Appendix 6: Draft sub-basin report – South Puget Sound

Puget Sound Vital Signs Floating Kelp Canopy Indicator Status and Trends in the South Puget Sound Sub-basin

Last updated: May 27, 2022

Recent trend:	Declining
Entire data record trend:	Declining
Overall trend:	Declining

Executive Summary

Kelp forests play critical ecological and cultural roles 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 South Puget Sound sub-basin, which spans 452 km (281 mi) of shoreline in the southernmost portion of the Salish Sea, south of Point Defiance near Tacoma (Figure 1).

Data Summary:
Annual kayak-based surveys at six sites were monitored by the Washington Department of Natural Resources in recent years (beginning in 2013 at some sites). Long-term trends are summarized between 1873 and 2018 based on a synthesis of 48 individual data sources that noted *Nereocystis luetkeana* presence and comprehensive surveys of floating kelp presence along the shoreline in 2013 and 2017.

Key findings:

- This sub-basin report presents a preliminary assessment. It is intended as a conceptual starting point for review, discussion, and further contributions.
- A single floating kelp species, *Nereocystis* occurs along the shorelines of South Puget Sound. It grows along approximately 25% of the shoreline. The vast majority of beds occur near the Tacoma Narrows, an area with strong currents and intense tidal mixing.
- Over the last 145 years, the linear extent of *Nereocystis* decreased 62% basin-wide between the 1870s and 2017, with extreme losses in two out of three reaches (96% in central and 83% in west). Compared to the maximum cumulative extent of all observations, this constitutes an 80% decrease. In the majority of segments where *Nereocystis* disappeared, the most recent observation was 4 decades ago, or earlier. The innermost floating kelp ever observed is at the southern tip of Squaxin Island, it persists and is monitored annually.
- At six sites monitored annually by kayak, floating kelp has not returned to two sites where losses occurred in 2017 and 2018 (Brisco and Devils Point). At Fox Island, the bed has gradually

declined since monitoring began in 2013 to less than 10 individuals in 2021. At Squaxin, bed area and maximum depth have declined since 2013, but are stable since 2017. Two additional sites near the Tacoma Narrows (Salmon Beach and Day Island) have been stable since sampling began (in 2019 and 2021, respectively).

- Multiple natural and human factors that are known to impact kelp could have contributed to observed patterns. In some areas in recent years, environmental conditions (such as temperature and nutrient concentrations) approached thresholds associated with decreased performance. Long-term data on these parameters is lacking, so it is not known whether they have changed over time.

Indicator Classification:

- The entire data record is classified as *declining*, based on major losses in the linear extent of floating kelp, documented in a synthesis of comprehensive observations between 1873 and 2017.
- The recent time period (2017-2021) is classified as *declining* based on annual kayak monitoring at 4 sites. Floating kelp disappeared at two sites, contracted to scattered plants at one site, and remained stable at one site.
- If strict data inclusion guidelines are adopted for the indicator, a reasonable alternative classification for SPS would be *insufficient data* or *concern* for the recent time period because the annual monitoring data covers a small portion of the floating kelp resource in the sub-basin. Additionally, the entire data record could be classified as *insufficient data* or *concern* due to the diverse data sources and lack of areal data that underlie the long-term assessment.

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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 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

The South Puget Sound (SPS) sub-basin spans 452 km (281 mi) of shoreline at the southern terminus of the Salish Sea (Figure 1). SPS connects to the Pacific Ocean through a network of basins and sills. Tidal currents and estuarine circulation primarily drive water flow and mixing. The most intense currents and regular (daily) mixing occur at the Tacoma Narrows, a narrow 1.5 km channel with a shallow sill (45 m) that connects SPS to the rest of Puget Sound. SPS is relatively protected from wave exposure, ranging from semi-protected to very protected in the regional shoreline classification dataset called the ShoreZone Inventory. SPS has complex shorelines composed of islands, passages and shallow inlets. Due to the area's glacial original, gravel, sand and mixed fine substrates from eroded glacial till and outwash predominate in the intertidal and shallow subtidal zones. Mixed coarse substrates are found along shorelines with strong currents and relatively long fetch. Tideflats of mud and/or sand predominate at the heads of the inlets and other shallow embayments.

