Appendix 4: Draft sub-basin report – Western Strait of Juan de Fuca

Puget Sound Vital Signs Floating Kelp Canopy Indicator

Status and Trends in the

Western Strait of Juan de Fuca Sub-basin

Last updated: May 27, 2022

Recent trend:	Stable
Entire data record trend:	Stable
Overall trend:	Stable

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 reports on status and trends of floating canopies in sub-regions throughout Washington State. This report presents assessment results for the Western Strait of Juan de Fuca sub-region, which spans 112.5 km (69.9 mi) of shoreline between Cape Flattery and to the western boundary of Crescent Bay (near Joyce).

Data Summary:
Fixed-wing aerial images processed by the Washington Department of Natural Resources from 1989 - 2021. Kayak surveys of floating kelp canopy conducted by the local Marine Resources Committee at one site in Clallam Bay.

Key Findings:

- Floating kelp is abundant along the western Strait of Juan de Fuca. Two species of floating kelp occur here, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*). Floating kelp covers between 3,800 and 8,900 acres per year, reflecting high natural year-to-year variability in response to environmental conditions.
- Bull kelp and giant kelp abundance have been relatively stable recently (past 5 years). The 33-year data record shows a slight increasing trend at the sub-basin scale, while a century-scale comparison suggests long-term stability.
- Future monitoring will allow us to determine whether increases over the last 33 years represent a meaningful 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.

Indicator Classification:

- Multiple sources provide evidence that, as a whole, floating kelp beds in this sub-region are stable. Some of the data suggest that a slight increasing trend is possible.
- Considering the entire data record, the sub-basin was classified as stable because a century-scale comparison showed that the bed area of zones (i.e., map indices) in 1911 generally fell within the range of values measured in the last three decades. Within the last three decades, a trends test showed a small, statistically significant increase in sub-basin canopy area. At the zone scale over the past three decades, 15 zones showed no trends while 7 increased, which also suggests overall stability. The bed area metric showed similar results to canopy area.
- In recent years, no statistical trend was evident in canopy area at the sub-basin scale. At a higher spatial resolution, most zones were stable (15), while 3 showed increases. Results were similar for the bed area metric.

Priorities for Future Research and Monitoring

- Enhance imagery to 4-band orthomosaics.
- Re-process existing survey data so that floating kelp abundance can be assessed at spatial scales finer than zones.
- Further explore floating kelp dynamics in relation to climate (e.g., assessing how trends are related to climate oscillations vs. long-term changes) and grazer dynamics (especially urchins).

Contents

Figures

Tables

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 sub-basin reports. 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-region covers the western portion of the Strait of Juan de Fuca (Figure 1).

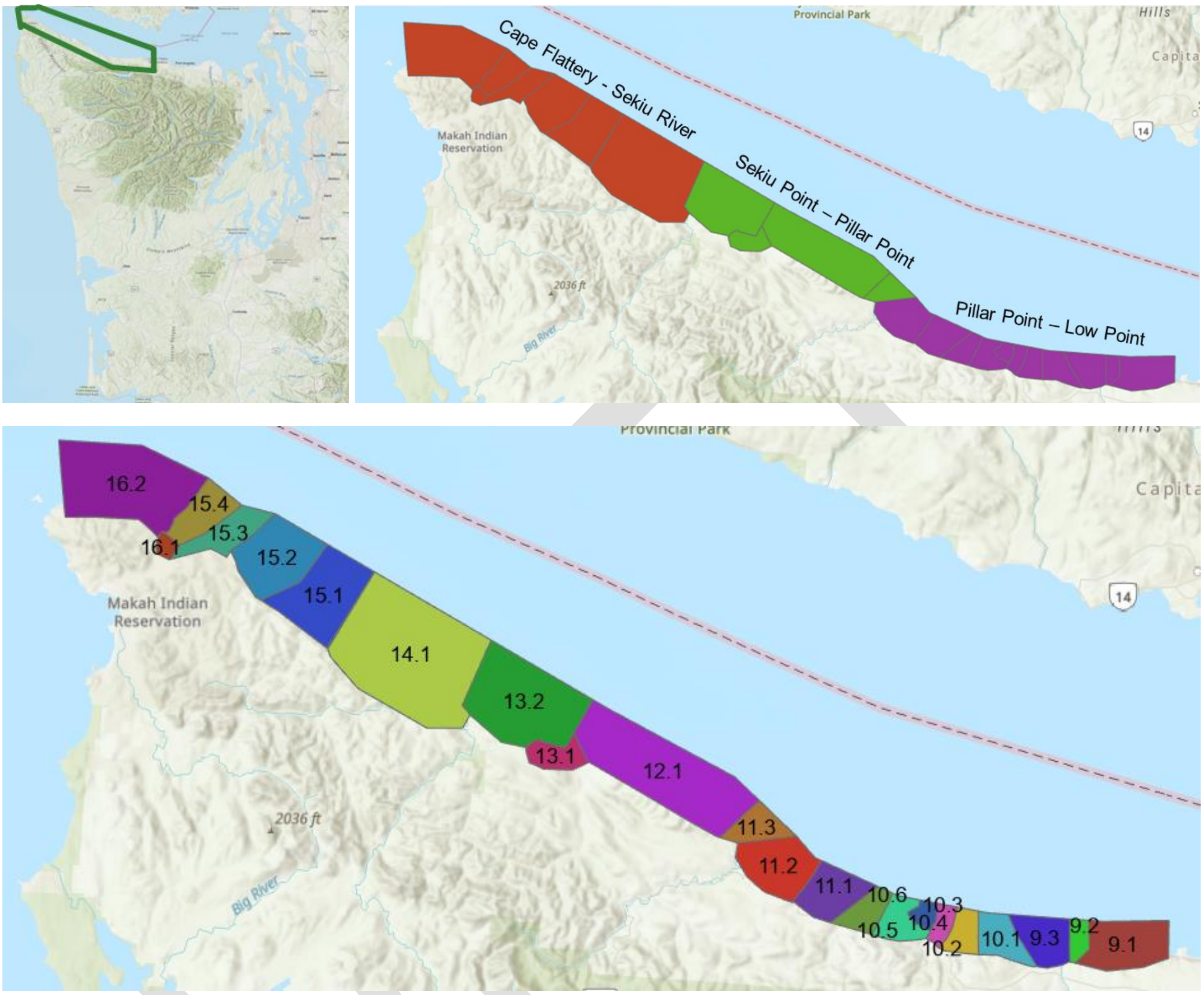


Figure 1. Maps of the Western Strait sub-basin.
Top left – map of western Washington State with a green polygon surrounding the Western Strait sub-region. Top right – close-up map of the Western Strait sub-region, labeled by reach. Bottom – close-up map of the Western Strait sub-region, labeled by zone (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 Western 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 Western Strait of Juan de Fuca Sub-basin.

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

1. DNR Coast and Strait data set (COSTR) – subset for the Western 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 Western Strait during each survey year.
    d. Includes both giant kelp (*Macrocystis*) and bull kelp (*Nereocystis*).
    e. Includes 22 zones (previously called "map indices") where kelp has been mapped, or 100% of kelp area in the sub-basin mapped.
2. Marine Resources Committee (MRC) kayak-based monitoring at Clallam Bay.
    a. Yearly kayak-based monitoring from 2017-2021.
    b. Kelp bed perimeter collected during peak kelp abundance (July-August).
    c. The defined kelp bed in Clallam Bay is the only MRC monitoring site in the Western Strait.

2.3 Other datasets 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

2.4 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 Western 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, MRC (Clallam Bay; 2017-2021)
Entire data record	32 years, COSTR (1989-2021)

Overall	COSTR: 1989-2021 MRC (Clallam Bay): 2017-2021

Following the general guidelines for kelp status time periods in the 'Indicator guidelines and procedures document', recent trends can be assessed with both the WA DNR COSTR 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.

