about kelp stressors and to increase kelp monitoring in Puget Sound and the larger Salish Sea. The Washington State Kelp Research and Monitoring Workgroup was created in 2021 with the primary purpose to foster collaboration and share findings on kelp research in Washington State. The workgroup meets quarterly and consists of a diverse group of participants from federal, state, local and tribal governments, academia, and the public. In Spring 2023, the Kelp Forest Monitoring Alliance of Washington State (including representatives from DNR, NW

Straits, Samish Indian Nation, University of Washington, Washington SeaGrant, and Marine Agronomics) released a statewide Floating Kelp Indicator for the Puget Sound Partnership's Vital Sign Dashboard (PSP 2024). The project team synthesized a suite of existing datasets from state agency monitoring, community science, and indigenous scientific knowledge to develop the Floating Kelp Bed Area Indicator (hereafter WA State Floating Kelp Indicator) and associated interactive web map (WA State Floating Kelp Bed Interactive Map). The Indicator assesses long-term status and trends of floating kelp at a sub-basin and location level (Berry et al. 2023).

In 2022, the state legislature passed Senate Bill 5619 directing DNR to develop a statewide framework for identification of priority kelp and eelgrass habitat. The legislation tasks the agency to conserve or recover at least 10,000 acres of kelp forests and eelgrass meadow habitat by 2040. DNR submitted the Statewide Kelp Forest and Eelgrass Meadow Health and Conservation Plan to the legislature in December 2023, outlining a two-step collaborative process for identifying priority habitat and developing actions to mitigate stressors and promote recovery of marine vegetation. DNR staff are currently working to implement the Plan, beginning with collaboration with tribal nations and other partners to apply the prioritization framework throughout Puget Sound and the coast.

1.2 DNR's Floating Kelp Monitoring Efforts

The Nearshore Habitat Program (NHP) at DNR monitors floating kelp in Puget Sound and along the Pacific coast with a set of nested monitoring efforts that utilize multiple survey methods (DNR 2024a). In South and Central Puget Sound, the program primarily relies on kayak-based surveys. To date, parameters include bed perimeter and minimum and maximum bed depth. In some years, density, cover, plant morphometrics and condition have been collected by kayak as well. Starting in 2020, the program began collecting UAS (drone) surveys of selected floating kelp beds (Berry and Cowdrey 2021, Cowdrey and Claar 2024) which added another layer to the monitoring program. DNR has also collected aerial kelp surveys on the Pacific Coast and Strait of Juan de Fuca using fixed wing airplanes since 1989 (Van Wagenen 2015, DNR 2024b). In 2022 and 2023, additional 4-band fixed-wing aerial imagery surveys were conducted in some regions of Puget Sound. With this network of monitoring sites and methods, DNR hopes to gain a better understanding of floating kelp abundance and persistence across Puget Sound and at individual sites. This report will highlight the floating kelp data collected by kayak from 2013 through field season 2023.

Program Objectives

The primary geographic focus of kayak monitoring is South Puget Sound (SPS) and Central Puget Sound (CPS), two areas of great concern for floating kelp loss. Kayak-based monitoring successfully detects narrow, low-density floating kelp forests that are often missed by remote sensing and are common in SPS and CPS. Kayak monitoring is also used for high resolution and multi-modal research at other locations in the Salish Sea. The program's central objectives are to:

- Track floating kelp trends in SPS and CPS through conducting annual surveys of bed extent and depth at 13 core monitoring sites. Results from these areas are synthesized with other data streams into the WA State Floating Kelp Indicator.
- Survey floating kelp beds in focus studies that address targeted research and management topics (as resources allow).
- Measure additional parameters related to floating kelp health and environmental conditions in order to enrich understanding of kelp drivers and response (as resources allow).

2 Methods

2.1 Study System

The Salish Sea is an inland fjord system that is comprised of the Strait of Juan de Fuca to the west, the Strait of Georgia to the north, and Puget Sound to the south. Due to its large size and diverse conditions, Puget Sound and the Strait of Juan de Fuca's Washington coastline are often divided into distinct sub-basins (Figure 1; Berry et al. 2023). The majority of the work detailed in this report took place in the inner sub-basins, Central Puget Sound (CPS) and South Puget Sound (SPS). Additional surveys took place in other sub-basins including Admiralty Inlet (ADM), the Eastern Strait of Juan de Fuca (EST), the San Juan Islands (SJI), and North Puget Sound (NPS).

The kayak monitoring program divides sites into "core sites", which are ongoing annual monitoring locations that are included in the WA State Floating Kelp Indicator, and "focus sites", which address project-specific questions and vary in monitoring time span. Core monitoring sites are located at current and historical floating kelp bed locations throughout SPS and CPS (orange dots on Figure 1). Before 2020, five sites were surveyed in SPS and the study area expanded in 2020 to include eight more sites (one in SPS and seven in CPS), bringing the number of core monitoring sites to 13 (six in SPS and seven in CPS, Figure 1). Focus sites are located in CPS, the Strait of Juan de Fuca, the San Juans Islands, and North Puget Sound (purple dots on Figure 1). Of the seven focus study sites, monitoring began at five sites starting in 2023 (see Table 1 for years surveyed for all sites).

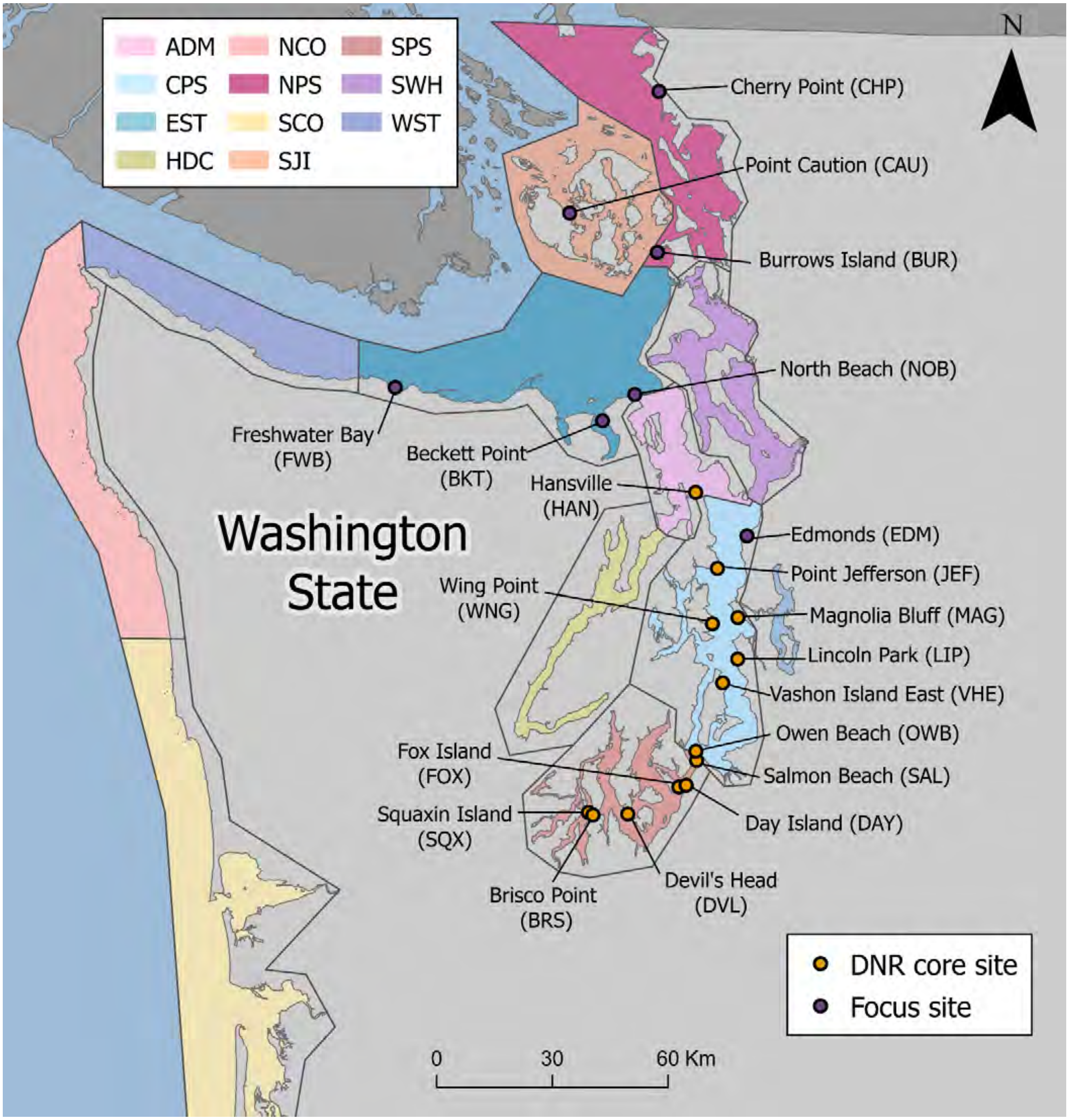

Figure 1. Map of the 20 floating kelp monitoring sites. Orange points represent DNR Nearshore Habitat Program's core floating kelp kayak monitoring sites (n = 13) and the purple points represent sites where kayak data were collected for focus floating kelp studies (n = 7). Each sub-basin is outlined in gray and has a unique color; Admiralty Inlet (ADM), Central Puget Sound (CPS), Eastern Strait (EST), Hood Canal (HDC), North Coast (NCO), North Puget Sound (NPS), South Coast (SCO), San Juan Islands (SJI), South Puget Sound (SPS), Saratoga-Whidbey Basins (SWH), and Western Strait (WST).

2.2 Field Work Overview

Prior to field work, we defined boundaries for each site in ArcMap or ArcGIS Pro (ESRI, Redlands, CA, USA). Sites were defined to encompass a historical or current floating kelp forest. Site size was determined based on an area that could be effectively surveyed within a single low tide and slack current period (Figure 2). Within each site, 13 regularly spaced across shore transects were created and oriented along the depth gradient for additional sampling. At sites with limited canopy extent, additional transects were defined for sub-sampling within the canopy.

Surveys were completed at each site within a two-hour window that bracketed a low tide of less than 0.0 MLLW to minimize the effect of water level and currents on bull kelp detection (Britton-Simmons et al. 2008). Based on site characteristics and on-the-ground observations of currents and floating kelp bed visibility, survey windows were adjusted on a site-by-site basis (see Table A1 for site-specific survey windows). To maximize floating kelp visibility on the surface and standardize field conditions, surveys were planned when wind speed was less than 10 kts (depending on the wind direction) and wind waves were one foot or less. To capture the maximum floating kelp bed extent, we sampled sites between mid-July and mid-September, when floating kelp abundance is known to be at its peak (with a single exception during extreme climatic conditions). A total of 20 sites were surveyed for floating kelp bed area and kelp bed depth for this report. The number of years surveyed and the types of data collected varied by site (Table 1).

Some data collected during this field work is not included in this report and will be incorporated into future analyses:

- Floating kelp density estimations (collected in 2018-2023)
- Plant morphometrics (collected in 2018, 2020)
- Water quality parameters using a SonTek CastAway-CTD and secchi disc (collected in 2020-2023)

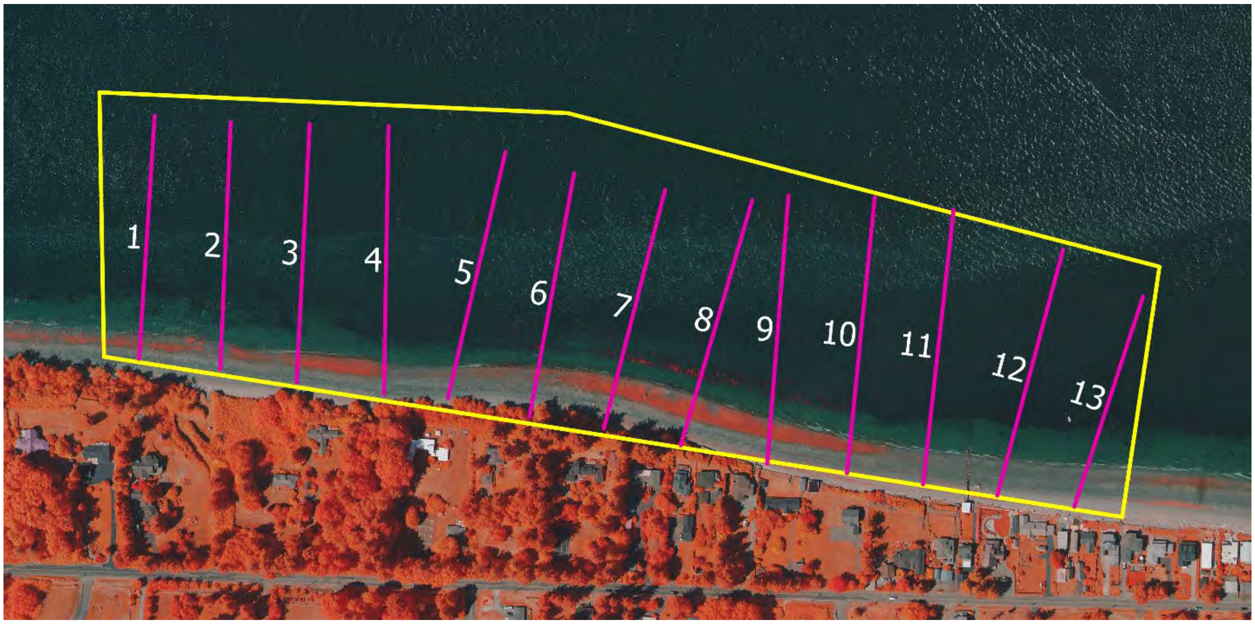

Figure 2. Example monitoring site map with site boundary (in yellow) and across shore transects (in pink).

Table 1. Floating kelp monitoring sites with site type, years surveyed, and data collected. Sites are divided into "core" sites that will continue to be monitored every year, and "focus" sites that are monitored opportunistically to support additional studies.

Site	Type	Years Surveyed	Data collected
Squaxin Island	Core	2013-2023 (except 2015)	Bed area and min/max depth
Brisco Point	Core	2013, 2017-2023	Bed area/Absence survey
Devil's Head	Core	2013, 2017-2023	Bed area/Absence survey
Fox Island	Core	2013, 2017-2023	Bed area
Day Island	Core	2020-2023	Bed area and min/max depth
Salmon Beach	Core	2018-2023	Bed area and min/max depth
Owen Beach	Core	2020-2023	Bed area and min/max depth
Vashon Island East	Core	2020-2023	Bed area and min/max depth
Lincoln Park	Core	2020-2023	Bed area and min/max depth
Magnolia Bluff	Core	2020-2023	Bed area and min/max depth
Wing Point	Core	2020-2023	Absence survey
Point Jefferson	Core	2020-2023	Absence survey
Hansville	Core	2021-2023	Bed area and min/max depth

Site	Type	Years Surveyed	Data collected
Edmonds	Focus	2020-2021, 2023	Min/max depth only prior to 2023, bed area added in 2023
North Beach	Focus	2018, 2020-2023	Min/max depth only prior to 2023, bed area added in 2023
Beckett Point	Focus	2023	Bed area and min/max depth
Freshwater Bay	Focus	2023	Bed area and min/max depth
Burrows Island	Focus	2023	Bed area and min/max depth
Point Caution	Focus	2023	Bed area and min/max depth
Cherry Point	Focus	2023	Bed area and min/max depth

2.3 Floating Kelp Bed Area

Floating kelp bed perimeters were collected from sit-on-top kayaks (3.4 m or 3.1 m length) or paddleboards (3.2 m length). A handheld Garmin GPSMap 62s or 78sc unit recorded the position of the boats during the survey. The spatial accuracy during the surveys was ± 2.1 – 2.7 m (reported by instruments based on satellite coverage at the time) (Berry et al. 2019). All floating kelp within the site boundary was mapped. To delineate the floating kelp bed, we utilized a 'connect-the-dot' method, kayaking around the perimeter of the bed staying within one meter of the outermost bulb of the bed (along the deep edge, the shallow edge, and the across-shore edge). To accurately capture the deep edge of the bed, we kayaked the deep side near low tide and slack current. Both floating and submerged plants were included in the perimeter.

Any floating kelp bulbs less than 25 m from the main bed were considered part of the bed and included in the perimeter. Any plants greater than 25 m from the bed were recorded as individual points separate from the bed. Based on past experimentation with a variety of distance thresholds, a fairly large distance threshold was adopted because in areas with low floating kelp density, surveys that used smaller distance thresholds and defined multiple beds were less consistent (Berry 2017). The 25-m threshold represents a distance that is easily observed from a slow-moving kayak or paddleboard.

We mapped the perimeter at least three times during one survey window and added additional replicates as time allowed. Annual estimates were based on replicates from the same day in summer, between mid-July and mid-September (with a single exception to accommodate extreme climatic conditions). After observing early seasonal die back of floating kelp at Squaxin Island in mid-July in 2016 (Berry 2017), we prioritized areas with warmer water temperatures to be surveyed earlier in the summer. At sites with very sparse floating kelp bulbs, GPS points were taken at all individual bulb locations, rather than collecting a bed perimeter. At sites where floating kelp is no longer present, a kayak or small boat slowly navigated the 13 transects spanning the site extent (see Figure 2) to systematically confirm absence.

Annual bed area estimates for each site were calculated by taking the mean of all perimeter replicates collected on the same day. For the core monitoring sites, site-level trend classifications (*increasing, no trend, decreasing, no floating kelp, total loss*) were assigned (Berry et al. 2023) for three different time periods (3 years, 5 years, entire data record). For sites with five or more years of data, the entire data record classification provides a comprehensive snapshot of all program data across all sites. It is important to note that the total number of survey years varies by site and sites with four or fewer years of surveys are classified as limited data. Trend classifications were informed by visual data inspection, expert knowledge, and simple linear regressions of annual bed area by year for each site individually for each time period. When assigning trends, we deprecated the regression results when the data violated regression assumptions (e.g., change was not linear), and relied more on expert knowledge and interpretation. Due to limited data, the 3-year regression results were subject to additional scrutiny in the context of expert knowledge.

At sites where no floating kelp was observed in any year of the assessment period, the site was assigned the classification of *no floating kelp*. If all plants disappeared over the assessment period (i.e. floating kelp was present during the assessment period, but not the most recent year), the trend was *total loss*. If bed area was greater than zero in the most recent year, the trend was informed by the p-value and slope of the linear regression, in addition to visual data inspection, and expert knowledge. We did not use a strict p-value threshold to inform trends; regression results were assessed in the context of the multi-year data pattern at each site. The statistical result was overruled in cases where linear regression would not be expected to detect change (i.e., non-linear patterns and limited temporal record). A positive change in bed area over time was classified as *increasing* while a negative change in bed area over time was classified as *decreasing*. No change in bed area (relative to past years) was classified as *no trend*. Sites with less than five years of data were classified as limited data for the 5-year recent trend and the entire data record trend.

2.4 Floating Kelp Depth Distribution

Minimum and maximum bed depth were measured at 13 regularly placed across-shore transects (Figure 2; Appendix F) at the shallowest and deepest plant along the transect, by lowering a weighted tape measure to the benthos (in shallow areas) and using a Vexilar LPS-1 hand-held digital sonar (in deep areas). The shallowest and deepest plant within 5 m of each transect were recorded as the minimum and maximum depths. Minimum and maximum bed depths were collected at each site between mid-July and mid-September. The entire length of each transect was searched for floating kelp within the 10 m wide swath, even if a transect didn't appear to have any floating kelp. In 2022, there was not enough floating kelp present at Squaxin Island to take minimum and maximum bed depth measurements along the defined transects so depth measurements were taken at each individual bulb or cluster of bulbs. Once in the office, we corrected measured depths using the measured depth, time of collection, and data from NOAA's verified tide levels (https://tidesandcurrents.noaa.gov/).

Differences between years in mean minimum and mean maximum depth were tested with a Welch's ANOVA, which does not require equality of variance or equal sample size (R Core Team 2023). If significant differences existed, we used a Games-Howell post hoc test to describe pairwise differences in minimum and maximum depth extent between years ($p < 0.05$) (Kassambara 2023).

Like the bed area trend classifications described in Section 2.3, trend classifications for maximum and minimum depth were assigned across three time periods (3 years, 5 years, entire data record) for core sites and two focus sites. Trend classifications were informed by visual data inspection, expert knowledge, and a linear regression of mean depth by year (similar to bed area, for more details see Section 2.3). If there was no floating kelp in any year of the assessment period, the site was assigned the classification of *no floating kelp*. If all plants disappeared over the assessment period, the trend was *total loss*. A negative change in depth was classified as *deeper* and a positive change was classified as *shallower*. Minor changes in bed depth (relative to other years) were classified as *no change*. Sites with less than five years of data were classified as *limited data* for the 5-year recent trend and the entire data record trend.

To complement the minimum and maximum depth data collected along transects, the depth distribution of each bed was estimated by spatially comparing the bed footprint to modelled bathymetry data. The bathymetric data used is a high resolution MLLW model of Puget Sound and the Strait of Juan de Fuca generated by NHP using USGS CoNED topobathymetric digital elevation models and NOAA's VDatum transformation grids (Cowdrey 2024). We calculated bed area per depth bin by running a zonal histogram in ArcGIS Pro (ESRI, Redlands, CA, USA) that divided each bed perimeter into 1-m depth bins. We corrected depth estimates to account for an observed offset between field data and the available draft of the modelled data (at the time of publishing) by shifting the modelled depth by -1 m.

To account for uncertainties related to modelled bathymetry data, depth distribution was visualized in 1-m bins and reported in 3-m bins (shallower than -3 m MLLW and successive 3-m increments). While the profiles provide valuable information on the depth distribution of floating kelp at individual sites, the depth values should be considered approximate; they incorporate inherent uncertainties in modelled bathymetry data, especially in shallow areas.

3 Results

3.1 Bed Area Summary

Because floating kelp beds naturally fluctuate in size from year to year in response to diverse drivers, assessing trends over different time periods often yields distinct results. In this report, a bed area trend designation was assigned for each core site over three different, but overlapping, time periods: three years, five years, and the entire data record (> 5 years). Sites with only four years of data were classified as *limited data* in both the 5-year recent and entire data record time periods. The seven focus study sites with only one year of bed area data were excluded from the trend analysis leaving 13 sites that were subject to a trend assessment.

Sharp declines and losses dominated the entire data record time period (6 out of 7 sites); one site was classified as *no trend*, two sites were classified as *decreasing*, and four sites were classified as *total loss* (Figure 3C, Table 2). Six of the 13 core sites were classified as *limited data* because they have less than 5 years of data. In contrast, stability and/or increases were more common in short-term trends. For the 5-year recent trend ($n = 7$), two sites were classified as *decreasing*, one site was classified as *no trend*, four sites had *no floating kelp*, and six sites were classified as *limited data* (<5 years of data) (Figure 3B, Table 2). For the 3-year recent trend ($n = 13$), four sites were classified as *increasing*, one site was classified as *decreasing*, four sites were classified as *no trend*, and four sites had *no floating kelp* (Figure 3A, Table 2).

At many sites, the trend classification differed among time periods (Figure 3, Table 2). For example, Squaxin Island was classified as *decreasing* for the 5-year and entire data record periods, which reflects a strong overall pattern of loss, including substantial losses at the beginning of time series (Figure 4). In contrast, during the 3-year assessments, there was *no trend* in bed area at Squaxin. While the assessment periods allow for comparison across distinct time periods, other site-specific temporal patterns can be important. For example, at Squaxin, a major loss occurred in 2022, followed by a partial recovery in 2023 (Figure 4). Section 3.3 considers patterns over time at each site in detail.

Extreme losses have occurred at most of the sites in South Puget Sound (SPS) since DNR began boat-based monitoring in 2013. Squaxin Island has decreased 78% since 2013, only scattered plants remain at Fox Island, and floating kelp disappeared from Brisco Point and Devil's Head without subsequent recovery (Figure 4 and Section 3.3). The spatial pattern of floating kelp in SPS in 2023 is striking; floating kelp is only found at Squaxin Island, the innermost floating kelp bed, and around the Tacoma Narrows, at the entrance to SPS. In the Tacoma Narrows vicinity, two sites have not experienced declines (Day Island and Salmon Beach), while Fox Island has experienced substantial declines. In Central Puget Sound, long-term data is limited at most sites (< 5 years of data). In the short-term, five CPS sites are stable or increasing.

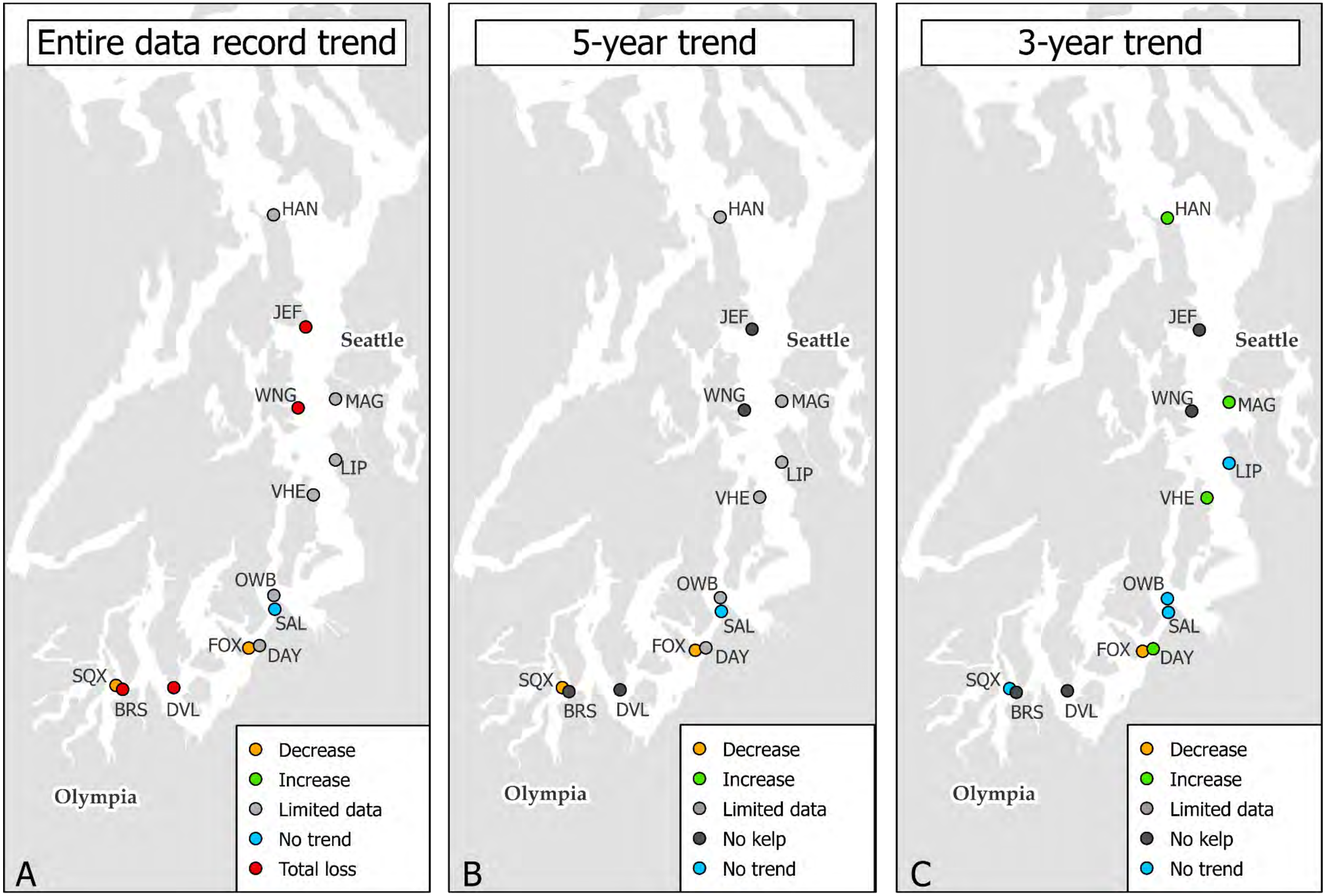

Figure 3. Trends in floating kelp bed area across three time periods for the 13 core DNR Nearshore Habitat Program kayak monitoring sites through 2023.

Table 2. Trend classifications for core monitoring sites over three time periods: 3 years, 5 years, and entire data record. Trends were determined by considering linear regression results for area estimates, visual data inspection, and expert knowledge.

Site	Entire data record trend	5-year recent trend	3-year recent trend
Squaxin Island (SQX)	Decreasing	Decreasing	No trend
Brisco Point (BRS)	Total loss	No floating kelp	No floating kelp
Devil's Head (DVL)	Total loss	No floating kelp	No floating kelp
Fox Island (FOX)	Decreasing	Decreasing	Decreasing
Day Island (DAY)	Limited data	Limited data	Increasing
Salmon Beach (SAL)	No trend	No trend	No trend
Owen Beach (OWB)	Limited data	Limited data	No trend
Vashon Island East (VHE)	Limited data	Limited data	Increasing
Lincoln Park (LIP)	Limited data	Limited data	No trend
Magnolia Bluff (MAG)	Limited data	Limited data	Increasing
Wing Point (WNG)	Total loss	No floating kelp	No floating kelp
Point Jefferson (JEF)	Total loss	No floating kelp	No floating kelp
Hansville (HAN)	Limited data	Limited data	Increasing

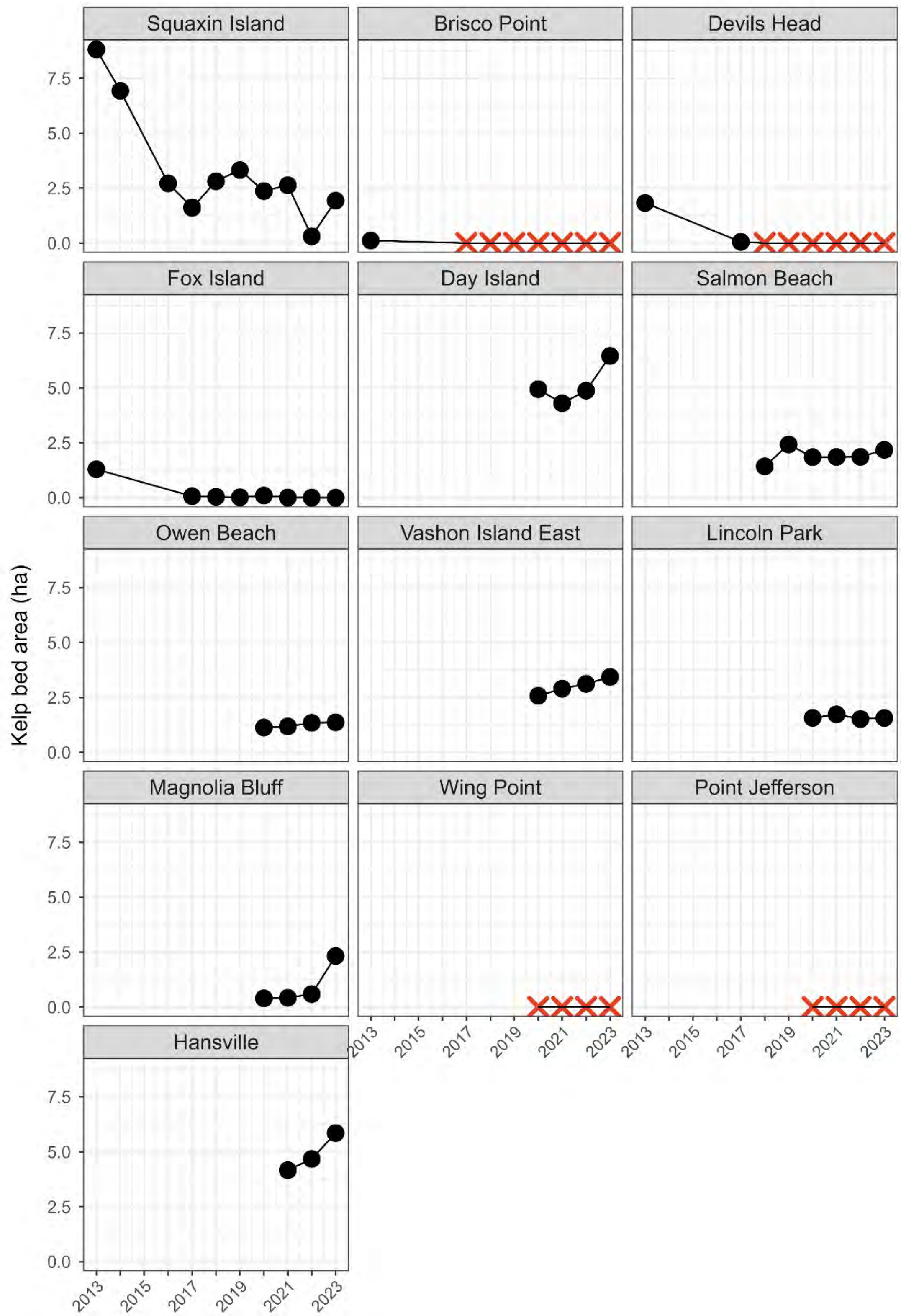

Figure 4. Floating kelp bed area at the 13 core DNR Nearshore Habitat Program kayak monitoring sites through 2023. Sites are arranged from innermost site in Puget Sound (Squaxin Island) to outermost site (Hansville). Black points represent floating kelp present, and red x's denote no floating kelp.

Extreme relative losses are evident between 2013 and 2017 in SPS (Figure 5). At Squaxin, where the longest data record exists, year-to-year comparisons show a consistent pattern of proportional decreases in bed area (Figure 5A). Between 2013 and 2017, floating kelp bed area decreased 82-100% at the four sites that were monitored in SPS (Figure 5B). At sites where floating kelp disappeared, it remains persistently absent (Devil's Head, Brisco Point). At sites where floating kelp persists, it has not returned to 2013 abundances (Squaxin Island, Fox Island). Unfortunately, the data record does not extend back to 2013 at the SPS sites that show stability (Salmon Beach, Day Island). The 2013-2017 time period brackets a marine heatwave, which is suspected to be a driver (see Discussion).

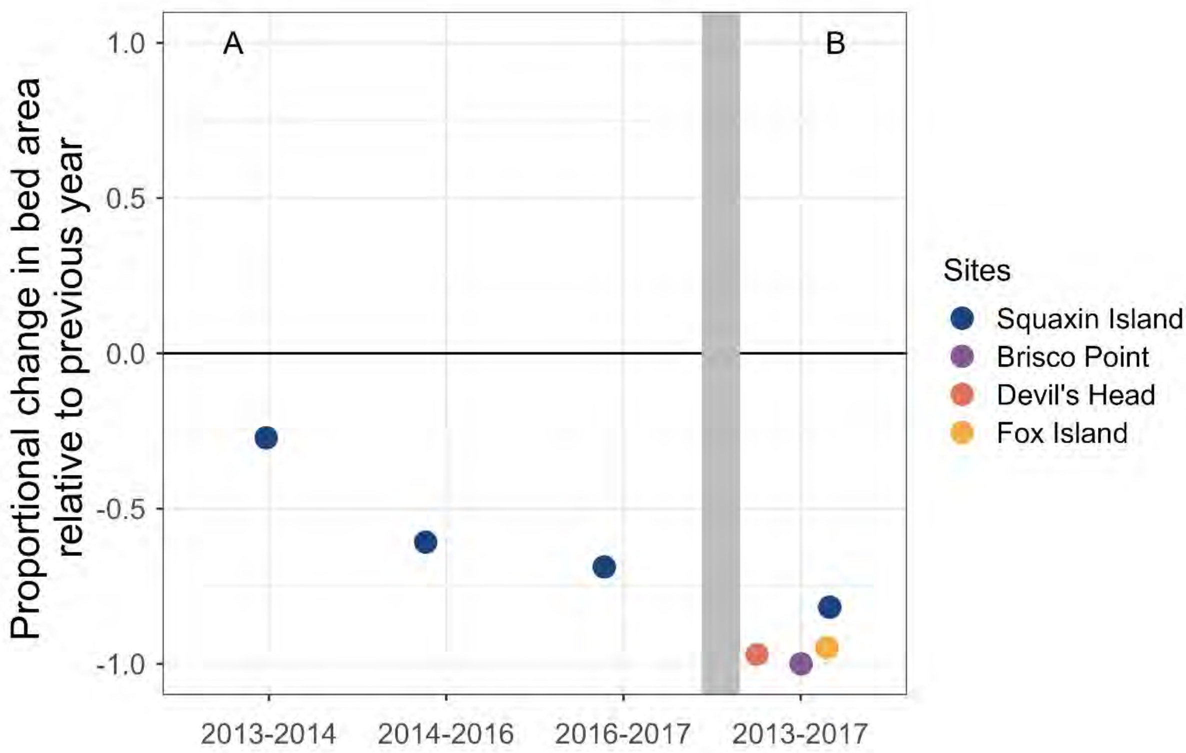

Figure 5. Proportional change in bed area A) between each sampling event at Squaxin Island from 2013 to 2017; and B) at four sites in SPS between 2013 and 2017.

Since 2020, the expanded annual site pool in SPS and CPS allows for comparison of year-to-year changes across nine sites with floating kelp present (Figure 6). Between 2020 and 2023, sites generally show variable year-to-year changes, rather than strong synchrony across sites and years. For the 2020-2021 and 2021-2022 time periods, the mean and median proportional change in bed area was similar (mean = -0.07, median = 0.05; mean = -0.08, median = 0.07, respectively). In contrast, for the 2022-2023 time period, the mean proportional change in bed area was 0.94 and the median was 0.17 (Figure 6). Some striking site-scale patterns are evident. Across all time periods, bed area at Fox Island decreased. In 2022, Squaxin Island decreased dramatically. Between 2022 and 2023, Squaxin Island and Magnolia Bluff exhibited large proportional increases (525% and 300%, respectively). Section 3.3 considers patterns at each site individually.

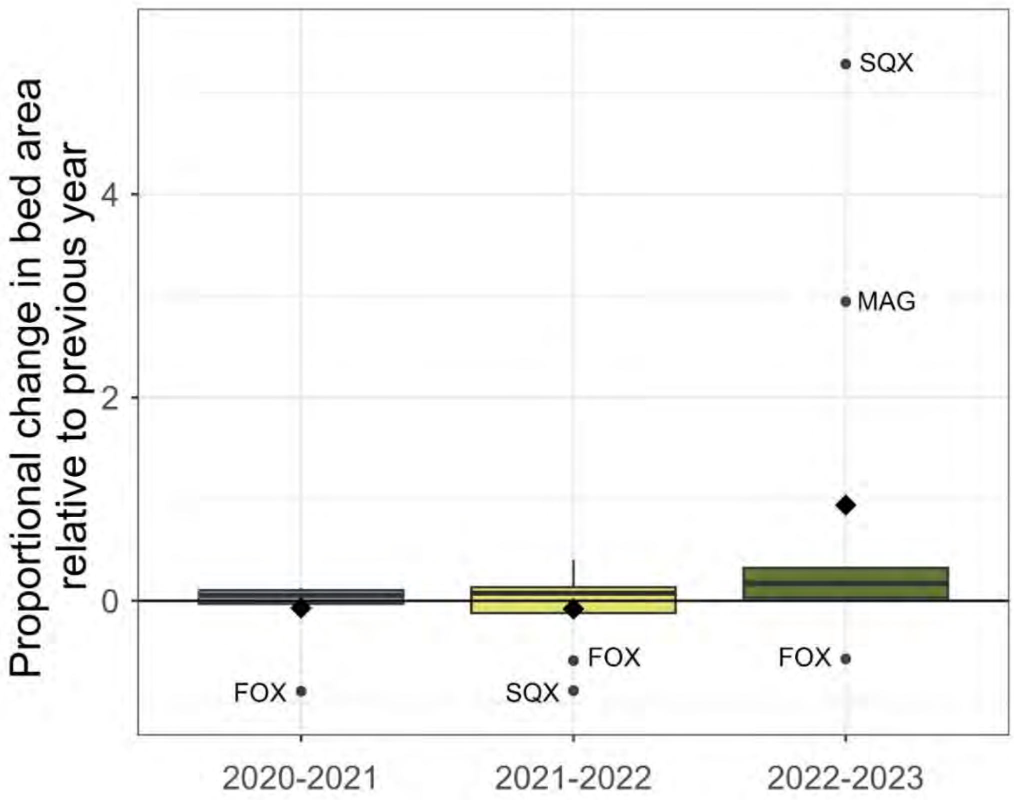

Figure 6. Annual proportional change in bed area at sites in SPS and CPS with floating kelp between 2020 and 2023 (*n* = 9). Circular points represent outliers (labeled with site code) and diamond points represent the mean.

3.2 Bed Depth Summary

Similar to bed area, floating kelp bed depth distribution fluctuates from year to year in response to diverse drivers, and assessing trends over different time periods often yields distinct results. A minimum and maximum depth trend designation was assigned for each core site over three different time periods: three years, five years, and the entire data record (> 5 years). Sites with less than five years of data were classified as *limited data* in both the 5-year recent and entire data record time periods. The two of the seven focus sites (Edmonds and North Beach) were included in the trend analysis because they had three or more years of data.

More sites exhibited changes in mean maximum depth than minimum depth over most time periods. Over the entire data record time period, maximum depth moved *shallower* at one site, there was *no change* in maximum depth at two sites, four sites experienced *total loss*, and eight sites had *limited data* (Table 3). For the 5-year trend, maximum depth moved *shallower* at one site, there was *no change* in maximum depth at one site, four sites had *no kelp*, and nine sites had *limited data*. The 3-year trend showed more changes, maximum depth moved *deeper* at two sites, maximum depth moved *shallower* at two sites, there was *no change* in maximum depth at five sites, four sites had *no kelp*, and two sites had *limited data* (Table 3).

Over the entire data record time period, minimum depth moved *shallower* at one site, there was *no change* in minimum depth at two sites, four sites experienced *total loss*, and eight sites had *limited data* (Table 3). For the 5-year trend, there was *no change* in minimum depth at two sites, four sites had *no kelp*, and nine sites had *limited data*. For the 3-year trend, minimum depth moved *shallower* at one site, there was *no change* in minimum depth at eight sites, four sites had *no kelp*, and two sites had *limited data* (Table 3).

While many sites did not exhibit large changes in mean minimum and maximum depths, a few sites showed clear trends. For example, the maximum depth at Squaxin Island moved shallower in all three time periods while there was no change in minimum depth in any time period. This shoaling of the deep edge of the bed is evident in the map of the kelp bed perimeters and corresponds to the decreasing floating kelp bed area at the site (more details in Section 3.3.1). Trends in depth also varied by time period. At North Beach, the minimum depth over the entire data record was classified as *shallower* while the 3-year recent trend was classified as *no change*. In 2018, the first year of data at North Beach, the floating kelp bed was recorded further offshore (deeper) than in subsequent years, driving the entire data record trend to be *shallower*. In contrast, during the 3-year recent trend time period, the minimum depth stayed consistent (more details in Section 3.4.2).

Table 3. Maximum and minimum depth trend classifications for core (and 2 focus) monitoring sites over three time periods: 3 years, 5 years, and the entire data record. Trends were determined by considering linear regression results for area estimates, visual data inspection, and expert knowledge. LD denotes limited data.

Site	**Maximum Depth**			**Minimum Depth**		
	Entire data record trend	**5-year recent trend**	**3-year recent trend**	**Entire data record trend**	**5-year recent trend**	**3-year recent trend**
Squaxin Island	Shallower	Shallower	Shallower	No change	No change	No change
Brisco Point	Total Loss	No kelp	No kelp	Total Loss	No kelp	No kelp
Devil’s Head	Total Loss	No kelp	No kelp	Total Loss	No kelp	No kelp
Fox Island	LD	LD	LD	LD	LD	LD
Day Island	L	LD	No change	LD	LD	No change
Salmon Beach	No change	No change	No change	No change	No change	Shallower
Owen Beach	LD	LD	No change	LD	LD	No change

Site	Maximum Depth			Minimum Depth		
	Entire data record trend	5-year recent trend	3-year recent trend	Entire data record trend	5-year recent trend	3-year recent trend
Vashon Island SE	LD	LD	No change	LD	LD	No change
Lincoln Park	LD	LD	No change	LD	LD	No change
Magnolia	LD	LD	Deeper	LD	LD	No change
Wing Point	Total Loss	No kelp	No kelp	Total Loss	No kelp	No kelp
Point Jefferson	Total Loss	No kelp	No kelp	Total Loss	No kelp	No kelp
Hansville	LD	LD	Deeper	LD	LD	No change
Edmonds	LD	LD	LD	LD	LD	LD
North Beach	No change	LD	Shallower	Shallower	LD	No change

Minimum and maximum floating kelp bed depths varied by site and year (Figure D1, Table D1). The depth distribution of floating kelp at all sites in 2023 ranged from -0.2 m to -13.7 m MLLW. Greater variation among sites occurred in maximum depth (Figure 7). Mean maximum depth at sites ranged from -2.3 m to -10.7 m MLLW. Deeper maximum depths occurred in the Tacoma Narrows (Day Island and Salmon Beach) and closer to the ocean (Hansville, North Beach, and Freshwater Bay) (Figure 7). Maximum depths were shallower in CPS, at Squaxin Island (-2.4 m MLLW), and at Beckett Point (-2.3 m MLLW).

Some sites exhibited high within-site spatial variability in minimum and maximum depths. Sites with high spatial variability in maximum depth include Lincoln Park (ranging from -1.0 to -6.9 m MLLW) and Magnolia Bluff (ranging from -1.0 to -8.0 m MLLW). Sites with high spatial variability in minimum depth include Day Island (-0.6 to -5.8 m MLLW), Edmonds (-0.5 to -5.3 m MLLW), and Magnolia Bluff (-1.0 to -7.4 m MLLW). Section 3.3 explores site-level trends in detail.

Overall, the majority of bed footprints were shallow (modelled using CoNED bathymetry data, described in Section 2.4). At 10 out of 16 sites, more than 85% of the bed footprint occurred shallower than -6 m MLLW in 2023 (Figure 8). Only six sites had more than 15% of their bed area deeper than -6 m MLLW: Freshwater Bay (72%), Salmon Beach (44%), Hansville (29%), North Beach (23%), and Burrows Island (20%). These depth distribution estimates represent the footprint of the bed, and do not consider density or gaps within the bed.

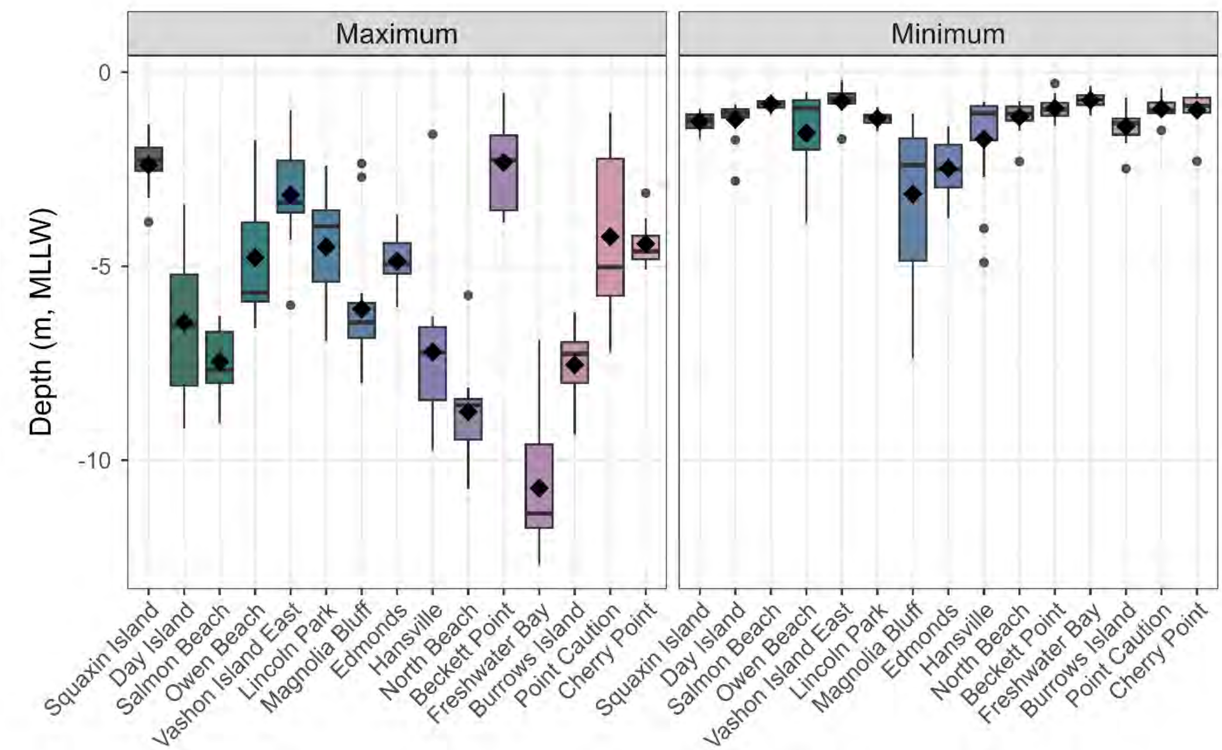

Figure 7. Minimum and maximum bed depth in 2023 at DNR floating kelp monitoring sites. Circular points represent outliers and diamond points represent the mean. Sites are arranged from south (Squaxin Island) to north (Cherry Point) and colored to be easily distinguishable. See sections 3.3 and 3.4 for more site-specific details.