SPS is the most distant basin in Puget Sound from oceanic influence and it naturally experiences lower flushing rates and longer water residence times. Bull kelp (*Nereocystis luetkeana*) is the only canopy forming kelp species.

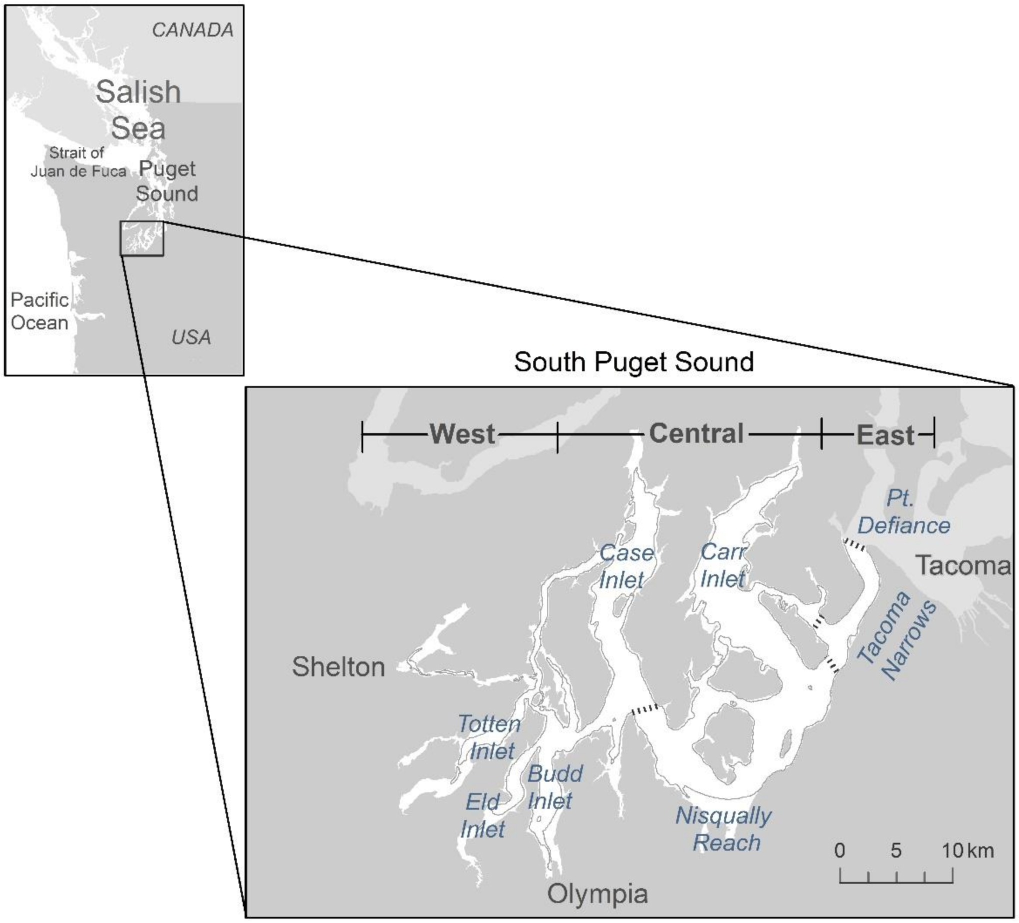


Figure 1. Western Washington State showing the location of South Puget Sound (A) and the South Puget Sound sub-basin (B).
The locations of the three reaches are described generally along the upper portion of the map, and precise boundaries are demarcated on the map with hash marks.

2. Data, methods, and analyses

2.1 Overview

Data collection, summarization, and analysis followed general guidelines described in the floating kelp canopy area guidelines on the project website. Below is a detailed description of how these guidelines were implemented for datasets in the South Puget Sound Sub-basin.

