

Floating Kelp Monitoring in Washington State: Statewide Summary Report

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Kelp Forest Monitoring Alliance of Washington State

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Kelp Forest Monitoring Alliance of Washington State

The Kelp Forest Monitoring Alliance of Washington State: Mission and Scope

The alliance unites a diverse set of organizations, working together to track floating kelp status and trends across Washington state. The alliance works to advance understanding and conservation through co-production of knowledge and information sharing. The primary product is the statewide floating kelp indicator, which synthesizes multiple monitoring datasets with other ways of knowing. The statewide indicator provides regional monitoring data to the Puget Sound Partnership's Vital Signs program and other research and management efforts. Through collaborations and partnerships, the alliance links floating kelp monitoring to broader ecosystem topics, including species that depend on floating kelp, understory kelp monitoring, stressors, restoration, and management.

ACKNOWLEDGMENTS

This document is part of a collaborative project to develop a floating kelp bed area indicator for the Puget Sound Partnership's Beaches and Marine Vegetation Vital Sign. It represents the first version of an indicator that will allow us to track the condition of kelp forests and communicate findings to the public.

The Nearshore Habitat Program is grateful to the Puget Sound Partnership for providing funding for the development of this indicator, and to the partner organizations and project team members who have invested significant time and resources in the development of this indicator.

DISCLAIMER

The data and interpretations in this report were prepared by the authors based on ongoing research and investigations. They do not necessarily reflect the views or policies of the affiliated organizations.

COVER PHOTO: Adam Obaza, Rockfish in kelp forest on Whidbey Island

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Executive Summary

Like terrestrial forests, kelp forests form extensive living structures that provide an array of valuable ecosystem goods and services. Kelp also has cultural importance to indigenous peoples. Kelp losses are widespread, both globally and in areas of Washington State, motivating the need for quantification of floating kelp status and change over time.

In order to rapidly fill information gaps and chart a long-term course for tracking kelp forests, a diverse alliance of organizations that value kelp has developed a statewide floating kelp indicator for the Puget Sound Partnership Vital Signs and the broader community. The group has formed an ongoing alliance to continue this work: *The Kelp Forest Monitoring Alliance of Washington State (KelpForestsWA)*.

This report presents the first statewide assessment of floating kelp, synthesized from existing monitoring data. Results are based on monitoring of floating kelp bed extent at 171 sampling locations, combined with indigenous scientific knowledge and other information sources.

Monitoring results show stark contrasts in the status of floating kelp in different areas of Washington State (Figure E1). Floating kelp status ranges from stable to substantial documented decline. Within these broad-scale patterns, long-term trends demonstrate localized exceptions to the prevailing pattern. Data availability varies across the state, ranging from having comprehensive long-term monitoring data to insufficient data for assessment.

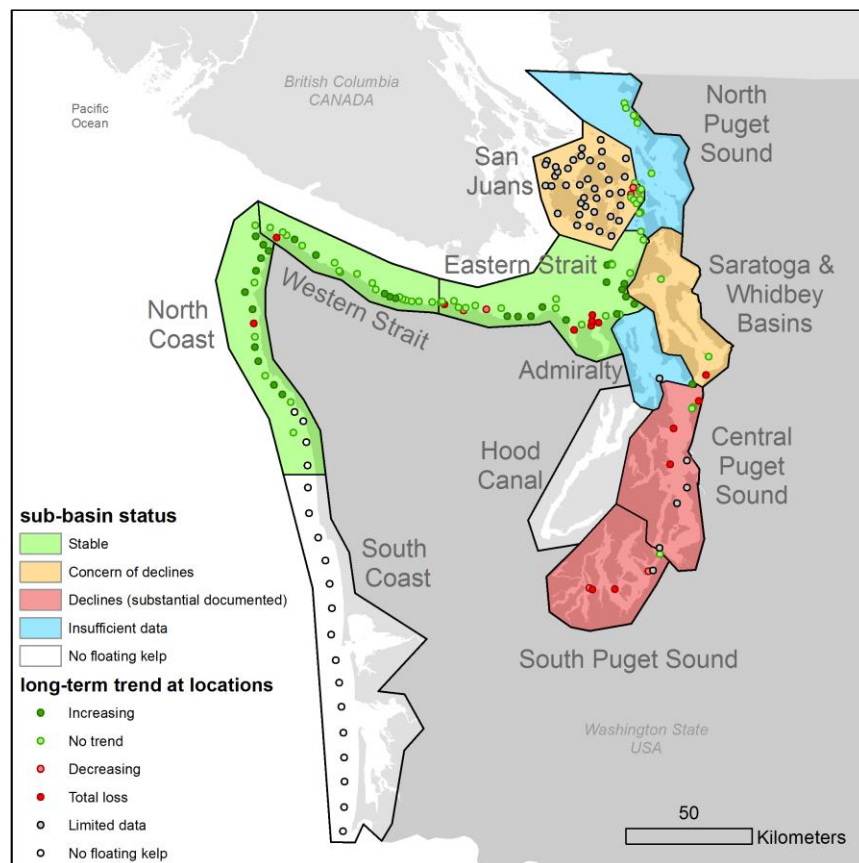


Figure E1. Floating kelp status in sub-basins (shaded polygons) and long-term trends at sampling locations (colored points). Link to [interactive map](#).

Key findings

- This is the first report for this indicator, and it was made possible by a unique collaboration among a diverse group of organizations and individuals, including state agencies, Tribes, community science, and NGOs. The results of this indicator will inform kelp management and restoration across Washington State.
- Data availability is uneven for assessing floating kelp across sub-basins. Within four sub-basins (out of eleven), data limitations preclude definitive assessments.
- Along the northern outer coast and Strait of Juan de Fuca, floating kelp populations are stable in the long-term (with high interannual variability). The majority of locations in these sub-basins show no long-term trend or increases over decades. One exception is the eastern Strait of Juan de Fuca near Protection Island, where substantial losses have been observed along some shorelines.
- Declines have been documented in Central and South Puget Sound, with total loss at a number of sites. Over a century time scale and longer, historical ecology studies indicate that floating kelp has disappeared from approximately 80% of the shorelines where it was observed in the past.
- There is concern that floating kelp has declined in the San Juan Islands, based on indigenous scientific knowledge and other reports. However, data limitations and a short temporal record of quantitative data limit trend certainty.
- Total loss of floating kelp has been observed along some shorelines at the entrance to Possession Sound, which leads to concern about the status of floating kelp in Saratoga and Whidbey sub-basin. However, data gaps prevent sub-basin assessment.
- In Admiralty Inlet and North Puget Sound, spatial and temporal data gaps preclude assessment. Monitoring results at a limited number of locations did not raise major concerns.
- To provide context for science and management, we constructed an order of magnitude estimate of current floating kelp abundance in each sub-basin, based on monitoring data and other inventories. The Western and Eastern Strait of Juan de Fuca each have approximately one-third of the total area of floating kelp beds. The north coast, San Juan Islands, and North Puget Sound contain between 5 and 20%. Admiralty Inlet and Saratoga/Whidbey sub-basins each contain 1-5%. Central and South Puget Sound each contain approximately 1% of the total resource. Floating kelp has not been recorded in Hood Canal or along the southern coast. This constitutes our best order-of-magnitude estimate of current distribution. It does not reflect historical distribution or extent, which we expect was much greater in many areas. We will refine this preliminary estimate over time.
- The integrated sub-basin status assessment can inform scientific and management priorities for sub-basins. Where floating kelp is stable, conservation is a priority. Where substantial declines are documented, stressor abatement and restoration are priorities. In areas with insufficient data, more monitoring is needed.
- Findings from the monitoring program are advancing the state of knowledge for floating kelp in Washington State. In future years, substantial enhancements are needed to fill data gaps. Priorities:
 - Fill gaps in monitoring data through expanding existing programs and incorporating other external datasets.
 - Implement methodological improvements and expand kelp parameters and metrics through upgrading monitoring methods to incorporate new technology.
 - Determine resources available for annual monitoring and identify core annual monitoring areas.

- Enhance geographic assessment area delineation. Complete and refine zone delineations, prioritizing areas with new incoming data. Refine the hierarchical system over time.
- Integrate existing historical datasets to increase the time span of the monitoring record.
- Explore linkages to environmental data. Physical and biological datasets will help to inform interpretation of monitoring results, especially in areas that are declining and increasing.

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Introduction

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 and Schindler, 2009; Essington et al., 2018; Shaffer et al., 2020). In Washington State, two kelp species form extensive buoyant canopies that float on the water surface, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*). Bull kelp is widespread, while giant kelp is restricted to the outer coast and western Strait of Juan de Fuca. 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 Puget Sound Kelp Conservation and Recovery Plan](#) (Calloway et al., 2020).

Kelp has cultural importance to indigenous peoples of the Pacific Northwest. It supports traditional food sources, as well as playing an important role in art, spirituality, and symbolism. The Tribes are the original stewards of the Salish Sea and continue to steward their lands and waters. Evidence from prehistoric artifacts, historical sources, and contemporary practices suggests Pacific Northwest kelp forests have a long prehistory as sustainable social-ecological systems. Thus, the traditional ecological knowledge, subsistence practices, and symbolic culture of the Tribes are essential contributions to kelp conservation in Puget Sound (Naar et al., 2020).

Concern about kelp losses is widespread, both globally and locally (summarized in Calloway et al., 2020). In recent years, studies have shown that dramatic losses predominate in some areas of Washington State, while other areas appear stable. The impacts of declines on the many species that depend on kelp are not understood. In 2020, [The Puget Sound Kelp Conservation and Recovery Plan](#) (Kelp Plan) outlined a research and management framework for coordinated action to improve understanding of trends, while also implementing recovery and protection (Calloway et al. 2020).

This document is a part of the floating kelp monitoring program developed by the Kelp Forest Monitoring Alliance of Washington State (KelpForestsWA). The program produces six data synthesis and communication products which include the Statewide Kelp Summary Report (this document), an [interactive map](#), [Puget Sound Info](#), [Project Website](#), [Monitoring Program Design and Data Assessment Protocols](#), and Dataset Descriptions. These products describe, support, or convey various aspects of the WA floating kelp indicator. Indicator information is tracked on the [Puget Sound Partnership's Vital Signs](#) program, and is used by Kelp Plan implementers and other organizations.

Methods

The indicator assesses long-term trends in the extent of canopy-forming kelp forests at sampling locations by tracking changes in the area of kelp floating on the water surface. The general approach is summarized here (See the [monitoring protocols](#) for details).

The Floating Kelp Bed Area Indicator is distinct from many other Puget Sound Vital Sign Indicators because the project team represents a broad-based alliance of organizations and communities that value kelp. A core consideration throughout the development of the Floating Kelp Bed Area Indicator was to

weave together multiple ways of knowing beyond quantitative scientific datasets. Two principles drive this approach. First, diverse engagement helps to ensure that conservation efforts reflect social values (Uffman-Kirsch et al., 2020). Second, projects with widespread engagement are more likely to result in positive conservation outcomes (LeFlore et al., 2021). Data sources include:

- Samish Indian Nation – classification of aerial imagery and Indigenous Scientific Knowledge.
- Northwest Straits Commission – volunteer kayak surveys conducted by Marine Resource Committees.
- The Washington State Department of Natural Resources (DNR) – classification of aerial imagery and kayak surveys.

To meet the identified needs to assess trends in floating kelp, the monitoring project has been phased to quickly provide basic information to managers and scientists while also defining a framework for incremental enhancement over time.

Methods to delineate floating kelp vary slightly among groups within the monitoring alliance. Survey techniques include small boat surveys and aerial imagery collection and classification. Data collection is restricted to summer months, when floating kelp forests are at their greatest seasonal extent. To maximize kelp detection, surveys are conducted during periods of low tide, slack currents, and calm weather.

