Appendix 5: Draft sub-basin report – Eastern Strait of Juan de Fuca

Puget Sound Vital Signs Floating Kelp Canopy Indicator: Status and Trends in the Eastern Strait of Juan de Fuca Sub-basin

Last updated: May 27, 2022

Recent trend:	increasing
Entire data record trend:	stable
Overall trend:	stable*

*General trends across the sub-basin reflect stable conditions in this area. However, localized declines suggest that additional caution is warranted in the far eastern portion of the sub-basin.

Executive summary

Kelp forests play a critical ecological and cultural role in marine ecosystems. The Puget Sound Vital Signs track this important resource using the floating kelp canopy indicator. The indicator tracks status and trends of floating canopies in sub-regions throughout Washington State. This report presents assessment results for the Eastern Strait of Juan de Fuca sub-region, from the western boundary of Crescent Bay (near Joyce) to Western Whidbey Island in the east (the shoreline from Admiralty Head to Deception Pass), which spans 208.6 km (126.6 mi) of shoreline. It also includes Smith and Minor Islands.

Data Summary

This sub-basin includes fixed-wing aerial images processed by the Washington Department of Natural Resources (COSTR) from 1989 – 2021 for the Eastern Strait as well as fixed-wing aerial images processed by the Washington Department of Natural Resources (AQRES) from 2012 – 2021 for Smith & Minor Islands Aquatic Reserves. Additionally, kayak surveys of floating kelp canopy were conducted by the local Marine Resources Committee at four sites. Other information sources include century-scale historical comparisons, research on the response of kelp to the Elwha Dam removal, and citizen observations.

Key Findings

- This sub-basin report presents a preliminary assessment. We are seeking review and further contributions prior to finalization.

- Floating kelp is abundant along the eastern Strait of Juan de Fuca. One species of floating kelp, bull kelp (*Nereocystis luetkeana*) dominates, while small pockets of giant kelp (*Macrocystis pyrifera*) have been recorded, primarily in the western portion of this sub-basin.
- Kelp canopy area ranged from 180 to 1,280 acres (73 to 518 hectares) per year along the eastern Strait Juan de Fuca (COSTR dataset) between 1989-2021, Kelp canopy area ranged from 94 to 944 acres (38 to 382 hectares) in the Smith and Minor Islands Aquatic Reserve (calculated between 2012-2021), reflecting high natural year-to-year variability in response to environmental conditions. Floating kelp in this region has been shown to respond strongly to climate, thriving in cool, nutrient-rich climate cycles.
- Floating kelp abundance has been increasing over the past 5 years (2017-2021) at the sub-basin scale. All of the five reaches were stable or increasing. Out of 31 zones, the majority (24) were stable and the remainder showed an increasing pattern. In both datasets, 2021 represented the largest canopy area in the monitoring record.
- The entire data record was classified as stable due to a mixture of increasing and stable observations. Strong increases were measured in the 33-year data record along the Strait of Juan de Fuca and in the 11-year record in the Smith and Minor Island Aquatic Reserve. In contrast, a century-scale comparison suggested losses along some shorelines over the longer term.
- The overall assessment of stable was assigned to account for the predominance of stable and increasing results at the decadal scale and some losses noted at the century scale. It is important to note that losses have been reported at some locations.
- In stark contrast to overall stability in the sub-basin, persistent losses in floating canopies were evident in zones within the eastern portion of the sub-basin, along the shorelines of the Miller Peninsula, Protection Island, and Cape George (west of McCurdy Point). Despite these persistent losses, the overall abundance in the reach (Jamestown to Port Townsend) remained stable due to relatively large canopies near Jamestown, McCurdy Point, and North Beach. Nearby, yet outside of the COSTR monitoring area, residents at Beckett Point observed low numbers of bull kelp individuals, in contrast to historical anecdotes of dense canopies.
- In 2011, floating kelp abundance near the Elwha River was impacted when a massive sediment influx associated with removal of two dams increased nearshore water column turbidity over large areas and sedimentation near the river mouth. Floating kelp abundance recovered naturally after suspended sediment levels returned to normal.
- In stark contrast to many other locations in the northeast Pacific, floating kelp populations in the eastern Strait of Juan de Fuca have generally remained healthy overall in recent years. Total abundance decreased in 2014 in response to a marine heat wave, then rebounded in 2015 and 2016 (in contrast to northern California, which never recovered). Observations of sea star wasting disease (SSWD) and limited aggregations of purple urchins were not associated with major floating kelp losses.
- Future monitoring will allow us to determine whether increases over the last 33 years represent a persistent change in kelp populations, or whether this is a short-term response to climate cycles (e.g., PDO, NPGO, ENSO) and/or other biotic and abiotic drivers.

Priorities for Future Research and Monitoring

- The highest priority for floating kelp monitoring is to continue annual assessments in the long-term monitoring areas, with the following enhancements:
    - Upgrade imagery collection procedures to a large format photogrammetric mapping camera system and 4-band imagery. Process orthomosaics.

- Explore ability to re-process existing survey data so that floating kelp abundance can be assessed at spatial scales finer than zones.

- Conduct additional research at sites of observed losses in order to assess multiple stressors and evaluate causes of local declines (especially Miller Peninsula, Protection Island, Cape George, and Beckett Point).
- Explore collaborations to advance understanding of the effect of SSWD and urchin grazing on floating kelp beds in the eastern Strait of Juan de Fuca.
- Improve understanding of the ecological role of kelp forests in the sub-basin through studies of kelp forest usage by fishes, birds, and other ecosystem components.

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1. Introduction

1.1 Floating kelp canopy area vital sign indicator

Kelp is an ecosystem engineer that provides habitat and food web support for myriad species of invertebrates, fishes, birds and mammals. In Puget Sound, for example, kelp forests are critical habitat for juvenile rockfish (*Sebastes* spp.), forage fish (including Pacific herring and surf smelt), as well as out-migrating juvenile and returning adult salmon (Love et al., 1991; Doty et al., 1995; Johnson & Schindler, 2009; Essington et al., 2018; Shaffer et al., 2020). Changes in kelp abundance can have cascading effects (Sunday et al., 2016). For more information on the ecological role of kelp, see The Knowledge Review in The Kelp Conservation and Recovery Plan (Calloway et al., 2020).

This document is a part of an effort to produce a *floating kelp canopy area* indicator for the Puget Sound Vital Signs. In 2020, the Puget Sound Partnership called for a new *floating kelp canopy area* indicator, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator will fill a current gap in scientific information about the condition of floating kelp canopies. It will also serve as a communications tool for sharing information with the public. *Floating kelp canopy area* indicator results will be available on Puget Sound Info – Vital Signs in June 2023. Detailed indicator information will be available on the Puget Sound Floating Kelp Hub Site. Summarized indicator results will be presented on the web sites in a format targeted for broad audiences. In addition, three types of technical documents describe the indicator in detail: (1) indicator assessment procedures, (2) sub-basin reports, (3) dataset descriptions.

The *floating kelp canopy area* is presented in through a three tiered hierarchical system – termed the “Blended Indicator”. At the highest level is the integrated info-map which is presented on Puget Sound Info – Vital Signs and the Puget Sound Floating Kelp Hub Site. One step down is sub-basin summary pages which are linked from the info-map on the Hub site. From there users can access the third tier sub-basin reports, such as this document. The purpose of sub-basin reports is to provide detailed information on the data, analyses, and results of kelp status and trends that are synthesized in the floating kelp canopy area indicator, including rationale for sub-basin trend designation.

1.2 Sub-basin overview

This sub-basin covers the eastern portion of the Strait of Juan de Fuca (Figure 1).

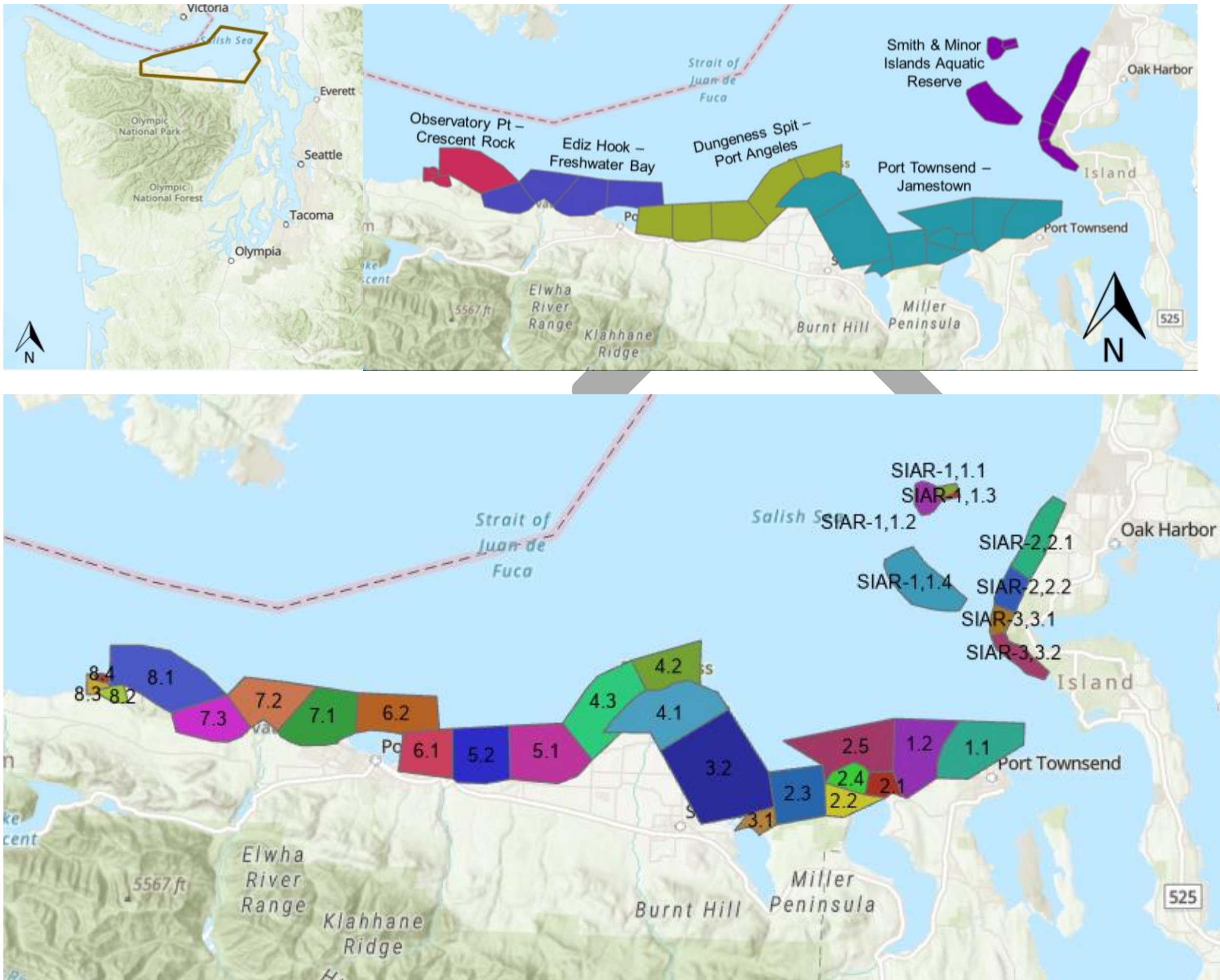

Figure 1. Maps of the Eastern Strait sub-basin.
Top left – map of western Washington State with a brown polygon surrounding the Eastern Strait sub-region. Top right – close-up map of the Eastern Strait sub-basin, labeled by reach. [Note: Shoreline between Port Townsend to Crescent Rock are part of the DNR COSTR dataset, and the Smith and Minor Islands Aquatic Reserve is part of the DNR AQRES dataset.] Bottom – close-up map of the Eastern Strait sub-region, labeled by zones (previously called "map indices").

2. Data, methods, and analyses

2.1 Overview

Data collection, summarization, and analysis followed general guidelines described in the 'Indicator guidelines and procedures document'. Below is a detailed description of how these guidelines were implemented for datasets in the Eastern Strait of Juan de Fuca Sub-basin.

2.2 Datasets analyzed for the indicator

Detailed dataset descriptions are available in Appendices (7-11). Below is a summary of the datasets that are included in the Eastern Strait of Juan de Fuca Sub-basin.

Three data sources are used for indicator creation, the Washington Department of Natural Resources Coast and Strait aerial kelp surveys, the Washington Department of Natural Resources Aquatic Reserve aerial kelp surveys, and Marine Resources Committee kayak-based surveys.

1. DNR Coast and Strait data set (COSTR) – subset for the Eastern Strait
    a. Yearly fixed wing aerial monitoring from 1989-2021 (no data in 1993).
    b. Aerial imagery collected during peak kelp abundance (mid-July to mid-September).
    c. Represents total cover of canopy kelp in the Eastern Strait during each survey year, with the exception of Smith and Minor Islands (see below).
    d. Includes primarily bull kelp (*Nereocystis*) with a few instances of giant kelp (*Macrocystis*).
    e. Includes 23 zones (previously called "map indices") where kelp has been mapped, or nearly 100% of kelp area in the sub-basin mapped (with the exception of Smith and Minor Islands (see below).
2. DNR Aquatic Reserve data set (AQRES) – subset for Smith and Minor Islands
    a. Yearly fixed wing aerial monitoring from 2011-2021.
    b. Aerial imagery collected during peak kelp abundance (mid-July to mid-September).
    c. Includes bull kelp (*Nereocystis*).
    d. Includes 8 zones (previously called "map indices") where kelp has been mapped.
3. Marine Resources Committee (MRC) kayak-based monitoring at four sites
    a. Yearly kayak-based monitoring from 2015-2021.
    b. Kelp bed perimeter collected during peak kelp abundance (July-August).
    c. Four sites: Freshwater Bay, Freshwater Bay-Observatory Point, North Beach, and Ebey's Landing

2.3 Other datasets and information considered

1. Comparison of COSTR data to Fertilizer Maps
    a. Compared COSTR data (including years 1989-2015; see above) with data collected from historical Fertilizer Maps (from 1911-1912).

b. Data were analyzed for the publication, “The dynamics of kelp forests in the Northeast Pacific Ocean and the relationship with environmental drivers”, published in *Journal of Ecology*. (Pfister et al., 2018) Link to paper at https://doi.org/10.1111/1365-2745.12908

2. Beckett Point Kelp Group is composed of community residents who observed bull kelp, understory kelp, and eelgrass in 2021 (Beckett Point Kelp Group, 2021)

2.4 Time period designation

We followed the general guidelines for analysis time periods outlined in the ‘Indicator guidelines and procedures document’. How these guidelines apply to the Eastern Strait of Juan de Fuca sub-basin is described below.