2.2 Datasets analyzed for the indicator

The two main datasets assessed in the SPS were:

1. Kayak-based monitoring at six sites that track annual floating kelp bed area, minimum and maximum bed depth, and other parameters (described in the DNR-kayak Data Description).
2. A historical ecology synthesis of 48 individual data sources that noted the presence of absence of N*ereocystis* over 145 years (Berry et al., 2021). This project summarized presence/absence observations in 1-km shoreline segments by year. The approach of tracking linear presence/absence allowed for integration of datasets sources that depicted the approximate location of *Nereocystis* along the shoreline, rather than precisely delineating the canopy footprint. The linear model used the -6.1 m (MLLW) bathymetric contour line because it represents a generalized maximum depth of *Nereocystis* beds in SPS. The spatial extent of data sources varied from a single location to the entire study area. The format and level of detail also varied widely, including text descriptions, generalized cartographic symbols, detailed delineations of bed perimeter and phycological studies which examined metrics such as density and phenology. In total, the study recorded 3,232 instances of *Nereocystis* presence/absence between 1873 and 2018 at 1-km segments.

2.3 Time period designation

We followed the general guidelines for analysis time periods outline in the floating kelp canopy areas. The following datasets were assessed:

Table 1. Definition of kelp status and trends analysis time periods for the South Puget Sound sub-basin.

Period	Duration
Recent	Annual kayak-based monitoring at 4 sites between 2017 and 2021.
Entire data record	Synthesis of historical records, with the earliest records in 1873. Annual kayak-based monitoring at 4 sites, starting as early as 2013.
Overall	Same as entire data record.

2.4 Analysis

Methods for long-term assessment of change in floating kelp extent throughout the sub-basin are detailed in Berry et al., 2020. Floating kelp distribution and changes over time in presence/absence were summarized over various time periods at the scale of the sub-basin and three reaches (Figure 1). This analysis considered 1-km segments rather than zones (a slightly large spatial unit employed in other sub-basin assessments.)

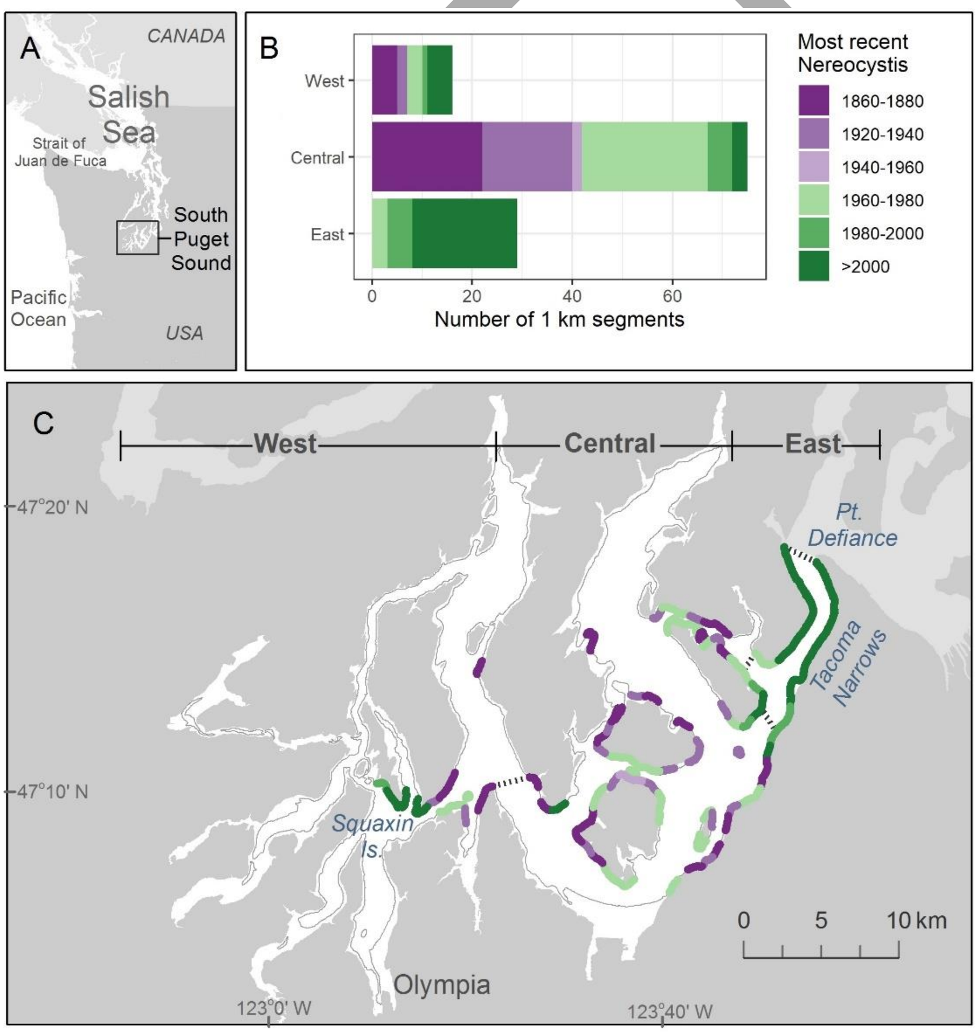
At four long-term monitoring sites, we assessed changes over time by testing for significant trends in annual bed area.