The primary statewide metric is floating kelp bed area. The bed is defined as the area encompassing kelp tissues floating on the water surface, including small gaps between adjacent individuals. This metric was selected because it has the most extensive available data, temporally and spatially. The distance threshold for grouping adjacent individuals into beds varies among individual monitoring protocols, ranging from 8 to 20 m. The program also tracks other parameters at a subset of sites, including canopy area (Figure 1).



Figure 1. Example of two floating kelp metrics, illustrated in aerial imagery. The floating kelp bed area metric tracks the perimeter of the forest floating on the surface (the blue polygon), which includes kelp individuals and gaps between them. Another common metric is canopy area (the red features within the polygon in the near infrared imagery), which includes floating individuals but excludes gaps between individuals. In Washington State, bed area data is more spatially and temporally extensive. At many locations, the floating kelp monitoring program tracks canopy area in addition to bed area. All available parameters are considered during trend assessment.

Long-term trends are reported by location, with two types of units: sites are surveyed by kayak (~1 km) and zones are surveyed with aerial imagery (~5-10 km). The size of monitoring locations varies with the extent of shallow subtidal habitat and also with monitoring methods – generally aerial photography captures larger zones (generally 5-10 km of shoreline) while kayaks are deployed at smaller sites (see Table 1 for location definitions).

Long-term trends are assessed at each location (site and zone; see Table 1) using simple linear regression. Regression analysis is performed over the entire data record available for a given location. Because the indicator is based on synthesis of available data, both the length and timing of data records vary among locations. At least 5 years of floating kelp bed area data (either 5 continuous years or a dataset that spans 5 years) is regressed against year (a p-value < 0.05 suggests a significant trend). Regression outputs are reviewed by an expert and over-ruled (i.e., changed) if the data violates statistical assumptions (e.g., linearity) or if the result fails to consider known kelp dynamics at particular locations or time periods (e.g., total loss). Generally, locations with a significant positive trend are assigned ‘increasing’, significant negative trend assigned ‘declining’, and no significant trend assigned ‘no trend’ (see Table 1 for trend categories).

Results at monitored locations are synthesized with other information sources to produce an integrated status assessment within each of 11 sub-basins that comprehensively span Puget Sound and the open coast of Washington State (see Table 1 for definitions). Ideally, status would be evaluated relative to a defined baseline or target. Since neither a baseline nor a target exist for floating kelp, the status

categories weave together information about change over time, condition, and information completeness for each sub-basin.

Floating kelp status determination considers long-term trend data at locations (described above) along with other information sources, including Indigenous Scientific Knowledge, historic shoreline extent of kelp based on nautical charts, expert and citizen science observations, agency reports, peer-reviewed scientific literature, and other grey literature. Dataset synthesis considers the magnitude of change, the signal-to-noise ratio, the time scale of the change, and other uncertainties or assumptions.

Table 1. Key Definitions

Location: the smallest spatial unit for trend assessment of floating kelp bed area with two types:

- Sites - individually identified areas, with a general size of ~1 km of shoreline. Surveyed by kayak.
- Zones - spanning ~5-10 km of shoreline, with boundaries placed at geomorphic features such as headlands. Surveyed using aerial photography. Zones are currently defined within 5 of the 11 sub-basins (the southern and northern coast, western and eastern Strait of Juan de Fuca, the San Juan Islands and DNR Aquatic Reserves).

Location trend categories:

- Increasing – positive (statistically significant) change in area over time
- No trend – no statistically significant change in area over time
- Decreasing – negative (statistically significant) change in area over time
- Total loss – floating kelp was present in the data record but absent in the most recent year
- Limited data – quantitative data are available but are not sufficient to perform regression or assess long-term changes using alternative methods
- No floating kelp – all surveys show absence of floating kelp

Sub-basin: the largest spatial unit for status assessment, based on large-scale oceanographic features that are associated with environmental conditions. Eleven sub-basins are delineated within Washington.

Sub-basin status categories:

- Stable – no long-term change in extent over time
- Concern of decline – data sources suggest losses but quantitative data lack sufficient spatial or temporal detail (low signal-to-noise ratio).
- Decline – data sources demonstrate major losses (high signal-to-noise ratio).
- Insufficient data – data sources do not provide sufficient spatial or temporal certainty to classify the sub-basin.
- No floating kelp – all available data sources show floating kelp has been absent historically and is currently absent.

Indigenous scientific knowledge – Indigenous science is about the knowledge of the environment and knowledge of the ecosystem that Indigenous Peoples have. It is the knowledge of survival since time immemorial and includes multiple systems of knowledge(s) such as the knowledge of plants, the weather, animal behavior and patterns, birds, and water among others. (definition from [Indigenous science – Canada.ca](#)).

Results

Temporal and Spatial Extent of Floating Kelp Monitoring Data

A total of 171 monitoring locations are included in the indicator dataset. The time span of the data record at locations varies widely (Figure 2). The most extensive temporal record exists along the Strait of Juan de Fuca and open coast, with more than 30 years of annual fixed wing aerial monitoring. Most of the locations in other regions have 10 years or fewer of data. After integrating all available data sources, four (out of 11) sub-basins did not have sufficient data to complete a definitive status assessment (Admiralty Inlet, North Puget Sound, The San Juan Islands, and Saratoga/Whidbey Basin). Note that two sub-basins (Hood Canal and Southern Coast) do not have any documented floating kelp.

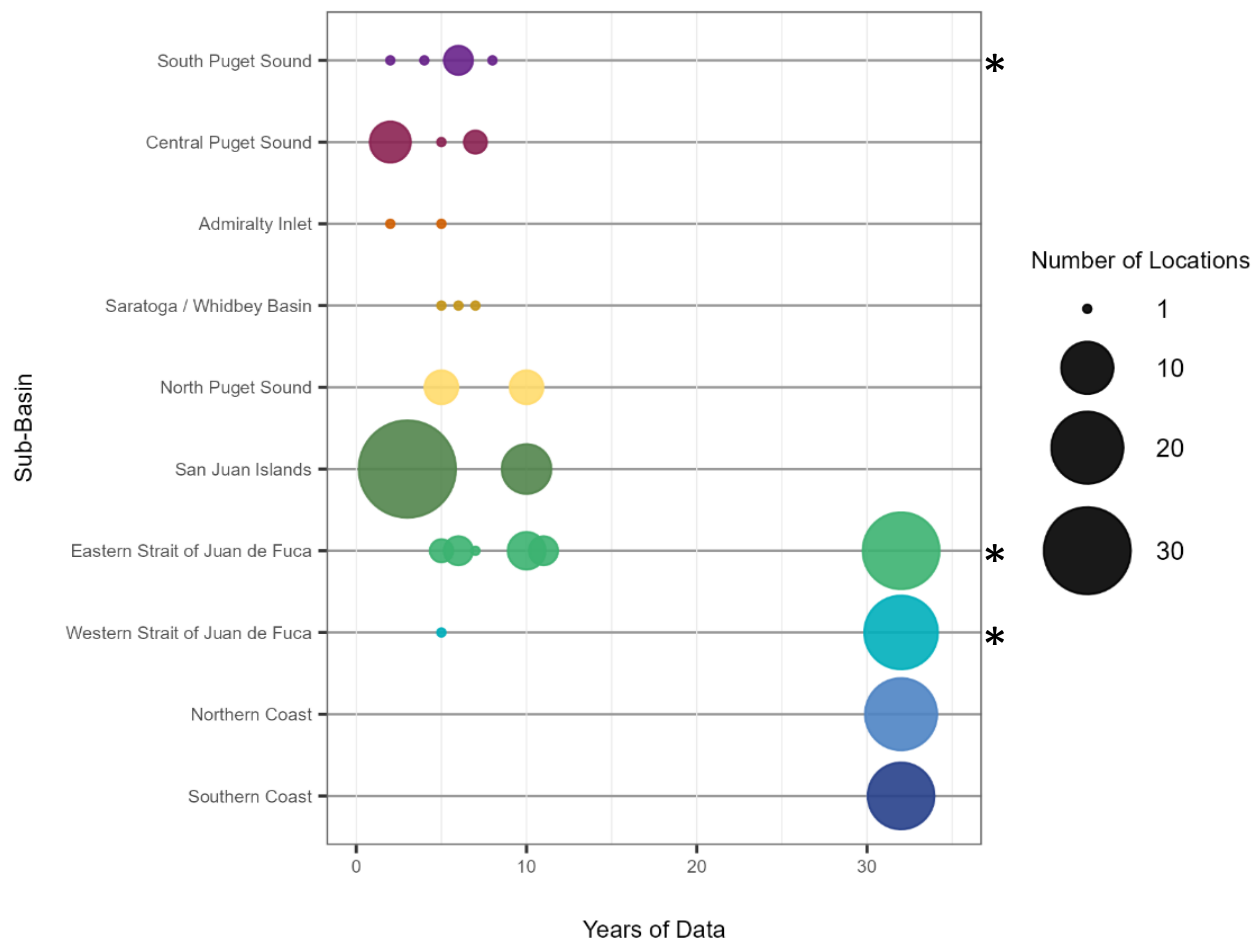


Figure 2. The number of years surveyed and count of monitoring locations (sites or zones) included in the floating kelp indicator. Sub-basins with an asterisk (*) also have historic data comparison studies included in the indicator assessment. Hood Canal is not included, because floating kelp has not been documented in this sub-basin, nor has repeat surveying been conducted.

The spatial extent of monitoring data varies widely by sub-basin (Figure 2 and Table 2). A large proportion of the shoreline within sub-basins along the coast and strait have annual monitoring data. The northern

coast (NCO), southern coast (SCO), Western and Eastern Strait of Juan de Fuca (WST and EST) have 75-100% coverage. The San Juan Islands (SJI) have comprehensive coverage but the time span is limited (generally <3 years) and there are uncertainties due to methodology (inconsistent tide and current conditions; see Dataset Description). In Central Puget Sound (CPS) and South Puget Sound (SPS), monitoring results from a limited number of locations are augmented by extensive long-term studies. In the other sub-basins, a tiny portion of the shoreline has monitoring data. In these areas, assessment was driven by additional data sources (noted in presentation of results).

Table 2. Number of sampling locations and percent of total nearshore habitat (between -15 m and -1 m, MLLW depth) monitored for floating kelp, summarized by sub-basin.

Sub-basin	Number of locations monitored	Percent of nearshore extent monitored	Considerations
Admiralty Inlet (ADM)	2	<1%	Sampling locations span low percentage of sub-basin and limited time period.
Central Puget Sound (CPS)	9	2%	Sampling locations span low percentage of sub-basin and limited time period. Comprehensive studies have identified floating kelp extent and long-term changes
Eastern Strait of Juan de Fuca (EST)	37	80%	More than 30 years of annual data for majority of sub-basin. Historical study provides century-scale comparison.
Hood Canal (HDC)	0	0%	No floating kelp observations known in the sub-basin (south of Lofall).
Northern coast (NCO)	20	100%	More than 30 years of annual data for majority of sub-basin.
North Puget Sound (NPS)	8	3%	Sampling locations span extremely low percentage of sub-basin and extremely limited time period.
Southern coast (SCO)	17	75%	No floating kelp observed along the southern portion of open coast. Data absent in embayments, but generally not potential floating kelp habitat.
San Juan Islands (SJI)	47	100%	Comprehensive monitoring using aerial photography. However, limited time span in most areas (<3 years). Strong currents and narrow beds challenge aerial photography methods.
South Puget Sound (SPS)	6	<1 %	Sampling locations span low percentage of sub-basin and limited time period. Comprehensive studies have identified floating kelp extent and long-term changes.
Saratoga / Whidbey Basin (SWH)	3	2%	Sampling locations span extremely low percentage of sub-basin and extremely limited time period.
Western Strait of Juan de Fuca (WST)	22	100%	More than 30 years of annual data for majority of sub-basin. Historical study provides century-scale comparison.