Table 1. Time period designation and corresponding data sets.

Period	Duration
Recent	5 years, COSTR (2017-2021) 5 years, AQRES (2017-2021) 5 years, 4 MRC sites (2017-2021)
Entire data record	32 years, COSTR (1989-2021) 10 years, AQRES (2012-2021)
Overall	COSTR: 1989-2021 AQRES: 2012-2021 4 MRC sites: 2015-2021

Following the general guidelines for kelp status time periods in the ‘Indicator guidelines and procedures document’, recent trends can be assessed with the WA DNR COSTR aerial survey dataset, the WA DNR AQRES aerial survey dataset, and the MRC kayak-based survey dataset, and longer-term trends can be assessed using the WA DNR COSTR aerial survey dataset (Table 1).

2.5 Analysis

For the COSTR aerial surveys GIS polygons of kelp bed and canopy area were processed and plotted with GIS. For each year, kelp bed and canopy area was summed in 23 unique nearshore areas termed “zones”. These units comprise approximately 5 to 15 km of shoreline and extend from the mean lower low water tide line (MLLW) to approximately 30 m depth. Zone boundaries were placed by considering geomorphology (e.g., shoreline type, substrate, exposure), and aligned with large geographical features such as bays, channels, headlands, etc. This created a single file of kelp bed area by year by zone upon which all analyses and plotting was performed.

Kelp bed area for each dataset were assessed by plotting kelp bed area for each survey as raw values, as an anomaly from the three survey mean, and as a percentage of the maximum kelp area. Plots of raw values were made at three different spatial scales: 1) whole dataset, 2) summarized by reach, and 3) summarized at zone (Figure 1). Anomalies were calculated as the proportional difference in kelp bed area in a given year compared to the mean kelp bed area over all survey years.

Year over year change in kelp bed area was assessed by regressing kelp bed area against survey year. From this regression, slope and p-values for each zone were extracted so that the direction and magnitude of change could be assessed. This information is visualized with bubble and slope plots. Bubble plots include a circle for each zone where the size of the circle is a function on the maximum proportional kelp bed area for the dataset (large circles are zones that have large kelp bed area). Circles are then colored by the slope of the regression line and the p-value of that slope. Slopes where $p > 0.05$ are determined to have no change in kelp bed area over the surveys and are colored grey. Slopes where $p \leq 0.05$ are colored dark red for negative slopes and green for positive slopes. Slope plots display the estimated slope and error for each zone. Regression analysis was conducted for the DNR COSTR aerial surveys for the recent time period (last 5 years: 2017 – 2021) and for the entire data record (33 years 1989-2021), as well as for the DNR AQRES aerial surveys for the recent time period (last 5 years: 2017-2021) and for the entire data record (11 years 2011-2021). These plots and analyses were performed at three different spatial scales; 1) whole dataset, 2) summarized by reach, and 3) summarized by zone (Figure 1).
In this sub-region, floating kelp area is reported in two ways: 1) As kelp *canopy* area (kelp plant area on the surface), and 2) as kelp *bed* area (kelp canopy plus the spaces between the plants). We report both here.

3. Results

3.1 Abundance and distribution of floating kelp canopy area

3.1.1 Float kelp canopy extent

In the DNR COSTR (Eastern Strait) dataset (1989-2021), the maximum amount of kelp canopy area detected in the Eastern Strait of Juan de Fuca was 518 hectares (1,280 acres), which occurred in the year 2021 (Figure 2). The minimum amount of kelp canopy area detected in the Eastern Strait of Juan de Fuca was 73 hectares (180 acres), which occurred in the year 1997 (Figure 2). Average kelp canopy cover abundance per year was 232 hectares (573 acres) [± 120 hectares s.d.].

In the DNR AQRES (Smith and Minor Islands) dataset (2012-2021), the maximum amount of kelp canopy area detected was 382 hectares (944 acres), which occurred in the year 2021 (Figure 2). The minimum amount of kelp detected in the Smith and Minor Islands Aquatic Reserve was 38 hectares (94 acres), which occurred in the year 2014 (Figure 2). Average kelp canopy cover abundance per year was 126 hectares (311 acres) [± 100 hectares s.d.].

3.1.2 Float kelp bed extent

In the DNR COSTR (Eastern Strait) dataset (1989-2021), the maximum amount of kelp detected in the Eastern Strait of Juan de Fuca was 1,833 hectares (4,529 acres), which occurred in the year 2021 (Figure 2). The minimum amount of kelp detected in the Eastern Strait of Juan de Fuca was 349 hectares (863 acres), which occurred in the year 1997 (Figure 2). Average kelp abundance per year was 824 hectares (2,035 acres) [± 350 hectares s.d.].

In the DNR AQRES (Smith and Minor Islands Aquatic Reserve) dataset (2012-2021), the maximum amount of kelp bed area detected was 856 hectares (2,115 acres), which occurred in the year 2021 (Figure 2). The minimum amount of kelp bed cover detected in the Smith and Minor Islands Aquatic Reserve was 174 hectares (430 acres), which occurred in the year 2015 (Figure 2). Average kelp abundance per year was 366 hectares (904 acres) [± 199 hectares s.d.].

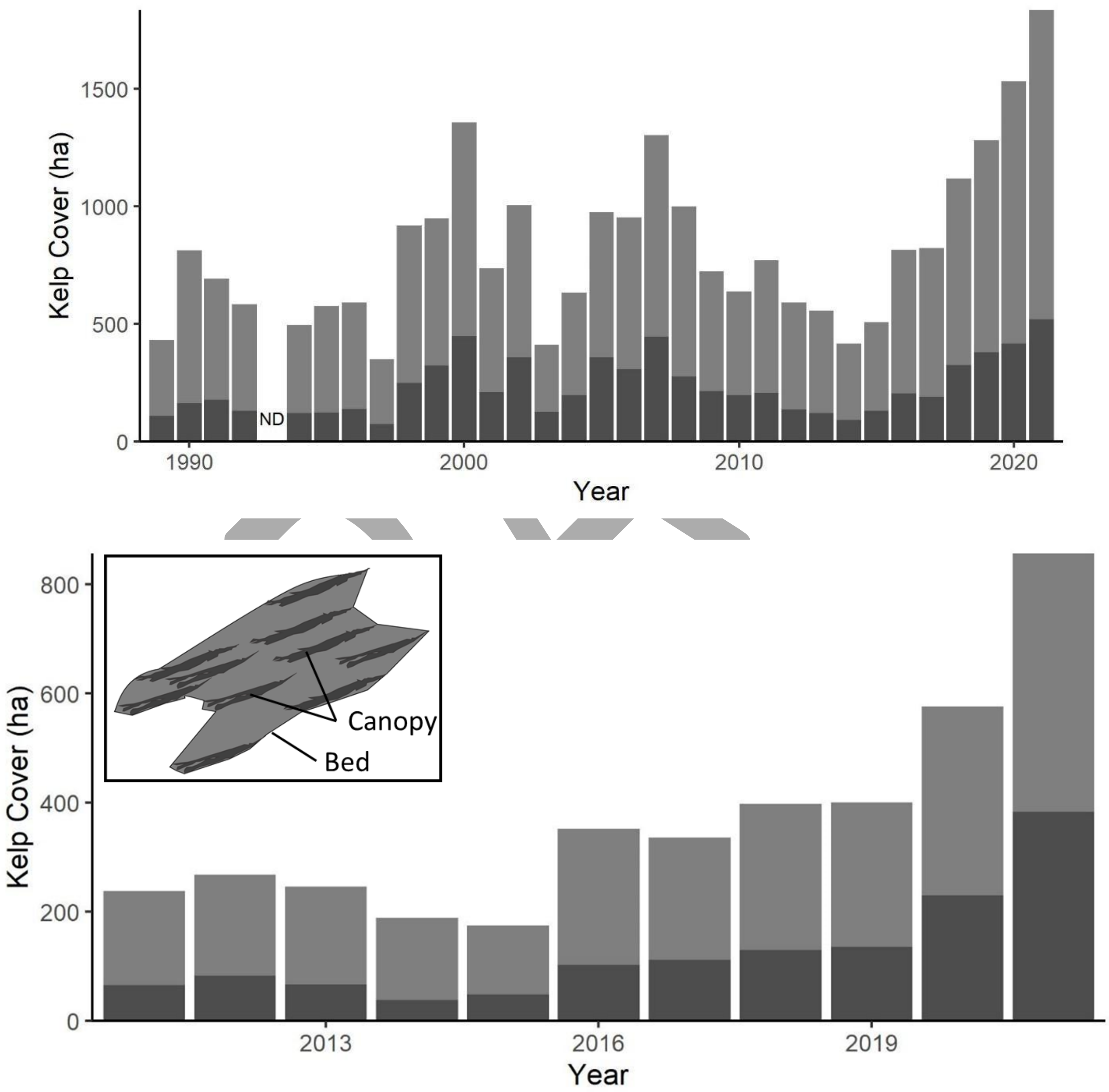

Figure 2. Kelp cover (canopy and bed) over time in the Eastern Strait.
Top - Total kelp cover from DNR COSTR (Eastern Strait) dataset from 1989 to 2021. Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area. Kelp cover was dominated by bull kelp (*Nereocystis luetkeana)*, with a negligible amount of giant kelp *Macrocystis pyrifera*. Note that no data was collected in 1993. Bottom – total kelp canopy cover from DNR AQRES (Smith and Minor Islands Aquatic Reserve) dataset from 2011-2021.

The reaches with the most kelp coverage were Ediz Hook – Freshwater Bay and Smith and Minor Islands Aquatic Reserve, followed by Dungeness Spit – Port Angeles (Figure 3).

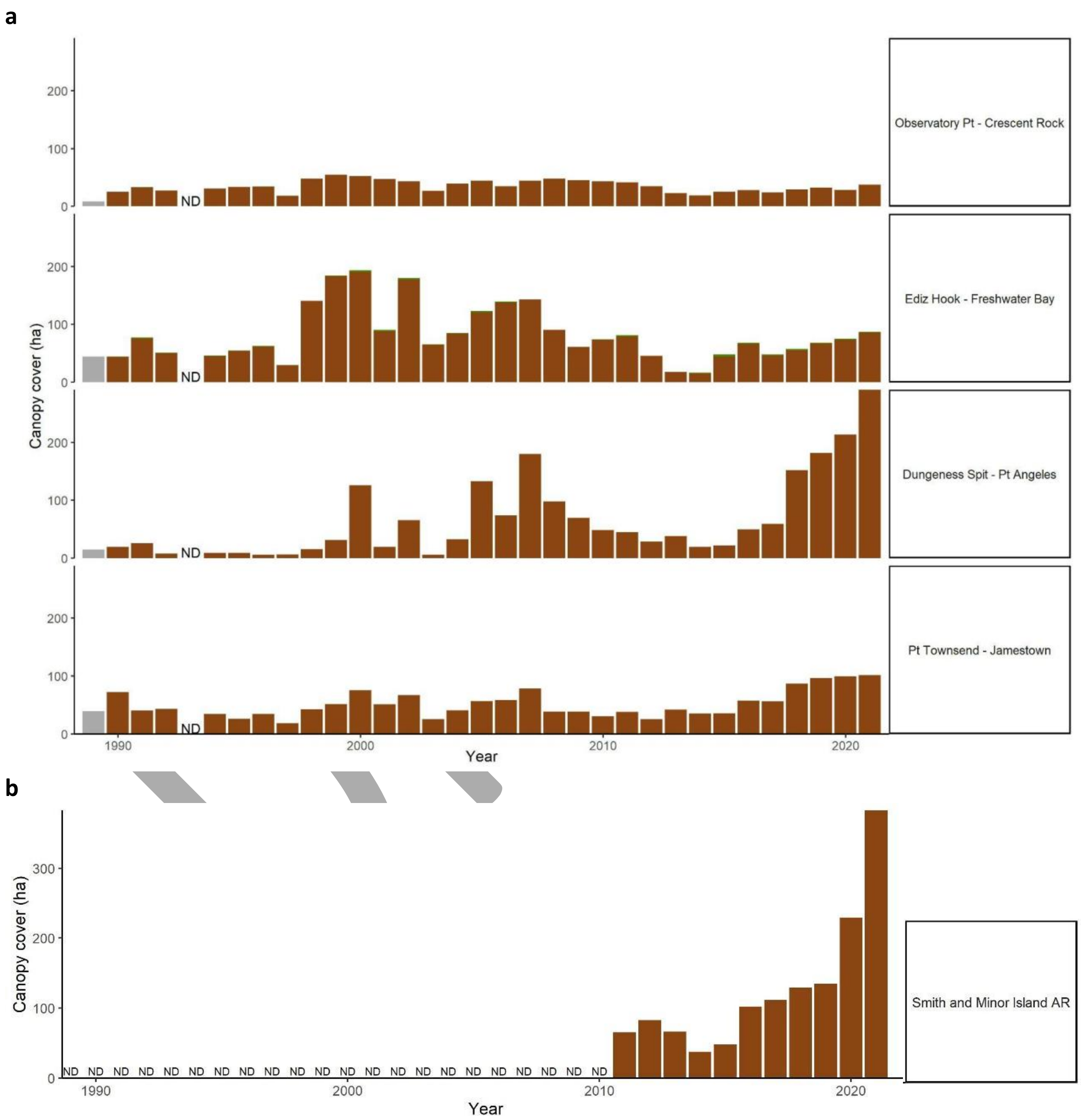

Figure 3. Total kelp canopy cover for each reach in the Eastern Strait.
a) Total kelp canopy cover from 1989 to 2021 for each reach in the Eastern Strait (COSTR dataset). Note that no data was collected in 1993, and that kelp species was not specified during the 1989 surveys (indicated as 'Unspecified' kelp species). b) Total kelp canopy cover from 2011 to 2021 for each reach in the Eastern Strait (AQRES dataset). Note that 2011 was the first year of complete data collection in the Smith and Minor Islands Aquatic Reserves.