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 were summed in 22 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 was 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 by 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 (32 years 1989-2021). 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 Floating kelp canopy extent

The maximum amount of kelp canopy area detected in the Western Strait of Juan de Fuca was 1,643 hectares (4,060 acres), which occurred in the year 2000 (Figure 2). The minimum amount of kelp canopy area detected in the Western Strait of Juan de Fuca was 442 hectares (1,092 acres), which occurred in the year 1989 (Figure 2). Average kelp canopy cover abundance per year was 945 hectares [± 291 hectares s.d.].

3.1.2 Floating kelp bed extent

The maximum amount of kelp detected in the Western Strait of Juan de Fuca was 3,625 hectares (8,958 acres), which occurred in the year 2000 (Figure 2). The minimum amount of kelp detected in the Western Strait of Juan de Fuca was 1,561 hectares (3,857 acres), which occurred in the year 1989 (Figure 2). Average kelp abundance per year was 2,433 hectares [± 458 hectares s.d.].

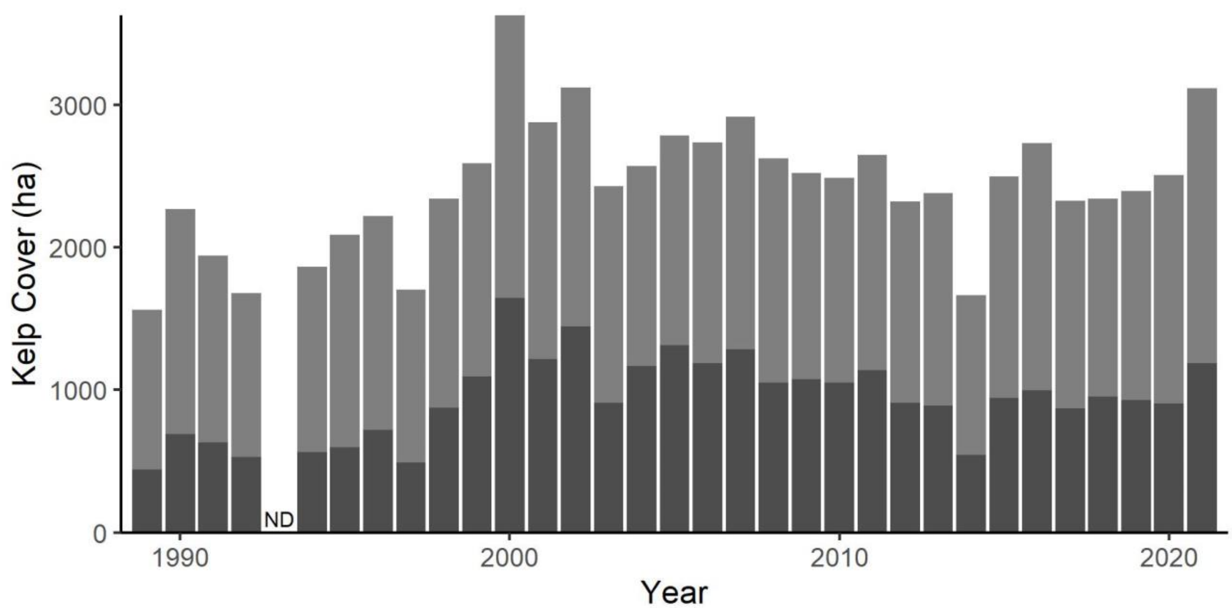


Figure 2. Total kelp canopy cover from 1989 to 2021.
Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area (includes both bull kelp, Nereocystis luetkeana, and giant kelp, Macrocystis pyrifera). Note that no data was collected in 1993. Data from COSTR (Western Strait) data set, includes all surveyed years to date (1989-2021).

3.1.3 Kelp canopy area – species composition

On average, 44% of total kelp canopy across the Western Strait of Juan de Fuca was composed of bull kelp (*Nereocystis*), and 57% of total kelp canopy was composed of giant kelp (*Macrocystis*). During the strongest *Nereocystis* year (1991), *Nereocystis* accounted for 56% of total canopy area while *Macrocystis* accounted for 44% of total canopy area. During the strongest *Macrocystis* year (1997), *Nereocystis* accounted for 24% of total canopy area while *Macrocystis* accounted for 76% of total canopy area.

In the Western Strait of Juan de Fuca, maximum bull kelp canopy area was 904 hectares (2,234 acres), which occurred in the year 2000, and minimum bull kelp canopy area was 116 hectares (287 acres), which occurred in the year 1997. Additionally, maximum giant kelp canopy area was 739 hectares (1,826 acres), which occurred in 2000, and minimum giant kelp canopy area was 279 hectares (689 acres) which occurred in 1991.

3.1.4 Kelp bed area – species composition

On average, 51% of total kelp bed area across the Western Strait of Juan de Fuca was composed of bull kelp (*Nereocystis*), and 57% of total kelp bed area was composed of giant kelp (*Macrocystis*). During the strongest *Nereocystis* year (2021), *Nereocystis* accounted for 60% of total bed area while *Macrocystis* accounted for 40% of total bed area. During the strongest *Macrocystis* year (1997), *Nereocystis* accounted for 38% of total bed area while *Macrocystis* accounted for 62% of total bed area.

In the Western Strait of Juan de Fuca, maximum bull kelp bed area was 2,173 hectares (5,370 acres), which occurred in the year 2000, and minimum bull kelp bed area was 650 hectares (1,606 acres), which occurred in the year 1997. Additionally, maximum giant kelp bed area was 1,452 hectares (3,588 acres), which occurred in 2000, and minimum giant kelp bed area was 855 hectares (2,113 acres) which occurred in the year 1991 (Figure 3).