Abundance and distribution of floating kelp in Washington State

Information on broad patterns in floating kelp abundance and distribution could inform science and management actions. However, efforts to estimate abundance are limited by major data gaps, as well as large natural year-to-year variability in floating kelp. (For example, the maximum extent of beds is 3.6 times the minimum extent in areas where multi-decadal monitoring data are available).

To provide context for science and management, we constructed an order of magnitude estimate of current floating kelp abundance in each sub-basin, based on monitoring data and other inventories (Figure 3). The Western and Eastern Strait of Juan de Fuca each have approximately one-third of the total area of floating kelp beds. The north coast, San Juan Islands, and North Puget Sound contain between 5 and 20%. Admiralty Inlet and Saratoga/Whidbey sub-basins each contain 1-5%. Central and South Puget Sound each contain approximately 1% of the total resource. Floating kelp has not been recorded in Hood Canal or along the southern coast. This constitutes our best order-of-magnitude estimate of current distribution. It does not reflect historical distribution or extent, which we expect was greater in many areas. We will refine this preliminary estimate over time as additional data are gathered and synthesized.

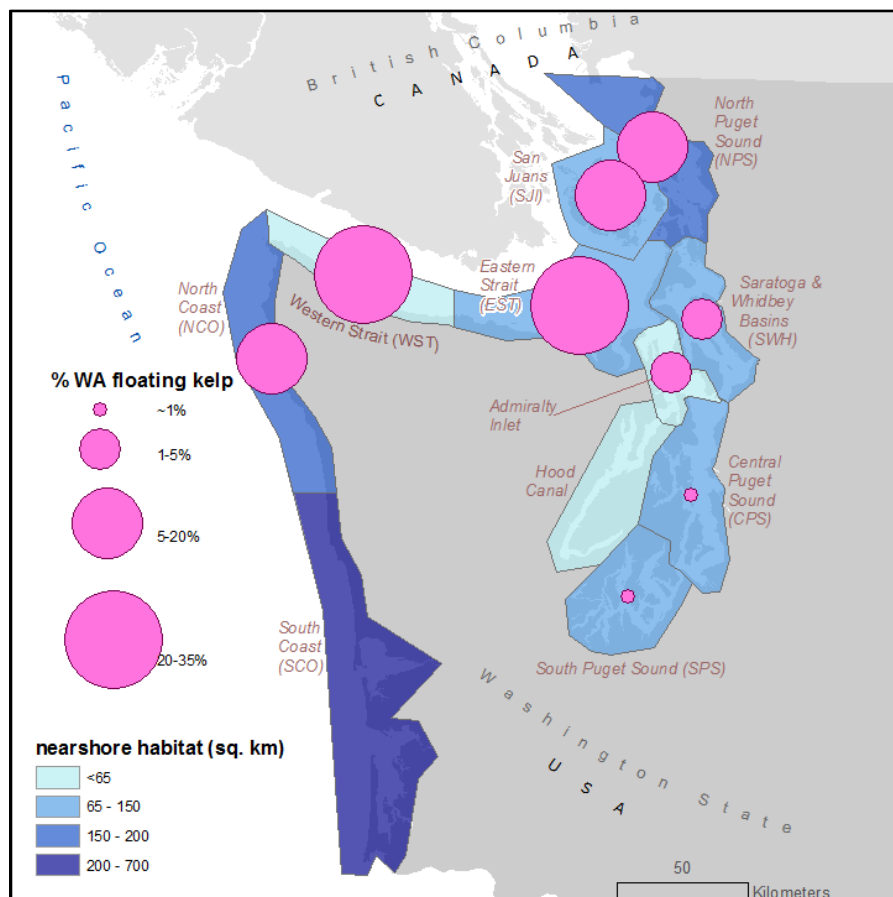


Figure 3. The area of nearshore habitat (between -15 m and -1 m depth relative to Mean Lower Low Water) and percent of total statewide floating kelp bed area by sub-basin. Nearshore habitat area was estimated using diverse bathymetry sources. The floating kelp area estimates represent order of magnitude extrapolations based on existing survey data and expert knowledge.

Floating kelp beds are generally more extensive closer to the open ocean in areas of high current and rocky substrate. Floating kelp distribution does not track closely with the total amount of nearshore habitat (the area between -15 m and -1 m depth, relative to Mean Lower Low Water). Many sub-basins have substantial areas that do not support floating kelp, such as sand flats, which lack hard substrate for floating kelp holdfast attachment.

Trends at Sampling Locations and Integrated Sub-basin Status

We assessed long-term trends at 171 sampling locations (Figure 4). Approximately half of the locations were categorized as no trend or increasing, while the remainder were classified as decreasing, total loss, limited data or no floating kelp. It is important to note that this statewide frequency count is skewed due to variability in the temporal extent of individual datasets (Figure 2), uneven distribution of sampling locations (Table 2), and greater abundance of data in three sub-basins - the north coast, and the Western and Eastern Strait of Juan de Fuca (Figure 1). To account for differences among datasets, the data interpretation synthesizes results at the sub-basin scale and balances trend results at locations along with data completeness and other information sources.

Trends in floating kelp extent at locations, integrated with other information sources, produce a starkly contrasting assessment of floating kelp status in different sub-basins of Washington State (Figure 5). Generally, sub-basins near oceanic influences show stability (i.e., the north coast and Strait of Juan de Fuca), while substantial documented declines have been detected in the innermost sub-basins (i.e., Central Puget Sound and South Puget Sound). In other areas, data limitations preclude definitive classification. In sub-basins with limited data, two are identified as areas of concern for decline (i.e., San Juan Islands and Saratoga/Whidbey), while two are identified as having insufficient data without major flags for concern (i.e., North Puget Sound and Admiralty Inlet). Within each sub-basin, long-term trends at specific locations are diverse, demonstrating some local exceptions to the prevailing pattern.

Appendix A contains individual summaries for each sub-basin. Key findings:

- Data availability is uneven for assessing floating kelp across sub-basins. Within four sub-basins (of eleven), definitive assessments were precluded by data limitations.
- Along the northern outer coast and Strait of Juan de Fuca, the majority of locations show no long-term trend or increasing trends over decades. As a result, the north coast (NCO), Western Strait of Juan de Fuca (WST) and Eastern Strait of Juan de Fuca (EST) are considered stable. Some locations showed statistically significant increasing trends. It is important to note that conditions during the early years strongly influence statistical trend test results.
- In contrast to overall stable conditions in the Eastern Strait of Juan de Fuca (EST), major losses occurred in the eastern portion along Miller Peninsula, Protection Island, and Cape George.
- Central and South Puget Sound have experienced substantial documented declines. Monitoring data from a small number of locations included evidence of declines and total losses. These spatially and temporally limited datasets were augmented with historical ecology studies over a century time scale and longer. The historical studies indicate that floating kelp has disappeared from approximately 80% of the shorelines (measured as cumulative maximum extent).

- There is substantial concern that floating kelp has declined in the San Juan Islands, based on indigenous scientific knowledge and other reports. However, data limitations preclude definitive assessment.
- Total loss of floating kelp occurred along some shorelines at the entrance to Possession Sound, which leads to concern about the state of floating kelp in Saratoga and Whidbey sub-basin. However, data limitations preclude definitive assessment.
- In Admiralty Inlet and North Puget Sound, spatial and temporal data limitations preclude assessment. Monitoring results at a limited number of locations did not raise major concerns.

The integrated sub-basin status assessment broadly identifies scientific and management priorities at the sub-basins scale. Where floating kelp is stable, conservation is a priority. Where substantial declines occurred, stressor abatement and restoration are priorities. Areas with insufficient data need increased monitoring.

Table 3. Summary of sub-basin status and kelp distribution

Sub-basin status	Number of sub-basins	Sub-basins	Total nearshore extent (ha (%))	Total linear extent (km at -6.1m isobath)	Range of statewide floating kelp bed area within each status category (mid-point)
Stable	3	Western Strait, Eastern Strait, North Coast	36,496 (20%)	513 (15%)	45-90% (67.5%)
Concern	2	San Juan Islands, Saratoga/Whidbey	21,090 (12%)	839 (24%)	6-25% (15.5%)
Decline	2	Central Puget Sound, South Puget Sound	21,818 (12%)	877 (25%)	2%
Insufficient Data	2	North Puget Sound, Admiralty Inlet	26,055 (15%)	565 (16%)	6-25% (15.5%)
No Floating Kelp	2	Hood Canal, South Coast	73,494 (41%)	737 (21%)	0

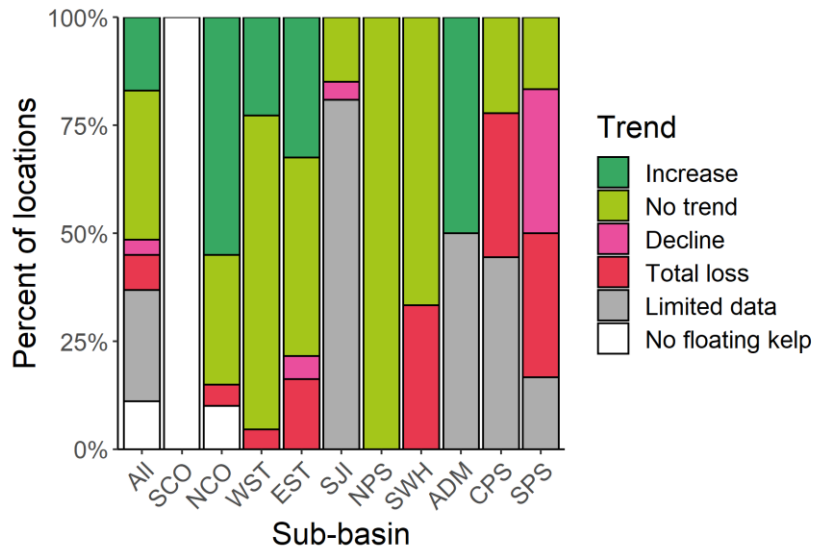
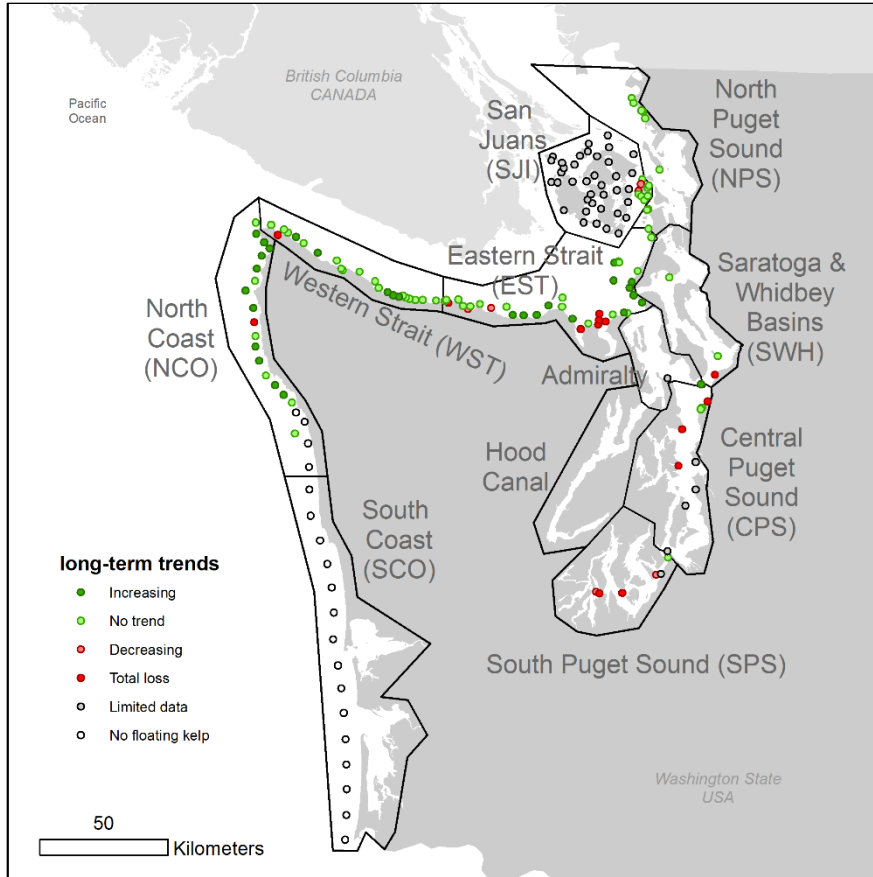


Figure 4. Long-term trends in floating kelp forest bed area at locations, visualized on a) map and b) bar chart, as proportion of all locations and within sub-basins. In NCO, WST, EST, and SJI, monitoring covers the majority of areas. In CPS and SPS, the kelp population is well represented, although the number of monitoring locations is low. In ADM, SWH, and NPS, the number of monitoring locations is low and should not be considered representative. HDC is excluded from the bar chart because there are no monitoring sites in this sub-basin.