Survey-to-survey trends are further visible when plotting kelp canopy area of a given survey as an anomaly from the long-term mean kelp canopy and bed area and as a percentage of maximum kelp canopy area (COSTR dataset, Figure 4; AQRES dataset, Figure 5).

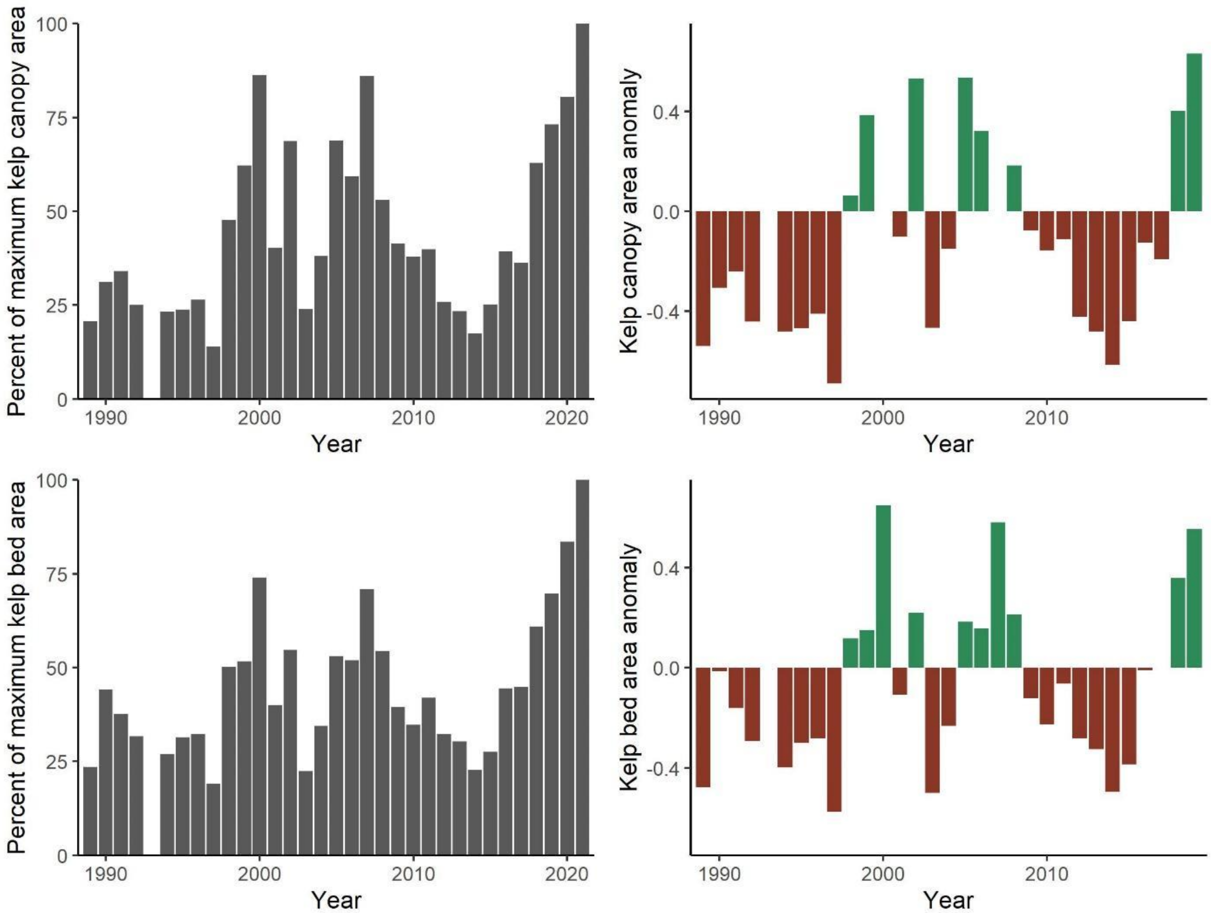

Figure 4. Kelp area anomalies for the Eastern Strait of Juan de Fuca.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean kelp area. Data from COSTR (Eastern Strait) data set, includes all surveyed years to date (1989-2021).

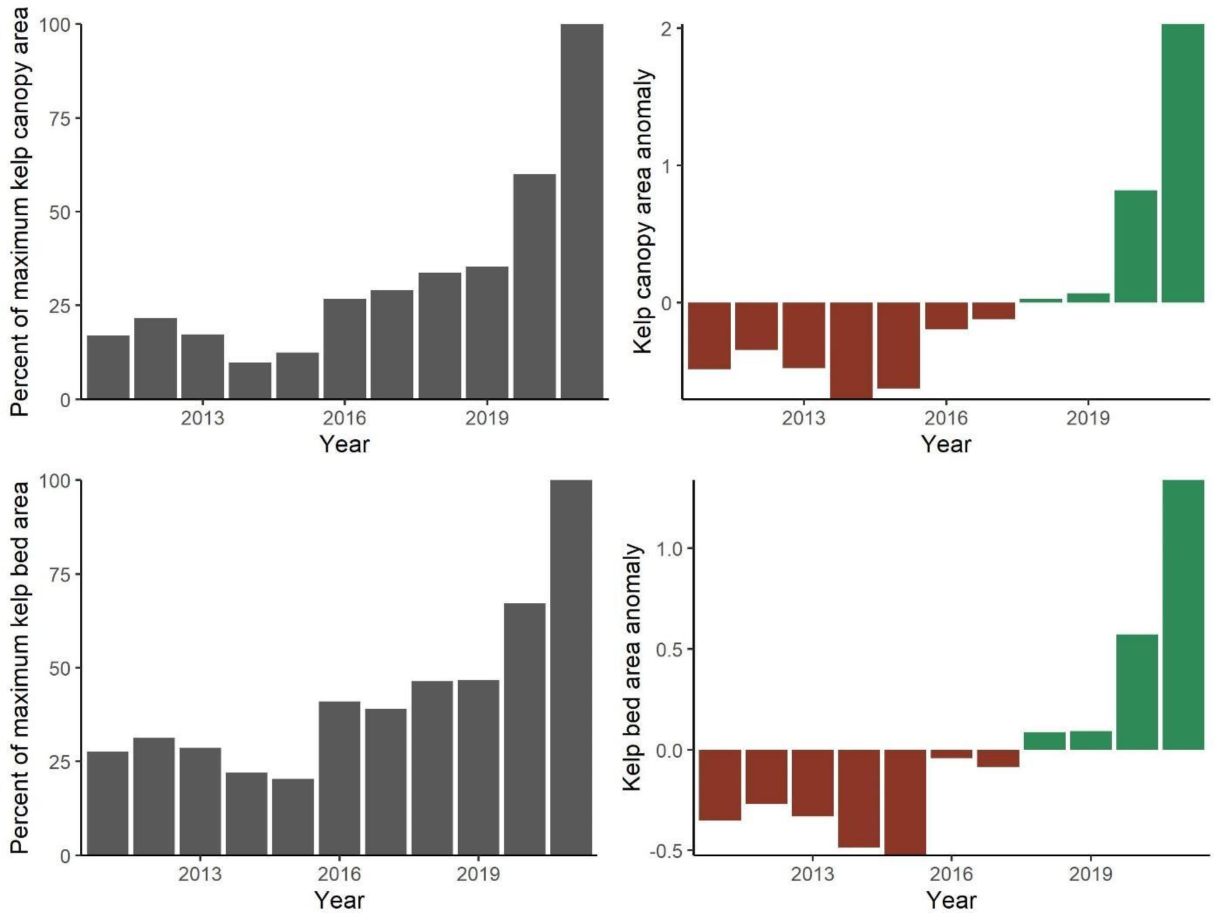

Figure 5. Kelp area anomalies for Smith and Minor Islands Aquatic Reserve.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean kelp area.

3.2 Trends in floating kelp canopy area

Full data set - COSTR

Of the 23 zones within the Eastern Strait of Juan de Fuca COSTR dataset, the kelp canopy area of 5 were increasing, 18 were stable, and no declines were detected during the years 1989-2021 (Figure 6).

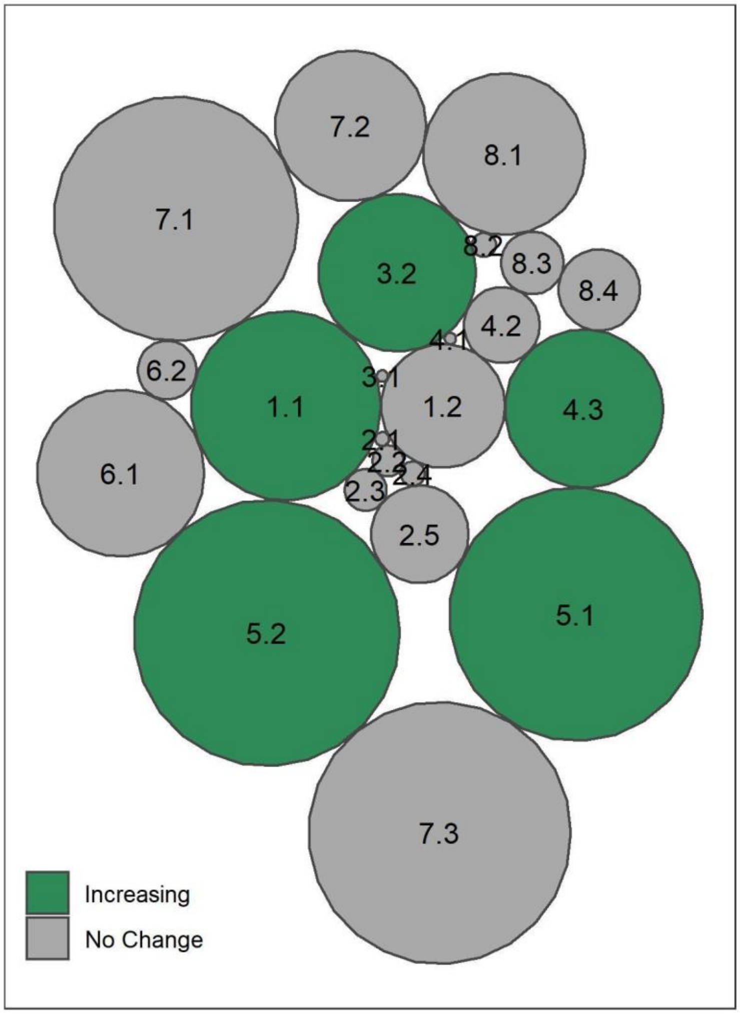

Figure 6. Kelp canopy area change over time for each zone in the full COSTR Eastern Strait dataset.
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum kelp canopy of that zone. Data from COSTR (Eastern Strait) data set, includes all surveyed years to date (1989-2021).

Throughout the full data set (1989-2021), kelp canopies in the most rapidly increasing zone (5.2) increased at an average rate of 2.1 hectares (5.2 acres) per year (Figure 7). When averaged across all zones, kelp canopies increased at a rate of 0.21 hectares (0.52 acres) per year [± 0.04 hectares s.e.].

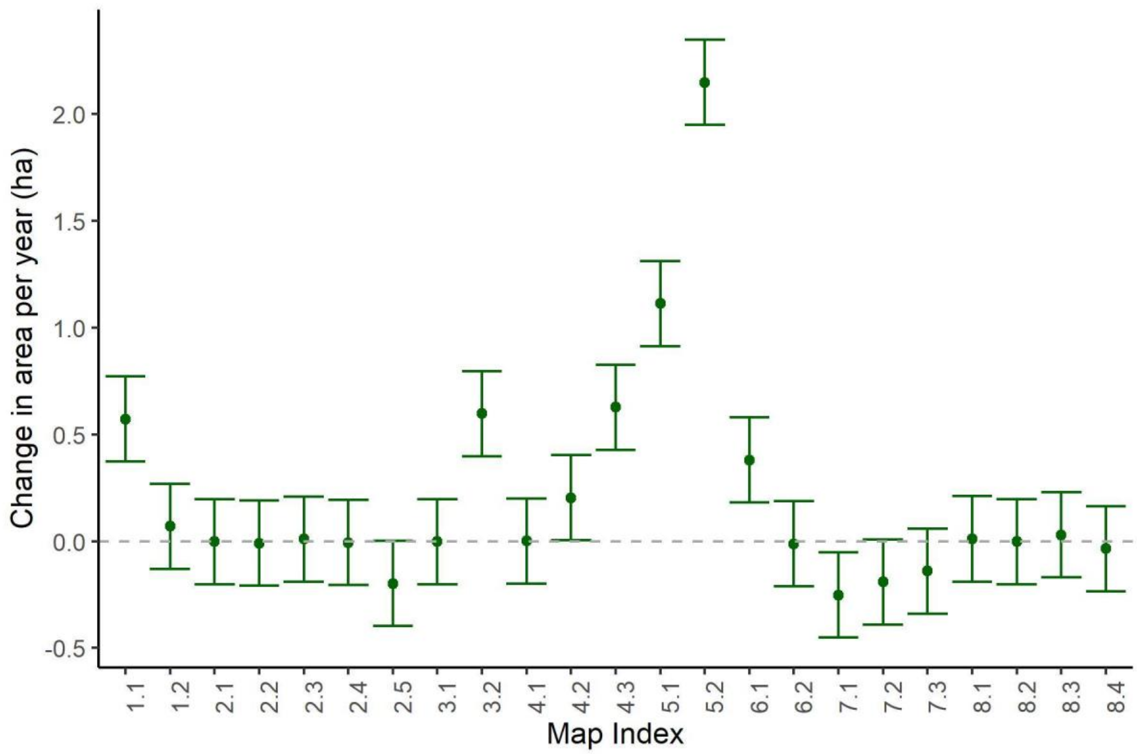

Figure 7. Kelp canopy area change over time of total kelp canopy, for each zone for the full COSTR Eastern Strait dataset. Zones corresponds to zones in Figure 1. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change. Data from COSTR (Eastern Strait) data set, includes all surveyed years to date (1989-2021).