3. Results

3.1 Long-term trends in the linear extent of floating kelp throughout the sub-basin

Based on all available data sources, *Nereocystis* occurred at least once along 26% of the SPS shoreline (120 of 452 1-km shoreline segments) between 1873 and 2018. *Nereocystis* never occurred in the extreme reaches of any inlets (Figure 2).

The data sources provide detail on patterns of persistence at segments and the timing of the most recent occurrence of *Nereocystis*. The East reach contained the greatest proportion of recent occurrences; *Nereocystis* occurred at 72% of the segments since 2000 and at all segments since 1960. In contrast, in the Central and West reaches, at the majority of segments the most recent *Nereocystis*



occurrence was prior to 1980 (89% and 63%, respectively).

Figure 2. Kelp distribution in the South Puget Sound sub-basin

(A). The most recent year in which floating kelp was observed within 1-km shoreline segments, as a total count sub-divided by reach and visualized in bar plots (B), and on a reach map (C). Marine waters in South Puget Sound (SPS) study area are depicted in white, terrestrial areas are shown in gray and marine areas outside the study boundary are shown in light gray. The -6.1 m bathymetric contour line denotes all shorelines where *Nereocystis* was observed to be present between 1873 and 2018, classified to reflect the year of the most recent observation of presence. Years were binned into 20-year increments, with two bins excluded due to lack of data. The general location of the reaches is demarcated at the bottom of the map, with precise boundaries identified by dotted gray lines on the map.

The long-term data record contained six synoptic snapshots of floating kelp distribution in SPS. The six synoptic snapshots showed a marked shift in the spatial distribution of kelp forests among reaches over time (Figure 3). The Central reach had the most shoreline with *Nereocystis* in 1876, 1935, and 1978 (74%, 63% and 48%, respectively) and a third of the total in 1911 (38%). In contrast, the Central basin only contained a tenth of the total extent in the two most recent surveys (12% in 1998 and 8% in 2017). The West reach generally contained a smaller proportion of the total shoreline with *Nereocystis* than the Central reach, 8-19% over the entire time period. Proportional decreases in Central and West corresponded to increases in the East, where the proportion increased from 8-44% during the earliest four surveys to 77-84% in the two most recent surveys.

The 1876 synoptic survey constitutes the oldest known comprehensive temporal baseline, surveyed early in the history of European settlement in the region and SPS. When compared to the most recent synoptic survey in 2017, *Nereocystis* extent decreased by 62% throughout the SPS study area, from 65 to 25 1-km segments. The most extreme losses occurred in the Central reach, where kelp decreased by 96%, followed by the West reach, where *Nereocystis* decreased by 83%. In the Central reach in 2017, *Nereocystis* occurred in only two isolated segments, while in the West reach *Nereocystis* was confined to a single bed that spanned two contiguous segments. In contrast, the linear extent in East reach more than tripled to 21 segments.

