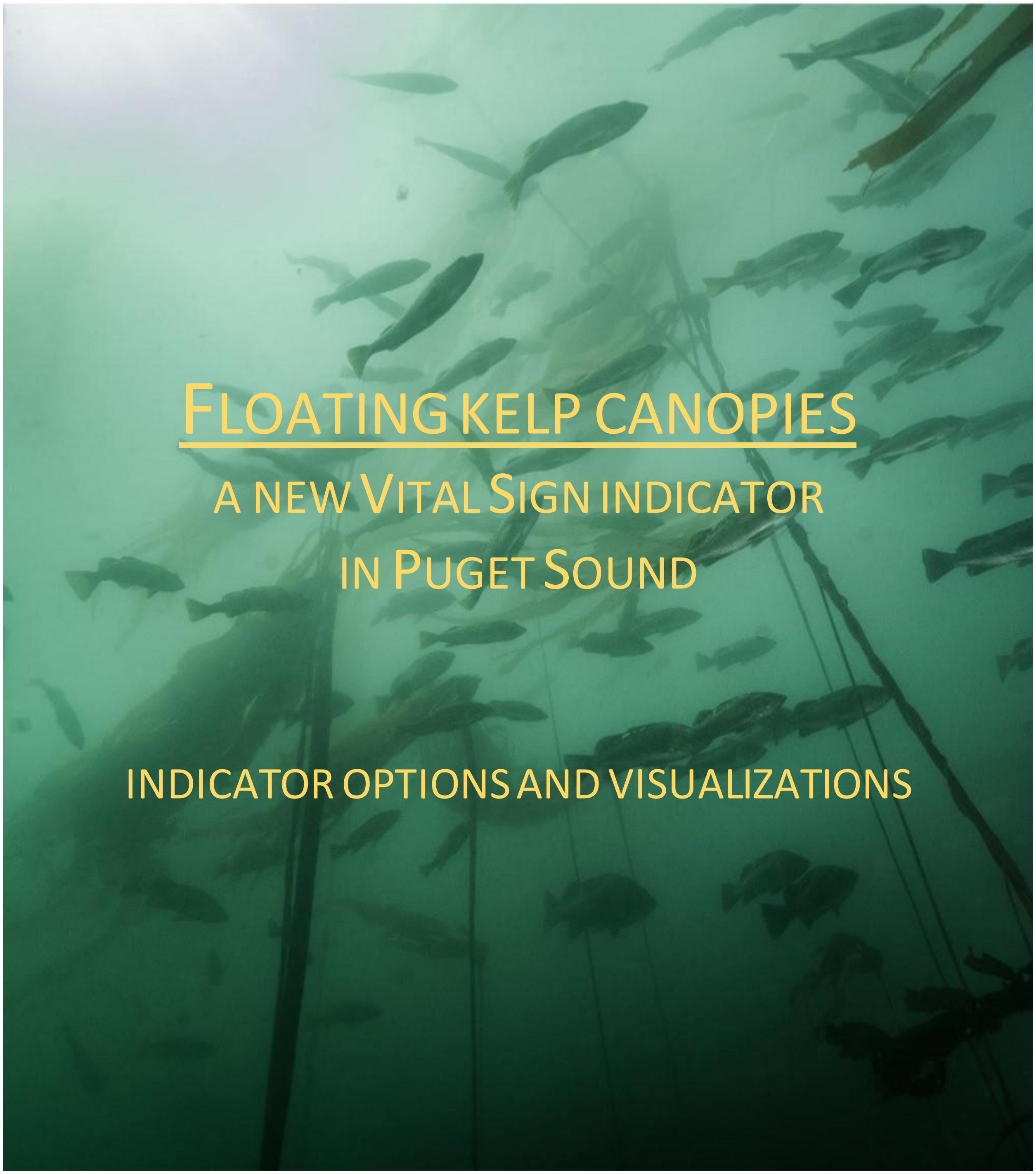


Floating kelp canopies

a new Vital Sign indicator in Puget Sound

Indicator options and visualizations

ACKNOWLEDGEMENTS

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

PROJECT TEAM

Sea Grant Washington: Nicole Naar

Samish Indian Nation: Todd Woodard, Casey Palmer-McGee

Northwest Straits Commission: Dana Oster, Suzanne Shull

MARINE AGRONOMICS: Tom Mumford

Washington Department of Natural Resources: Helen Berry, Danielle Claar, Pete Dowty, Elizabeth Spaulding, Bart Christiaen, Lisa Ferrier, Tyler Cowdrey, Julia Ledbetter

University of Washington: Megan Dethier, Wendel Raymond

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. This document represents an initial scoping effort, produced rapidly in order to solicit early guidance from the Puget Sound community.

CITATION

Raymond, W.W., H. Berry, D. Claar, P. Dowty, E. Spaulding, B. Christiansen, L. Ferrier, J. Ledbetter, N. Naar, T. Woodard, C. Palmer-McGee, T. Cowdrey, D. Oster, S. Shull, T. Mumford, M. Dethier. 2022. Floating kelp canopies: a new Vital Sign indicator in Puget Sound, Indicator Options and Visualizations.

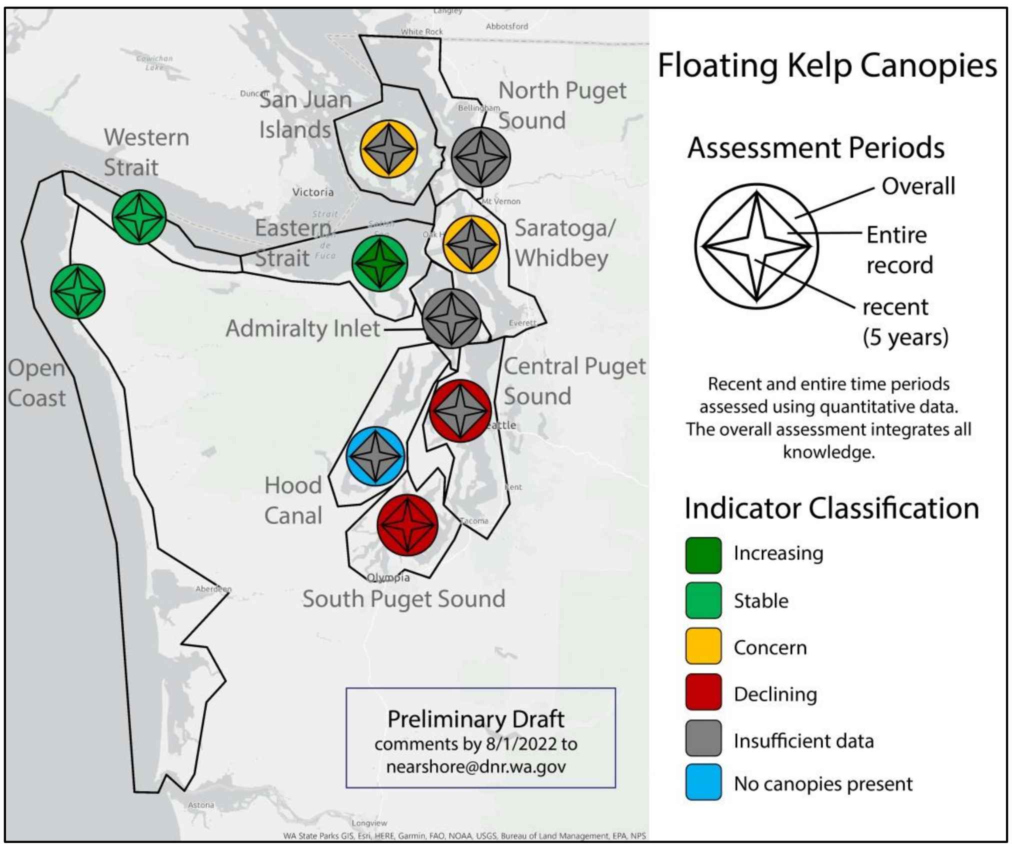
COVER PHOTO: Adam Obaza, Rockfish in kelp forest on Whidbey Island

Executive Summary

This report presents indicator options and visualizations to support development of the *floating kelp canopy area* indicator, a newly identified biophysical indicator for the Puget Sound Partnership's *Beaches and Marine Vegetation* Vital Sign. It represents the second phase of a multi-part project. The project will culminate in May 2023 with posting of the newly developed indicator and associated results on PS Info, the Vital Sign reporting system.

This indicator development project is distinct from many other efforts because the *Project Team* represents a broad-based alliance of organizations and communities that value kelp. The principle driving this approach is that diverse engagement will both enrich the indicator and strengthen its connection to kelp conservation and restoration actions.

What's new in this report? The report presents a prototype indicator.



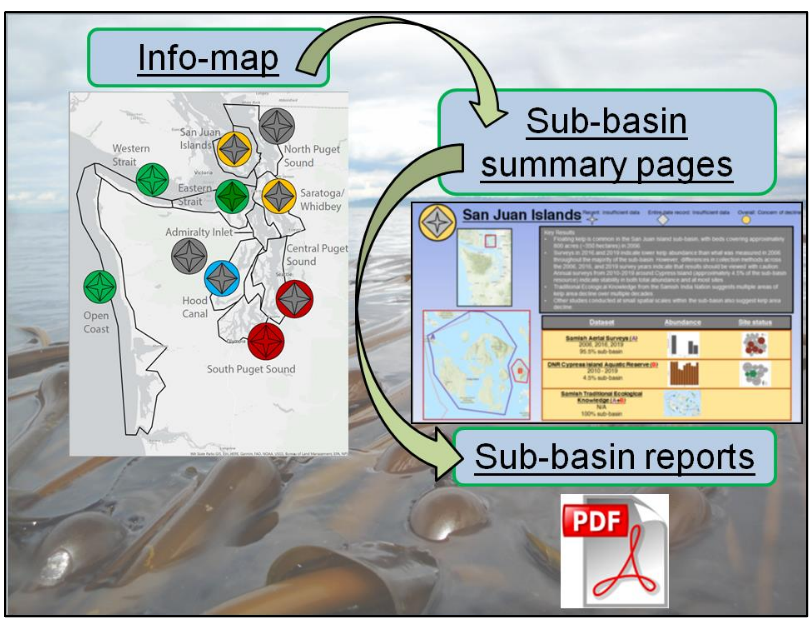
Feedback on the prototype from the community will drive further development. Ways to comment (via nearshore@dnr.wa.gov):

- Submit written comments by August 1, 2022.
- Attend the workshop on June 7, 2022.
- Contact the *Project Team* at any time for small group discussions.

The prototype is based on key considerations for five themes that were identified and refined during initial scoping (click on the hyperlinks to navigate to the section of the report):

Theme	**Key Considerations**
Indicator audience and use	• Diverse audiences. • Single simple figure for rapid communication. • Detailed products that drill down into the data.
Temporal priorities	• Short-term (years). • Long-term (decades).
Geographical assessment priorities	• Sub-basins within Puget Sound. • Smaller assessment units to capture finer scale dynamics. • Include the open coast.
Metrics and Data	• Maximize use of available data, while also considering data limitations. • Initial datasets will include canopy and bed perimeter from DNR, MRC volunteers and the Samish Indian Nation. Other available data will also be included. • The program must be scalable to match available resources. • A strategic plan is needed to identify future expansion.
Critical linkages	• The indicator is limited to describing status and trends. • Linkages are needed to stressors, management actions, ecosystem components, and human well-being.

The prototype products first summarize results and then drill down with increasing detail. A single info-map graphic visually communicates the overall assessment. Sub-basin web pages summarize key findings. Sub-basin reports (in PDF format) document detailed results.



The proposed indicator is a synthesis of existing data from state agency monitoring, community science surveys, and Indigenous Scientific Knowledge. We anticipate that the indicator produced during this project will be incrementally improved over time. In addition to defining and constructing the indicator, the project identifies priorities for enhancing and expanding it in the future.

There are many ways to participate. Your contributions could be part of the indicator project or part of broader efforts associated with the *Puget Sound Kelp Conservation and Recovery Plan* (*Kelp Plan*):

- Share datasets to be included in the indicator;
- Suggest priorities for the indicator to address;
- Contribute other information that enriches our understanding of indicator results;
- Define measures of success;
- Provide guidance on how the indicator meets needs to understand kelp condition and how it is changing;
- Communicate why kelp is important.

This report falls within Phase 2 of this multi-phase project. Each phase of the project includes opportunities to provide feedback:

Phase 1. Initial Scoping: Complete *Identify indicator requirements, priorities, and candidate datasets*	● Report released: Jan. 11, 2022 ● *Online workshop: Jan. 13, 2022, 10 am – 12 pm* ● Public comments released: Mar. 15, 2022
Phase 2. Indicator Options: *Explore indicator options through data visualization*	● Report release: May 30, 2022 (this report) ● *Online workshop: Jun. 7, 2022, 10am – 12 pm* ● Public comments due: Aug. 1, 2022
Phase 3. Proposed Indicator *Select and refine indicator*	● Report release: December 20, 2022 ● *Online workshop: Jan. 10, 2023, 10 am – 12 pm* ● Public comments due: Mar. 15, 2023

We welcome feedback on any part of the project and report, including:

1. For **geographic assessment areas**, we are proposing 10 sub-basins with the ability to drill down. How well does this proposal meet our diverse ecological, cultural, and management goals? (Section 2.10)

2. How well do our proposed **status and trend categories** meet our goal to rapidly communicate the essential scientific and management relevant information? (Section 2.8 – 2.9; Appendices 1 - 6)

3. How well do our proposed **time periods** address information needs of scientists, managers, and communities? (Section 2.8; Appendices 1 – 6)

4. How well does the **linked set of communication products** meet our goal to balance simple communication with additional detail? (Section 2.14; Appendices 1 – 6)

5. Our long-term goal is to meaningfully engage with diverse communities and link to other kelp science and management. How are we doing toward meeting that goal?
6. Do you prefer a three-level (recent, entire data record, and overall) or two-level (recent, and entire data record) kelp status icon? Why? (Section 2.14.2.1; Appendix 1).
7. Do sub-basin summary pages balance detail with accessibility? Is anything missing? (Section 2.14.2.2; examples in Appendix 2).
8. Do sub-basin reports provide sufficient detail understand kelp status and trends and justification for indicator classification? (Section 2.14.3.2; Appendices 3 – 6).\
9. Do the dataset descriptions provide sufficient information on datasets and links to further information? (Section 2.14.3.3; Appendices 7 – 11).

For more information on the project or to join the mailing list, visit the Kelp hub website (https://kelp-canopy-vital-sign-for-puget-sound-wadnr.hub.arcgis.com/) or contact us at nearshore@dnr.wa.gov

Table of Contents

Figures

Tables

1. Introduction

1.1. Overall Project Goal and Approach

The overall goal of this project is 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. The final *floating kelp canopy area* indicator will be displayed in the Puget Sound Partnership Puget Sound Info website. Further project information and documentation on current project status and products will be available on the Kelp Hub Website.

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). 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).

1.2. Project Description

1.2.1. Project team and contributors

Participants in *floating kelp canopy area* indicator development are divided into two groups:

- The *Project Team* of 10-15 staff who primarily complete the project;
    - Washington State Department of Natural Resources (DNR) - Helen Berry, Pete Dowty, Lisa Ferrier, Bart Christiaen, Julia Ledbetter, Danielle Claar, Elizabeth Spaulding, Tyler Cowdrey
    - Samish Indian Nation - Todd Woodard, Casey Palmer-McGee
    - Northwest Straits Commission - Dana Oster, Suzanne Shull
    - University of Washington - Megan Dethier, Wendel Raymond
    - Washington Sea Grant - Nicole Naar
    - Marine Agronomics - Tom Mumford
- *Contributors* who provide guidance through data sharing, document review, meetings, and workshops.

The *Project Team* is composed of a broad-based alliance of partners that have been collaborating informally. We are using a unique blend of state agency monitoring, community science, Indigenous Scientific Knowledge, and academic research to define the *floating kelp canopy area* indicator and synthesize existing data. Project partners include:

- The Washington State Department of Natural Resources (DNR) is the state steward for kelp, eelgrass and other aquatic vegetation. DNR's Nearshore Habitat Program has conducted kelp monitoring for 30 years. It is also the indicator lead for the *eelgrass area* component of the *Beaches and Marine Vegetation* Vital Sign.
- The Samish Indian Nation works to preserve, protect and enhance culturally significant natural resources in Samish Territory, which encompasses culturally important kelp habitats in the San Juan Islands and nearby shorelines. Through the tribe's strong connection with the natural world, they have observed kelp declines and species struggling to survive and adapt. They are incorporating local indigenous knowledge into their scientific monitoring program.
- The Northwest Strait Commission is a community-led collaboration working to protect and restore the marine environment of northwest Washington. It provides funding and technical coordination for 7 county-based Marine Resources Committees (MRCs). MRCs serve as advisors to local governments and lead projects that make positive regional impacts, such as the volunteer-based kelp canopy monitoring program.
- The University of Washington's Friday Harbor Laboratories (FHL) provides ecological analysis expertise and links the indicator to ongoing kelp research. FHL is known worldwide for research and teaching in marine-related sciences. Visiting and resident scientists and their students conduct a wide array of research projects related to kelp. FHL is the academic home for one postdoctoral research fellow working on kelp ecophysiology and several other researchers with decades of experience related to kelp.
- Washington Sea Grant (WSG) funds and conducts marine research, outreach, and education to support the health and sustainability of Washington's vibrant communities and marine resources. WSG acts as a neutral convener and unbiased broker of place-based information, bringing together academic, tribal, industry, government, and other partners to address complex coastal environmental issues. Various WSG staff collaboratively work on kelp conservation, recovery, and management within Puget Sound.