When comparing both kelp canopy area with kelp bed area change over time for the full data set (Figure 8), five zones were increasing over time for both metrics. The remainder of zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

While floating kelp beds in the eastern Strait have generally increased or remained stable, a marked shift in distribution was noted within the Jamestown to Pt Townsend Reach (Figure 8). Floating kelp disappeared from the central portion of the reach, and has been persistently absent for more than a decade in some areas. However, decreases in abundance associated with these losses were not detected at the reach scale due to the presence of large, health beds at Jamestown, McCurdy Point and Fort Worden.

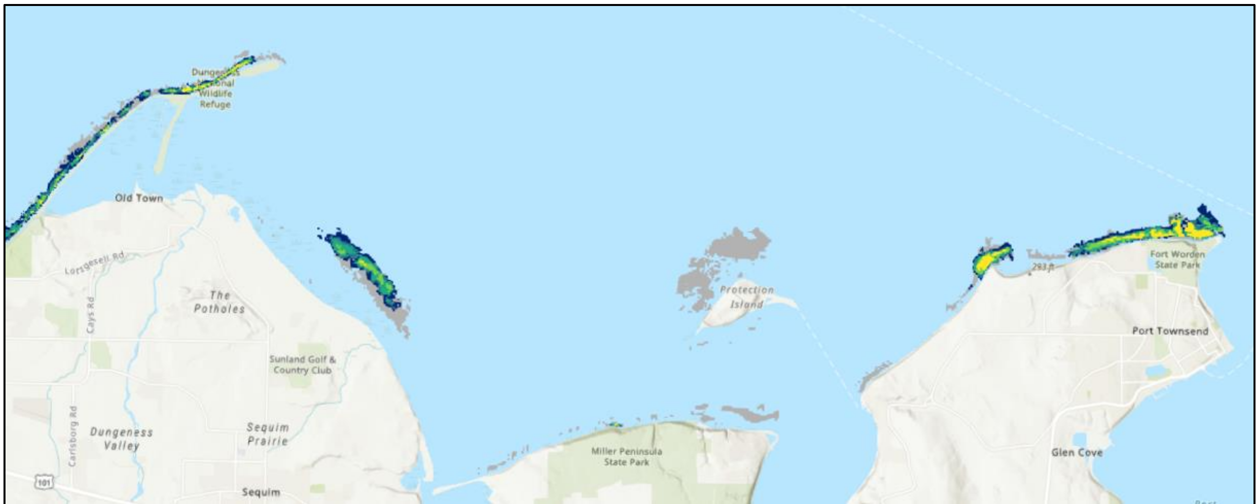

Figure 8. Heat map of kelp bed occurrence along the Jamestown to Port Townsend Reach.
Grey areas denote locations where kelp beds occurred historically but have been absent in recent years. The heat maps of shades from blue to yellow indicate increasing persistence (years of kelp presence). Losses within the central portion of the reach are not evident due to the large, healthy beds at Jamestown, McCurdy Point and Fort Worden. Data from COSTR (Eastern Strait) data set, 2015-2019.

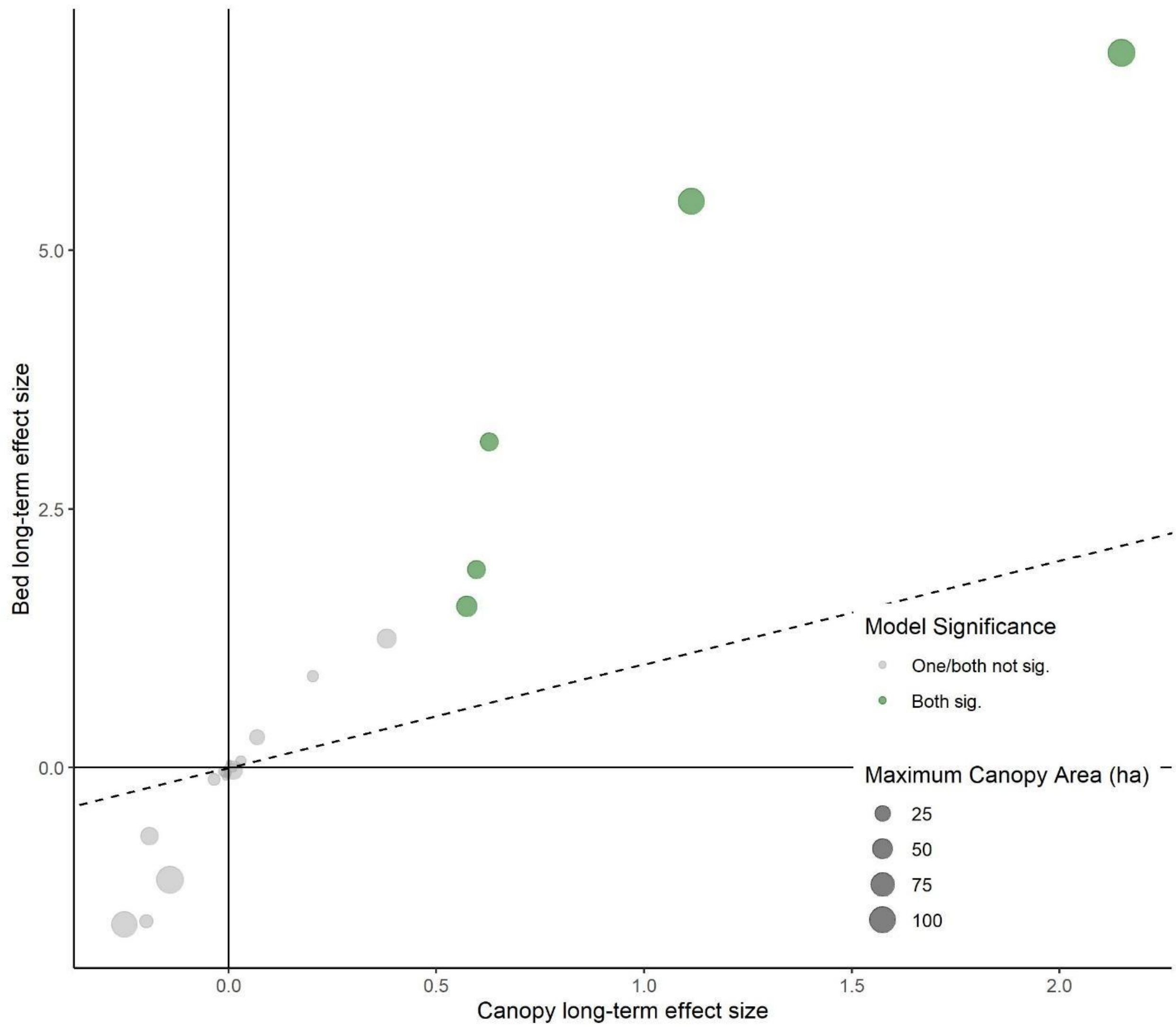

Figure 9. Comparison of rate of change in kelp area between canopy and bed measurements for the full COSTR Eastern Strait dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points in the bottom-left quadrant of the figure indicate declines in both bed and canopy area. Points are colored green if both change in bed area and change in canopy area were significant over time, and they are colored green if change over time for either or both measures (i.e., bed and/or canopy) was not statistically significant.

Full data set – AQRES – Smith and Minor Islands Aquatic Reserve (2012-2021)

Of the 8 zones within the Eastern Strait of Juan de Fuca AQRES dataset for Smith and Minor Islands Aquatic Reserve, the kelp canopy area of 4 were increasing, 4 were stable, and no declines were detected during the years 2012-2021 (Figure 10).

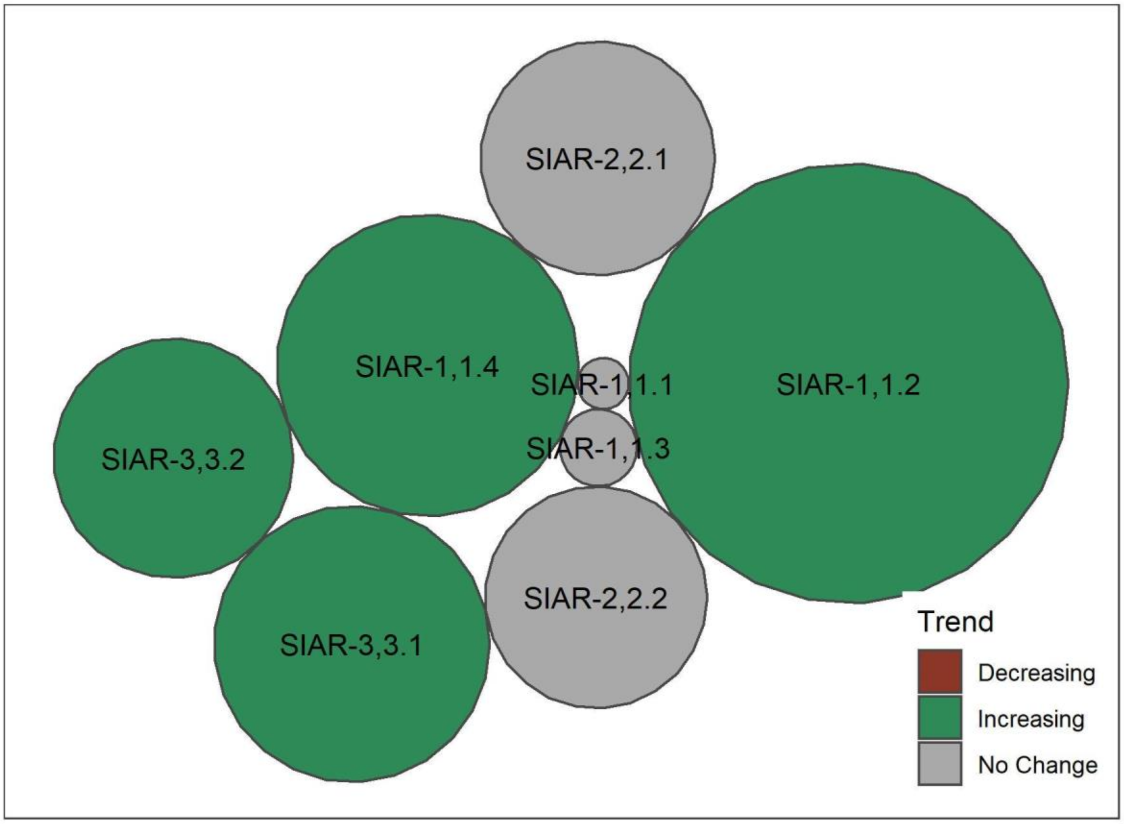

Figure 10. Kelp canopy area change over time for each zone in the Smith and Minor Islands Aquatic Reserve (2012-2021). Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum kelp canopy of that zone.

Throughout the full data set (2012-2021), kelp canopies in the most rapidly increasing zone (SIAR-1,1.2) increased at an average rate of 7.8 hectares (19.3 acres) per year (Figure 11). When averaged across all zones, kelp canopies increased at a rate of 3.0 hectares (7.5 acres) per year [± 0.38 hectares s.e.].

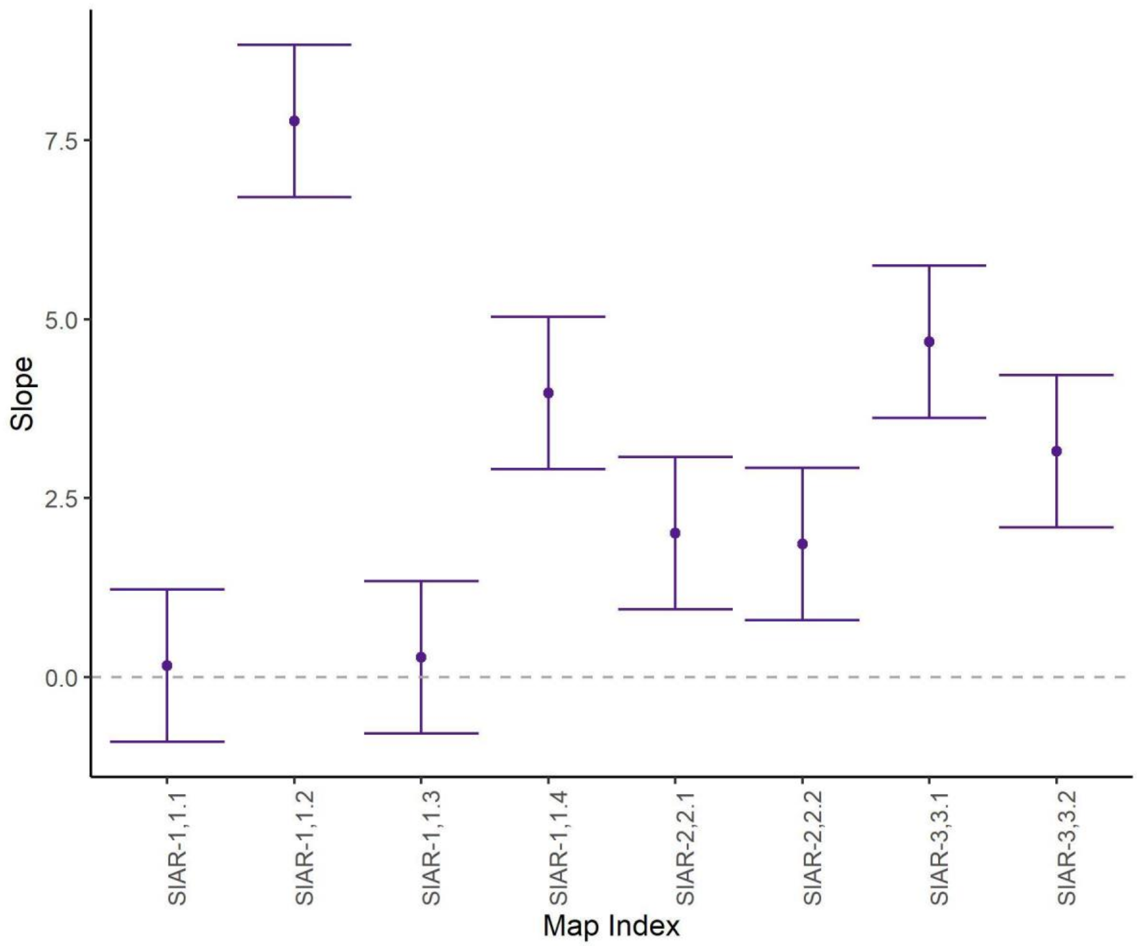

Figure 11. Kelp canopy area change over time of total kelp canopy in the Smith and Minor Aquatic Reserves (2012-2021), for each zone.
Zones correspond to zones in Figure 1. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change.