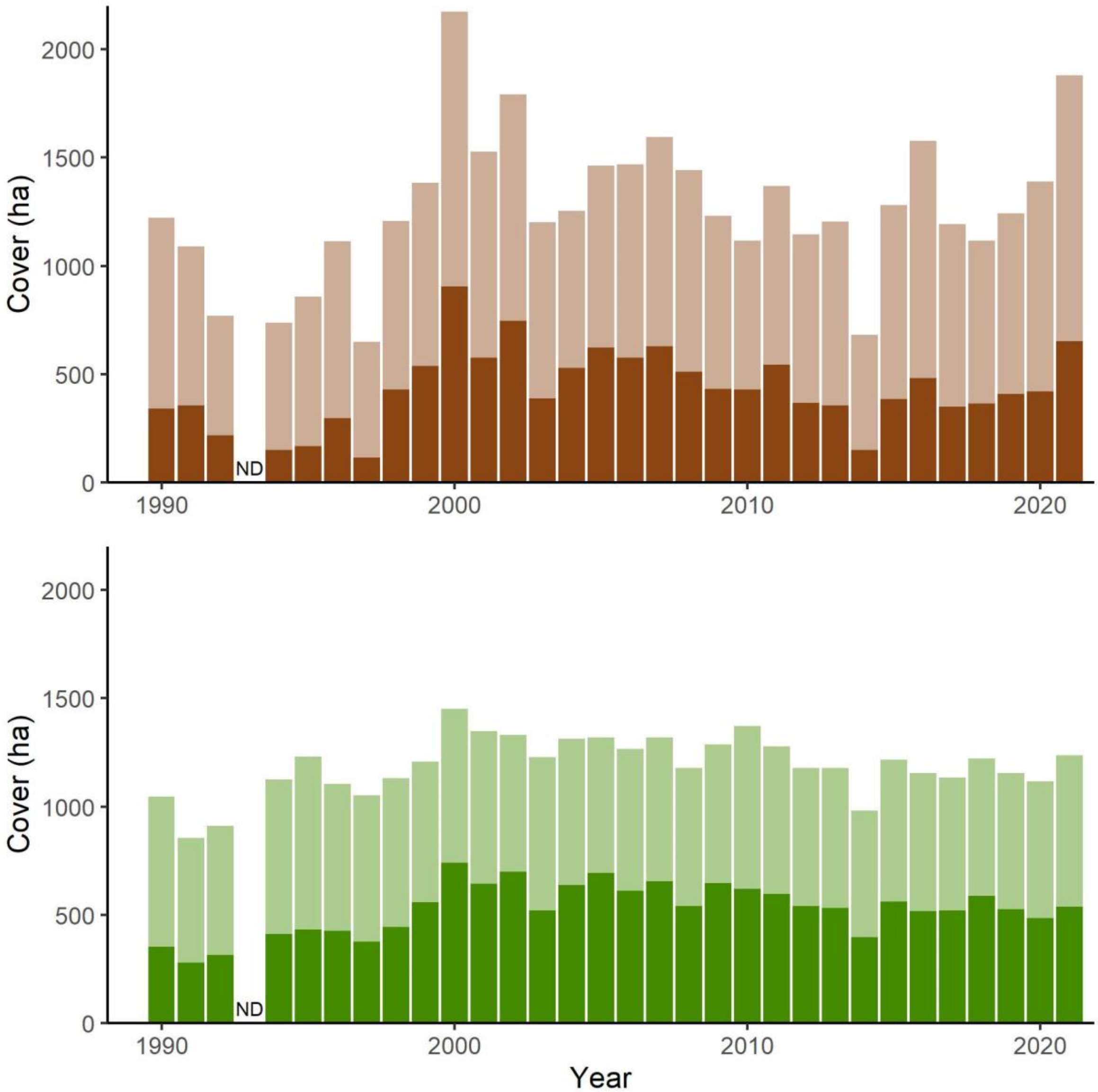


Figure 3. Total kelp cover (including both bull kelp, Nereocystis luetkeana [in brown], and giant kelp, Macrocystis pyrifera [in green]) from 1990 to 2021.
Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area. Note that no data was collected in 1993, and that kelp species was not specified during the 1989 surveys (indicated as 'Unspecified' kelp species). Data from COSTR (Western Strait) data set, includes all surveyed years to date (1989-2021).

The reach with the most kelp coverage was Low Point – Pillar Point, followed by Sekiu River – Cape Flattery (Figure 4).

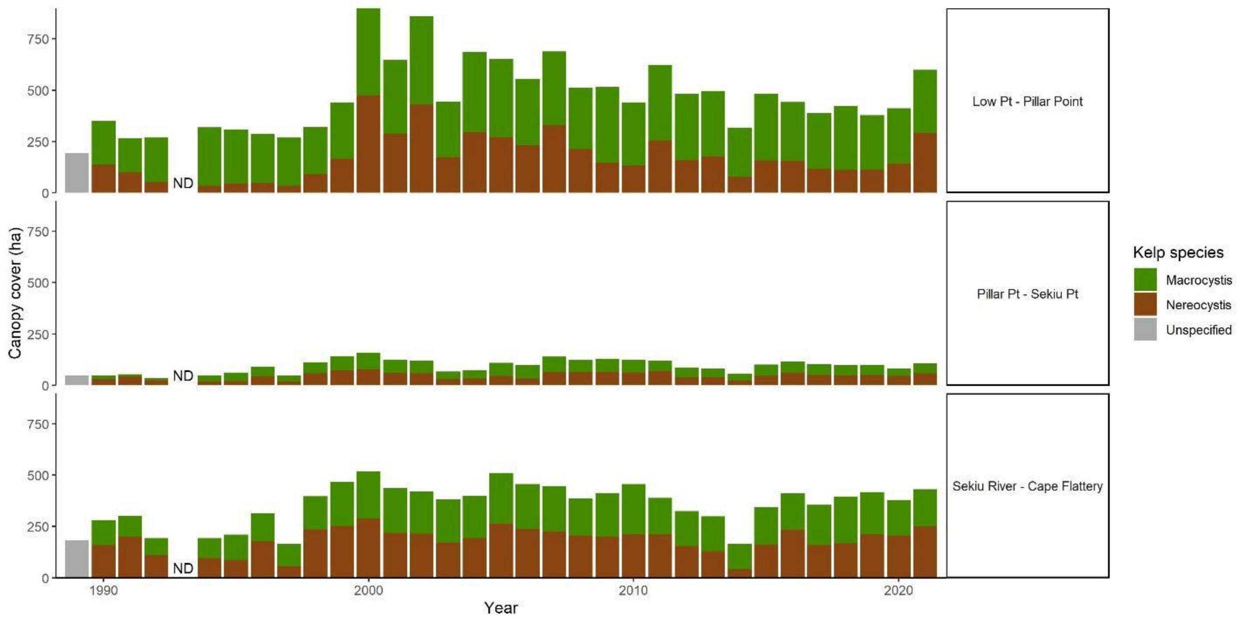


Figure 4. Total kelp cover (including both bull kelp, Nereocystis luetkeana [in brown], and giant kelp, Macrocystis pyrifera [in green]) from 1990 to 2021 for each reach in the Western Strait.
Note that no data was collected in 1993, and that kelp species was not specified during the 1989 surveys (indicated as 'Unspecified' kelp species). Data from COSTR (Western Strait) data set, includes all surveyed years to date (1989-2021).

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 area and as a percentage of maximum kelp canopy area (Figure 5).