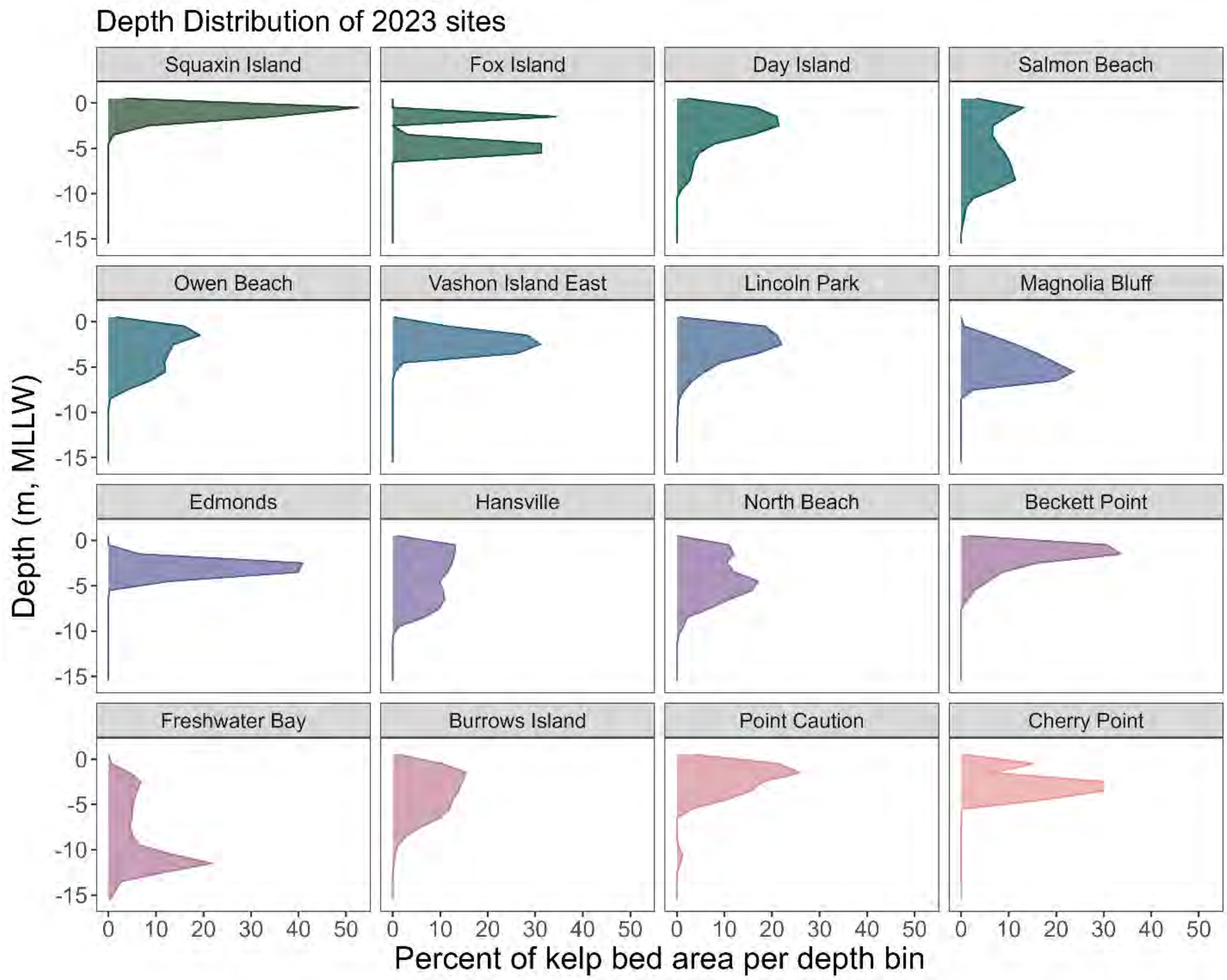

Figure 8. Floating kelp bed depth distribution in 2023 at each site, estimated by spatial comparison of the bed footprint to modelled bathymetry data. Sites are arranged from south (Squaxin Island) to north (Cherry Point) and colored to be easily distinguishable.

3.3 Site-level Status and Trends for Core Sites

This section presents the full data record for bed area and depth distribution at 13 core sites, presented from south to north (e.g. Squaxin Island in South Puget Sound to Hansville in Admiralty Inlet).

3.3.1 Squaxin Island (SQX)

The Squaxin Island site is located on the southern shoreline of Squaxin Island, approximately 10 km north of the city of Olympia. The site occurs in Squaxin Island Tribe waters, and the Tribe is its primary steward. The site experiences complex currents due to its location at the junction of five passages and relatively large wind waves due to the long southern fetch into Budd and Eld

Inlets. It constitutes the innermost location of floating kelp in Puget Sound, both currently and over the century-scale historical record (Berry et al. 2021). Boat-based monitoring by DNR began in 2013 with surveys from a small, motorized boat (2013-2014) and kayaks/paddleboards in subsequent years. DNR has deployed continuous underwater temperature, light, and depth sensors since 2021. SCUBA divers from DNR's Geoduck Compliance Team monitor underwater transects annually using the Reef Check protocol (Reef Check Foundation 2024).

Bed Area

Squaxin Island was classified as *no trend* for the 3-year recent trend and *decreasing* for the 5-year recent trend and entire data record trend (Table 2). During the entire monitoring period (2013-2023), bed area has declined 78%, from 8.8 ha to 1.9 ha (Figure 9, Table C1). Bed area exhibited a steep decline between 2013 and 2017 before rebounding slightly in 2018. Between 2019 and 2021, bed area varied but stayed relatively stable. In 2022, bed area declined to the smallest documented area, a 97% decline relative to 2013. In 2022, only 85 individual plants were observed, and of those, 20-25 plants had no blades (on July 14). In 2023, a partial natural recovery occurred, with bed area increasing to 1.9 ± 0.19 ha (mean ± SE).

The spatial pattern of decline has been a progressive contraction, shrinking on both the alongshore and waterward edges (Figure 9). During the partial recovery is 2023, the bed expanded over its previous footprint.

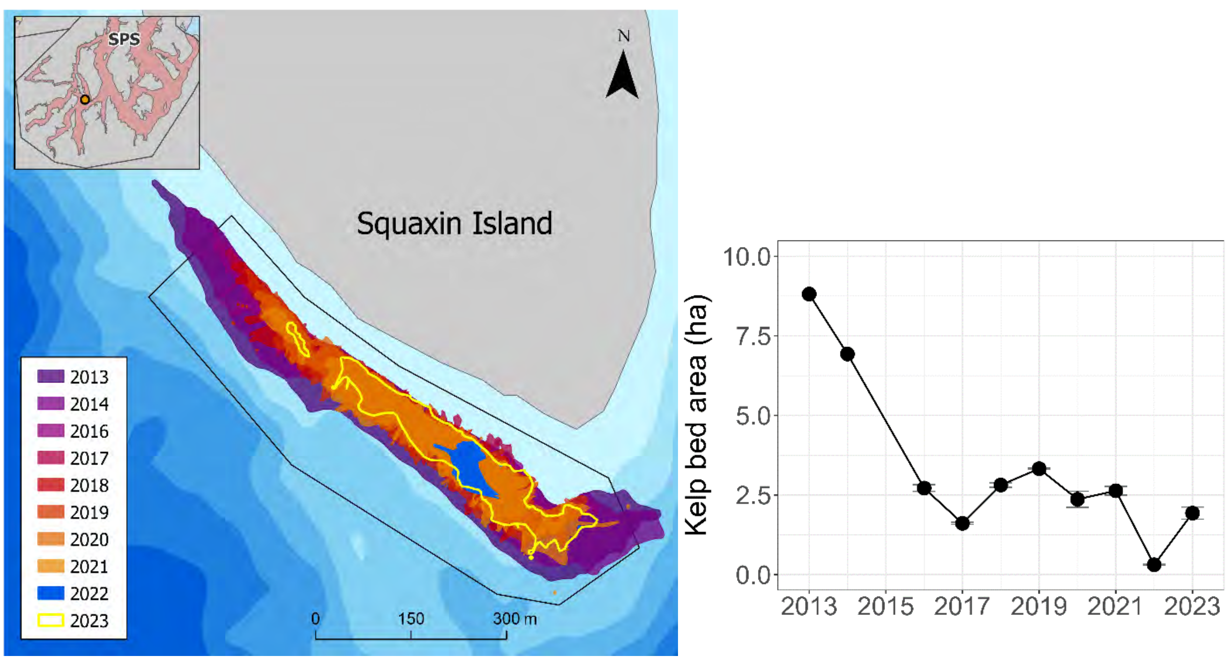

Figure 9. Map of Squaxin Island floating kelp bed perimeters, colored by year. Black box represents the site boundary (left), and graph of Squaxin Island mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -1.86 m to -4.38 m MLLW between 2013 and 2023 (Figure 10, Table C1). Mean maximum depth has contracted substantially since 2013, from a 2013 depth of -4.4 m moving up to -2.4 m MLLW in 2023. Mean minimum depth ranged from -1.0 m to -1.9 m between 2016 and 2023 (Figure 10, Table C1).

Mean maximum bed depth at Squaxin differed significantly between years (Welch's ANOVA, $F_{8,39} = 13.14$, $p < 0.001$). A Games-Howell post-hoc test showed that 2013 did not significantly differ from 2014 or 2019 but significantly differed from 2016 ($p < 0.001$), 2017 ($p < 0.001$), 2018 ($p = 0.001$), 2020 ($p < 0.001$), 2021 ($p = 0.01$), and 2023 ($p = 0.001$). Additionally, bed area in 2014 significantly differed from 2016 ($p < 0.001$), 2017 ($p < 0.001$), 2020 ($p = 0.01$), and 2023 ($p = 0.02$). In contrast, mean minimum depth was not significantly different among years (Welch's ANOVA, $F_{6,29} = 1.54$, $p = 0.20$).

In 2022, the depth of all individual plants/clusters were recorded because so few plants occurred along the transects. In 2022, the mean depth of individual plants/clusters was much shallower than the 2021 mean maximum depth and deeper than the 2021 mean minimum depth (Figure 10, Table C1). In 2023, mean maximum depth was slightly deeper than in 2022, and comparable to mean maximum depth in 2021 (Table C1). Similarly, mean minimum depth in 2023 was slightly shallower than in 2022 and close to mean minimum depth in 2021.

In addition to maximum depth contraction, the number of transects with floating kelp has decreased. Between 2016 and 2021, floating kelp was absent on two to three transects a year, and some transects just had one plant. In 2023, floating kelp was absent from five of the 13 transects (Table D1).

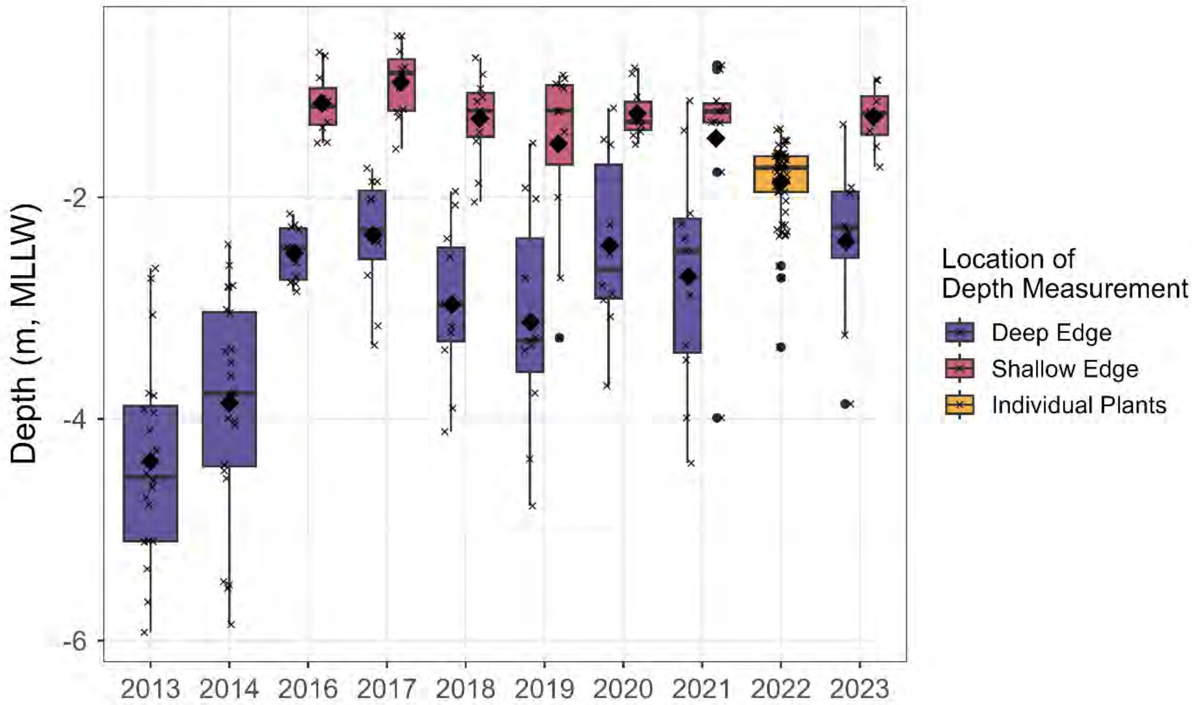

Figure 10. Minimum and maximum depth of floating kelp bed at Squaxin Island between 2013 and 2023. No minimum bed depth collected in 2013 and 2014. In 2022, depth was not collected along transects but at each floating kelp individual/cluster encountered. 2013 is significantly different from 2016-2018, 2020, 2021, and 2023. 2014 is significantly different from 2016, 2017, 2020 and 2023 (2022 was not included in this analysis). Circular points represent outliers, diamond points represent the means, and small x's represent each individual measurement.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). In all years at Squaxin Island, peak distribution (80 – 100% of the bed footprint) occurred shallower than -3 m MLLW. Between 2013 and 2022, the bed gradually contracted along the entire depth distribution, to a tiny and shallow remnant of the 2013 bed footprint (Figure 11). In 2023, a partial recovery showed expansion at the distribution peak, yet limited expansion deeper. In 2023, most of the bed occurred shallower than -3 m MLLW. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

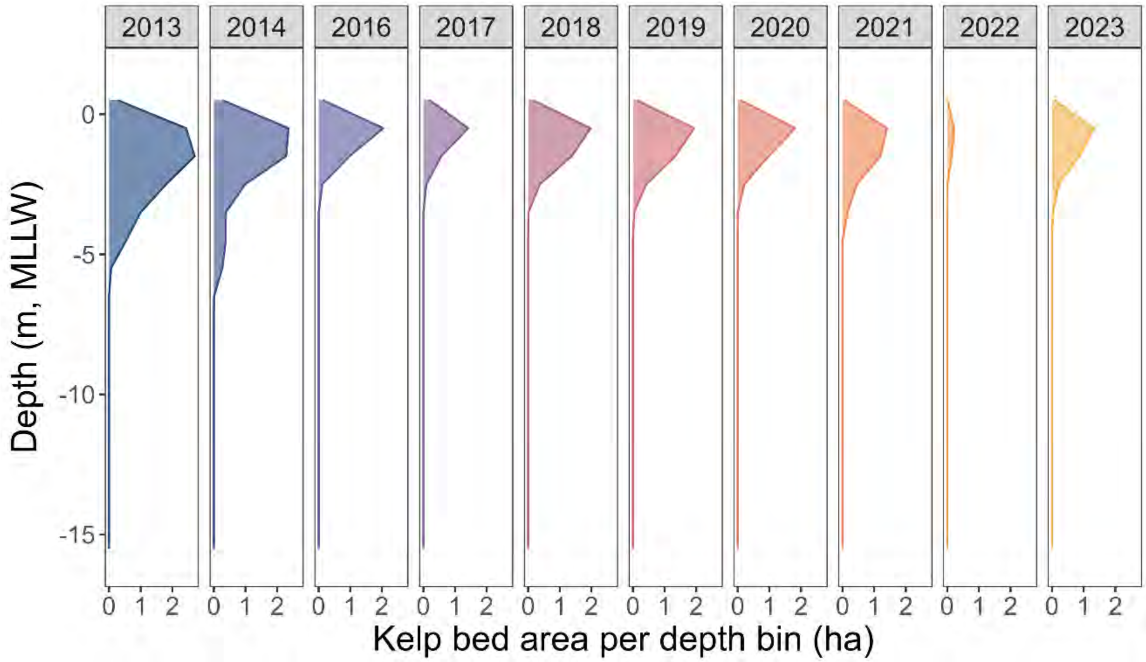

Figure 11. Squaxin Island floating kelp bed depth distribution from 2013-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

Elevated water temperature is a known stressor for floating kelp (Wernberg et al. 2016, Smale 2020), and the two steep declines in bed area at Squaxin Island coincide with periods of elevated water temperature. The decline in floating kelp between 2013 and 2017 occurred during the 2014 marine heatwave in the eastern Pacific Ocean that negatively impacted floating kelp along the West Coast (Rogers-Bennett and Catton 2019). The summer of 2021 also saw elevated water temperatures in South Puget Sound (PSEMP 2022), which preceded the second steep decline at Squaxin in 2022. Thermal limits for bull kelp gametophyte growth and sporophyte production have been documented at 16°C and 18°C (Weigel et al. 2023). Temperature sensor data from Squaxin Island showed that in 2021, the water temperature exceeded the 16°C threshold for a total of 618 hours across 68 days, which preceded the 2022 decrease in floating kelp (McClure et al. in review). In 2022, the water temperature exceeded the 16°C threshold for a total of just 360 hours across 56 days, which preceded the 2023 partial recovery at the site (McClure et al. in review).

Overall, monitoring observations suggest that the Squaxin Island site is at high risk of further decline or total loss. In addition to elevated water temperatures, observations during field surveys suggest that other suspected stressors include grazing and mechanical damage by large numbers of kelp crabs, competition with the introduced alga *Sargassum muticum*, sedimentation, low water clarity, damage by boat propellers, anthropogenic nutrient input, low genetic diversity, and limited recruitment. Substrate for attachment may be limited, but there is no evidence of substrate changes during the period of decline.

Following the observed 2022 decrease, the Squaxin Island Tribe and Puget Sound Restoration Fund (PSRF), in collaboration with DNR, initiated a bull kelp restoration effort at the site that included outplanting seeded lines in early 2023 (S. Steltzner, pers. comm.). Restoration work and monitoring are ongoing (Pyle 2023).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.2 Brisco Point (BRS)

The Brisco Point floating kelp monitoring site is located on the southern tip of Harstine Island where Peale Passage meets Dana Passage, less than one km east of the Squaxin Island site. Annual DNR monitoring data includes 2013 (surveyed by small, motorized boat) and then by small boat or kayak annually between 2017-2023.

Bed Area

Brisco Point was classified as *no floating kelp* for the 3-year and 5-year recent trends and as *total loss* for the entire data record trend (Table 2). In 2013, bed area was 0.1 ha and located on the west side of the point (Figure 12; Table C2). In 2017, no floating kelp was present. Annual site visits between 2018 and 2023 found that floating kelp has been persistently absent.

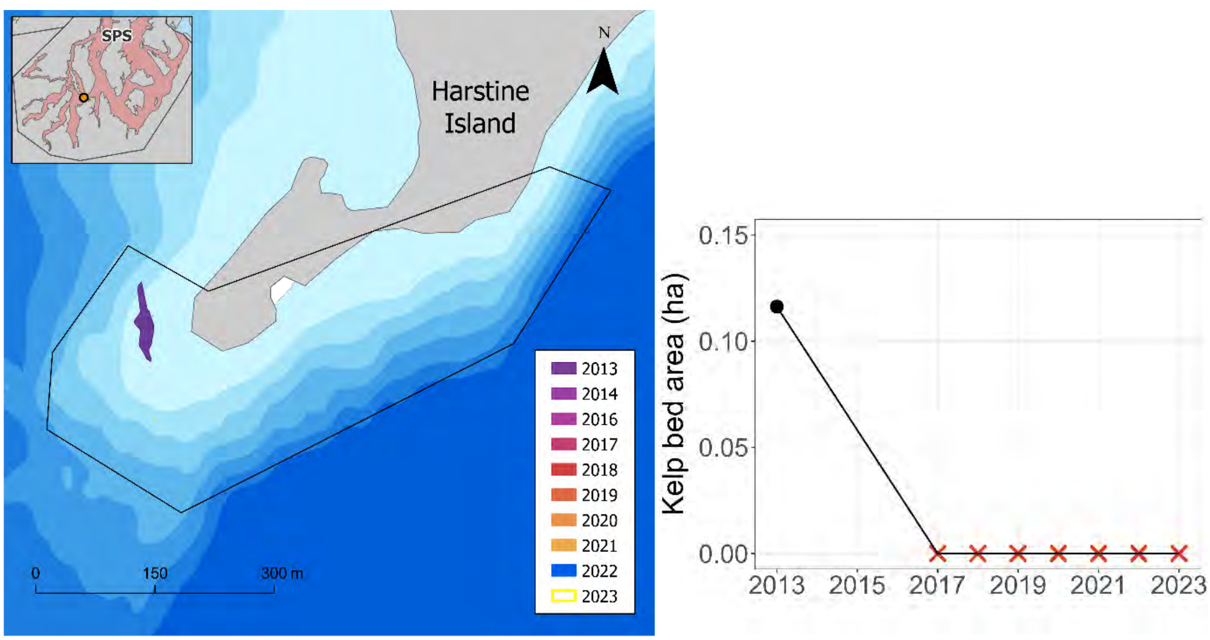

Figure 12. Map of Brisco Point floating kelp bed perimeters, colored by year. Black box represents the site boundary (left), and graph of Brisco Point kelp bed area by year. Red x's represent no floating kelp present (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

No field surveys of minimum and maximum bed depths took place at Brisco Point prior to bed disappearance. The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). In 2013, the entire bed was estimated to be shallower than -3 m MLLW (Figure 13), which is substantially shallower than most sites (Figure 8). The depth distribution estimate is approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

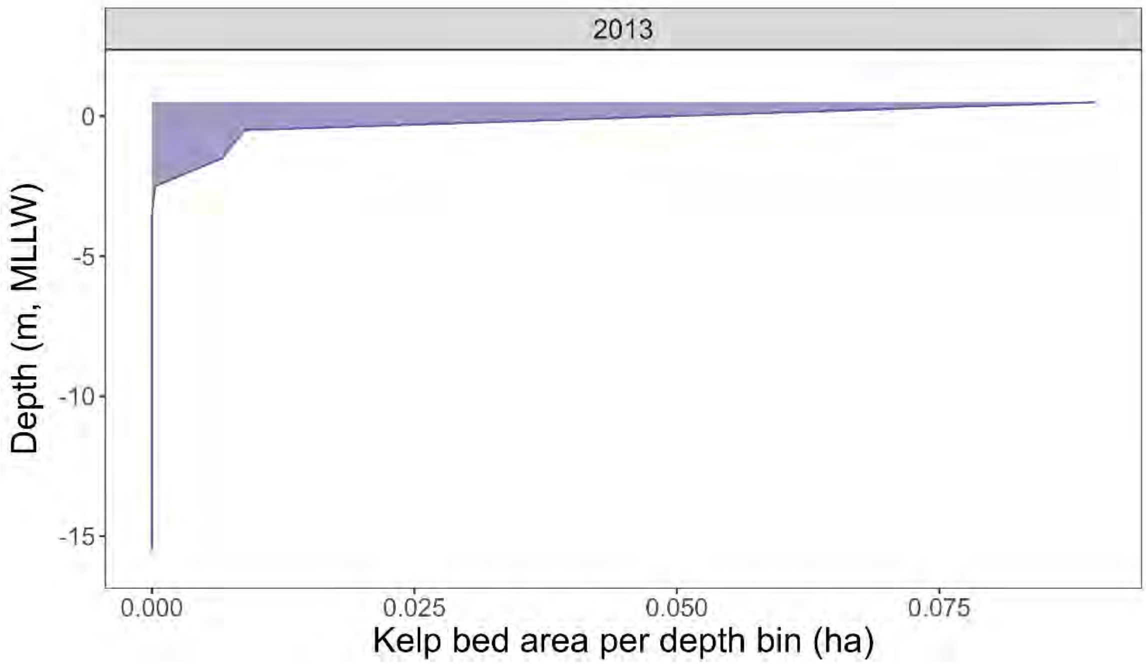

Figure 13. Brisco Point floating kelp bed depth distribution in 2013, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

The loss of the small floating kelp bed at Brisco Point between 2013 and 2017 coincided with the 2014 marine heatwave. Declines occurred over the same time period at other floating kelp beds in SPS (Squaxin Island, Devil's Head, Fox Island). Floating kelp has not been recorded since 2013.

In addition to elevated water temperatures, multiple factors could have driven floating kelp losses. Based on observations during field surveys, other suspected stressors at the site include low tide exposure, sedimentation, low genetic diversity, anthropogenic nutrient input, low water clarity, damage by boat propellers, and limited recruitment. Substrate for attachment may be limited, but there is no evidence of substrate changes during the period of decline.

3.3.3 *Devil's Head (DVL)*

The Devil's Head floating kelp monitoring site is located on the southern shoreline of Key Peninsula on the southwest end of Drayton Passage in South Puget Sound. Annual DNR monitoring data includes 2013 (surveyed by small boat) and then by small boat or kayak annually between 2017-2023. Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024).

Bed Area

Devil's Head was classified as *no floating kelp* for the 3-year and 5-year recent trends and as *total loss* for the entire data record trend (Table 2). The floating kelp bed area decreased 97% between 2013 and 2017, from 1.8 ha to 0.06 ha (Figure 14; Table C3). By 2018, floating kelp at the site was absent, and yearly surveys in subsequent years have not recorded any floating kelp.

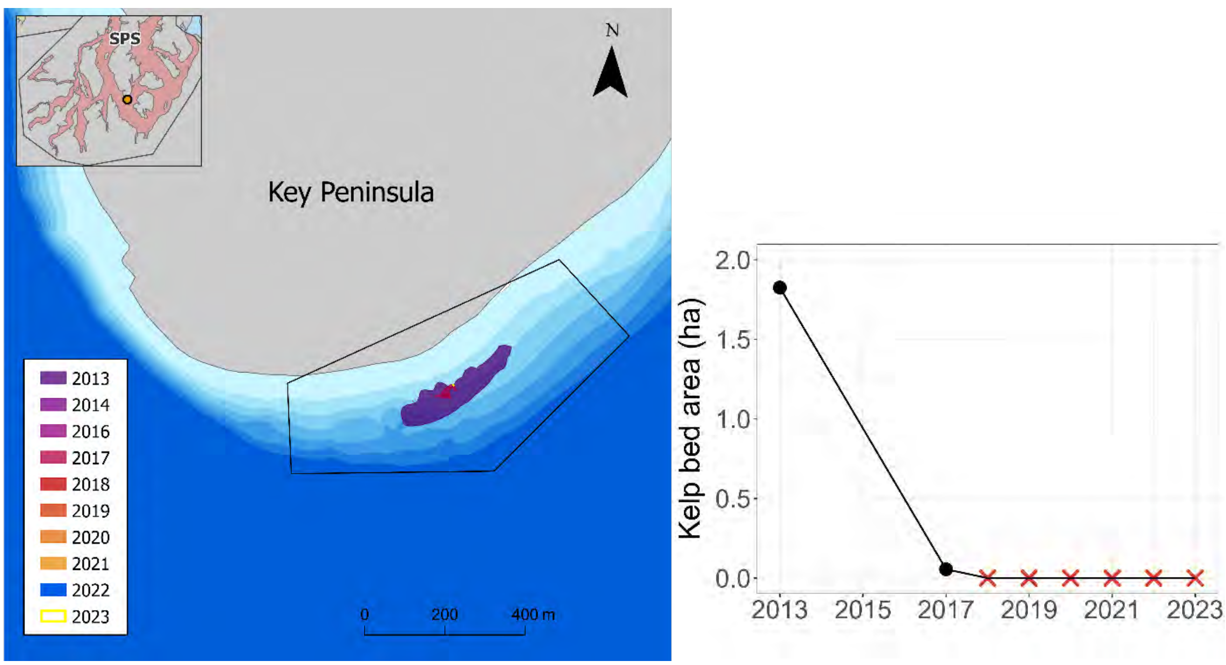

Figure 14. Map of Devil's Head floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Devil's Head kelp bed area by year. Red x's represent no floating kelp present (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

No field surveys of minimum and maximum depths took place prior to bed disappearance. The depth distribution of the bed in 2013 and 2017 was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). In both survey years, the peak distribution occurred shallower than -6 m MLLW (Figure 15). However, the profiles contrasted strongly between years. In 2013, the bed extended relatively deep in comparison to other sites; approximately 30% of the bed occurred deeper than -6 m and it extended to -11 m, relatively deep compared to many floating kelp beds in SPS and CPS (Figure 8). In 2017, the entire bed was restricted to shallower than -6 m MLLW. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

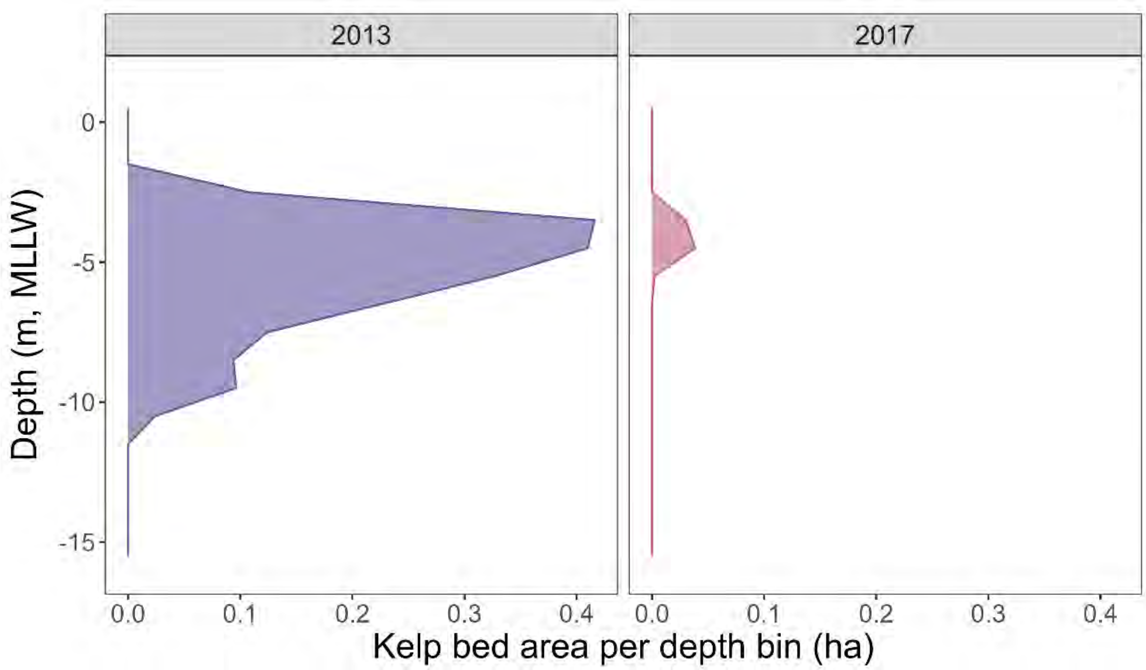

Figure 15. Devil's Head floating kelp bed depth distribution in 2013 and 2017, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

The decline of the floating kelp bed at Devil's Head between 2013 and 2017 coincides with the 2014-2016 marine heatwave and declines documented at other floating kelp beds in SPS (Squaxin Island, Brisco Point, Fox Island). Floating kelp has not been observed since 2017, representing a total loss.

Multiple factors could have driven floating kelp losses. Based on observations during field surveys, suspected stressors at the site include damage by boat propellers, sedimentation, low genetic diversity, and anthropogenic nutrient input. In 2023, Devil's Head was more than 10 km distant from other floating kelp beds; making isolation from propagules an important factor that could be limiting recovery. Substrate for attachment may be limited, but there is no evidence of substrate changes during the period of decline.

Unlike other beds that experienced total losses around 2014-2016, the floating kelp at Devil's Head extended relatively deep prior to shoaling considerably and disappearing. This distinct depth distribution, and its pattern of change, may provide additional clues about site conditions and stressors.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.4 Fox Island (FOX)

The Fox Island floating kelp monitoring site is located on the southeastern shoreline of Fox Island just south of Fox Point in South Puget Sound. Annual DNR monitoring data includes 2013 (surveyed by small boat) and then by kayak annually between 2017-2023. Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024).

Bed Area

Fox Island was classified as *decreasing* for the 3-year and 5-year recent trend as well as the entire data record trend (Table 2). Bed area decreased 95% between 2013 and 2017, from 1.3 ha in 2013 to 0.07 ha in 2017. Since 2018, less than ten scattered plants have been found each year throughout the site (Figure 16, Table C4).

Floating kelp contracted from south to north over the monitoring period. After 2013, floating kelp has been restricted to the northern end of the site (Figure 16).

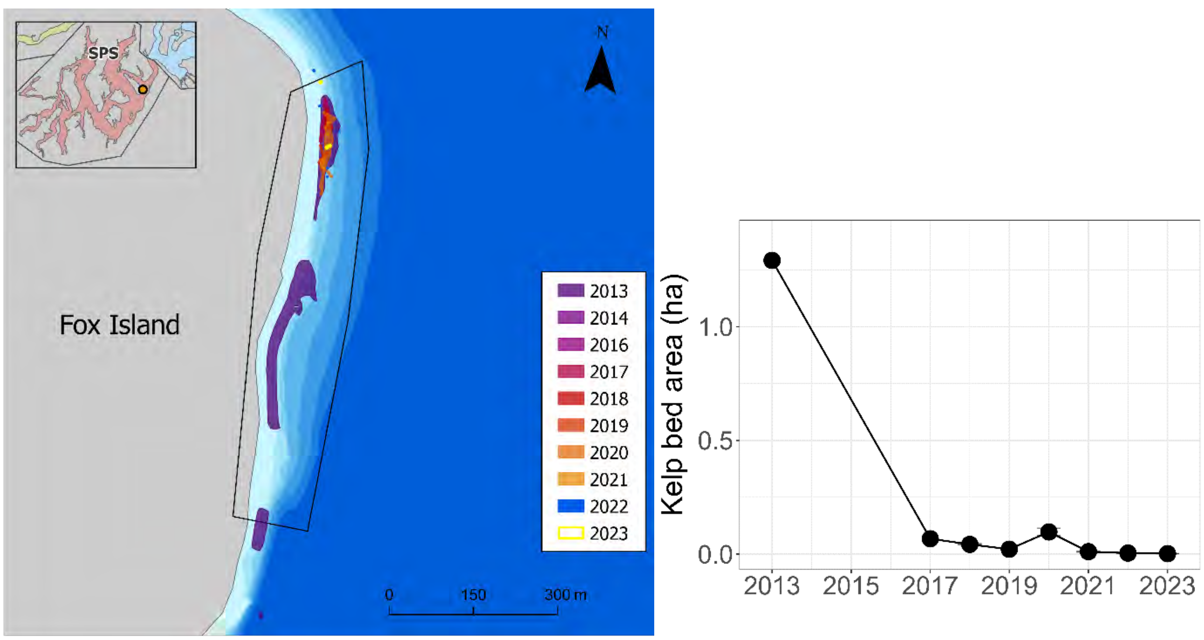

Figure 16. Map of Fox Island floating kelp bed perimeters, colored by year. Black box represents the site boundary (left), and graph of Fox Island mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Minimum and maximum bed depths were not calculated along regularly spaced transects at Fox Island due the extremely limited extent of the alongshore bed. Individual depths were noted for some plants. In 2022, two of the five floating kelp plants were exposed at low tide (-1.1 m MLLW). In 2023, only two plants were observed, found at depths of -2.9 m and -5.1 m MLLW.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Fox Island in 2013, a strong distribution peak occurred shallower than -3 m MLLW and a second peak occurred around -6 m MLLW. A third of the bed occurred between -6 and -9 m MLLW which is relatively deep compared to other beds in SPS (Figure 8). In 2017, extent decreased across all depth bins, to a remnant, with a peak shallower than -3 m MLLW, and 25% of the bed between -3 m and -6 m MLLW (Figure 17). In 2020, the peak distribution shifted deeper, with 80% of the bed between -3 m and -6 m MLLW. Since 2020, the bed has contracted across its depth distribution. Unlike other sites which contracted to shallower depths (i.e. Squaxin Island and Devil's Head), some individuals persist at Fox Island in deeper zones. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

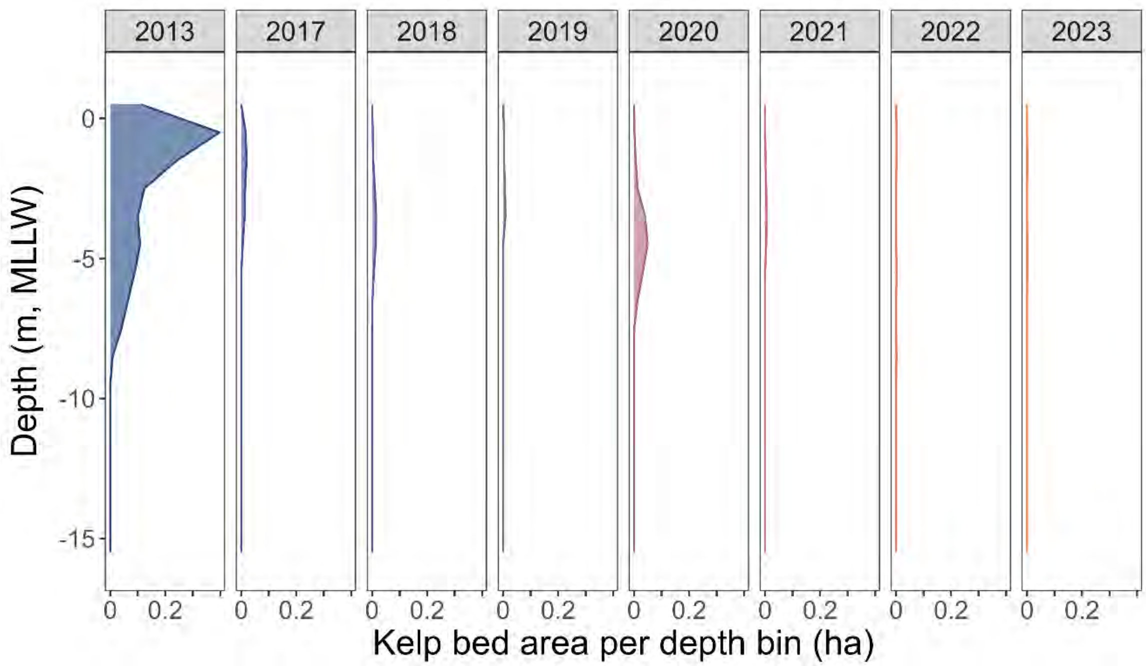

Figure 17. Fox Island floating kelp bed depth distribution from 2013-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

<u>Interpretation of site patterns and trends</u>

The floating kelp bed at Fox Island has declined during every monitoring time period. Only two individuals were observed in 2023. The two individuals appeared healthy, with numerous long blades and reproductive sori. However, recruitment is likely severely limited, making the likelihood high of total loss in the future.

Unlike sites further within SPS, the Fox Island site experiences cooler water temperatures due to intense currents and mixing associated with the Tacoma Narrows (Berry et al. 2021). Based on observations during field surveys, suspected stressors at the site include damage by boat propellers, sedimentation, low genetic diversity, and anthropogenic nutrient input. Isolation from propagules is an important factor that could be limiting recovery. Substrate for attachment may be limited, but there is no evidence of substrate changes during the period of decline.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.5 Day Island (DAY)

The Day Island floating kelp monitoring site is located west of Narrows Marina, on the south end of the Tacoma Narrows in South Puget Sound. Annual DNR kayak-based monitoring began at Day Island in 2020.

Bed Area

Day Island was classified as *increasing* for the 3-year recent trend. Because only four years of survey data exist, it was classified as *limited data* for the 5-year recent trend and the entire data record trend (Table 2). Floating kelp bed area estimates were similar in 2020 and 2022 (4.3-4.9 ha). In 2021, bed area was 13% smaller, and the bed did not extend as far south as in other years. Bed area increased 30% between 2022 and 2023 to 6.5 ha (Figure 18, Table C5). The larger bed area in 2023 reflects minor expansions at locations along the deep and shallow edges, as well as alongshore, relative to other years.

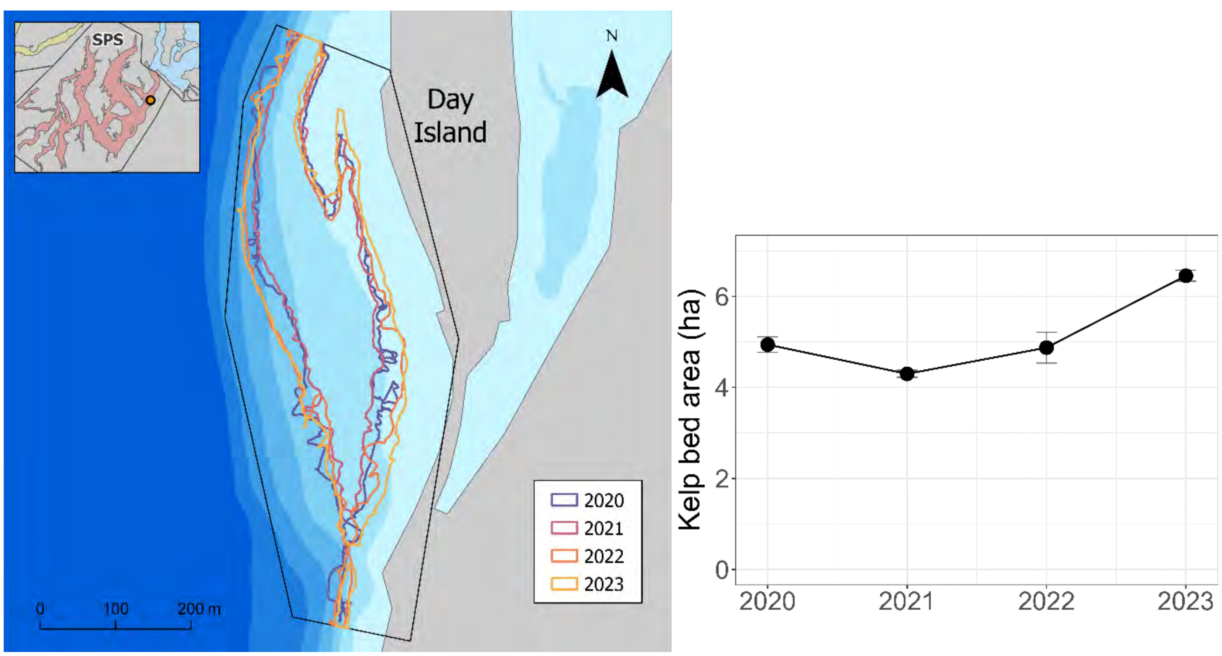

Figure 18. Map of Day Island floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Day Island mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -5.1 m to -6.5 m MLLW between 2020 and 2023 (Figure 10, Table C5). Mean maximum bed depth at Day Island was not significantly different among years (Welch's ANOVA, $F_{3,22}$ = 1.58, p = 0.22) but was deepest in 2023. (Figure 19). The absolute range of maximum depths measured was greatest in 2020 (-2.8 m to -8.6 m MLLW) and 2023 (-0.3 m to -9.2 m MLLW) and smallest in 2021 (-3.4 m to -6.4 m MLLW).

Mean minimum depth ranged from -1.2 m to -1.8 m MLLW between 2020 and 2023 (Figure 10, Table C5). Mean minimum bed depth varied slightly between 2020 and 2023 and was shallowest in 2023 (Figure 19, Table C5) but there was no significant difference among years (Welch's ANOVA, $F_{3,23}$ = 1.00, p = 0.41).

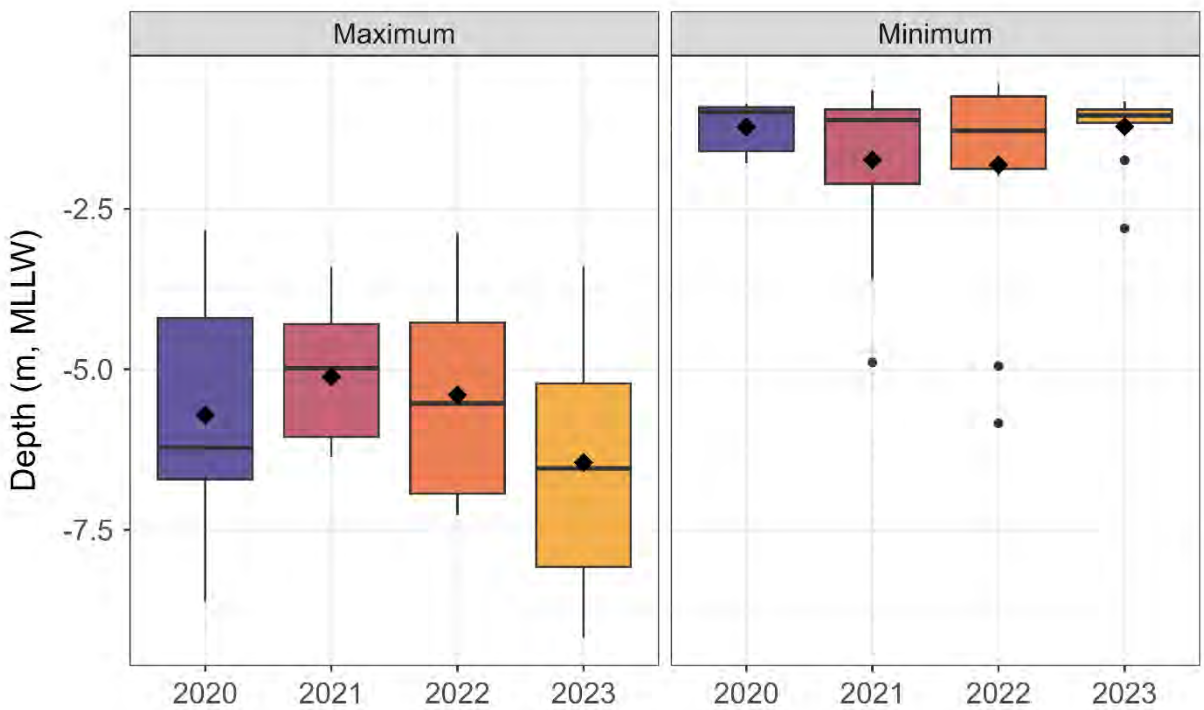

Figure 19. Minimum and maximum depth of floating kelp bed at Day Island between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated using spatial comparison of the bed footprint to modelled bathymetry data (Section 2.4). At Day Island, depth distribution was similar in all years. Distribution peaked around -3 m MLLW and 90% of the bed was shallower than -6 m. The profile extended to approximately -12 m MLLW (Figure 20). In 2023, bed area appeared to be greater in the shallower depth bins, a pattern which supports the results for bed perimeter and the minimum and maximum depth. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

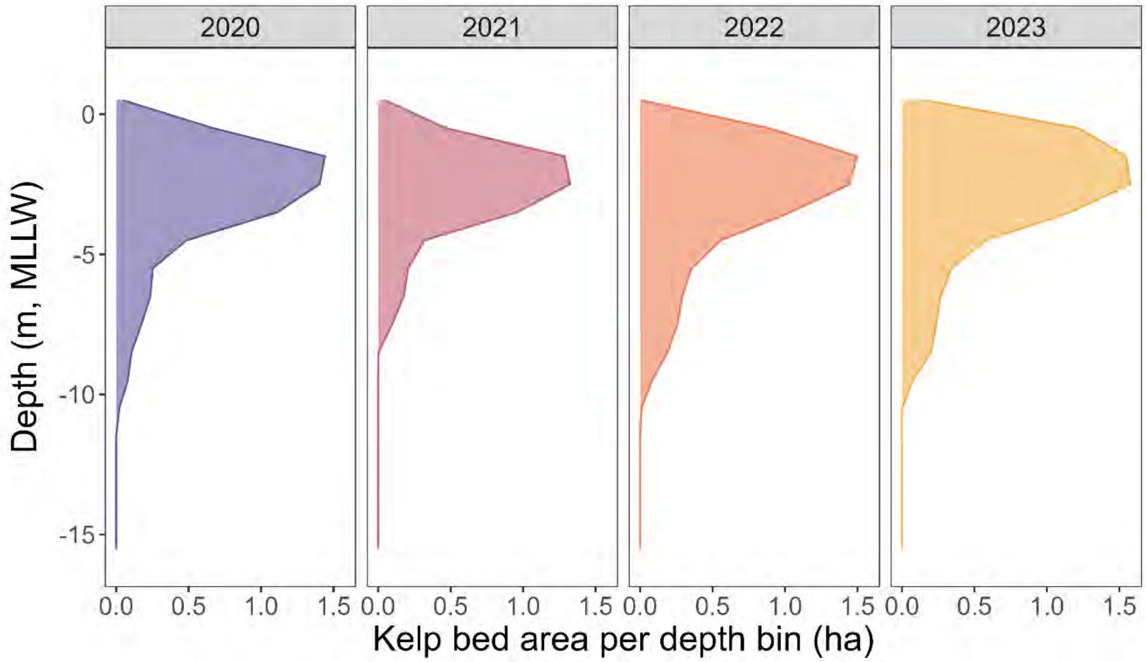

Figure 20. Day Island floating kelp bed depth distribution (as area per 1-m depth bin) from 2020-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

Bed perimeter data and depth data suggest that in 2023 the bed expanded into shallower water and remained stable in deeper areas. Overall, existing data suggestions this site is stable.