When comparing both kelp canopy area with kelp bed area change over time for the full data set (Figure 12), three zones were increasing over time for both metrics. The remainder of zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

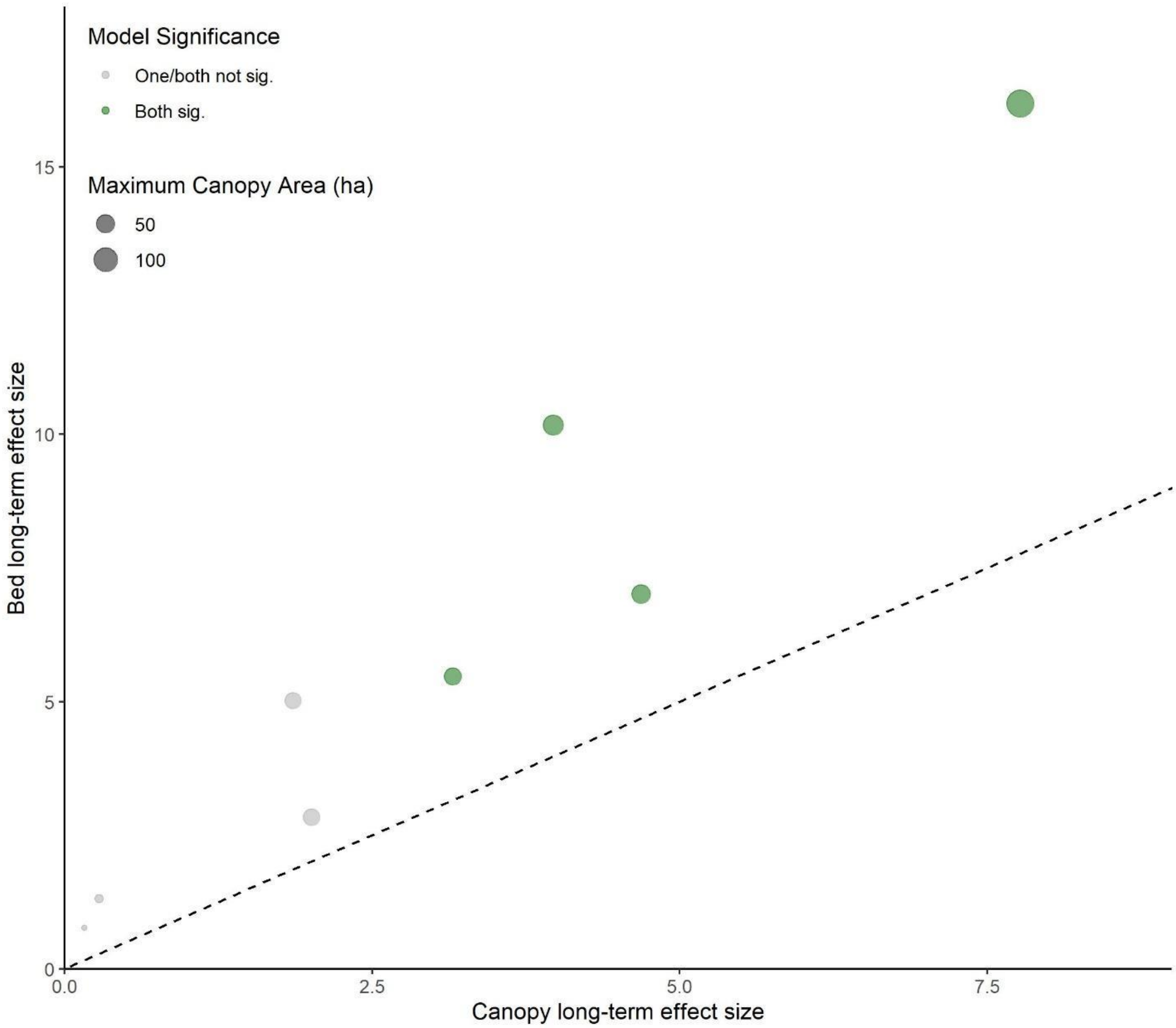

Figure 12. Comparison of rate of change in kelp area between canopy and bed measurements for Smith and Minor Islands Aquatic Reserve (2012-2021).
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points in the bottom-left quadrant of the figure indicate declines in both bed and canopy area. Points are colored green if both change in bed area and change in canopy area were significant over time, and they are colored green if change over time for either or both measures (i.e., bed and/or canopy) was not statistically significant.

Past five years (2017-2021) – COSTR dataset

Of the 23 zones within the Eastern Strait of Juan de Fuca COSTR dataset, the kelp canopy area of 6 were increasing, 17 were stable, and no declines were detected during the years 2017-2021 (data from COSTR – Eastern Strait subset) (Figure 13).

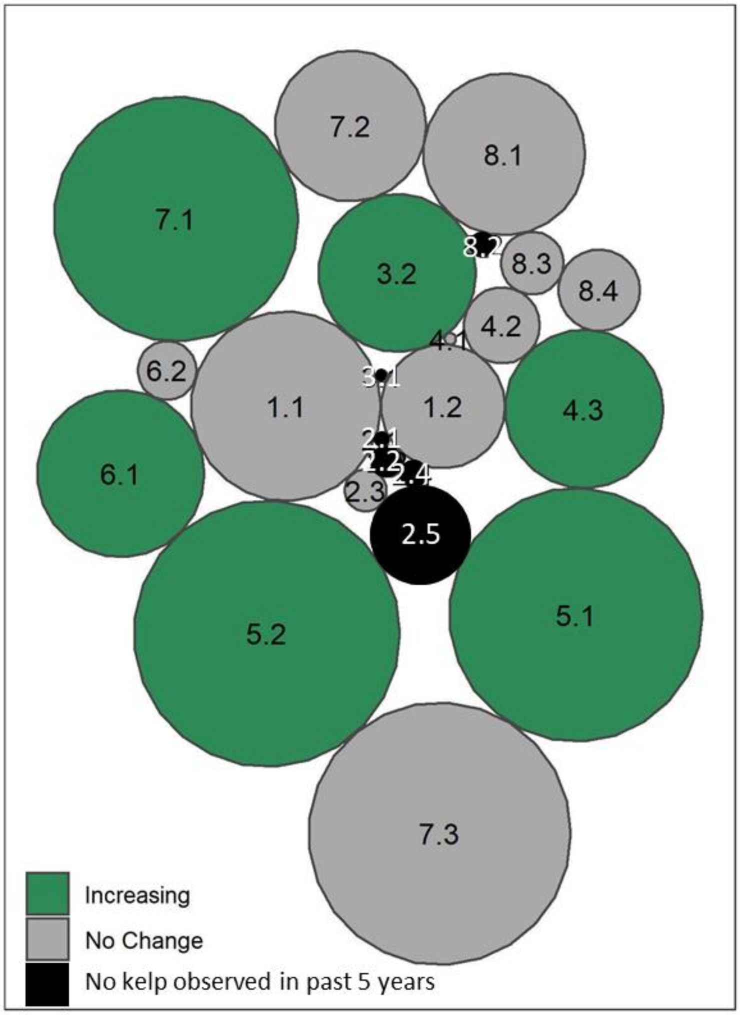

Figure 13. Kelp canopy area change over time for each zone in the COSTR Eastern Strait dataset during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum kelp canopy of that zone. Black bubbles indicate zones that had kelp in the past, but kelp has not been observed in those zones for at least five years. Data from COSTR (Eastern Strait) data set.

During the past five years, kelp canopies in the most rapidly increasing zone (5.1) increased at an average rate of 21.9 hectares (54.1 acres) per year. When averaged across all zones, kelp canopies increased at a rate of 3.8 hectares (9.4 acres) per year [± 0.4 hectares s.e.] (Figure 14).

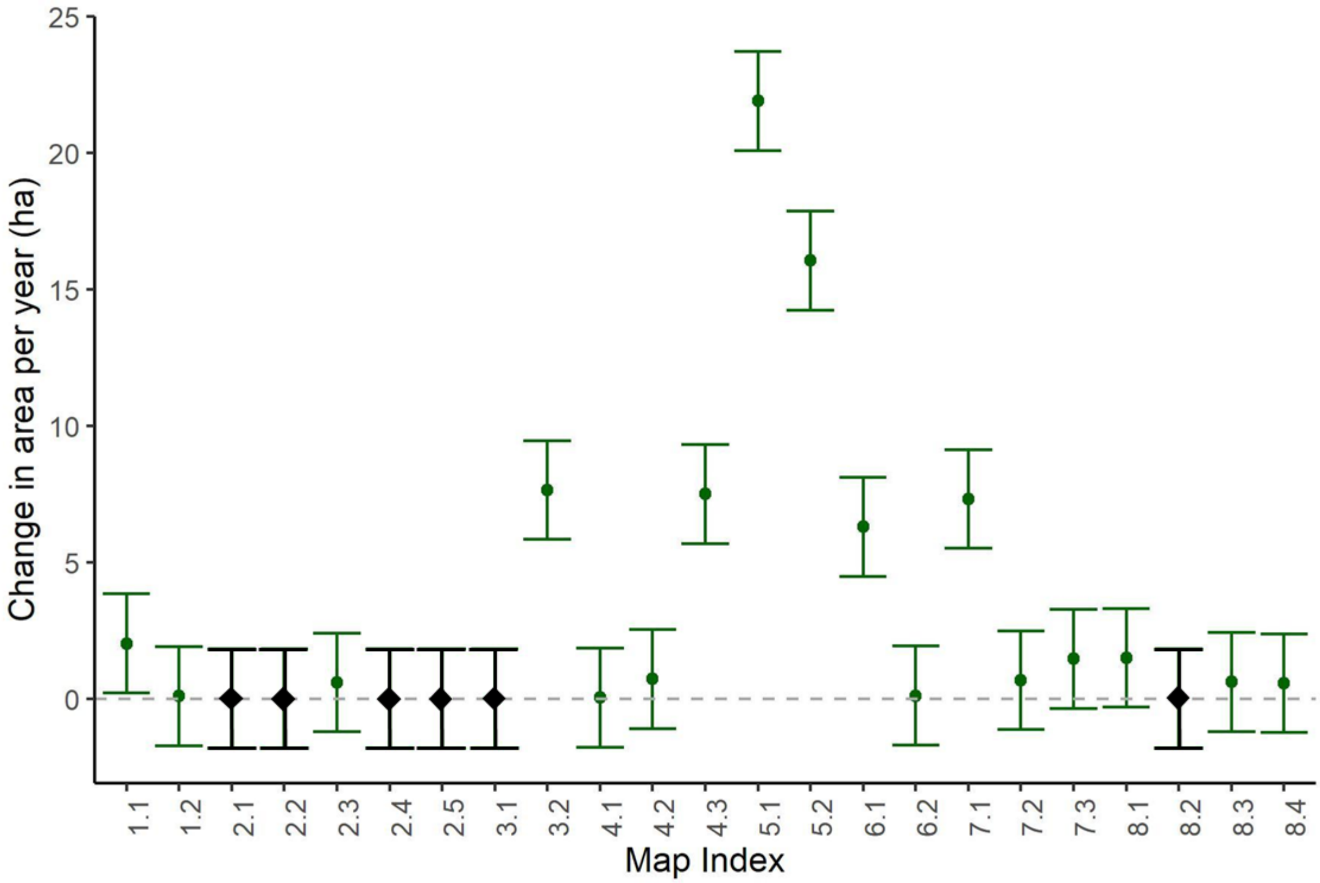

Figure 14. Kelp canopy area change over time of total kelp canopy during the past five years (2017-2021), for each zone in the COSTR Eastern Strait dataset.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change. Black diamonds and associated error bars indicate zones that had kelp in the past, but kelp has not been observed in those zones for at least five years. Data from COSTR (Eastern Strait) data set, includes survey years (2017-2021).