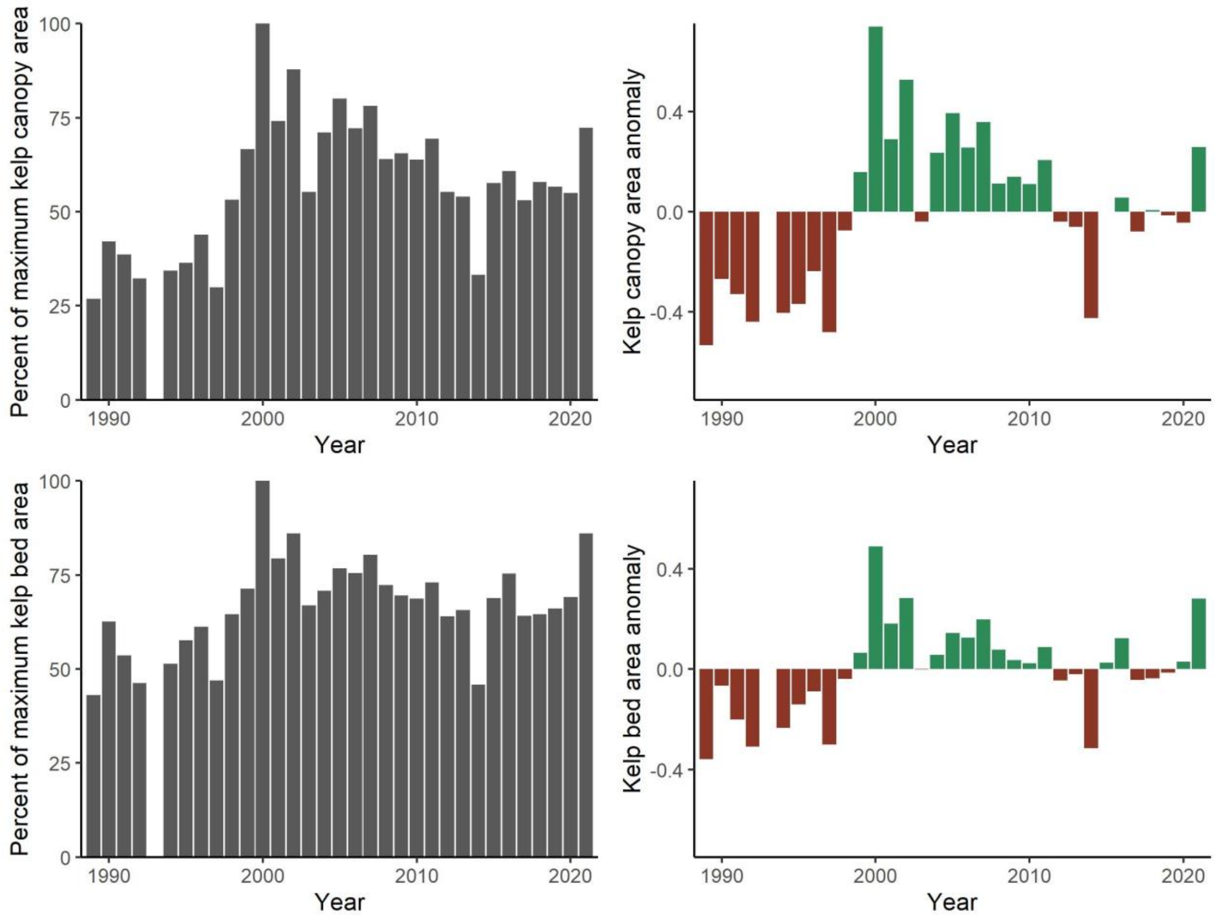


Figure 5. Kelp area anomalies for the Western Strait of Juan de Fuca.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean kelp area. Data from COSTR (Western Strait) data set, includes all surveyed years to date (1989-2021).

3.2 Trends in floating kelp canopy area

Entire data record - COSTR dataset

Of the 22 zones within the Western Strait of Juan de Fuca, the kelp canopy area of 7 were increasing, 15 were stable, and no declines were detected during the years 1989-2021 (data from COSTR – Western Strait subset) (Figure 6).

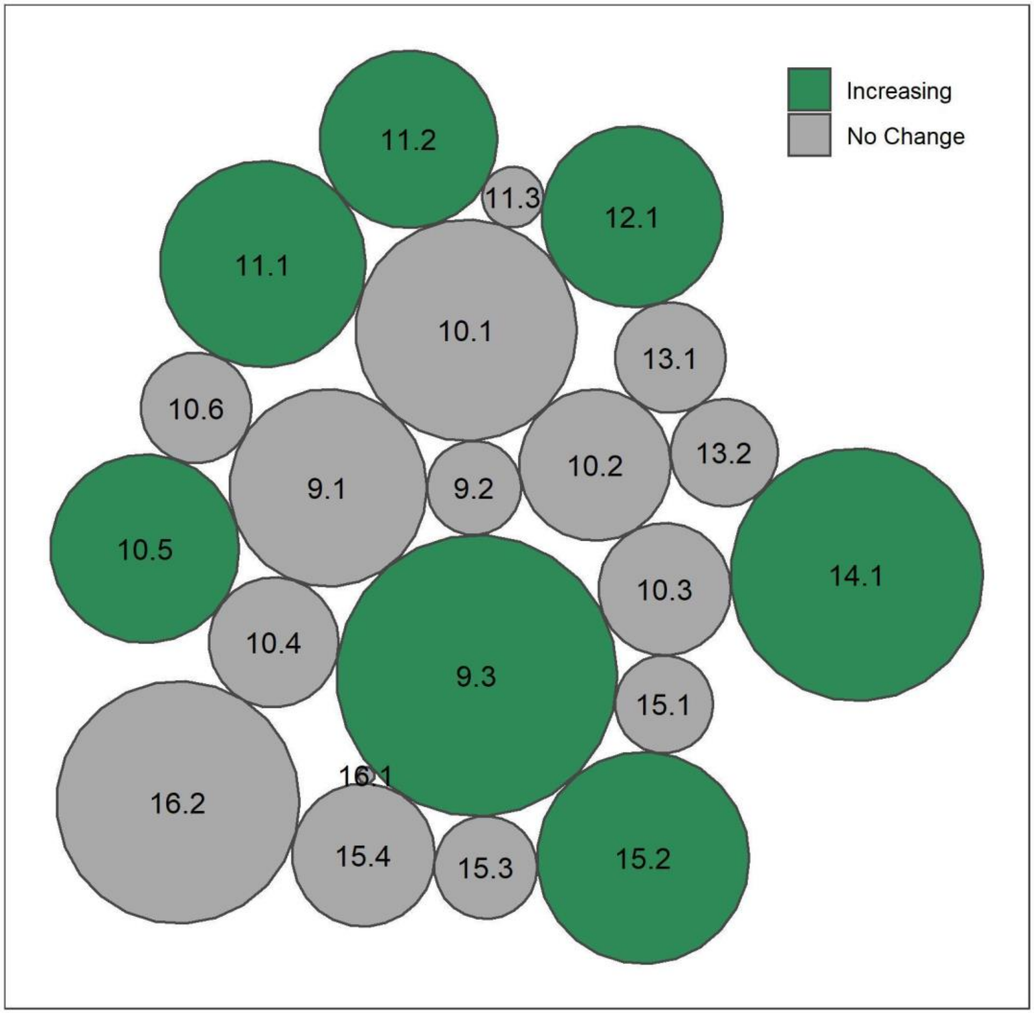


Figure 6. Kelp canopy area change over time (1989-2021) for each zone in the Western Strait of Juan de Fuca. Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent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

Throughout the full data set (1989-2021), kelp canopies in the most rapidly increasing zone (14.1, located near Sekiu River) increased at an average rate of 1.6 hectares (4.0 acres) per year (Figure 7). When averaged across all zones, kelp canopies increased at a rate of 0.44 hectares (1.09 acres) per year [± 0.07 hectares s.e.].

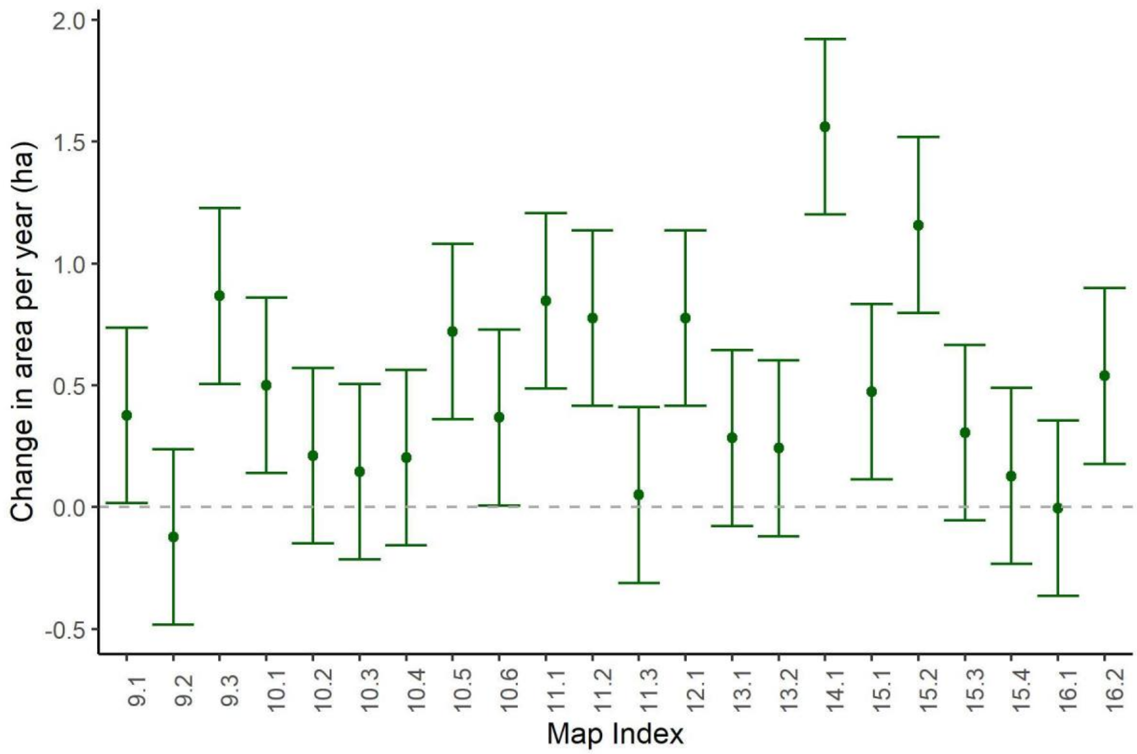


Figure 7. Kelp canopy area change over time of total kelp canopy, including both bull kelp and giant kelp, for each zone. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change. Data from COSTR (Western Strait) 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), only three zones were increasing over time for both metrics. The remaining zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