3.3.6 Salmon Beach (SAL)

The Salmon Beach floating kelp monitoring site is located on the northeast shoreline of the Tacoma Narrows, just north of the Tacoma Narrows Bridge at the boundary of Central and South Puget Sound. The Tacoma Narrows is an area of intense tidal currents and mixing, with consistently lower water temperatures and higher water nutrient concentrations than SPS (Berry et al. 2021). The shoreline at the site is steep, a common geomorphological type in the Tacoma Narrows. The site is adjacent to the Salmon Beach community, a historical neighborhood of waterfront houses set on pilings that dates back to the early 1900s (Edwards 2006). Annual DNR kayak-based monitoring began at Salmon Beach in 2018. DNR has deployed continuous underwater temperature, light, and depth sensors since 2021. SCUBA divers from DNR's Geoduck Compliance Team monitor underwater transects annually using the Reef Check protocol (Reef Check Foundation 2024).

Bed Area

Salmon Beach was classified as *no trend* for the 3-year and 5-year recent trend and the entire data record trend (Table 2). Bed area was smallest in 2018 (1.4 ha) and largest in 2019 (2.4 ha) and then consistent in size from 2020 to 2022 (1.9 ha) before increasing slightly to 2.2 ha in 2023 (Figure 21, Table C6). Most differences in bed perimeter among years can be attributed to slight variation in the location of the deep edge of the bed (Figure 21). The location of the shallow boundary showed little movement in most years. However, slight changes in the shallow boundary were associated with changes in minimum depth along the steep shoreline (next section).

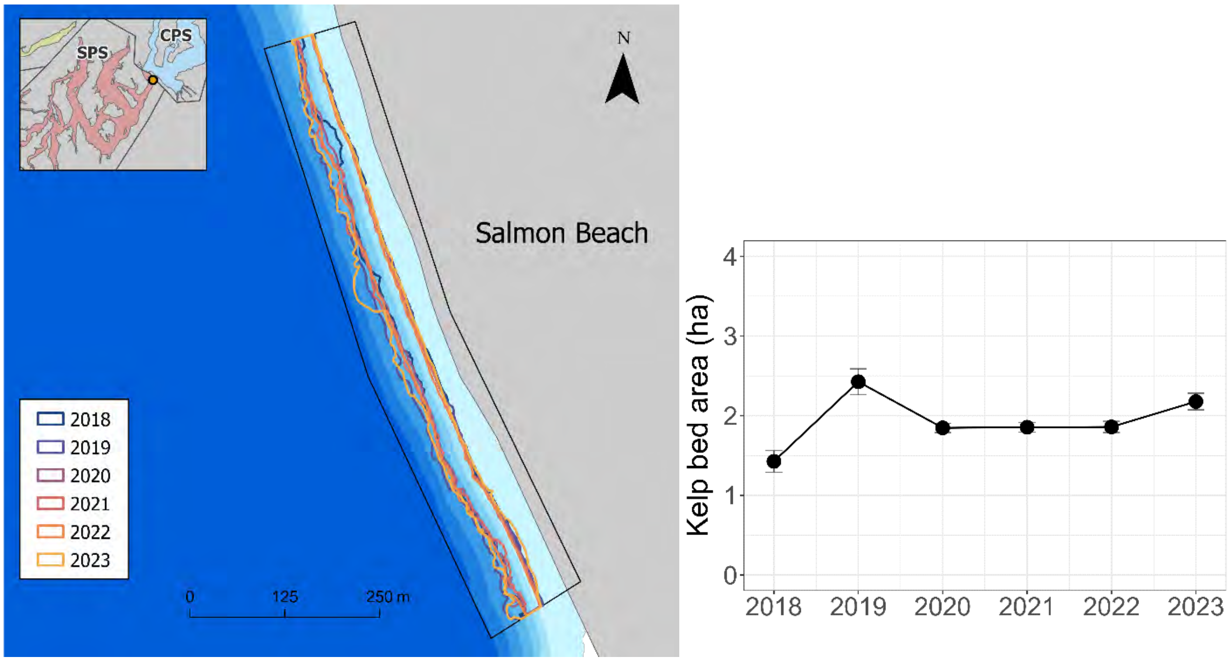

Figure 21. Map of Salmon Beach floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Salmon Beach mean floating kelp bed area by year. Error bars are SE (right). Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from –7.1 m to -8.0 m MLLW between 2018 and 2023 (Figure 10, Table C6). Maximum bed depth was not significantly different among all surveyed years (Welch's ANOVA, $F_{5,33} = 0.50$, $p = 0.77$; Figure 22). Mean maximum bed depth was deepest in 2019 and shallowest in 2018.

Mean minimum depth ranged from -0.7 m to -1.1 m MLLW between 2018 and 2023 (Figure 10, Table C6). Mean maximum bed depths between 2020 and 2023 were very similar (Figure 22, Table C6). However, mean minimum bed depth differed significantly between years (Welch's ANOVA, $F_{5,33} = 8.09$, $p < 001$). A Games-Howell post hoc test showed that 2018 significantly differed from 2019 ($p = 0.02$), 2019 was significantly different than 2020 ($p = 0.03$) and 2021 ($p < 0.001$), and 2021 was significant different than 2023 ($p = 0.05$). Even with the significant differences between years, the largest difference in yearly mean minimum depth was only 0.4 m (Table C6).

We interpreted differences in maximum depth with caution at Salmon Beach due to the steep site geomorphology. Substantial differences in depth over short distances introduced more measurement uncertainty than at more gently sloping sites

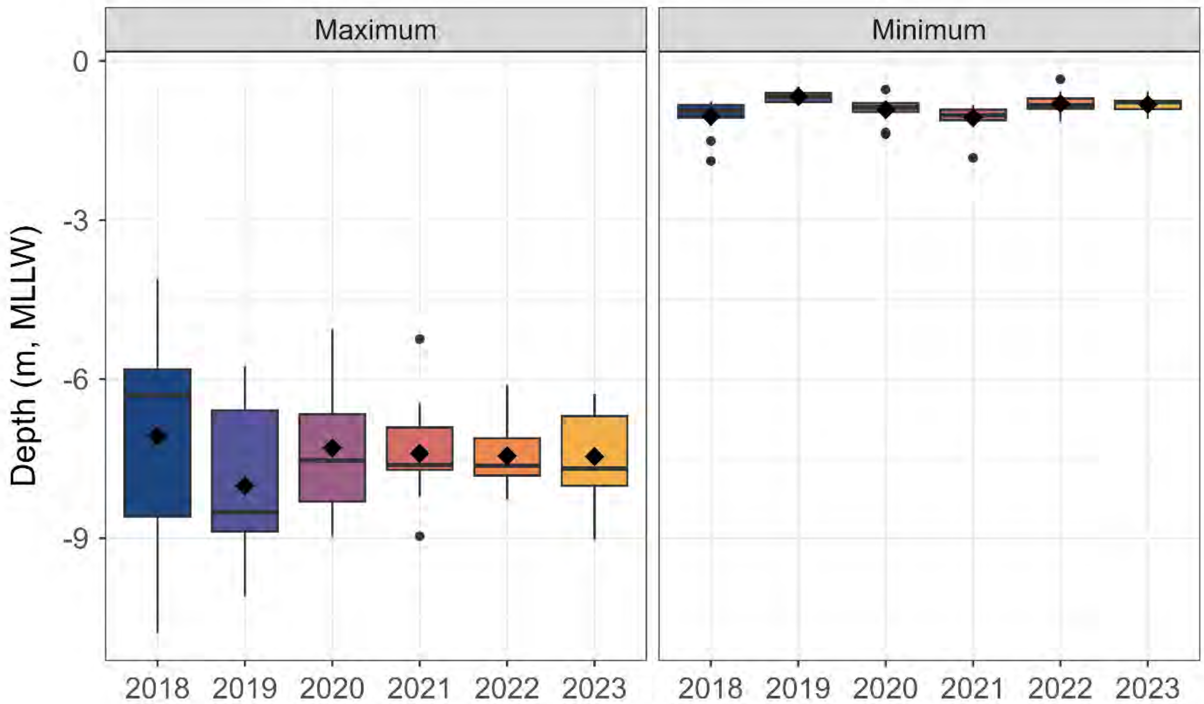

Figure 22. Minimum and maximum depth of floating kelp bed at Salmon Beach between 2018 and 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Salmon Beach, a consistent pattern was evident in all years, with a peak in bed area shallower than -3 m MLLW and a second peak near -9 m MLLW (Figure 23). Across all years, 50-75% of the bed area fell between 0 and -6 m MLW. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

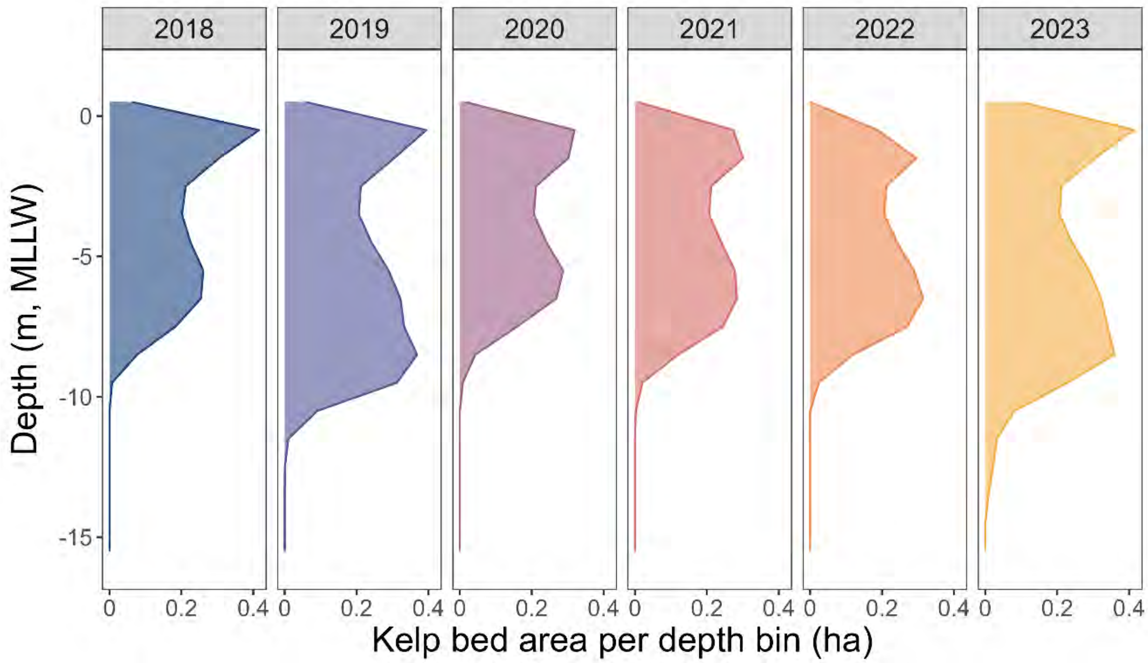

Figure 23. Salmon Beach floating kelp bed depth distribution (as area per 1-m depth bin) from 2018-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

<u>Interpretation of site patterns and trends</u>

Floating kelp in the Tacoma Narrows has persisted for at least the past 150 years (Berry et al. 2021) and the Salmon Beach floating kelp bed has seen no significant change over the past six years of kayak monitoring. Stability at this location is likely due, in part, to cooler water temperatures, high water column nutrients and strong currents relative to other areas within SPS and CPS. Overall, the floating kelp bed at this site appears to be stable over the past six years.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.7 Owen Beach (OWB)

The Owen Beach floating kelp monitoring site is located on the northeast shoreline of Point Defiance, just east of the entrance to the Tacoma Narrows in Central Puget Sound. Annual DNR kayak-based monitoring began at Owen Beach in 2020. SCUBA divers from the Point Defiance Zoo and Aquarium monitor underwater transects every summer using the Reef Check protocol (Reef Check Foundation 2024).

Bed Area

Owen Beach was classified as *no trend* for the 3-year recent trend, and *limited data* for the 5-year recent trend and the entire data record trend, because the site only has four years of data (Table 2). No trend is evident in bed area, which ranged from 1.1 ha in 2020 to 1.4 ha in 2023, (Figure 24, Table C7). The location of the bed perimeter varied slightly along both the shallow and deep edges among years (Figure 24).

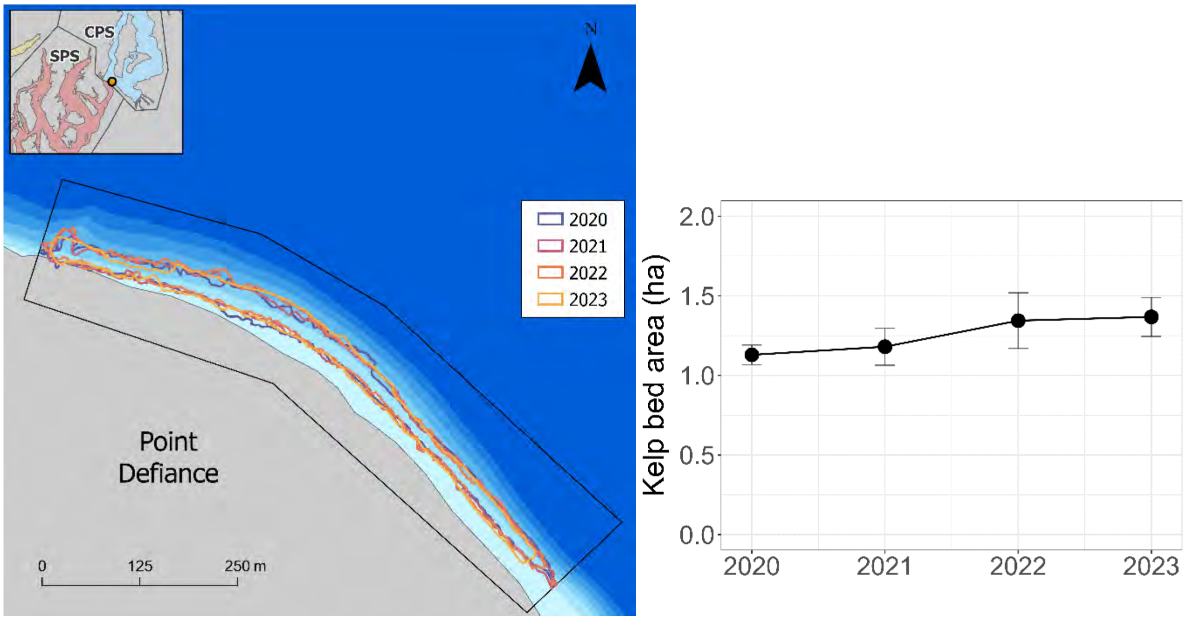

Figure 24. Map of Owen Beach floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Owen Beach mean kelp bed area by year. Error bars are SE (right). Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -4.7 m -5.3 m MLLW between 2020 and 2023 (Figure 25, Table C7). It was not significantly different between years (Welch's ANOVA, $F_{3,26}$ = 0.46, p = 0.71; Figure 25). Mean maximum depth was deepest in 2022 (Table C7). 2022 also had the greatest absolute range of maximum depth (-1.8 m to -6.9 m MLLW).

Mean minimum depth ranged from -1.1 m and -1.6 m MLLW between 2020 and 2023 (Figure 25, Table C7). Minimum depth differed significantly between years (Welch's ANOVA; $F_{3,24}$ = 3.09, p = 0.05), and 2020 significantly differed from 2022 (Games-Howell post hoc test, p = 0.03). The absolute range in minimum depth was shallowest in 2020 (-0.8 m to -1.5 m MLLW) and deepest in 2023 (-0.5 m to -3.9 m MLLW) (Figure 25).

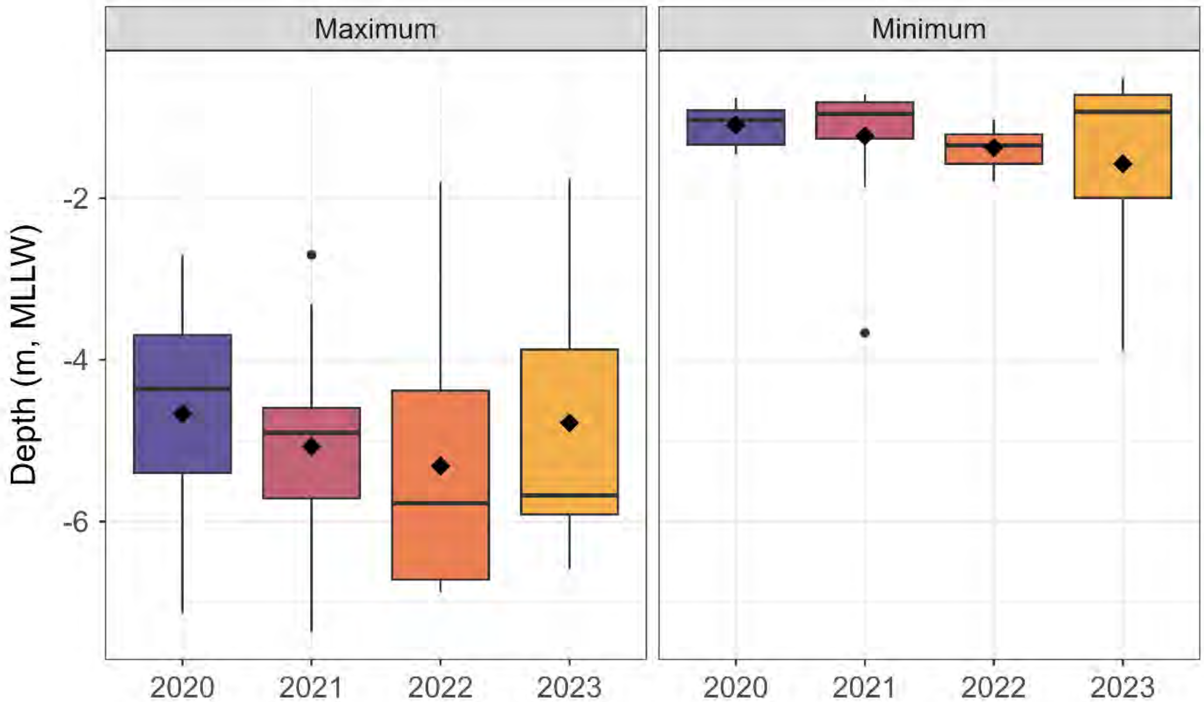

Figure 25. Minimum and maximum depth of floating kelp bed at Owen Beach between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated using spatial comparison of the bed footprint to modelled bathymetry data (Section 2.4). In all years, peak distribution occurred at approximately -3 m MLLW with 40-50% of the bed area shallower than -3 m MLLW (Figure 26). It extended to approximately -10 m MLLW which is relatively deep compared to most SPS sites, yet similar to other sites near the Tacoma Narrows (Figure 8). The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

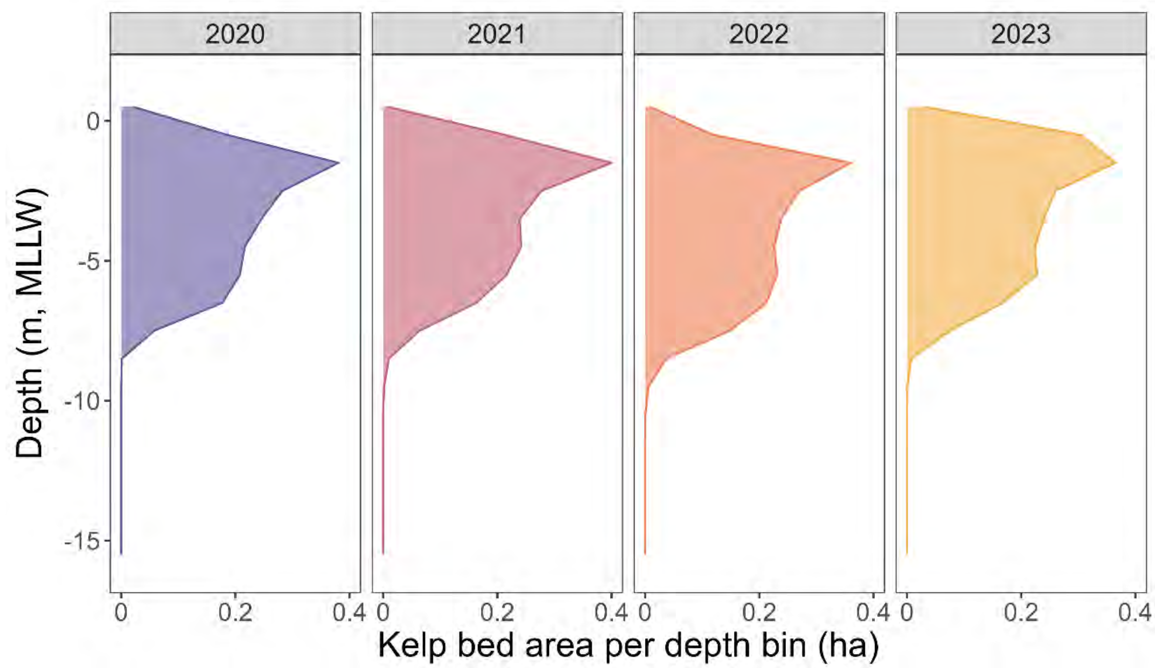

Figure 26. Owen Beach floating kelp bed depth distribution (as area per 1-m depth bin) from 2020-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

The narrow, serpentine pattern in bed perimeters at Owen Beach reflect its bed characteristics; narrow and fringing, with low-density portions. Wide gaps among plants drove relatively large ranges in maximum depth estimates (Figure 25), as some plants are too far from the transect to be included as a maximum depth. Overall, the floating kelp bed at this site appears stable.

3.3.8 Vashon Island East (VHE)

The Vashon Island East floating kelp monitoring site is located on the northeast shoreline of Vashon Island between Dolphin Point and Point Beals in Central Puget Sound. Annual DNR kayak-based monitoring began at the site in 2020. The Vashon Nature Center began kayak and snorkel surveys at the site in 2023. Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024).

Bed Area

Vashon Island East was classified as *increasing* for the 3-year recent trend, and *limited data* for the 5-year recent trend and the entire data record trend. The site has four years of data (Table 2). Bed area increased approximately one hectare between 2020 (2.6 ha) and 2023 (3.4 ha) (Figure 27, Table C8). Most of the perimeter variation between years is concentrated on the deep edge of the bed (Figure 27), it was driven by isolated individuals or clusters on the deep side of the site that sometimes fell within the distance threshold of the main perimeter and sometimes constituted individual perimeters. In 2022 and 2023, the northwest end of the bed was more dense and was mapped as part of the main bed, unlike in 2020 and 2021 where plants on the northwest end were mapped as individual plants or a separate bed.

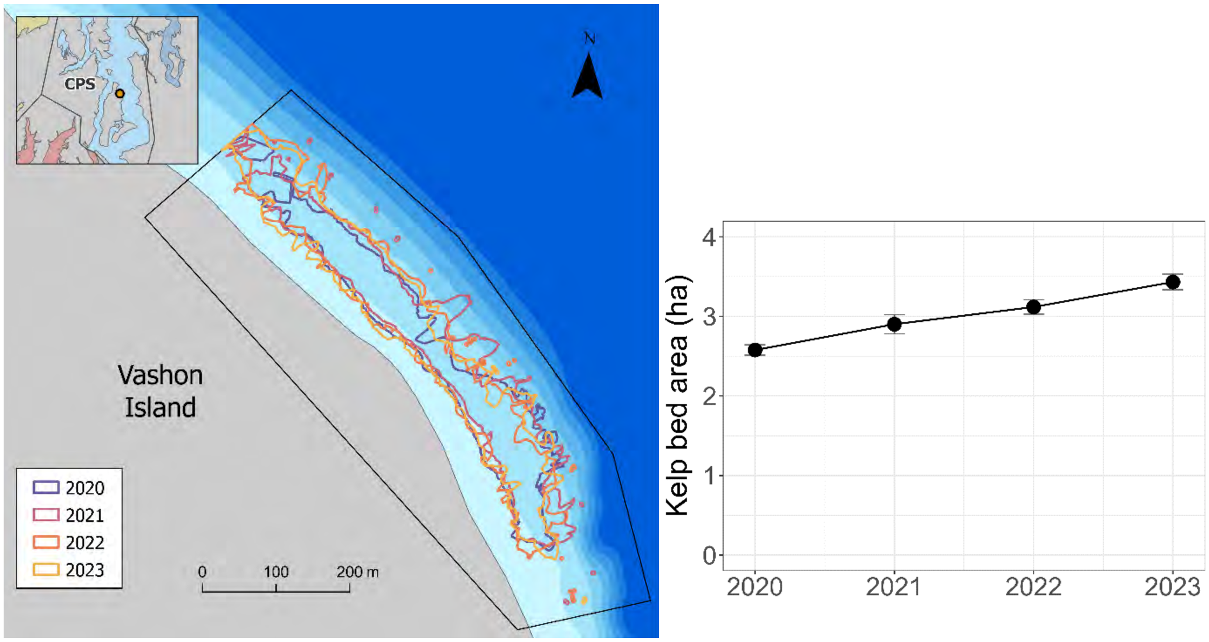

Figure 27. Map of Vashon Island East floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Vashon Island East mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -2.8 m to -3.7 m MLLW between 2020 and 2023 (Figure 10, Table C8). Mean maximum bed depth was deepest in 2021 and shallowest in 2020 (Table C8). Maximum depth was not significantly different among years (Welch's ANOVA, $F_{3,21} = 1.75$, $p = 0.19$; Figure 28). The absolute range of maximum depths was slightly larger in 2021 (-1.7 to -6.8 m MLLW) and 2023 (-1.0 to -6.0 m MLLW) compared to 2020 and 2021. The outliers in maximum depth estimates could be attributed to the solitary deep plants that in some locations occurred more than 25 m waterward of the main bed perimeter (Figure 28).

Mean minimum depth ranged from -0.8 m and -1.3 m MLLW (Figure 10, Table C8). Mean minimum depth differed significantly between years (Welch's ANOVA, $F_{3,21} = 3.35$, $p = 0.04$), with 2022 significantly different than 2023 (Games-Howell post-hoc test; $p = 0.03$). Mean minimum bed depth was shallowest in 2021 and deepest in 2022 (Table C8). The absolute range of minimum depth was smallest in 2021 (-0.7 to -1.4 m MLLW) compared to the other years.

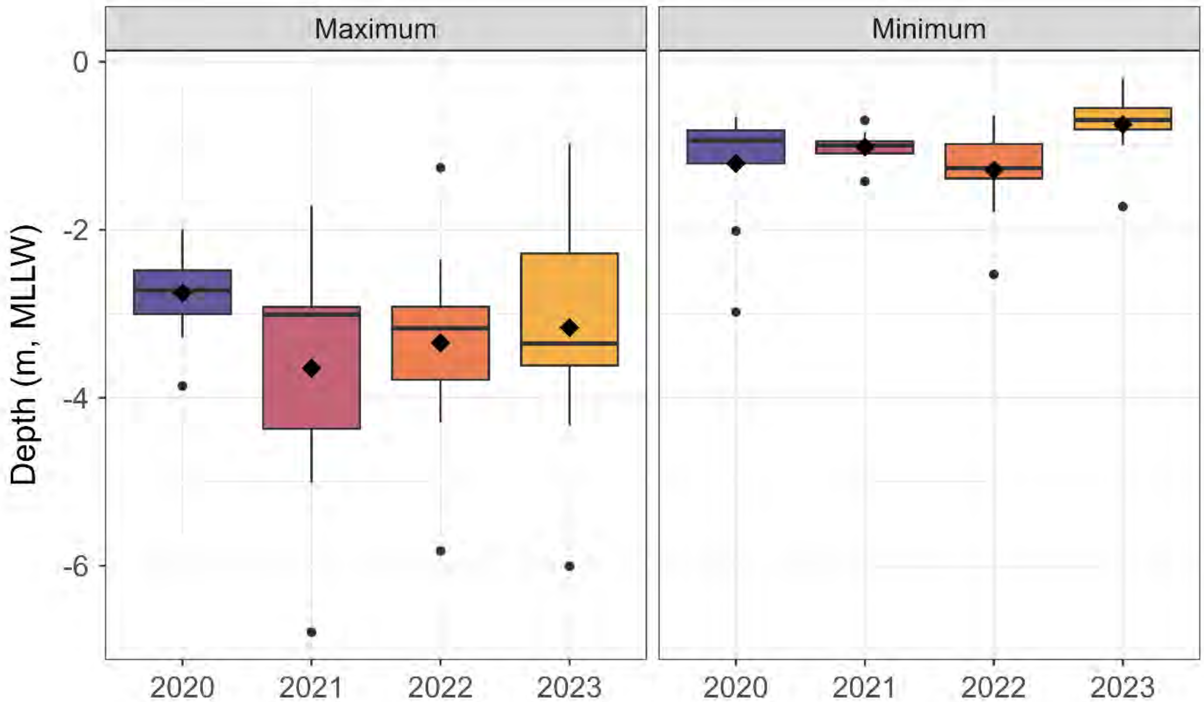

Figure 28. Minimum and maximum depth of floating kelp bed at Vashon Island East between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Vashon Island East, a consistent distribution pattern was evident in all years, with a peak in bed area at approximately -3 m MLLW and a limited portion (1% or less) of the bed deeper than -6 m MLLW (Figure 29). The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

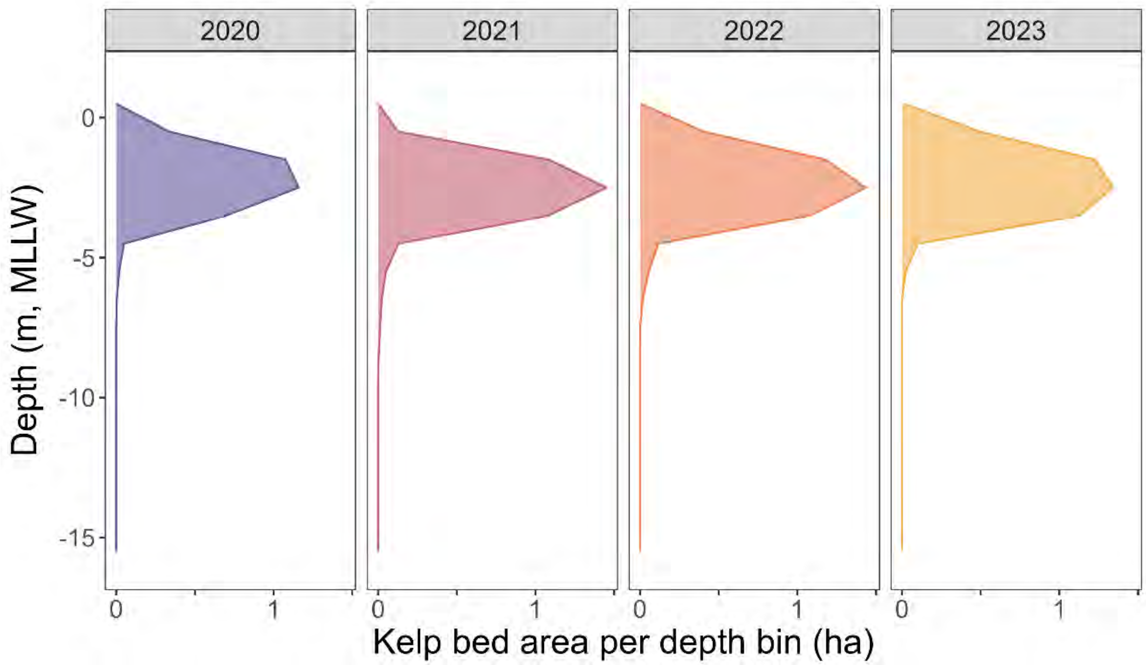

Figure 29. Vashon Island East floating kelp bed depth distribution (as area per 1-m depth bin) from 2020-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

At Vashon Island East, solitary plants are often found growing deeper than the main floating kelp bed. Yearly fluctuations in density influenced whether isolated plants were included in the bed perimeter (< 25 m away) or were mapped as solitary perimeters, which accentuated differences among years in bed area estimates. Despite the low density on the deep edge of the bed, bed area increased over three years. Changes in density also influenced maximum bed depth estimates because plants that were more than five meters from the transect were not included in the depth measurement.

3.3.9 Lincoln Park (LIP)

The Lincoln Park floating kelp monitoring site is located on the northern shoreline of Point Williams, south of downtown Seattle in Central Puget Sound. It lies adjacent to the Fauntleroy neighborhood and to a public park managed by the City of Seattle since 1922. Annual DNR kayak-based monitoring began at the site in 2020. Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024).

Bed Area

Lincoln Park was classified as *no trend* for the 3-year recent trend. Because the site has four years of data, it was classified as *limited data* for the 5-year recent trend and the entire data record (Table 2). In all monitoring years, the floating kelp bed at the Lincoln Park site has consisted of two main lobes, located at the northern and southern ends of the site, with scattered plants in between. Floating kelp bed area has been relatively consistent since monitoring began (1.5-1.7 ha) (Figure 30, Table C9). The location of the deep edge of the northern lobe differed from year-to-year, while the southern lobe varied annually at the shallow edge (Figure 30). The distance between the two main lobes fluctuated from year to year. In 2020 the two lobes were separated by gaps and a small patch. In 2021, the lobes merged via a narrow band of floating kelp. In 2022 and 2023, the lobes were separated by a small gap.

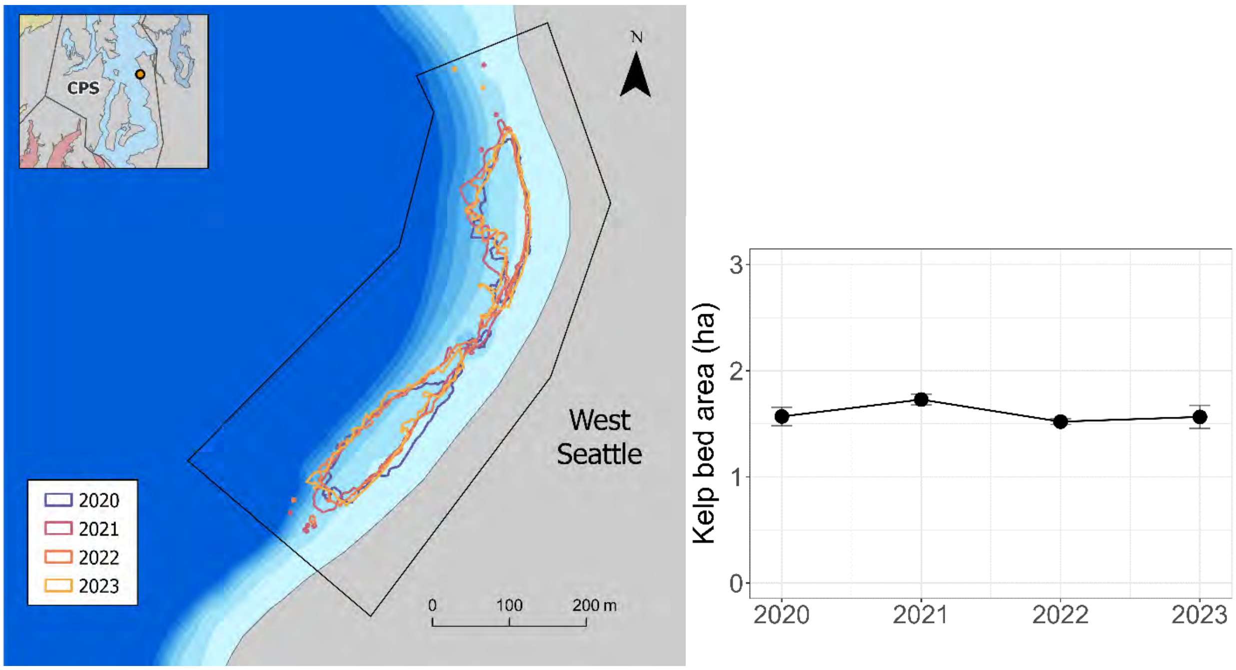

Figure 30. Map of Lincoln Park floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Lincoln Park mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -3.3 to -3.7 m MLLW between 2020 and 2023 (Figure 10, Table C9). It was not significantly different among years (Welch's ANOVA, $F_{3,22} = 0.95$, $p = 0.43$; Figure 31), however, estimates deepened slightly between 2020 and 2023 (Table C9). The absolute range of maximum depths was large for every year but was smallest in 2023 (range = -1.0 to -6.2 m MLLW in 2020, -1.2 to -6.3 m MLLW in 2021, -1.3 to -6.3 m MLLW in 2022, -2.4 to -6.9 m MLLW in 2023).

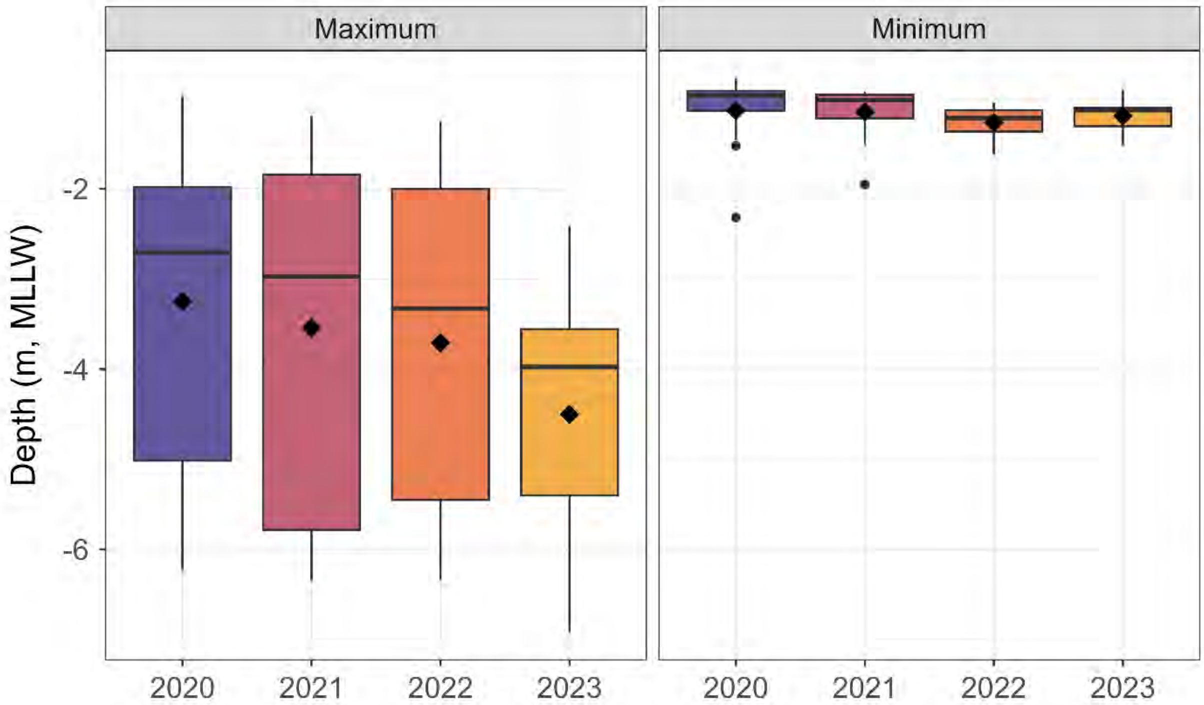

Figure 31. Minimum and maximum depth of floating kelp bed at Lincoln Park between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

Pronounced spatial variation was evident in maximum depth across the site (Figure 31, Figure 32, Figure 33). Maximum depth was deepest within the two main lobes, reaching -6 m MLLW or deeper. It was considerably shallower along the boundaries, approximately -2 m MLLW or shallower. Each year, five transects along the boundaries of the main beds (transects 1, 2, 6, 7, 13) had only one plant present (recorded as both the minimum and maximum depth) or the deepest and shallowest plants were very close together (Figure 32 and Figure 33; Table D1).

Minimum bed depth ranged from -1.1 to -1.3 m MLLW (Figure 31 and Table C9). It was not significantly different among years (Welch's ANOVA, $F_{3,22} = 0.55$, $p = 0.65$). Mean minimum depth was slightly deeper in 2022 and 2023 than it was in 2020 and 2021 (Table C9).

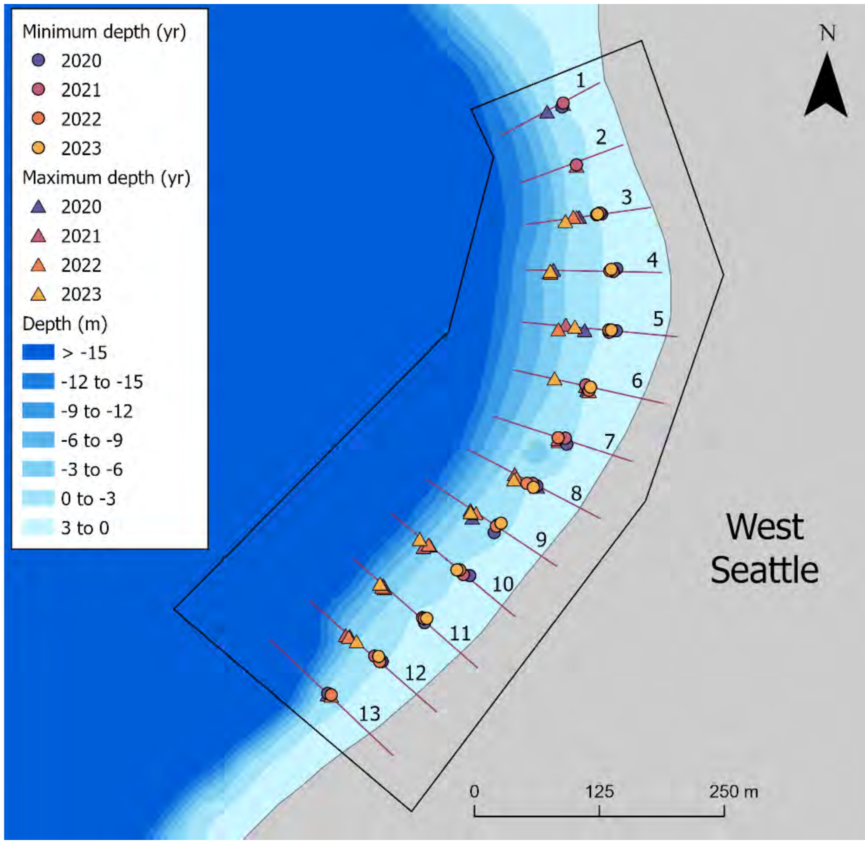

Figure 32. Location map of each minimum (circle) and maximum (triangle) depth measurement along 13 transects at Lincoln Park in 2020 – 2023.

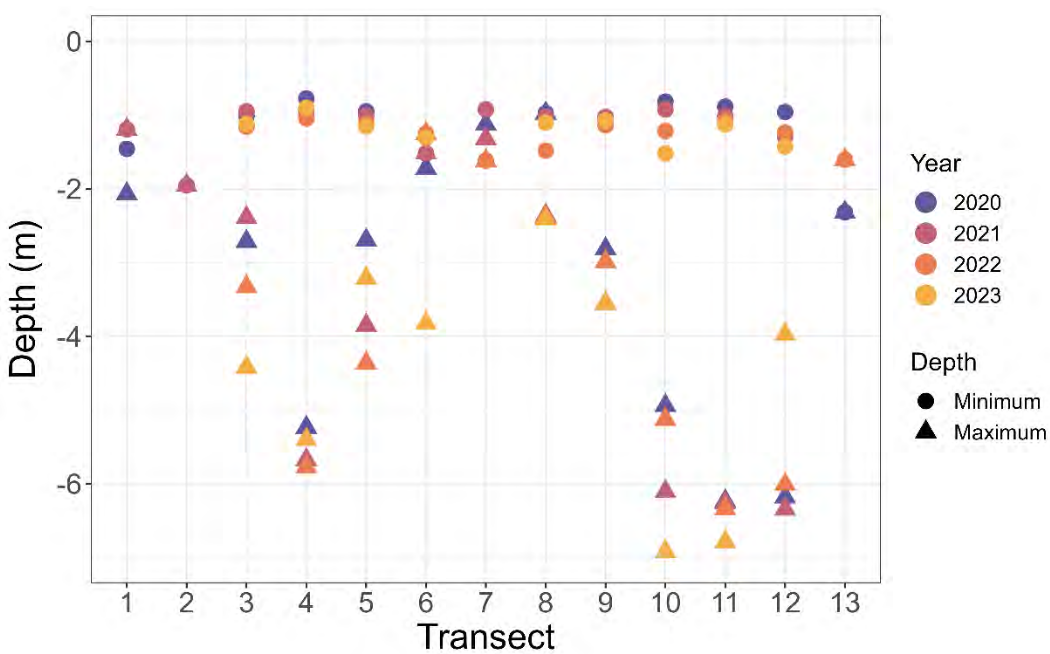

Figure 33. Minimum (circle) and maximum (triangle) depths along each transect at Lincoln Park in 2020-2023.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Lincoln Park, a consistent distribution pattern was evident in all years, with 60-65% of bed area shallower than -3 m MLLW and a limited portion of the bed extending to approximately -9 m MLLW (Figure 34). Year-to-year differences in area occurred around the peak depth, at approximately -3 m. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

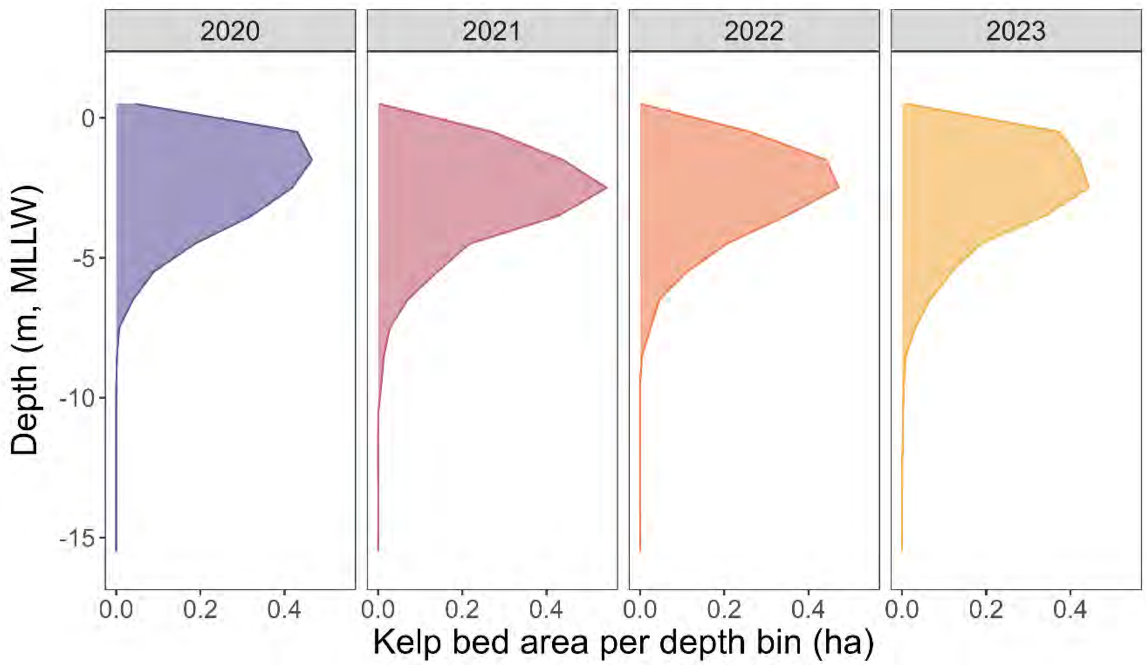

Figure 34. Lincoln Park floating kelp bed depth distribution (as area in ha per 1 m depth bins) from 2020-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

<u>Interpretation of site patterns and trends</u>

Studies as early as 1915 show that the bed at Lincoln Park has persisted for over a century (Rigg 1915). In the limited four-year kayak monitoring record at Lincoln Park, the bed shape, area, and depth distribution have remained remarkably consistent. Overall, the site appears to be stable. Pronounced, persistent spatial differences exist; two lobes extend relatively deep, punctuated by gaps and sparse areas.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see <u>study fact sheet</u> for more information).