When comparing both kelp canopy area with kelp bed area change over time (Figure 15), six zones were increasing during the past five years for both metrics. The remainder of zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

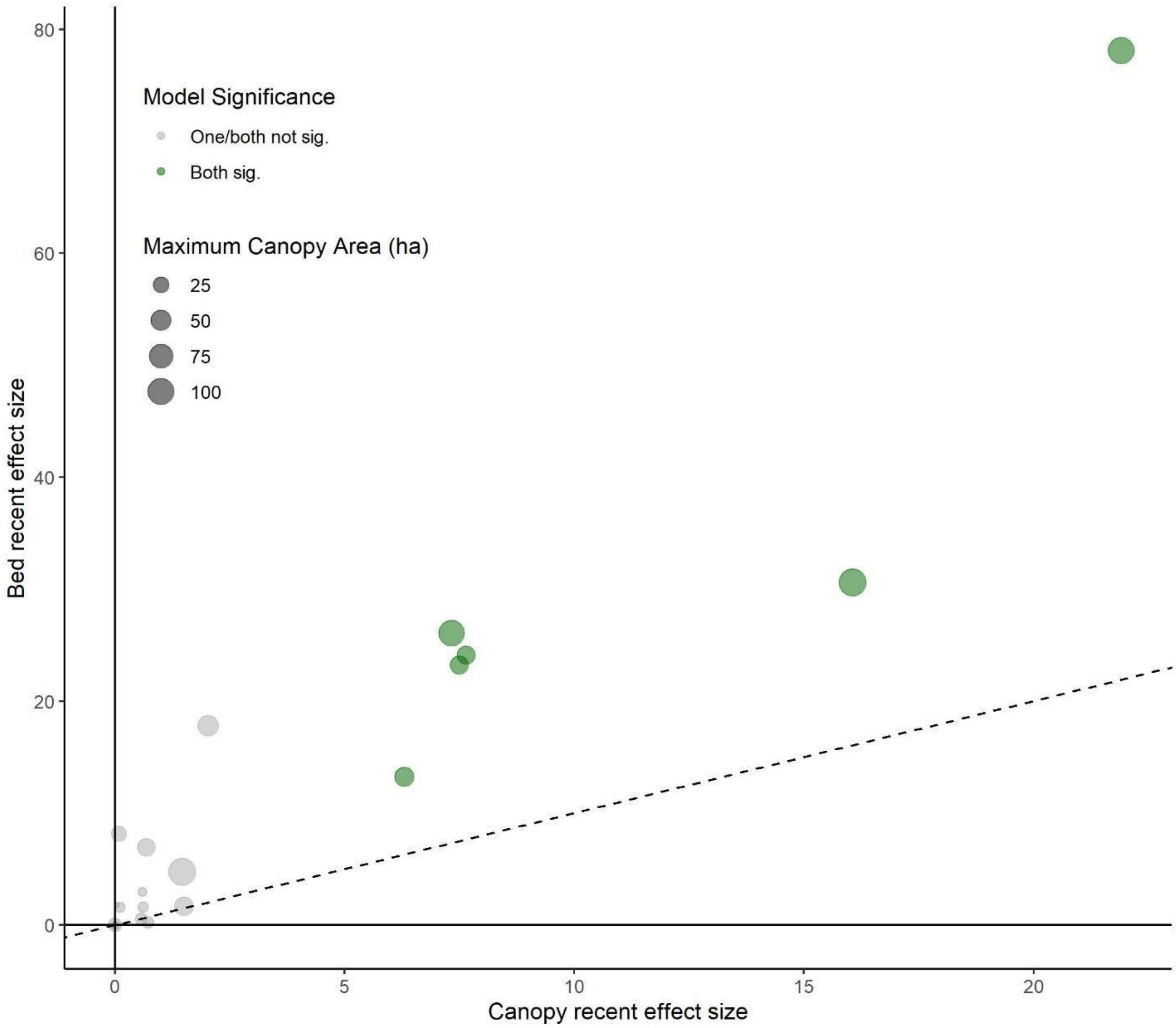

Figure 15. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021) for each zone in the COSTR Eastern Strait dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points in the bottom-left quadrant of the figure indicate declines in both bed and canopy area. Points are colored green if both change in bed area and change in canopy area were significant over time, and they are colored grey if change over time for either or both measures (i.e., bed and/or canopy) was not statistically significant.

Past five years (2017-2021) – AQRES – Smith and Minor Islands Aquatic Reserve

Of the 8 zones within the Eastern Strait of Juan de Fuca AQRES dataset (Smith and Minor Islands Aquatic Reserves), the kelp canopy area of 4 were increasing, 4 were stable, and no declines were detected during the years 2017-2021 (Figure 16).

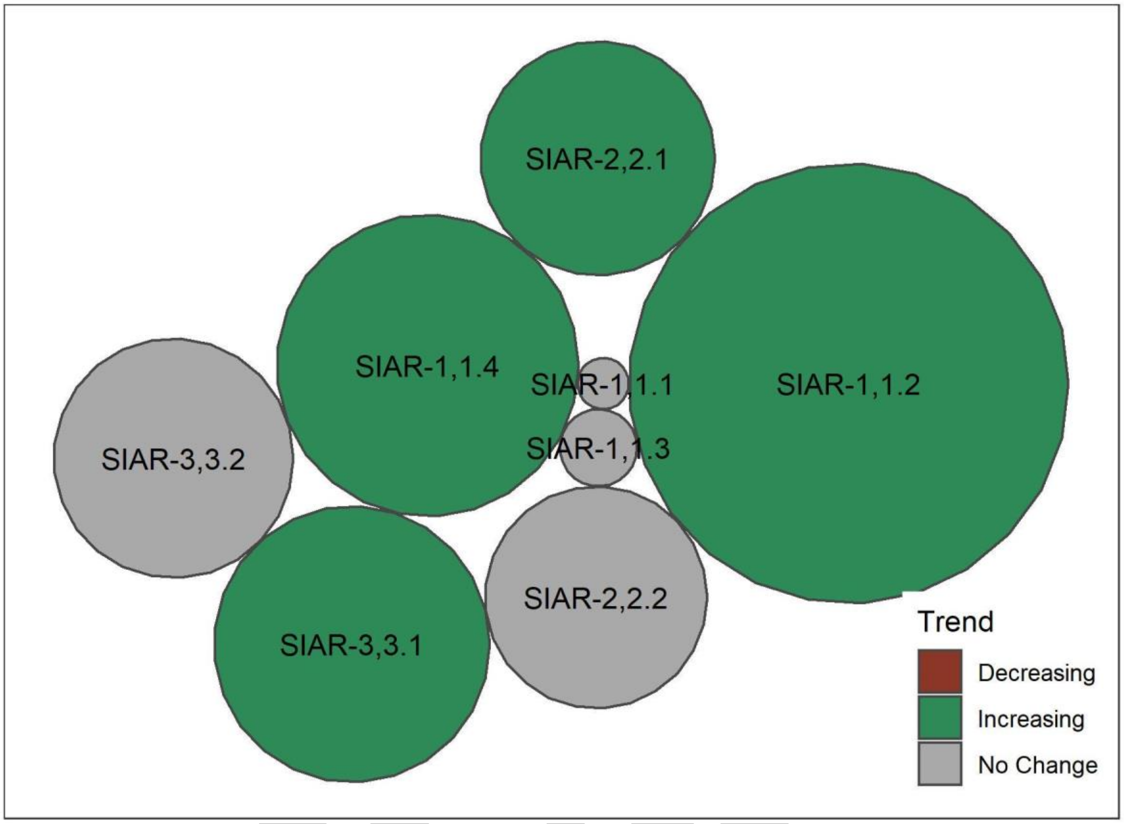

Figure 16. Kelp canopy area change over time for each zone in the Smith and Minor Islands Aquatic Reserve during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum kelp canopy for that zone.

During the past five years, kelp canopies in the most rapidly increasing zone in the Smith and Minor Islands Aquatic Reserve (SIAR-1,1.2) increased at an average rate of 22.6 hectares (55.8 acres) per year. When averaged across all zones, kelp canopies increased at a rate of 8.0 hectares (19.8 acres) per year [± 1.12 hectares s.e.] (Figure 17).

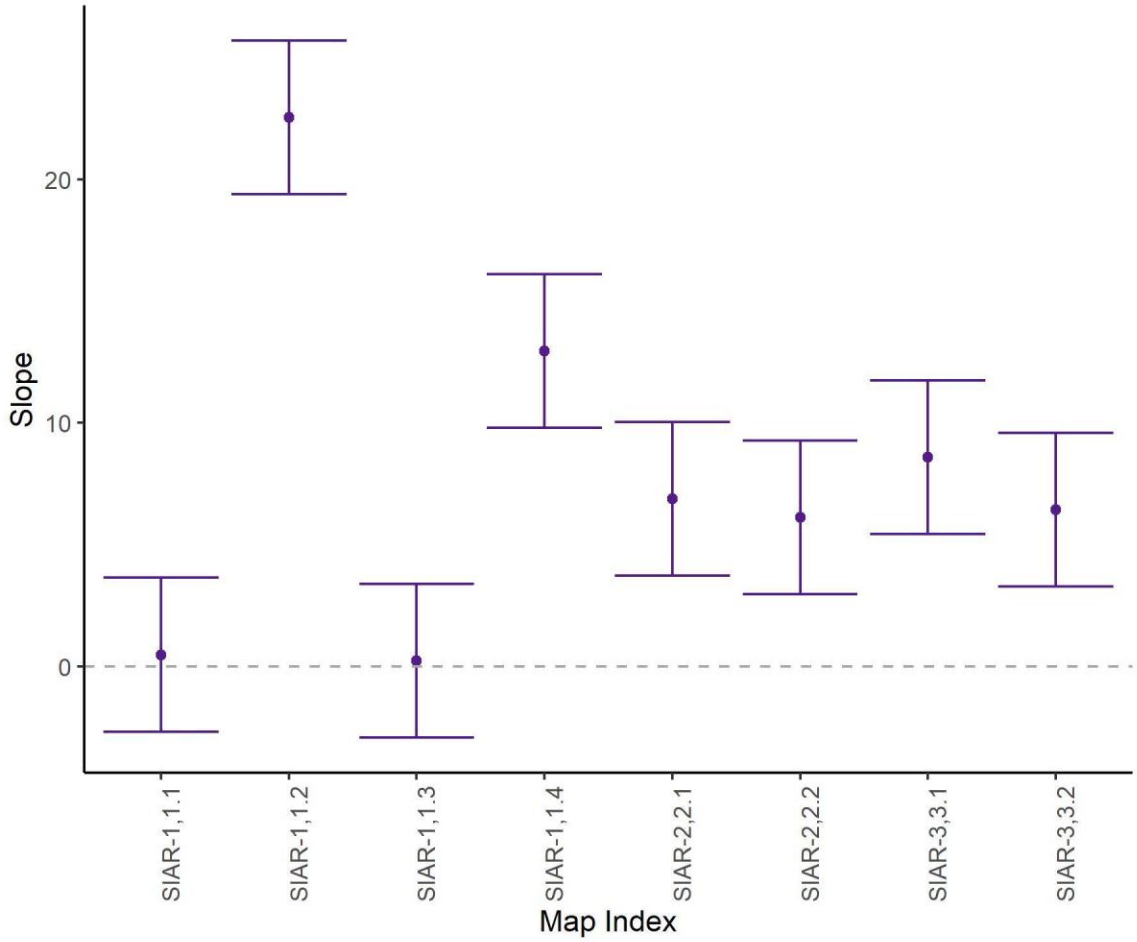

Figure 17. Kelp canopy area change over time of total kelp canopy in each zone during the past five years (2017-2021) in the Smith and Minor Islands Aquatic Reserve.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change.

When comparing both kelp canopy area with kelp bed area change over time in the Smith and Minor Island Aquatic Preserve (Figure 18), two zones were increasing during the past five years for both metrics. The remainder of zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

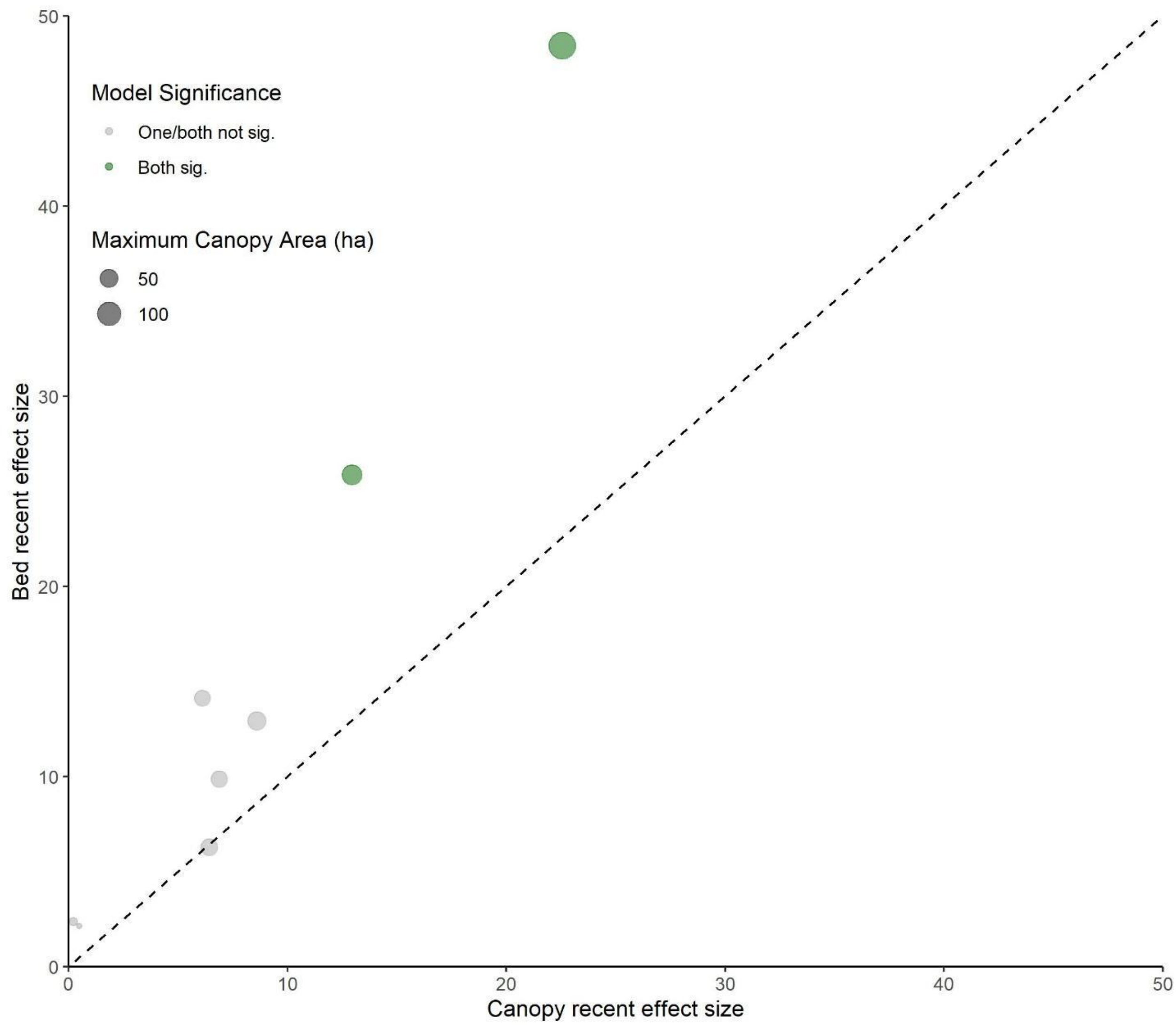

Figure 18. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021) for the Smith and Minor Islands Aquatic Reserve dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points in the bottom-left quadrant of the figure indicate declines in both bed and canopy area. Points are colored green if both change in bed area and change in canopy area were significant over time, and they are colored grey if change over time for either or both measures (i.e., bed and/or canopy) was not statistically significant.