The *Project Team's* overall goal is to encourage widespread engagement at many levels, ranging from people who use the information to those who help produce it. Ultimately, the indicator is envisioned as a connector between many organizations and communities that value kelp (Figure 2). Two key driving forces are the Puget Sound Partnership's Vital Signs program (Section 2.1) and the Kelp Plan.

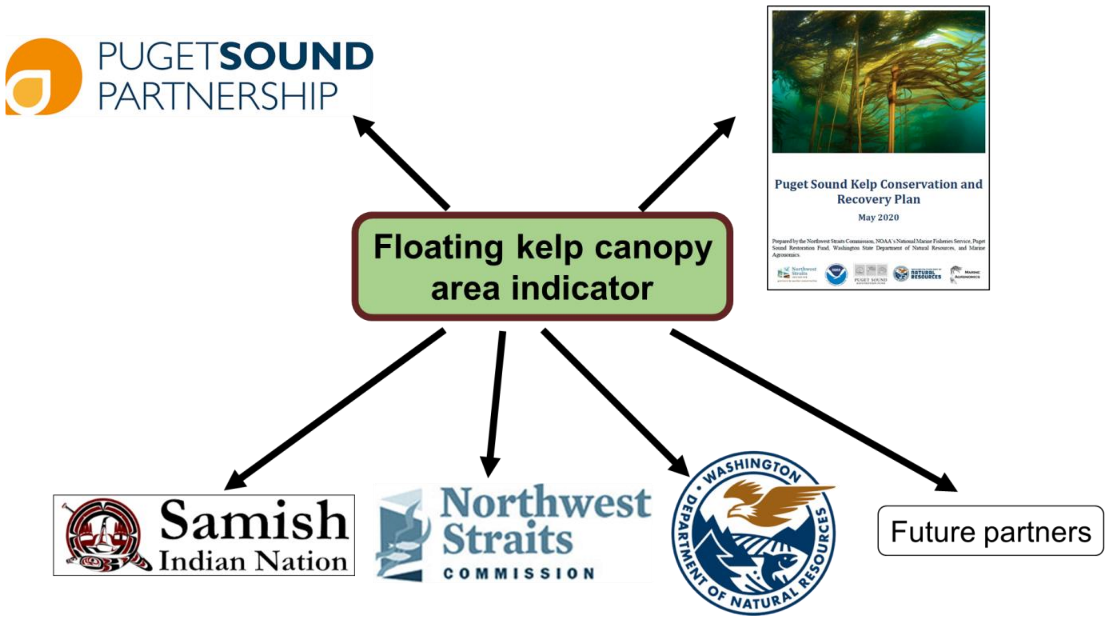


Figure 1: Conceptualization of connections facilitated by the indicator to the Puget Sound Partnership, The Kelp Plan, The *Project Team* and future partners.

1.2.2. Project phases and schedule

The project began in January 2022 and will be completed in May 2023 (Figure 2). During this period, three linked phases will incrementally define the indicator. Each phase incorporates a formal call for external guidance and feedback (Table 1). Targeted outreach has been recommended as the approach that is most likely to spark meaningful participation. Therefore, the *Project Team* will also reach out for guidance and feedback from key constituents through informal meetings.

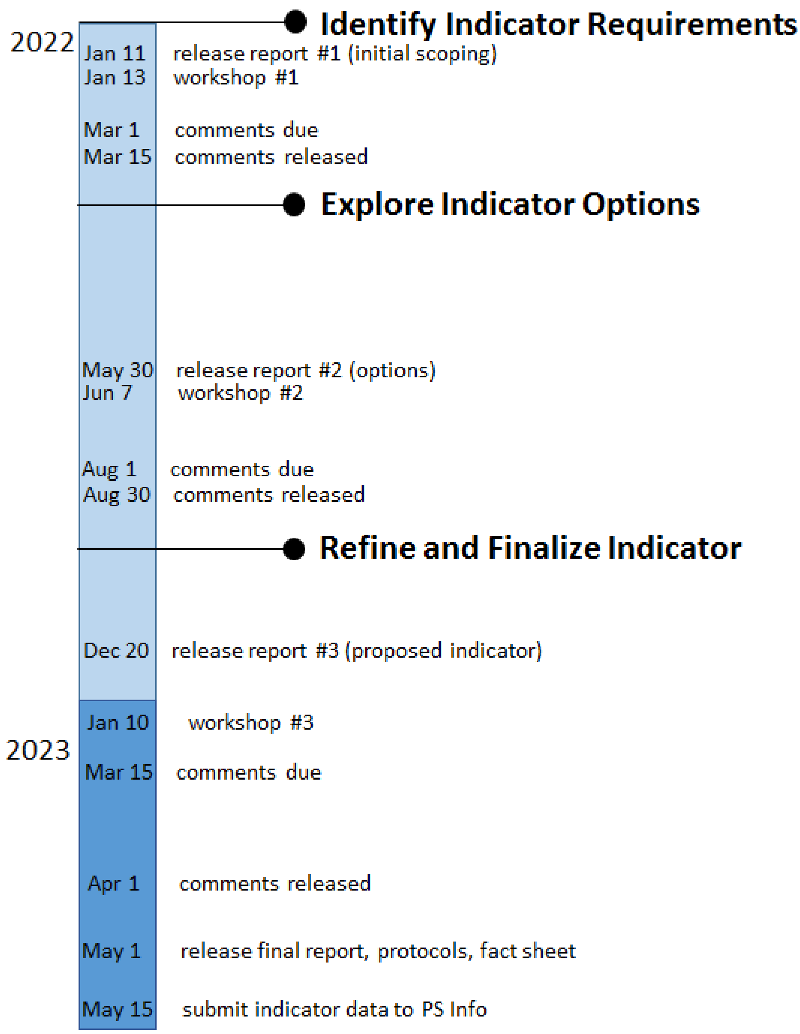


Figure 2: Overview of project phases and timeline.

Phase 1. Identify indicator requirements.

The *Project Team* gathered comments from Report 1 and Workshop 1 to help guide further phases of the project. Comments were centered on five key questions outlined in Report 1 and are shown below.

1. Indicator audience and use: Who is the indicator for? How will it be used?
2. What time spans should the indicator consider? Why?
3. What geographic assessment areas are important? Why?
4. What metrics and data should be included in the initial indicator? The future indicator?
5. The indicator is limited to describing status and trends in floating kelp canopies. What linkages are most important?

Phase 2. Explore indicator options through data analysis and visualization

This report. The *Project Team* explored potential indicator metrics, visualizations, and products through analysis and visualization of existing datasets. The strengths and limitations of various metrics and visualization options are weighed using the framework developed in Phase 1. Feedback to Phase 2 products will be used to guide final indicator development in Phase 3.

Phase 3. Refine and finalize indicator

The *Project Team* will select and refine the final indicator by considering feedback to the options presented in Phase 2. The final indicator metric and its visualization will be reported on the Partnership Vital Sign Web Site. To connect the indicator to the broader community, indicator results will include links to work by project partners. A final report will document indicator construction methods and priorities for future enhancement. Protocols will document data collection methods.

Table 1: Opportunities for public feedback in the indicator development process.

Phase 1. Initial Scoping *Identify indicator requirements, priorities, and candidate datasets*	• Report released: Jan. 11, 2022 • *Online workshop: Jan. 13, 2022, 10 am – 12 pm* • Public comments due: Mar. 1, 2022
Phase 2. Indicator Options *Explore indicator options through data visualization*	• Report released: May 30, 2022 (this report) • *Online workshop: Jun. 7, 2022, 10 am – 12 pm* • Public comments due: Aug. 1, 2022
Phase 3. Finalize Indicator *Select and refine indicator*	• Report released: December 20, 2022 • *Online workshop: Jan. 10, 2023, 10 am – 12 pm* • Public comments due: Mar. 15, 2023

1.3. Outcomes

Two final project outcomes will directly fulfill the Partnership Vital Sign program needs: 1) a report describing the initial *floating kelp canopy area* indicator and a framework to guide future contributions and prioritize incremental improvements; and 2) release of initial indicator results on Puget Sound Info. If resources are available, the following additional products are prioritized for completion:

- An interactive website and data viewer that presents the indicator in a user-friendly format.
- A peer-reviewed publication.

Our broad objective is to use the *floating kelp canopy area* indicator as an overarching communication tool to integrate diverse local and regional scales of work and connect groups that are often isolated from one another: tribes, local communities, agency scientists, and managers. The *Project Team* brings together unique perspectives, along with a shared commitment to kelp stewardship and monitoring. Engagement begins with our bottom-up approach for constructing the indicator based on local datasets. It will be amplified by the *Project Team*, who participate in a number of formal and informal networks, including but not limited to: Kelp Conservation and Recovery Plan implementers, the PSEMP Nearshore Workgroup and Steering Committee, the Puget Sound Kelp Research and Monitoring

Workgroup, MRCs, state and federal managers, and academic researchers. Ultimately, our approach to indicator development strives to provide insight into greater Puget Sound as a whole, while also connecting directly back to the local scale to inform and inspire recovery actions through protection, restoration, and adaptive management.

1.4. Purpose of this report

The primary purpose and goal of this report is to present floating kelp canopy indicator options and visualizations to contributors for feedback. The Project Team combined feedback from Report 1 and Workshop 1 and additional feedback received thus far with available kelp data to create options and visualizations using a sample of kelp data around Washington State. This includes options at multiple levels of detail of the indicator, from sub-basins to small (kilometer) scale. The proposed indicator is presented in Section 2 of this report with proposed communication products detailed in Section 2.14 and Appendix 1-11. Feedback on these options will be critical for the development of the floating kelp canopy area indicator.

2. Proposed indicator

2.1. Puget Sound Partnership Vital Signs program and requirements

This section describes standards for the construction and use of indicators within the Puget Sound Partnership, which provides the overarching framework for the *floating kelp canopy* indicator. It then defines the proposed indicator, including data collection guidelines.

In 2007, Washington State legislators established The Puget Sound Partnership (Partnership) with a mandate to restore and conserve a healthy Puget Sound ecosystem (RCW 90.71). The program is directed to apply an ecosystem-based management approach to achieve Puget Sound recovery, which is defined through six statutory ecosystem recovery goals:

- Healthy human population;
- Vibrant quality of life;
- Thriving species and food web;
- Protected and restored habitat;
- Abundant water;
- Healthy water quality.

Like many other ecosystem management and recovery efforts, the Partnership uses ecological indicators to guide ecosystem management and recovery efforts. A series of projects have identified and refined the Vital Sign indicators of biophysical conditions and human wellbeing (summarized in Report 1).

The Vital Signs are part of a system of related efforts to direct recovery actions and track progress:

- The Action Agenda charts the course toward recovery by tracking regional strategies and specific actions needed to recover Puget Sound.
- PS Info is the Partnership's online platform for monitoring ecosystem health, including progress on the Vital Signs and Action Agenda implementation tracking.
- The State of the Sound is a biennial report to the Legislature on progress toward the recovery of Puget Sound. The most recent report, released in 2021, found that "Puget Sound is not doing well, but we see signs of progress."
- Strategic Initiatives are regional priorities that have been emphasized in the Action Agenda and funded through the National Estuary Program since 2012. Conservation and recovery strategies for marine vegetation, specifically kelp, are included within the Habitat Strategic Initiative.
- Implementation strategies are plans that describe a chain of outcomes that need to be achieved in order to move toward Vital Sign targets. Implementation strategies have been developed for a subset of the Vital Signs. Kelp conservation and recovery will be included within the newly-designated *Marine Vegetation Implementation Strategy*.

The basic requirements for Vital Sign indicators are that they must be scientifically sound, pertinent to regional ecosystem goals, reliable and practical to measure (O'Neill et al., 2018). These requirements are similar to other indicator programs (e.g., Niemeijer and de Groot, 2008; Schomaker, 1997; NRC, 2000). The most recent Vital Sign indicator framework identified ten criteria, grouped into four topics (O'Neill et al., 2018):

- Conceptual validity
  - Theoretically-sound.
  - Responds predictably and is sufficiently sensitive to changes in a specific ecosystem attribute.
- Data and statistical properties
  - High signal-to-noise ratio.
  - Consistently measurable.
  - Spatial and temporal variation understood.
- Feasibility
  - Operationally manageable.
  - Cost-effective.
- Management and reporting needs
  - Relevant to management concerns.
  - Responds predictably and is sufficiently sensitive to changes from specific management actions.
  - Linkable to scientifically-defined reference points and progress targets.

As a group, the portfolio of Vital Sign indicators should adequately assess and report on efforts to recover Puget Sound (O'Neill et al., 2018). Key communications requirements for indicators are to inform the public and policy makers about: 1) the state of the ecosystem, 2) progress towards the desired condition, and 3) the effectiveness of management strategies.

Indicators are generally reported sound-wide, as well as within smaller geographic assessment units. Indicators assess changes over time in a defined metric. Examples of types of metrics include abundance (such as eelgrass area) and chemical concentrations (such as in Toxics in Fish). There two sound-wide reporting categories for classifying the performance of indicators: (https://vitalsigns.pugetsoundinfo.wa.gov/VitalSignIndicator/ViewAll):

- PROGRESS distills the change relative to a baseline reference. Options include: getting better, mixed results, no trend, getting worse and insufficient data.
- STATUS distills the status of the indicator relative to its recovery target. It identifies whether the indicator is below or near the target (or there is insufficient data). A subset of indicators have defined recovery targets.

The Vital Sign reporting platform prioritizes high level summaries of results. Each indicator is described in an introductory paragraph, single data visualization, and limited bulleted results. Color-coded symbols describe indicator status and progress toward its recovery goal. Additional results are provided in supplemental pages, as well as links to other information sources.

Like other programs, The Partnership has emphasized the importance of conceptual models and causal frameworks to understand relationships between ecosystem health, stressors, human activities and management. The ultimate Partnership goal is to achieve a balance between human use and environmental integrity. Appendix 11 includes the conceptual frameworks for the entire program and the Beaches and Marine Vegetation Vital Sign that houses the *floating kelp canopies* indicator.

2.2. Community engagement

Developing a *floating kelp canopy area* indicator for the Puget Sound Vital Signs represents the latest opportunity to build momentum and support for the broader goals envisioned in the *Puget Sound Kelp Conservation and Recovery Plan* (*Kelp Plan*). Central to that vision is meaningful community engagement realized through diverse participation, intentional outreach, and transdisciplinary co-creation of knowledge. The *Project Team* is committed to incorporating these values into the indicator development process, while recognizing both the challenges and opportunities presented by this approach.

2.2.1. Vision

Diverse participation in conservation research is important for both ethical and practical reasons. Conservation is ultimately about values (Borgerhoff Mulder and Coppolillo, 2005), and engagement by a diversity of constituents in Washington State helps ensure marine conservation reflects social values and has social legitimacy (Uffman-Kirsch et al., 2020). Diverse participation also enhances the potential for success because projects with widespread engagement are more likely to result in positive conservation outcomes (LeFlore et al., 2021). By including representatives from state government, the Samish Indian Nation, community science, and academia, the composition of the *Project Team* lends institutional diversity to the indicator development project. We plan to further increase participation by holding public workshops and opportunities for public comment at each phase of indicator development (Figure 2 and Table 1). All interested constituents are welcome to attend workshops and share comments, which will also be made publicly available.

We know, however, that simply marking an event as "open to the public" is insufficient for ensuring meaningful engagement, especially from groups typically excluded from region-wide monitoring efforts. Thus, intentional outreach to citizen scientists/volunteers and Tribes is a key element of the *Project Team*'s community engagement strategy for indicator development. Community scientists and volunteers serving on MRCs advise local county governments and can use indicator results as a communication tool to further expand engagement in coastal communities across Washington State.

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, 2020).

Encouraging diverse participation and including diverse perspectives makes possible the last element of the *Project Team*'s vision for community engagement: transdisciplinary co-creation of knowledge (Mauser et al., 2013, Figure 3). Transdisciplinary integrated research represents a departure from the traditional "way of doing business," which tends to rely solely on Western science (Johnson et al., 2016) and encourages specialization and knowledge silos (Campbell, 2005[1969]). But this approach holds potential for addressing complex societal challenges that are beyond the scope of individual disciplines (Mauser et al., 2013; Kaiser et al., 2019). Our goal is for diverse participation to promote the weaving together of diverse knowledges, such that the indicator synthesizes data from state agencies, community/citizen science, and Indigenous science.