3.3.10 Magnolia Bluff (MAG)

The Magnolia Bluff floating kelp monitoring site is located on the northeast shoreline of Elliot Bay, north of downtown Seattle and west of Elliot Bay Marina in Central Puget Sound. The shoreline experiences relatively large waves due to its large fetch to the south, the predominant wind direction. Annual DNR kayak-based monitoring began at the site in 2020. SCUBA divers from Puget Sound Restoration Fund monitor underwater transects every summer using Reef Check protocols (Reef Check Foundation 2024). Seattle Aquarium surveys the benthic habitat with underwater remotely operated vehicles (ROVs).

Bed Area

Magnolia Bluff was classified as *increasing* for the 3-year recent trend. Because the site only has four years of data, it was classified as *limited data* for the 5-year recent trend and the entire data record (Table 2).

In all monitoring years, the majority of the floating kelp bed was located along the eastern portion of the site, with scattered plants and clusters found along the western portion (Figure 35). Bed area ranged from 0.4-0.6 ha between 2020 and 2022. In 2023, it increased to 2.3 ha, four times its previous extent (Figure 35, Table C10). The bed perimeter in 2023 encompassed the previous year's perimeters on all sides and extended further west. However, density was lower in the expanded perimeter. Additionally, along the western portion of the site, the number of floating kelp clusters increased in 2023. Despite the major increase in area over the last 3 years, the 3-year regression result was not significant ($p = 0.28$). We dismissed the statistical result due to the limited time span of the dataset and the non-linear pattern of change.

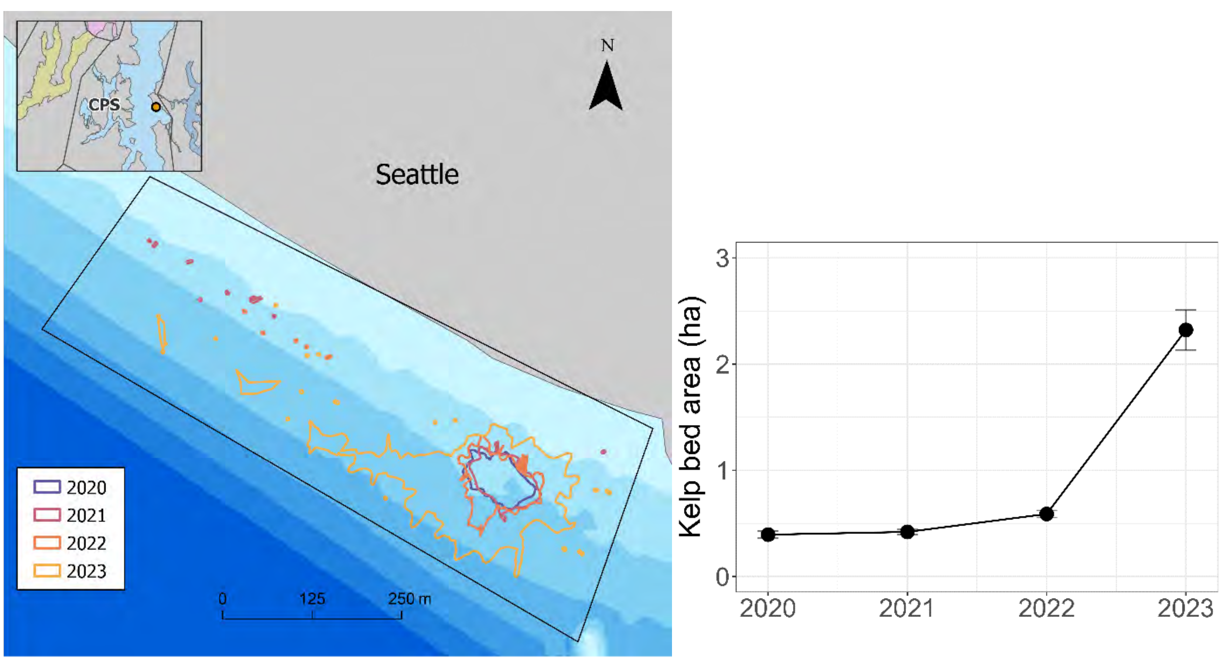

Figure 35. Map of Magnolia Bluff floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Magnolia Bluff mean kelp bed area by year. Error bars are SE (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -3.0 m to -6.1 m MLLW between 2020 and 2023 (Figure 36, Table C10). Mean maximum bed depth differed significantly between years (Welch's ANOVA, $F_{3,13} = 11.20$, $p < 0.001$), and 2023 significantly differed from 2021 ($p < 0.001$) and 2022 ($p = 0.003$) (Games-Howell post-hoc tests). Mean maximum depth was deepest in 2023, almost 3 m deeper than previous years (Figure 36, Table C10). The range of absolute maximum bed depth is large in all years but largest in 2023 (-1.0 to -5.4 m MLLW in 2020, -1.4 to -4.4 m MLLW in 2021, -1.9 to -4.6 m MLLW in 2022, -2.4 to -8.0 m MLLW in 2023) (Figure 36).

Mean minimum depth ranged from -2.3 m to -3.1 m MLLW (Figure 36, Table C10). Mean minimum depth was not significantly different among years (Welch's ANOVA, $F_{3,13} = 1.11$, $p = 0.38$). (Figure 36, Table C10) but was deepest in 2023 and shallowest in 2022 (Table C10). Similarly, the absolute range in minimum depth was largest in 2023 (-1.1 to -7.4 m MLLW) and smallest in 2022 (-1.9 to -3.0 m MLLW).

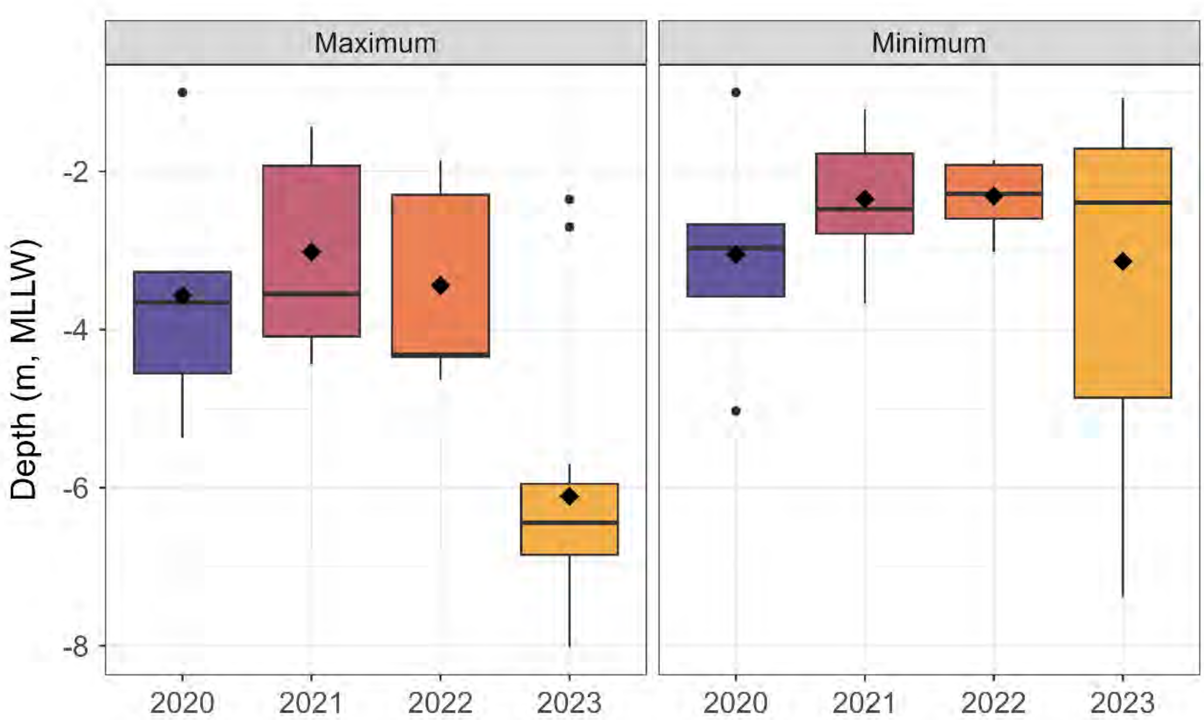

Figure 36. Minimum and maximum depth of floating kelp bed at Magnolia Bluff between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

There was a spatial pattern in maximum depth across the site; the deepest bed depths occurred on the east side of the site, which is more apparent in 2020 – 2022. The locations of each minimum and maximum depth point illustrate that kelp was absent on many of the 18 transects or only one individual was present (Figure 37 and Figure 38, Tables D1 and D2). In contrast to the other survey years, 2023 had only two transects that were absent of floating kelp. Additionally, on transects with floating kelp present in 2023 (16 of 18 transects), floating kelp was recorded deeper than in previous years.

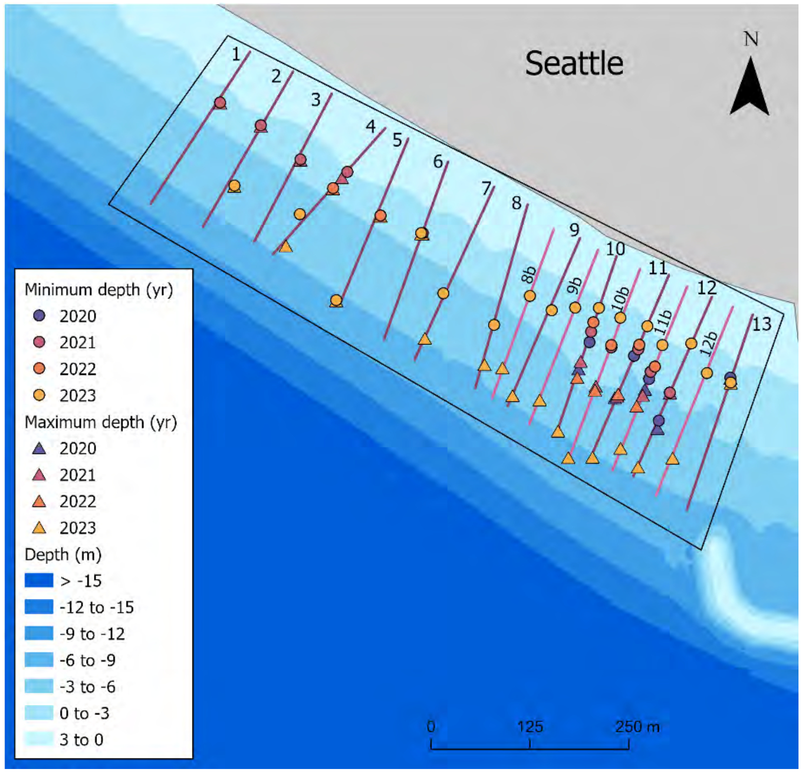

Figure 37. Location map of each minimum (circle) and maximum (triangle) depth measurement along 13 transects at Magnolia Bluff in 2020 – 2023.

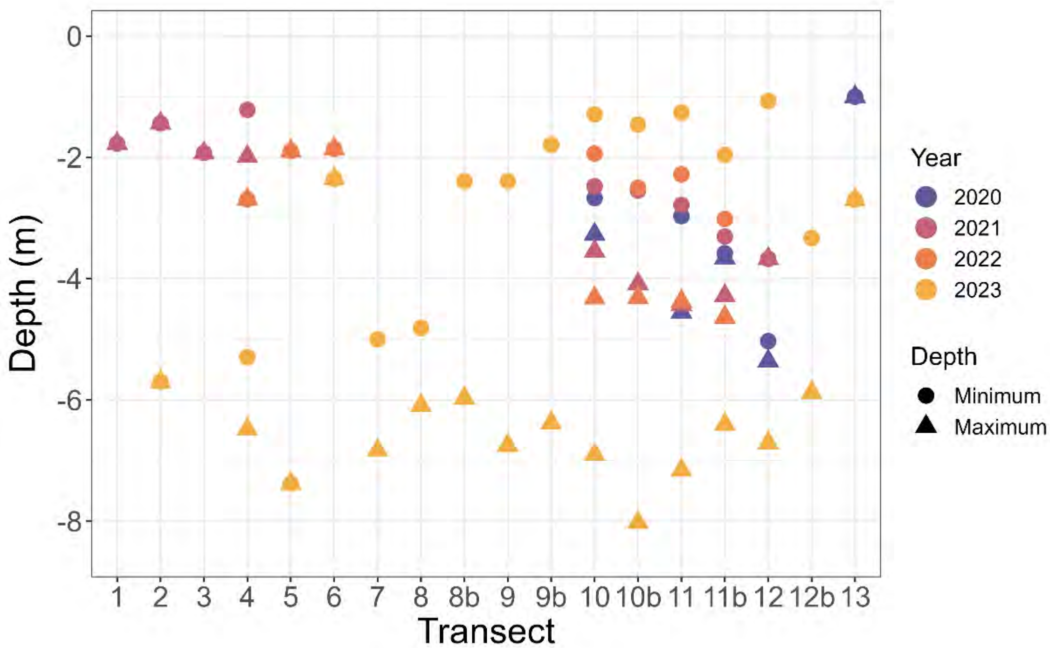

Figure 38. Minimum (circle) and maximum (triangle) depths along each transect at Magnolia Bluff in 2020-2023.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Magnolia Bluff, between 2020 and 2022, a consistent pattern was evident in depth distribution, with a single, sharp peak occurring around -3 m MLLW (Figure 39). In 2023, floating kelp bed area expanded substantially throughout the depth range, the distribution peak shifted to approximately -5 m MLLW and 20% of the bed area was deeper than -6 m MLLW. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

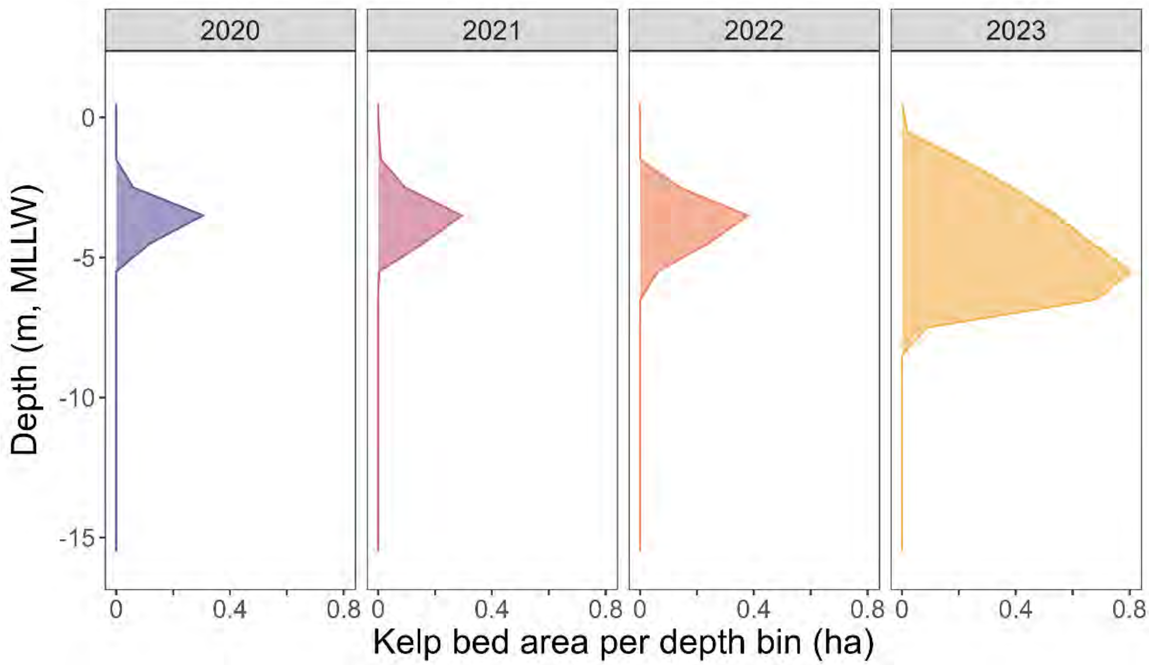

Figure 39. Magnolia Bluff floating kelp bed depth distribution (as area per 1-m depth bin) from 2020-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

Floating kelp bed area at this site increased fourfold in 2023 and maximum depth increased. Patterns in density were evident. The bed was most dense at the core of the 2023 perimeter, where floating kelp occurred in 2020-2022. In contrast, density was relatively low in newly expanded portions of the bed.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.11 Wing Point (WNG)

The Wing Point floating kelp monitoring site is located on the southeastern side of Bainbridge Island at the entrance to Eagle Harbor in Central Puget Sound. Wing Point is the site of a floating kelp bed that was lost around 2017 (Berry 2017). DNR began monitoring at Wing Point by small boat in 2020. SCUBA divers from Puget Sound Restoration Fund monitor underwater transects every summer using Reef Check protocols (Reef Check Foundation 2024).

Bed area and depth distribution

Wing Point was classified as *no floating kelp* for the 3-year and 5-year recent trend and *total loss* for the entire data record trend. Multiple information sources recorded an extensive and persistent floating kelp bed at Wing Point prior to 2017. From 2020 to 2023, boat-based surveys found that floating kelp was absent at the site (Figure 40).

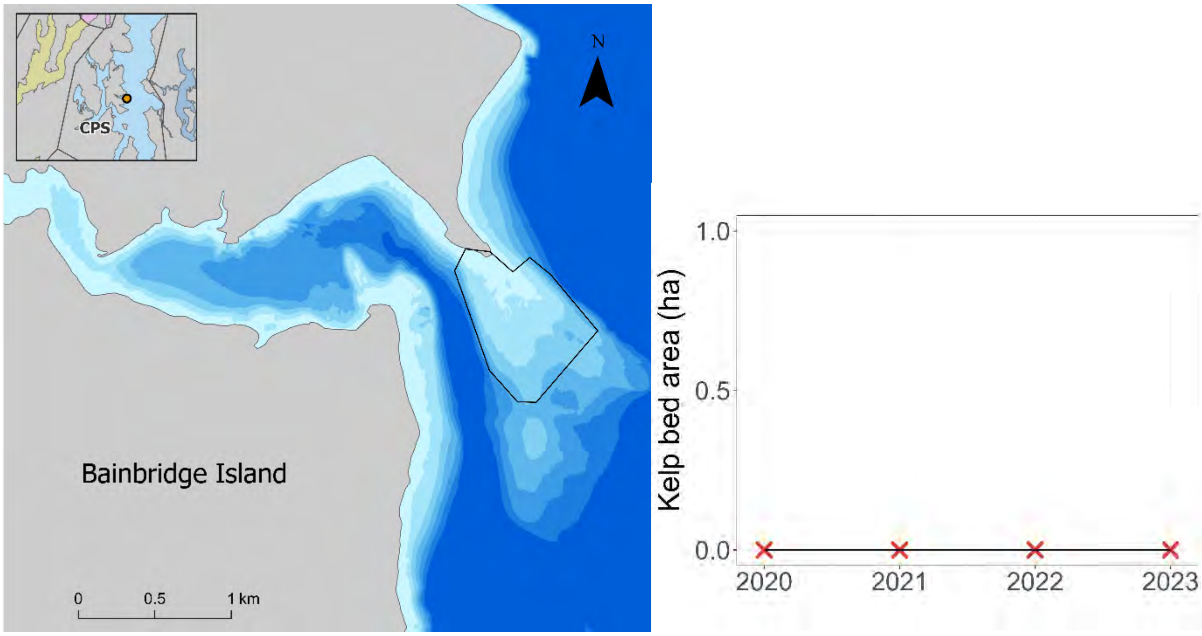

Figure 40. Map of Wing Point floating kelp monitoring site. Black box represents the site boundary (left) and graph of Wing Point kelp bed area by year. Red x's represent no floating kelp present (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Interpretation of site patterns and trends

Historical navigation charts depicted an extensive, persistent floating kelp at Wing Point since European settlement. In recent decades, major concerns have been raised about the bed's condition. In 2016, only a few isolated plants were observed, most of which lacked blades (Berry 2017). We estimate that floating kelp has been persistently absent from the site since 2017.

The disappearance of floating kelp from Wing Point occurred around the time of an extreme marine heatwave, so elevated water temperatures could have contributed to losses. Based on observations during field surveys, other suspected stressors at the site include damage by boat propellers, sedimentation, grazing and mechanical damage by kelp crabs, low genetic diversity, anthropogenic nutrient input, and recruitment limitation.

The disappearance of floating kelp from Wing Point represented the disappearance of the final remaining bed along the shorelines of Bainbridge Island. Floating kelp occurred historically along the eastern shorelines of Bainbridge Island, as well as along the northern and southern passes.

Future work is planned to synthesize data about the extent of the floating kelp bed and related environmental conditions at Wing Point.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.3.12 Point Jefferson (JEF)

The Point Jefferson monitoring site is located on the southern shoreline of Point Jefferson, east of the entrance to Port Madison in Central Puget Sound. DNR began monitoring at Point Jefferson by small boat in 2020. SCUBA divers from Puget Sound Restoration Fund conduct bull kelp restoration experiments and monitor underwater transects every summer using Reef Check protocols (Reef Check Foundation 2024).

Bed area and depth distribution

Point Jefferson was classified as *no floating kelp* for the 3-year and 5-year recent trend and *total loss* for the entire data record trend. DNR began monitoring after floating kelp disappeared from the site. From 2020 to 2023, boat-based surveys found that floating kelp was absent at the site (Figure 41).

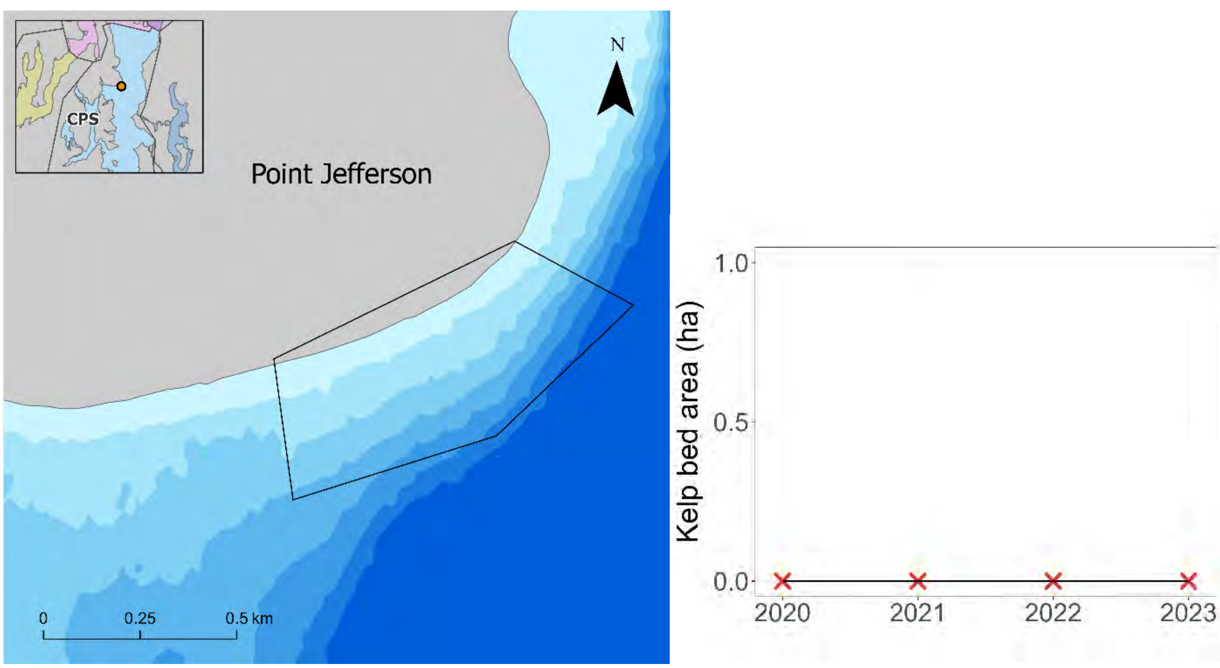

Figure 41. Map of Point Jefferson floating kelp monitoring site. Black box represents the site boundary (left) and graph of Point Jefferson kelp bed area by year. Red x's represent no kelp present (right). Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Interpretation of site patterns and trends

An 1868 US Coast Survey navigation chart depicted a floating kelp bed along the shoreline adjacent to Point Jefferson. The Suquamish Tribe and locals report that an extensive floating kelp bed occurred along the shoreline historically and disappeared from the site decades ago. Floating kelp has not been observed in recent decades, making this a site of total loss. Indigenous and local knowledge suggest that one suspected stressor is propeller damage, as boats commonly drove through the bed. Detailed research, including analyzing historical data records, could enrich our understanding of temporal trends and precise timing of disappearance.

The Puget Sound Restoration Fund is conducting restoration experiments at Point Jefferson which will provide insight into site suitability.

3.3.13 Hansville (HAN)

The Hansville floating kelp monitoring site is located on the north end of Kitsap Peninsula between Foulweather Bluff and Point No Point in Admiralty Inlet. The site is adjacent to the Hansville community and west of the Norwegian Point County Park. Annual DNR kayak-based monitoring began at the site in 2020 but the 2020 bed area data was excluded from analysis due to uncertainties.

Bed Area

Hansville was classified as *increasing* for the 3-year recent trend. It is classified as *limited data* for the 5-year recent trend and the entire data record because the site only has three years of data (Table 2). Floating kelp bed area increased 35% between 2021 and 2023, from 4.2 ha to 5.5 ha (Figure 42, Table C11). The expansion was concentrated along the deep edge of the bed and along the eastern boundary, two areas with sparse patches of floating kelp (Figure 42).

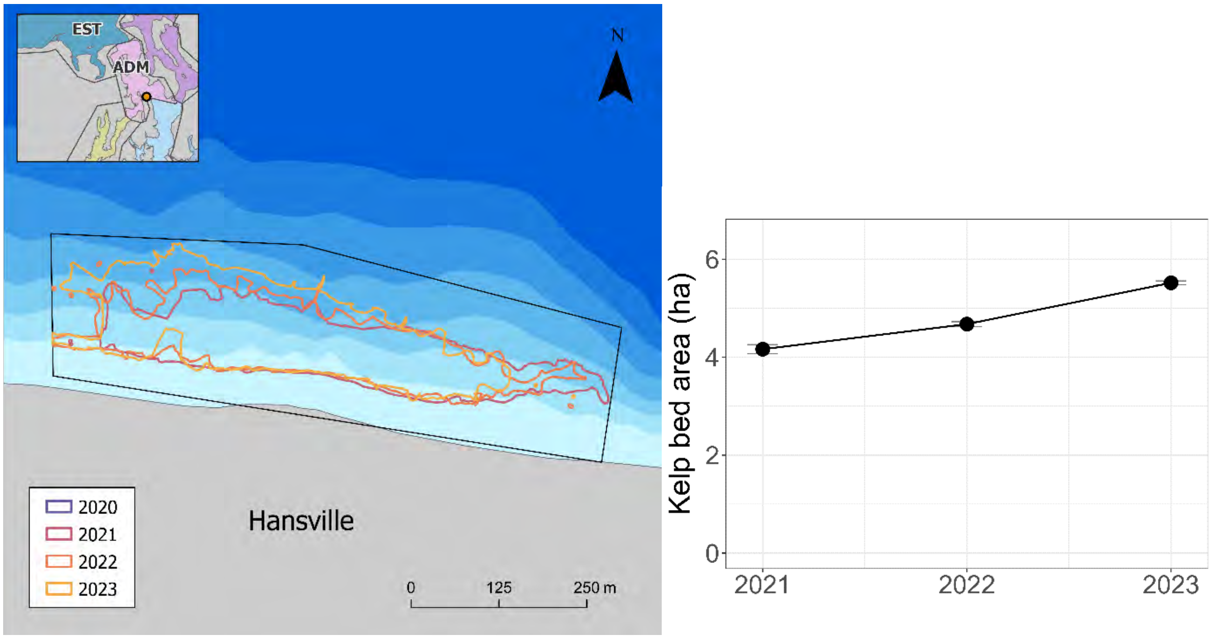

Figure 42. Map of Hansville floating kelp bed perimeters, colored by year. Black box represents the site boundary (left) and graph of Hansville mean kelp bed area by year. Error bars are SE (right). Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -3.0 m to -6.1 m MLLW between 2020 and 2023 (Figure 43, Table C11). During this time period, it deepened progressively (Figure 43, Table C11) and differed significantly between years (Welch's ANOVA, $F_{3,23} = 6.50$, $p = 0.002$). Mean maximum depth in 2022 significantly differed from 2020 (Games-Howell post-hoc test, $p = 0.003$).

Mean minimum depth ranged from -1.6 to -1.9 m MLLW between 2020 and 2023 (Figure 43, Table C11). Mean minimum bed depth was not significantly different among years (Welch's ANOVA, $F_{3,25} = 0.31$, $p = 0.82$), though the mean minimum depth in 2022 was slightly shallower than the other years.

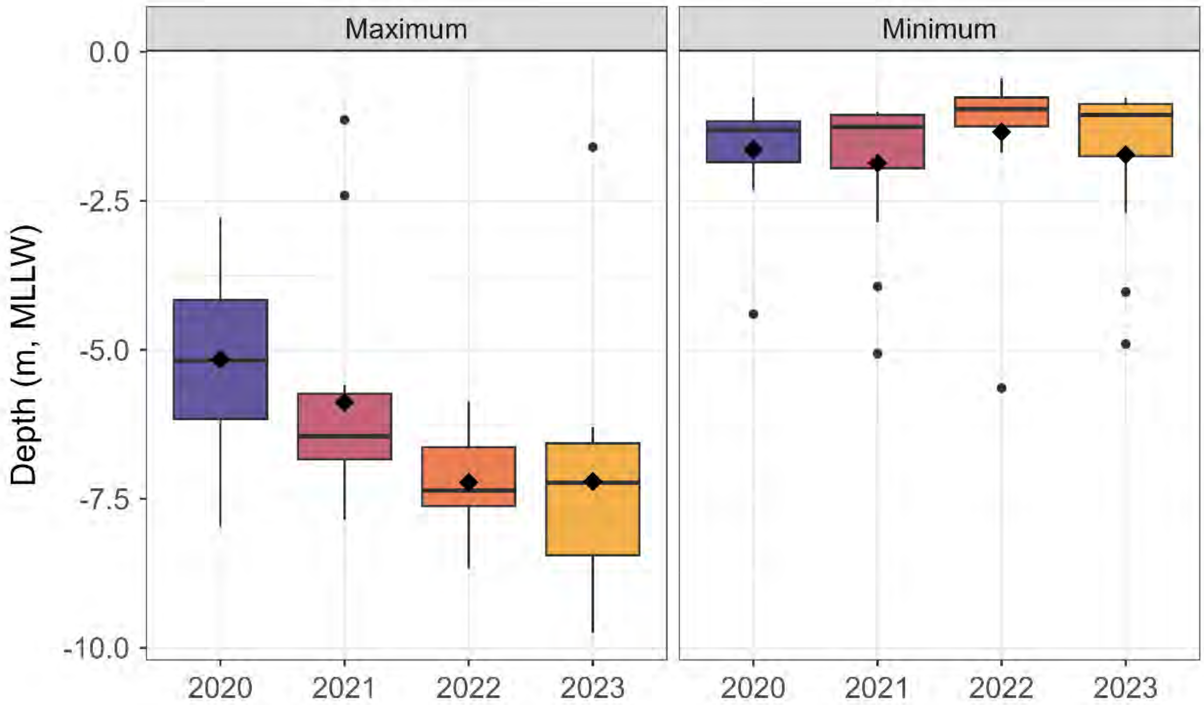

Figure 43. Minimum and maximum depth of floating kelp bed at Hansville between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Hansville, depth distribution was similar in 2021 and 2022, with a single, sharp peak around -3 m MLLW (Figure 44). In contrast, depth distribution in 2023 showed two peaks, a shallow peak at approximately -3 m MLLW, and a deeper peak at approximately -7 m MLLW. In 2023, 30% of the bed area was deeper than -6m. The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

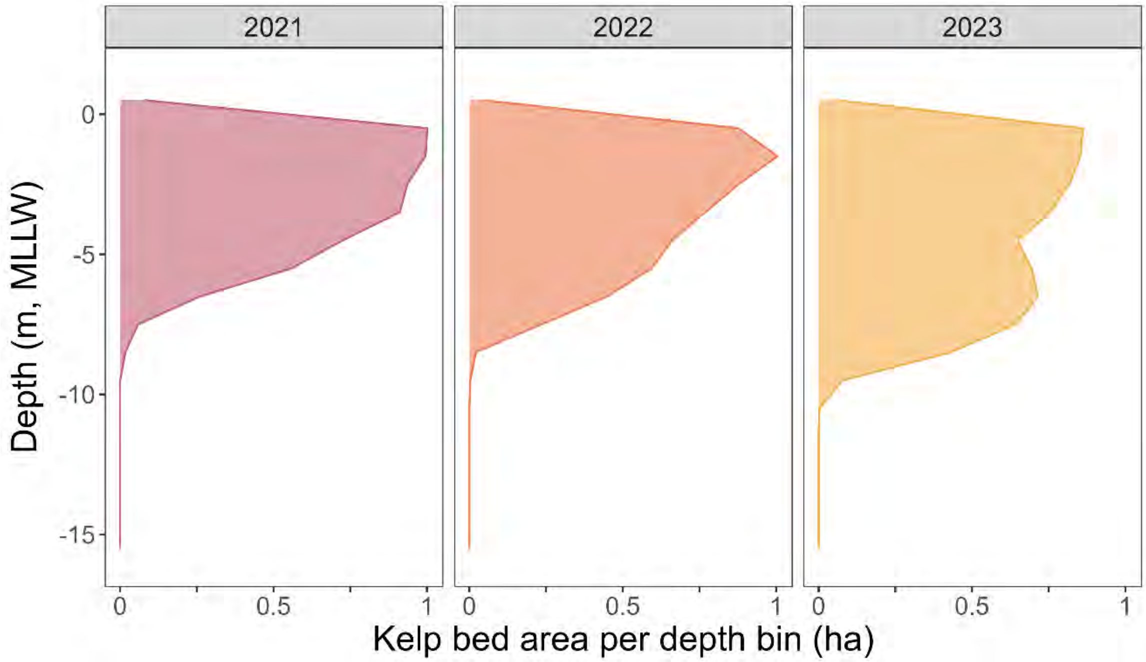

Figure 44. Hansville floating kelp bed depth distribution (as area per 1-m depth bin) from 2021-2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

Surveys show that floating kelp bed at Hansville has increased over the last three years, however this temporal record is extremely limited.

Bed area could be under reported in 2023 due to subtle timing related to currents. Near the end of the survey window, kayakers observed a small bed on the eastern side of the site, which was not captured during the survey window. Future surveys will further consider survey timing.

3.4 Focus Study Sites

Floating kelp bed surveys at focus sites support investigations into targeted scientific and management topics. This section presents bed area and depth distribution estimates at individual focus sites that were surveyed in 2023.

3.4.1 Edmonds (EDM)

The floating kelp monitoring site is located north of the Edmonds ferry terminal and the Edmonds Underwater Park, which lies north of Edwards Point in Central Puget Sound. DNR's annual kayak-based monitoring of bed depth began at the site in 2020 (except 2022). In 2023, floating kelp bed perimeters were added to the DNR monitoring effort. In addition to DNR's annual monitoring, the Snohomish County MRC and NW Straits have conducted kayak surveys at the site annually since 2015 (Ledbetter and Berry 2023, NW Straits 2024). Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024). Scientists from NOAA conduct ecological research on rockfishes at the site.

Bed Area

In 2023, floating kelp bed area was 4.2 ± 0.16 ha. In addition to a large, consolidated bed, individual bulbs occurred on the southern edge of the site (Figure 45, Table C12).

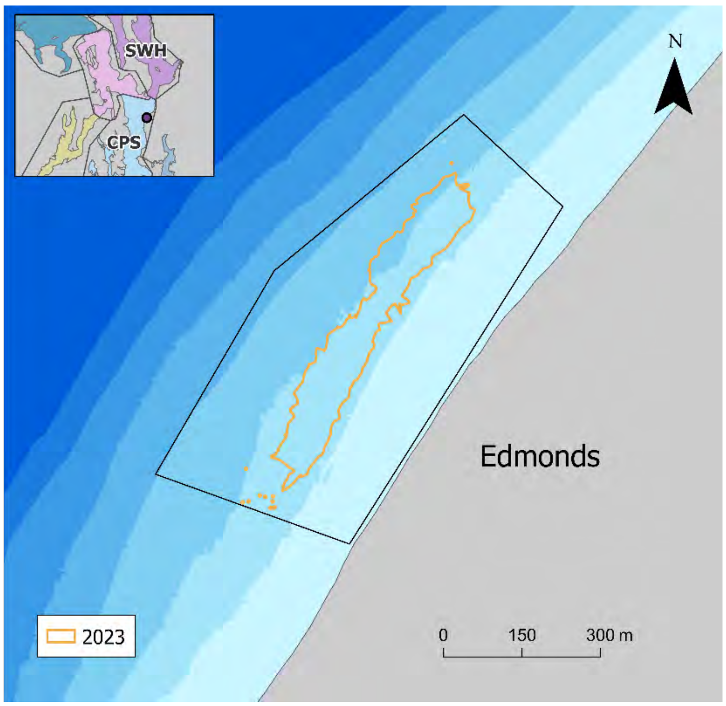

Figure 45. Map of Edmonds floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -4.2 m to -4.9 m MLLW in 2020, 2021 and 2023 (Figure 46, Table C12). Mean maximum bed depth was slightly deeper in 2023 than in 2020 and 2021 (Figure 46, Table C12) but they were not significantly different (Welch's ANOVA, $F_{2,24} = 1.56$, $p = 0.23$). The absolute range of maximum depths was larger in 2020 (-1.1 to -5.3 m MLLW) than in 2021 (-3.6 to -5.6 m MLLW) and 2023 (-3.7 to -6.1 m MLLW).

Mean minimum depth ranged from -2.4 m to -2.9 m MLLW (Figure 46, Table C12). Mean minimum bed depth was not significantly different among years (Welch's ANOVA, $F_{2,22} = 0.20$, $p = 0.82$) but was shallower in 2020 than in 2021 and 2023. The absolute minimum depth range was slightly smaller in 2023 (-1.4 to 3.8 m MLLW) than in 2020 (-0.5 to -4.0 m MLLW) and 2021 (-0.9 to -5.3 m MLLW).

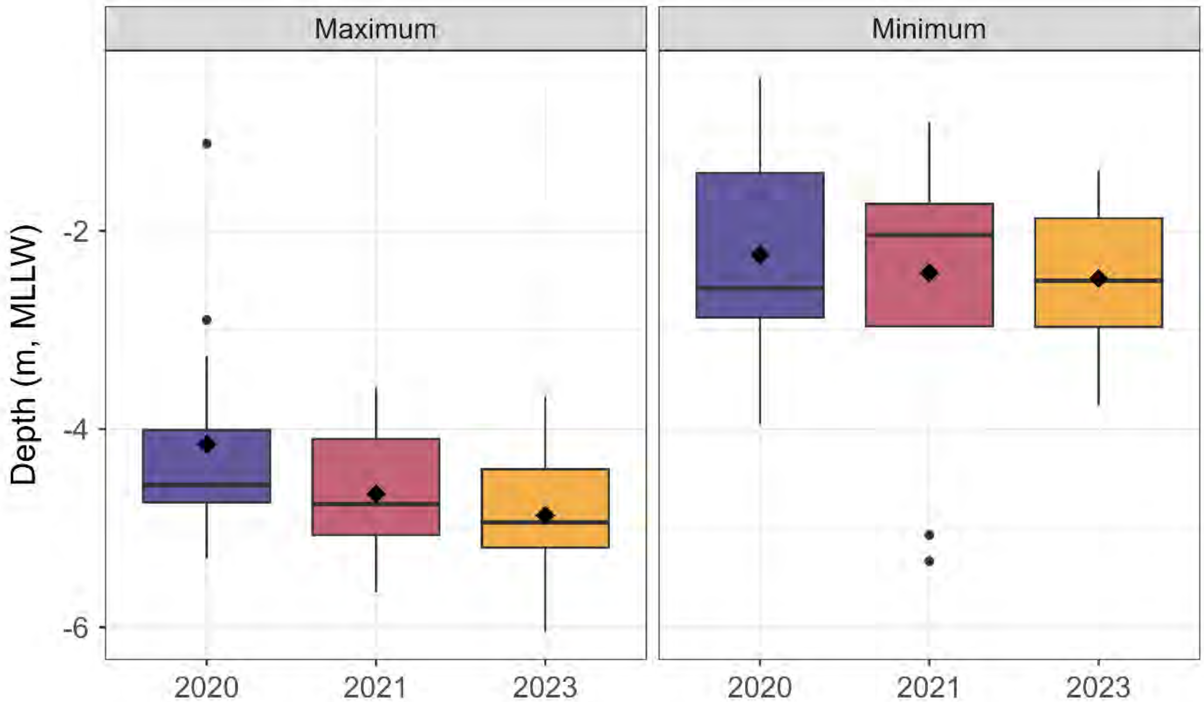

Figure 46. Minimum and maximum depth of floating kelp bed at Edmonds between 2020, 2021, and 2023. Circular points represent outliers and diamond points represent the mean.

Floating kelp was shallower on the south end of the site than on the north end of the site in 2020 and 2021 but not in 2023 (Figure 47). Minimum and maximum bed depth varied year to year along each transect (Figure 48, Table D1).

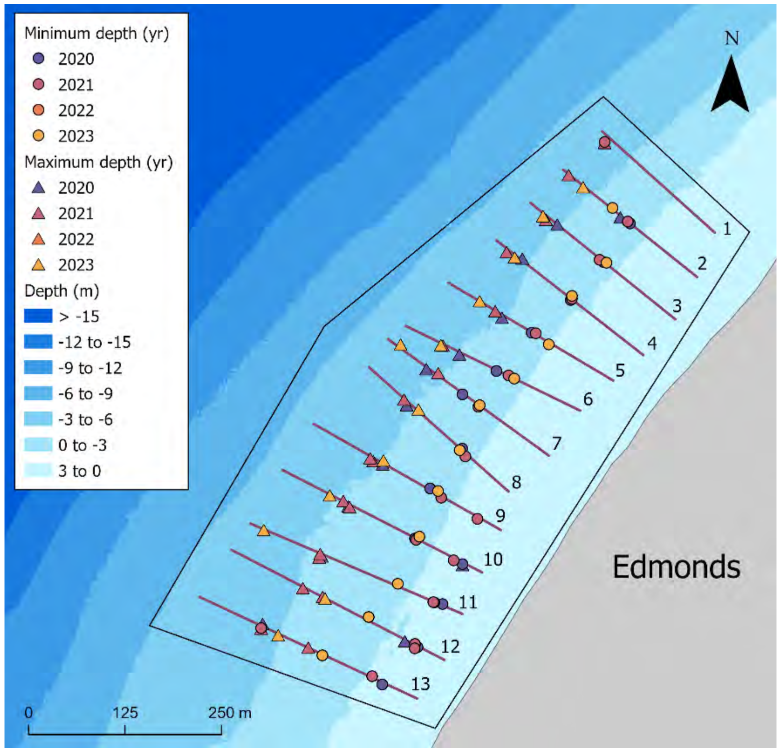

Figure 47. Location map of each minimum (circle) and maximum (triangle) depth measurement along 13 transects at Edmonds in 2020, 2021, and 2023.