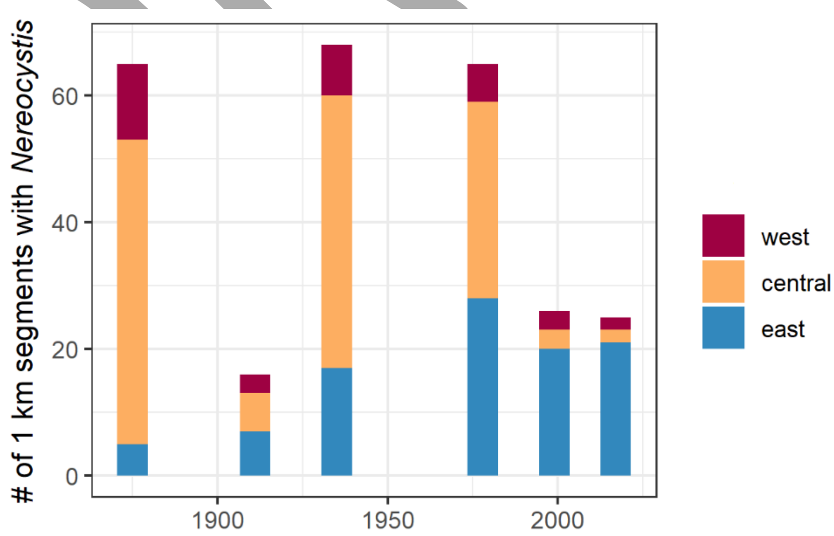


Figure 3. Number of 1-km segments with *Nereocystis* present between 1876 and 2017, based on six comprehensive snapshot surveys, summarized over three reaches.

Recent estimates (1998 and 2017) are dramatically reduced relative to estimates in 1876, 1935 and 1978. The 1911 estimate could represent a low point in kelp extent, but likely reflects methodological differences in survey methods (a harvest study).

The linear extent of floating kelp in SPS contracted further in recent years, as described in section 3.2 Figure 4 describes known floating kelp extent in SPS as of 2021, summarized along 1-km shoreline segments.

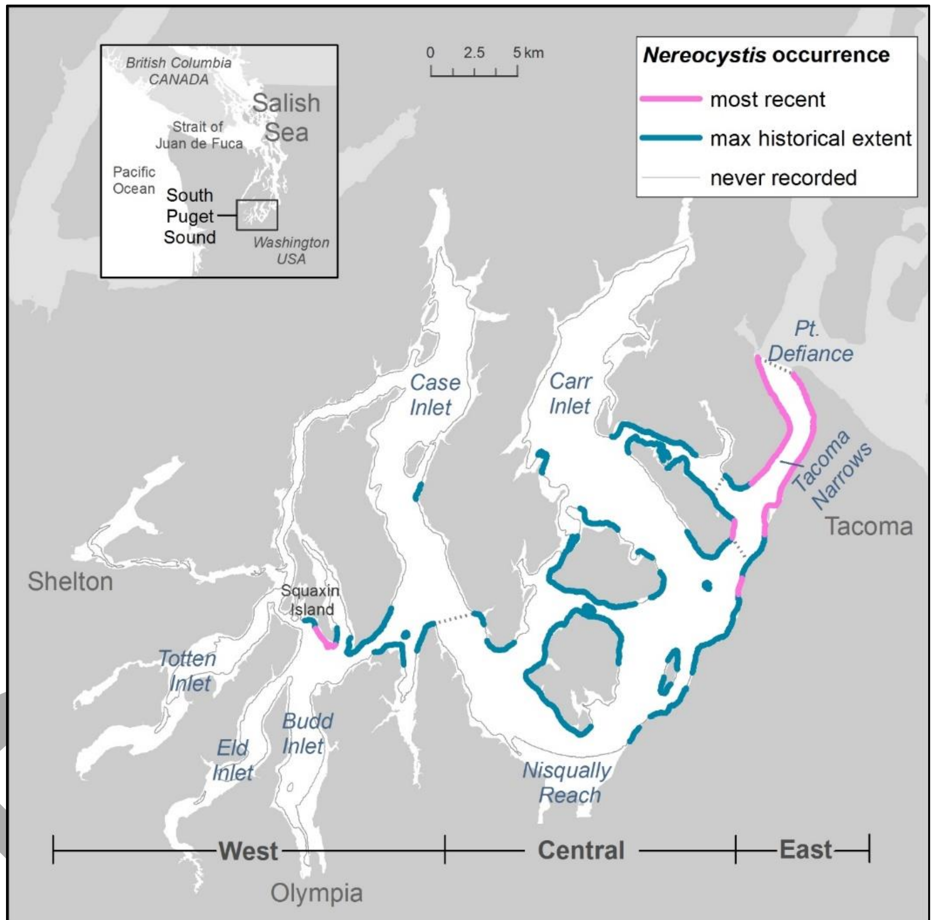
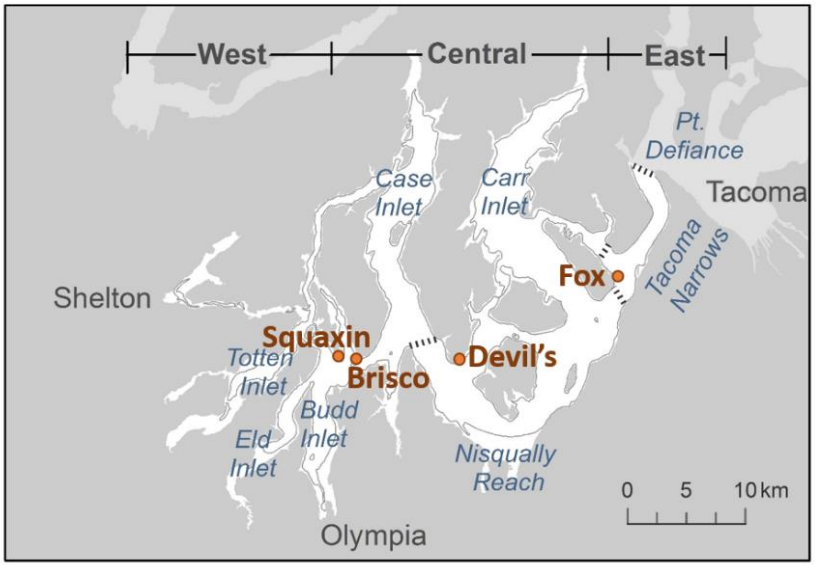