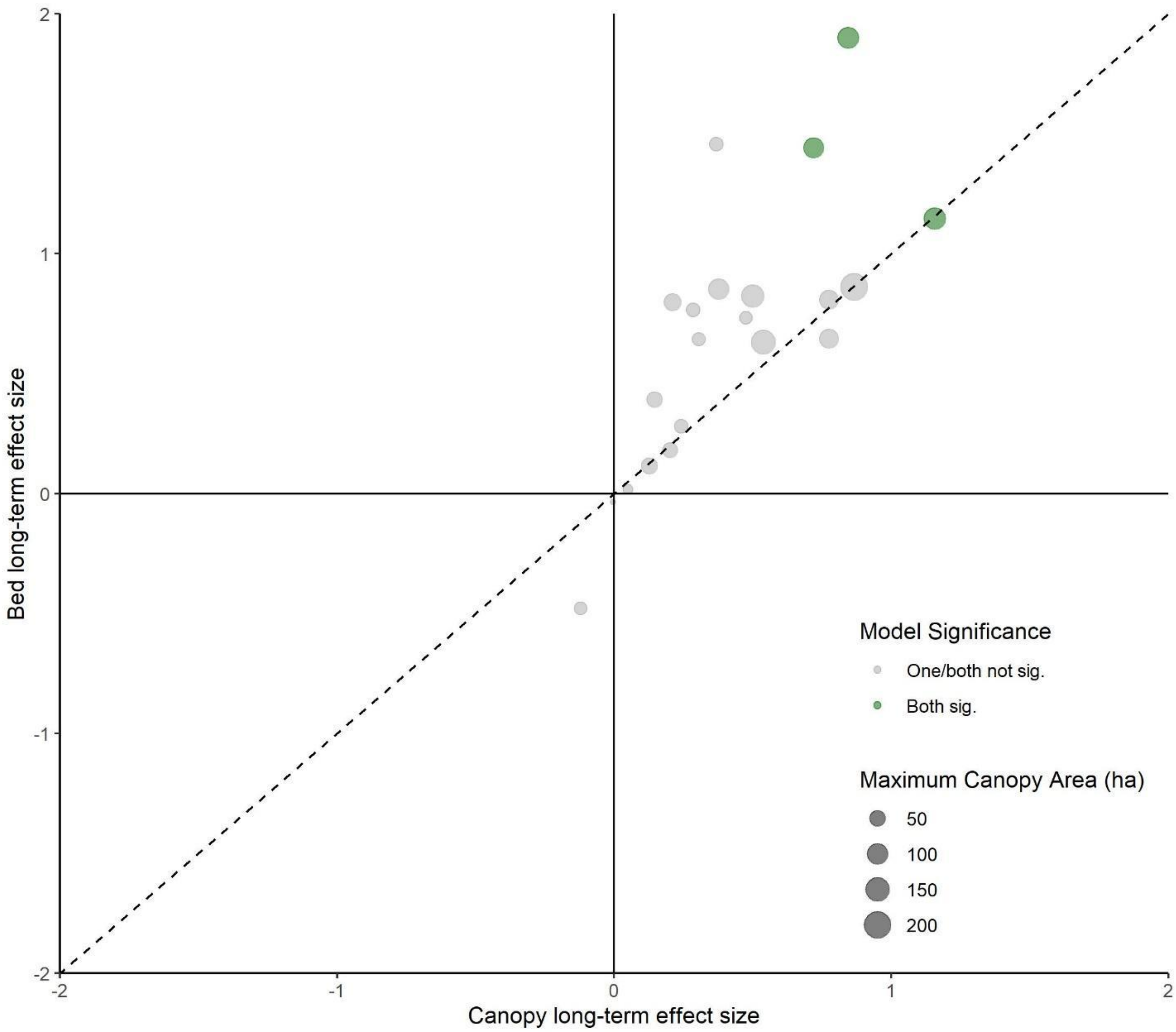


Figure 8. Comparison of rate of change in kelp area between canopy and bed measurements.
Each circle represents a zone, and they are scaled by the maximum canopy area detected in that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points 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 gray *if change over time for either or both measures (i.e., bed and/or canopy) was not statistically significant.*

Past five years - COSTR dataset - (2017-2021)

Of the 22 zones within the Western Strait of Juan de Fuca, the kelp canopy area of 3 were increasing, 19 were stable, and no declines were detected during the years 2017-2021 (data from COSTR – Western Strait subset) (Figure 9).

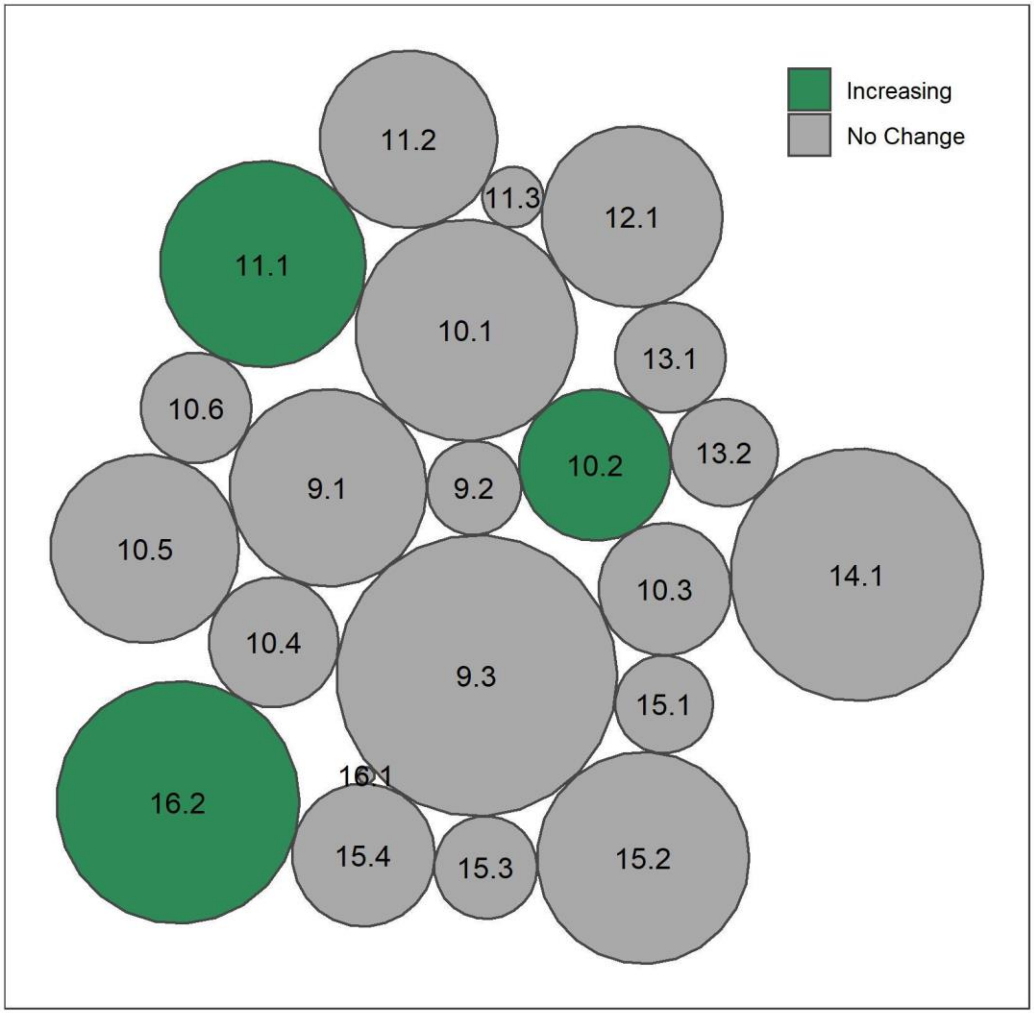


Figure 9. Kelp canopy area change over time for each zone in the Western Strait of Juan de Fuca during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum kelp canopy at that site. Data from COSTR (Western Strait) data set.