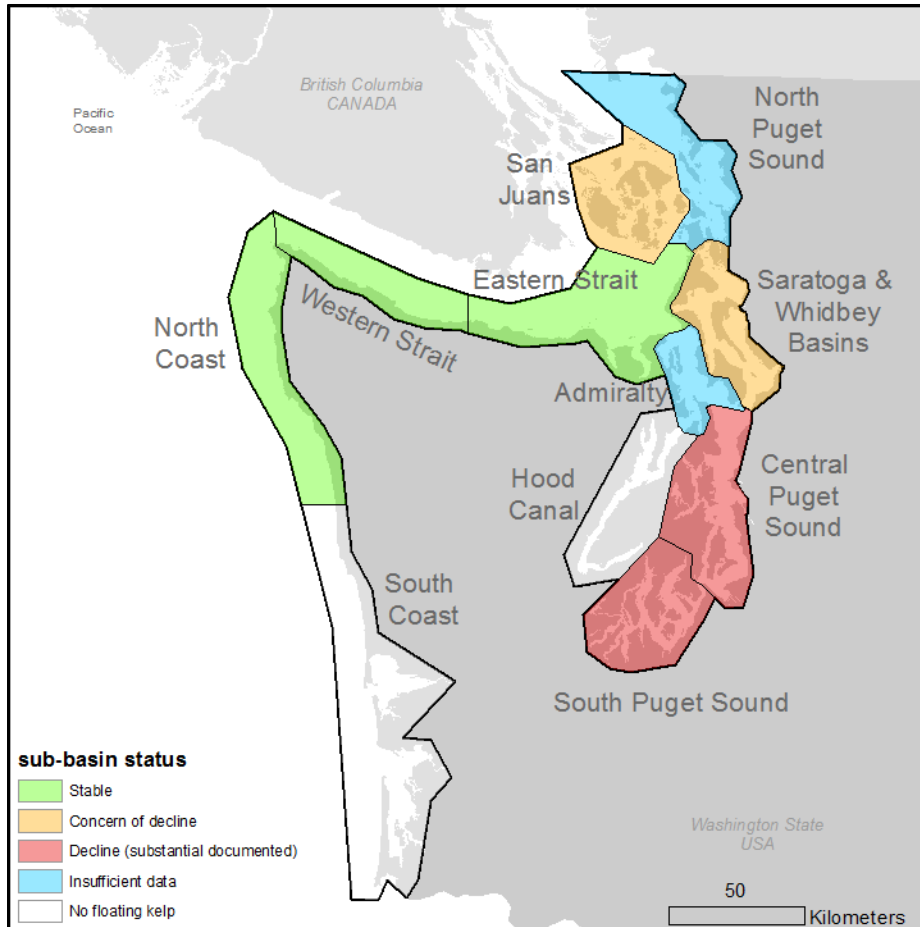


Figure 5. Status of floating kelp in sub-basins throughout Washington State

Three sub-basins are classified as “Stable”, two as “Concern”, two as “Decline”, two as “Insufficient Data”, and two as “No Floating Kelp” (Table 2). Relative proportions of floating kelp within each status category vary based on which metric is being used (i.e., total nearshore extent, total linear extent, or proportion of statewide floating kelp within each category). Approximately two-thirds of statewide floating kelp bed area in WA is stable (Table 3, “Stable”), approximately one-third has data gaps limiting definitive assessment (Table 3, “Concern” and “Insufficient Data”), approximately one-fifth of floating kelp is either concern or documented decline (Table 3, “Concern”, “Decline”). However, when total linear extent is considered, only 15% of linear extent is classified as “Stable”, while nearly half of linear extent is classified as “Concern” or “Decline”. This comparison between metrics is important, because while statewide floating kelp bed area is reassuring (i.e., 67% is “Stable”), total linear extent is much worse (i.e., 15% is “Stable”, while 49% is “Concern” or “Decline”). While it is encouraging that the areas with the largest floating kelp populations are currently stable, loss of floating kelp across large swaths of coastline (e.g., South and Central Puget Sound) likely threaten migration corridors of associated species, floating kelp population connectivity, and resilience of nearshore ecosystems. Furthermore, these estimates do not account for floating kelp losses that occurred before consistent nearshore monitoring began, which could alter estimates of loss and historical floating kelp distribution.

Discussion

Multiple natural and human factors that impact kelp could be contributing to observed patterns. Floating kelps experience a natural high degree of variability in abundance on inter-annual and decadal scales. This variability is often linked to fluctuations in water temperature via large-scale climate oscillations (Pfister et al., 2018). Other stressors include water turbidity, sedimentation, algal epiphytes, water column nutrients, and grazers (Hollarsmith et al., 2022). Sea urchins are known for their ability to completely denude kelp beds in other regions; however, this phenomenon has not been observed in Washington State. Other grazers, such as kelp crabs (*Pugettia producta*) and *Lacuna* spp. snails may exert stronger grazing pressure, especially in areas with moderate waves and currents. Sea star wasting disease (SSWD) may have decreased natural predation levels on some grazers (Schultz et al., 2016; Menge et al., 2016; Rogers-Bennett and Catton 2019; Eisaguirre et al., 2020).

A general pattern has been observed in Washington State; concern about floating kelp losses increases with distance from the coast into Puget Sound. Along this gradient, both natural and human stressors increase.

Increasing water temperatures and climate change are major emerging concerns. In many regions within the northeast Pacific, including Washington State, floating kelp populations dropped around 2014 during a marine heat wave. Floating kelp recovery in Washington State was spatially complex. Along the outer coast and Strait of Juan de Fuca, total floating kelp extent rebounded in 2015. In contrast, recovery was delayed until 2017 at Cherry Point in North Puget Sound. At some sites in inner basins, total losses were observed and beds have not recovered (such a Mukilteo in Saratoga Passage and Devil's Head in South Puget Sound).

In some areas of Puget Sound in recent years, elevated water temperatures and low nutrient concentrations approached thresholds associated with decreased physiological performance and reproductive success in kelps (Hurd et al. 2014, Muth et al. 2019, Berry et al. 2021, Khangaonkar et al. 2021). The global ocean is warming due to the thermal impacts of greenhouse gases (IPCC 2022), and some coastal regions, including the Salish Sea, are warming more rapidly (Riche et al. 2014, Khangaonkar et al. 2019). However, long-term data on these parameters is lacking, so spatial and temporal patterns in temperature and nutrient concentrations are not well understood.

This is only the first iteration of the statewide assessment of floating kelp, produced with existing data in order to address pressing needs for greater understanding of status and trends. We believe that the assessment reliably identifies broad patterns in floating kelp abundance and distribution. It also creates a model for integrating diverse information sources in a holistic approach to synthesizing floating kelp data. Future monitoring will be devoted to further developing our understanding and linking findings to research, restoration, and conservation actions.

The Project Team identified priorities for enhancement of the monitoring program (discussed in the [monitoring program design report](#)). Future enhancements will require additional funding; highlights include:

1. Fill gaps in ongoing monitoring through expanding existing programs and incorporating other external datasets, especially in sub-basins identified to have limited data in the status assessment.
2. Implement methodological improvements and expand kelp parameters and metrics through upgrading monitoring methods to incorporate new technology. Also, describe a greater range of kelp parameters and metrics. Proposed expansions could be tested first at a subset of sites.
3. Determine resources available for annual monitoring and identify core annual monitoring areas. If comprehensive annual monitoring is not feasible, the study area will need to be sub-divided into core areas surveyed annually and other areas surveyed less frequently, as is done by the [DNR Submerged Vegetation Monitoring Program](#) (Christiaen et al. 2022, Dowty et al. 2022).
4. Integrate existing historical datasets to increase the time span of the monitoring record. Expanding the temporal baseline will increase understanding of changes over time. The sub-basin status assessment identifies major data gaps.
5. Enhance geographic assessment area delineation. Complete and refine zone delineations, prioritizing areas with new incoming data. Refine the hierarchical system over time.
6. Explore linkages to environmental data. Physical and biological datasets will help to inform interpretation of monitoring results (i.e., declines or increases of floating kelp area). Consider testing synthesis of existing data and new data collection at a subset of sites.

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Appendix A

Appendix A. Sub-basin summaries (sorted alphabetically)

Sub-basin: Admiralty Inlet (ADM)

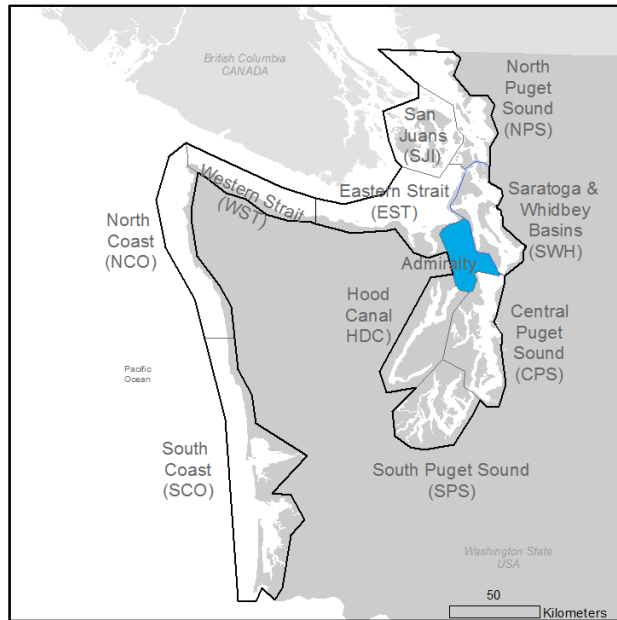
[Statewide report](#)

[Interactive map](#)

[Web site](#)



Sub-basin assessment: insufficient data



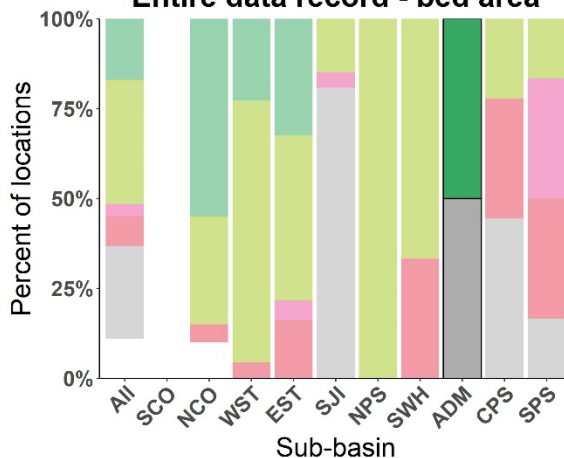
Key Findings:

- **Floating kelp is common along portions of the Admiralty Inlet.** While the sub-basin is relatively small, it has extensive floating kelp resources in areas where appropriate habitat conditions exist, such as rocky substrates. One species occurs here, bull kelp (*Nereocystis luetkeana*).
- **There is insufficient data to assess floating kelp in this sub-basin.** Only two locations are currently monitored, comprising less than 1% of the nearshore habitat in the sub-basin. The sites are monitored by the Island County Marine Resource Committee (MRC) and the Washington Department of Natural Resources Nearshore Habitat Program.
- **In this sub-basin, increased monitoring is a high priority.** A better understanding of status and trends could inform future research and management.