Figure 4. Distribution of floating kelp in 2018 compared to the maximum cumulative recorded extent between 1873 and 2018.
Presence/absence data are summarized in 1-km linear shoreline segments.

3.2 Changes in floating kelp bed area at annual monitoring sites

Four sites in SPS monitored annually by kayak have sufficient data for assessment of recent trends between 2017 and 2021 (Figure 5). At Brisco Point and Devil's Head, floating kelp disappeared (in 2017 and 2018, respectively) and has not yet returned. At Fox Island, floating kelp bed area contracted to a few scattered plants. At Squaxin Island, floating kelp bed area stabilized following losses relative to 2013 and 2014. The monitoring period generally brackets the onset and recovery from the 2013-2017 marine heat wave. At two other sites, Salmon Beach and Day Island, the data record is insufficient for recent trends analysis because surveys began in 2018 and 2020, respectively.



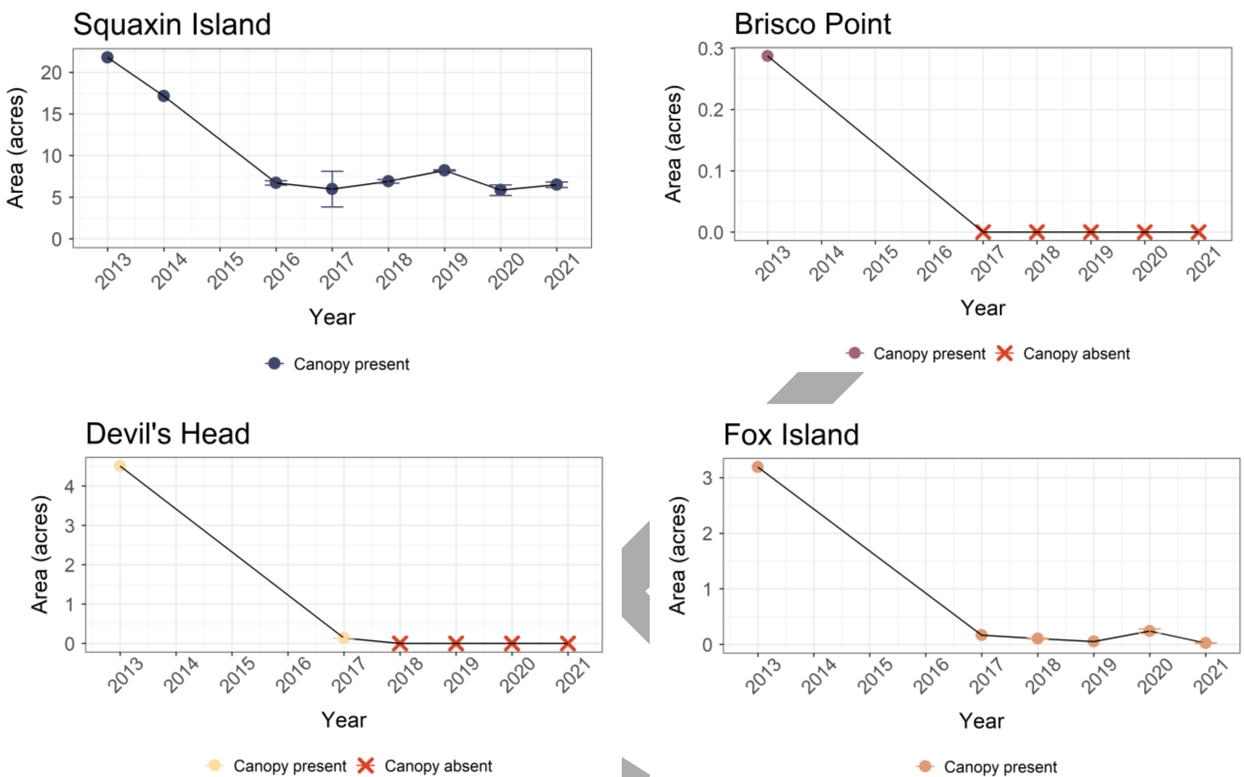


Figure 5. Map of site locations, and bed area at each site with sufficient data records for recent trends assessment (Squaxin Island, Brisco Pt, Devils Head, Fox Island.)

3.3 Determination of sub-basin trend designation

Despite a lack of consistent, long-term monitoring data in South Puget Sound, historical ecology and recent monitoring data demonstrate extensive floating kelp losses. The sub-basin is classified as *declining* over the entire monitoring record because floating kelp disappeared from the majority of shorelines where it was found historically. Floating kelp extent along the shoreline decreased 62% basin-wide between the 1870s and 2017, with extreme losses in the two out of three reaches (96% in Central and 83% in West). In the majority of segments where *Nereocystis* disappeared, the most recent observation was 4 decades ago, or earlier.

The recent time period (2017-2021) is classified as *declining* based on annual kayak monitoring results at four sites. Floating kelp disappeared at two sites, declined to scattered plants at one site, and remained stable at one site.

The overall classification of *declining* is based on the consistent findings of losses over both the entire data record and the recent time period (2017 to 2021).