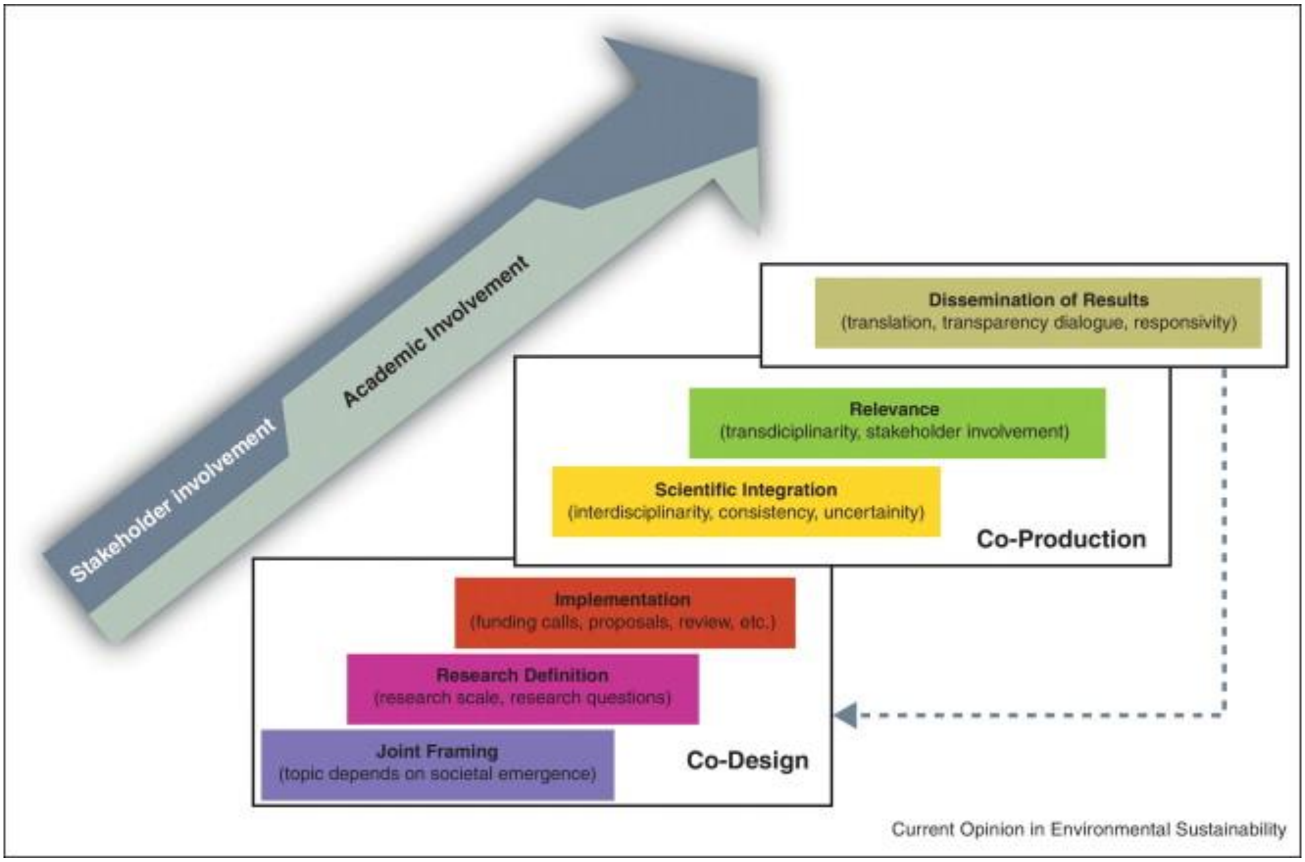


Figure 3: Framework for interdisciplinary and transdisciplinary co-creation of knowledge (from Mauser et al., 2013)

2.2.2. Challenges and opportunities

We recognize, however, that transdisciplinary, integrated co-creation of knowledge is a long-term and challenging process. Given existing constraints, it is an aspiration that will more likely be realized at the longer timescale and broader scope of the Kelp Plan. Indicator development must fit within an existing framework with its own goals and objectives, process, and standards and requirements (see section 2.1). The two-year project timeline is also relatively brief from the perspective of building trust between diverse partners, forging meaningful relationships, and reconciling differences between perspectives and approaches (Kotaska, 2019). Finally, contrary to the principles of co-design shown in Figure 2, the indicator project is designed (i.e., framed, defined, and funded) to be consistent with the Puget Sound Vital Sign framework.

Despite these challenges, indicator development provides many opportunities for enhancing community engagement around kelp conservation. Our ability to co-design the floating kelp canopy area indicator may be limited, but we can lay the groundwork for co-production (Figure

3) by synthesizing different sources of data/information and collectively determining the relevant timescale, geographic scale, etc. We also have the opportunity to collaboratively develop a framework for community engagement that informs future projects in support of the Kelp Plan. In other words, we want to lay the groundwork for the next iteration of the co-creation of knowledge cycle (Figure 3), so that it includes both co-design and co-production and moves us closer to our vision of diverse participation, intentional outreach, and transdisciplinary focus.

Community engagement in this project can therefore take many forms and be targeted at different goals and objectives operating at different timescales and scopes. Direct engagement in the indicator development project will necessarily be more narrowly defined to ensure consistency with the Puget Sound Partnership Vital Signs framework. Direct contributions to indicator development might include, but are not limited to:

- Sharing datasets to be included in the indicator;
- Suggesting priorities for the indicator to address, such as the time spans that the indicator considers (for example, shorter time spans are often preferred for feedback to management while longer time spans are preferred for cultural and ecological perspectives).
- Providing guidance on how the indicator meets individual needs to understand how kelp is doing and how it is changing.
- The *Project Team* also encourages contributions that might not neatly fit within the narrower boundaries of indicator development, but can be incorporated into the broader long-term project of the Kelp Plan. Potential ways to engage at this level include, but are not limited to:
- Contributing other information that enriches our understanding of indicator results and could be referenced as additional information (e.g., additional datasets, cultural or scientific studies, historical records, or other forms of knowledge);
- Defining measures of success to guide metric definition and later target setting (such as: total abundance, habitat usage by valued species, cultural uses).
- Linking the indicators to actions that conserve and protect kelp.
- Communicating why kelp is important to you, your community, and Puget Sound and articulating how floating kelp canopy area is linked to social-ecological well-being.

Leveraging the reputation and reach of the Puget Sound Partnership Vital Sign program presents an important opportunity to increase visibility and amplify communication around kelp conservation and recovery. In a spirit of relationship and exchange, we hope that the intentional and reflexive approach to community engagement in developing the floating kelp canopy area indicator contributes to making the Vital Sign program itself more inclusive, participatory, and transdisciplinary.

2.3. Key indicator attributes

The initial scoping process (Phase 1) explored what indicator attributes are most important. Table 2 synthesizes feedback, framed in terms of themes and considerations. The complete initial scoping report, public comments, and workshop recording are available on the project web site.

The Phase 1 public comments generally confirmed and further refined the draft themes and considerations that were presented in the initial scoping report. One notable difference is that public comments did not identify conceptual model development as a high priority. Therefore, the *Project Team* chose to rely on the conceptual frameworks developed as part of the Vital Signs. While conceptual models were not identified as a high priority, feedback confirmed the potential value of three types of conceptual models:

- A simple conceptual model could communicate common understanding rapidly to a broad audience.
- A 'kelp canopy centric' model could provide additional insight to the general *Beaches and Marine Vegetation* model within the Vital Signs.
- Advanced models could advance understanding and target additional actions.

Table 2: Summarized feedback during Phase 1 on key themes and considerations.

Theme	Key Considerations
Indicator audience and use	• Diverse audiences. • Single simple figure for rapid communication. • Detailed products that drill down into the data.
Temporal priorities	• Short-term (years). • Long-term (decades).
Geographical assessment priorities	• Sub-basins within Puget Sound. • Smaller assessment units to capture finer scale dynamics. • Include the open coast.
Metrics and data	• Maximize use of available data, while also considering data limitations. • Initial datasets will include canopy and bed perimeter from DNR, MRC volunteers, and the Samish Indian Nation. Other available data will also be included. • The program must be scalable to match available resources. • A strategic plan is needed to identify future expansion.
Critical linkages	• The indicator is limited to describing status and trends. • Linkages are needed to understand relationships to stressors, management actions, ecosystem components, and human well-being.

2.4. Background on canopy-forming kelp in Washington State

Washington State is home to 22 species of kelp (Mumford, 2007; Calloway et al., 2020). Two kelp species form extensive floating canopies, giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*). Giant kelp is limited to the open coast and the western Strait of Juan de Fuca. Bull kelp is broadly distributed; it occurs in all of the oceanographic sub-basins throughout greater Puget Sound, except Hood Canal. Floating kelp canopies grow along approximately 11% of Washington's shoreline, but are less widespread than understory kelp, which is found along 33% of the shoreline (Figure 3; Nearshore Habitat Program, 2001). Floating kelp canopies are generally more abundant in areas with strong waves and currents, proximate to oceanic influence.

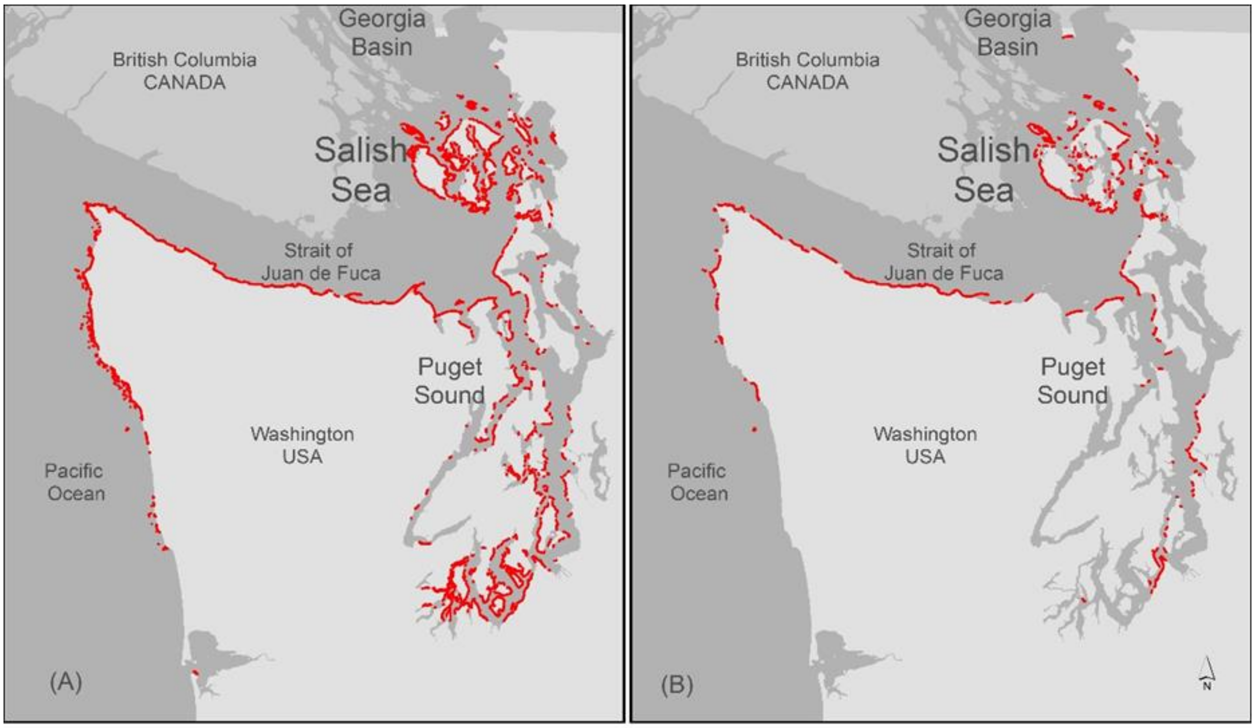


Figure 4: (A) understory and (B) floating kelp distribution in Washington State (Nearshore Habitat Program, 2001).

Giant kelp is a perennial species, the sporophyte phase living up to 9 years (Schiel and Foster, 2006). Bull kelp sporophytes are annuals, with few plants surviving through the winter following the spring/summer/fall growing season. These differing life histories suggest that giant kelp is a competitive dominant, while bull kelp is 'ruderal', and thrives under disturbance conditions (Dayton, 1985). Along the open coast and Strait of Juan de Fuca, bull kelp has shown much higher magnitude year-to-year variation (Pfister et al., 2018). Despite evidence of life history and ecological differences between the two species, the two species covaried positively in their sporophyte abundances over hundreds of kilometers and decades, which suggest that environmental factors primarily drove their dynamics rather than competition (Pfister et al., 2018). Both species have a microscopic gametophyte life stage about which little is known.

Among kelp species, abundance is positively related to relatively colder water temperatures and higher nutrient concentrations at multiple life stages, and is often linked to large-scale climate drivers (Dayton, 1985; Cavanaugh et al., 2011; Wernberg et al., 2012; Wernberg et al, 2016; Pfister et al., 2018; Muth et al., 2019; Hamilton et al., 2020). Because cold sea surface temperatures are often associated with increased nitrate, the relative role of each factor is difficult to separate. Local interactions such as herbivory and trophic cascades are also associated with patterns in kelp abundance (Graham, 2002; Watson and Estes, 2011; Smith et al., 2021). Variation in abundance has also been associated with other physical conditions, notably light, water motion, and substrate. Many human activities are known to impact kelp, including development, agriculture, and forestry (Wernberg et al., 2019). Researchers have identified factors including warming (Filbee-Dexter et al., 2016; Wernberg et al., 2019), eutrophication

(Moy et al., 2012), acidification (Connell and Russell, 2010), changes to community structure (Steneck et al., 2013), and sedimentation (Rubin et al., 2017) as contributing factors that often interact. There is a pressing need to identify the extent to which human activities are impacting kelp forest condition.

Describing trends in kelp forests is difficult because kelp species generally show high seasonal and inter-annual variability, and long-term data are lacking. In the most recent global assessment of all kelp species, Krumhansl et al. (2016) determined that kelp abundances on Washington State's open coast were stable, however this result was limited by a lack of long-term studies. The same study excluded greater Puget Sound from comparison due to insufficient data.

Local research and observations show that trends in floating kelp canopies are geographically distinct within Washington State. Major concerns exist about floating kelp losses within portions of Puget Sound. Traditional and local ecological knowledge from Tribes, residents, citizen-science surveys and historical analyses suggest substantial declines in extent in some areas and stability in other areas (described below).

Annual aerial surveys of the open coast and Strait of Juan de Fuca represent the longest-term dataset of floating kelp canopies. These data show high interannual variability but stability over the time span of decades (Pfister et al., 2018). Kelp dynamics between 1989 and 2015 were strongly related to large scale climate indices. Climate index correlations suggest that higher kelp cover occurred when seawater was colder and more nitrogen rich. Further comparison to historical maps along the Strait of Juan de Fuca showed that floating kelp canopy abundance over the last century was generally stable, with minor decreases in bed area along the far eastern shorelines, near Port Townsend.

Long-term studies in South Puget Sound and Central Puget Sound identified major declines over more than a century; recent floating kelp extent represented 20% of all historical observations (Figure 4). Many of the losses that were summarized in these studies were observed at relatively small spatial scales (1-10 km), including the disappearance of bull kelp from the shorelines of Bainbridge Island over the last 2 decades (observed by the Puget Sound Restoration Fund staff). Detailed temporal analysis within South Puget Sound showed that declines occurred across the whole time period, rather than abruptly (Berry et al., 2021). Floating kelp remains common in areas with intense currents and mixing, such as the Tacoma Narrows and Admiralty Inlet. Beds in other areas also persist but overall the outcomes in these areas are mixed. This spatial pattern suggests that areas with intense currents and mixing could be refugia from common kelp stressors. However, notable exceptions to this general spatial pattern underline the fact that other factors also determine floating kelp canopy distribution.

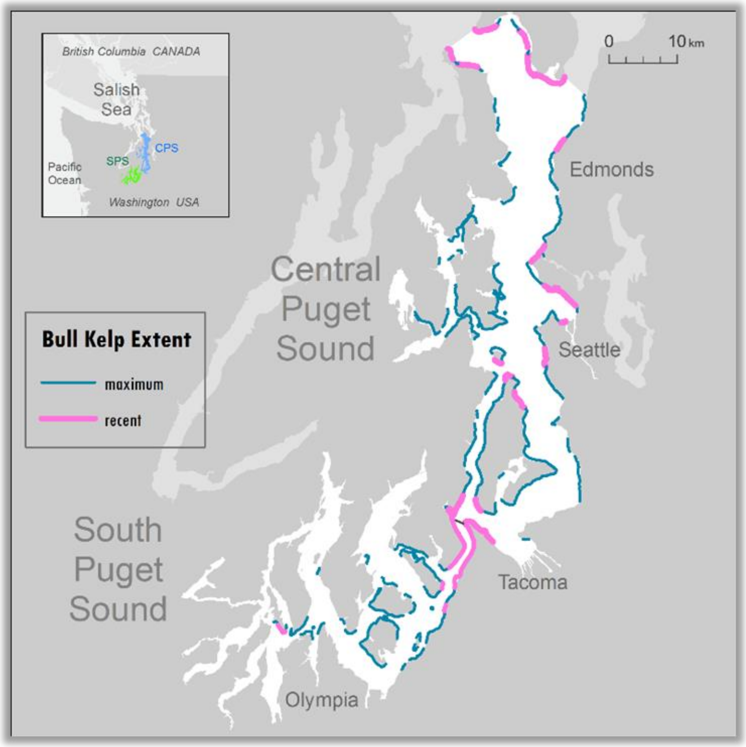


Figure 5: Comparison of the recent extent of bull kelp canopies to the cumulative maximum of all recorded observations in South Puget Sound and Central Puget Sound. The cumulative maximum extent was synthesized from historical data sources, including charts, surveys and (Berry et al., 2020, Berry et al., 2021).