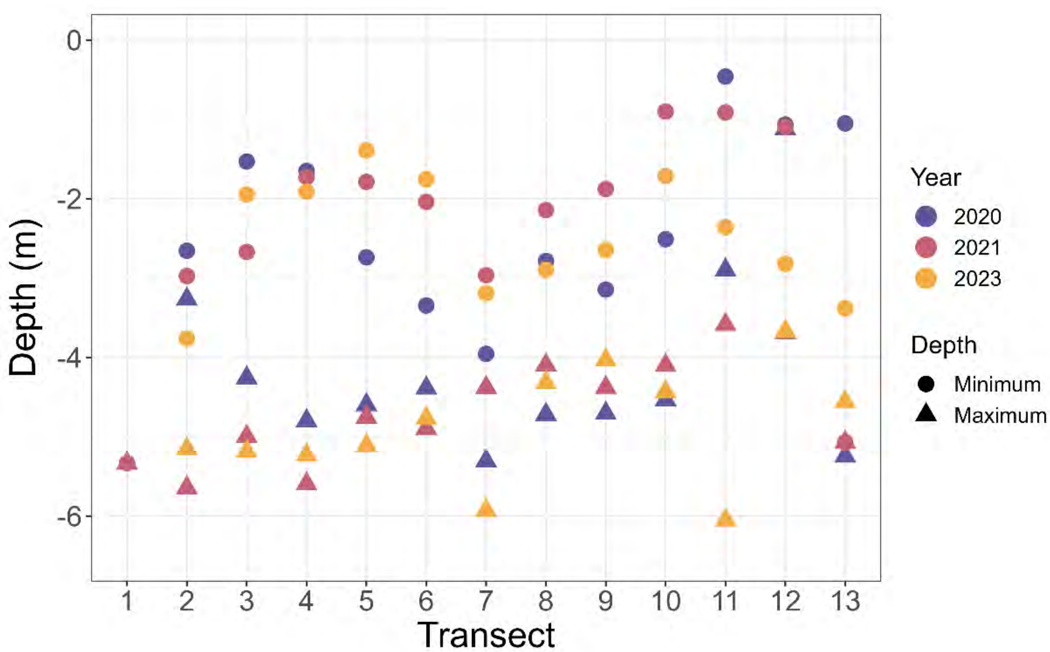

Figure 48. Minimum (circle) and maximum (triangle) depths along each transect at Edmonds in 2020-2021, and 2023.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Edmonds, the depth distribution profile showed a single, sharp peak occurring around -3 m MLLW (Figure 49). A minor portion of the bed occurred deeper than -5 m MLLW. The bed footprint is relatively shallow relative other beds in Admiralty Inlet and the eastern Strait of Juan de Fuca (Figure 8). Depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

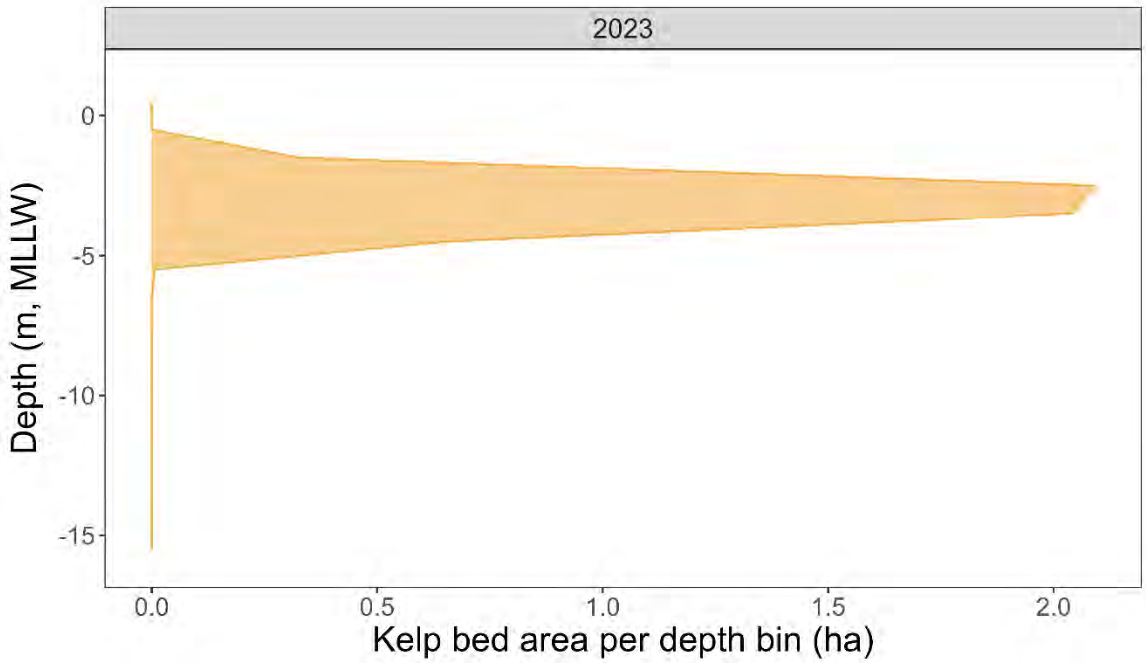

Figure 49. Edmonds floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

At the Edmonds site, monitoring by DNR is co-located with the Snohomish County Marine Resources Committee (MRC)/NW Straits floating kelp kayak monitoring site. The Snohomish County MRC has collected floating kelp bed perimeters for this site annually since 2015 using a different protocol than DNR (Ledbetter and Berry 2023). The bed perimeters collected by the MRC have included two distinct floating kelp beds within in the DNR site boundary, a small shallow bed on the south end of the site that has contracted over time and a larger, deeper bed that extents the length of the site. The bed perimeters collected by the Snohomish MRC can be viewed on the MRC StoryMap (NW Straits 2024). The spatial location of these two beds explains the uneven minimum depth pattern seen in Figure 47 and Figure 48. In 2023, the DNR depth data did not capture the shallow bed and the MRC survey only found scattered plants where the shallow bed perimeter was previously mapped (J. Whitty, pers. comm.).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.4.2 North Beach (NOB)

The North Beach floating kelp monitoring site is located on the north side of Quimper Peninsula, west of Point Wilson in the Strait of Juan de Fuca. Annual DNR kayak-based monitoring of bed depth began at the site in 2018 (except 2019). In 2023, floating kelp bed area was added to the DNR monitoring effort. In addition to the DNR monitoring, the Jefferson County MRC and NW Straits have been monitoring the floating kelp bed area at North Beach since 2015 (Ledbetter and Berry 2023, NW Straits 2024). SCUBA divers from Reef Check and Puget Sound Restoration Fund monitor underwater transects every summer using Reef Check protocols (Reef Check Foundation 2024).

Bed Area

In 2023, floating kelp bed area was 10.1 ± 0.17 ha. Scattered solitary plants were present off the deep edge of the bed, mainly on the east side of the site (Figure 50, Table C13).

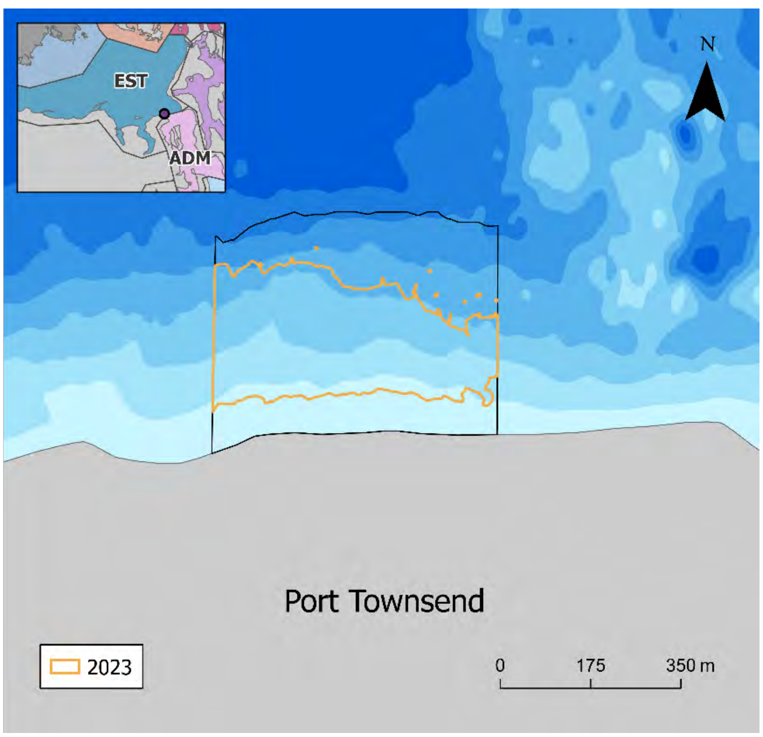

Figure 50. Map of North Beach floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth ranged from -8.1 m to -10.7 m MLLW in 2018 and 2020 – 2023 (Figure 51, Table C13). Mean maximum bed depth was deeper in 2021 and 2022 than in 2018, 2020, and 2023 (Figure 51, Table C13). Maximum depth differed significantly between years (Welch's ANOVA, $F_{4,21}$ = 9.42, $p < 0.001$), with 2018 significantly different than 2021 and 2022 (Games-Howell post-hoc tests; $p < 0.001$ and $p = 0.02$, respectively).

Mean minimum depth ranged from -1.0 m and -2.8 m MLLW (Figure 51, Table C13). Mean minimum bed depth was deeper in 2018 than in subsequent years. Minimum bed depth differed significantly between years (Welch's ANOVA, $F_{4,26}$ = 12.38, $p < 0.001$), with 2018 significantly different than 2020 ($p < 0.001$), 2021 ($p = 0.001$), 2022 ($p < 0.001$) and 2023 ($p < 0.001$) and 2020 significantly different than 2021 ($p = 0.01$) (Games-Howell post-hoc tests).

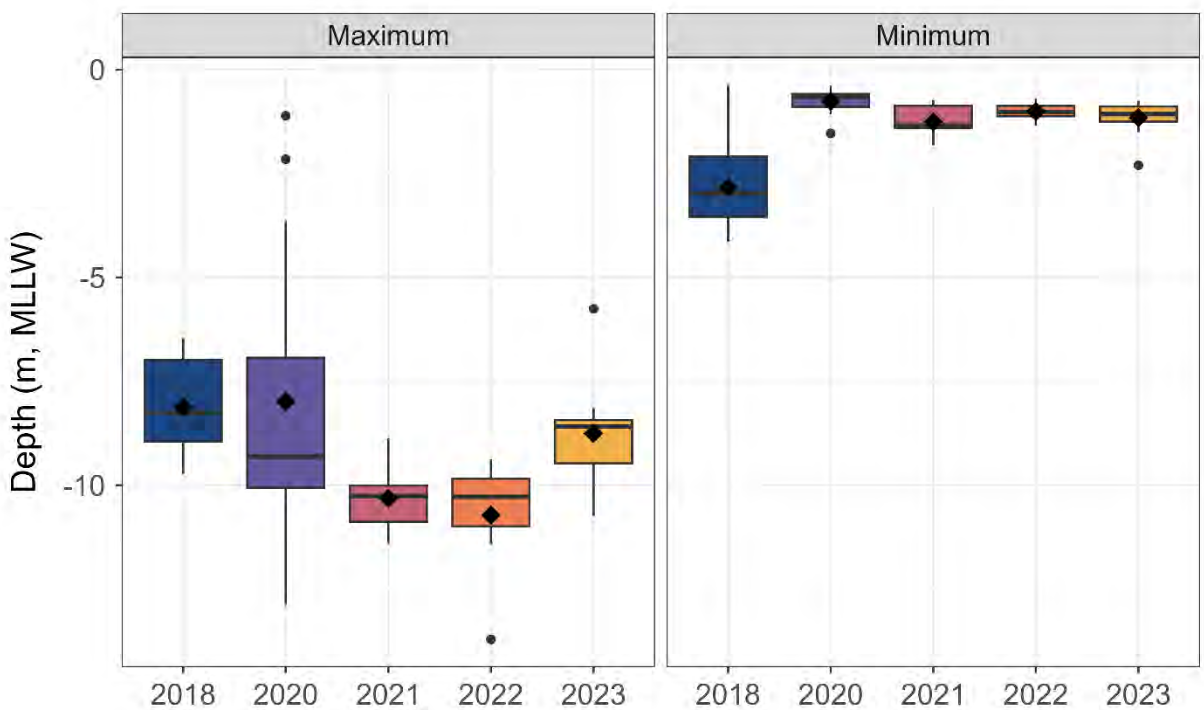

Figure 51. Minimum and maximum depth of floating kelp bed at North Beach between 2020 and 2023. Circular points represent outliers and diamond points represent the mean.

The points collected in 2018 at shallow and deep edge side of each transect (in blue) consistently fall inside the points collected in 2020-2023 (Figure 52), indicating that the floating kelp bed was smaller and farther offshore in 2018 than it was in subsequent years.

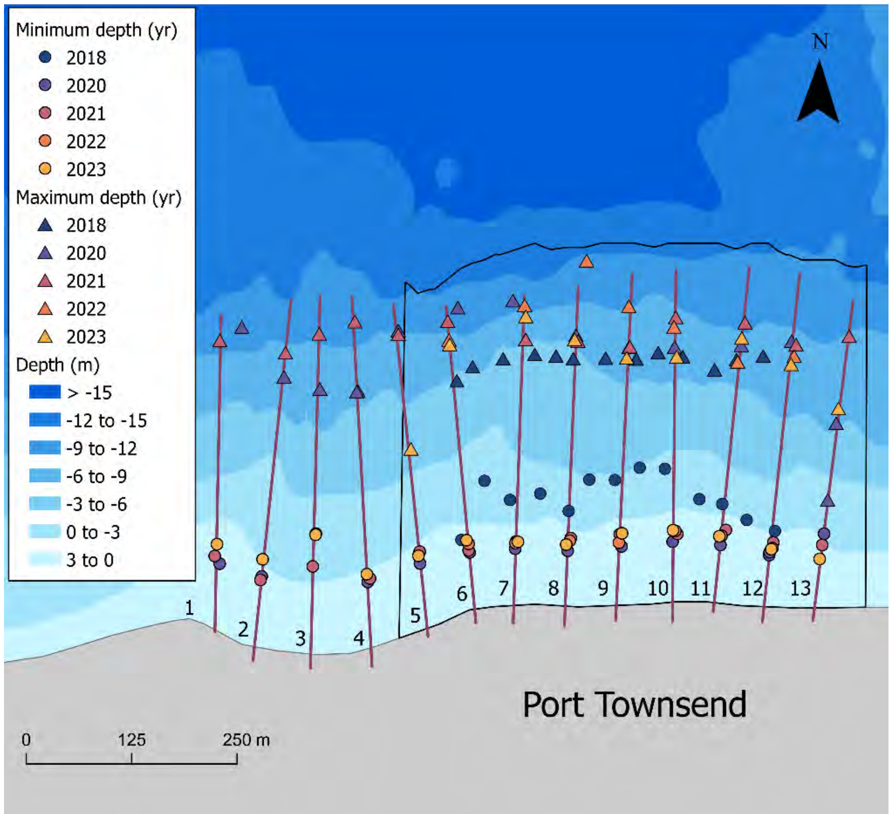

Figure 52. Location map of each minimum (circle) and maximum (triangle) depth measurement along 13 transects at North Beach. Depth points in 2018 were taken along different transects than in 2020 – 2023, only the 2020 – 2023 transects shown on map.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At North Beach, two distribution peaks were evident, a shallow peak at approximately -3 m MLLW and a deep peak at approximately -5 m MLLW (Figure 53). The bed extends relatively deep in comparison to other sites (Figure 8), 20% of the bed area was deeper than -6 m MLLW. Depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

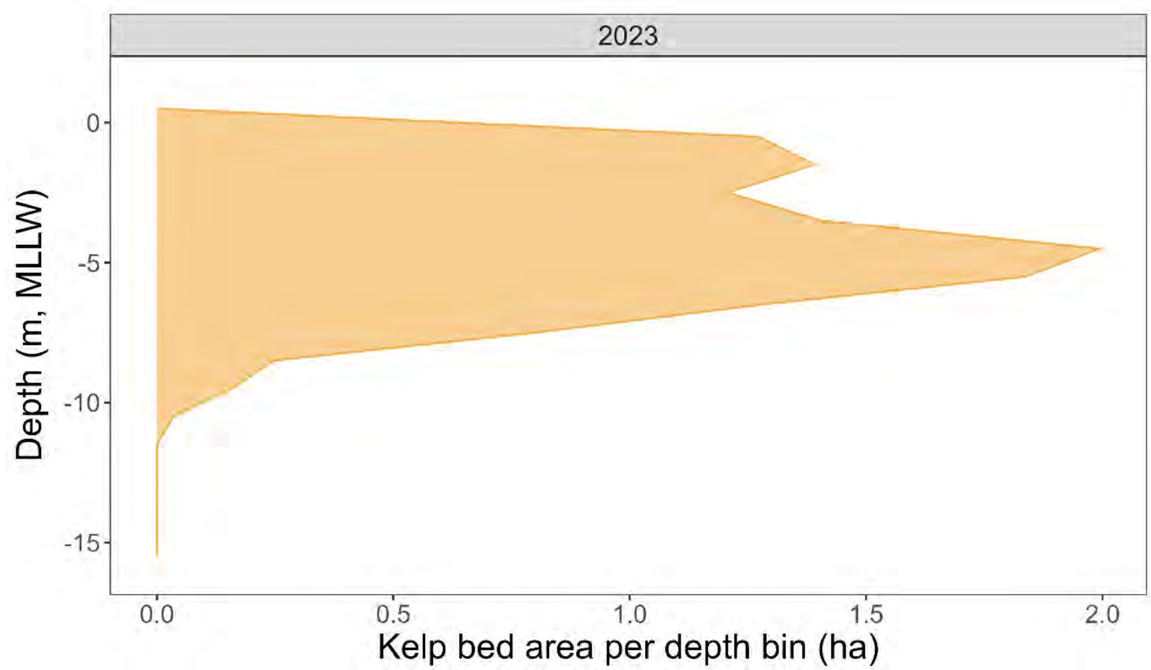

Figure 53. North Beach floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns and trends

North Beach is a co-located monitoring site with the Jefferson County MRC/NW Straits. The Jefferson MRC has collected floating kelp bed perimeters annually at this site since 2015 using a different protocol than used by DNR (Ledbetter and Berry 2023). The narrower depth range collected by DNR in 2018 is supported by bed perimeters collected by the Jefferson County MRC, which show the floating kelp bed smaller and farther offshore in 2018 and 2019. In 2020 the shallow edge of the bed moved back towards shore. The bed perimeters collected by the Jefferson MRC can be viewed on the MRC StoryMap (NW Straits 2024).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.4.3 Freshwater Bay (FWB)

The Freshwater Bay floating kelp monitoring site is located in the center of Freshwater Bay, west of the mouth of the Elwha River delta in the Eastern Strait of Juan de Fuca. Tribes use the area for commercial, ceremonial, and subsistence purposes. Other common uses include recreation, shoreline access, boat launching, and commercial and recreational harvest.

DNR has monitored floating kelp canopies at the site with aerial photography since 1989, as part of a larger project that spans the entire Strait of Juan de Fuca and exposed coast (Van Wagenen 2015, DNR 2024b). Multiple studies of nearshore conditions exist at the site, as part of a multi-year study of dam removal on the Elwha River (i.e. Rubin et al. 2011, Rubin et al. 2017, Rubin et al. 2023). The Clallam County MRC and NW Straits have monitored floating kelp annually at Freshwater Bay since 2016. SCUBA divers monitor underwater transects every summer using the Reef Check protocol (Reef Check Foundation 2024). DNR conducted kayak-based monitoring at the site in 2023 as part of targeted research.

Bed Area

In 2023, bed area was 28.5 ± 1.44 ha (Figure 54, Table C14). The shallow portion of the bed was very dense, while the deeper portion was sparse.

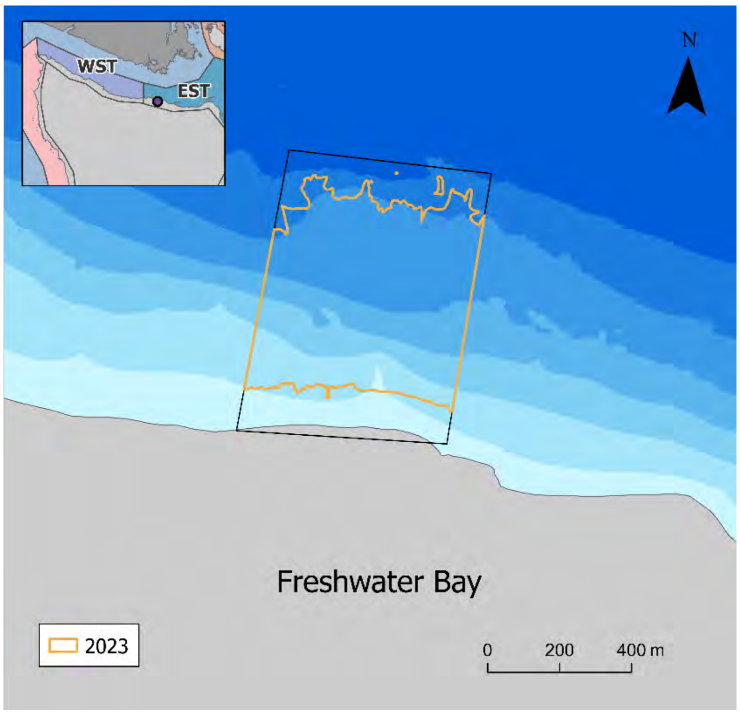

Figure 54. Map of Freshwater Bay floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum bed depth was -10.7 ± 1.7 m MLLW and the absolute range of maximum depth was -6.9 m to -12.7 m MLLW (Figure 55, Table C14). Mean minimum depth was -0.2 ± 0.23 m MLLW and the absolute range of minimum depth was -0.4 m to -1.1 m MLLW.

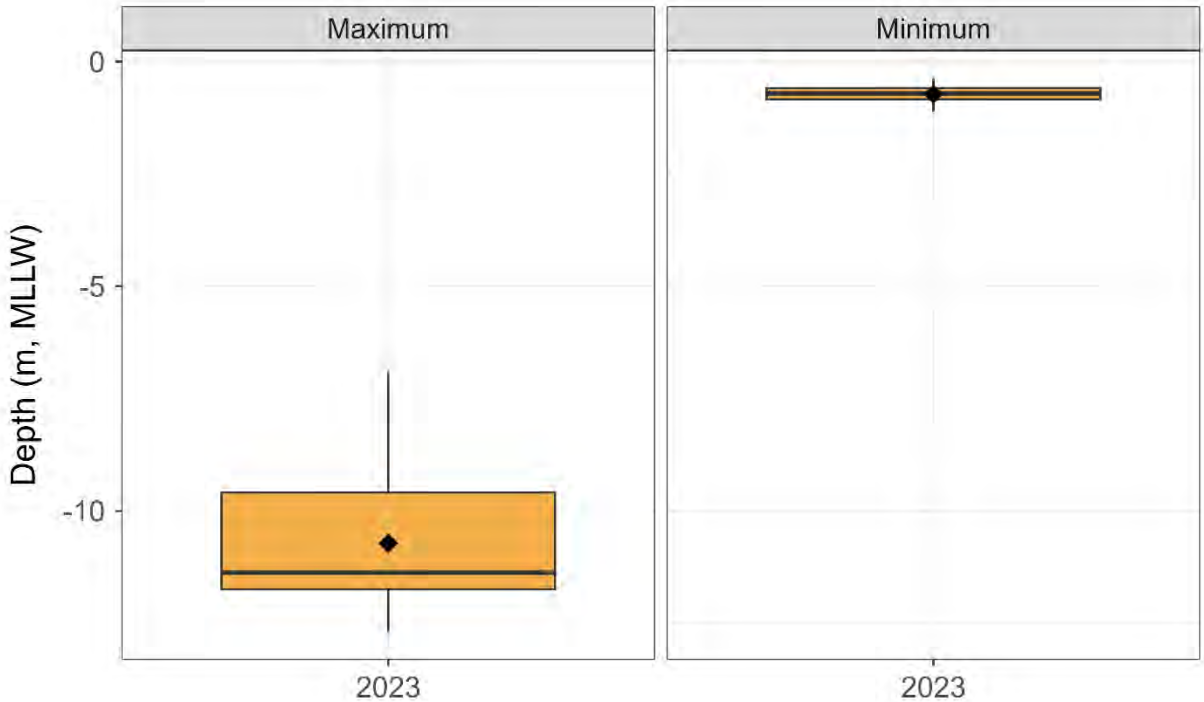

Figure 55. Minimum and maximum depth of floating kelp bed at Freshwater Bay in 2023. Diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Freshwater Bay, two distribution peaks were evident, a shallow peak at approximately -3 m MLLW and a deep peak at approximately -12 m MLLW (Figure 56). Overall, the Freshwater Bay site extends substantially deeper than any other core or focus site sampled in 2023 (Figure 8), with 70% of the bed area deeper than -6 m MLLW, and 15% deeper than -9 m MLLW. Depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

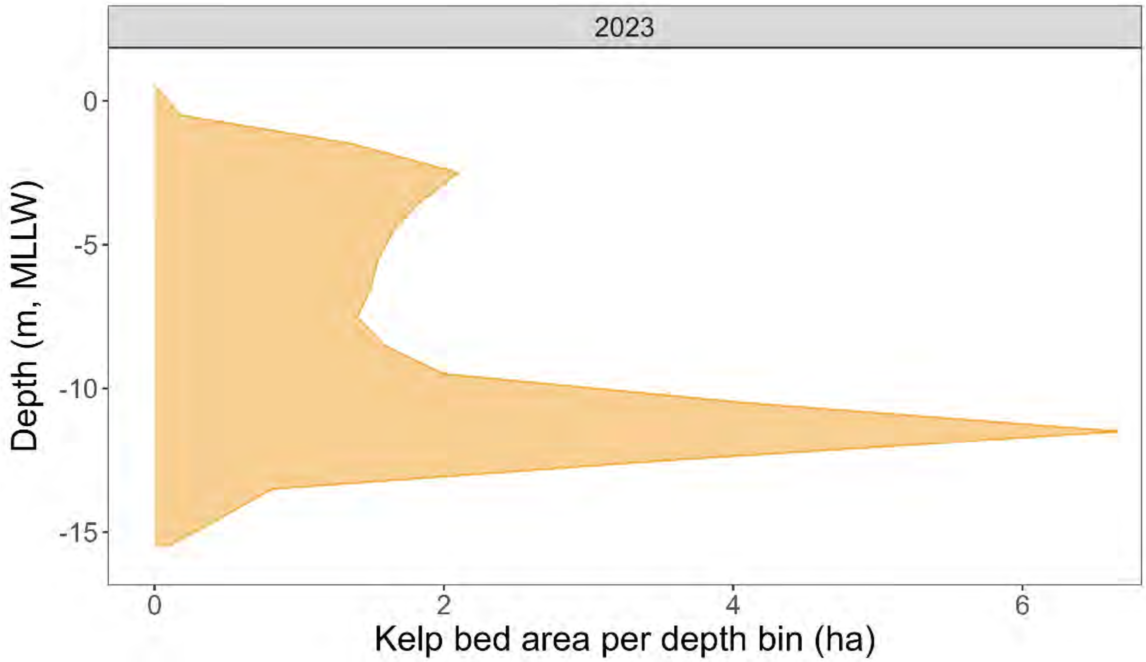

Figure 56. Freshwater Bay floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns

At Freshwater Bay in 2023, the floating kelp bed extended substantially deeper than at every other site in this monitoring study, and the footprint was an order of magnitude larger than at most other sites. This stark difference in bed extent and depth generally reflects regional differences in bed characteristics, with deeper and larger beds occurring along the Strait of Juan de Fuca.

In 2023, there was a distinct difference in floating kelp density between the shallow and deep areas of the bed. In the shallow portion, floating kelp was dense and was comprised of bull kelp with patches of giant kelp (*Macrocystis pyrifera*). Around -6 m MLLW, the dense bull kelp/giant kelp bed transitioned to sparse patches of bull kelp. The density pattern could be related to patterns in benthic substrate composition and the availability of bedrock and boulder substrate (Rubin et al. 2011).

Two multi-year monitoring studies have documented declines in the floating kelp bed area at Freshwater Bay, as reported in the WA State Floating Kelp Indicator (Appendix B in Claar et al. 2024). DNR long-term aerial photography-based monitoring noted an overall declining trend between 1989 and 2022. Within this long-term pattern, major losses occurred during 2012-2014, the period of peak sediment outflow associated with dam removal on the Elwha River (Rubin et al. 2017, Rubin et al. 2023). Bed area increased in 2015, which is likely associated with decreased turbidity from dam removal and the end of a marine heatwave (Claar et al., in review).

Since 2015, DNR aerial photography-based monitoring documented an overall downward trajectory in bed area, amidst high interannual variation. MRC kayak-based surveys showed a decline between 2016 and 2022 (NW Straits 2024). Declines during this period were likely associated with accumulation of fine sediments from the Elwha River. While most fine sediments that exit the river are exported from the area by strong waves and currents, multiple studies have documented the accumulation of fine sediments at the river mouth and in eastern Freshwater Bay (Rubin et al. 2017, Rubin et al. 2023).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.4.4 Beckett Point (BKT)

The Beckett Point floating kelp monitoring site is located on the north side of Beckett Point on the northeast portion of Discovery Bay in the Eastern Strait of Juan de Fuca. The point is owned by the Beckett Point Fisherman's Club, a historic community that was originally built as a summer colony. Residents of Beckett Point have observed a decline in floating kelp at the site. DNR conducted kayak-based at the site in 2023.

Bed Area

In 2023, bed area was 1.1 ha. Because the bed was sparse, GPS points were also collected at each individual plant or cluster, in addition to the perimeter survey (Figure 57). Approximately 400 floating kelp individuals were present.

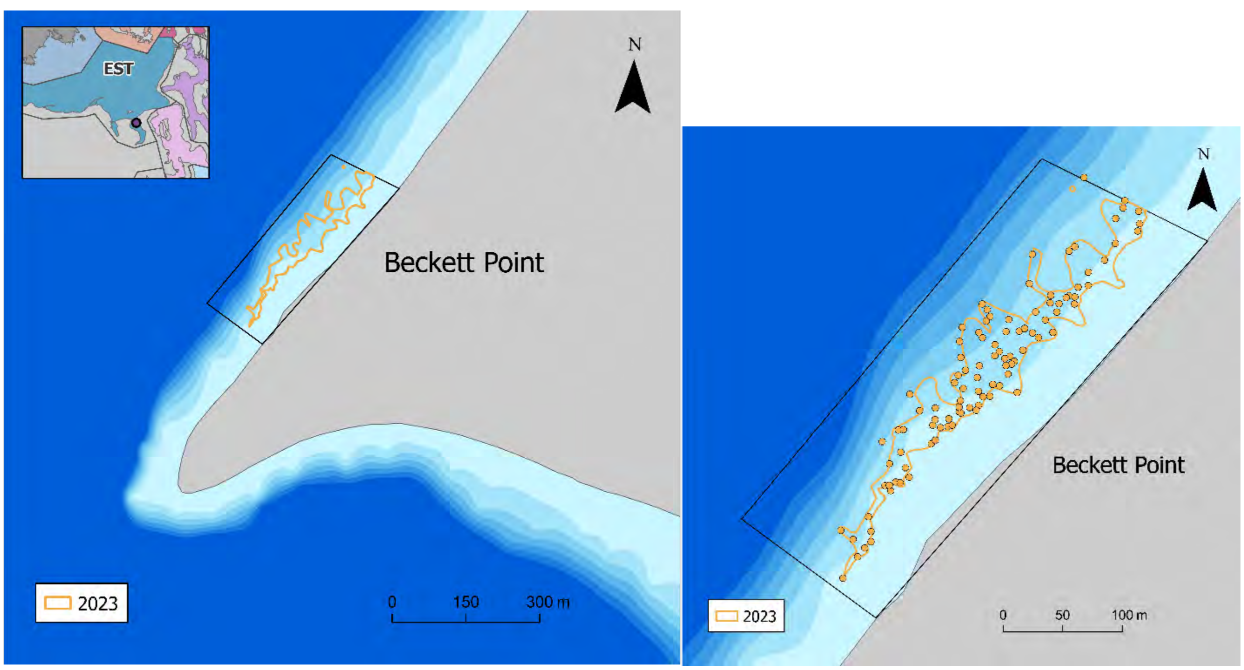

Figure 57. Map of Beckett Point floating kelp bed perimeter in 2023 (left) and map of the bed perimeter with the points taken at every floating kelp plant or cluster (right). Black box represents the site boundary. Sub-basin code in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth at Beckett Point was -2.3 ± 1.07 m MLLW and the absolute range of maximum depths was -0.5 m to -3.9 m MLLW (Figure 58, Table C15). Mean minimum depth was -0.9 ± 0.30 m MLLW and the absolute range of minimum depths was -0.3 m to -1.4 m MLLW.

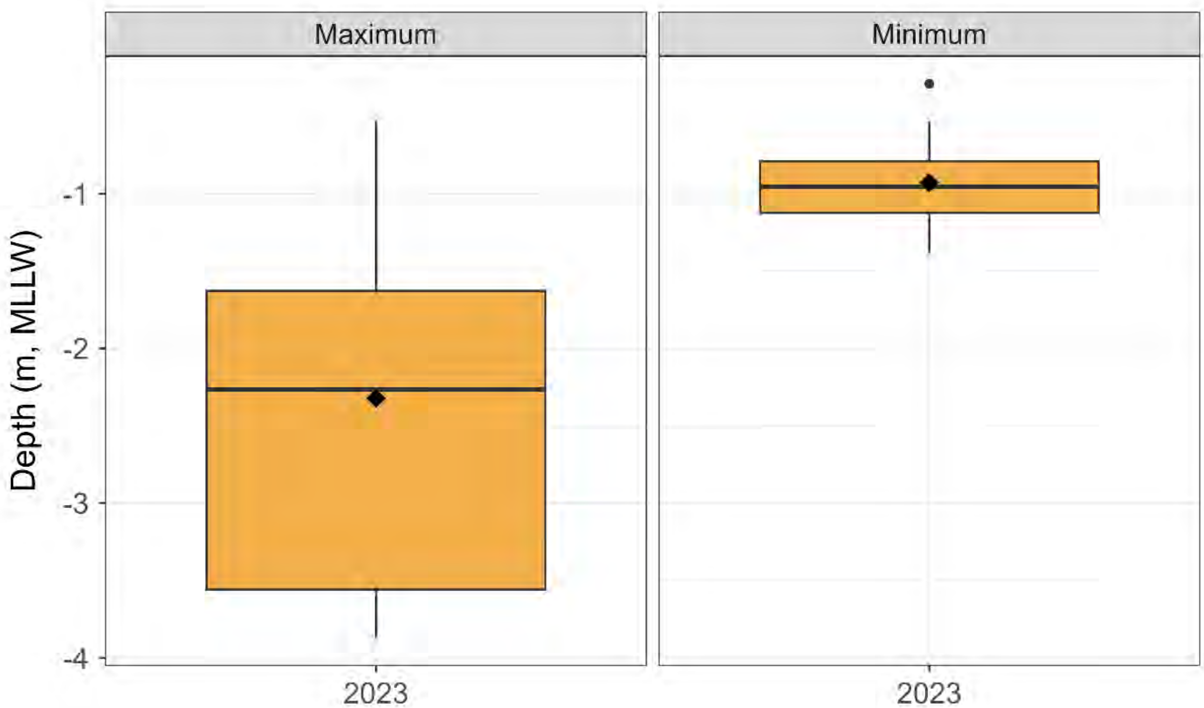

Figure 58. Minimum and maximum depth of floating kelp bed at Beckett Point in 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Beckett Point, a single, shallow distribution peak occurred shallower than -3 m MLLW (Figure 59) and 80% of the bed area was shallower than -3 m MLLW. Depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

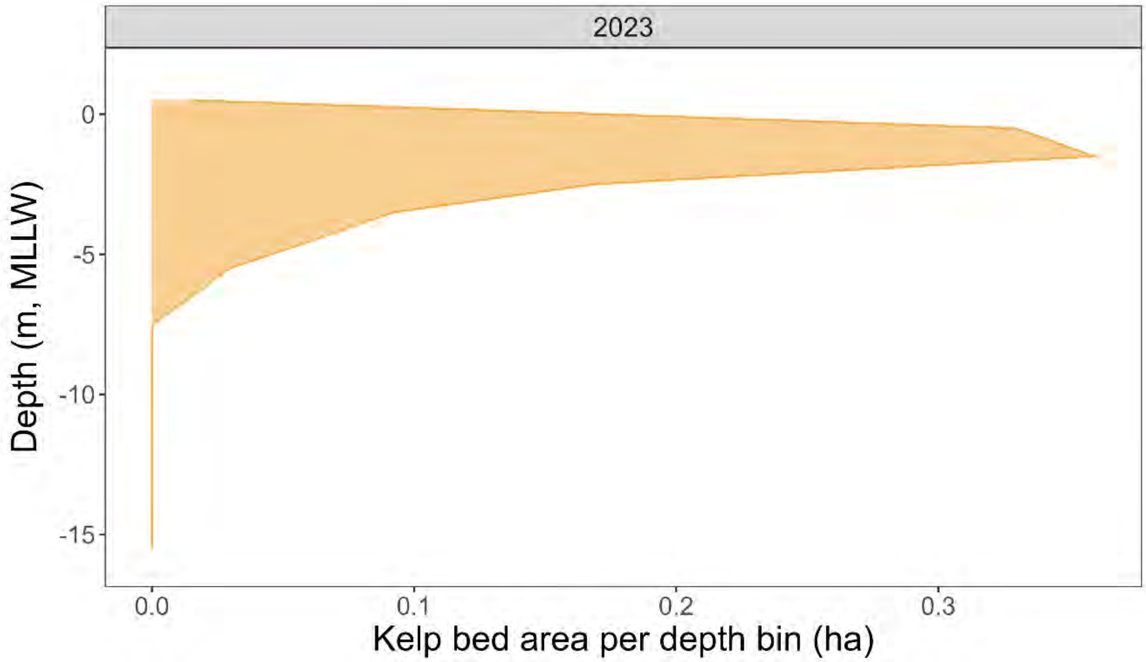

Figure 59. Beckett Point floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns

The floating kelp bed at Beckett Point in 2023 was sparse and shallow. Floating kelp was observed growing in and around an eelgrass bed throughout the site. Some floating kelp was also observed growing on buoys and buoy anchors. Residents at Beckett Point have been monitoring the bed since 2020 and have observed a decline (K. Hanson, pers. comm). The WA State Floating Kelp Indicator does not include Beckett Point but has shown long-term declines in floating kelp nearby (Miller Peninsula and Protection Island) (Appendix B in Claar et al. 2024, DNR 2024b). DNR will continue annual kayak surveys at the site if resources allow.

3.4.5 Burrows Island (BUR)

The Burrows Island floating kelp monitoring site is located adjacent to the lighthouse on the western shoreline of Burrows Island in North Puget Sound. The site occurs at the junction of Rosario Strait and the eastern Strait of Juan de Fuca, along a major marine transportation route. It is exposed to substantial waves and currents. Tribes use floating kelp in the area for commercial, ceremonial and subsistence purposes, the floating kelp bed adjacent to the lighthouse is noted by the Samish Indian Tribe to be a location of significance (Palmer-McGee 2022). DNR conducted kayak-based monitoring at the site in 2023 as part of targeted research.

SCUBA divers from the Samish Indian Nation monitor underwater transects every summer using the Reef Check protocol (Reef Check Foundation 2024).

Bed Area

In 2023, floating kelp bed area was 1.9 ± 0.04 ha. The widest portion of the bed lies adjacent to the Burrows Island Lighthouse, the bed narrows to the southeast (Figure 60, Table C16).

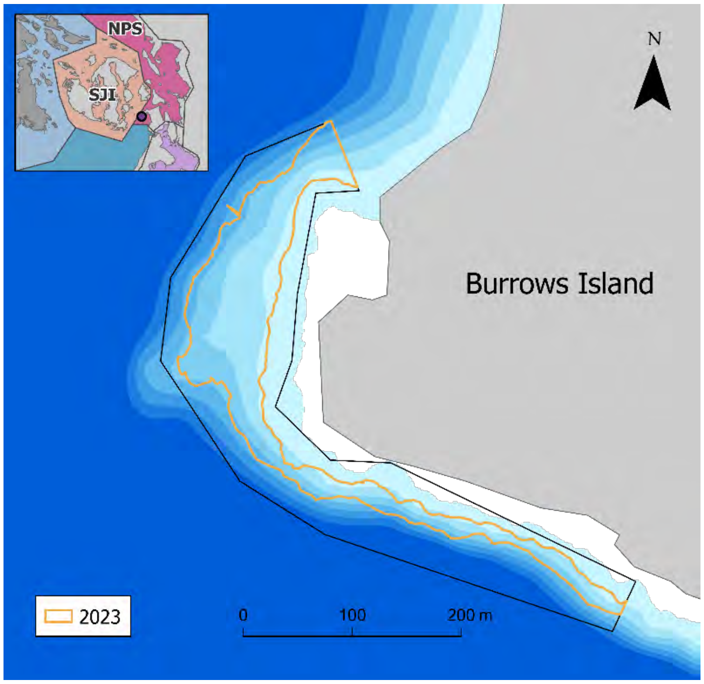

Figure 60. Map of Burrows Island floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth was -7.5 ± 0.9 m MLLW and the absolute range of maximum depths was -6.2 m to -9.3 m MLLW (Figure 61, Table C16). Mean minimum depth was -1.4 ± 0.46 m MLLW and the absolute range of minimum depths was -0.7 m to -2.5 m MLLW.

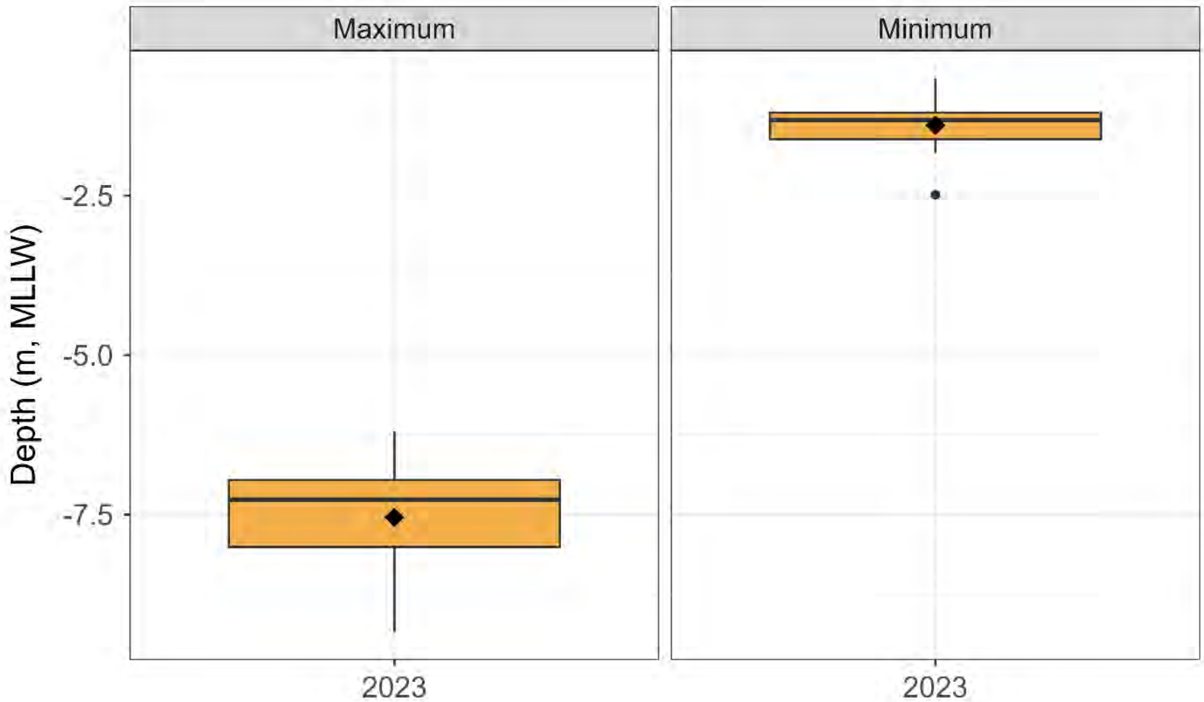

Figure 61. Minimum and maximum depth of floating kelp bed at Burrows Island in 2023. Circular points represent outliers and diamond points represent the mean**.**

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Burrows, peak distribution occurred at approximately -3 m MLLW, with a substantial portion of the bed (60%) occurring deeper than the peak, to depths up to -12 m MLLW (Figure 62). The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

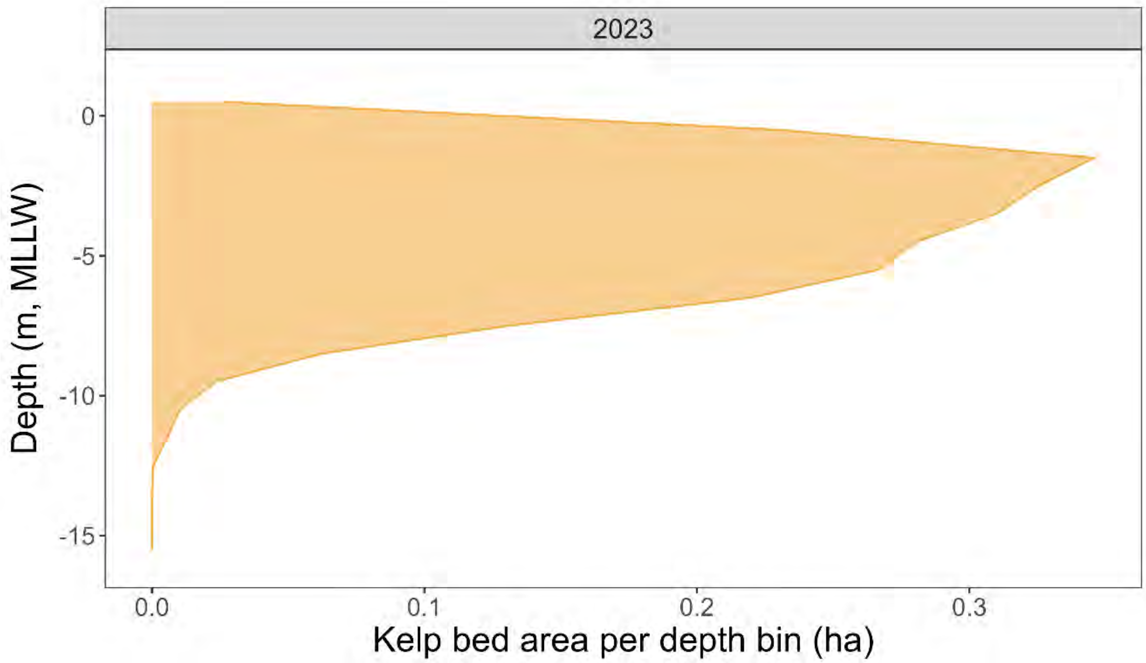

Figure 62. Burrows Island floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns

Data on the Burrows Island floating kelp bed is extremely limited, however, it appears to be stable and experience strong year-to-year variability, a common attribute of floating kelp beds (Palmer-McGee 2022, Claar et al. 2024, WA Floating Kelp Indicator Interactive Map).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.4.6 Point Caution (CAU)

The Point Caution floating kelp monitoring site is located north of Friday Harbor along the shorelines of San Juan Island, in San Juan Channel. It is exposed to wind waves from the north and to strong tidal currents. The southern portion of the site lies within the Friday Harbor Marine Protected Area, which is closed to harvest of bottomfish, shellfish, and other invertebrates. The adjacent southern shoreline lies within the Friday Harbor Laboratories Biological Preserve. Tribes use floating kelp in the area for commercial, ceremonial, and subsistence purposes. DNR conducted kayak-based monitoring at the site in 2023 as part of targeted research.

Bed Area

In 2023, floating kelp bed area was 0.2 ± 0.02 ha (Table C17). The majority occurred in a patch in the center of the site, while sparse individual plants occurred on either side of the patch, mostly in the shallows (Figure 63).

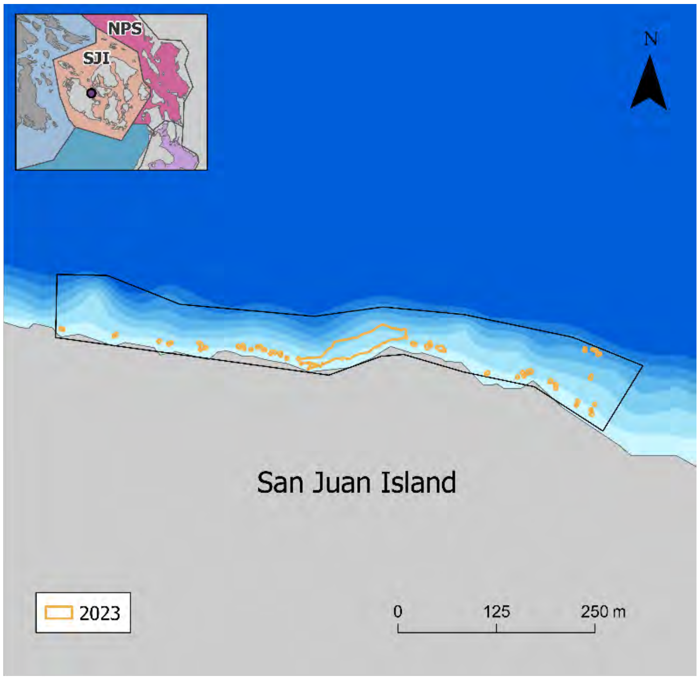

Figure 63. Map of Point Caution floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth at Point Caution was -4.2 ± 2.23 m MLLW, and the absolute range of maximum depths was -1.0 m to -7.2 m MLLW (Figure 64, Table C17). Mean minimum depth was -0.9 ± 0.29 m MLLW and the absolute range of minimum depths was -0.4 m to -1.5 m MLLW. Some isolated individuals were observed in the lower intertidal zone that were not captured along the depth survey transects.