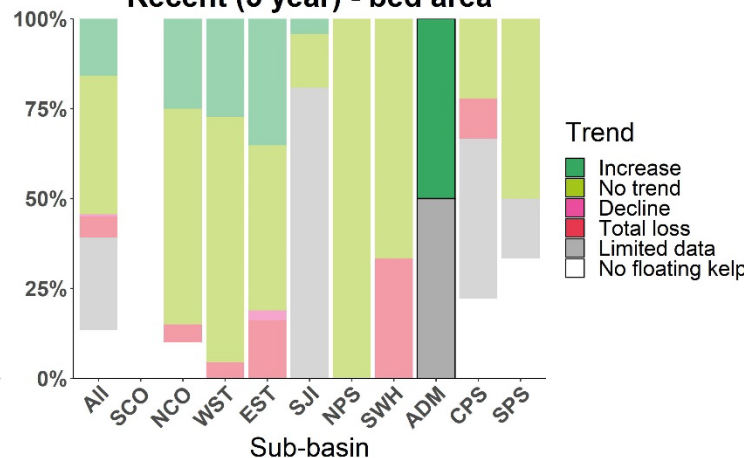
Sub-basin details

number of locations monitored	2	
count of long-term trends at locations	increasing	1
	no trend	0
	decreasing	0
	total loss	0
	limited data	1
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	6,534	
% of nearshore habitat monitored in sub-basin	< 1%	
% of WA floating kelp beds in sub-basin	1-5%	

Entire data record - bed area



Recent (5 year) - bed area



Trend

- Increase
- No trend
- Decline
- Total loss
- Limited data
- No floating kelp

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Central Puget Sound (CPS)

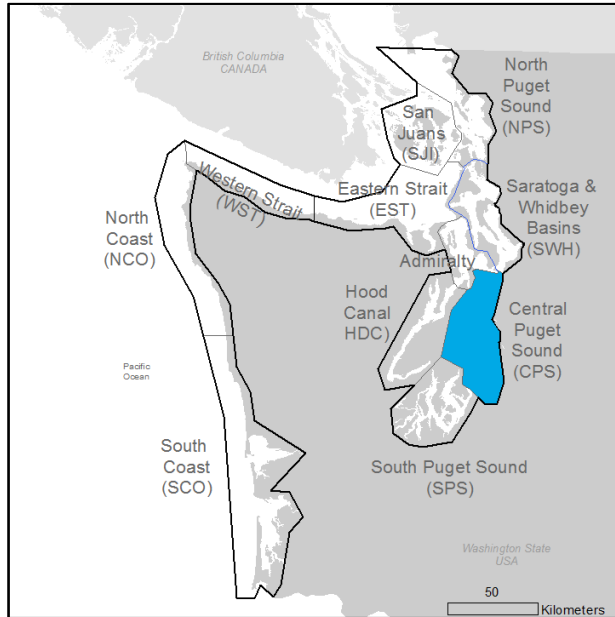
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[Interactive map](#)

[Web site](#)



Sub-basin assessment: **substantial documented declines**



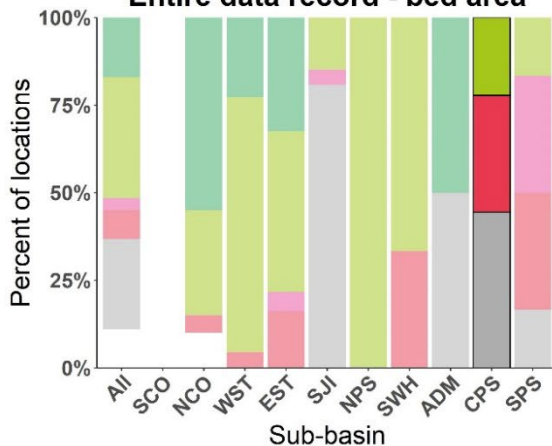
Key Findings:

- **Floating kelp is uncommon along the shorelines of Central Puget Sound.** One species of floating kelp occurs here, bull kelp (*Nereocystis luetkeana*).
- **Central Puget Sound is identified as sub-basin of concern due to substantial documented declines.** A historical ecology study spanning 145 years found that bull kelp has disappeared from approximately 80% of the shorelines of Central Puget Sound (compared to the maximum cumulative extent of all observations).
- **The pattern of bull kelp loss vs persistence is complex.** Bainbridge Island and other areas stand out for extensive losses while beds persist in Elliott Bay, along the shoreline between Seattle and Edmonds, Lincoln Park, Vashon Island, Blake Island, and near Tacoma Narrows.
- **Eight locations are monitored annually for floating kelp.** At two locations, there is no trend and at two locations there has been a total loss. The remaining 4 locations have not been monitored long enough to reliably assess trends.
- **Priorities in this sub-basin include addressing stressors and restoration, as well as conserving existing beds.**

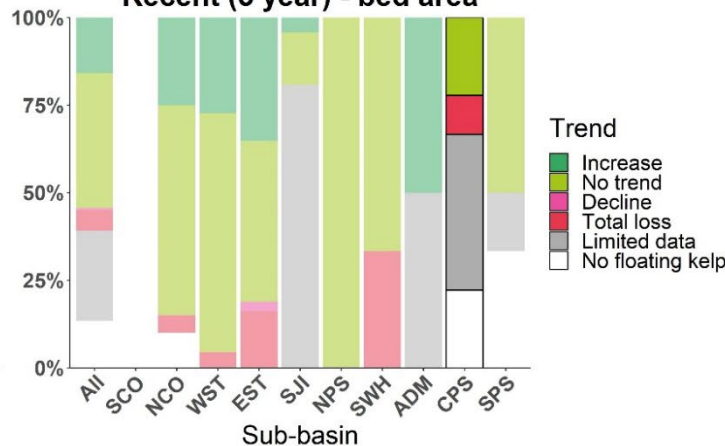
Sub-basin details

number of locations monitored	9	
count of long-term trends at locations	increasing	0
	no trend	2
	decreasing	0
	total loss	3
	limited data	4
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	9,599	
% of nearshore habitat monitored in sub-basin	2%	
% of WA floating kelp beds in sub-basin	<1%	

Entire data record - bed area



Recent (5 year) - bed area



Trend

- Increase
- No trend
- Decline
- Total loss
- Limited data
- No floating kelp

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Eastern Strait (EST)

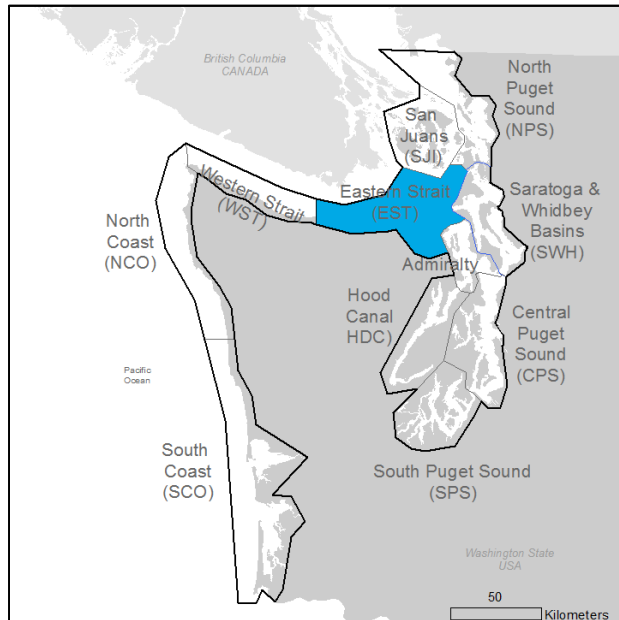
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Sub-basin assessment: **stable**

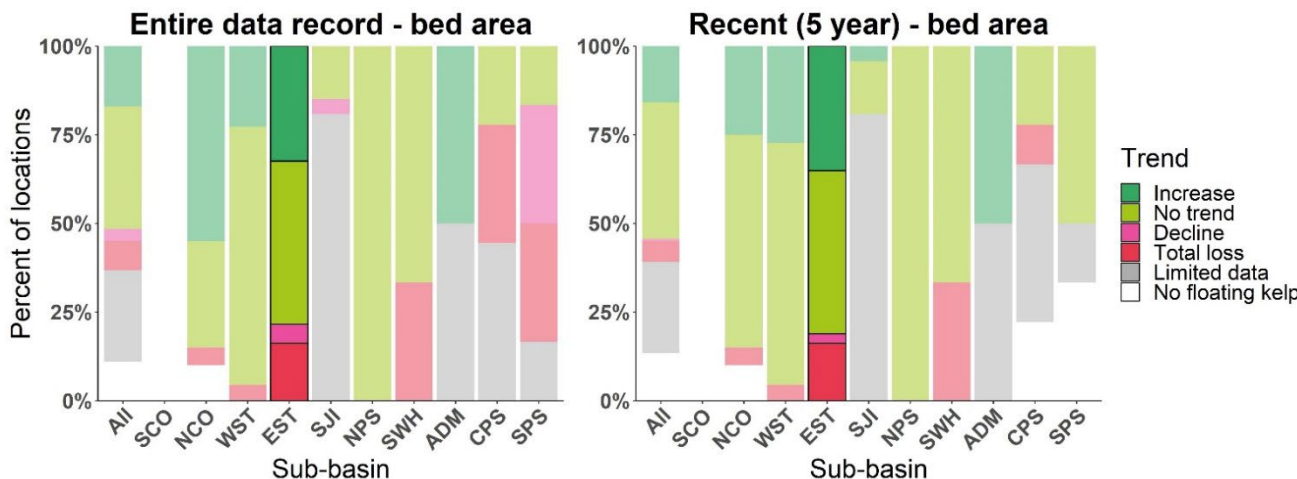


Key Findings:

- **Floating kelp is abundant along the eastern Strait of Juan de Fuca.** Bull kelp (*Nereocystis luetkeana*) predominates, while giant kelp (*Macrocystis pyrifera*) is limited to small beds in the western portion of the sub-basin.
- **Monitoring data in this region is spatially and temporally extensive.** The majority of nearshore areas (~78%) have monitoring data. The longest data record is three decades of annual aerial photography between Port Townsend and Crescent Bay. Shorter datasets exist for other areas.
- **Considering all available data, the sub-basin is classified as stable** because the number of locations with *increasing* and *no trend* classifications greatly outnumber decreases.
- **In stark contrast to overall stability within the sub-basin, persistent losses have been detected** along the shorelines of the Miller Peninsula, Protection Island, and Cape George.
- **Research and restoration are priorities where persistent losses have occurred.**

Sub-basin details

number of locations monitored	37	
count of long-term trends at locations	increasing	12
	no trend	17
	decreasing	2
	total loss	6
	limited data	0
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	14,098	
% of nearshore habitat monitored in sub-basin	80%	
% of WA floating kelp beds in sub-basin	20-40%	



The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Hood Canal (HDC)

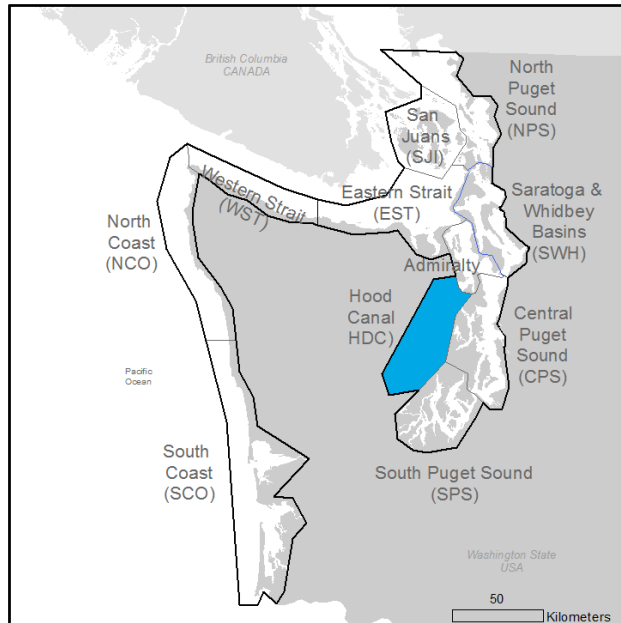
[Statewide report](#)