In recent years, complex patterns of losses and stability have been observed. These data records span a pronounced marine heat wave that occurred around 2013-2016 in Puget Sound (Khangaonkar, 2021), and the timing and severity of declines and rebounds may be related to local water temperatures. Additionally, sea star wasting disease may have indirectly affected kelp populations through trophic interactions:

- Within South Puget Sound, substantial declines occurred at all four of the beds monitored by DNR between 2013 and 2019. At two sites, bull kelp disappeared and has not returned (Berry et al., 2019; Calloway et al., 2020). Between 2018 and 2020, monitoring sites were added in the Tacoma Narrows and Central Puget Sound. The data records for these sites are not yet long enough to test for changes over recent years.
- Since 2015, community-science kayak surveys detected substantial kelp canopy losses at sites near Mukilteo and Meadowdale in Snohomish County, without subsequent recovery (more information available from Snohomish County MRC). Kelp in other areas monitored by the MRCs was relatively stable during this time period, or dropped and then rebounded.
- Along the open coast and Strait, total canopy area decreased to half of its long-term average in 2014, then rapidly rebounded in 2015 (DNR, unpublished data). The strong rebound contrasts with persistent losses in northern California during this time period (Rogers-Bennett and Catton, 2020).
- At DNR's northern aquatic reserves, floating kelp canopy declines were observed in 2014, followed by recovery. However, the timing of recovery was distinct across the

reserves; the sub-areas proximate to oceanic influence and mixing began to recover in 2015, while increased abundances at the Cherry Point Aquatic Reserve were delayed until 2017 (DNR unpublished data).

The Samish Indian Nation used aerial photography from the San Juan Islands to compare estimates of kelp bed extent between 2004 (or 2006) and 2016. Results found that abundance in 2016 was 30% lower (Palmer-McGee, 2022). Over longer time periods, Indigenous Scientific Knowledge (also known as Traditional Ecological Knowledge) interviews with fishermen suggested areas of change and loss.

It is important to link observations related to floating kelp canopy status and trends to both stressors and management actions. Puget Sound experiences more human impacts and it may be more sensitive to stressors because the water is naturally warmer and has longer residence times. The *Kelp Plan* identified a compelling need to increase our understanding of kelp distribution and trends, with the associated tasks of linking observations to stressors in order to drive management actions. Identification of stressors and management actions are major future tasks to be addressed through the *Kelp Plan* and related efforts.

2.5. Background on floating kelp canopy monitoring techniques

Floating kelp canopy species are distinct from other kelp species because they have buoyant bulbs and blades that float on the water surface. Because floating kelp canopies are visible from the surface, a variety of 'above water' survey techniques are possible, especially remote sensing and boat-based surveys. Above water techniques are generally more rapid and cover larger areas than underwater methods, such as SCUBA. Underwater techniques are anticipated to be primary tools for the future Vital Sign indicator *understory kelp condition*. It is likely that some benthic measures of canopy-forming species will also be included in those surveys, such as holdfast density.

Remote sensing is an established tool for surveying and monitoring floating kelp canopies due to its ability to efficiently describe spatial patterns in canopy area density and condition (reviewed in Cavanaugh et al., 2021). The most common tools are passive optical sensors with coverage in the visible and near infrared (NIR) portions of the electromagnetic spectrum because vegetation reflects the incident radiation flux in the NIR region while seawater absorbs it (Jensen et al., 1980). In locations where other features occur close to the kelp canopies, it is substantially more challenging to use spectral characteristics to distinguish kelp from other features (i.e., land, intertidal substrate, breaking waves, other vegetation species). A variety of image analysis methods have been used (reviewed in Schroeder et al., 2019). Challenges related to remote sensing of kelp canopy increase in severity from south to north along the west coast of North America, due to more cloud cover, higher amplitude tides and currents, more complex topography, steeper bathymetry, greater turbidity and lower sun angles (Cavanaugh et al., 2021). The effects of currents and tides have been investigated most extensively (Britton-Simmons et al., 2008), and can have profound impacts on the extent of visible canopy in portions of Washington State. While the challenges in Washington State are greater, currents and tides have been shown to have major, site-specific impacts on canopy estimates in California also (Cavanaugh et al., 2021). Additionally, kelp forests tend to be narrow and lower density along the steep fjord shorelines in Puget Sound, which further challenges detection in imagery.

The most common remote sensing platforms are satellites, fixed wing airplanes, and drones. In Washington State, fixed wing platforms have been the most successful because they can be deployed during narrow windows when low tides and slack currents coincide with calm sea state during late summer. They can also collect imagery with meter or sub-meter scale resolution. Satellite platforms have longer revisit times (from days to weeks), which decreases the likelihood of capturing imagery during narrow time windows with acceptable conditions. Another challenge related to most existing satellite sensors is resolution; kelp canopies in Washington tend to be narrow and close to shore, making them difficult to detect by Landsat and other sensors. New satellite sensors, such as WorldView-2 may provide regional scale capabilities (Cavanaugh et al., 2021). At the local scale, drones provide a promising new platform for collecting high resolution imagery, with the ability to capture approximately 1 km of shoreline per low-tide along Puget Sound shorelines per low tide sampling event (Berry and Cowdrey, 2021).

At the local scale, small boats and other ground-based techniques can be highly effective at capturing detailed observations. Boat-based and drone techniques have been employed successfully at sites in greater Puget Sound (discussed in next section). Generally, the techniques that have been most successful in greater Puget Sound fall into the regional scale and local scale categories (Figure 5). A multi-scale monitoring approach with an emphasis on tools at the regional and local scale is likely to be most effective in Washington State for monitoring kelp canopies in the near term.

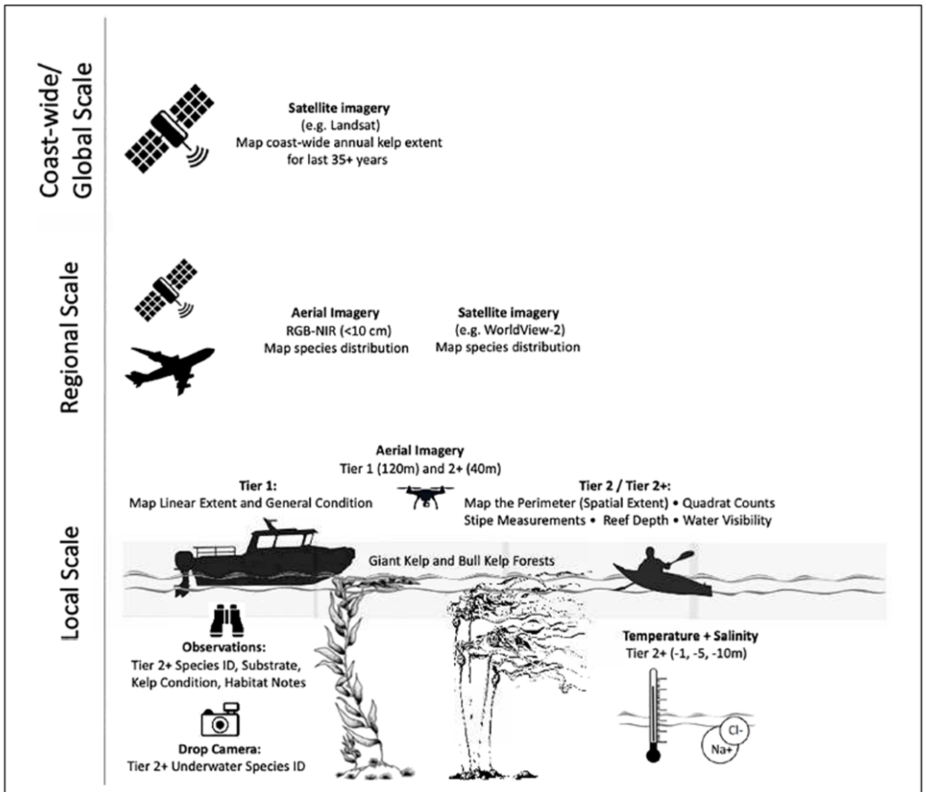


FIGURE 3 | Multi-scale canopy kelp monitoring approach taken by the Marine Plan Partnership. Local scale observations are separated into Tiers which represent increasing complexity of measurements.

Figure 6: Multi-scale canopy monitoring approach from the Marine Plan Partnership (MaPP) in British Columbia (from Cavanaugh et al., 2021).

2.6. Guidelines for data collection and inclusion

A primary objective of the initial indicator is to rapidly produce a reliable assessment of kelp status and trends, which will be enhanced over time. This approach will allow us to produce data-driven assessments of floating kelp canopy area status and trends in the majority of sub-basins of Puget Sound. However, other data sources may be available in some locations that may not be directly comparable to contemporary quantitative kelp data. Our goal is to honor all types of data through a blended approach that is flexible for the types of data available in a given sub-basin. This approach requires development of generalized guidelines for data collection and assessment that are applied in a custom manner in individual cases.

The proposed indicator will primarily synthesize data created using the following data collection techniques:

- Airborne imagery and satellite collected from a fixed wing or drone platform or satellite. Satellite imagery is not included in Phase 2 indicator datasets due to lack of appropriate data identified. Preferred environmental conditions are specified because the visible canopy is known to be strongly influenced by tidal stage, currents, and weather conditions (Britton-Simmons et al. 2008). Preferred equipment is identified, but can be relaxed in order to expand the available data for consideration, with acknowledgement of additional uncertainty. Specifications include:
    - Environmental factors
        - Seasonal window: period of maximum extent, approximately July 15 - September 15.
        - Tidal stage of +1 ft MLLW or lower.
        - Slack currents (generally a one hour window that precedes and follows low tide, but slack current is offset in many areas)
        - Calm sea state (generally surface winds < 10 knots and minimal swell)
        - Cloud free skies.
    - Imagery characteristics
        - Ground Sample Distance = 6 inch or smaller preferred
        - Spectral properties: 4-band RGBN sensors or multispectral sensors preferred.
        - Digital georeferenced imagery.
- Ground-based surveys from small boats, such as kayaks or skiffs. Spatial extent of canopy is acquired with handheld GPS units and bed/environmental characteristics are recorded on field datasheets. Environmental conditions also require low tide.

- Traditional/Indigenous Scientific Knowledge that document the occurrence of floating canopy kelps.
- Historic reports/publications that document presence/absence of floating canopy kelps that use substantially different methods from contemporary sources and/or are temporally discontinuous with contemporary data sources.
- Personal observations from local experts on that document the occurrence of floating canopy kelps.

Because specifications and methods vary by project, documented procedures will be produced for each individual dataset that is included in the indicator, and will be referenced in the sub-basin reports (Section 2.14).

2.7. Guidelines for data assessment and analysis

A primary objective of the indicator is to present as much floating kelp canopy data as possible that follow the general guidelines in Section 2.6. This may mean presenting diverse datasets together. While this produced challenges, using as much data as possible provides the most complete picture of kelp canopy area in Washington State. In general this means that individual datasets may need specific attention to match the high level framework to present data in, namely the proposed Info-map (see Section 2.14). It is important to note that individual sub-basin assessments are based on distinct groups of data, collected with different techniques, spatial/temporal coverage and assumptions. Because of this we produced (and recommend users consider) sub-basin reports (Section 2.14) that detail the analysis and trends of canopy kelp in a given sub-basin. Datasets that don't meet assumptions for quantitative analysis in a given sub-basin will not follow the regression analysis described below. Alternatively, these will be assessed and synthesized with quantitative data depending on their structure. Guidelines for this synthesis are detailed in Section 2.9 and how they are specifically applied will be detailed in sub-basin reports (see Section 2.14 and Appendices 3 - 6).

General guidelines for assessing and analyzing contemporary quantitative datasets and categorizing datasets are below and in Sections 2.8 and 2.9:

- At a minimum we will present status and trends at the sub-basin scale (see section 2.10).
- We will address differences in techniques among datasets by only conducting analysis within datasets and considering uncertainty, especially total spatial and temporal extent of data while also considering data limitations (i.e., tides and currents). If multiple datasets exists for a sub-basin, results from separate analyses will be compared following the guidelines in Section 2.9
- Canopy and/or bed (see Section 2.9) area should be summarized annually and at as many spatial scales as possible (see Section 2.10). This structure will allow for a wide range of analyses that can toggle spatial and temporal scale.
- Since most raw data on floating kelps are spatially defined polygons, this will mean splitting polygons by sub-basin, reach, zone, and site delineations (see definitions in Section 2.10).
- Year over year change in kelp bed/canopy area should be assessed using the general regression equation 1.

Equation 1: $$kelp\ area = \beta\ year \times \beta\ spatial\ unit + \varepsilon$$

Where $kelp\ area$ is the bed/canopy area, $year$ is the calendar year in which the kelp area was surveyed and *spatial unit* is a categorical variable of the spatial unit in which the kelp area is summarized. If data allow, this regression should be run where $year$ is bounded by the last 5 years of data ('recent' see Section 2.8) and for all years ('entire data record' see Section 2.8), and for as many *spatial units* smaller than sub-basin as are available (see Section 2.10). This will allow an assessment of kelp bed/canopy trends at recent and entire data record time spans across multiple spatial groupings. Note that the intercept is removed in equation 1. Below is an example of how equation 1 is parameterized in the R programming language.

```
lm(kelp.area ~ 0 + year + zone, data = kelp.data)
```

The leading zero removes the intercept and `kelp.data` is a data frame where each row is a unique combination of `year` and `zone` with its associated kelp area. For this provisional scoping effort we elected to remove the intercept because doing so removes the mean *year* and *spatial unit* response from fitting *kelp area*. This allows annual growth rate to be more easily compared across sub-basins. However, we acknowledge that this assumes that the theoretical *year* 0 and the absence of a *spatial unit* there would be 0 *kelp area*.

The extent to which Equation 1 can be implemented is dependent on the structure of the dataset. Therefore, the form and extent of dataset analyses are detailed in sub-basin reports (see Section 2.14 and Appendices 3 - 6).

If data allows for regression analysis, results can be displayed multiple ways that are detailed in sub-basin reports (see Section 2.14 and Appendices 3 - 6). At a minimum, a synthesis of regression results for all datasets within a sub-basin will be reflected in the color of the kelp status icon for appropriate time spans (see Section 2.8) and presented in visual summary and technical products (see Section 2.14).

2.8. Guidelines for time period delineations

Canopy kelps experience a high degree of year-to-year variability and are sensitive to changes in environmental conditions. Therefore assessing trends in kelp canopy area at multiple time scales is useful for understanding kelp status. Table 3 defines three time periods where assessments of kelp canopy status and trends are made. Proposals of how these time periods, along with kelp status, are displayed are detailed in Section 2.14 and Appendices 1 - 6. In recognition that the Partnership places on rigorous scientific assessment we propose incorporating data that does not conform to conventional scientific analysis in an "overall' assessment category. See Section 2.14.2 and Appendix 1 for an alternative that incorporate all types of knowledge into the two time periods.

Table 3: Proposed time periods for sub-basin scale assessment of the floating kelp canopy indicator

Name	Definition
Recent	The most recent 5-year period. Recent trends address responses to management actions and ongoing observations but they are often driven by weather and climate conditions.
Entire data record	The time span of the existing record varies by sub-basin and dataset. The initial indicator will present results for all available time spans and then document the final result. Longer time spans are weighted more heavily in final classification.
Overall	Synthesis of recent and entire data record as well as qualitative incorporation of other data sources (as available) from the sub-basin.

The ability to make assessments of kelp trends at each time span will depend on the structure of the dataset in question. This decision and rationale will be detailed in sub-basin reports (see Section 2.14 and Appendices 3 - 6).

2.9. Guidelines for status and trends classification categories

The proposed indicator will assess floating kelp canopy primarily at the sub-basin scale in order to capture known differences in kelp condition in sub-areas across the landscape. Both canopy and bed metrics will be considered to the extent possible with available data using statistical tests or descriptive statistics (Section 2.7) that are appropriate to the datasets (Table 4). Canopy is the preferred metric, where available, because it is the more precise measure of abundance. While it is a less precise measure of abundance, bed area provides areal estimates and can be collected with a variety of methods, including kayak. Existing data suggests that changes over time are often similar when considering canopy vs bed area. At locations where both canopy and bed area results are available, assessment will consider canopy area first and secondarily consider consistency with bed area results. Shoreline linear extent metrics are least preferred because they are the least precise. However, where other data are lacking, they can effectively capture patterns in presence and major changes in extent. Linear metrics can also serve to reduce datasets with incompatible spatial representation to a common denominator thereby facilitating direct comparisons. Linear extent data is often also available over larger spatial extents. Where data is available, total area will be evaluated in order to understand the overall abundance of the resources. In addition, a count of the status of individual sub-areas such as reaches and zone will identify changes in abundance over smaller areas that are not visible in total abundance estimates.