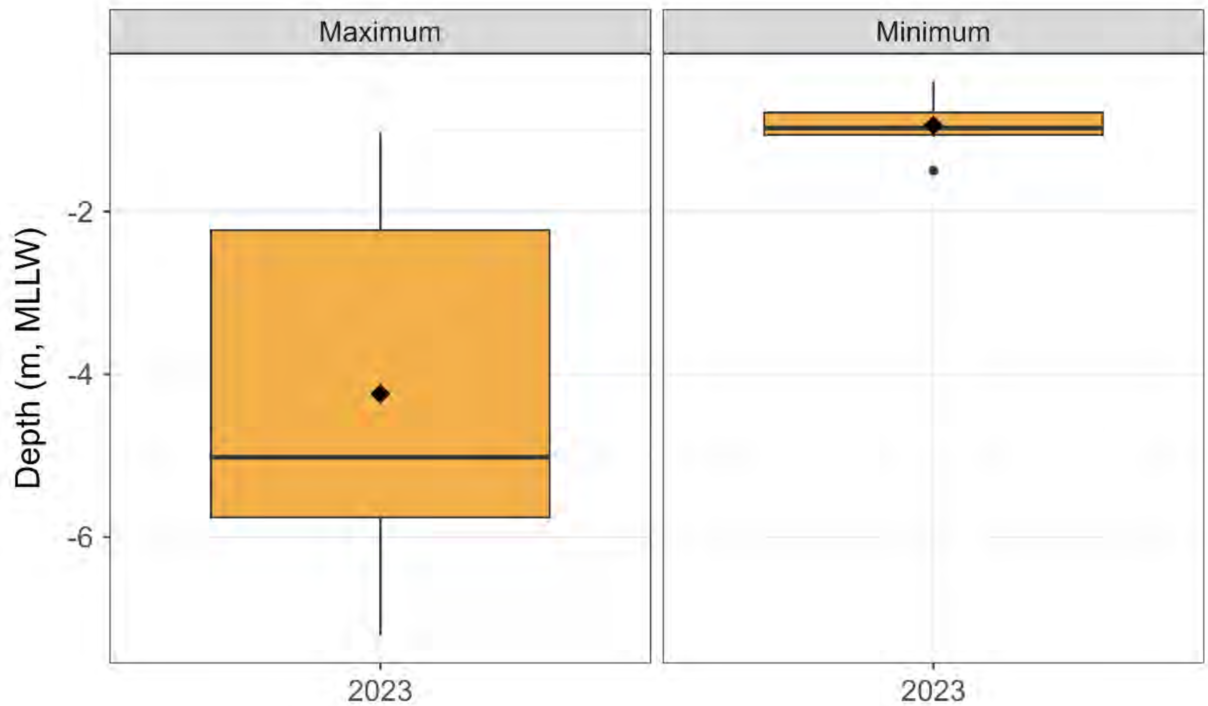

Figure 64. Minimum and maximum depth of floating kelp bed at Point Caution in 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Point Caution, two distribution peaks were evident, a shallow peak at approximately -3 m MLLW and a minor deep peak at approximately -12 m MLLW (Figure 65). The deep peak accounted for less than 5% of the bed area. Depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

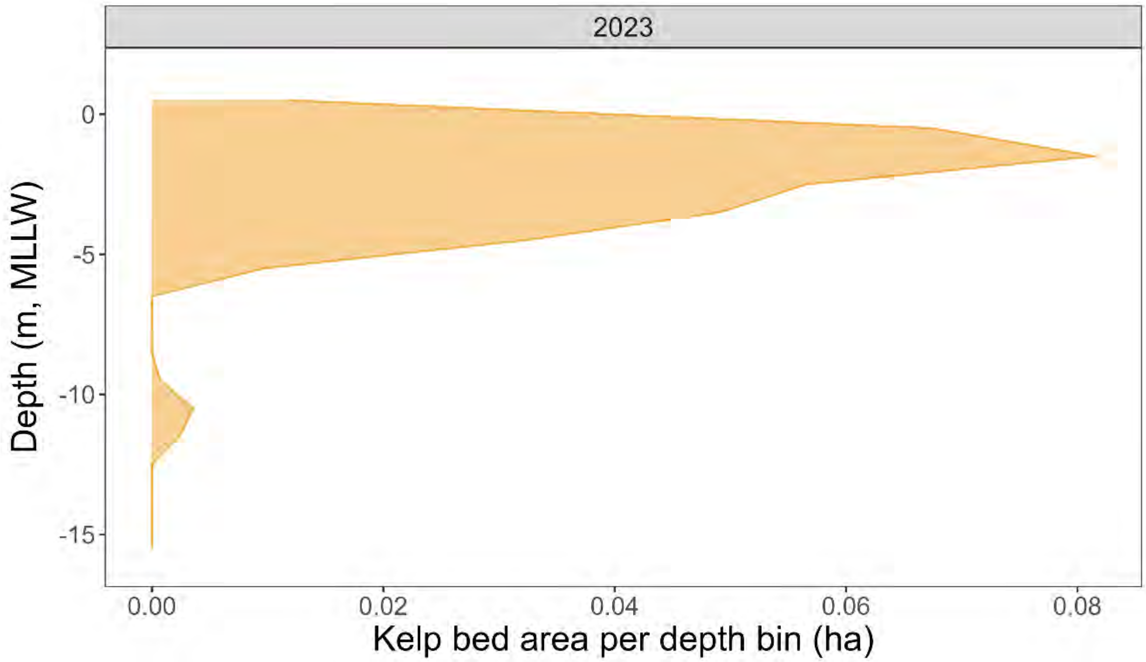

Figure 65. Point Caution floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

<u>Interpretation of site patterns</u>

Major concerns exist about floating kelp losses in portions of the San Juan Islands, yet data limitations lead to substantial uncertainty (Palmer-McGee 2022, Claar et al. 2024). The northeastern shoreline of San Juan is one location of particular concern; historical maps depicted many beds (Rigg 1911, Cameron 1915) that have been persistently absent (Berry and Mumford 2011, Mumford pers. comm). In recent years, floating kelp has been uncommon along the northeastern shoreline (Palmer-McGee 2022, Appendix B: Zone 8, NW San Juan Island in Claar et al. 2024).

Potential stressors at the site are not well understood. During surveys, observers noted many diminutive, solitary sporophytes in the low intertidal in August, an uncommon occurrence.

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

3.4.7 Cherry Point (CHP)

The Cherry Point floating kelp monitoring site is located in the Strait of Georgia, along a wave-exposed shoreline that drops off steeply into deep water, and supports abundant marine vegetation, fish and wildlife (DNR 2017). Tribes use the area for commercial, ceremonial, and subsistence purposes. The site also lies within the DNR Cherry Point Aquatic Reserve. DNR conducted kayak-based monitoring at the site in 2023 as part of targeted research.

DNR has been monitoring the site with aerial photography since 2011. The Whatcom County MRC and NW Straits have monitored floating kelp by kayak at the site annually since 2017. Reef Check SCUBA divers monitor underwater transects every summer (Reef Check Foundation 2024).

Bed Area

In 2023, floating kelp bed area was 5.5 ha. At this site, the floating kelp bed grows as two separate beds, one shallow and one deep, that connect in some places across the site (Figure 66).

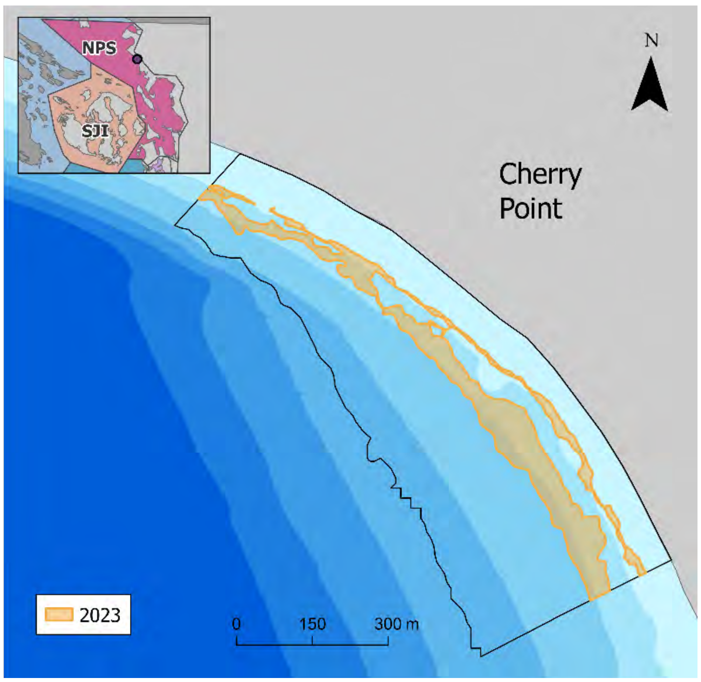

Figure 66. Map of Cherry Point floating kelp bed perimeter in 2023. Black box represents the site boundary. Sub-basin codes in inset map corresponds to sub-basins defined in Figure 1.

Depth Distribution

Based on depth data from across shore transects (Appendix F), mean maximum depth in 2023 was -4.4 ± 0.60 m MLLW and the absolute range of maximum depths was -3.1 m to -5.1 m MLLW (Figure 67, Table C18). Mean minimum depth was -1.0 ± 0.51 m MLLW and the absolute range of minimum depths was -0.6 m to -2.3 m MLLW.

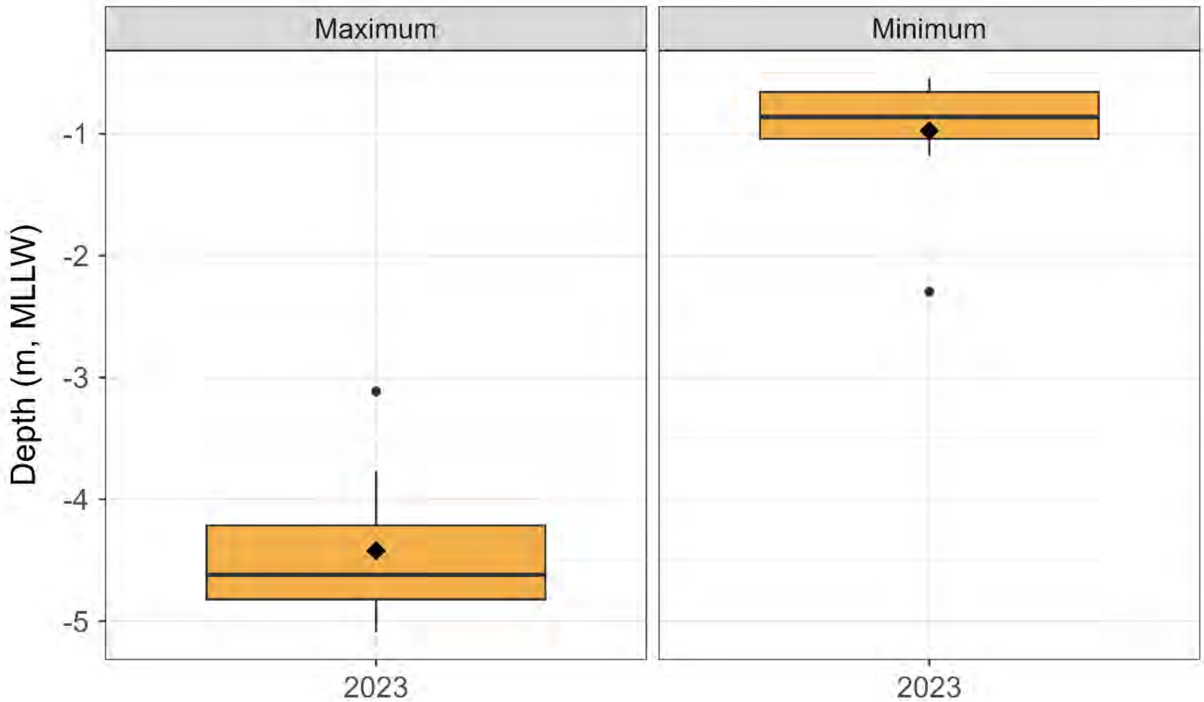

Figure 67. Minimum and maximum depth of floating kelp bed at Cherry Point in 2023. Circular points represent outliers and diamond points represent the mean.

The depth distribution of the bed was estimated by spatially comparing the bed footprint to modelled bathymetry data (Section 2.4). At Cherry Point in 2023, approximately half of the bed occurred shallower than -3 m MLLW and half occurred between -3 and -6 m MLLW (Figure 68). Deeper than -6 m, the profile dropped to zero abruptly, whereas many other sites taper gradually (Figure 8). The depth distribution estimates are approximate due to uncertainties related to modelled bathymetry data, especially in shallow areas.

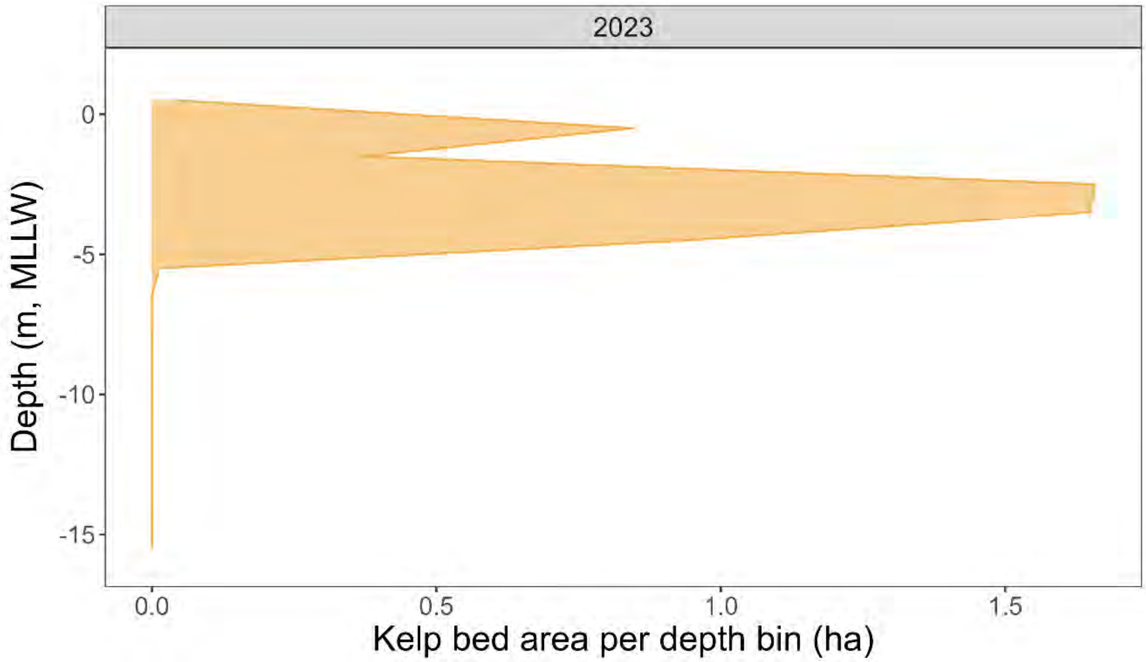

Figure 68. Cherry Point floating kelp bed depth distribution (as area per 1-m depth bin) from 2023, estimated by spatial comparison of the bed footprint to modelled bathymetry data.

Interpretation of site patterns

In 2023, the Cherry Point floating kelp bed occurred in two alongshore bands, along the shallow and deep boundaries of a bed of non-native *Sargassum muticum*. The two bands of floating kelp connected in the northern and central portions of the bed (Figure 66). *Sargassum* was abundant during the floating kelp survey on July 14, then senesced later in the summer (August 13).

In addition to competition with the *Sargassum*, suspected stressors at the site include elevated water temperature and low nutrients (Wiegel et al. 2023).

The Cherry Point kayak monitoring site constitutes a portion of the floating kelp resource within the Aquatic Reserve. Aerial photography-based monitoring throughout the Aquatic Reserve found that floating kelp bed area has been variable and stable since 2011. Major losses begin during the marine heatwave around 2014, followed by recovery in 2017 (WA State Floating Kelp Interactive Map, Claar et al., in review).

This site is included in an intensive collaborative study initiated in 2024 to explore environmental conditions and differential bull kelp performance at sites throughout Puget Sound, *Identification of factors associated with patterns in floating kelp loss and resilience through coordinated monitoring and research* (see study fact sheet for more information).

4 Discussion

4.1 Trends in bed area and depth

Floating kelp beds provide important habitat and ecosystem services to nearshore systems. In Puget Sound there are major concerns of floating kelp loss in the inner basins, especially South and Central Puget Sound. Floating kelp bed area trends from DNR's annual floating kelp monitoring program show signals of loss and stability in South Puget Sound (SPS) and Central Puget Sound (CPS) that vary by site and time period. Bed area trends were assessed over three time periods (3 years, 5 years, entire data record) and the time period considered influenced the trend designation. Across the entire data record, floating kelp declines and loss dominate the trends; four sites experienced total loss, two sites decreased in bed area, and one site showed no trend in bed area (six sites had limited data) (Figure 3C). However, over the past three years (2021-2023), four sites showed an increase in bed area, one site decreased in bed area, four sites showed no trend in floating kelp bed area, and four sites had no floating kelp present (Figure 3A).

Floating kelp bed area also varied spatially throughout the study area. In SPS, much of the floating kelp was concentrated around the Tacoma Narrows (Fox Island, Day Island, and Salmon Beach). While Day Island and Salmon Beach appear stable, Fox Island is at risk of being lost. Only two floating kelp plants were observed at Fox Island in 2023. Further into SPS, two sites were lost completely and have not recovered (Brisco Point and Devil's Head), and one site (Squaxin Island) has experienced steep declines over the past 10 years. Squaxin Island is the innermost floating kelp bed in Puget Sound, and the bed area declined 97% between 2013 and 2022 to just 85 plants. The site saw a partial recovery in 2023, but the floating kelp bed is still only 22% of its 2013 bed area. In CPS, two sites lost floating kelp before annual kayak monitoring began in 2020 (Point Jefferson and Wing Point) and five sites showed slight variation in bed area between years but overall stability. However, six of the 13 sites in SPS and CPS only have three or four years of data, so these trends could change as additional data is collected.

Spatial patterns were also apparent in mean maximum bed depth. Mean maximum depth was shallowest at Squaxin Island and deeper in the Tacoma Narrows and at sites closer to the ocean. The deeper bed depths recorded at sites in the Tacoma Narrows, Admiralty Inlet, and the Strait of Juan de Fuca could be related to the cooler waters of these areas. These areas are deeper and more well mixed which could result in cooler water temperatures and increased water clarity that could benefit floating kelp growth and expand potential floating kelp habitat to deeper depths.

Many knowledge gaps exist when it comes to understanding the complex nature of bull kelp dynamics in Puget Sound (Calloway et al. 2020). The results from this annual monitoring program can shed light on local changes in floating kelp abundance and regional patterns of floating kelp persistence and loss across both years (short-term) and decades (long-term).

4.2 Recent and historical losses in South and Central Puget Sound while other regions are largely stable

The entire data record trends in this report were dominated by declines; four sites were classified as total loss (Brisco Point, Devil's Head, Wing Point, and Point Jefferson), two sites were classified as decreasing (Squaxin Island and Fox Island), and one site was classified as no trend (Salmon Beach). The floating kelp beds at Brisco Point (Figure 12) and Devil's Head (Figure 14) declined and were lost between 2013-2017 and 2018, respectively. No recovery has been observed at the sites, despite continued annual monitoring. The Wing Point floating kelp bed was a historically large bed near the mouth of Eagle Harbor on Bainbridge Island. In 2016, a few isolated plants were observed at Wing Point (Berry 2017) and the bed was lost shortly thereafter. The site on Point Jefferson was a historical floating kelp bed that the Suquamish Tribe and locals report was lost decades ago. Both Wing Point and Point Jefferson have been monitored annually since 2020, and like Brisco Point and Devil's Head, no floating kelp recovery has been observed.

The loss of these floating kelp beds, and the steep declines documented at Squaxin Island (Figure 9) and Fox Island (Figure 16), fit into a larger pattern of floating kelp loss in SPS and CPS over the last century. A synthesis of historical and recent surveys shows that the amount of floating kelp in 2017, compared to an 1878 baseline, decreased 63% throughout South Puget Sound, with the central portion of SPS decreasing 96% and the western portion of SPS decreasing 83% (Berry et al. 2021). Similarly, in the last 145 years, floating kelp has disappeared from about 80% of shorelines in Central Puget Sound (DNR unpublished data), with most floating kelp now found in Admiralty Inlet and the Tacoma Narrows.

When the recent floating kelp losses and declines are put in context with the documented historical floating kelp losses, the long-term trend of floating kelp decline in SPS and CPS is evident. While pockets of resilience exist (i.e., the Tacoma Narrows), the combination of the recent and historical floating kelp data led the WA State Floating Kelp Indicator (with data through 2022) to assign SPS and CPS sub-basins as having substantial documented declines. However, not all sub-basins in the Indicator show the same pattern of decline (Claar et al. 2024). Floating kelp appears stable in sub-basins closer to the ocean (Northern Coast, Western Strait of Juan de Fuca, and Eastern Strait of Juan de Fuca sub-basins), while other sub-basins are concern of decline (San Juans Islands and Saratoga-Whidbey sub-basins) or have limited data to determine a status (North Puget Sound and Admiralty Inlet sub-basins) (Claar et al. 2024). Continued monitoring of floating kelp throughout SPS and CPS, and across all the sub-basins, is needed, as well as research into the stressors associated with floating kelp loss and persistence.

Floating kelp growth and persistence can be affected by a suite of environmental conditions and biological interactions including elevated water temperature, light availability, nutrient availability, grazing by invertebrates, and competition with other algal species (Wernberg et al. 2016). Often, floating kelp can be impacted by multiple stressors simultaneously. DNR's current floating kelp monitoring program does not monitor stressors associated with floating kelp loss, but a list of potential stressors was compiled based on observations at each site by DNR staff (Table E1).

4.3 Elevated temperature and floating kelp persistence

Elevated water temperature is one of many potential stressors that can affect floating kelp growth and persistence. Recent research on the effects of elevated water temperature on bull kelp found that short-term exposure of bull kelp blades to warm temperatures (21°C) reduced growth in both low and high nutrient concentrations, which could indicate susceptibility to thermal stress over short time spans (Fales et al. 2023). Additionally, thermal limits for gametophyte growth and sporophyte production were found at 16°C and 18°C (Weigel et al. 2023). Temperatures exceeding these thresholds were recorded in the field by Weigel et al. (2023) at multiple sites throughout Puget Sound during the summer of 2022, including Squaxin Island.

Squaxin Island provides an opportunity to consider elevated temperature as a stressor. Squaxin Island has experienced two large declines in floating kelp bed area since 2013. The first decline occurred between 2013 and 2017 and the second between 2021 and 2022. Not only did bed area decrease, but the depth distribution of floating kelp contracted on both the shallow and deep edges. Elevated water temperature could be one explanation for the loss of floating kelp at the site. The decline in floating kelp between 2013 and 2017 coincides with the 2014 marine heatwave that negatively impacted floating kelp along the West Coast (Rogers-Bennett and Catton 2019). The marine heatwave showed more extreme and prolonged warming effects in SPS and CPS compared to other sub-basins (with the exception of areas near the Strait of Georgia; Khangaonkar et al. 2021). There were also elevated water temperatures in Puget Sound during the summer of 2021 (PSEMP 2022), which preceded the 2022 decline at Squaxin Island. Temperature sensor data from Squaxin Island showed water temperatures at -3 m MLLW exceeded the 16°C threshold identified by Weigel et al. (2023) roughly twice as often in 2021 as in 2022 (618 hours over 68 days vs 360 hours over 56 days, respectively) (McClure et al. in review). The shorter threshold exceedance time in 2022 preceded the 2023 partial recovery of the Squaxin floating kelp bed, suggesting that the 2022 decline could have been influenced by the elevated water temperature in the summer of 2021.

Elevated water temperature is not the only possible stressor on Squaxin Island bull kelp. The floating kelp could also be limited by light availability (the site is often turbid), unsuitable substrate, consumption and physical damage by kelp crabs (abundant kelp crabs have been observed on plants at the site), and competition with other algae species (*Sargassum* and *Desmerestia* were abundant at the site in 2022). It appears likely that, rather than any single stressor, the interaction of stressors at Squaxin Island contribute to the dramatic decline in bull kelp bed area over the last decade.

4.4 Co-locating monitoring and research

Furthering our understanding of local and regional floating kelp trends and potential floating kelp stressors is critical to informing management, conservation, and restoration. To fill important knowledge gaps identified by the Kelp Plan, DNR works with local, regional, and state partners to coordinate floating kelp research and often tries to co-locate monitoring sites. For example, the Nearshore Habitat Program collaborates with University of Washington and Friday Harbor Labs to develop and test research questions about the effect of stressors on floating kelp growth and condition. Laboratory studies investigating the effect of elevated water temperature and nutrients have been conducted using bull kelp collected from DNR monitoring sites. These studies have led to insight into how different life stages of bull kelp respond to elevated water temperatures (Weigel et al. 2023) and short-term exposure to different temperature and nutrient concentrations (Fales et al. 2023).

A new intensive study, the *Investigation of Floating Kelp Resilience and Loss through Linked Research and Monitoring*, was initiated by DNR and partners in January 2024 to investigate factors associated with floating kelp loss and persistence across Puget Sound using coordinated research and monitoring. The study will collect a suite of environmental parameters, floating kelp bed and condition metrics, floating kelp performance metrics, and benthic community metrics at 15 sites throughout Puget Sound, most of which are included in this report (see study fact sheet for more information). The research and monitoring will be conducted by a diverse group of partners including DNR, University of Washington, Puget Sound Restoration Fund, Reef Check, University of Chicago, Northwest Straits Initiative, and the Samish Indian Nation.

In addition to these research and monitoring efforts, data from DNR's annual floating kelp monitoring program is being used to target areas for restoration and management action. The DNR-documented losses at Squaxin Island helped to inform floating kelp restoration efforts at the site. The Squaxin Island Tribe and Puget Sound Restoration Fund led an effort in early 2023 to restore bull kelp at the site by outplanting lines seeded with gametophytes collected from the site. The restoration work is ongoing, but bull kelp was successfully grown on the lines in 2023 and was independent from the natural bed recovery. Annual floating kelp monitoring data is also being used to inform the selection of priority areas for conservation and recovery as part of the Kelp Forest and Eelgrass Meadow Health and Conservation Plan (RCW 79.135.440). This plan, passed by the Washington State Legislature and signed into law in 2022, aims to conserve and restore at least 10,000 acres of kelp and eelgrass habitat by 2040.

The sites presented in this report are part of a larger network of DNR floating kelp monitoring sites that utilize multiple survey methods, including kayak, UAS, and fixed-wing photography. Some of the kayak monitoring sites are co-located with UAS monitoring sites as well as being included in fixed-wing aerial surveys. Due to distinct site-level characteristics, the survey method varies by site. For example, while fixed-wing photography often fails to detect narrow, low-density beds that can be captured by kayak surveys, it can monitor large, dense beds in remote locations that would be difficult to kayak. By using multiple floating kelp monitoring methods, DNR is working to collect a mosaic of floating kelp bed area trends to assess floating kelp status throughout the state.

4.5 Conclusions

Severe declines and total losses dominate long-term trends in floating kelp at sites in South and Central Puget Sound. Of the seven sites with more than five years of data, four sites have experienced total loss of floating kelp, two sites declined substantially over the past decade (Squaxin Island and Fox Island), and one site had no trend in bed area over six years. The monitoring results show that floating kelp declines continue to dominate trends in SPS and CPS and support retaining the current WA State Floating Kelp Indicator status assessment for the sub-basins.

In contrast to the long-term trends, stability and/or increases are common in SPS and CPS over recent years. Among the seven sites with at least five years of data, the 5-year trends showed two sites decreasing, one site with no trend, and four sites with no floating kelp. The 3-year trends showed four sites increasing, one site decreasing, four sites with no trend, and four sites with no floating kelp.

The survey data enriches our understanding of floating kelp depth distribution. Floating kelp depth distribution varied strongly by location and the majority of the bed footprints were shallow. At 10 out of 16 sites, more than 85% of the bed footprint occurred shallower than -6 m (MLLW). Deeper mean maximum depths occurred closer to oceanic influence and in areas of intense mixing. Mean minimum depth was less variable across sites and at 13 out of 15 sites, mean minimum depth was shallower than -2 m MLLW.

Co-locating monitoring with research and restoration has led to collaborative stressor research with the University of Washington that identified temperature thresholds associated with physiological impacts to multiple kelp life stages (Weigel et al. 2023, Fales et al. 2023). The results strongly suggest that elevated temperatures are associated with declines at some sites. In addition, DNR's kayak monitoring results support restoration and management actions and have informed floating kelp restoration at Squaxin Island and the Statewide Kelp Forest and Eelgrass Meadow Health and Conservation Plan.

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Appendix A: Survey windows

Table A1. Low tide survey windows for each site used to collect annual monitoring data. Optimal survey windowed are based on field observations of local effects of tides and currents on canopy visibility. Bolded tide stations denote harmonic stations, tide stations not bolded are subordinate stations.

Site	Optimal survey window	Tide Station
Squaxin Island	1 hour before low to 1 hour after low	Dofflemeyer Point (9446800)
Brisco Point	1 hour before low to 1 hour after low	Dofflemeyer Point (9446800)
Devil's Head	1 hour before low to 1 hour after low	Devil's Head (9446671)
Fox Island	1 hour before low to 1 hour after low	Tacoma Narrows Bridge (9446486)
Day Island	30 min after low to 2 hours after low	Tacoma Narrows Bridge (9446486)
Salmon Beach	1 hour before low to 1 hour 30 min after low	Tacoma Narrows Bridge (9446486)
Owen Beach	1 hour before low to 1 hour after low, deep edge must be done 30 min on either side of low	Tahlequah, Neil Point (9446375)
Vashon SE	45 min before low to 1 hour 30 min after low	Point Vashon (9446025)
Lincoln Park	1 hour before low to 1 hour after low	Point Vashon (9446025)
Magnolia	1 hour before low to 1 hour after low	**Seattle** (9447130)
Wing Point	1 hour before low to 1 hour after low	Eagle Harbor, Bainbridge Island (9445882)
Point Jefferson	1 hour before low to 1 hour after low	Port Jefferson (9445683)

Site	Optimal survey window	Tide Station
Hansville	1 hour before low to 1 hour after low, deep edge done 30 min on either side of low	Hansville (9445526)
Edmonds	1 hour before low to 1 hour after low	Edmonds (9447427)
North Beach	1 hour before low to 1 hour after low, deep edge must be done 30 min on either side of low	**Port Townsend** (9444900)
Freshwater Bay	1 hour before low to 1 hour after low	Crescent Bay (9443826) Ediz Hook (9444122)
Beckett Point	1 hour before low to 1 hour after low	Gardiner (9444705)
Burrows Island	1 hour before low to 1 hour after low	Burrows Bay (Allan Island) (9448683)
Point Caution	1 hour before low to 1 hour after low	**Friday Harbor** (9449880)
Cherry Point	1 hour before low to 1 hour after low	**Cherry Point** (9449424)

Appendix B: Recent and long-term trend regressions

This appendix contains the outputs from the linear regressions used to help inform bed area trends at the DNR core monitoring sites.

Table B1. Regression outputs for the 3-year, 5-year, and entire data record time frames for each site, with slope and p-value from each regression. Bold p-values indicate significance ($p < 0.05$).

Site	3-year Recent Trend		5-year Recent Trend		Entire Data Record		Years of data
	Slope	p-value	Slope	p-value	Slope	p-value	
Squaxin Island	-0.35	0.81	-0.48	0.21	-0.62	**0.005**	10
Brisco Point	---	---	---	---	---	---	8
Devil’s Head	---	---	---	---	---	---	8
Fox Island	-0.004	0.15	-0.01	0.37	-0.11	**0.02**	8
Day Island	1.07	0.17	---	---	0.51	0.28	4
Salmon Beach	0.16	0.33	-0.05	0.63	0.06	0.53	6
Owen Beach	0.09	0.26	---	---	0.09	0.04	4
Vashon Island	0.27	0.07	---	---	0.28	**0.002**	4
Lincoln Park	-0.08	0.46	---	---	-0.02	0.68	4
Magnolia Bluff	0.95	0.28	---	---	0.59	0.17	4
Wing Point	---	---	---	---	---	---	4
Point Jefferson	---	---	---	---	---	---	4
Hansville	0.67	0.09	---	---	0.68	0.09	3

Appendix C: Summary tables of kelp bed area and depth

The tables in this appendix present the mean kelp bed area and the mean maximum and minimum bed depths for each site.

Table C1. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Squaxin Island. In 2022, depth was taken at each plant, rather than along transects, so only one mean depth is reported. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2013	8.8 [1]	-4.4 ± 0.91 [20]	ND
2014	6.9 [1]	-3.9 ± 0.98 [24]	ND
2016	2.7 ± 0.1 [3]	-2.5 ± 0.25 [11]	-1.2 ± 0.28 [11]
2017	1.6 ± 0.03 [3]	-2.3 ± 0.53 [11]	-1.0 ± 0.33 [11]
2018	2.8 ± 0.07 [5]	-3.0 ±0.70 [11]	-1.3 ± 0.40 [11]
2019	3.3 ± 0.02 [3]	-3.1 ± 1.02 [11]	-1.5 ± 0.81 [11]
2020	2.4 ± 0.26 [3]	-2.4 ± 0.81 [10]	-1.2 ± 0.23 [10]
2021	2.6 ± 0.13 [3]	-2.7 ± 1.02 [11]	-1.5 ± 0.88 [11]
2022	0.3 ± 0.02 [3]	-1.9 ± 0.38* [53]	-1.9 ± 0.38* [53]
2023	1.9 ± 0.19 [4]	-2.4 ± 0.80 [8]	-1.3 ± 0.10 [8]

*mean depth for all plants observed in 2022, not distinguished between minimum and maximum.

Table C2. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Brisco Point. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD)	Mean minimum bed depth (m) (± SD)
2013	0.1 [1]	ND	ND
2017	0	ND	ND
2018	0	ND	ND
2019	0	ND	ND
2020	0	ND	ND
2021	0	ND	ND
2022	0	ND	ND
2023	0	ND	ND

Table C3. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Devil's Head. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD)	Mean minimum bed depth (m) (± SD)
2013	1.8 [1]	ND	ND
2017	0.1 ± 0.0001 [2]	ND	ND
2018	0	ND	ND
2019	0	ND	ND
2020	0	ND	ND
2021	0	ND	ND
2022	0	ND	ND
2023	0	ND	ND

Table C4. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Fox Island. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD)	Mean minimum bed depth (m) (± SD)
2013	1.3 [1]	ND	ND
2017	0.1 [1]	ND	ND
2018	0.04 ± 0.003 [3]	ND	ND
2019	0.02 [1]	ND	ND
2020	0.1 ± 0.02 [2]	ND	ND
2021	0.01 ± 0.002 [2]	ND	ND
2022	0.004 ± 0.002 [2]	ND	ND
2023	0.001 ± 0.0006 [2]	ND	ND

Table C5. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Day Island. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	4.9 ± 0.17 [4]	-5.7 ± 1.85 [10]	-1.2 ± 0.38 [10]
2021	4.3 ± 0.08 [4]	-5.1 ± 1.02 [12]	-1.7 ± 1.30 [12]
2022	4.9 ± 0.34 [5]	-5.4 ± 1.45 [13]	-1.8 ± 1.67 [13]
2023	6.6 ± 0.12 [5]	-6.5 ± 1.86 [12]	-1.2 ± 0.56 [12]

Table C6. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Salmon Beach. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2018	1.4 ± 0.14 [5]	-7.1 ± 1.92 [13]	-1.0 ± 0.33 [13]
2019	2.4 ± 0.16 [5]	-8.0 ± 1.44 [13]	-0.7 ± 0.11 [13]
2020	1.9 ± 0.06 [3]	-7.3 ± 1.27 [13]	-0.9 ± 0.23 [13]
2021	1.9 ± 0.06 [4]	-7.4 ± 092 [13]	-1.1 ± 0.25 [13]
2022	1.9 ± 0.07 [3]	-7.5 ± 0.59 [13]	-0.8 ± 0.20 [13]
2023	2.2 ± 0.10 [9]	-7.5 ± 0.14 [13]	-0.8 ± 0.14 [13]

Table C7. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Owen Beach. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	1.1 ± 0.06 [4]	-4.7 ± 1.33 [13]	-1.1 ± 0.24 [13]
2021	1.2 ± 0.12 [4]	-5.1 ± 1.37 [13]	-1.2 ± 0.80 [13]
2022	1.3 ± 0.17 [3]	-5.3 ± 1.64 [13]	-1.4 ± 0.23 [13]
2023	1.4 ± 0.12 [4]	-4.8 ± 1.65 [12]	-1.6 ± 1.21 [12]

Table C8. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Vashon Island East. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	2.6 ± 0.07 [5]	-2.8 ± 0.54 [11]	-1.2 ± 0.69 [11]
2021	2.9 ± 0.12 [6]	-3.7 ± 1.45 [10]	-1.0 ± 0.19 [10]
2022	3.1 ± 0.09 [5]	-3.4 ± 1.11 [12]	-1.3 ± 0.50 [12]
2023	3.4 ± 0.10 [5]	-3.2 ± 1.34 [12]	-0.8 ± 0.37 [12]

Table C9. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Lincoln Park. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	1.6 ± 0.09 [4]	-3.3 ± 1.89 [12]	-1.1 ± 0.44 [12]
2021	1.7 ± 0.05 [3]	-3.5 ± 2.05 [12]	-1.2 ± 0.31 [12]
2022	1.5 ± 0.03 [6]	-3.7 ± 1.90 [11]	-1.3 ± 0.21 [11]
2023	1.6 ± 0.11 [4]	-4.0 ± 1.56 [9]	-1.2 ± 0.19 [9]

Table C10. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Magnolia Bluff. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	0.4 ± 0.03 [4]	-3.6 ± 1.65 [5]	-3.1 ± 1.46 [5]
2021	0.4 ± 0.02 [6]	-3.0 ± 1.21 [9]	-2.4 ± 0.83 [9]
2022	0.6 ± 0.03 [5]	-3.4 ± 1.24 [7]	-2.3 ± 0.45 [7]
2023	2.3 ± 0.19 [4]	-6.1 ± 1.52 [16]	-3.1 ± 1.91 [16]

Table C11. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Hansville. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	ND	-5.2 ± 1.52 [12]	-1.6 ± 0.98 [12]
2021	4.2 ± 0.09 [4]	-5.9 ± 1.94 [13]	-1.9 ± 1.30 [13]
2022	4.7 ± 0.05 [6]	-7.2 ± 0.78 [12]	-1.4 ± 1.40 [12]
2023	5.9 ± 0.19 [4]	-7.2 ± 2.13 [12]	-1.7 ± 1.40 [12]

Table C12. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at Edmonds. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2020	ND	-4.2 ± 1.19 [12]	-2.4 ± 1.07 [12]
2021	ND	-4.7 ± 0.68 [13]	-2.4 ± 1.41 [13]
2023	4.2 ± 0.16 [3]	-4.9 ± 0.71 [12]	-2.5 ± 0.75 [12]

Table C13. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for each year sampled at North Beach. Data not collected denoted as [ND]. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2018	ND	-8.1 ± 1.13 [13]	-2.8 ± 1.08 [13]
2020	ND	-8.0 ± 3.70 [13]	-0.8 ± 0.30 [13]
2021	ND	-10.3 ± 0.82 [13]	-1.3 ± 0.37 [13]
2022	ND	-10.7 ± 1.47 [7]	-1.0 ± 0.21 [7]
2023	10.1 ± 0.17 [4]	-8.8 ± 1.40 [9]	-1.2 ± 0.42 [13]

Table C14. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for 2023 at Freshwater Bay. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2023	28.5 ± 1.44 [2]	-10.7 ± 1.65 [13]	-0.7 ± 0.23 [13]

Table C15. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for 2023 at Beckett Point. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2023	1.1 [1]	-2.3 ± 1.07 [13]	-0.9 ± 0.30 [13]

Table C16. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for 2023 at Burrows Island

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2023	1.9 ± 0.04 [4]	-7.5 ± 0.88 [13]	-1.4 ± 0.46 [13]

Table C17. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for 2023 at Point Caution. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2023	0.2 ± 0.02 [4]	-4.2 ± 2.23 [10]	-0.9 ± 0.29 [10]

Table C18. Mean kelp bed area (ha) and mean maximum and minimum depth depths (m) for 2023 at Cherry Point. Sample site listed in brackets [n].

Year	Mean kelp bed area (ha) (± SE) [n]	Mean maximum bed depth (m) (± SD) [n]	Mean minimum bed depth (m) (± SD) [n]
2023	5.5 [1]	-4.4 ± 0.60 [10]	-1.0 ± 0.51 [10]

Appendix D: Transect Depths

This appendix contains a summary graph and tables that include the minimum and maximum depth (relative to MLLW) of each transect sampled for each year and each site.

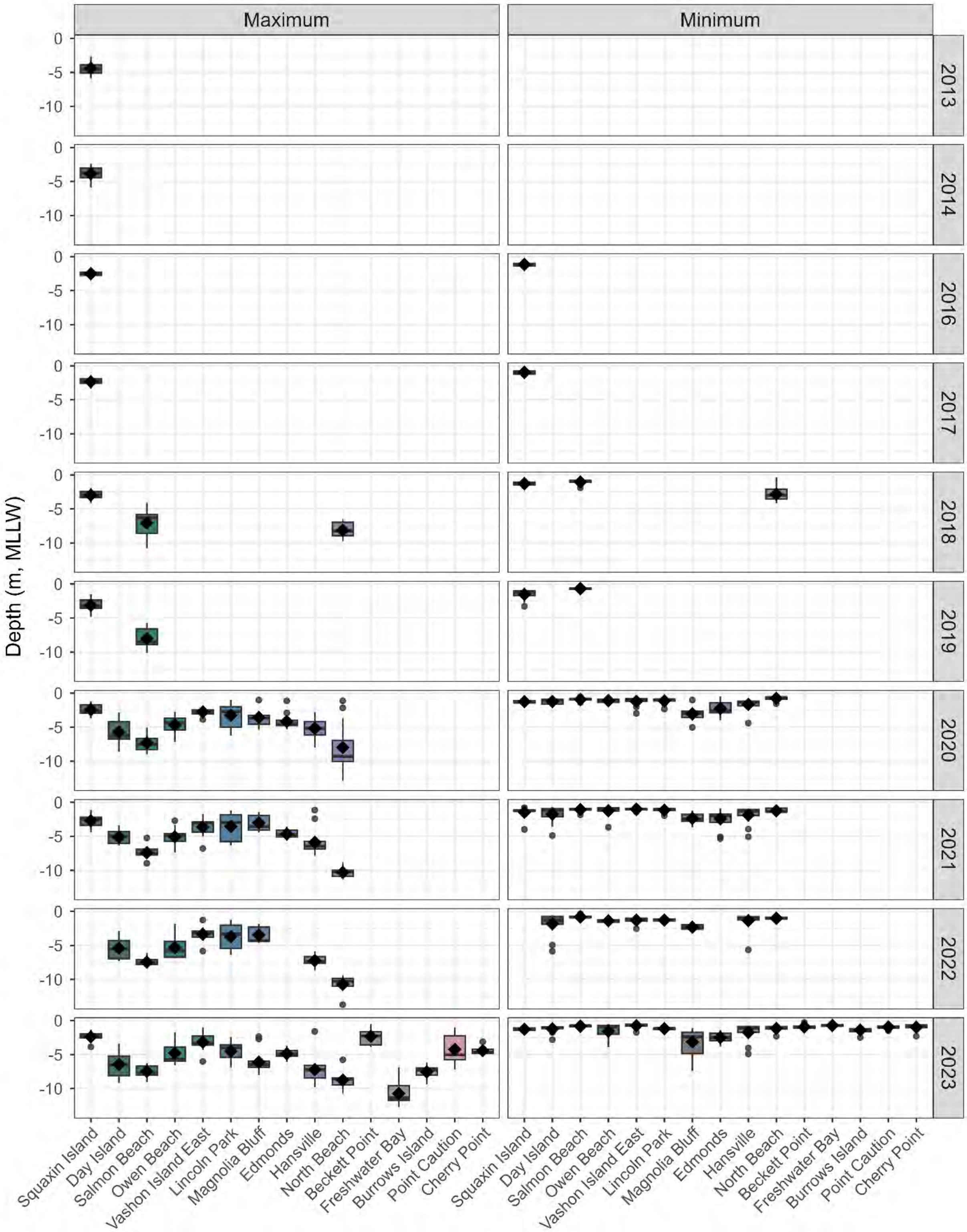

Figure D1. Minimum and maximum bed depth at DNR floating kelp monitoring sites. Circular points represent outliers and diamond points represent the mean. Sites are arranged from south (Squaxin Island) to north (Cherry Point) and colored to be easily distinguishable. Depth at Squaxin Island in 2022 was collected with modified method. See sections 3.3 and 3.4 for more site-specific details.

Table D1. Minimum and maximum depths (m MLLW) collected along each transect at each site for each year surveyed. Depths at Squaxin were not collected on established transects in 2013 and 2014 and are no included in this table. Dashed lines (---) indicate that no kelp was encountered along the transect. Transects not sampled are denoted with NA. Years with (+) denotes years where transect location/number do not match other years. Sites with a star (*) have supplemental transect depths in a separate table (Tables 2 and 3).