[Interactive map](#)

[Web site](#)

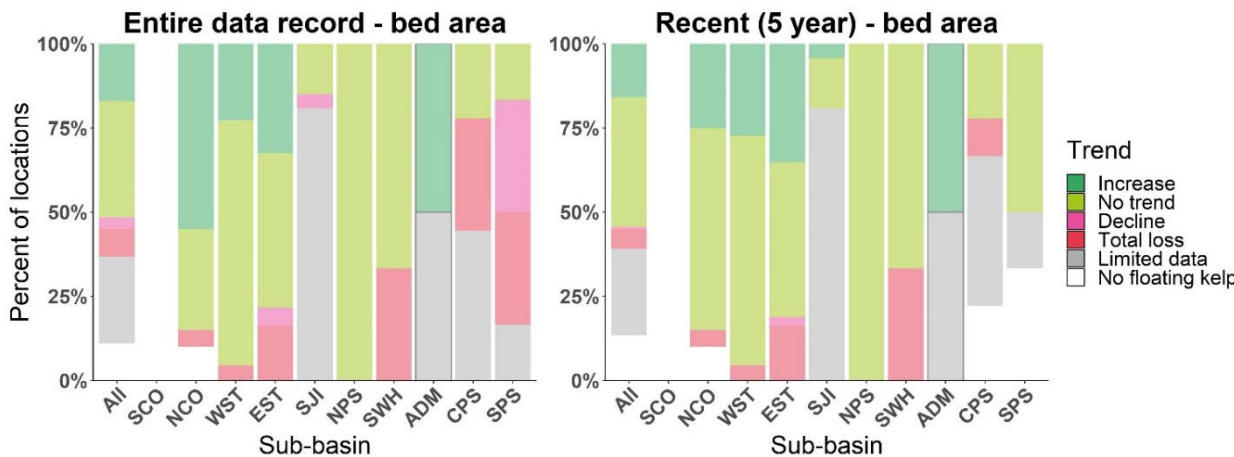


Sub-basin assessment: no floating kelp



Key Findings:

- **No observations of floating kelp are known in Hood Canal south of Lofall.** This sub-basin is understood to have limited floating kelp habitat, due to abundant sandy substrate and naturally elevated water temperatures.
- **The first priority for this sub-basin is to confirm presence/absence of floating kelp** through small boat surveys during early summer (periods of low tide and slack currents).



Sub-basin details

number of locations monitored	0	
count of long-term trends at locations	increasing	0
	no trend	0
	decreasing	0
	total loss	0
	limited data	0
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	3,695	
% of nearshore habitat monitored in sub-basin	0%	
% of WA floating kelp beds in sub-basin	0%	

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). Hood Canal is not included because there are no sampling locations in the sub-basin.

Sub-basin: Northern Coast (NCO)

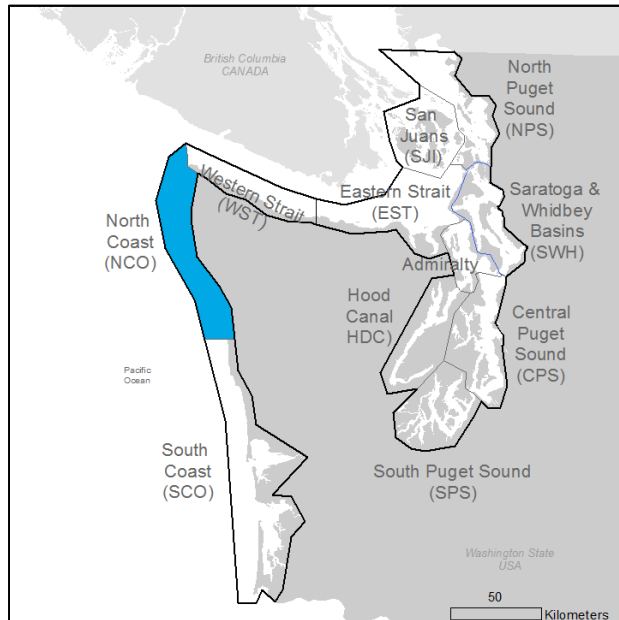
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Sub-basin assessment: **stable**



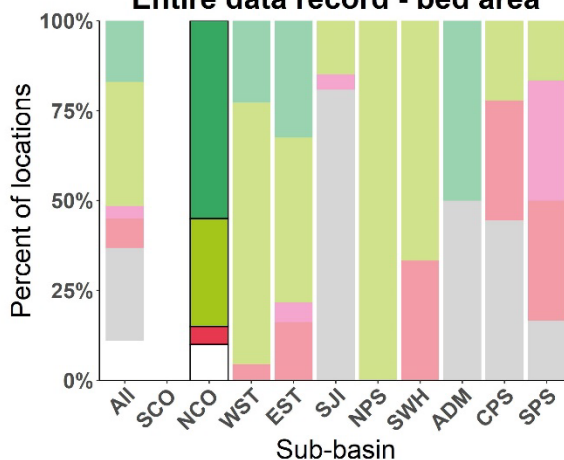
Key Findings:

- **Floating kelp is abundant along the northern coast.** Two species occur here, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*).
- **This area has spatially and temporally extensive monitoring data.** Annual monitoring surveys has been conducted since 1989 (except 1993) using aerial photography.
- **Considering all available data, the sub-basin is classified as stable** because the number of locations with *increasing* and *no trend* classifications greatly outnumbers the number of decreasing locations.
- **An extensive monitoring record in this sub-basin allows us to assess additional parameters** (beyond our main indicator, trends in bed extent at locations). Other parameters showed similar patterns, these include: canopy area at locations, total bed area, and canopy area throughout the sub-basin.

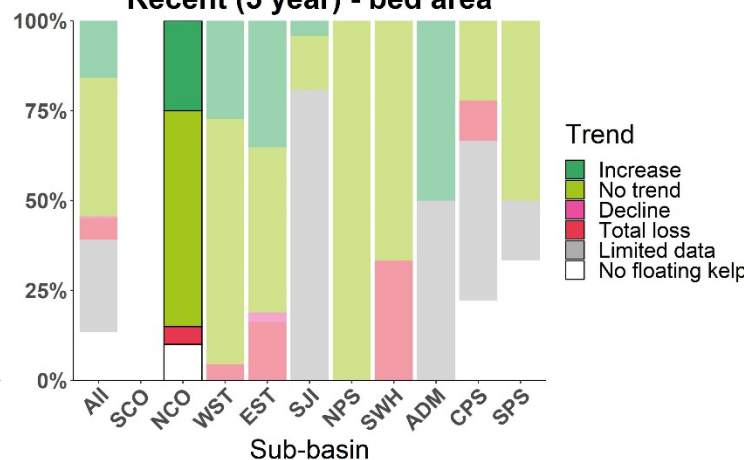
Sub-basin details

number of locations monitored	20	
count of long-term trends at locations	increasing	11
	no trend	6
	decreasing	0
	total loss	1
	limited data	0
	no floating kelp	2
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	17,388	
% of nearshore habitat monitored in sub-basin	100%	
% of WA floating kelp beds in sub-basin	5-20%	

Entire data record - bed area



Recent (5 year) - bed area



Trend

- Increase
- No trend
- Decline
- Total loss
- Limited data
- No floating kelp

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: North Puget Sound (NPS)

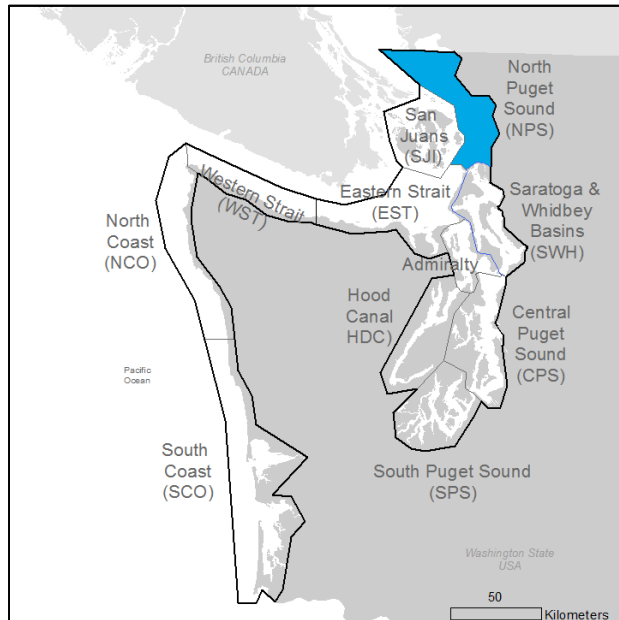
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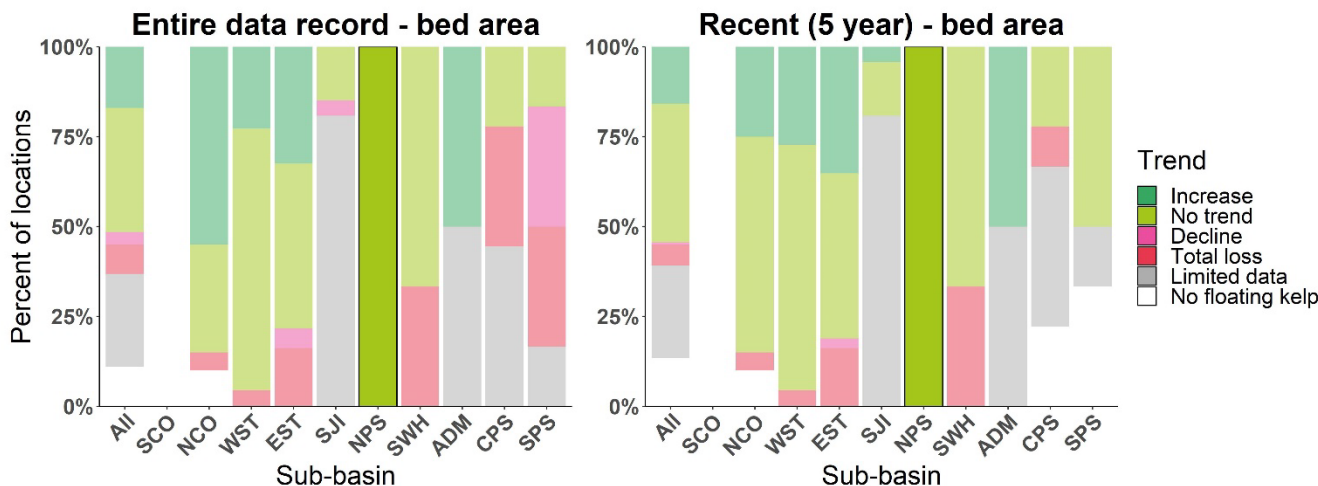
Sub-basin assessment: insufficient data



Key Findings:

- **Floating kelp is common in portions of North Puget Sound** where suitable habitat conditions exist. It generally occurs along the rocky shorelines, it is rare in the extensive sandy flats that are common in this sub-basin. One species occurs in the sub-basin, bull kelp (*Nereocystis luetkeana*).
- **There is insufficient data to assess floating kelp in this sub-basin.** Only 10 locations are monitored, comprising approximately 3% of the nearshore habitat in the sub-basin. The locations are monitored by Skagit County and Whatcom County Marine Resource Committees (MRCs) and the Washington Department of Natural Resources Nearshore Habitat Program. All of the monitored sites showed no trend over time.
- **The priority in this sub-basin is to increase monitoring** in areas with floating kelp habitat.