Status and trend classification assessment will occur over all the recent, entire data record, and overall time periods for the appropriate datasets (Section 2.8). For presentation of simplified results to a broad audience, all data will be rolled up into one of seven categories for each sub-basin (Table 5) that describe indicator abundance in terms of whether it is increasing, decreasing, stable, concern, data-deficient, or absent. These categories adopt the standard ‘stop light’ color coding convention for rapid interpretation (see proposed examples in Section 2.14).

Table 4: Proposed metrics and spatial aggregation categories for sub-basin scale assessment of the floating kelp canopy indicator.

Type	Description
metric	canopy area bed area shoreline linear extent
spatial aggregation scale	total abundance frequency of increasing, decreasing, or stable sites

Table 5: Proposed categories for sub-basin scale assessment of the floating kelp canopy indicator.

Name	Description
Increasing	Statistically significant increase or clear pattern of increase over time in summary statistics.
Stable (no trend)	Non-significant trend test or pattern without strong slope over time in summary statistics.
Concern	Patterns in the data suggest potential losses but uncertainties preclude definitive classification, either due to data uncertainties or subtle patterns. This category identifies a need for further research or monitoring.
Declining	Significant trend test or clear pattern of loss over time in summary statistics.
Insufficient data	Cases: 1) Available data lacks sufficient spatial or temporal coverage. 2) Uncertainties in the data limit its use for assessment of changes over time.
None present / documented	No bull kelp documented in the sub-basin. This category potentially applies to Hood Canal, pending further investigation.

In the best case scenario, clear trends in kelp area for a given time span will be evident from visual (plots) and regression analysis (see Section 2.7) for all datasets in a sub-basin. However, given the paucity of existing datasets, the diversity of datasets included in the indicator project, and the potential for multiple datasets to exist in a single sub-basin, it is likely that this will not always be the case (Section 2.6). Therefore, we outline guidelines for synthesizing patterns, results, and information from these potential sources below, with specifics actions documented in sub-basin reports.

In general we place a relatively heavy weight on data-driven patterns, although differences among intra sub-basin datasets may make one-to-one data comparisons challenging or inappropriate. In an effort to not exclude data, we suggest the following considerations in making final kelp status and trend designations at all time spans. If and how these considerations are applied are detailed in each sub-basin report (see section 2.14, Appendices 3 - 6). Considerations include:

- Patterns indicated by field survey data: What information can be gained from plots and regression output? What is the relative strength of those trends? What proportion of total sub-basin kelp area do these data cover? What level of uncertainty is associated with those data?
- Indigenous Scientific Knowledge: If available, what does Indigenous Scientific Knowledge indicate about floating kelp area in the sub-basin and how does it compare to other observations? What is the magnitude of difference? What is the time separation? What uncertainties are associated with the various datasets?
- Other data: If available, what does other data sources (e.g. peer-reviewed, gray literature) indicate about floating kelp in the sub-basin? What is the magnitude of difference? What is the time separation? What level of uncertainty is associated with those data?
- Outside expert opinion: Floating kelp is a nearshore species and therefore is often visible to members of the public, researchers, managers, etc. Presenting findings from the above list to individuals or groups with local knowledge may provide a useful check on status and trends. In that process it will be important to consider the following. What proportion of total sub-basin kelp area do these data cover? What is the magnitude of difference? What is the time separation? What level of uncertainty is associated with those data?

2.10. Geographic assessment areas

Most Vital Sign indicators are summarized throughout greater Puget Sound, and also tracked within spatial sub-divisions that capture meaningful differences in the indicator, such as 'spawning per river' for Chinook salmon. For indicators such as kelp, that have widespread distribution and are known to respond to local and regional conditions, sub-areas are generally based on prioritized physical, biological, and/or management factors.

This section proposes a series of hierarchical geographical areas for evaluating and reporting floating kelp canopy. The hierarchical structure and the levels within it consider related physical, chemical, biological, and management factors (Table 6).

Table 6: Proposed hierarchical geographic assessment levels

Name	Description	Approximate Number of Units Statewide	Size (shoreline km per feature)
study area	All saltwater areas throughout Washington State	1	to be calculated
sub-basin	Areas with similar oceanographic conditions, sub-divided at shallow sills.	10	~100-1000 km
reach	Intermediate scales of consideration that group stretches encompassing multiple site groups. Delineations between reaches focus on large geomorphological boundaries taking into account features such as fetch, shoreline type, and aspect.	10s-100	~10-100 km
zone	Units of shoreline with similar geomorphic characteristics. Variable in length. Divided at breaks in geomorphology with boundaries placed at features such as headlands. (Shoreline units in this category are also called "map indices")	100s	~1-10 km
1-km segment	Equally-sized stretches of shoreline, defined as 1-km of shoreline along the -6 m bathymetry contour. Delineated statewide as part of the DNR SVMP and Marine Vegetation Atlas.	1000s	1 km
site	Custom boundaries defined for specific research and/or management objectives. E.g. DNR kayak sites	undefined (custom)	~1 km

2.10.1. Study area

We propose that the floating kelp canopy area indicator study area span all of Washington State's saltwater shorelines. While the exposed coast lies outside of the Puget Sound Partnership planning area, understanding status and trends in kelp canopies in this distinct region is critical from an ecological perspective in order to compare conditions in the inland sea to the exposed coast. It is also critical to comparing observations within Washington State to adjacent regions and globally. The importance of including the exposed coast was a strong theme in feedback from a broad cross-section of scientists, federal and state managers, NGOs, citizens, and tribes (see comments on the initial scoping during Phase 1.).

2.10.2. Sub-basins

We recommend adopting oceanographic sub-basins as the first major division of the Washington State study area. Within greater Puget Sound, basic oceanographic processes are commonly captured by subdividing the region into sub-basins, with the boundaries placed at shallow, interconnecting sills. In addition to capturing oceanographic characteristics, sub-basins divide the study area into areas with similar environmental characteristics and stressors. Finally, sub-basins prove useful for reporting results to general audiences because the geographic names of the water bodies are widely recognized.

The challenge in defining sub-basins is to capture the most important spatial differences and to select a number that is tractable for sampling and reporting. Increasing the number of sub-basins can allow for greater spatial discrimination, but in cases that rely on sampling this requires greater sampling effort in order to collect a sufficient number of samples to characterize conditions. Because the initial *floating kelp canopy* indicator is based on integration of existing data rather than probabilistic sampling, sampling effort is minimally considered in reference to the number and size of sub-basins. Substantial spatial and temporal data gaps currently limit our current ability to report trends for many sub-basins (see section 2.12). Future considerations of floating kelp canopy monitoring efforts will consider sub-basin size and location for sufficient reporting.

Many sub-basin delineations exist, with clear commonalities and minor differences. For the *floating kelp canopy* indicator, we recommend adapting a widely used sub-basin delineation that was created by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). Figure 6 outlines ten proposed sub-basins and also notes uncertainties related to the precise placement of boundaries (Table 7). We recommend limiting the total number of sub-basins to ten or fewer in order to maintain a tractable number for reporting. Major differences between the proposed sub-basins and the PSNERP delineation:

- The Strait of Juan de Fuca is split into western and eastern portions in order to subdivide gradients in conditions. Many other classifications split these areas, including NOAA's Rockfish Recovery Plan and Marine Areas (Harvest Management). Existing research hypothesizes differences in kelp canopy dynamics between the Western and Eastern Strait.
- The San Juan Islands and North Puget Sound are proposed as distinct sub-basins (rather than lumped into San Juan Islands and Georgia Strait). The classification of the San Juan Islands often varies among delineations, with three main alternatives: independent, lumped with Georgia Strait, or lumped with the Strait of Juan de Fuca. The San Juan Islands have intermediate characteristics overall and strong gradients. The north and south portions are more similar to adjacent areas in many attributes than they are to each other.
- The name 'Admiralty Inlet' is proposed as more distinct and easily recognizable (rather than 'North Central Puget Sound').
- The name 'Central Puget Sound' is proposed as more distinct and easily recognizable (rather than 'South Central Puget Sound').

While sub-basins are useful for spatial summation, the precise placement of boundaries can be somewhat arbitrary where there is no clear physical basis for boundary placement. Table 7 describes the provisional placement of boundaries in eight locations that often challenge boundary determination.

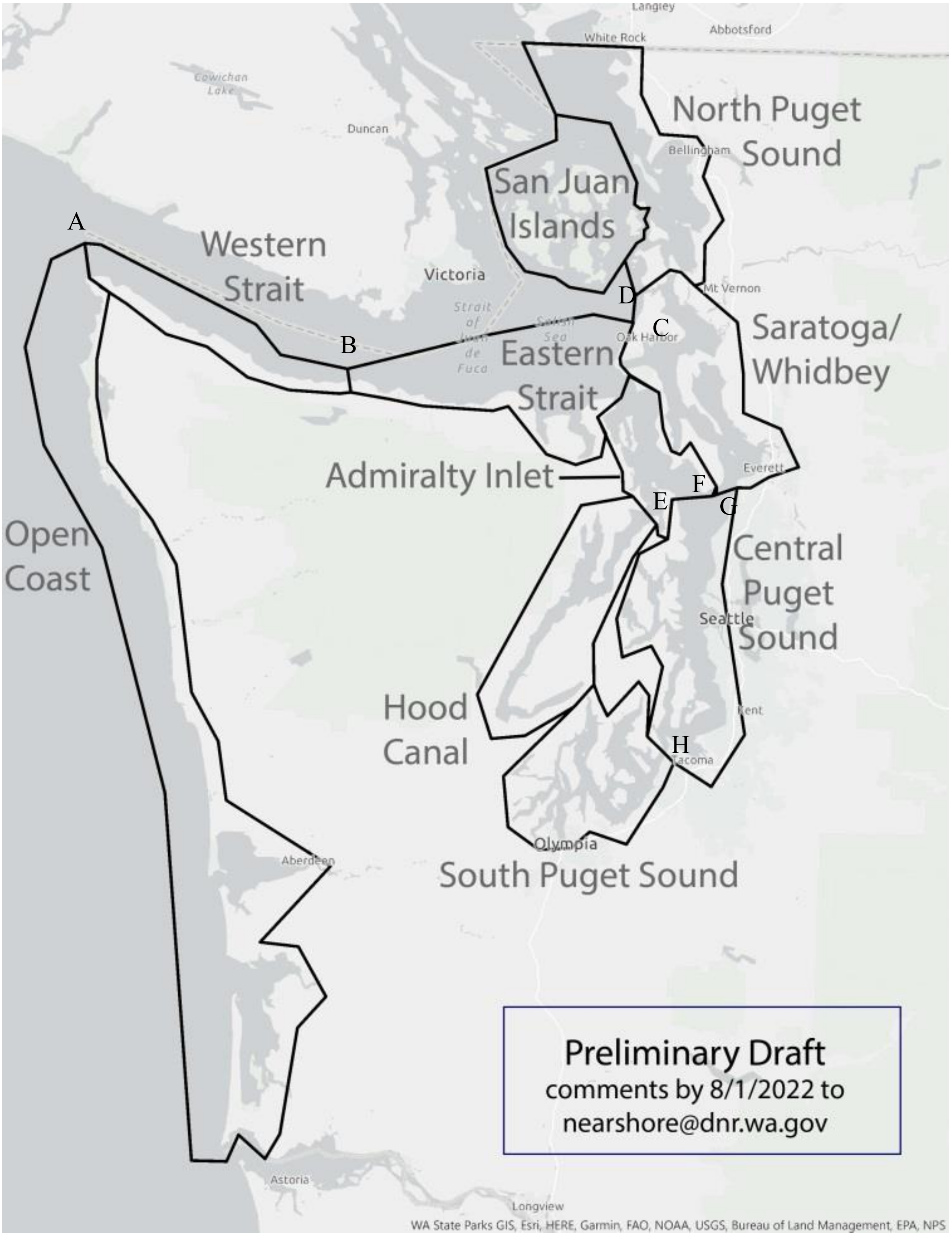


Figure 7: Proposed sub-basins for the floating kelp canopy indicator. Letters identify areas of uncertainty for sub-basin designation, described in Table 7.

Table 7: Uncertainties related to sub-basin delineation for feedback

Letter in Map	Feature	Description
A	Boundary between Western Strait and Exposed Coast sub-basins	Tatoosh Island and Cape Flattery are placed within the Exposed Coast sub-basin, just outside of the boundary of the Western Strait sub-basin.
B	Boundary between Western Strait and Eastern Strait	Placed west of Crescent Bay, where giant kelp (*Macrocystis*) canopies become common. Alternative boundaries: 1) the Victoria Sill (east of Port Angeles), identified in NOAA's Rockfish Recovery Plan and other delineations; 2) Low Point, a Marine Area boundary for Harvest Management and other delineations.
C & D	Boundary between the Eastern Strait, the San Juan Islands, North Puget Sound and Admiralty Inlet	Western Whidbey Island is currently placed in the Eastern Strait, in consideration of large fetch (C). Smith Island is also included (C). Deception Pass constitutes the boundary between three sub-basins, with the Eastern Strait to the south, North Puget Sound to the north and Saratoga/Whidbey to the east. North Puget Sound begins at Deception Pass and contains all shorelines to the north, except the San Juan Islands (D). The San Juan Archipelago and Cypress Island are placed within the San Juan Islands sub-basin. The boundary between the Eastern Strait and Admiralty Inlet extends from Point Wilson to Admiralty Head.
E	Hood Canal	The northern boundary of Hood Canal occurs south of the bridge. Floating kelp canopies have not been reported in this sub-basin.
F	Northern boundary of Central Puget Sound	The northern boundary of Central Puget Sound is placed between Possession Point and Point-No-Point.
G	Saratoga/Whidbey boundary	The southern boundary is placed at Possession Point, near the southern boundary of Marine Area 8-2 (Harvest Management).
H	Boundary between South Puget Sound and Central Puget Sound	The boundary is placed at Point Defiance, with the Tacoma Narrows falling within South Puget Sound.

2.10.3. Reaches

Reaches describe areas that encompass scales of 10-100 km of shoreline. They serve as an intermediate scale of identification, by lumping stretches of shoreline with similar characteristics within sub-basins.

In order to examine their utility, reaches have been defined for 'proof of concept' within the Western Strait, Eastern Strait, San Juan, and South Puget Sound sub-basins (see San Juan Sub-Basin Report). Reaches allow for rolling up of status and trends data for examination of differences within and among nearby locations within sub-basins (or across sub-basin boundaries). Reaches are defined to occur within a single sub-basin, with coincident boundaries.

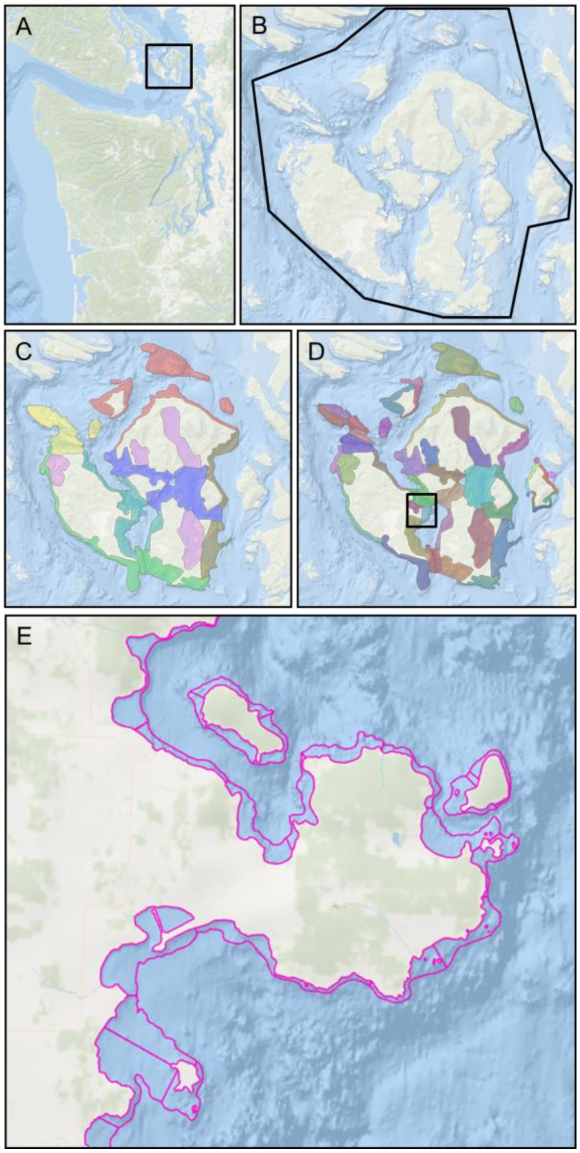


Figure 8: Coastal Washington State (A) with San Juan Islands inset, San Juan Islands sub-basin (B), reaches within sub-basin (C), site groups within reaches (D) with detailed inset, 1 km site polygons (E).