Site	Year		Depth (m MLLW) at Each Transect													Mean	± SD
			1	2	3	4	5	6	7	8	9	10	11	12	13		
Beckett Point	2023	Min	-0.53	-1.32	-1.12	-1.13	-0.94	-0.95	-0.96	-0.87	-0.99	-0.79	-0.79	-0.29	-1.38	-0.93	0.30
		Max	-0.53	-1.32	-1.63	-1.74	-2.35	-3.56	-2.27	-3.87	-3.67	-1.79	-3.67	-2.42	-1.38	-2.32	1.07
Burrows Island	2023	Min	-1.15	-1.47	-1.28	-1.31	-1.61	-1.83	-0.84	-1.33	-1.71	-1.20	-2.48	-1.28	-0.66	-1.40	0.46
		Max	-8.57	-9.34	-8.65	-6.88	-7.43	-6.68	-7.26	-7.2	-7.64	-6.19	-8.01	-6.96	-7.26	-7.54	0.88
Cherry Point	2023	Min	-2.30	NA	NA	NA	-0.75	-0.82	-0.63	-1.18	-0.91	-0.55	-0.57	-1.03	-1.05	-0.98	0.51
		Max	-4.86	NA	NA	NA	-4.71	-4.62	-4.43	-5.09	-3.77	-3.12	-4.62	-4.14	-4.88	-4.42	0.60
Day Island	2020	Min	-0.95	-1.70	-1.55	-0.87	-0.98	-0.90	-1.00	-1.62	-1.80	-0.90	---	---	---	-1.23	0.38
		Max	-8.60	-6.47	-6.19	-7.67	-6.25	-4.54	-6.80	-2.83	-3.70	-4.09	---	---	---	-5.71	1.85
	2021	Min	-0.97	-0.93	-0.74	-0.65	-0.98	-0.96	-1.25	-1.51	-2.04	-2.32	-3.60	---	-4.89	-1.74	1.30
		Max	-6.01	-6.02	-6.19	-6.37	-6.16	-4.85	-3.98	-4.36	-4.09	-3.40	-5.07	---	-4.89	-5.12	1.02
	2022	Min	-0.55	-0.75	-0.58	-0.71	-0.87	-1.18	-1.28	-1.72	-1.88	-1.32	-1.99	-4.95	-5.84	-1.82	1.67
		Max	-5.53	-6.94	-7.09	-7.14	-7.26	-5.74	-4.27	-2.88	-4.06	-3.79	-4.39	-5.26	-5.84	-5.40	1.45
	2023	Min	-1.04	-1.15	-1.74	-0.83	-0.83	-1.02	-1.05	-1.13	-1.19	-0.99	-0.85	---	-2.81	-1.22	0.56
		Max	-6.08	-8.28	-8.38	-9.19	-8.01	-6.77	-7.08	-4.64	-3.39	-3.88	-6.32	---	-5.41	-6.45	1.86
Edmonds	2020	Min	---	-2.66	-1.53	-1.65	-2.74	-3.35	-3.96	-2.79	-3.15	-2.51	-0.46	-1.07	-1.05	-2.24	1.07
		Max	---	-3.27	-4.26	-4.80	-4.60	-4.39	-5.31	-4.72	-4.71	-4.53	-2.90	-1.12	-5.24	-4.15	1.19
	2021	Min	-5.33	-2.97	-2.67	-1.73	-1.79	-2.04	-2.96	-2.14	-1.88	-0.90	-0.91	-1.09	-5.07	-2.42	1.41
		Max	-5.33	-5.64	-5.00	-5.59	-4.76	-4.90	-4.38	-4.10	-4.38	-4.10	-3.59	-3.69	-5.07	-4.66	0.68
	2023	Min	---	-3.76	-1.95	-1.91	-1.39	-1.76	-3.19	-2.89	-2.65	-1.71	-2.36	-2.82	-3.38	-2.48	0.75
		Max	---	-5.15	-5.18	-5.23	-5.11	-4.77	-5.93	-4.32	-4.03	-4.43	-6.05	-3.67	-4.56	-4.87	0.71
Freshwater Bay	2023	Min	-0.66	-0.73	-0.37	-0.71	-1.04	-0.84	-0.63	-0.54	-1.03	-0.42	-0.59	-0.73	-1.11	-0.72	0.23
		Max	-9.55	-6.90	-11.86	-11.38	-11.75	-11.12	-11.45	-10.69	-12.70	-8.56	-12.36	-11.50	-9.59	-10.72	1.65
Hansville	2020	Min	-0.76	-1.84	-1.23	-0.83	-1.01	-1.63	-1.22	-1.87	-1.32	-1.30	-2.32	-4.40	---	-1.64	0.98
		Max	-7.97	-6.68	-5.84	-6.09	-6.37	-3.52	-2.79	-4.37	-5.63	-4.73	-3.55	-4.40	---	-5.16	1.52
	2021	Min	-1.14	-1.95	-1.06	-2.85	-1.26	-1.06	-1.02	-1.01	-1.07	-1.26	-1.60	-3.94	-5.07	-1.87	1.30
		Max	-1.14	-2.41	-5.74	-5.59	-6.96	-7.49	-7.86	-6.50	-6.45	-6.84	-6.22	-6.43	-6.82	-5.88	1.94
	2022	Min	-0.52	-1.26	-1.25	-0.96	-0.82	-0.87	-0.97	-1.12	-0.45	-0.63	-1.69	-5.64	---	-1.35	1.40
		Max	-7.39	-7.33	-8.02	-7.61	-7.15	-7.65	-6.48	-6.29	-5.87	-6.69	-7.57	-8.67	---	-7.23	0.78
	2023	Min	-0.85	-0.78	-4.90	-0.95	-1.27	-0.88	-0.80	-0.94	-1.17	-1.44	-2.71	-4.03	---	-1.73	1.40
		Max	-1.60	-9.67	-9.75	-8.80	-8.33	-7.58	-6.52	-6.59	-7.47	-6.94	-6.99	-6.30	---	-7.21	2.13
Lincoln	2020	Min	-1.46	---	-1.01	-0.78	-0.95	-1.52	-0.92	-0.98	-1.03	-0.82	-0.89	-0.96	-2.32	-1.14	0.44

Site	Year		Depth (m MLLW) at Each Transect													Mean	± SD
			1	2	3	4	5	6	7	8	9	10	11	12	13		
Park		Max	-2.07	---	-2.72	-5.24	-2.70	-1.72	-1.13	-0.98	-2.81	-4.94	-6.24	-6.18	-2.32	-3.25	1.89
	2021	Min	-1.19	-1.95	-0.95	-0.96	-1.01	-1.52	-0.92	-1.02	-1.03	-0.92	-1.01	-1.29	---	-1.15	0.31
		Max	-1.19	-1.95	-2.39	-5.68	-3.85	-1.52	-1.32	-2.36	-3.55	-6.11	-6.26	-6.35	---	-3.54	2.05
	2022	Min	---	---	-1.16	-1.05	-1.12	-1.25	-1.62	-1.48	-1.14	-1.22	-1.07	-1.24	-1.61	-1.27	0.21
		Max	---	---	-3.33	-5.77	-4.37	-1.25	-1.62	-2.38	-2.99	-5.13	-6.34	-6.01	-1.61	-3.71	1.90
	2023	Min	---	---	-1.12	-0.90	-1.15	-1.31	---	-1.10	-1.07	-1.52	-1.13	-1.43	---	-1.19	0.19
		Max	---	---	-4.42	-5.40	-3.22	-3.82	---	-2.41	-3.56	-6.92	-6.79	-3.98	---	-4.50	1.56
Magnolia Bluff*	2020	Min	---	---	---	---	---	---	---	---	---	-2.67	-2.97	-5.03	-1.00	-3.05	1.46
		Max	---	---	---	---	---	---	---	---	---	-3.27	-4.55	-5.36	-1.00	-3.57	1.65
	2021	Min	-1.77	-1.44	-1.93	-1.22	---	---	---	---	---	-2.48	-2.79	-3.67	---	-2.35	0.83
		Max	-1.77	-1.44	-1.93	-1.99	---	---	---	---	---	-3.55	-4.43	-3.67	---	-3.02	1.21
	2022	Min	---	---	---	-2.69	-1.90	-1.86	---	---	---	-1.94	-2.28	---	---	-2.31	0.45
		Max	---	---	---	-2.69	-1.90	-1.86	---	---	---	-4.32	-4.38	---	---	-3.44	1.24
	2023	Min	---	-5.70	---	-5.30	-7.38	-2.35	-5.0	-4.81	-2.39	-1.29	-1.26	-1.07	-2.70	-3.14	1.91
		Max	---	-5.70	---	-6.49	-7.38	-2.35	-6.83	-6.09	-6.75	-6.90	-7.16	-6.71	-2.70	-6.11	1.52
North Beach	2018+	Min	-0.37	-3.54	-2.97	-3.37	-1.97	-3.98	-3.87	-3.49	-4.13	-2.73	-2.67	-2.09	-1.77	-2.84	1.08
		Max	-7.40	-8.25	-6.57	-6.92	-6.46	-6.98	-8.25	-8.95	-8.79	-9.05	-8.77	-9.54	-9.72	-8.13	1.13
	2020	Min	-0.60	-1.07	-1.53	-0.96	-0.56	-0.58	-0.57	-0.76	-0.65	-0.89	-0.38	-0.71	-0.63	-0.76	0.30
		Max	-12.88	-7.41	-6.93	-7.65	-10.91	-12.25	-3.64	-9.70	-9.31	-2.15	-9.80	-10.06	-1.11	-7.98	3.70
	2021	Min	-0.80	-0.80	-1.73	-0.73	-1.04	-0.86	-1.65	-1.37	-1.35	-1.33	-1.38	-1.41	-1.82	-1.25	0.37
		Max	-11.40	-10.01	-10.69	-11.05	-10.11	-10.69	-8.87	-8.87	-9.75	-10.26	-10.88	-10.12	-11.36	-10.31	0.82
	2022	Min	NA	NA	NA	NA	NA	-1.11	-1.02	-1.13	-0.70	-1.34	-0.86	-0.88	NA	-1.00	0.21
		Max	NA	NA	NA	NA	NA	-10.55	-11.42	-13.71	-9.79	-10.28	-9.38	-9.90	NA	-10.72	1.47
	2023	Min	-1.50	-1.44	-2.30	-1.07	-0.82	-1.11	-0.81	-0.75	-1.25	-1.15	-0.98	-0.88	-0.91	-1.15	0.42
		Max	NA	NA	NA	NA	-5.76	-9.47	-10.74	-8.43	-8.58	-8.45	-9.90	-9.32	-8.13	-8.75	1.40
Owen Beach	2020	Min	-1.01	-0.91	-0.97	-1.22	-0.77	-0.76	-1.03	-0.85	-1.39	-1.16	-1.46	-1.34	-1.37	-1.10	0.24
		Max	-7.14	-2.71	-6.69	-5.40	-5.91	-3.15	-4.83	-4.13	-3.69	-4.36	-3.59	-4.91	-4.21	-4.67	1.33
	2021	Min	-1.35	-0.96	-1.26	-0.77	-1.00	-0.81	-0.71	-0.92	-0.81	-1.11	-1.86	-0.78	-3.67	-1.23	0.80
		Max	-7.37	-5.71	-7.28	-6.04	-4.90	-3.86	-3.31	-4.98	-2.70	-4.86	-5.67	-4.65	-4.59	-5.07	1.37
	2022	Min	-1.35	-1.31	-1.79	-1.35	-1.70	-1.12	-1.28	-1.13	-1.03	-1.42	-1.60	-1.57	-1.21	-1.37	0.23
		Max	-5.20	-6.87	-6.72	-6.53	-6.75	-6.79	-5.96	-5.77	-1.80	-2.58	-4.38	-4.36	-5.38	-5.31	1.64
	2023	Min	-3.18	-3.42	-3.88	-1.60	-0.87	-0.88	-0.98	-0.65	-0.52	-1.48	-0.72	-0.72	---	-1.58	1.21
		Max	-5.85	-5.54	-6.59	-6.18	-5.82	-5.81	-6.09	-4.23	-2.22	-3.15	-4.11	-1.76	---	-4.78	1.65
Point Caution*	2023	Min	---	---	-1.08	-1.50	---	---	-0.90	-0.40	-1.04	---	---	---	---	-0.94	0.29
		Max	---	---	-1.08	-1.50	---	---	-5.63	-5.26	-1.04	---	---	---	---	-4.24	2.23
Salmon Beach	2018	Min	-1.02	-1.02	-0.83	-1.89	-1.07	-0.83	-0.78	-1.51	-1.22	-0.82	-0.94	-0.87	-0.77	-1.04	0.33
		Max	-6.05	-5.92	-7.98	-10.79	-8.66	-5.46	-8.59	-8.92	-4.11	-5.82	-6.31	-5.09	-8.24	-7.07	1.92

Site	Year		Depth (m MLLW) at Each Transect													Mean	± SD
			1	2	3	4	5	6	7	8	9	10	11	12	13		
	2019	Min	-0.60	-0.68	-0.74	-0.79	-0.81	-0.80	-0.78	-0.57	-0.63	-0.52	-0.48	-0.70	-0.60	-0.67	0.11
		Max	-5.75	-5.92	-6.27	-8.87	-8.68	-8.51	-7.75	-9.31	-10.10	-9.54	-8.60	-8.29	-6.59	-8.01	1.44
	2020	Min	-0.79	-0.87	-0.54	-0.77	-0.85	-0.88	-1.38	-1.03	-0.82	-1.35	-0.75	-0.96	-0.96	-0.92	0.23
		Max	-6.85	-5.58	-6.66	-5.48	-7.98	-8.30	-8.31	-8.34	-7.49	-8.31	-7.54	-8.97	-5.06	-7.30	1.27
	2021	Min	-0.91	-0.92	-0.83	-1.83	-1.02	-1.02	-1.12	-1.10	-0.84	-1.03	-1.13	-1.02	-1.16	-1.07	0.25
		Max	-8.22	-6.91	-7.58	-7.32	-7.71	-7.62	-8.11	-7.71	-6.47	-8.96	-7.67	-5.24	-6.72	-7.40	0.92
	2022	Min	-0.58	-0.63	-0.84	-0.83	-0.84	-0.83	-0.82	-0.71	-0.90	-0.95	-1.14	-0.99	-0.34	-0.80	0.20
		Max	-6.91	-7.12	-6.83	-7.54	-7.73	-7.63	-7.82	-7.82	-8.08	-8.27	-7.72	-6.11	-7.25	-7.45	0.59
	2023	Min	-0.83	-0.91	-0.75	-1.09	-0.68	-0.74	-0.75	-0.78	-0.88	-0.97	-057	-0.76	-0.93	-0.82	0.14
		Max	-6.38	-6.28	-7.70	-7.73	-6.35	-6.70	-7.65	-7.69	-8.01	-8.28	-8.46	-6.74	-9.03	-7.46	0.14
Squaxin Island	2016[+]	Min	-1.13	-0.69	-0.72	-1.50	-1.18	-1.19	-1.37	-1.32	-0.92	-1.11	-1.51	NA	NA	-1.15	0.28
		Max	-2.45	-2.46	-2.29	-2.72	-2.25	-2.78	-2.15	-2.77	-2.59	-2.27	-2.85	NA	NA	-2.51	0.25
	2017[+]	Min	-1.21	-0.88	-0.68	-1.23	-1.01	-0.85	-1.27	-0.82	-0.54	-0.54	-1.56	---	---	-0.96	0.33
		Max	-2.02	-2.02	-1.86	-2.70	-3.33	-2.37	-2.29	-2.41	-1.74	-1.86	-3.16	---	---	-2.34	0.53
	2018	Min	-1.26	-1.10	-0.74	-1.14	-1.02	-0.89	-1.22	-1.41	-1.49	-1.87	-2.04	---	---	-1.29	0.40
		Max	-2.07	-4.12	-1.95	-2.54	-3.22	-3.17	-3.90	-3.38	-2.96	-2.37	-2.96	---	---	-2.97	0.70
	2019	Min	---	-0.90	-0.93	-0.97	-1.00	-1.41	-1.23	-1.22	-1.02	-2.73	-2.00	-3.27	---	-1.51	0.81
		Max	---	-1.51	-1.92	-2.01	-4.36	-3.77	-4.78	-3.38	-3.29	-2.73	-3.34	-3.27	---	-3.12	1.02
	2020	Min	---	---	-1.41	-1.27	-1.09	-1.32	-1.32	-1.44	-0.88	-1.52	-0.83	-1.35	---	-1.24	0.23
		Max	---	---	-1.52	-1.48	-1.19	-2.80	-3.70	-2.92	-2.51	-2.87	-2.25	-3.08	---	-2.43	0.81
	2021	Min	---	---	-1.32	-1.22	-1.13	-1.18	-0.85	-1.33	-1.22	-1.32	-0.81	-1.77	-3.99	-1.47	0.88
		Max	---	---	-2.15	-1.40	-1.13	-3.47	-2.49	-2.88	-2.24	-3.34	-2.37	-4.40	-3.99	-2.71	1.02
	2023	Min	---	---	---	-1.13	---	-0.94	-1.40	-1.23	-1.25	-1.54	-0.94	-1.73	---	-1.27	0.10
		Max	---	---	---	-3.24	---	-1.34	-1.91	-1.96	-2.31	-2.28	-2.25	-3.86	---	-2.40	0.80
Vashon Island East	2020	Min	-2.02	-2.98	-1.23	-1.19	-0.82	-0.99	-0.81	-0.92	-0.94	-0.78	-0.66	---	---	-1.21	0.69
		Max	-2.02	-2.98	-2.70	-2.61	-2.74	-3.03	-2.36	-2.72	-3.28	-3.86	-1.99	---	---	-2.75	0.54
	2021	Min	---	-1.42	-1.11	-0.70	-1.00	-0.97	-1.10	-0.94	-1.07	-0.84	-0.99	---	---	-1.01	0.19
		Max	---	-3.00	-2.92	-3.67	-2.92	-2.84	-1.71	-6.79	-5.01	-4.60	-3.02	---	---	-3.65	1.45
	2022	Min	-2.53	-1.53	-1.79	-1.01	-0.90	-0.85	-0.64	-1.27	-1.30	-1.06	-1.34	---	-1.26	-1.29	0.50
		Max	-4.29	-5.82	-2.93	-4.01	-3.08	-2.93	-2.89	-3.71	-3.27	-3.63	-2.35	---	-1.26	-3.35	1.11
	2023	Min	-1.72	-0.55	-0.76	-0.54	-0.95	-0.20	-0.56	-0.63	-0.76	-0.75	-0.55	-0.99	---	-0.75	0.37
		Max	-4.33	-3.44	-3.97	-3.44	-3.09	-3.27	-2.37	-2.01	-6.01	-3.50	-1.57	-0.98	---	-3.16	1.34

Table D2. Minimum and maximum depths (m MLLW) collected at each supplemental transect between 2020 and 2023 at Magnolia Bluff. Dashed lines (---) indicate that no kelp was encountered along the transect.

Site	Year		Depth (m MLLW) at Each Transect					Mean	± SD
			8b	9b	10b	11b	12b		
Magnolia Bluff	2020	Min	---	---	---	-3.58	---	-3.05	1.46
		Max	---	---	---	-3.66	---	-3.57	1.65
	2021	Min	---	---	-2.55	-3.31	---	-2.35	0.83
		Max	---	---	-4.09	-4.28	---	-3.02	1.21
	2022	Min	---	---	-2.50	-3.02	---	-2.31	0.45
		Max	---	---	-4.32	-4.64	---	-3.44	1.24
	2023	Min	-2.39	-1.79	-1.46	-1.96	-1.33	-3.14	1.91
		Max	-5.97	-6.38	-8.02	-6.40	-5.88	-6.11	1.52

Table D3. Minimum and maximum depths (m MLLW) collected at each supplemental transect in 2023 at Point Caution.

Site	Year		Depth (m MLLW) at Each Transect					Mean	± SD
			6b	6c	7b	7c	8b		
Point Caution	2023	Min	-0.75	-0.74	-0.97	-1.07	-0.98	-0.94	0.29
		Max	-4.42	-4.82	-5.93	-5.23	-7.21	-4.24	2.23

Appendix E: Candidate floating kelp stressors

Floating kelp can often be impacted by multiple stressors simultaneously. DNR's current floating kelp monitoring program does not monitor stressors associated with floating kelp loss, but a list of potential stressors was compiled based on observations at each site by DNR staff (Table E1).

Table E1. Candidate floating kelp stressors classified as "likely" (X), "potential" (?), or "unlikely" (-) at each monitoring site. Classifications based on site observations by DNR staff.

Site	Possible stressors							
	Elevated water temperature	High water column turbidity	Limited substrate for attachment	Urchin grazing	Kelp crabs	Competition with Sargassum	Recruitment limitation	Boat traffic
Squaxin Island	X	X	?	-	X	X	X	X
Brisco Point	X	?	-	-	-	?	?	-
Devil's Head	X	-	?	-	?	?	?	?
Fox Island	X	-	?	-	?	X	X	-
Day Island	-	-	-	-	-	X	-	-
Salmon Beach	-	-	-	-	-	X	-	X
Owen Beach	-	-	-	-	-	-	-	X
Vashon Island East	-	-	-	-	-	-	-	-
Lincoln Park	-	X	-	-	-	-	-	X
Magnolia Bluff	-	X	-	-	-	-	-	X
Wing Point	?	?	?	-	X	?	X	X
Point Jefferson	-	?	?	-	?	?	X	X
Hansville	-	-	X	-	-	-	-	-
Edmonds	-	?	X	-	?	-	-	-
North Beach	-	X	-	-	-	-	-	-
Freshwater Bay	-	?	X	?	?	?	-	-
Beckett Point	-	?	X	-	?	?	?	?
Burrows Island	-	?	-	-	?	?	-	?
Point Caution	-	?	-	-	?	?	-	-
Cherry Point	X	?	?	-	?	X	-	-

Appendix F: Site transect maps

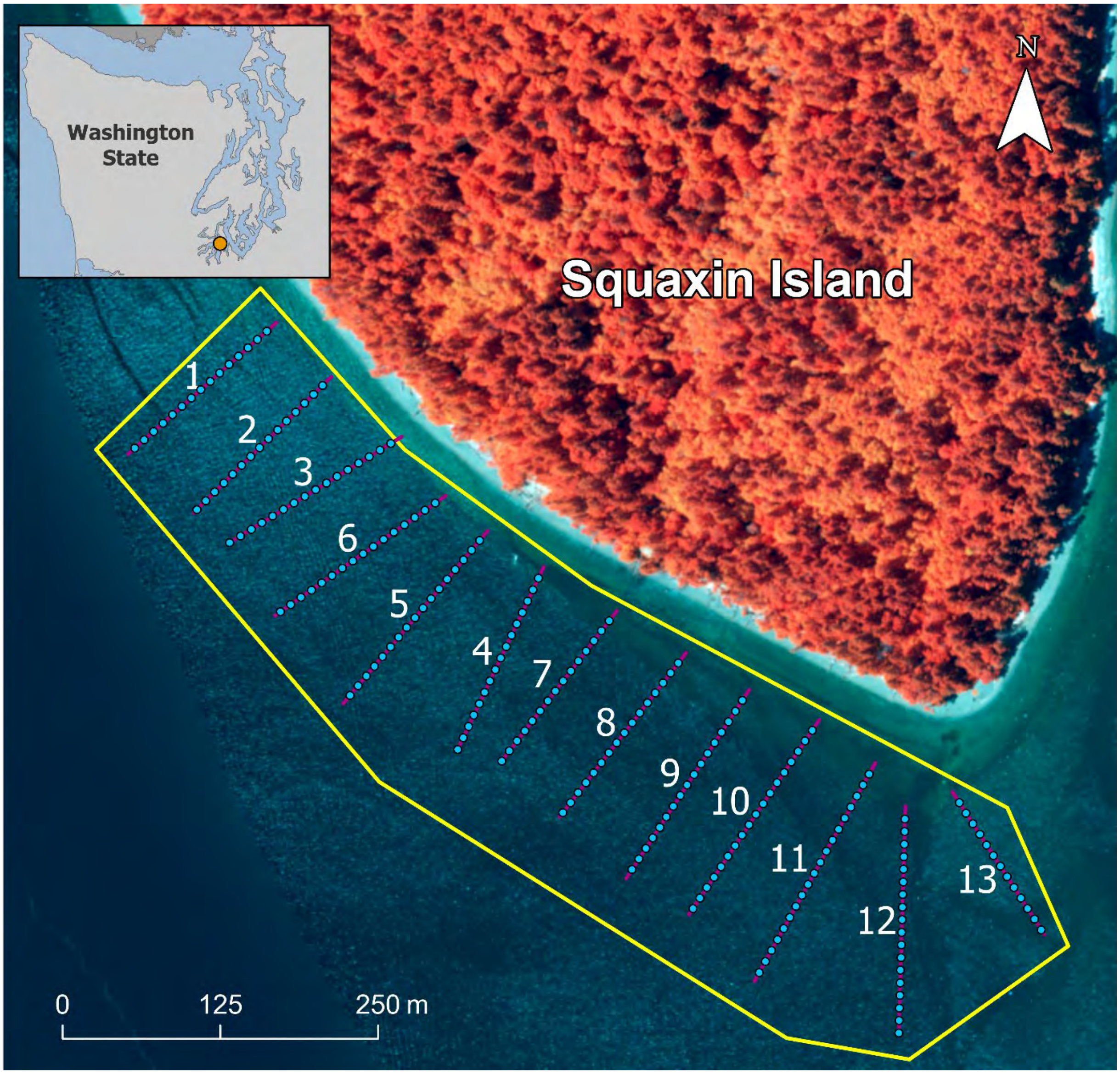

Figure F1. Map of the Squaxin Island numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

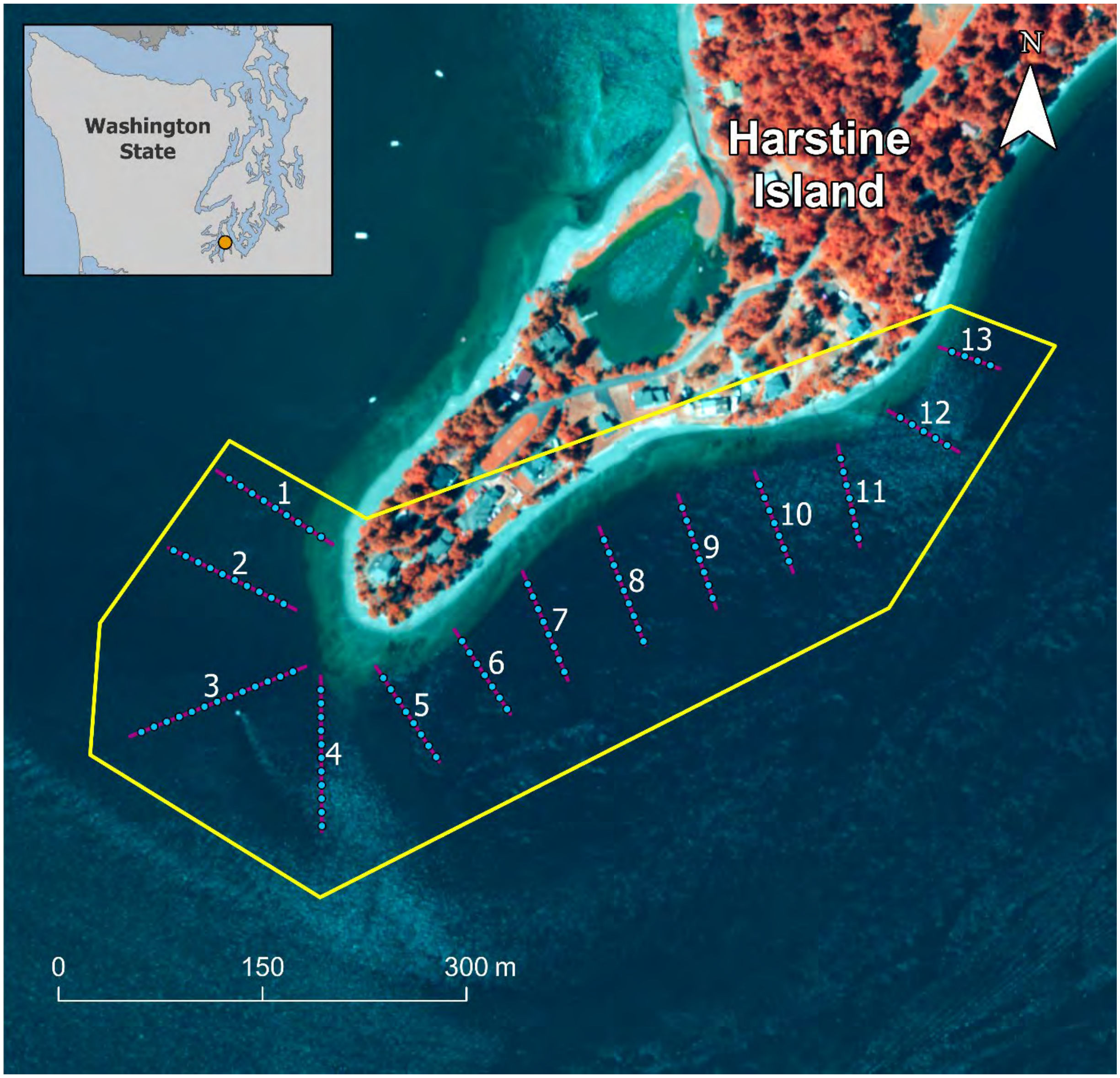

Figure F2. Map of the Brisco Point numbered transect lines. Transect lines were boated to confirm kelp absence at the site. The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

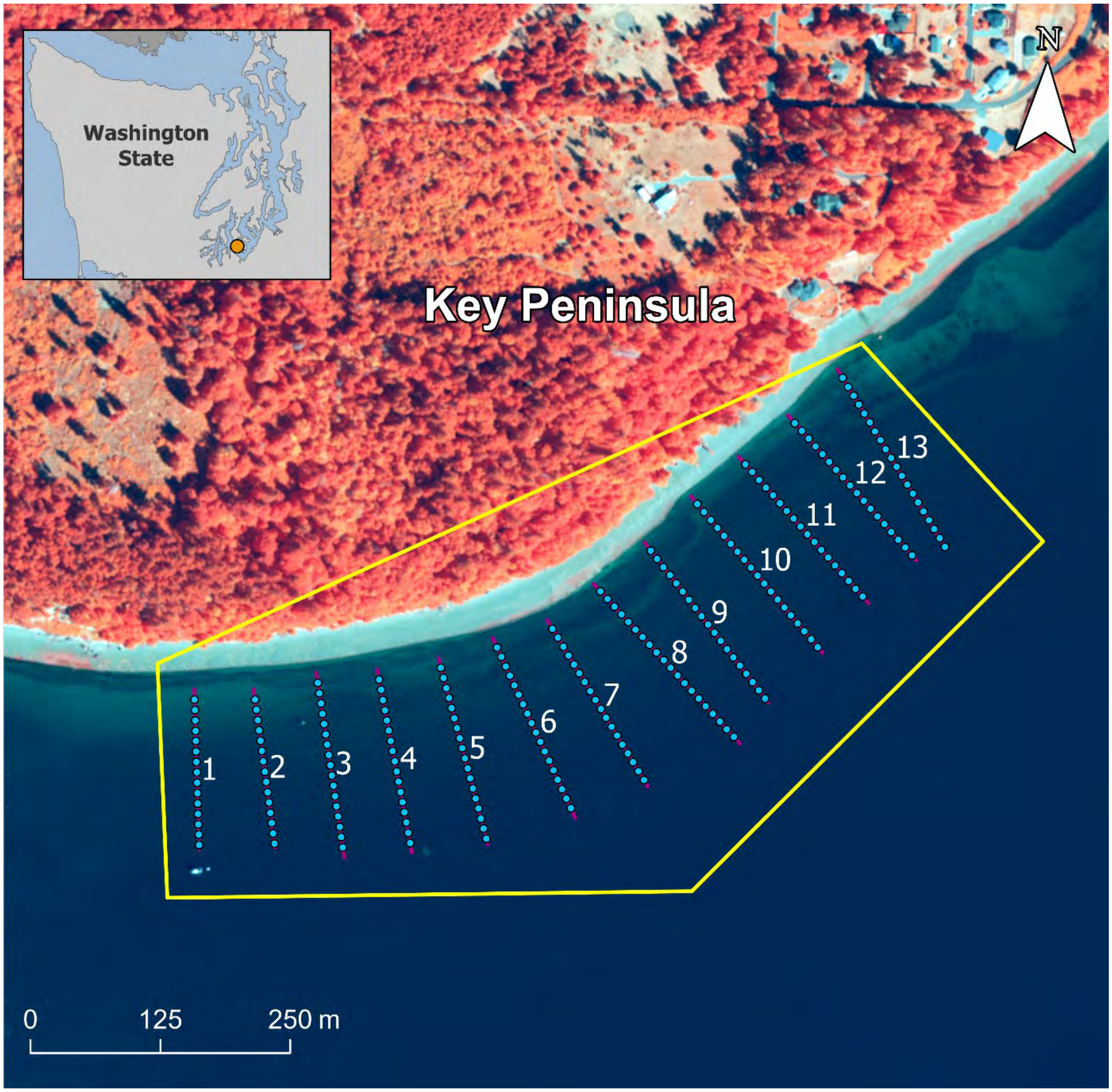

Figure F3. Map of the Devil's Head numbered transect lines. Transect lines were boated to confirm kelp absence at the site. The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

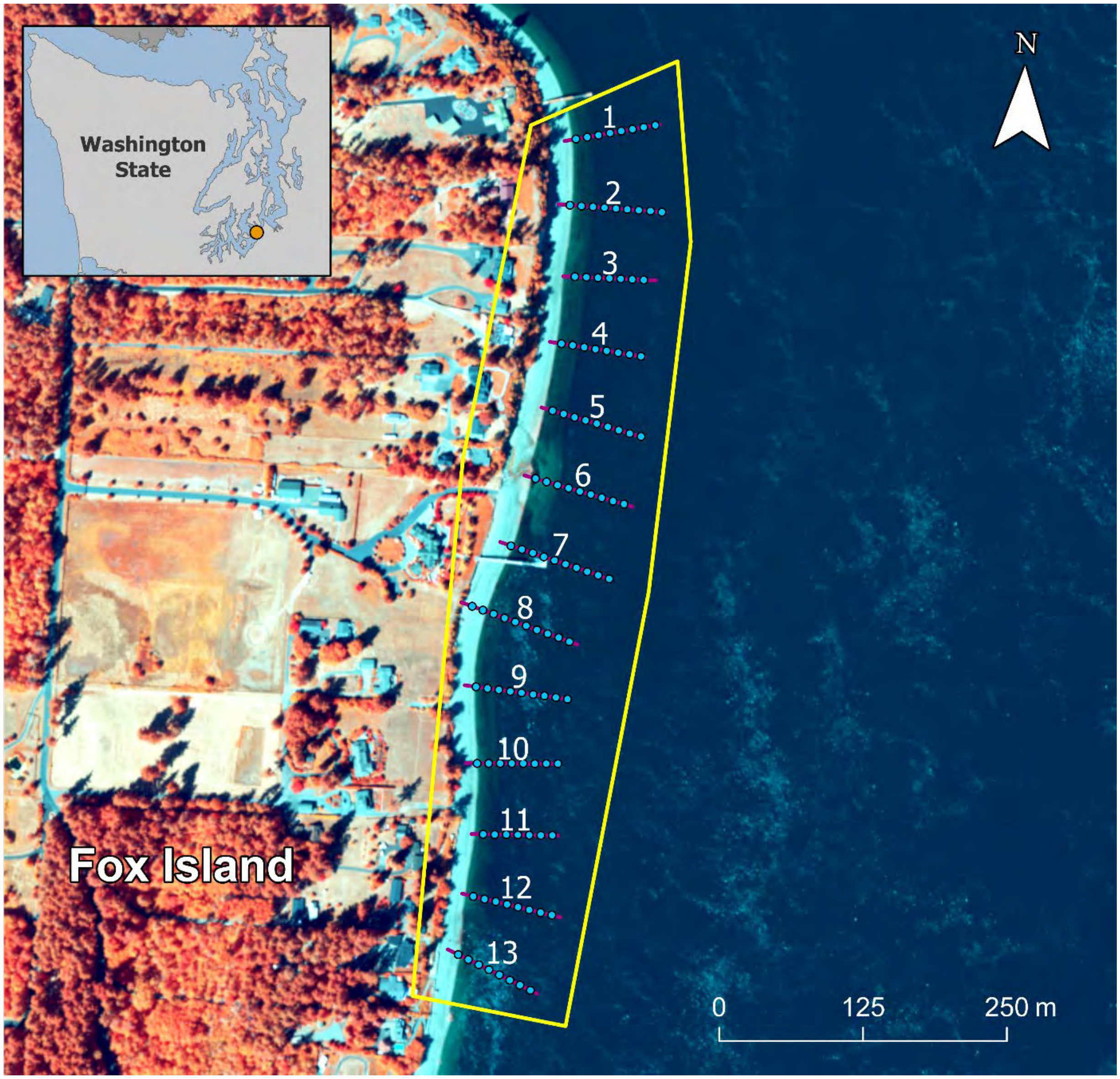

Figure F4. Map of the Fox Island numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

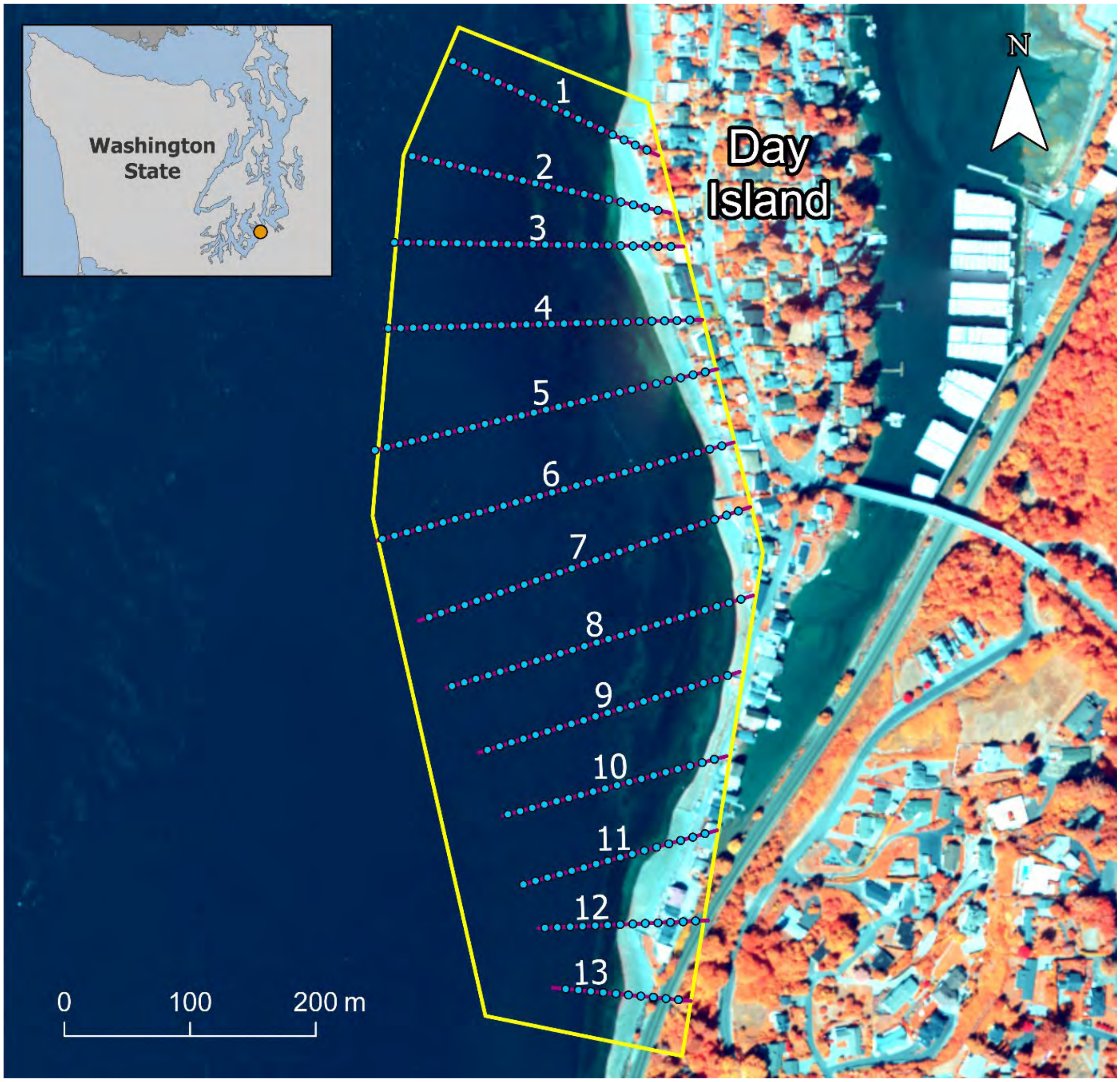

Figure F5. Map of the Day Island numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

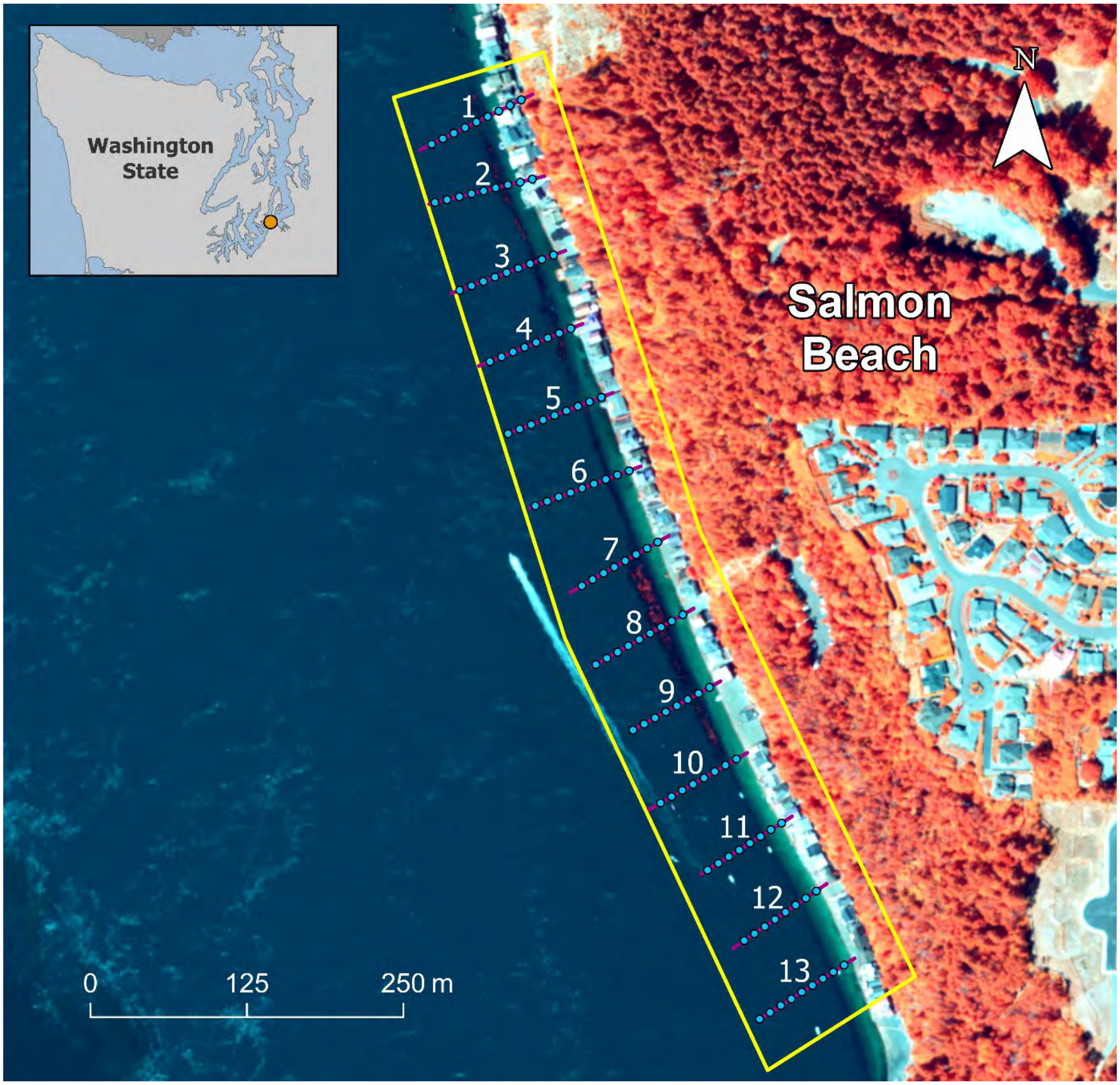

Figure F6. Map of the Salmon Beach numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

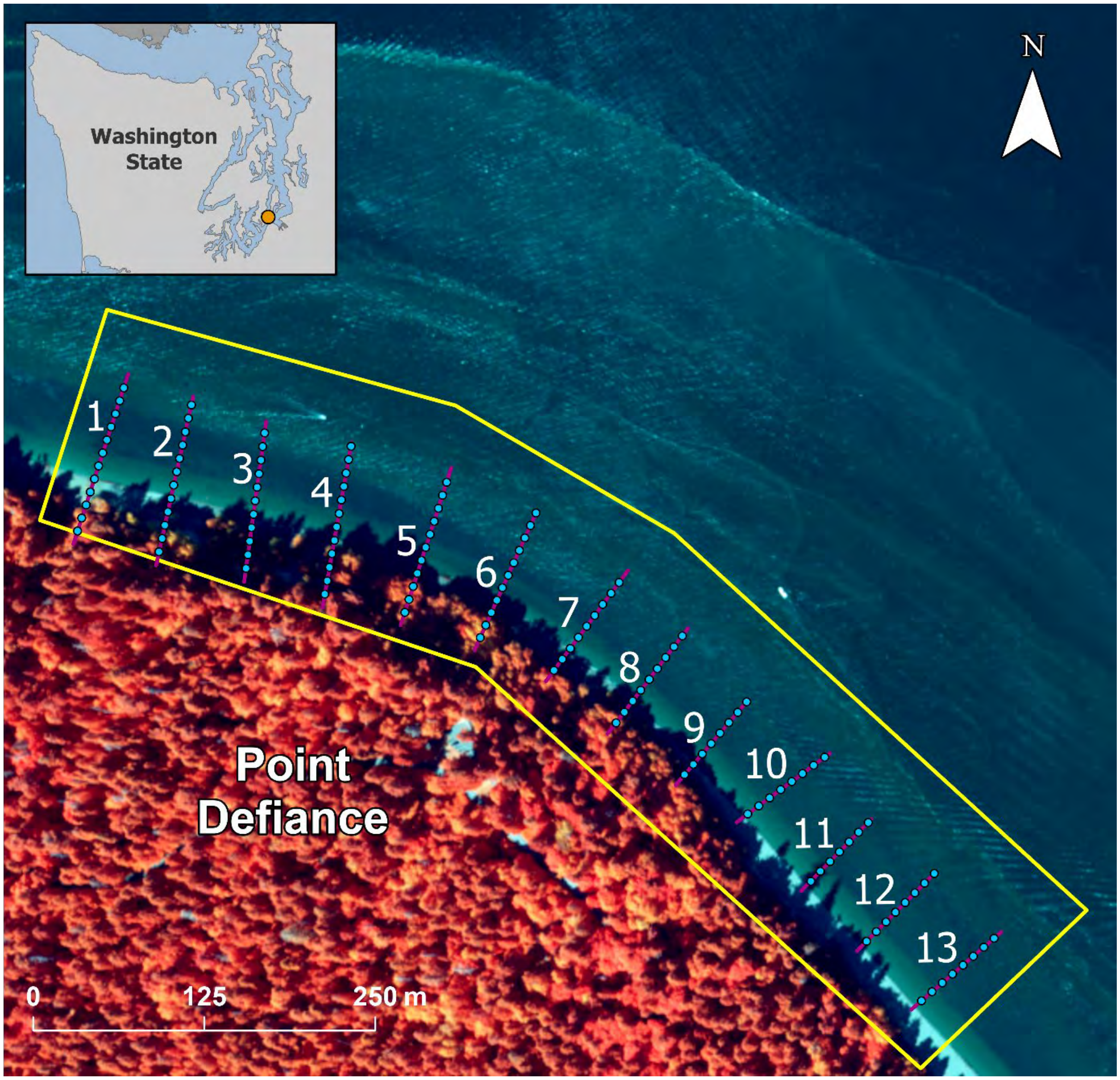

Figure F7. Map of the Owen Beach numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

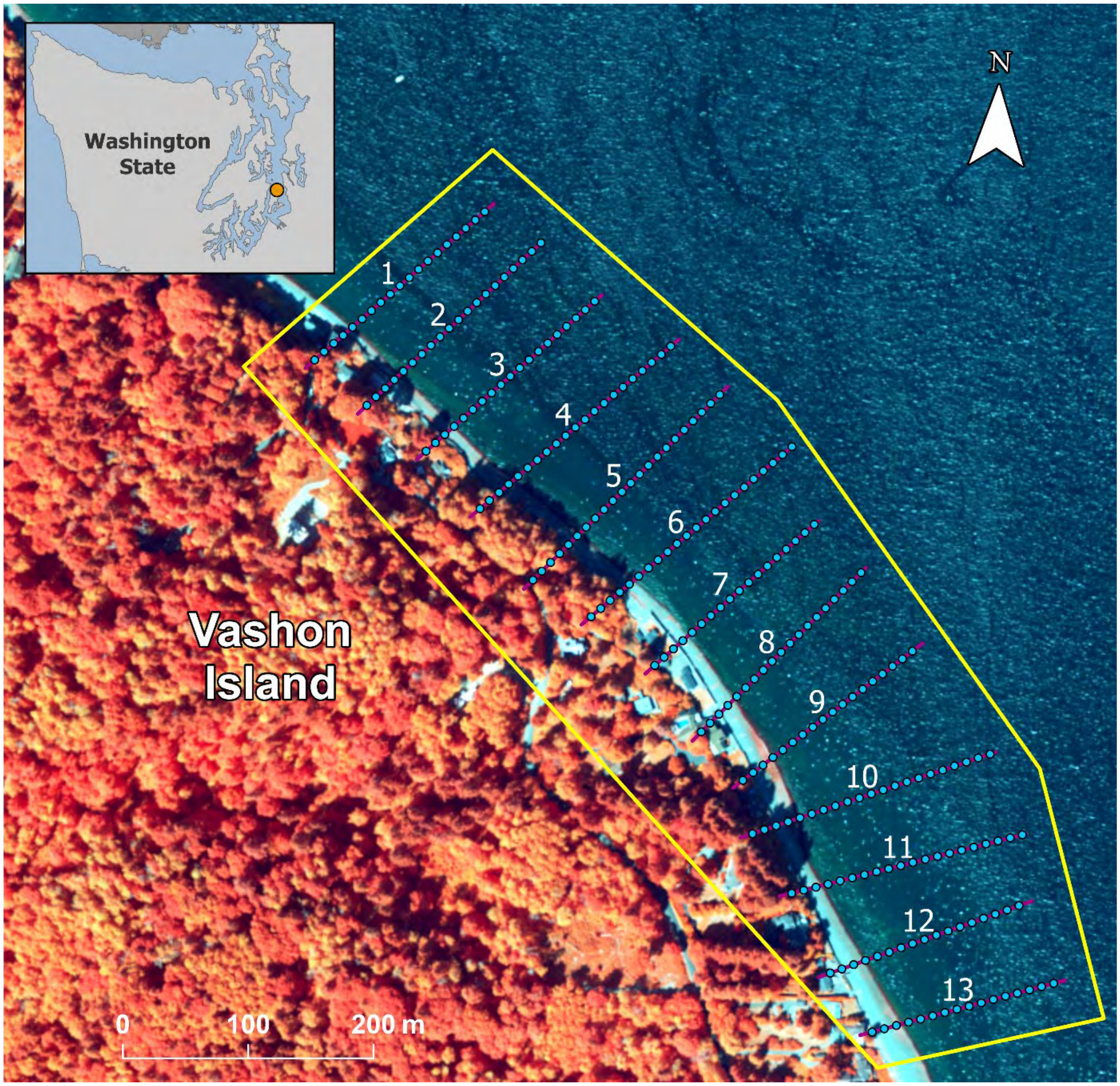

Figure F8. Map of the Vashon Island East numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