Marine Resources Committee kayak-based survey data

Bed area at Freshwater Bay has been relatively stable since monitoring began in 2016 (Figure 19). Area decreased slightly between 2017 and 2019, from 67 hectares to 48 hectares before stabilizing. The change in area was concentrated on the eastern end of the bed, which was wider and extended further east in 2016 and 2017 then contracted in recent years. In comparison to the MRC volunteer survey result, the COSTR aerial photography survey noted a decrease in density in the general area, but the density change was relatively limited and did not lead to an overall decrease in canopy or bed area in the zone during this period. The observed bed contraction or density decrease may be related to fine sediment deposition and sediment movement associated with the Elwha River. A massive influx of sediment began in 2011 when removal began on two dams on the Elwha River (Rubin et al 2017). The eastern portion of Freshwater Bay is known to be an area of sediment accumulation (Foley & Warrick 2017, Glover 2019). Ongoing studies have examined kelp dynamics in this location and linkages to sediment. At a nearby subtidal index site, Rubin et al (2022) noted that the understory kelp community in 2021 was similar to before dam removal. However, sediment conditions could be highly localized.

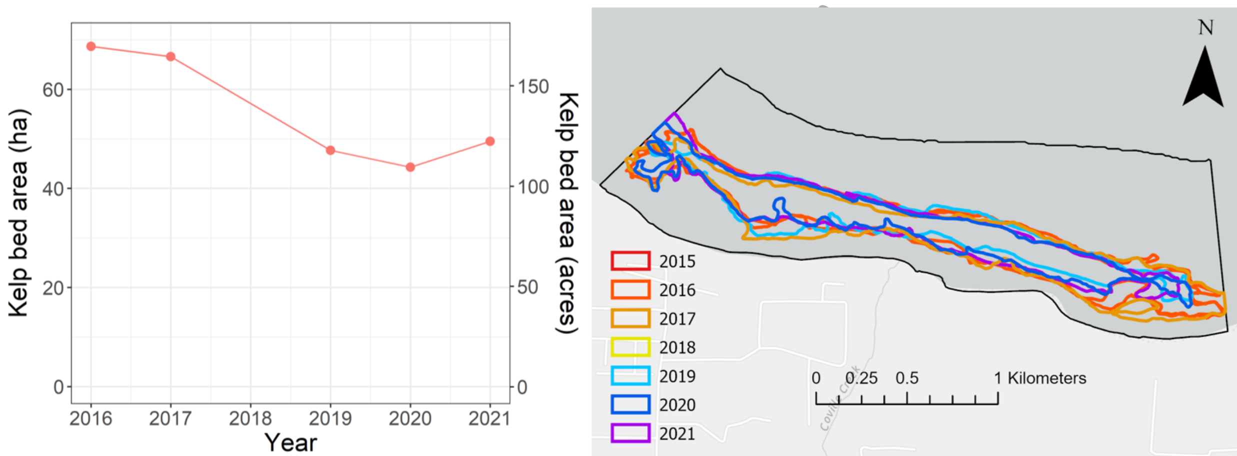

Figure 19. Changes in kelp bed area at the MRC monitoring site in Freshwater Bay.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

Bed area at Observatory Point was small and variable (Figure 20). The footprint of the bed shifted slightly year to year, in some years the bed extended further into Freshwater Bay and in others it did not. The kelp bed area fluctuated between 0.25 hectares and 0.58 hectares with the largest area of 0.58 hectares in 2018. Large numbers of sea urchins have been reported anecdotally at Observatory Point, so it is a site of interest for tracking floating kelp canopy abundance.

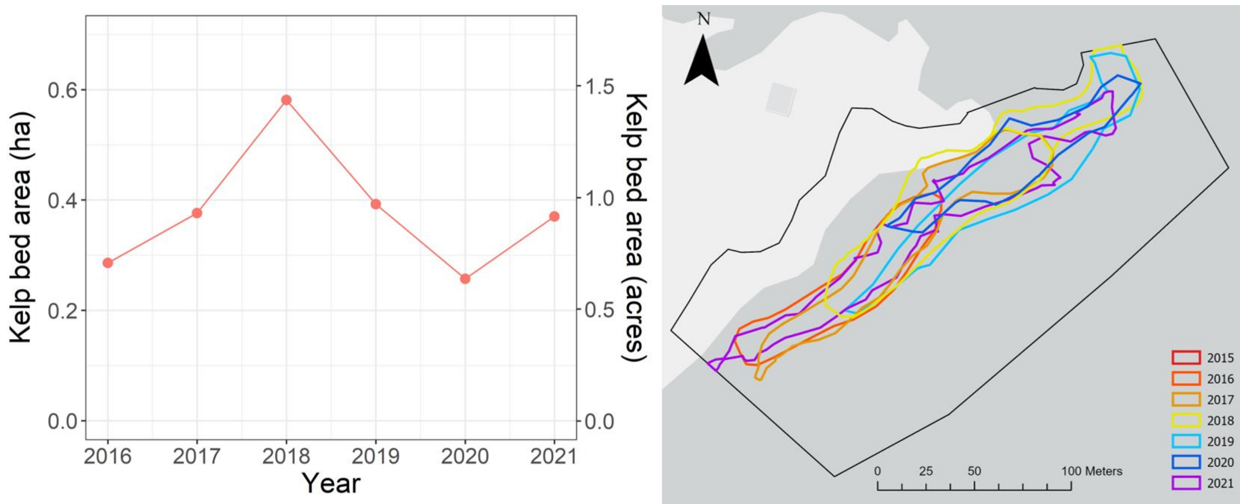

Figure 20. Changes in kelp bed area at the MRC monitoring site at Observatory Point.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

Bed area at North Beach has been variable in both area and footprint (Figure 21). Area decreased between 2016 and 2018 to 4 hectares before increasing to 10 hectares in 2021. In 2018 and 2019, the kelp bed was smaller and was farther offshore than in other years. The shape of the bed perimeter also varied year to year. Volunteers reported low density floating kelp occurred outside the mapped perimeter. Minor changes in the bed footprint could be due to the density threshold that is used to determine bed extent.

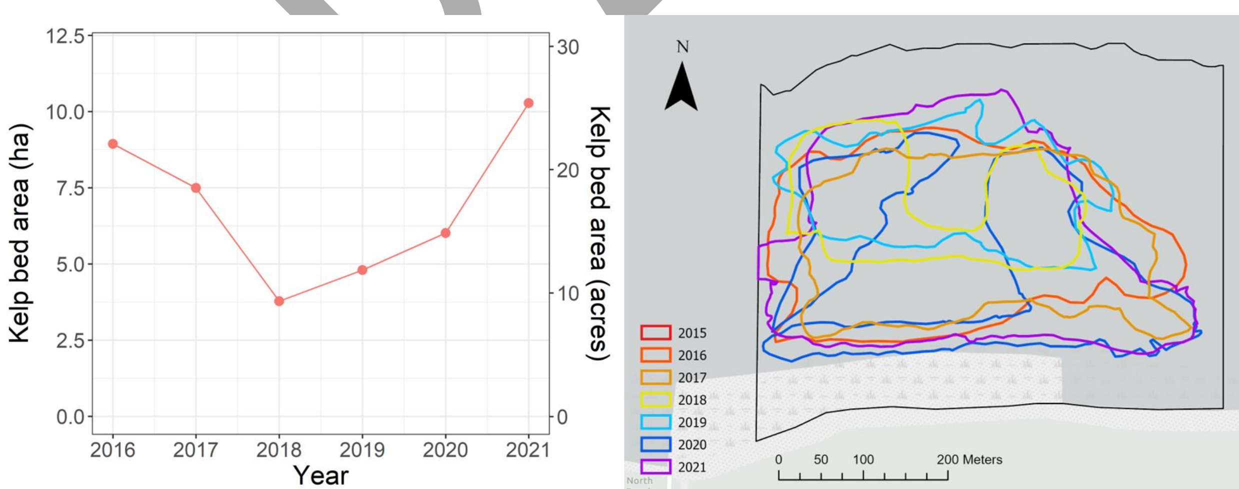

Figure 21. Changes in kelp bed area at the MRC monitoring site at North Beach.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

Bed area at Ebey's Landing was consistently around 8 hectares between 2015 and 2018 (Figure 22). In 2019, the bed expanded into deeper water and extended further to the southeast, which increased the area to approximately 14 hectares. Since 2019, the kelp bed has persisted at the larger size. According to MRC volunteers, the 2019 jump in bed area coincided with a bed expansion that merged with a second kelp bed to the southeast of the MRC monitored bed. However, for an accurate comparison between years, the merged bed perimeters were cropped at the maximum extent of the 2018 survey, before the two beds merged. The kayak volunteers at this site observed less than 5% difference among observers in mapped bed area, so uncertainty related to observers is believed to be minimal.

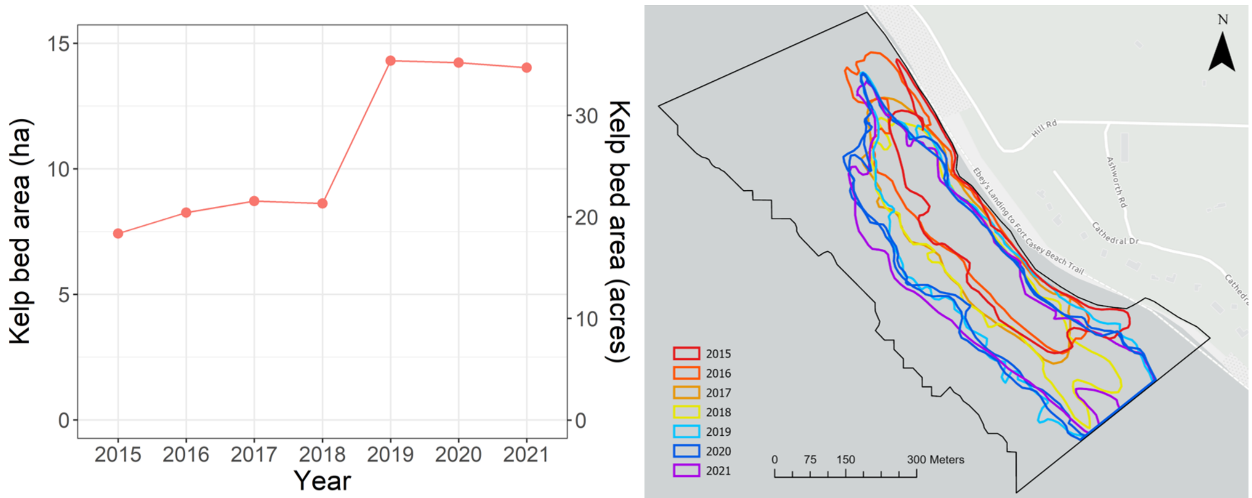

Figure 22. Changes in kelp bed area at the MRC monitoring site at Ebey's Landing.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the survey area

3.3 Other datasets

Comparison of COSTR data to Fertilizer Maps

a. In the Eastern Strait of Juan de Fuca, a comparison of floating bed area in 1911 and modern years found that 6 zones had substantially larger beds in the previous century. In the remaining 5 zones, historical and modern bed area estimates overlapped. This comparison suggests that kelp abundance may have experienced declines during the past century, especially at zones (i.e., map indices) that were documented to have higher relative kelp abundances in 1911-1912 (Figure 23). The majority of zones with diminished modern beds were located along the eastern boundary of the Strait of Juan de Fuca, where annual monitoring has recorded persistent losses in recent decades.

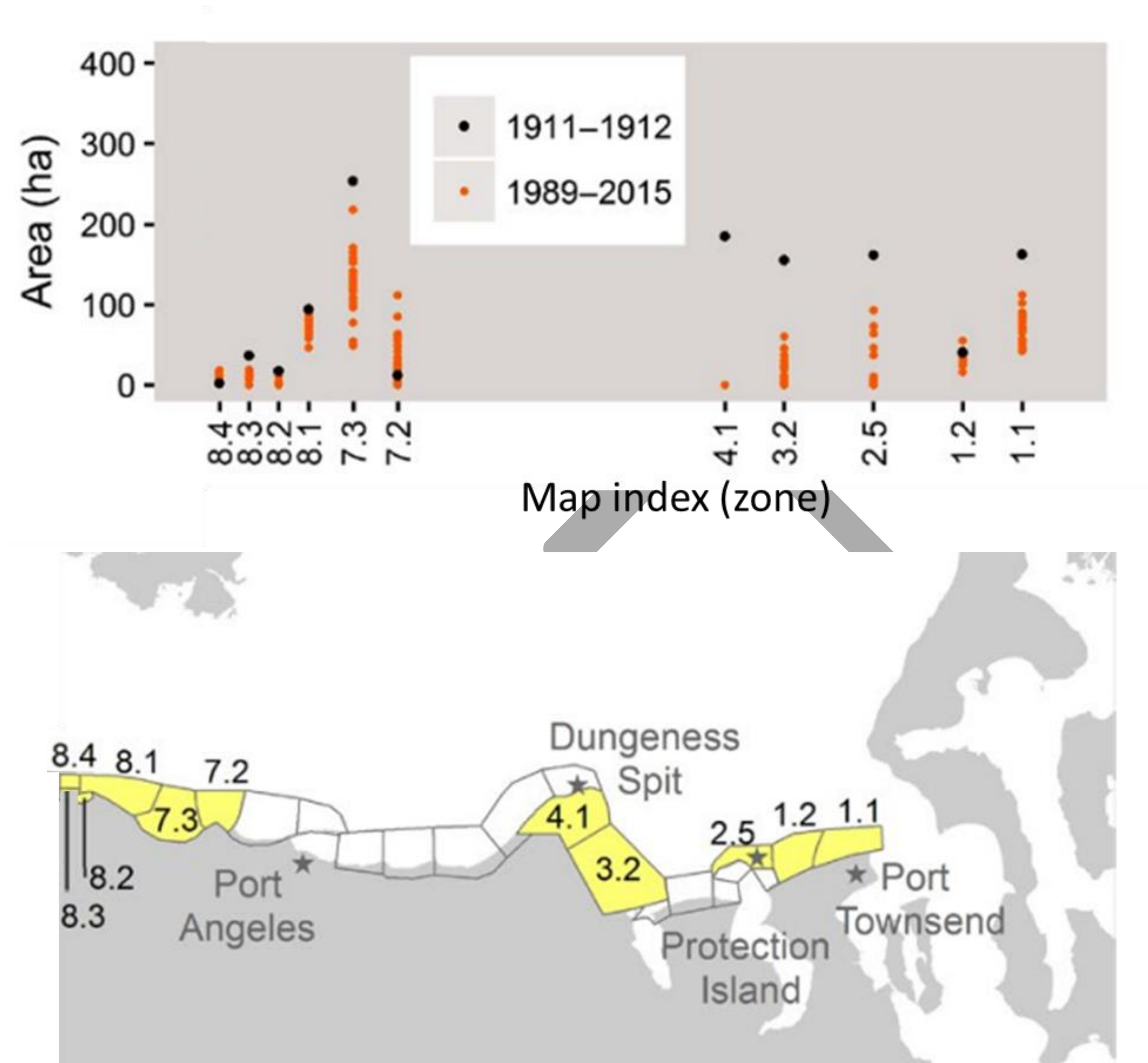

Figure 23. Comparison of Fertilizer Maps and COSTR data, from Pfister, Berry, and Mumford 2018.
Top panel shows historical kelp canopy area (collected in 1911-1912; black dots) and recent kelp canopy area (collected in 1989-2015; orange dots). Bottom panel shows the location of each zone (highlighted in yellow) within the Eastern Strait of Juan de Fuca. “Zone” and “Map Index '' are synonymous in this figure.