2.10.4. Zones, 1 km segments, and sites

We propose three options for the highest resolution units of geographical assessment, to be defined comprehensively within sub-basins as part of the initial indicator. For the initial indicator, we have implemented the option that can be most rapidly produced will be implemented within each sub-basin:

- Zones: This is a proposed name change from "map index". Span stretches of shoreline ranging from approximately 1 km to 10 km in shoreline length. Units are variable in length because they are defined to encompass areas with similar geomorphic characteristics, such as embayments. Boundaries are placed at features such as headlands. Polygons can be delineated fairly rapidly to encompass the depth range where kelp would occur. Map indices have been defined for the following sub-basins: exposed coast, Western Strait, Eastern Strait, San Juan Islands.
- 1 km segments: State-wide sites consist of 1 km segments of shoreline, measured at the -6 m bathymetry contour. Sites have been defined state-wide by DNR for the Submerged Vegetation Monitoring Program and applied for floating kelp monitoring in CPS and SPS. However, additional work is needed in most regions to expand the depth range of the site polygons to encompass floating kelp habitat. In regions with complex nearshore bathymetry and convoluted shorelines, such as the San Juan Islands, expansion of polygons to deeper depth ranges requires substantial effort.
- Sites: Custom sites vary in size and were created for specific small-scale research and or management activities. For example, custom sites have been defined for kayak, drone and other high resolution assessments by the MRCs, DNR and other organizations.

Proposed implementation plan:

- Due to the substantially greater effort involved in implementing 1-km sites for kelp monitoring, we propose that the initial indicator use sites in sub-basins where they have previously been implemented (South Puget Sound and Central Puget Sound); and map indices in all other sub-basins. During implementation, the project team will further consider the utility of each unit, along with the effort necessary to implement within the sub-basin.

2.11. Data management

Data used for indicator development spans multiple organizations and cooperative agreements. The organizations that collect and curate these data sets will retain the rights to these data and therefore serve as the long term stewards of those data. The floating kelp canopy indicator uses these data with permission through cooperation and collaboration with organizational partners. As a part of the indicator communication products (see section 2.14) the project will produce dataset descriptions which summarize each dataset, along with additional processing or interpretation related to inclusion in the indicator. The dataset descriptions also link to detailed metadata and other documentation that is provided by the data owner.

Table 8: Overview of datasets currently used for indicator development. Note this does not include other non-quantitative sources used in status and trend delineations. See sub-basin reports (Section 2.14 and Appendices 3-5).

Dataset	Owner/ Originator	Years	Frequency	Methods	Coverage
Long-term monitoring of the Coast, Strait using Aerial Photography (COSTR)	Washington Department of Natural Resources	1989 - 2021	annual	fixed-wing aerial	comprehensive
Long-term monitoring of the Aquatic Reserves using Aerial Photography (AQRES)	Washington Department of Natural Resources	2011 - 2021	annual	fixed-wing aerial	comprehensive
Samish Kelp Canopy Surveys in Traditional Territory (Samish)	Samish Indian Nation	2006, 2016, 2019	infrequent, planned for every 3 years	fixed-wing aerial	comprehensive
Volunteer Kayak Monitoring by Marine Resources Committees (MRC-kayak)	Northwest Straits Commission	2015 – 2021	annual	kayak bed perimeter	17 sites
Kayak Monitoring by DNR in Central and South Puget Sound (DNR-kayak)	Washington Department of Natural Resources	2013, 2017 – 2021	Annual depending on location	kayak bed perimeter	13 sites
Shoreline survey of floating kelp presence of central Puget Sound (CPS-boat)	Washington Department of Natural Resources	2019	infrequent	boat transect	comprehensive
Shoreline survey of floating kelp presence of south Puget Sound (SPS boat)	Washington Department of Natural Resources	2013, 2017	infrequent	boat transect	comprehensive

2.12. Priorities for enhancement

In the course of developing this first iteration of the *floating kelp canopy area* indicator, the Project Team and contributors have identified areas where management, research, and engagement related to kelp can be enhanced in the future. However, such activities will likely require additional funding.

2.12.1. Overall strategic direction

Currently, the kelp vital sign indicator is informed by data collected using diverse methods, including fixed-wing aerial surveys, drone surveys, and kayak surveys. The current strategic direction is to continue to conduct and support current monitoring efforts, while expanding and enhancing both data collection and analysis methods.

The DNR monitoring team is finalizing a field data collection proposal for 2022, which includes expanded fixed-wing aerial imagery surveys. This field work will explore the standardization of large-area imagery collection and processing in areas with large floating kelp beds. This imagery will be collected using well-established, widely used equipment for this region: 4-band digital imagery collected from a fixed-wing aerial platform. Additionally, geo-rectified imagery will be collected in ideal conditions (slack current, low tide, optimal sun angle, etc.), to obtain comparable data across sub-regions. The data collected during this fieldwork will also inform the formalization of imagery processing and classification techniques by DNR for use with the floating kelp vital sign.

In addition to expanded aerial data collection, teams will continue to use boat and drone-based surveys at existing sites, including small, low-density floating kelp beds.

Data collection during summer 2022 will provide scoping information to define resources needed for various options for monitoring extent and frequency of floating kelp canopies in Washington State. This will be particularly useful for further developing the strategic direction of aerial kelp monitoring by providing information on the resources needed to collect these data. Ideally, DNR would collect imagery of floating kelp canopies throughout Washington State annually in order to detect trends in kelp distribution and abundance at a fine scale. However, due to limited resources, this approach is currently not feasible to maintain, and there are multiple alternative approaches that would allow detections of trends in floating kelp distribution and abundance (Figure 10). There are two general options to reduce costs for floating kelp canopy monitoring, and each has its own tradeoffs regarding data usage into the future. The first alternative (Alt A) would be to identify core areas for annual monitoring, such that only certain areas of kelp canopy in the state are monitored. The benefit of this approach is that those locations would have frequent surveys, allowing for fine-scale detection of trends and change. The second alternative (Alt B) is to monitor all shorelines in Washington, but with rotating panels (i.e., a subset of sites is sampled each year, and each individual site is sampled every 3 or 5 years). The benefit of this approach is that all shorelines are monitored, but the tradeoff is that high frequency trends may be more difficult to detect, due to less frequent data collection at each location. Satellite imagery shows promise to augment or replace fixed wing aerial imagery.

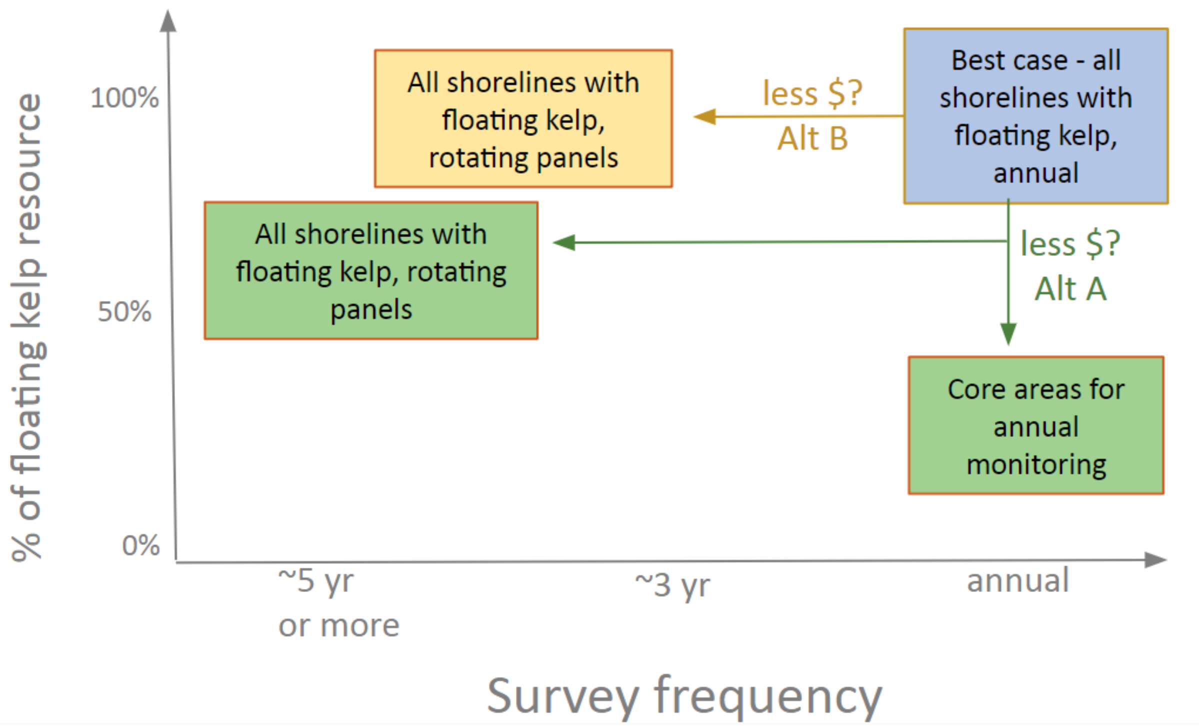


Figure 9: Scope and alternatives for frequency and temporal coverage of floating kelp canopies in Washington State. At the top right corner, all kelp in the state would be monitored annually (ideal from a data-collection perspective, but feasibility is heavily dependent on funding availability). As you move down or to the left in the figure, operating cost decreases, but there are trade-offs with the quantity of data that is collected.

2.12.2. Current research needs

Below is a list of current research needs developed by the *Project Team* from the perspective of indicator development. This is not meant to be comprehensive or final. Acting on these research needs will depend on funding and partnerships.

- Determine cost and resources needed for large-scale fixed-wing aerial surveys of kelp canopy, and further develop alternatives for the strategic plan moving forward.
- Further develop understanding of uncertainty in survey measurements related to environmental conditions.
  - Possible approach: consider flying multiple 'passes' of certain areas during fixed-wing and drone surveys
- Explore satellite and airborne multispectral sensors as long-term options for floating kelp canopy monitoring. Current satellite products do not capture a representative extent of kelp canopies in Washington State, but improved imagery technologies and/or analysis algorithms may make this a valid option for the future.
- Fill gaps in currently available data by leveraging historical studies
  - Possible data sources: analyze available imagery (e.g., NAIP), synthesize diverse sources
- Expand linkages to other datasets and programs with an eye towards potential future program expansion and broadening collaborations.

2.13. Linkages

2.13.1. Overview

The indicator is limited to describing status and trends in floating kelp canopies. However, to be effective, it needs to link broadly to research and management actions. This section provides an overview of key envisioned connections to efforts that are outside of the direct scope of the indicator yet are critical to its overall success.

2.13.2. The Kelp Plan

In 2020, the Kelp Conservation and Recovery Plan (*Kelp Plan*) called for coordinated action to protect and restore kelp in the face of documented losses in some areas and widespread concerns (Calloway et al., 2020). The Kelp Plan provides a framework for coordination to deepen understanding of the value of kelp to Puget Sound ecosystems, to identify trends, to prioritize stressors, and to mobilize management responses. The floating kelp canopy area indicator is one component of many actions that address the six strategic goals identified in the Kelp Plan.

The Kelp Plan implementers will serve as the primary umbrella organization for coordinating kelp-related activities, coordinated by the Northwest Straits Commission. We propose that the indicator Project Team participates in that group to maintain broad connections between the floating kelp canopy indicator and other scientific and management work related to kelp.

Conceptual models and causal frameworks are commonly used to understand relationships between ecosystem health, stressors, human activities and management. The Partnership has developed conceptual models for the PSEMP program, and for the floating kelp canopies indicator within the Beaches and Marine Vegetation Vital Sign (Appendix 12).

The Project Team proposes exploring the potential usefulness of further conceptual model development in the context of the Kelp Plan implementers. A simple conceptual model could be a useful communications tool to rapidly convey collective understanding of the system and deepen public understanding. More advanced models could drive research and management actions.

2.13.3. Linkages to management

In order to drive conservation and recovery actions, it is important to link the indicator to management responses. This linkage is particularly challenging given the distributed nature of tribal, private, local, state, and federal management entities. The Project Team proposes that management connections be considered primarily through participation in the Puget Sound Ecosystem Management Program (PSEMP), Kelp Plan implementation (above) and the Habitat Strategic Initiative for Marine Vegetation.

2.13.4. Linkages to research and monitoring

Like many other indicators, the strength of the *floating kelp canopies* indicator is that it will summarize scientific understanding of conditions at a regional scale. This strength comes with limitations, including: 1) the indicator does not explicitly examine stressors that might be driving observed trends; 2) the indicator does not conduct intensive, high-resolution research. Connections are needed between the indicator *Project Team* and other work that addresses these topics. These connections could be made through regional coordination groups (see Partners and Groups, below).

Research into stressors is a high priority because they can be linked to management actions. Stressor research often takes place through targeted research projects. Sentinel sites - or other high resolution, intensive monitoring sites - are also common complements to large area indicator work. These could be newly established or built on established at locations of substantial existing research, such as: Tatoosh Island, Elwha, FHL sites, etc.

2.13.5. Partners and groups

The *Project Team* proposes collaborating whenever possible to strengthen connections with local land stewards, managers and scientists. We envision partnerships with individual organizations to be unique. They could be formal or informal, and vary in length. Partnerships with tribal nations are of paramount importance from scientific, management and cultural perspectives.

Regional groups provide important coordination hubs. Priorities for participation include: The *Kelp Plan* implementers, the PSEMP Nearshore Workgroup, the UN Kelp Node, and the Puget Sound Kelp Research and Monitoring Workgroup.

Formal partnerships with local managers and other organizations interested in improved management could strengthen related research, community involvement, and management actions. Potential examples include:

- Samish Indian Nation
- Northwest Straits Commission and Marine Resources Committees
- DNR Aquatic Reserves Program
- The Pew Charitable Trusts

Formal or informal collaborations for research and monitoring could include:

- Ongoing Elwha shoreline research including: USGS, Lower Elwha, and SeaGrant.
- University of Chicago (long-term monitoring at Tatoosh Island, in coordination with the Makah Indian Tribe).
- Academic institutions, including UW Friday Harbor Laboratories
- The Olympic National Marine Sanctuary
- Reef Check
- UN Kelp Node
- Puget Sound Restoration Fund (restoration and sub-tidal monitoring)
- NOAA
- WDFW

Question for feedback: what partnerships should be prioritized for *floating kelp canopies* indicator work? What groups should the *Project Team* reach out to? We would like to hear from potential partners.

2.14. Communication products

2.14.1. Overview

The proposed *Blended Indicator* (Figure 11) will include two product types; (1) visual summary products and (2) technical products. Visual summary products will include the proposed *Info-map* and *Sub-basin summary pages*. The *Info-map* will be posted on the Puget Sound Partnership "Puget Sound Info" website and link to the Kelp Hub website. The *Info-map* will be duplicated on the Kelp Hub website which will also house *Sub-basin summary pages*. Technical products serve as the ultimate documentation of the indicator and therefore support visual summary products. There will be three technical products; (1) indicator guidelines and procedures, 2) sub-basin reports, and 3) dataset descriptions. These documents will be accessible in PDF form on the Kelp Hub website. Pending available funding and data, all visual summary products and technical documents will be updated annually.

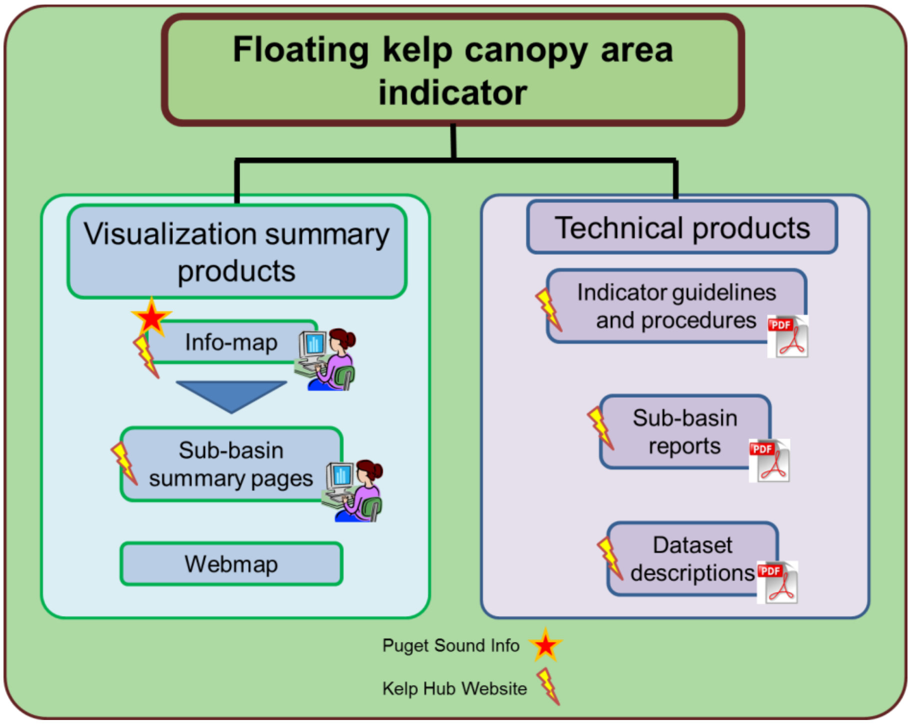


Figure 10: Schematic representation of the proposed *Blended Indicator* for the floating kelp canopy area indicator. The documents package will consist of PDFs of indicator assessment procedures, sub-basin reports, and dataset descriptions. These documents will be housed in the Kelp Hub website. The indicator visualization will consist of interactive webpages. The *info-map* will be housed on Puget Sound Info website and the kelp hub website, and sub-basin summary pages will be housed on the kelp hub website. From sub-basin summary pages, users will be able to access sub-basin report PDFs. Furthermore a unifying webmap will be created that will host raw kelp area polygons and sites as available.