Sub-basin details



number of locations monitored	8	
count of long-term trends at locations	increasing	0
	no trend	8
	decreasing	0
	total loss	0
	limited data	0
no floating kelp	0	
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	19,521	
% of nearshore habitat monitored in sub-basin	3%	
% of WA floating kelp beds in sub-basin	5-20%	

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Southern Coast (SCO)

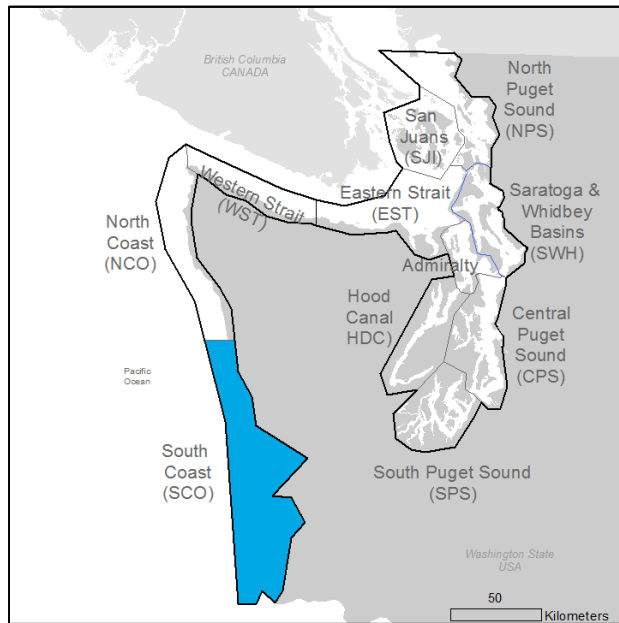
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[Interactive map](#)

[Web site](#)



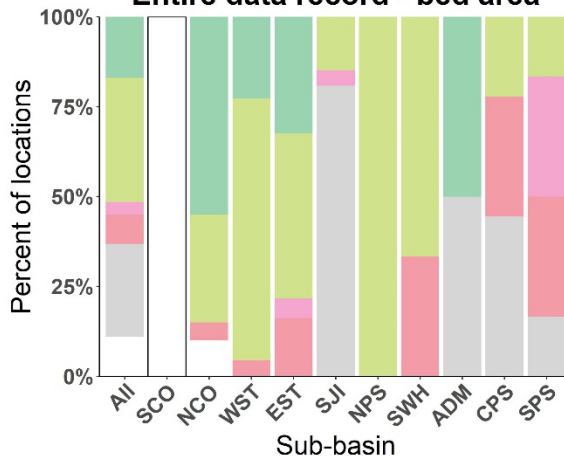
Sub-basin assessment: no floating kelp



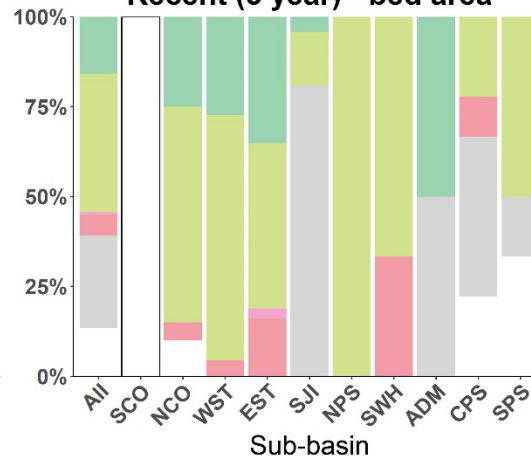
Key Findings:

- **No floating kelp observations exist along the southern coast.** This sub-basin is understood to have limited floating kelp habitat due to abundant sandy substrate. The southern coast has been monitored annually from Copalis to the Columbia River since 1989 (except 1993) using aerial photography. The extensive embayments of Grays Harbor and Willapa Bay are not monitored for floating kelp, but they are not believed to provide floating kelp habitat. These areas provide important sandy and estuarine habitats to a wide range of species.
- **The priority in this sub-basin is to confirm the historical and current absence of floating kelp.**

Entire data record - bed area



Recent (5 year) - bed area



Trend

- Increase
- No trend
- Decline
- Total loss
- Limited data
- No floating kelp

Sub-basin details

number of locations monitored	17	
count of long-term trends at locations	increasing	0
	no trend	0
	decreasing	0
	total loss	0
	limited data	0
	no floating kelp	17
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	69,799	
% of nearshore habitat monitored in sub-basin	75%	
% of WA floating kelp beds in sub-basin	0%	

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: San Juan Islands (SJI)

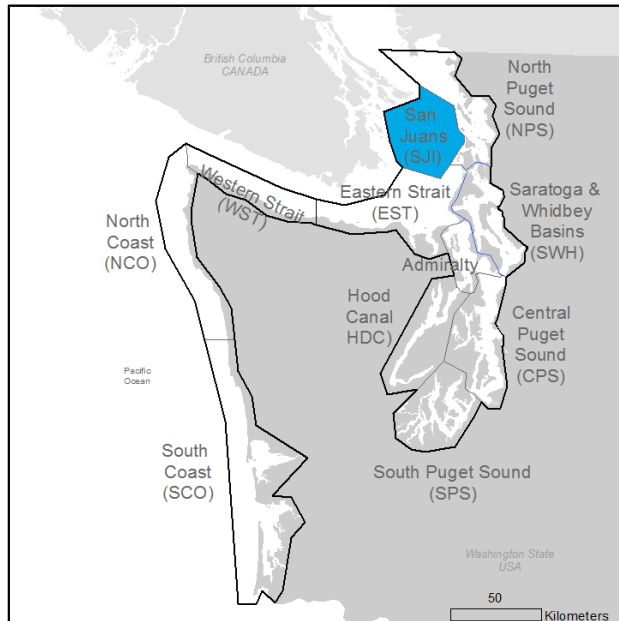
[Statewide report](#)

[Interactive map](#)

[Web site](#)



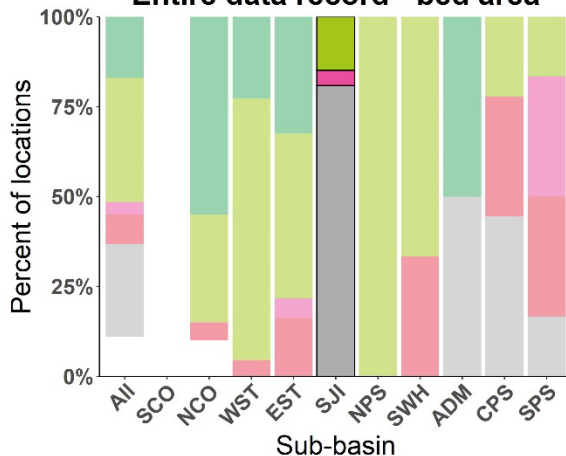
Sub-basin assessment: concern of declines



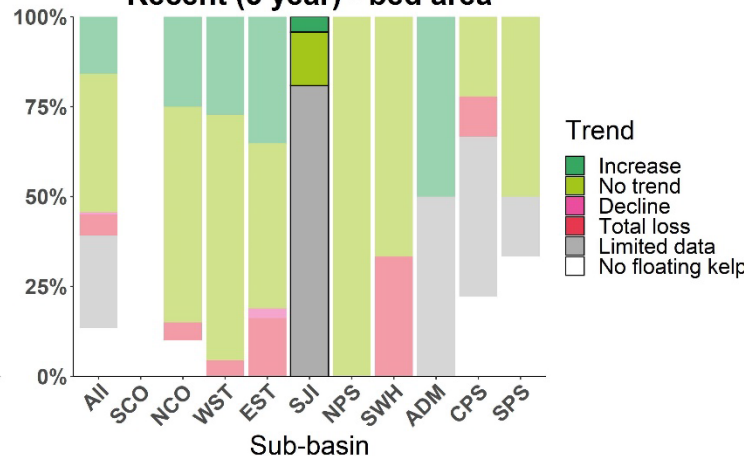
Key Findings:

- **Floating kelp is abundant along the shorelines of the San Juan Islands** where appropriate habitat conditions exist. One species occurs here, bull kelp (*Nereocystis luetkeana*).
- **There is concern of declines in the sub-basin, yet data limitations preclude definitive classification.** Virtually all nearshore areas have been surveyed more than once, but most locations have only three years of surveys and data limitations that don't allow for trends assessment (the imagery wasn't controlled for tides or currents, which are known to impact the amount of visible canopy). Annual surveys from 2010-2019 around Cypress Island (4.5% of the resource) indicate stability in total abundance, as well as within most locations.
- **Indigenous Scientific Knowledge (ISK) gathered by the [Samish Indian Nation](#) suggests multiple areas of decline in floating kelp canopies over decades.** Other studies conducted at smaller spatial scales within the sub-basin suggest kelp area decline. One area of concern is San Juan Channel, on eastern San Juan Island.
- **The priority is to collect sufficient survey information** to support a robust assessment.

Entire data record - bed area



Recent (5 year) - bed area



Sub-basin details

number of locations monitored		47
count of long-term trends at locations	increasing	0
	no trend	7
	decreasing	2
	total loss	0
	limited data	38
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)		10,452
% of nearshore habitat monitored in sub-basin		100%
% of WA floating kelp beds in sub-basin		5-20%

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: South Puget Sound (SPS)

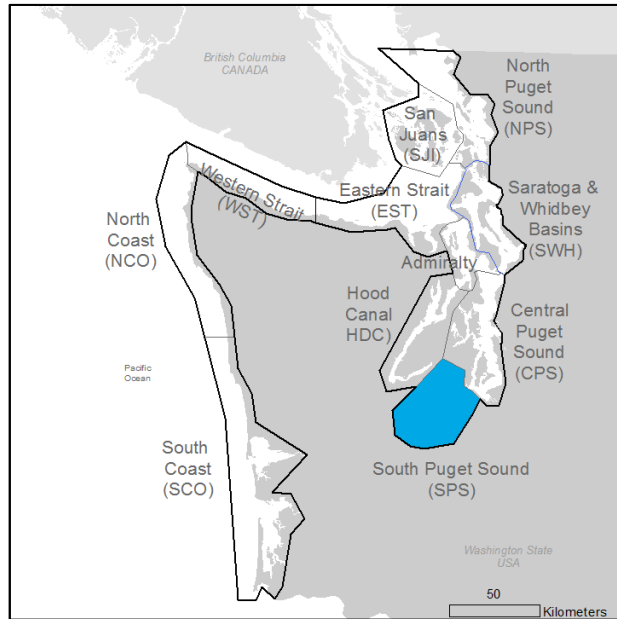
[Statewide report](#)

[Interactive map](#)

[Web site](#)



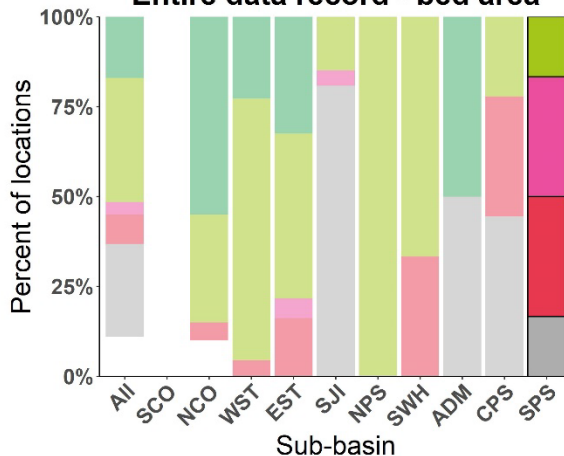
Sub-basin assessment: **substantial documented declines**