The data used to assess floating kelp in SPS has limitations. If narrow guidelines are adopted for data inclusion in the indicator assessment, a reasonable alternative classification for SPS for the recent time period would be *concern* because the annual monitoring data covers a small portion of the floating kelp resource in the sub-basin. Additionally, the entire data record could be classified as *insufficient data* or *concern* due to the diverse methodologies that were synthesized and lack of areal estimates. While these procedural considerations are important for consistency in assessments among sub-basins, the datasets clearly lead to an overall assessment of *decline* for the SPS sub-basin.

Table 2: Summary of floating kelp canopy area status and trend category designation for recent, entire data record time spans, and overall assessment

Recent	Decline	
Entire data record	Decline	
Overall	Decline	
Indicator Classification	**Decline**	

Discussion

3.4 Datasets used in sub-basin assessment

The historical synopsis comprehensively assessed of long-terms changes in SPS. While the simplified linear model successfully detected major shifts in abundance and distribution, it would likely only be appropriate in areas of extreme loss.

The spatial extent of recent data is extremely limited. This assessment considered four sites. Future assessments will include two additional sites in the Tacoma Narrows, where floating kelp remains common (added in 2018 and 2020). In order to understand changes in floating kelp more broadly in SPS, it may prove useful to conduct additional comprehensive linear surveys. The most recent comprehensive linear survey was conducted in 2017.

3.5 Potential drivers of observed trends and linkages to ecosystem components

SPS experienced profound floating kelp losses in both extent and distribution over 145 years. The most extreme decreases occurred in the Central and West reaches; the most recent dataset identified only one isolated location with *Nereocystis* remaining in each of these reaches. Many of the observed losses in the West and Central reaches have persisted for four decades or longer, which demonstrates they are not associated with inter-annual variation. In contrast, the East reach appeared stable or increasing.

The observed trend of *Nereocystis* decrease in SPS over 145 years contrasts sharply with findings along the Strait of Juan de Fuca, at the entrance to the Salish Sea. There, kelp forest area generally remained stable over the last century, except along the eastern boundary—the area farthest from oceanic influence and closest to anthropogenic development (Pfister et al. 2018, Western Strait and Eastern Strait sub-basin reports).