2.14.2. Visual summary products

Below is the proposed structure of visualization options for the *floating kelp canopy area* ecological indicator for the *Beaches and Marine Vegetation* Vital Sign. The visual summaries of the indicator are structured into two nested levels, the integrated Info-map, and Sub-basin summaries plus an additional integrated Washington canopy kelp webmap. This nested structure is meant to allow users to view both general and detailed trends in different spatial regions. The integrated Info-Map will serve as the top level of the indicator displaying kelp canopy status and trends for each sub-basin. Sub-basin summaries provide plots, tables, and key points related to the status and trends of kelp canopies in the sub-basin.

For this report we have created the integrated Info-Map, and sub-basin summaries for four sub-basins; San Juan Islands, Western Strait of Juan de Fuca, Eastern Strait of Juan de Fuca, and South Puget Sound to serve as examples in Section 2.14.2.2 and Appendices 3 - 6. These sub-basins were selected because they represent a spatial range, a range in kelp status, and a range of data types and resolution. Feedback from these examples will be used to create the final initial indicator (Report 3) to be released December 2022 and May 2023.

2.14.2.1. Integrated Info-Map

This visualization serves as the initial/highest level of the floating kelp canopy area indicator and is meant to communicate the status and trends of kelp in each sub-basin and state-wide. Upon project completion (May 2023) a static version of the info-map will be presented on the Puget Sound Partnership website and an interactive version on the Kelp Hub website. An example of this static image is presented in Appendix 1.

The presented examples are variations on a theme which is to display the status and trends of kelp canopy area in each sub-basin. In the current examples we have aimed to create streamlined visuals that are easy to understand, with the knowledge that more detail is available in the sub-basin summaries and reports.

The key difference between the two versions presented is the inclusion of an “overall” category or not. The three level (recent, entire data record, and overall) status and trend icon makes a distinction between where quantitative and non-quantitative is knowledge is (Section 2.6 – 2.9). The recent and entire data record classifications are based solely on quantitative analysis results. The overall classification considers all knowledge. In contrast, the two level (recent, and entire data record), considers all knowledge in both time periods.

Key considerations for these visuals are:

- Is the overall format understandable to a diverse set of potential users?
- Do you prefer the two or three level classification?
- Is the status and trend of kelp canopy area in each sub-basin clear?
- Are the colors/symbols used distinct/understandable?
- Is the amount of information presented adequate? Should there be more? Less?

2.14.2.2. Sub-basin summary pages

This visualization provides more detail on the status and trends of kelp canopy area for a given sub-basin. The goal is to provide more information than what can be easily present on the Integrated Info-Map but still in an easy-to-understand format. Examples of sub-basin summaries are for the San Juan Islands, Western Strait of Juan de Fuca, and South Puget Sound sub-basins are presented in Appendix 2. Examples differ in their presentation or emphasis of certain information, but all contain the same general categories/elements detailed below.

Components

- Kelp status icon: The kelp status icon is the central graphic to display kelp status for each sub-basin and is displayed at the Info-Map, Sub-Basin Summary, and Sub-Basin Report level. The icon is split into three levels; recent, entire data record, and overall kelp trend (Table 9 – 10, section 2.8). The inner, four-pointed star represents recent trends. The mid-level diamond represents the entire data record trend. The outer circle represents the overall trend. In each sub-basin, the data analysis and timespans will be customized based on available data, and detailed in the sub-basin report. Colors of each symbol represent the kelp status itself (Table 9-10, section 2.9).
- Key results: Bulleted list of key results of kelp status and trends in the sub-basin. The goal is to be brief and to-the-point, highlighting notable trends and patterns in the sub-basin.
- Maps: A map or maps of the sub-basin with sub-areas (e.g., reaches, site groups) delineation as needed. Sub-area delineations may include datasets or areas where raw data is summarized.
- Dataset information: Brief list of metadata for the datasets used in the sub-basin. This will include the dataset name, survey years, and proportion of sub-basin the dataset covers.
- Plots: At least one plot of kelp abundance through time and one plot displaying site level trends.
- Links: Links to the integrated info-map, sub-basin report, and dataset descriptions will be provided.

Considerations

Appendix 2 displays multiple options for sub-basin summary pages for the San Juan Islands, Western Strait of Juan de Fuca, Eastern Strait of Juan de Fuca, and South Puget Sound sub-basins. There are potentially many permutations of information we would like to present and we value feedback on our examples.

We would also like feedback on sub-basin summaries in general. Key considerations for sub-basin summaries are:

- Is the overall format understandable to a diverse set of potential users?
- Are the general components appropriate? Would you like to see something else? Is there too much?
- What would you like to interact with? For example, would you want to be able to see a larger version of a plot or map?
- Is the hierarchical logic apparent and understandable? Does it need to be? Is it important that users 'know where they are' in the nested levels of information of the Blended Indicator?

Table 9: Key of shapes used in the kelp status icon used in the three level status and trend icon. Detailed definitions of time periods are found in section 2.7: Guidelines for time period delineations.

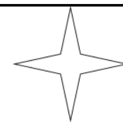
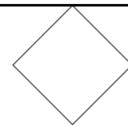
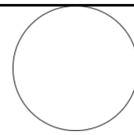
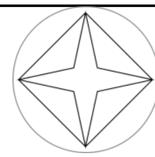
Recent trend	
Entire data record trend	
Overall trend	
Indicator classification	

Table 10: Key of shapes used in the kelp status icon used in the two level status and trend icon. Detailed definitions of time periods are found in section 2.7: Guidelines for time period delineations.

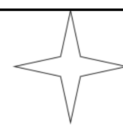
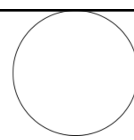
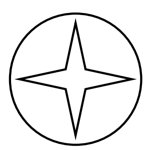
Recent trend	
Entire data record trend	
Indicator classification	

Table 11: Key of colors used to delineate kelp status in a given time period. Detailed definitions of kelp status delineations are found in section 2.8 Guidelines for status and trend classification categories.

	Kelp status
	Increasing
	Stable
	Concern
	Declining
	Insufficient data
	None present / expected

2.14.2.3. Webmap

Adjacent to the hierarchical structure of the info-map and sub-basin summary pages we propose the creation of an integrated Washington canopy kelp webmap. This will follow a similar structure of the Puget Sound Eelgrass Monitoring Data Viewer, but will differ in that it will include floating kelp canopy data from multiple data sources.

2.14.3. Technical products

Below is the proposed structure of the technical products for the *floating kelp canopy area* ecological indicator for the *Beaches and Marine Vegetation Vital Sign*. There will be three technical products; (1) indicator guidelines and procedures, 2) sub-basin reports, and 3) dataset descriptions. Here, we provide an overview of what these products include, what they include, and how they work together and work with the visual summary products.

For this report we have created a draft indicator guidelines and procedures document, and example sub-basin reports for the San Juan Islands, Western Strait of Juan de Fuca, Eastern Strait of Juan de Fuca and South Puget Sound sub-basins, and dataset descriptions for all current datasets analyzed. These are available in Appendices 3 - 11. These sub-basins were selected because they represent a spatial range, a range in kelp status, and a range of data types and data resolution. Feedback from these examples will be used to create the final initial indicator (Report 3) to be released December 2022 and May 2023.

2.14.3.1. Indicator guidelines and procedures document

The floating kelp canopy area procedures reference document will contain general procedures, guidelines, and rationale for creating the blended indicator. This will include content on the strategic vision, geographic assessment areas, overarching data management and access, priorities for data enhancement, and linkages to research, management, and partners. This document will be updated annually.

The first draft of this document is represented in sections 2.1 – 2.13 of this report. As the indicator development project nears completion, these sections will be combined in a separate stand-alone PDF document.

2.14.3.2. Sub-basin reports

The floating kelp canopy area sub-basin reports will contain details on the data, methods, analyses, and results from each sub-basin. These reports are meant to stand-alone for each sub-basin, providing specific details on kelp status and trends for the dataset(s) used in the sub-basin. Therefore, these reports expand on the general procedures described in the procedures reference document as they pertain to the specific sub-basin. Sub-basin reports will also serve as a repository for plots and tables of floating kelp canopy area, and describe the rationale for trend designation. These reports will be updated whenever new data for a sub-basin is available, ideally annually. This report contains draft examples from three sub-basin reports for the San Juan Islands, Western Strait of Juan de Fuca, and South Puget Sound sub-basins. We welcome feedback on content in these examples. Each sub-basin report will follow the same general structure with the content differing by sub-basin. The goal is that each report can stand alone as the end-point analysis documentation for the floating kelp canopy indicator. Example sub-basin reports for the San Juan Islands, Western Strait of Juan de Fuca, Eastern Strait of Juan de Fuca and South Puget Sound sub-basins are found in Appendix 3 – 6.

Components

- Executive summary: General overview of the status and trends of kelp canopy area in the sub-basin. This will be very similar to the "Key Results" section from the sub-basin summary page
- Introduction: General information on the *floating kelp canopy area* vital sign indicator and the sub-basin in question. Details on the location and features of the sub-basin. This section will highlight key geographic and oceanographic features, development, and the species of canopy kelp present.
- Data, methods, and analyses: This section will detail the kelp canopy area datasets in the sub-basin and how they were analyzed. This will expand on the general guidelines outlined in the procedures reference document. This section will include details for all datasets on other datasets that pertain to the sub-basin but are not formally analyzed, the time periods of the data, and the analysis methods.
- Results: This section will report results on the status and trends of kelp canopy area in the sub-basin. This section will rely heavily on plots and tables but will also report general summary values such as minimum and maximum area by year, and average trend (increase/decrease). Plots will show canopy area through time for the whole sub-basin and smaller sub-areas. If data allow, plots of kelp canopy area anomaly (e.g., from maximum and long-term mean) will also be plotted. Trends in kelp canopy area will also be plotted for all available time periods. Finally, this section will detail the determination of sub-basin trend designation, including rationale of why the status icon (info-map and sub-basin summary page) is classified (colored) as it is.
- Discussion: This section will place results in context and connect that patterns seen in the particular sub-basin to related kelp activities in the region. The section will also include a discussion of the patterns of kelp from other data sources not formally analyzed (e.g., Samish Indigenous Scientific Knowledge) in the indicator. Discussion points will include priorities of future sampling and data uncertainties, connections to candidate stressors, management activities, and ecological connections.
- Conclusion: Final wrap up the sub-basin and the most recent data on floating canopy kelps therein.

- References and Contributors: List of information sources, including people and organizations who contributed expertise to the sub-basin report. This may include tribes, Marine Resource Committees, NGOs, citizen groups, etc.

2.14.3.3. Dataset descriptions

Each dataset that is used in the indicator will be documented in a dataset description report. These reports provide an overview of the dataset, including the spatial extent, metrics, assessment units, survey years, survey frequency, methods summary, and data access. These reports also describe procedures for integrating the dataset into the floating kelp canopy indicator, including consideration of features or nuances that affect data use.

The dataset descriptions are intended to provide a plain-language overview of the dataset, not to replace detailed metadata. The dataset description includes links to detailed metadata that is produced by the data owner/manager. Dataset descriptions will be updated as needed. Appendices 7-11 contain draft dataset descriptions. We welcome feedback on these examples.

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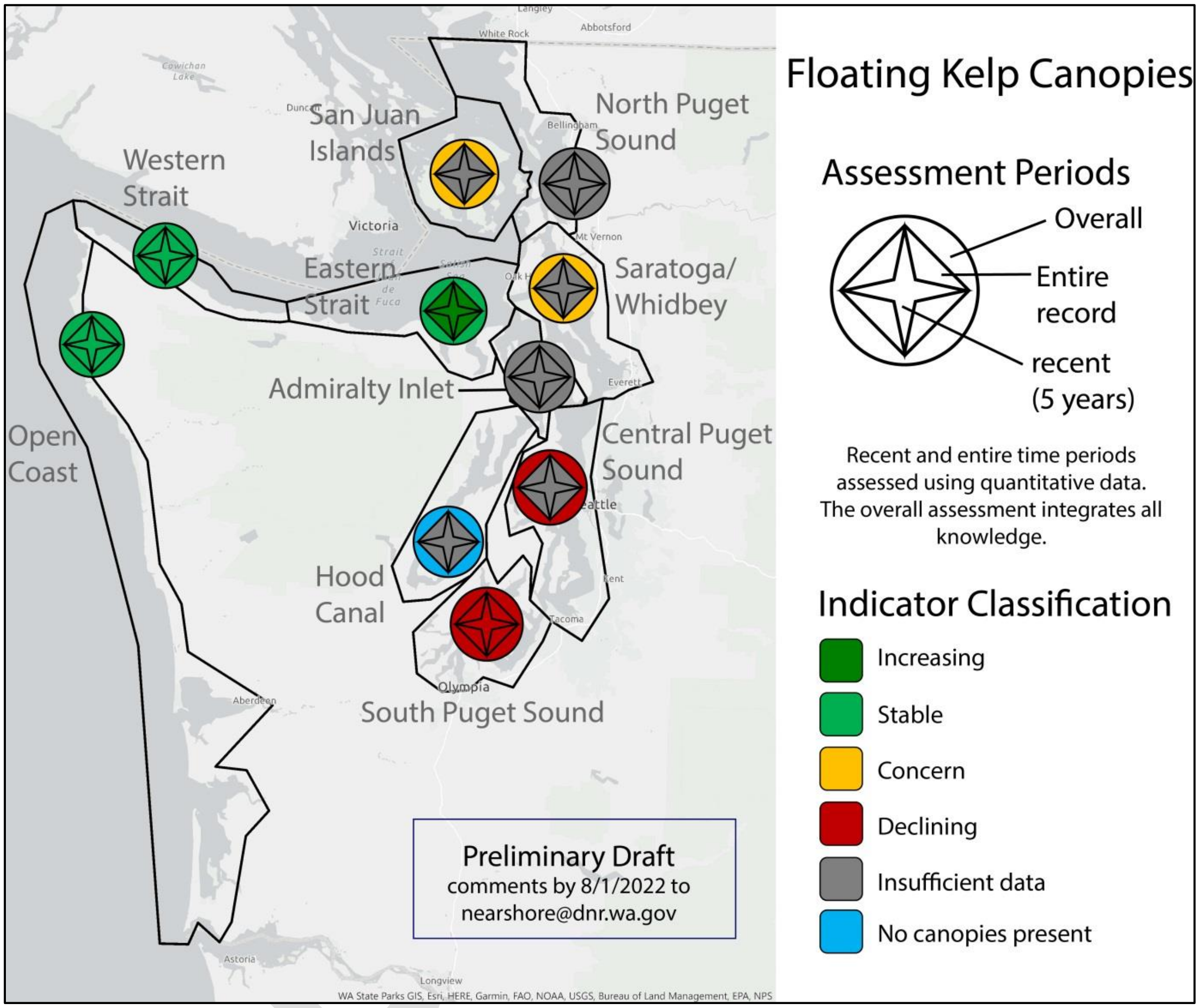
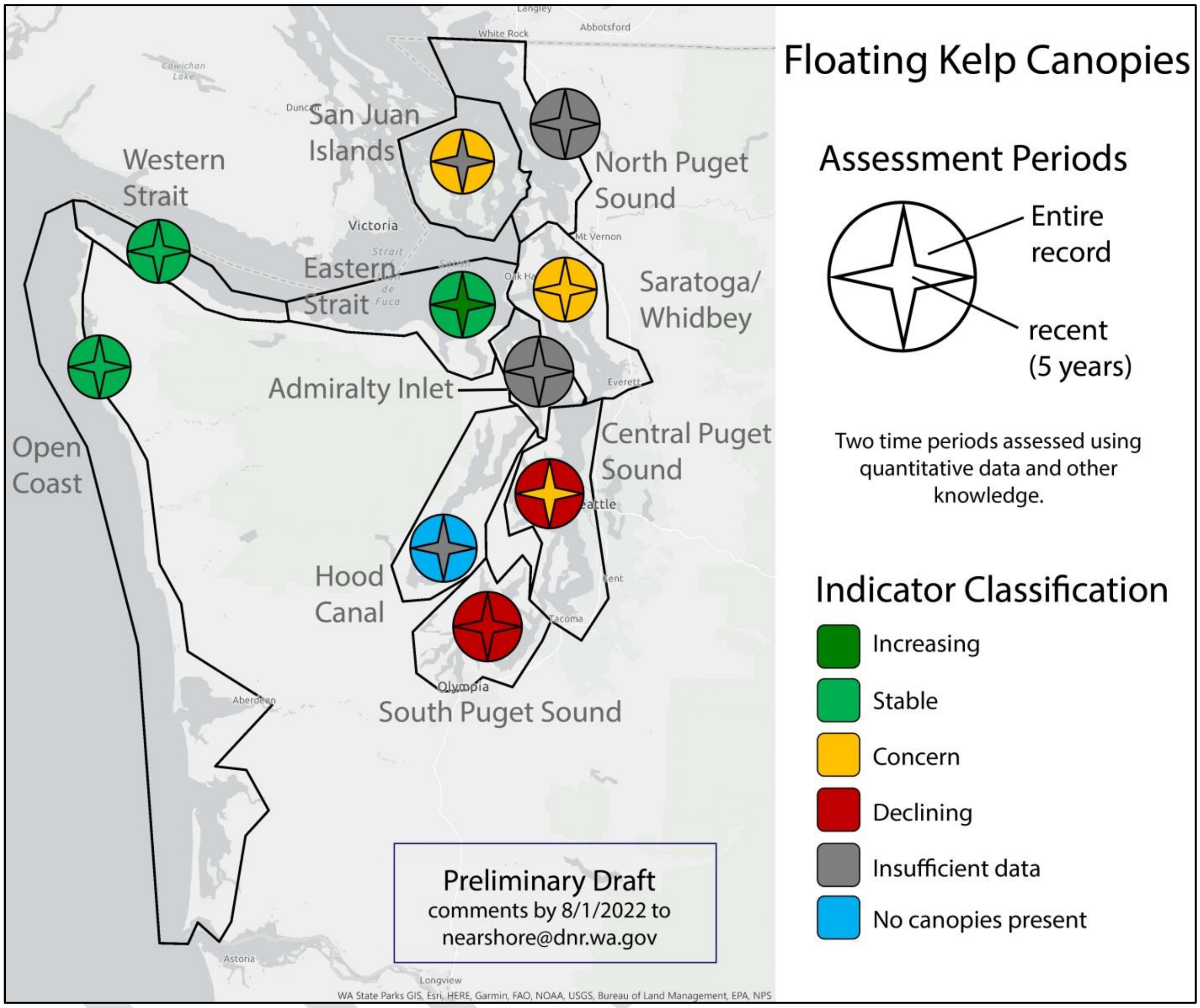
Appendix 1: Draft integrated info-maps