During the past five years, kelp canopies in the most rapidly increasing zone (11.1) increased at an average rate of 10.2 hectares (25.2 acres) per year. When averaged across all zones, kelp canopies increased at a rate of 2.4 hectares (6.0 acres) per year [± 0.5 hectares s.e.] (Figure 10).

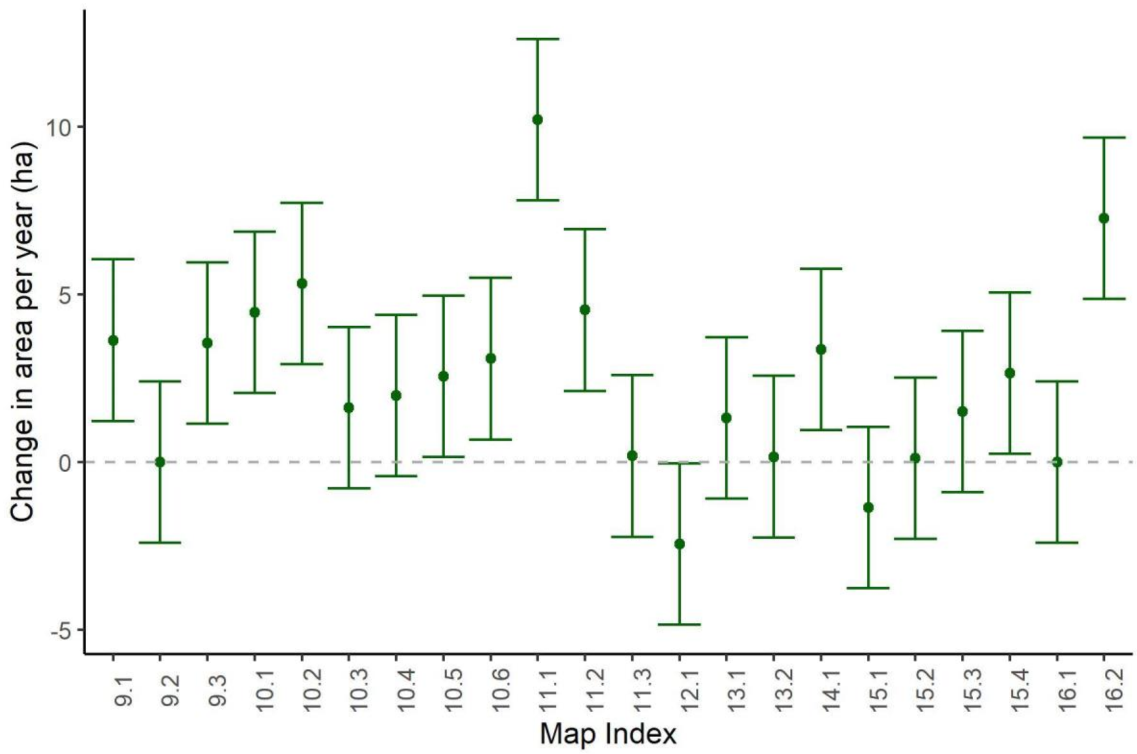


Figure 10. Kelp canopy area change over time of total kelp canopy during the past five years (2017-2021), including both bull kelp and giant kelp, for each zone.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change. Data from COSTR (Western Strait) data set, includes survey years (2017-2021).

When comparing both kelp canopy area with kelp bed area change over time (Figure 11), only two zones were increasing during the past five years for both metrics. The remaining zones did not have significant detectable changes for either/both metrics (i.e., kelp bed area and/or kelp canopy area).

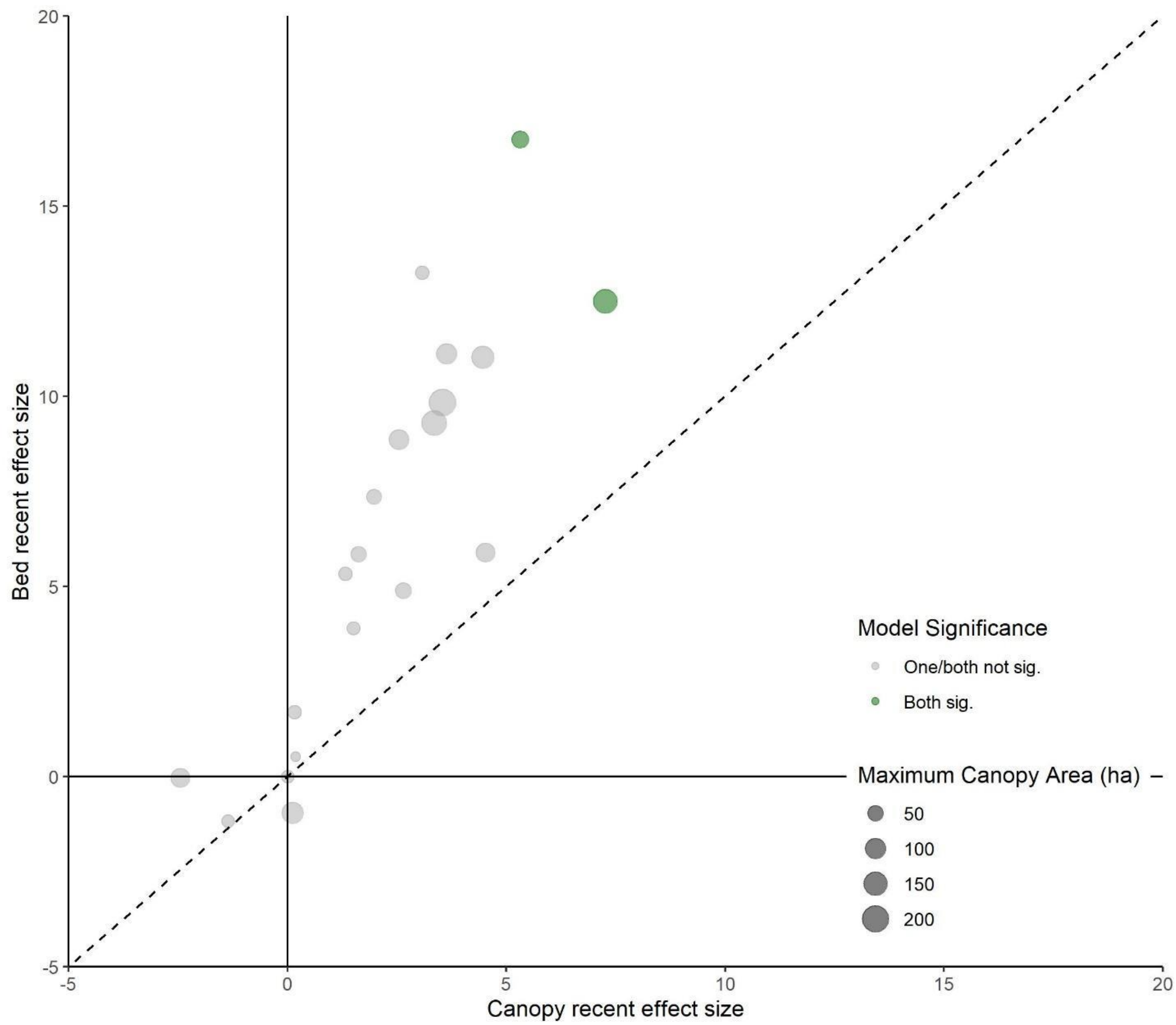


Figure 11. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021).
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in 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 gray 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 (2017-2021)