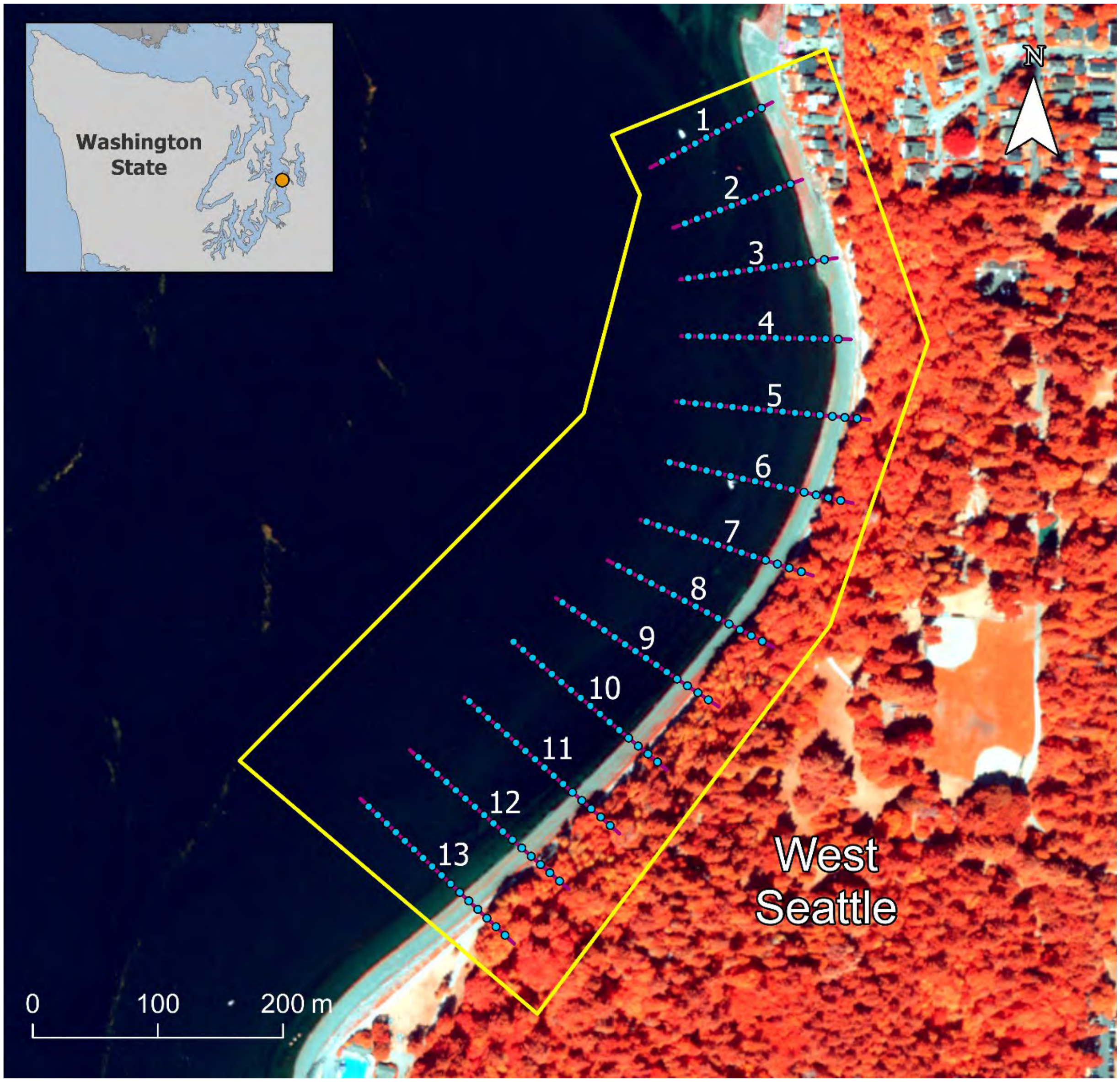

Figure F9. Map of the Lincoln Park numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

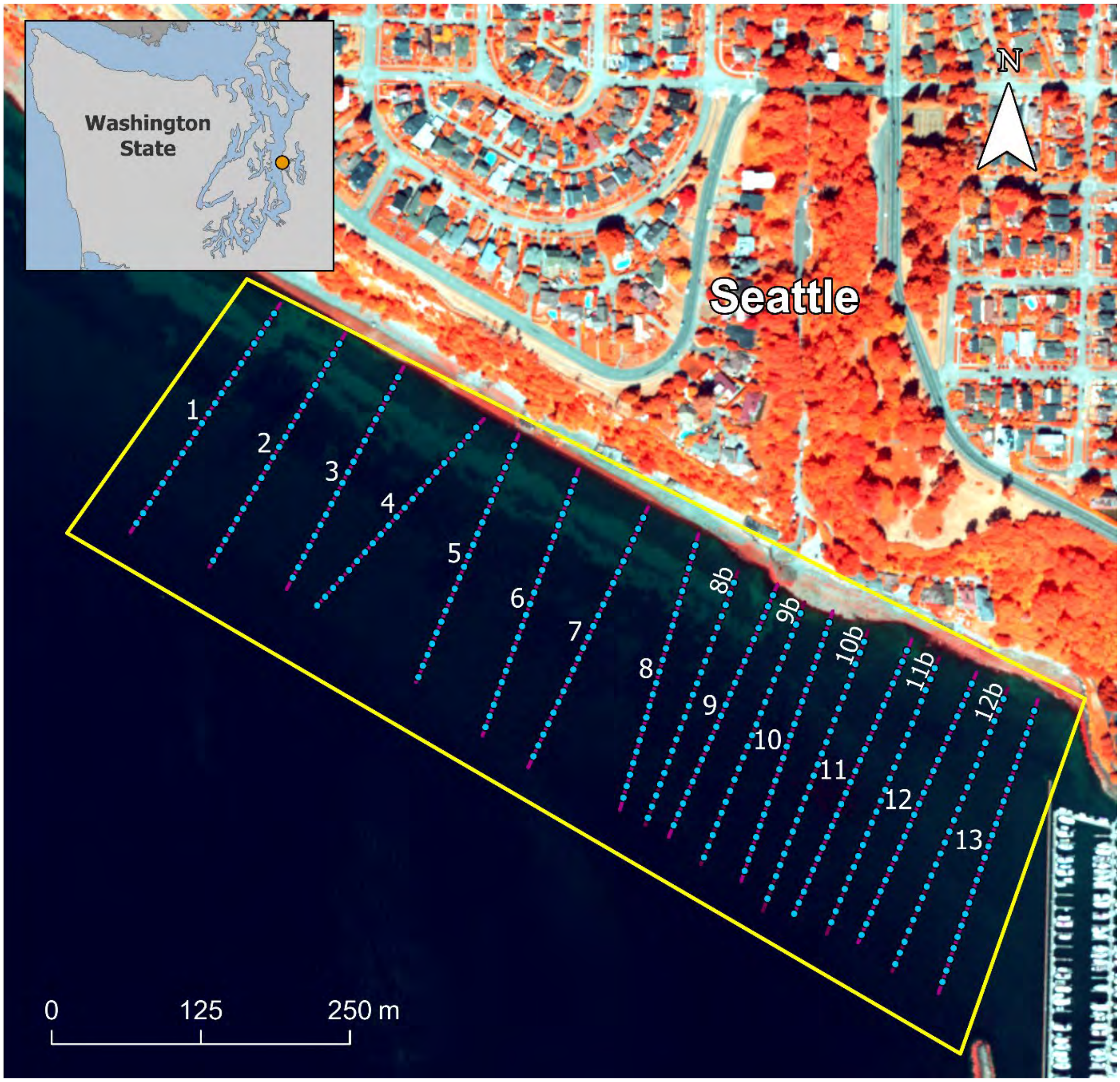

Figure F10. Map of the Magnolia numbered transect lines. Because of the small size of the kelp bed, sub-transects were added to this site (8b-12b), denoted in dark pink. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

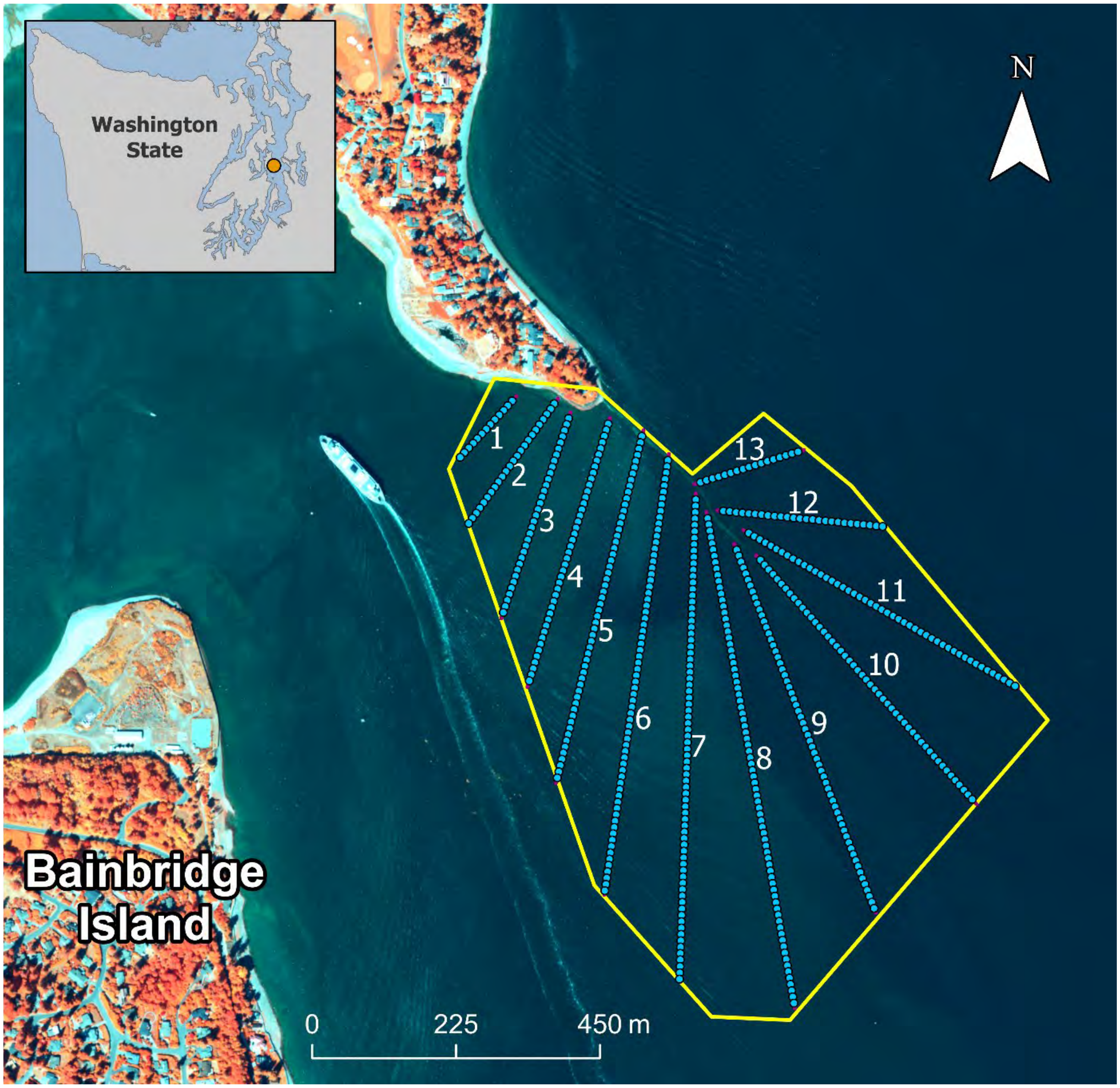

Figure F11. Map of the Wing Point numbered transect lines. Transect lines were boated to confirm kelp absence at the site. The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

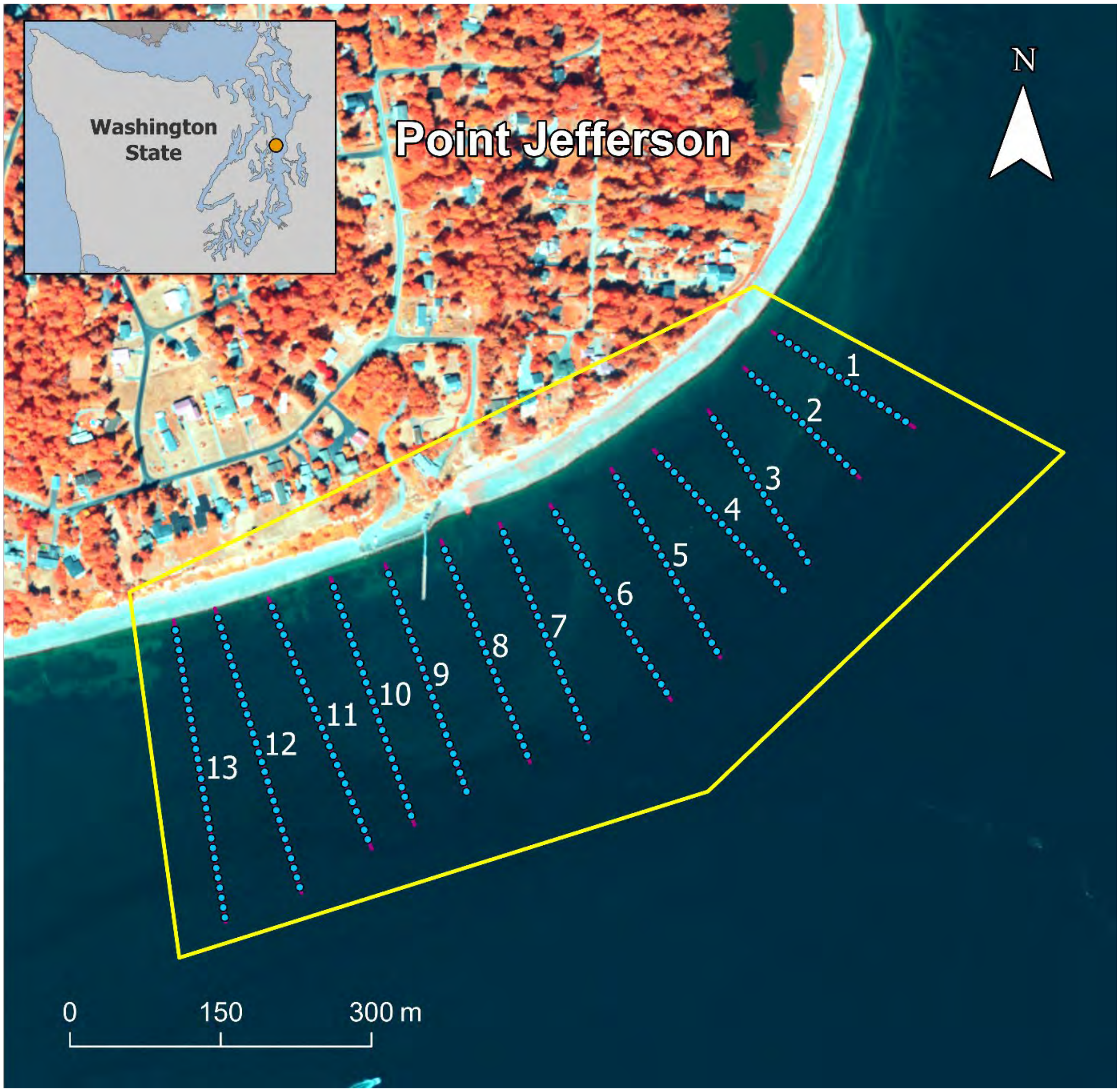

Figure F12. Map of the Point Jefferson numbered transect lines. Transect lines were boated to confirm kelp absence at the site. The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

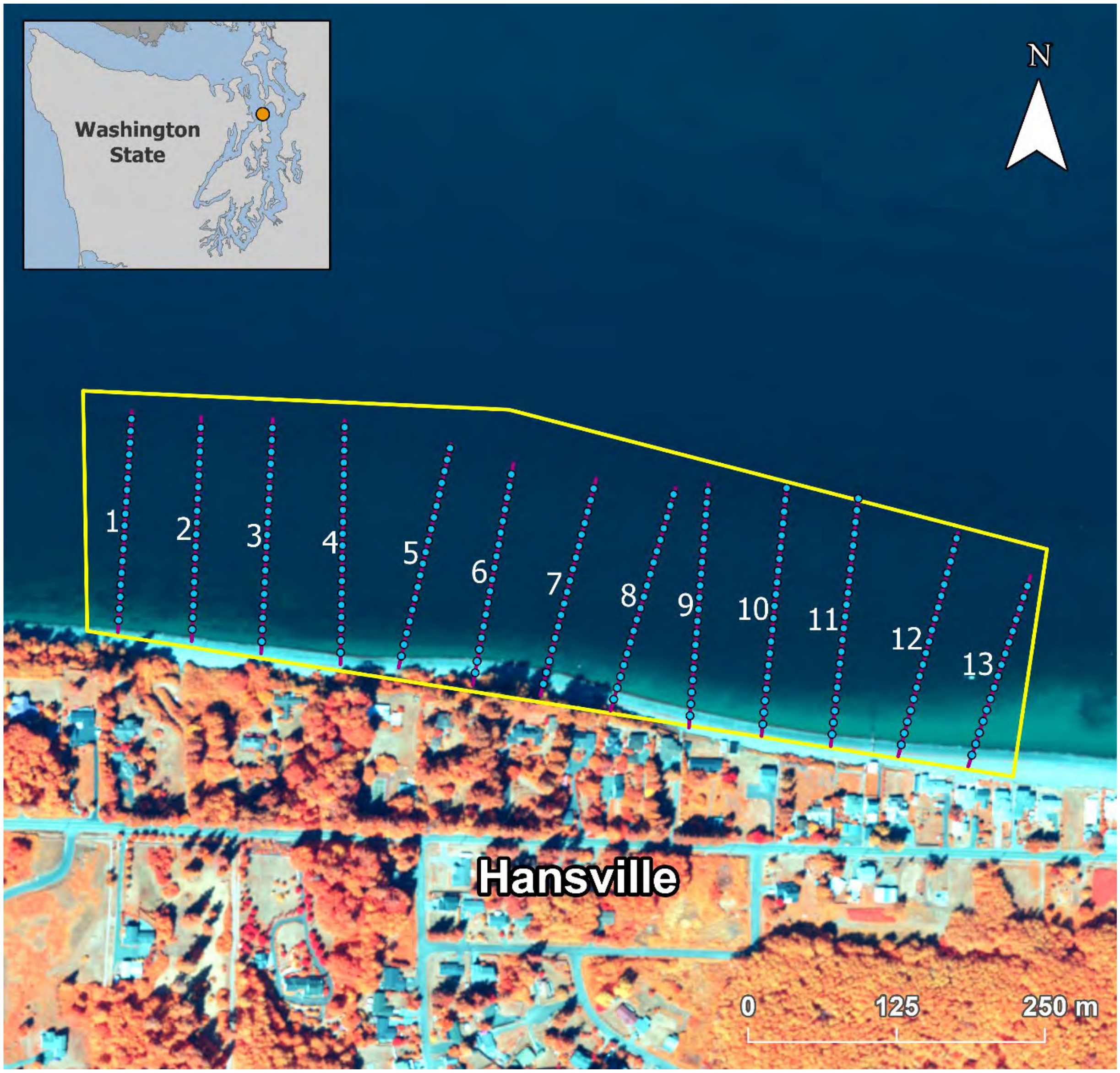

Figure F13. Map of the Hansville numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

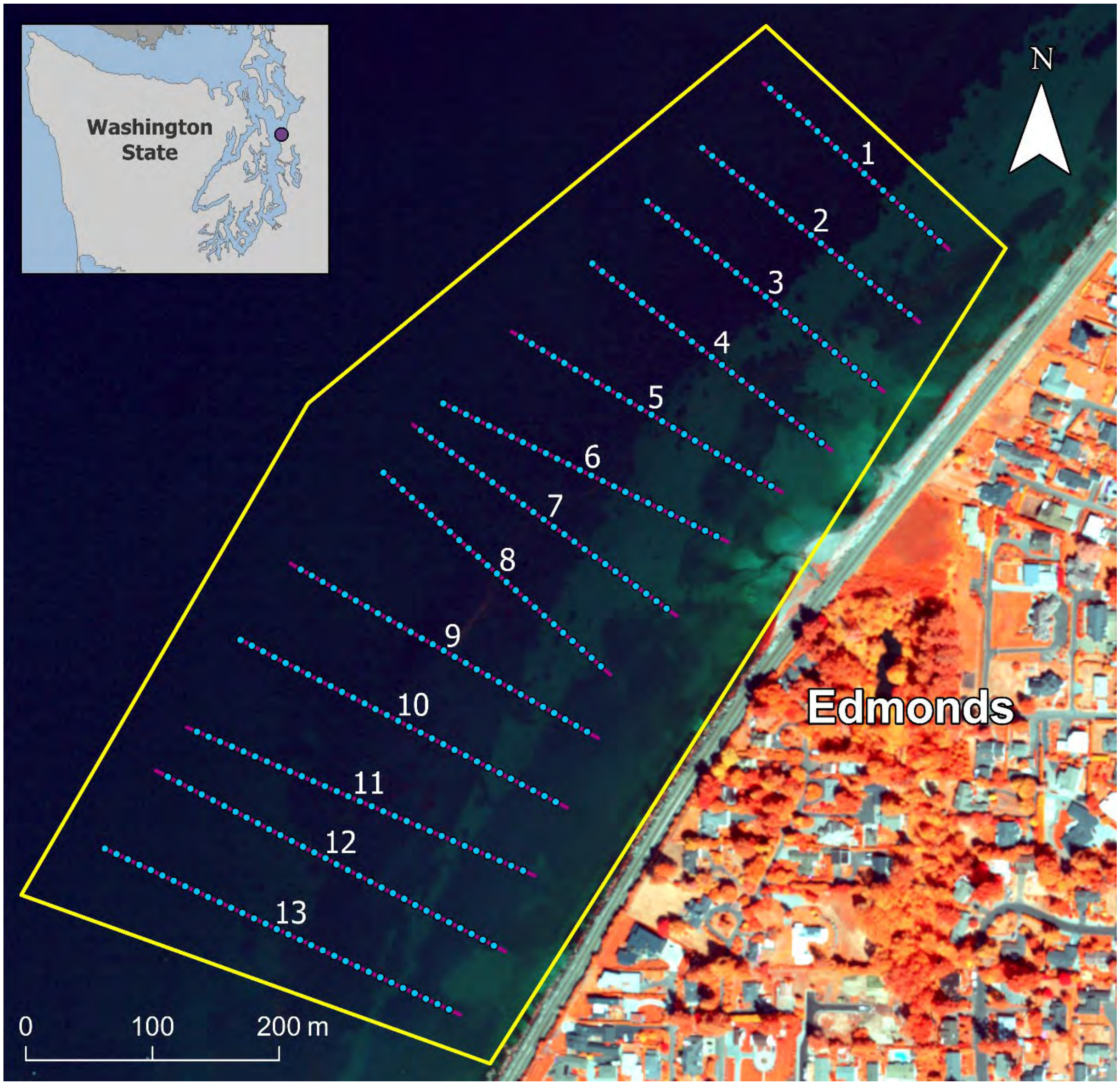

Figure F14. Map of the Edmonds numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

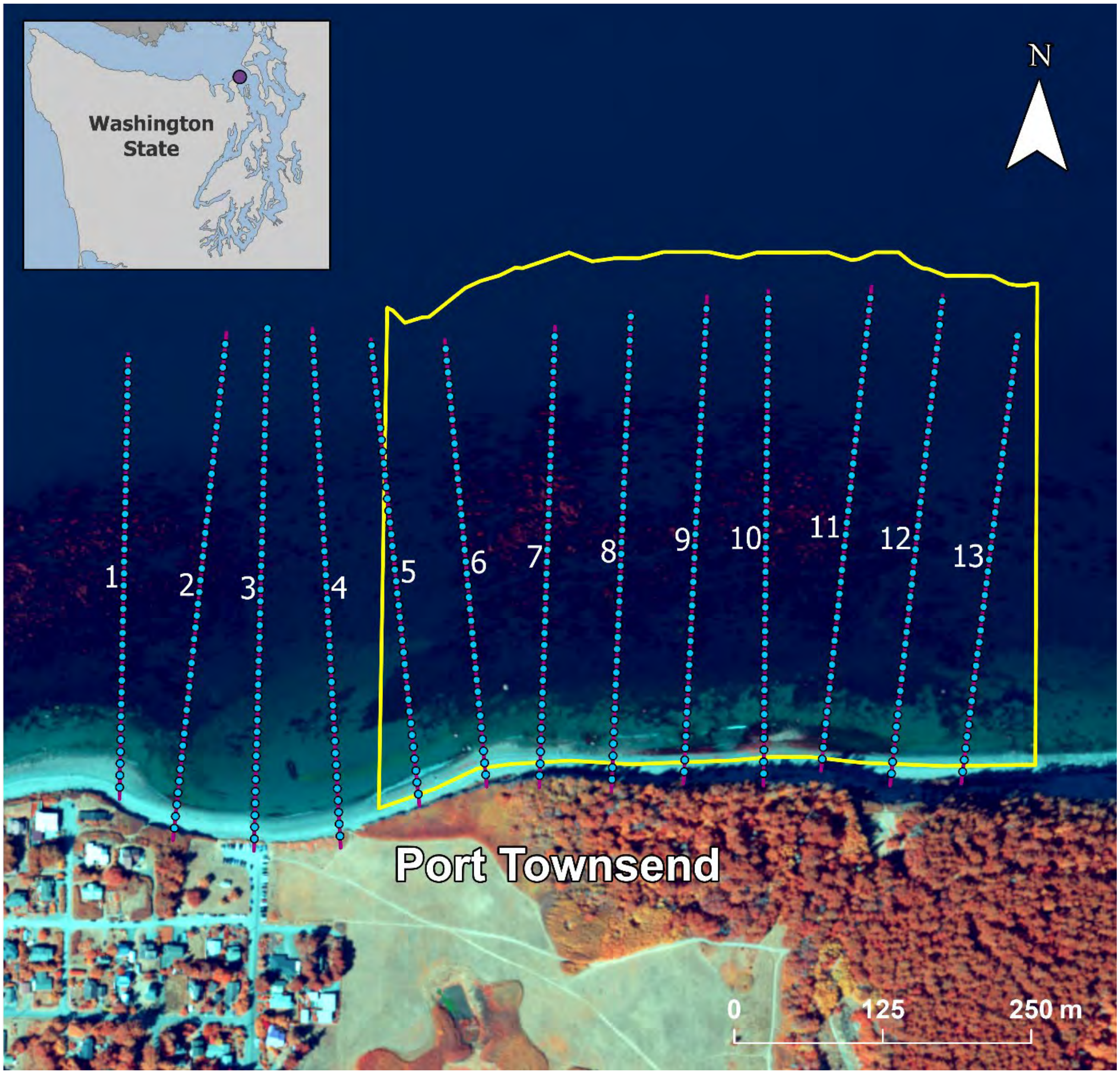

Figure F15. Map of the North Beach numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

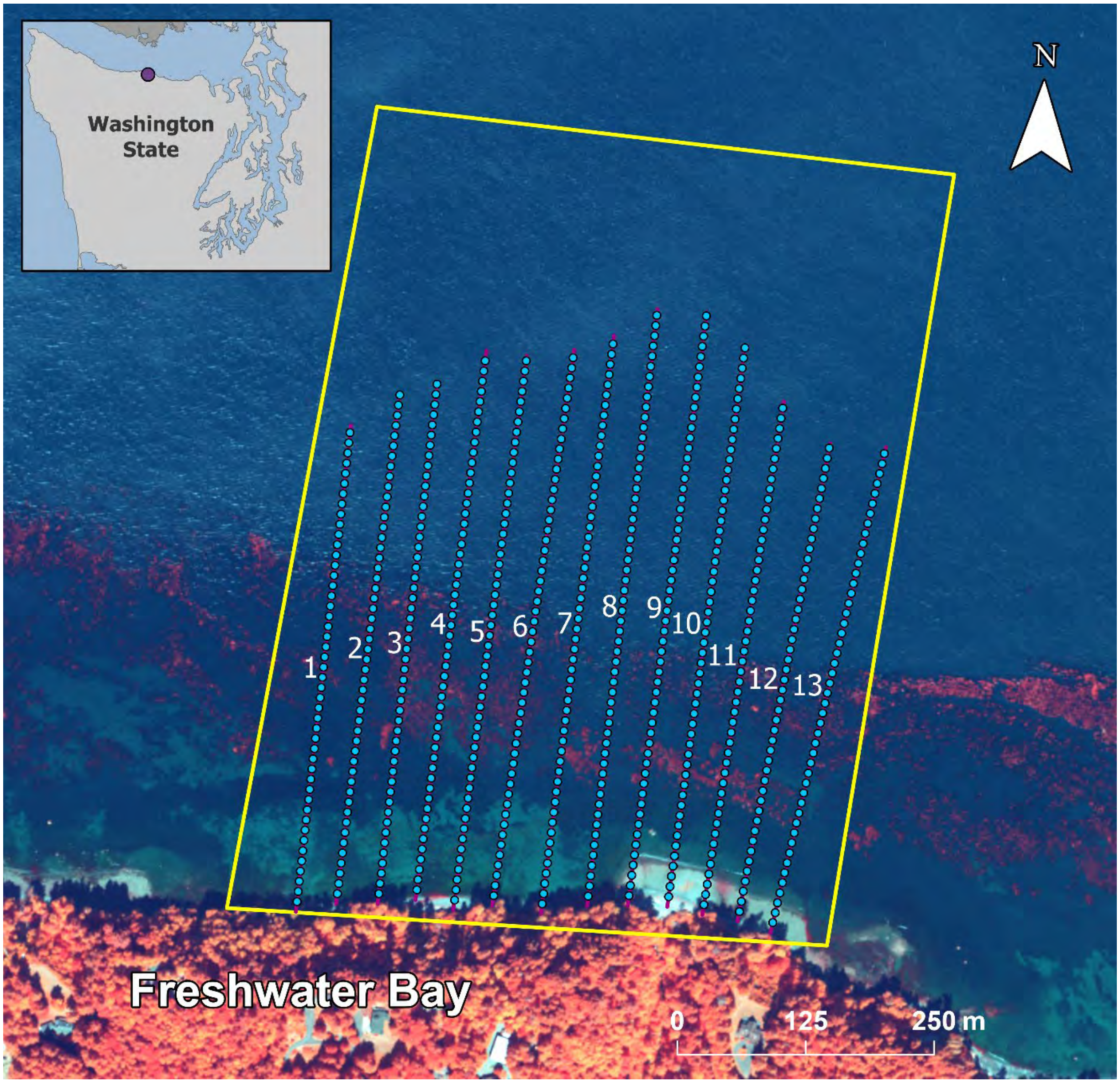

Figure F16. Map of the Freshwater Bay numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

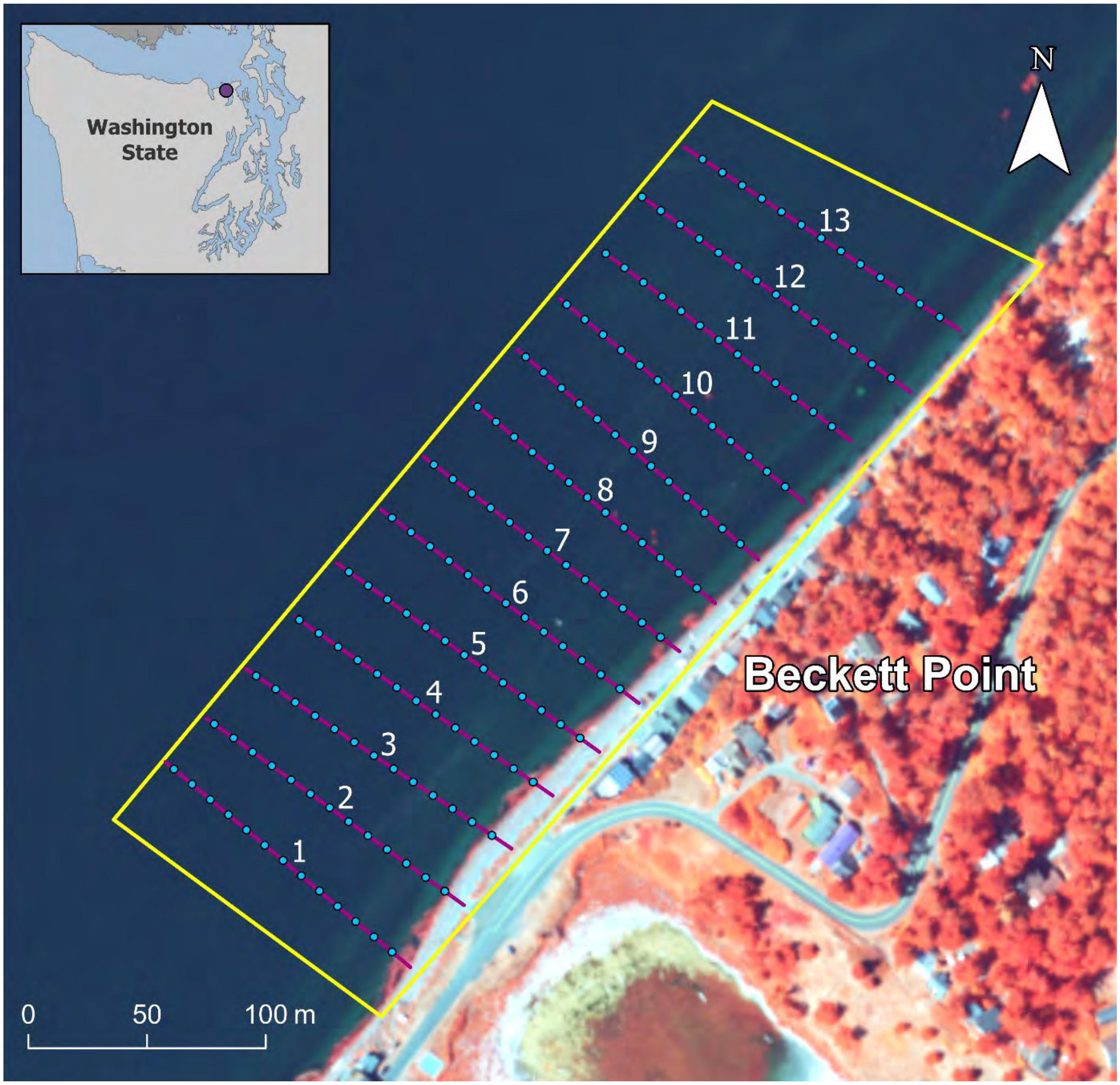

Figure F17. Map of the Beckett Point numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

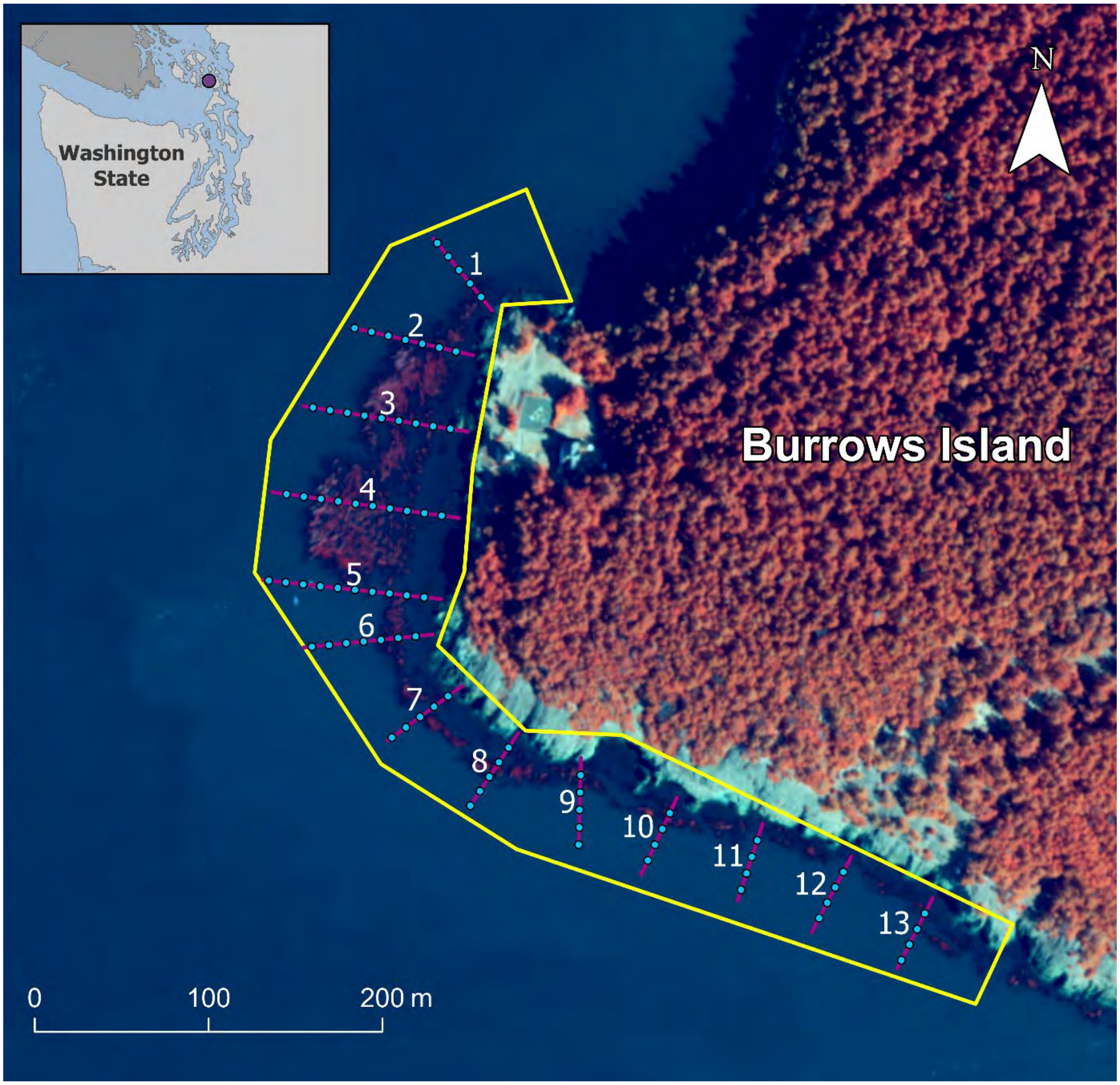

Figure F18. Map of the Burrows Island numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

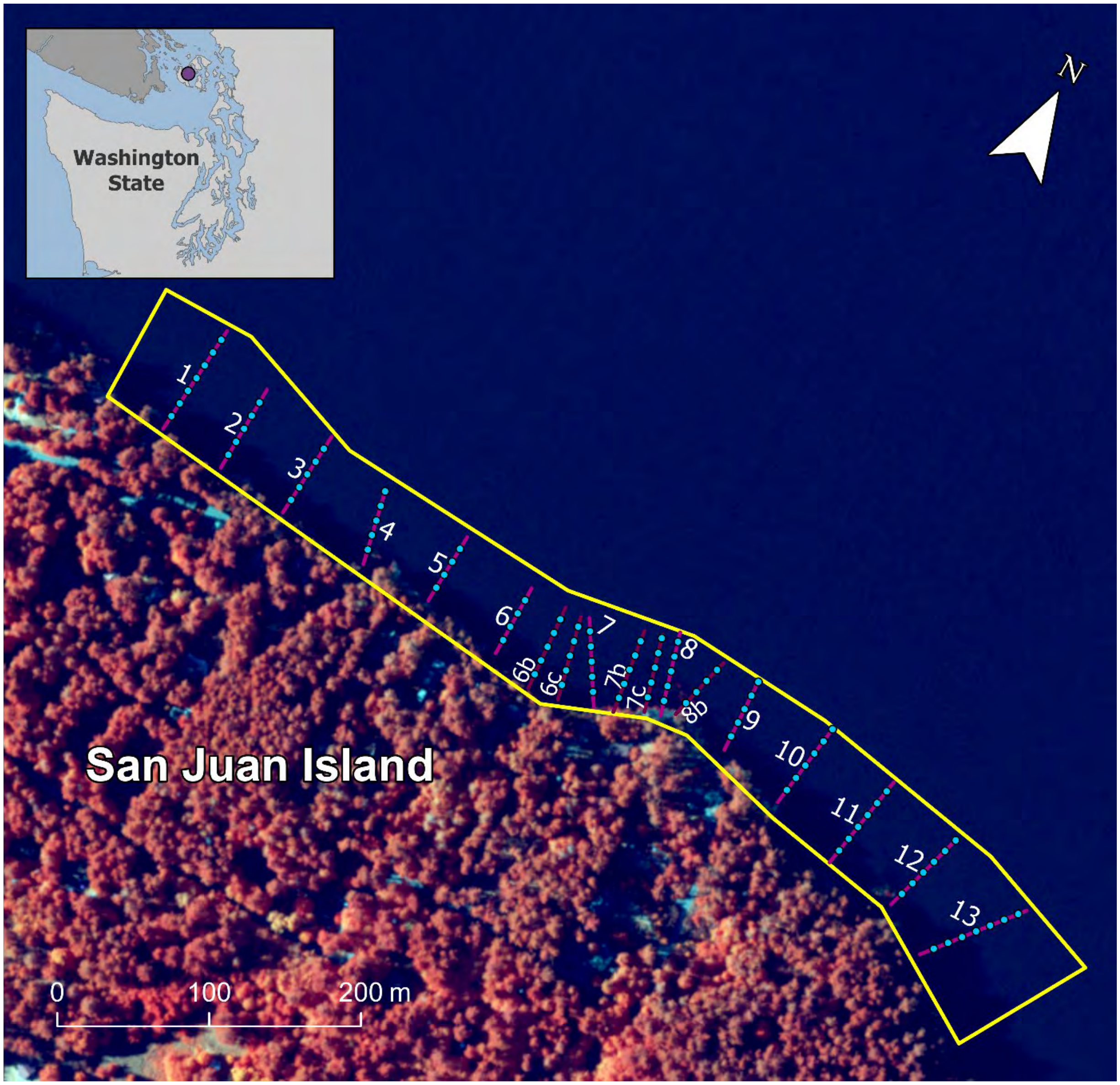

Figure F19. Map of the Point Caution numbered transect lines. Because of the small size of the kelp bed, sub-transects were added to this site (6b-c, 7b-c, 8b), denoted in dark pink. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).

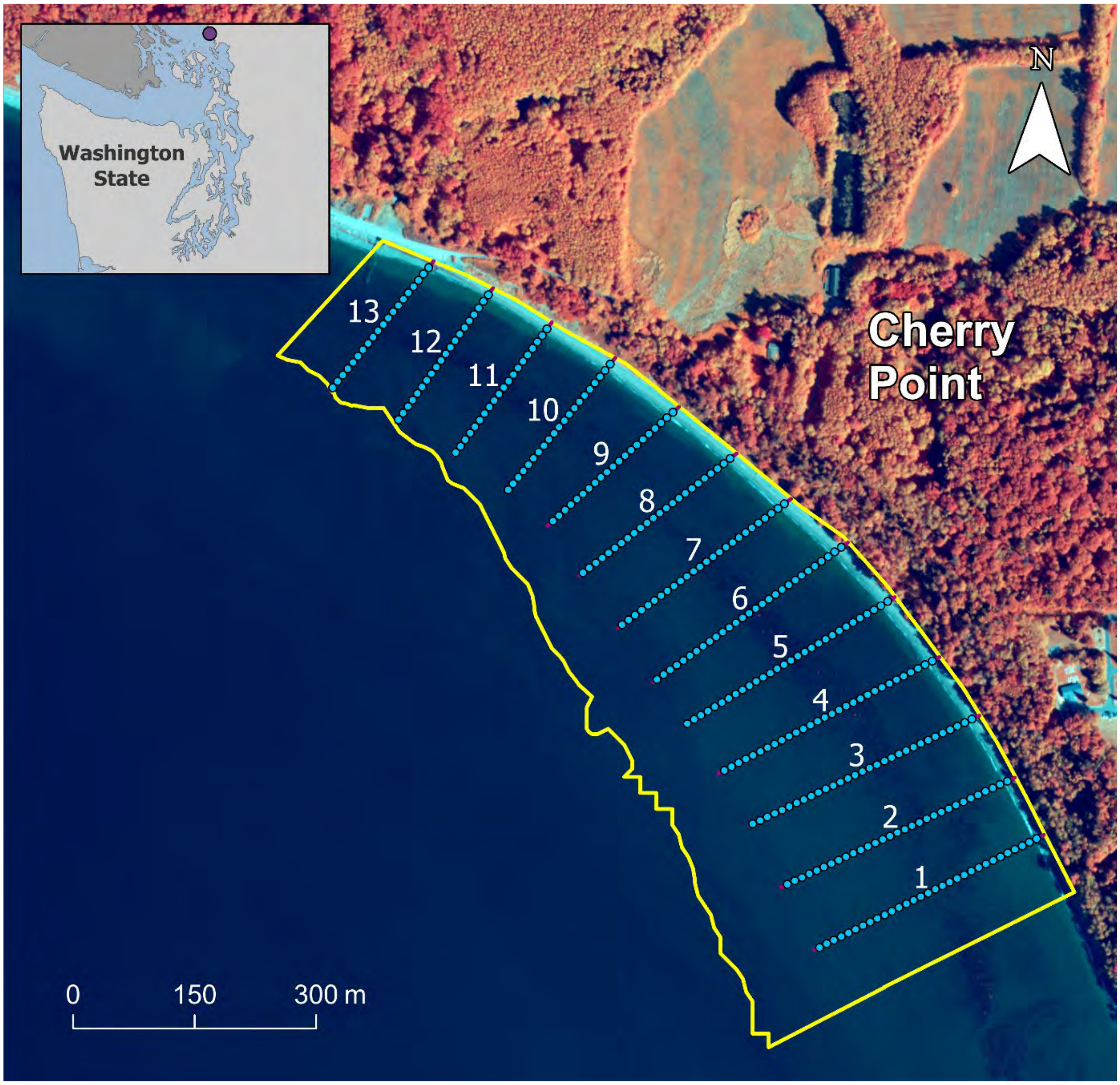

Figure F20. Map of the Cherry Point numbered transect lines. Minimum and maximum depth measurements were taken along the transects (pink). The yellow line represents the site boundary and blue points represent regularly spaced sampling locations (data from sampling points will be included in subsequent reports).