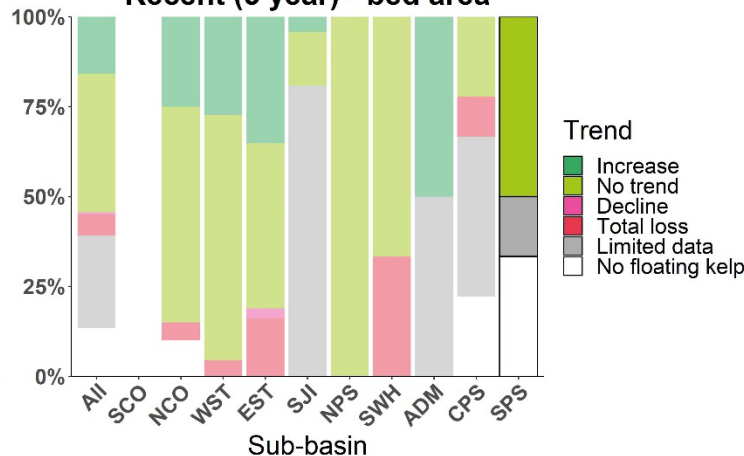
Key Findings:

- **Floating kelp is uncommon along the shorelines of South Puget Sound.** One species of floating kelp occurs here, bull kelp (*Nereocystis luetkeana*).
- **South Puget Sound is identified as sub-basin of concern due to substantial documented declines.** A [historical ecology study spanning 145 years](#) found that bull kelp has disappeared from approximately 80% of the shorelines (compared to the maximum cumulative extent of all observations).
- **Bull kelp has disappeared from most of the sub-basin.** It persists along shorelines near the Tacoma Narrows and at Squaxin Island.
- **Six locations are monitored annually for floating kelp.** At two locations, bull kelp has disappeared, at two locations it is declining, at one location there is no trend, and at one location the monitoring time span is too short for assessment.
- **Priorities in this sub-basin include addressing stressors and restoration, as well as conserving existing beds.**

Entire data record - bed area



Recent (5 year) - bed area



Sub-basin details

number of locations monitored	6	
count of long-term trends at locations	increasing	0
	no trend	1
	decreasing	2
	total loss	2
	limited data	1
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	12,219	
% of nearshore habitat monitored in sub-basin	<1%	
% of WA floating kelp beds in sub-basin	<1%	

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Saratoga & Whidbey Basins (SWH)

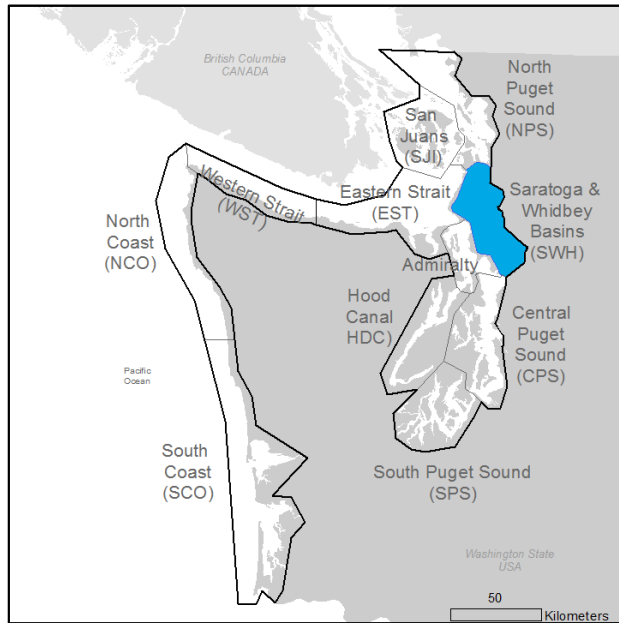
[Statewide report](#)

[Interactive map](#)

[Web site](#)



Sub-basin assessment: concern of declines



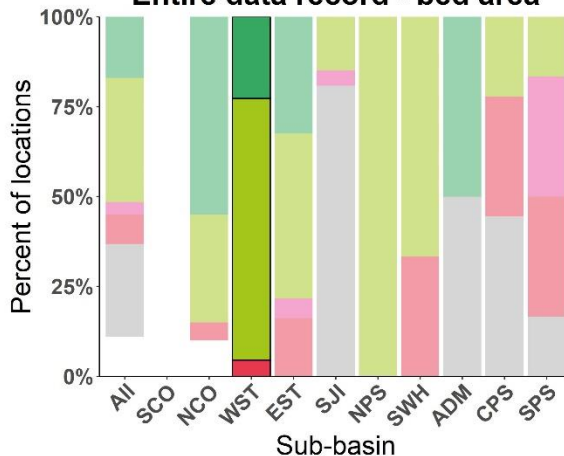
Key Findings:

- **Floating kelp is found in isolated areas of Saratoga Passage and Whidbey Basin** where suitable habitat conditions exist. It generally occurs along rocky shorelines and near exposed headlands. It does not occur in the extensive sandy flats that are common in this sub-basin. One species occurs in the sub-basin, bull kelp (*Nereocystis luetkeana*).
- **There is concern of declines in the sub-basin, yet data limitations preclude definitive classification.** Only 3 locations are monitored, comprising approximately 2% of the nearshore habitat in the sub-basin. The bull kelp bed at Mukilteo disappeared, while no trend was observed at Polnell Point and Hat Island. The locations are monitored by Snohomish County and Island County Marine Resource Committees (MRCs).
- **The priority in this sub-basin is to increase monitoring** in areas with floating kelp habitat.

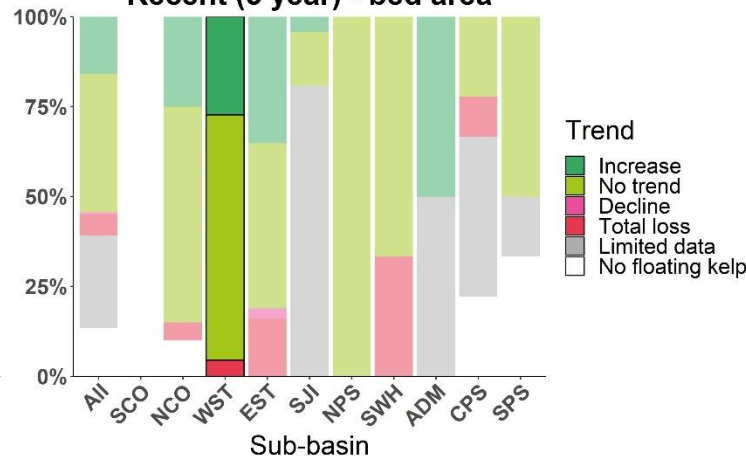
Sub-basin details

number of locations monitored	3	
count of long-term trends at locations	increasing	0
	no trend	2
	decreasing	0
	total loss	1
	limited data	0
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	10,638	
% of nearshore habitat monitored in sub-basin	2%	
% of WA floating kelp beds in sub-basin	1-5%	

Entire data record - bed area



Recent (5 year) - bed area



Trend
 Increase
 No trend
 Decline
 Total loss
 Limited data
 No floating kelp

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.

Sub-basin: Western Strait (WST)

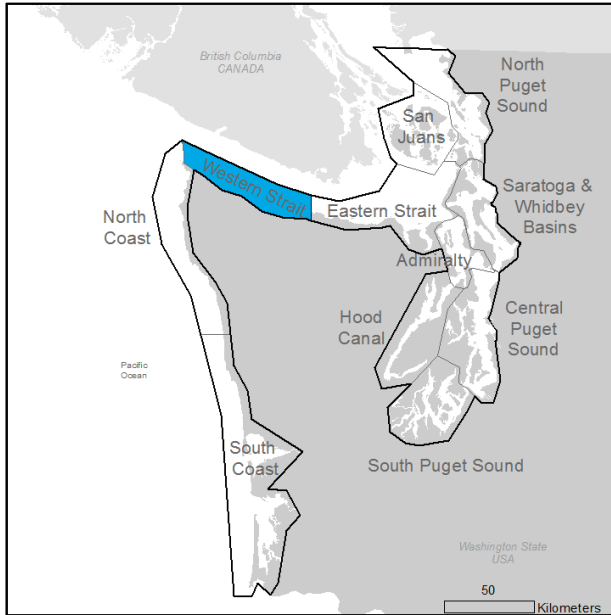
[Statewide report](#)

[Interactive map](#)

[Web site](#)



Sub-basin assessment: **Stable**



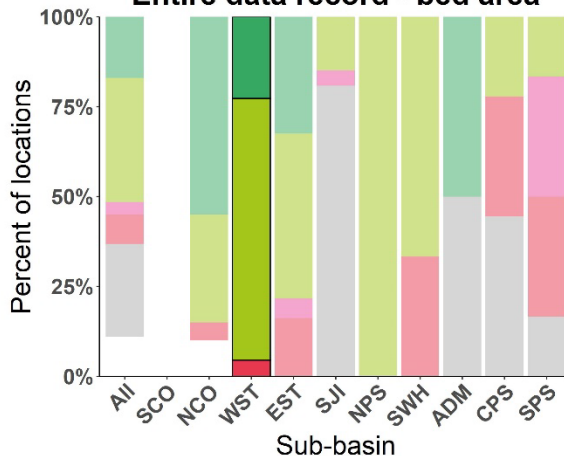
Key Findings:

- **Floating kelp is abundant along the western Strait of Juan de Fuca.** Two species occur here, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*).
- **Monitoring data is spatially and temporally extensive.** The majority of nearshore areas (~100%) have been monitored annually since 1989 (except 1993) by aerial photography. Kayak-based survey data is available at some sites.
- **Considering all available data, the sub-basin is classified as stable** because the number of locations with *increasing* and *no trend* classifications greatly outnumbers the number of *decreasing* classifications (figures below). Additionally, historical data suggests stability over the last century – a century-scale comparison showed that the bed area within zones in 1911 generally fell within the range of values measured in the last three decades.
- **An extensive monitoring record in this sub-basin allows us to assess additional parameters** (beyond our main indicator, trends in bed extent at locations). Other parameters showed similar patterns, these include: canopy area at locations, total bed area, and canopy area throughout the sub-basin.

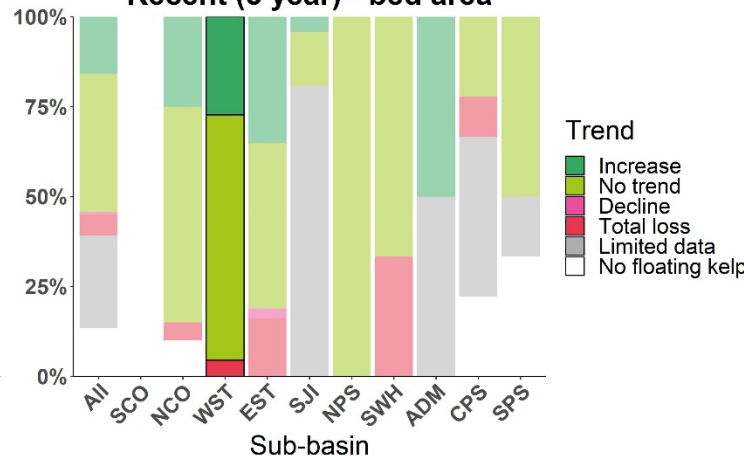
Sub-basin details

number of locations monitored	23	
count of long-term trends at locations	increasing	5
	no trend	16
	decreasing	0
	total loss	2
	limited data	0
	no floating kelp	0
Nearshore habitat (from -15 m to -1 m, MLLW) in sub-basin (ha)	5,010	
% of nearshore habitat monitored in sub-basin	100%	
% of WA floating kelp beds in sub-basin	20-40%	

Entire data record - bed area



Recent (5 year) - bed area



Trend
 Increase
 No trend
 Decline
 Total loss
 Limited data
 No floating kelp

The bar charts show the count of locations by trend category for two time periods (long-term on left, recent on right). Within each chart, the left-most bar includes all locations in WA state (all). Subsequent bars correspond to individual sub-basins, sorted spatially from coast (left) to innermost basin (right). The arrow identifies this sub-basin.