Kelp forest losses in SPS have continued in recent years. Contraction or disappearance occurred at all four monitoring sites since 2013. The most recent losses coincide with a major marine heat wave that began in late 2013. The greatest losses of kelp were found in areas with elevated temperature, lower nutrient concentrations, and relatively low current velocities. In recent decades, bull kelp has predominantly grown along shorelines with intense currents and mixing, where temperature and nutrient concentrations did not reach thresholds for impacts to bull kelp performance, and high current speeds likely excluded grazers.

Overall, these findings suggest that kelp beds along shorelines in the Salish Sea that are sheltered from waves and currents are more sensitive to water quality, temperature, pollution and climate change. In contrast, shorelines with strong currents and deep-water mixing, such as the Tacoma Narrows in South Puget Sound, appear to provide a refuge for kelp beds from common natural and human stressors.

Waves and currents can also mediate biotic stressors. In the San Juan Archipelago in northern Puget Sound, mesograzers, especially the small snail *Lacuna vincta,* play an important role in mortality to *Nereocystis* in hydrodynamically quiescent habitats; periods of weak currents allow grazers to crawl up and structurally damage stipes, making them vulnerable to shear under strong, infrequent tidally driven drag force (Duggins et al., 2001). While *Lacuna* snails were not commonly observed in SPS in recent years, kelp crabs (*Pugettia producta*) were abundant on the blades, bulbs and stipes in the *Nereocystis* forests that were not subjected to regular, intense currents. Kelp crabs preferentially consume fresh *Nereocystis* in Puget Sound, and laboratory and field experiments suggest that they may play an important role in mediating the growth and survival of *Nereocystis* in the Salish Sea (Dobkowski, 2017; Dobkowski et al., 2017). Sea urchins can control kelp populations, especially in the absence of predators, however sea urchins were observed to be absent or rare in SPS.

Many other factors that are known to drive kelp abundance likely also played a role in the observed changes in *Nereocystis* distribution in SPS. Human activities—especially logging and coastal development—have increased sediment, nutrient and pollutant loads to coastal ecosystems (summarized in Schiel et al., 2006). These factors are associated with the global 'flattening of kelp forests', through altering competitive interactions with turf algae Filbee-Dexter et al., 2018). In SPS, widespread deforestation began in the mid-1850s, and likely profoundly increased sedimentation. Changes to nearshore biotic interactions, often through fishing/harvest, can alter controls on grazer populations by decreasing predation (Steneck et al., 2002). In SPS, rockfish (Palsson et al., 2009) and other groundfish (Palsson et al., 1998), salmonids (NMFS, 2005) and forage fish (Greene et al., 2015) populations have been dramatically reduced relative to historical levels. These species occupy middle to high trophic positions, directly and indirectly influencing populations of kelp grazers (Davenport et al., 2014). Alterations to disturbance regimes following changes in trophic dynamics can also facilitate competition between *Nereocystis* and other macroalgal species. In the absence of disturbance, perennial algae can exclude annual kelp species such as *Nereocystis*. The invasive perennial alga *Sargassum muticum*, which was observed at many historical and current *Nereocystis* sites in SPS, can competitively exclude native kelp through shading (Britton-Simmons, 2004). Compounding the effects of these diverse stressors, sporophyte mortality may impact basin wide bed connectivity because most spores settle within a few meters of the parent sporophyte (Gaylord et al., 2012).

Given the importance of floating kelp habitats to ecosystem structure, the profound losses in SPS underscore a need to investigate the potential causes of change, possible management responses, and linkages to other species.

3.6 Priorities for future sampling

This assessment of floating kelp resources brings to light a series of research and monitoring priorities that could be undertaken, contingent upon available funding and resources:

- Continue annual assessments at monitoring sites. As resources allow, expand data collection to include drone surveys for detailed descriptions of bed.
- Explore the capability of fixed wing imagery to detect kelp forest canopies in SPS. In previous studies, fixed wing imagery surveys have been challenged by the narrow, low density character of beds in SPS, coupled with intense currents and high tidal amplitude.
- Conduct additional research at sites of observed losses in order to assess multiple stressors and evaluate causes of local decline.
- 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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