- The kelp bed area at Clallam Bay has been variable (Figure 12). The bed area fluctuated yearly, and decreased overall from 10 hectares in 2017 to 6 hectares in 2021. The smallest area recorded was 5.3 hectares in 2020. Volunteers reported that the 2020 estimate was smaller than the actual bed footprint because volunteers avoided rocks and waves.
- The shallow edge of the bed extended closer to shore in 2017 and 2018, but moved offshore in subsequent years. This shift in bed footprint could indicate the bed contracted or it could be due

to changing kelp density that is not captured by the survey due to defined threshold distances between bulbs set in the MRC protocol (see the dataset description).

- Clallam County MRC volunteers have noted that the site is a high energy environment and the substantial wave action and storms could be influencing the kelp bed density and area.
- The bed area and shape identified by volunteers was generally similar to the aerial imagery and the COSTR data. Slight differences in results may be attributed to methodological differences between surveys.

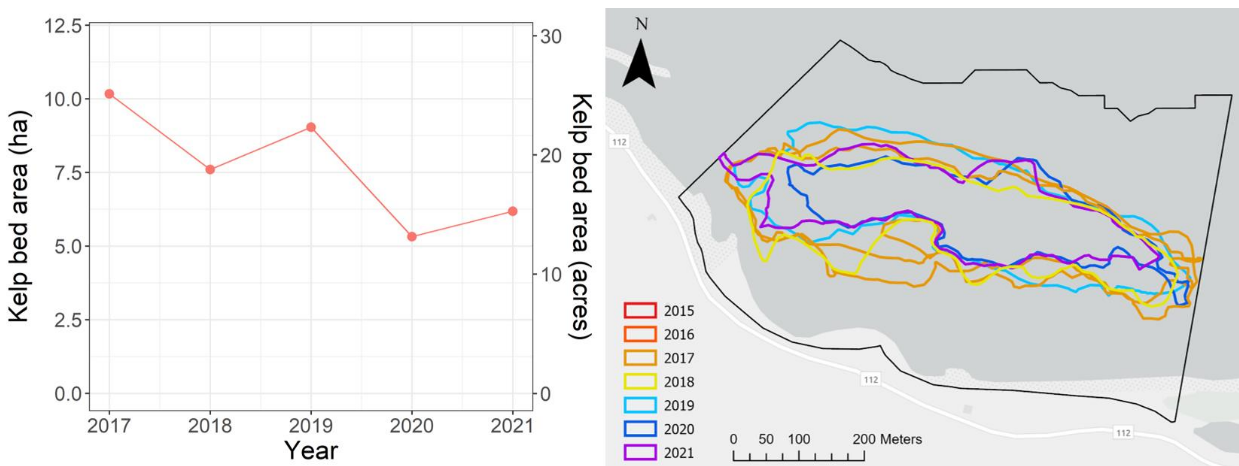


Figure 12. Changes in kelp bed area at the MRC monitoring site in Clallam Bay. Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey assessment extent.

3.3 Other datasets

- Comparison of COSTR data to Fertilizer Maps
    a. For the Western Strait of Juan de Fuca, this analysis suggests that kelp abundance is generally stable, but that kelp populations experience a large amount of variability over time (Figure 13).

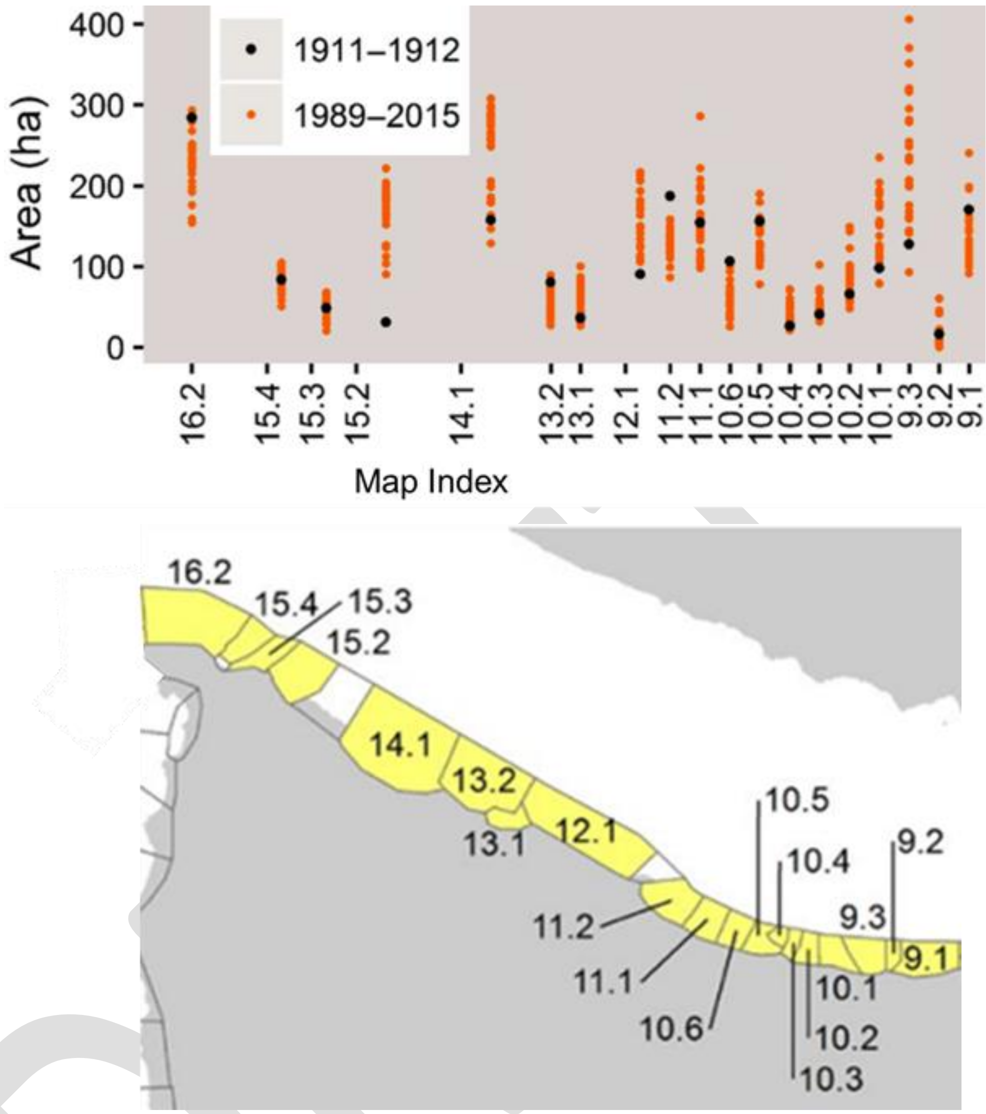
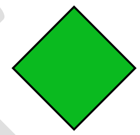
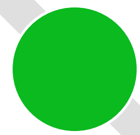
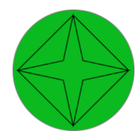


Figure 13. Comparison of Fertilizer Maps and COSTR data, from Pfister, Berry, and Mumford 2018.
Top panel shows historical kelp canopy area (collected in 1911-1912; black dots) and recent kelp canopy area (collected in 1989-2015; orange dots). Bottom panel shows the location of each zone ("map index"; highlighted in yellow) within the Western Strait of Juan de Fuca.