Observations by the Beckett Point Kelp Group

At Beckett Point, which is located on the northeastern shore of Discovery Bay, community volunteers observed floating kelp near the boat ramp in May, June, and July, 2021 (Beckett Point Kelp Group, 2021). They noted hundreds of drifting individuals and tens of anchored individuals, and concluded that the feature fell below the minimum threshold of the MRC monitoring protocol. The feature would also likely fall below the detection limit of aerial photography. This survey fills an important gap because it is outside of the annual monitoring reach between Jamestown to Port Townsend (COSTR dataset). The volunteers have heard local reports that floating kelp was dense historically near Beckett Point, and they are exploring historical records and photographs. They proposed the site as a candidate for restoration.

The volunteers also confirmed the presence of a well-established floating kelp bed along the north shore of the Miller Peninsula (captured in zone 2.3 of COSTR), a dense and wide bed at McCurdy Point (captured in zone 1.2 of COSTR), and no attached canopies on Dallas Bank (corresponding to zone 2.5 of COSTR, where no beds were detected).

3.4 Determination of sub-basin trend designation

Analysis of recent trends within the Eastern Strait subset of the COSTR data set (2017-2021) showed a yearly increase of 3.3 hectares (8.2 acres) of kelp canopy area (total increase of 16.5 hectares over the five-year time period), and six out of 23 zones had significant increases in floating kelp canopy area, so this dataset is classified as increasing in the short-term. Analysis of the Eastern Strait subset of the COSTR data set (1989-2021) indicates that kelp has been increasing slowly over the past 33 years, with a statistically significant annual increase of 0.2 hectares (0.5 acres) per year, however, only 5 out of 23 zones exhibited increases in floating kelp canopy area during this time, so this dataset is classified as stable over the full dataset.

Analysis of recent trends within the AQRES Smith and Minor Islands dataset (2017-2021) showed a yearly increase of 8 hectares (19.8 acres) of floating kelp canopy area, and four out of eight zones had significant increases in floating canopy area, so this dataset is classified as increasing in the short-term. Analysis of the AQRES Smith and Minor Islands full dataset (2012-2021) showed a yearly increase of 3 hectares (7.8 acres) of floating kelp canopy area, and four out of eight zones had significant increases in floating canopy area, so this dataset is classified as increasing over the full dataset.

Visualization of floating kelp canopy extent at four MRC kayak survey sites suggests that there has been a substantial amount of variability in kelp abundance over the past seven years. One site, Ebey's Landing, showed strong increases. Freshwater Bay appeared to contract along the eastern boundary. Two sites (North Beach and Observatory Point) appeared to be variable but stable.

Analysis of the Eastern Strait subset of the COSTR data set (1989-2015) compared to the Fertilizer Surveys conducted in 1911-1912 suggests that kelp abundance likely experienced declines at multiple locations during the past century, particularly in the eastern portion of the Eastern Strait. More recently, persistent declines have been noted within the central portion of the Jamestown to Pt Townsend reach. However, these losses are not evident in abundance estimates at the scale of the reach because of large adjacent beds comprise the majority of bed area.

Taken together, these data and observations lead us to classify this sub-basin as "stable" overall.

Table 2. Determination of sub-basin trend designation

Recent (5 years)	increasing	
Entire data record	stable	
Overall trend	stable*	
Indicator Classification	**stable**	

*General trends across the sub-basin reflect stable conditions in this area. However, localized declines suggest that additional caution is warranted in the far eastern portion of the sub-basin.

4. Discussion

4.1 Datasets used in sub-basin assessment

Floating kelp canopy data in the eastern Straits sub-basin is extensive, in comparison to many other sub-basins in Washington state. The majority of the shoreline (>98%), has annual monitoring data for 11-33 years (described below). Limited portions of the shoreline lack ongoing monitoring surveys, including:

- Sequim Bay and Discovery Bay. Within Discovery Bay, community observations at Beckett Point partially address this data gap.
- Western Whidbey Island shorelines that are outside the Smith and Minor Aquatic Reserve. To the northeast, unsurveyed shorelines span from Joseph Whidbey State Park to Deception Pass. To the southeast, unsurveyed shorelines span from south of Ebey's Landing Beach to Admiralty Head.

WA DNR aerial data (COSTR dataset) provide a comprehensive survey of floating kelp canopy area for the years surveyed for a large portion of the sub-basin. This dataset provides consistent data between 1989 and 2021, with the exception of 1993 when images were not collected. The consistency of this data set over time provides confidence in the status and trends calculated for this sub-basin over the past 3 decades.

WA DNR aerial data (AQRES dataset) provide a comprehensive survey of floating kelp canopy area for the years surveyed in the Smith and Minor Island Aquatic Reserve, a location with extensive floating kelp. This dataset provides consistent data between 2012 and 2021, providing confidence in assessing recent trends in this area over the last decade.

Marine Resources Committee kayak-based survey data at four sites provides additional insights at a fine spatial scale. This dataset also shows substantial inter-annual variability at each site, with one site potentially showing a decline (Freshwater Bay), one site showing a kelp bed expansion (Ebey's Landing), and two sites showing variability but no apparent directional change. Additional years of survey data at these sites will support interpretation of trends over time. Results at two volunteer sites showed general similarities with other datasets:

1) The volunteers recorded a bed contraction near the eastern edge of Freshwater Bay, where oceanographic surveys reported new accumulations of fine sediment associated with Elwha River discharge (Rubin et al 2017);
2) The volunteers recorded bed expansion at Ebey's Landing, which is south of the Smith and Minor Aquatic Reserve, where major increases were recorded over a similar period.

At Beckett Point, surveys by volunteers identified an area with limited floating kelp that is outside the extent of the monitoring datasets. This bed is below the resolution of the MRC monitoring protocol and would likely be below the detection limits of the COSTR aerial photography. The community will continue to survey the bed, they are also exploring historical data to assess whether losses have occurred over time.

A century-scale comparative study (Pfister et al., 2018) suggests that kelp abundance may have experienced declines, especially at locations that were documented to have relatively large beds in 1911-1912. This raises concern regarding the longer-term trajectory of kelp in the Eastern Strait of Juan de Fuca, with particular emphasis on locations on the eastern boundary of the strait, which are closer to human impacts and farther from oceanic influence. Another location with substantially lower modern floating kelp abundance was Freshwater Bay, which is located adjacent to the mouth of Elwha River. Freshwater Bay experienced major changes in habitat associated with dam construction and eventual removal (discussed below).

4.2 Potential Drivers of Observed Kelp Trends and Linkages to Ecosystem Components

Floating kelp canopies along the eastern Strait of Juan de Fuca exhibited high year-to-year variability over both short and long time scales. High variability in abundance is a common characteristic of floating kelp, and particularly high variability has been noted in bull kelp, the dominant species in the eastern Strait. Long-term analysis found that variability in kelp cover in the eastern Strait sub-basin was strongly related to large scale climate indices (Pfister et al., 2018). Increased kelp cover occurred when the Pacific Decadal Oscillation and the Oceanic Niño Index were negative and the North Pacific Gyre Oscillation was positive, conditions where seawater is colder and more nitrogen rich.

In addition to climate cycles, many physical and biological factors are known to drive floating kelp abundance (Dayton, 1985). Floating kelp requires solid substrates for attachment, adequate light, and water column nutrients. It generally occurs in habitats with waves or currents. Grazing by herbivores can strongly influence kelp distribution and abundance, with changes in herbivory pressure often linked to changes in predator populations. Kelp losses across the globe have generated widespread concern (reviewed in Krumhansl et al., 2016), but trends appear to be regionally distinct. Widespread human activities can impact kelp, including development, agriculture, forestry, and harvest. The eastern Strait of Juan de Fuca represents a mid-point along a gradient in environmental conditions and human activities; distant from the open ocean yet within well-mixed waters, distant from the urbanized portions of Puget Sound yet more developed than the western Strait and open coast.

In recent years, floating kelp communities in the eastern Strait appear to be generally healthy, in stark contrast to many locations in the northeast Pacific. Major factors that likely drove kelp abundance in the eastern strait in recent years include Elwha Dam removal, sea star wasting disease, the 2013-2015 marine heat wave and urchin population increases (discussed below).

Floating kelp canopies declined in 2012 within the reach that brackets the Elwha River, from Ediz Hook to Freshwater Bay (Figure 3). These declines were likely associated with Elwha River restoration actions, which released massive sediment loads during a staged, three-year project to remove two dams. Research documented extensive understory kelp losses between Ediz Hook and Freshwater Bay, driven by sediment deposition near the mouth and elevated suspended sediments throughout the reach. The long-term monitoring record showed that floating kelp canopy declines began in 2012 and continued in 2013 (Figure 3). In 2014, kelp canopies experienced region-wide declines, which were likely due to a marine heat wave (discussed below). In late 2013, a major marine heat wave (MHW) occurred in the northeast Pacific. The COSTR and AQRES datasets show substantial drops in the eastern Straits that corresponded temporally to kelp losses observed in northern California (Rogers-Bennett & Catton, 2020). Unlike northern California, kelp canopy area rebounded quickly in 2015 along the Olympic Peninsula shorelines to Port Townsend. Floating kelp canopy abundance returned to previous levels in 2016 in the Smith and Minor Aquatic Reserve, which suggests that recovery may have been delayed along a gradient into the Salish Sea (Claar et al., 2022).

In 2013, a sea star wasting disease (SSWD) epidemic led to the largest sea star die-off event seen on the northeastern Pacific Coast, affecting 20 species of sea stars (Hamilton et al., 2021). The Sunflower star *Pycnopodia helianthoides*, an important predator in kelp forest ecosystems, experienced catastrophic declines (Hamilton et al., 2021). The disappearance of this important predator and other species of sea stars has been linked to trophic cascades and kelp losses (Schultz et al., 2019; Rogers-Bennett & Catton, 2019). As in other regions, major sea star declines have been noted in the eastern Strait (Sanchez et al., 2022). Overall floating kelp abundance remains healthy. Other effects on kelp ecosystems need further study.

Sea urchins are important grazers in kelp forest ecosystems (Watson & Estes, 2011). In the northeast Pacific in recent years, major increases in populations of the purple urchin *Strongylocentrotus purpuratus* have been linked to kelp forest declines (e.g. Rogers-Bennett & Catton, 2019). Potential drivers linked to urchin population increases include elevated temperatures and SSWD (Bonaviri et al., 2017). Along the eastern Strait, large aggregations of urchins have been observed in Freshwater Bay and along shorelines to the west, to the sub-basin boundary near Crescent Bay. However, they were limited in size to small patches (Frierson et al., 2021; Andrews et al., 2021; Rubin et al. 2021; Sanchez et al., 2021). Kelp decreases associated with sea urchins were also limited to small patches.

While kelp forests are recognized as important components of coastal systems, their ecological roles are poorly understood. A recent study by Shaffer, Munsch, and Cordell (2020) in the eastern Strait quantified functional linkages for forage fishes and salmonids. They found that zooplankton that were important components of fish diets were significantly more abundant in kelp forests than open-water habitat. They also recorded greater presence and abundance of zooplankton, juvenile salmonids, and forage fishes in kelp forests compared to adjacent open-water habitats.

4.3 Priorities for future research and monitoring

This assessment of floating kelp resources in the eastern Strait of Juan de Fuca brings to light a series of research and monitoring priorities that could be undertaken, contingent upon available funding and resources:

- The highest priority for floating kelp monitoring is to continue annual assessments in the long-term monitoring areas (the COSTR and AQRES datasets). If funding is available, the following enhancements are prioritized for these datasets:
    - Upgrade imagery collection procedures to a large format photogrammetric mapping camera system and 4- band imagery. Process and classify orthomosaics.
    - Explore ability to re-process existing survey data so that floating kelp abundance can be assessed at spatial scales finer than zones.
- Conduct additional research at sites of observed losses in order to assess multiple stressors and evaluate causes of local declines (especially Miller Peninsula, Protection Island, Cape George, and Beckett Point).
- Explore collaborations to advance understanding of the effect of SSWD and urchin grazing on floating kelp beds in the eastern Strait of Juan de Fuca.
- Synthesize floating kelp canopy data with other nearshore community datasets in order to understand linkages between floating kelp and nearshore communities.
- Improve understanding of the ecological role of kelp forests in the sub-basin through studies of kelp forest usage by fishes, birds and other ecosystem components.

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