3.4 Determination of sub-basin trend designation

Analysis of the Western Strait subset of the COSTR data set (2017-2021), showed no trend in the last 5 years, so the region is classified as stable in the short-term. During the past 5 years (2017-2021), the number of zones with stable floating kelp canopy area (19 zones) greatly outnumbered the number of zones experiencing increases (3 zones). Analysis of the Western 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 0.6 hectares (1.5 acres) per year. Over the full COSTR dataset (1989-2021), floating kelp canopy area was increasing in seven individual zones, while floating kelp canopy area in the remaining 15 zones was stable. Analysis of the Western Strait subset of the COSTR data set (1989-2015) compared to the Fertilizer Surveys conducted in 1911-1912 suggests that floating kelp canopy area has been approximately stable in this region over the past 100 years. **<u>Therefore, this region is classified as stable.</u>**

Table 2. Determination of sub-basin trend designation

Short-term trend	stable	
Long-term trend	stable	
Overall trend	stable	
Indicator Classification	**stable**	

4. Discussion

4.1 Datasets used in sub-basin assessment

WA DNR aerial data provide a comprehensive survey of floating kelp canopy area for the years surveyed in the sub-basin. This data set provides consistent data between 1989 and 2021, with the exception of 1993 when images were not collected. This data set also includes kelp species identification (*Macrocystis* vs. *Nereocystis*) for all survey years except 1989 (when kelp species were not identified). The consistency of this data set over time gives us a high level of confidence in the status and trends calculated for this region at the scale of aerial photography based surveys.

A century-scale comparative study (Pfister et al., 2018) suggests long-term stability of kelp distribution throughout the Western Strait. This increases our confidence that kelp populations in the Western Strait, while variable between years, have been consistent over the long term.

MRC kayak surveys at Clallam Bay over the last five years suggest a slight decline in kelp bed area in the recent past. This observation warrants continued survey efforts to determine whether the observed change represents uncertainties in the protocol, natural variation or changes in bed extent.

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

Floating kelp canopies along the western 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, a common species in the western Strait. Long-term analysis found that variability in kelp cover in the western Strait 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 western Strait of Juan de Fuca represents near-oceanic conditions along a gradient in environmental conditions and human activities; adjacent to the open ocean, within well-mixed waters, and distant from the urbanized portions of Puget Sound.

In recent years, floating kelp communities in the western 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 western strait in recent years include sea star wasting disease, the 2013-2015 marine heat wave and urchin population increases (discussed below).

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 datasets show substantial drops in the western Straits that corresponded temporally to kelp losses observed in northern California (Rogers-Bennett & Catton, 2019). Unlike northern California, kelp canopy area rebounded quickly in 2015 along the Olympic Peninsula. Floating kelp canopy abundance returned to previous levels in subsequent years along shorelines to the east, 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 western Strait. 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 western Strait, large aggregations of urchins have been observed in various locations, however aggregations were limited to small patches (Frierson et al., 2021; Andrews 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) that spanned the eastern and western Strait sub-basins 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.

1.2 Priorities for future research and monitoring

This assessment of floating kelp resources in the western 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 dataset). 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.
- 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.

5. References

Andrews (2021). Preliminary observations of urchin and kelp abundance along the strait of Juan de Fuca, open coast and Elwha River nearshore. Joint presentation to the Puget Sound Kelp Research and Monitoring Workgroup, May 12, 2021. Available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/kelp-research-and-monitoring-workgroup

Bonaviri C, Graham M, Gianguzza P, Shears NT (2017) Warmer temperatures reduce the influence of an important keystone predator. *Journal of Animal Ecology* 86(3):490-500. https://doi.org/10.1111/1365-2656.12634

Calloway M, Oster D, Mumford Jr. TF, Berry H. (2022) Appendix B, The Knowledge Review. In: the Puget Sound kelp conservation and recovery plan. Olympia, WA: Northwest Straits Commission. Available from: https://nwstraits.org/media/2924/appendix_a_knowledge_review.pdf

Claar DC, Berry H, Christiaen B (2022) Kelp forest responses to the 2014 marine heat wave: Clues about environmental patterns and gradients within the southern Salish Sea. 2022 Salish Sea Ecosystem Conference presentation

Dayton PK (1985) Ecology of kelp communities. *Annual review of ecology and systematics* 16(1):215-245.

Doty DC, Buckley RM, West JE (1995) Identification and protection of nursery habitats for juvenile rockfish in Puget Sound, Washington. *Puget Sound Research '95 Proceedings.* Puget Sound Water Quality Authority, Olympia, WA Pg. 181–190

Essington T, Klinger T, Conway-Cranos T, Buchanan J, James A, Kershner J, Logan I, West J (2018) The biophysical condition of Puget Sound: Biology. *University of Washington Puget Sound Institute*, Tacoma, WA.

Frierson (2021) Preliminary observations of urchin and kelp abundance along the strait of Juan de Fuca, open coast and Elwha River nearshore. Joint presentation to the Puget Sound Kelp Research and Monitoring Workgroup, May 12, 2021. Available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/kelp-research-and-monitoring-workgroup

Hamilton SL, Saccomanno VR, Heady WN, Gehman AL, Lonhart SI, Beas-Luna R, Francis FT, Lee L, Rogers-Bennett L, Salomon AK, Gravem SA (2021) Disease-driven mass mortality event leads to widespread extirpation and variable recovery potential of a marine predator across the eastern Pacific. *Proc. Royal Soc. B.* 288(1957): 20211195. https://doi.org/10.1098/rspb.2021.1195

Johnson SP, Schindler DE (2009) Trophic ecology of Pacific salmon (*Oncorhynchus* spp.) in the ocean: a synthesis of stable isotope research. *Ecological Research*, 24(4):855-863.

Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, Cavanaugh KC, Connell SD, Johnson CR, Konar B, Ling SD, Micheli F (2016) Global patterns of kelp forest change over the past half-century. *Proceedings of the National Academy of Sciences*, 113(48):13785-13790.

Love MS, Carr MH, Haldorson LJ (1991) The ecology of substrate-associated juveniles of the genus *Sebastes*. *Environmental Biology of Fishes* 30(1):225-243.

Pfister CA, Berry HD, Mumford T (2018) The dynamics of kelp forests in the Northeast Pacific Ocean and the relationship with environmental drivers. *Journal of Ecology* 106(4):1520-33. https://doi.org/10.1111/1365-2745.12908

Rogers-Bennet L and Catton CA (2019) Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Scientific Reports* 9(1):1-9. https://doi.org/10.1038/s41598-019-51114-y

Schultz JA, Cloutier RN, Côté IM (2019) Evidence for a trophic cascade on rocky reefs following sea star mass mortality in British Columbia. *PeerJ* 4:e1980. https://doi.org/10.7717/peerj.1980

Shaffer JA, Munsch SH, Cordell JR (2020) Kelp forest zooplankton, forage fishes, and juvenile salmonids of the northeast pacific nearshore. *Marine and Coastal Fisheries* 12(1):4-20.

Sunday JM, Fabricius KE, Kroeker KJ, Anderson KM, Brown NE, Barry JP, Connell SD, Dupont S, Gaylord B, Hall-Spencer JM, Klinger T, Milazzo M, Munday PL, Russell BD, Sanford E, Thiyagarajan V, Vaughan MLH, Widdecombe S, Harley CDG (2016) Ocean acidification can mediate biodiversity shifts by changing biogenic habitat. *Nature Climate Change* 7:81–85. https://doi.org/10.1038/nclimate3161

Watson J, Estes JA (2011) Stability, resilience, and phase shifts in rocky subtidal communities along the west coast of Vancouver Island, Canada. *Ecological Monographs* 81(2):215-239.