Example 1

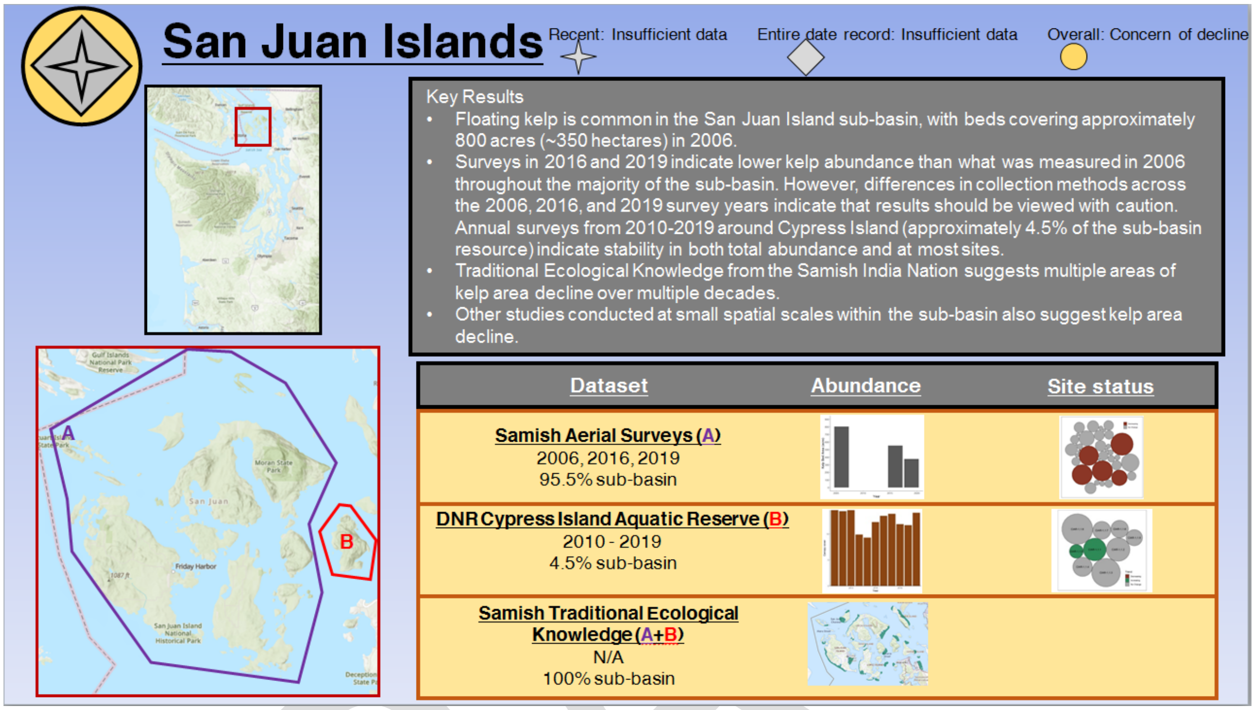


Example 2

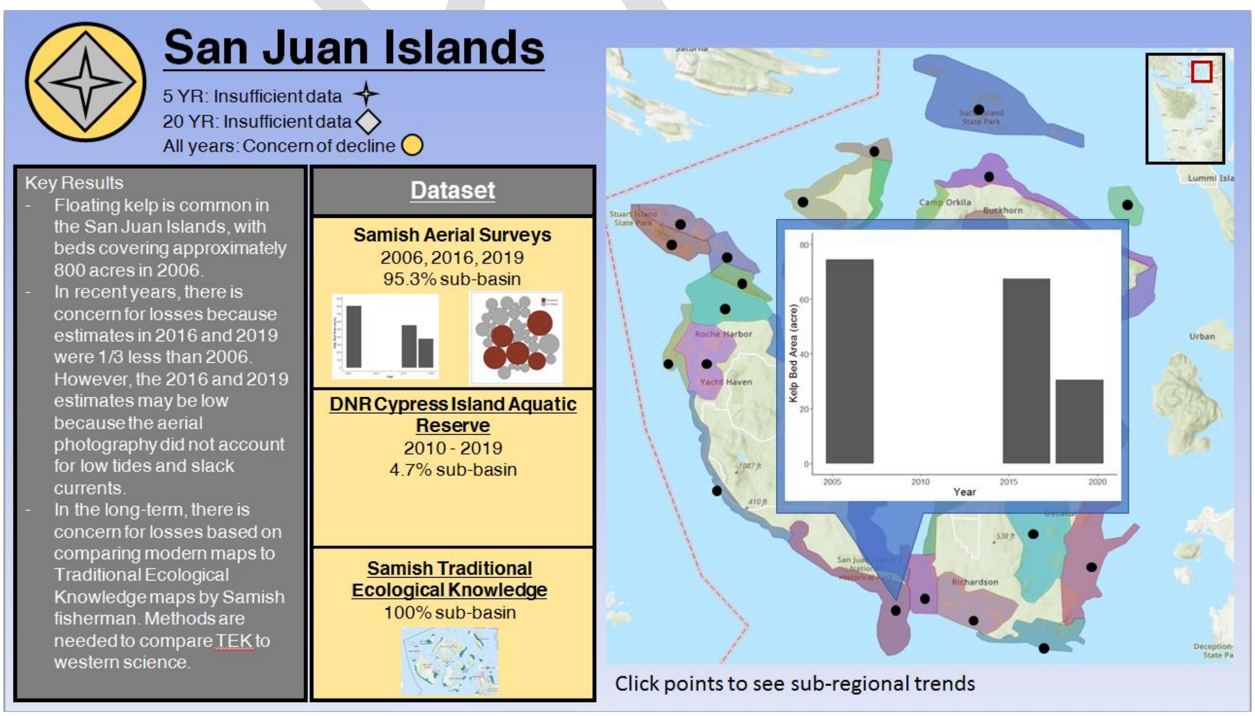

Floating Kelp Canopies
Assessment Periods
Entire record
recent (5 years)
Two time periods assessed using quantitative data and other knowledge.
Indicator Classification
Increasing
Stable
Concern
Declining
Insufficient data
No canopies present
San Juan Islands
North Puget Sound
Western Strait
Eastern Strait
Saratoga/ Whidbey
Admiralty Inlet
Open Coast
Central Puget Sound
Hood Canal
South Puget Sound
Victoria
Everett
Tacoma
Olympia
Aberdeen
Astoria
Longview
Abbotsford
White Rock
Mt Vernon
Preliminary Draft
comments by 8/1/2022 to
nearshore@dnr.wa.gov
WA State Parks GIS, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

Appendix 2: Draft sub-basin summary pages

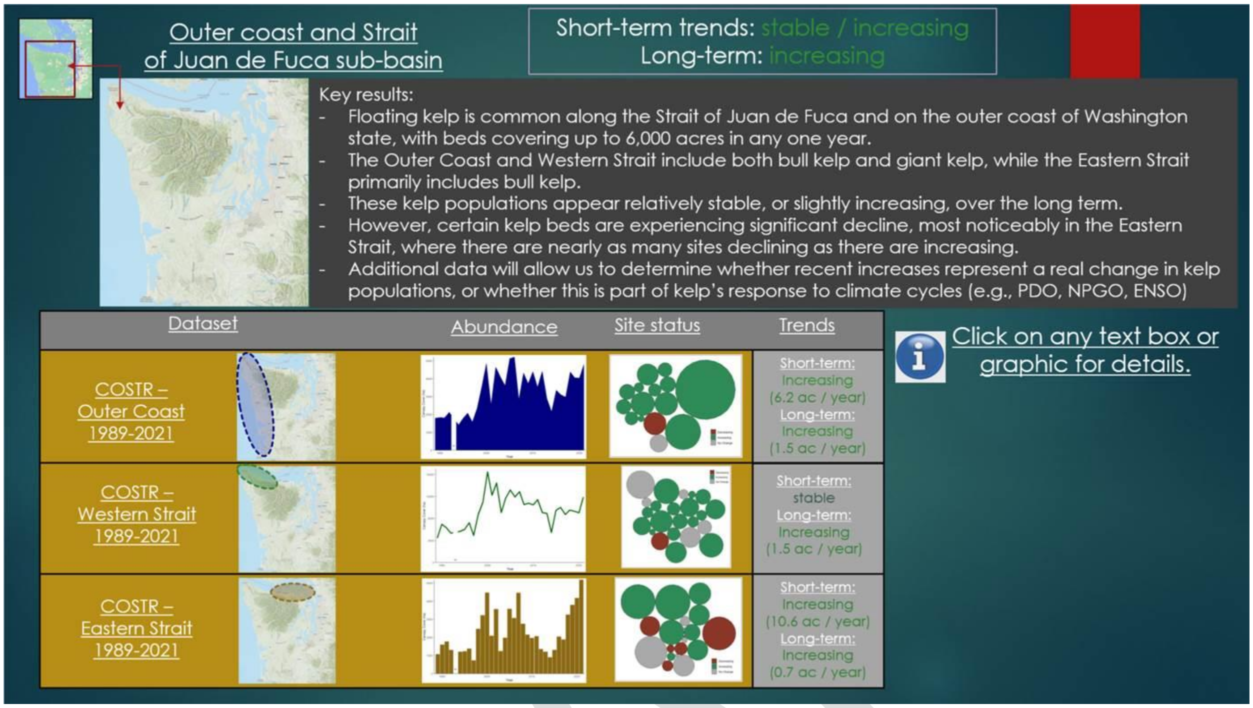
Example 1



Example 2



Example 3



Outer coast and Strait of Juan de Fuca sub-basin
Short-term trends: stable / increasing
Long-term: increasing
Key results:
- Floating kelp is common along the Strait of Juan de Fuca and on the outer coast of Washington state, with beds covering up to 6,000 acres in any one year.
- The Outer Coast and Western Strait include both bull kelp and giant kelp, while the Eastern Strait primarily includes bull kelp.
- These kelp populations appear relatively stable, or slightly increasing, over the long term.
- However, certain kelp beds are experiencing significant decline, most noticeably in the Eastern Strait, where there are nearly as many sites declining as there are increasing.
- Additional data will allow us to determine whether recent increases represent a real change in kelp populations, or whether this is part of kelp's response to climate cycles (e.g., PDO, NPGO, ENSO)
Dataset
Abundance
Site status
Trends
COSTR – Outer Coast 1989-2021
Short-term: Increasing (6.2 ac / year)
Long-term: Increasing (1.5 ac / year)
COSTR – Western Strait 1989-2021
Short-term: stable
Long-term: Increasing (1.5 ac / year)
COSTR – Eastern Strait 1989-2021
Short-term: Increasing (10.6 ac / year)
Long-term: Increasing (0.7 ac / year)
Click on any text box or graphic for details.

Appendix 3: Draft sub-basin report – San Juan Islands

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

Last updated: May 27, 2022

Recent trend:	Insufficient data
Entire data record trend:	Insufficient data
Overall trend:	Concern

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 San Juan Islands sub-basin, which spans 687.8 km (427.4 mi) of shoreline and includes islands in the San Juan Archipelago and Cypress Island (Fig. 1).

Data Summary:

Fixed-wing aerial images processed by the Samish Indian Nation from 2006, 2016, and 2019 and images collected by the Washington Department of Natural Resources from 2011 - 2021 at the Cypress Island Aquatic Reserve were analyzed. Indigenous Scientific Knowledge on floating canopy kelp collected by the Samish Indian Nation was also examined to assess multi-decadal trends. Independent studies of floating kelp in Neushul (1967), Berry and Mumford (2011), and Spencer (2006) were also considered.

Key findings:

- Floating kelp is common in the San Juan Island sub-basin, with beds covering approximately 800 acres (350 hectares) in 2006.
- Surveys in 2016 and 2019 indicate lower kelp abundance than what was measured in 2006 throughout the majority of the sub-basin. However, differences in collection methods across the 2006, 2016, and 2019 survey years indicate that results should be viewed with caution. Specifically, the 2016 and 2019 surveys did not account for tide elevation and currents, which have been shown to have a large effect on the amount of visible floating kelp.
- Annual surveys from 2010-2019 around Cypress Island (approximately 4.5% of the sub-basin resource) indicate stability in total abundance, as well as within most zones.

- Indigenous Scientific Knowledge gathered by the Samish Indian Nation suggests multiple zones of decline in the kelp area over decades.
- Other studies conducted at small spatial scales within the sub-basin suggest kelp area decline, one area of concern is San Juan Channel, on eastern San Juan Island.
- Multiple sources raise concerns about floating kelp status and trends; however these sources cover limited areas, limited time periods or rely on different methods/systems of knowing that cannot be combined with quantitative data. Notably, Indigenous Scientific Knowledge data from the Samish Indian Nation indicates more extensive floating kelp beds in the past compared to what was observed in 2006, 2016, or 2019. Other sources suggest losses in some areas, but data gaps preclude detailed assessment.

Priorities for Future Research and Monitoring

- The highest priority is to continue to collect comprehensive aerial data in the Cypress Island Aquatic Reserve annually and process San Juan County Aerial imagery when conducted. Currently, County flights are planned to occur every three years.
    - Upgrade San Juan County imagery to match methods used by Washington Department of Natural Resources. Priorities would be to conduct flights during low current and low tide conditions, use consistent image processing procedures, and conduct flights annually.
- Conduct additional research at locations that indicate losses
- Continue collaboration with Samish Indian Nation on aerial and Indigenous Scientific Knowledge
- Encourage re-sampling of Marine Resource Committee kayak kelp monitoring sites.

Table of Contents

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 and 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 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 San Juan Island sub-basin encompasses all of the nearshore areas in San Juan County and Cypress Island (Figure 1). This region features numerous rocky islands separated by deep channels. This geology coupled with large tidal exchanges creates strong currents. To the south the basin is bordered by the eastern Strait of Juan de Fuca which connects to the Pacific Ocean. To the north lies the southern Strait of Georgia including the mouth of the Fraser River in Canada. South and southwest facing shorelines are often subject to relatively strong winds and waves from prevailing storms. Floating and understory kelps are found throughout the sub-basin due to the combination of hard substrates, nutrient replete waters, and high currents. Bull kelp (*Nereocystis luetkeana*) is the only canopy forming kelp species and dominates many of the sub-basin's rocky shorelines.

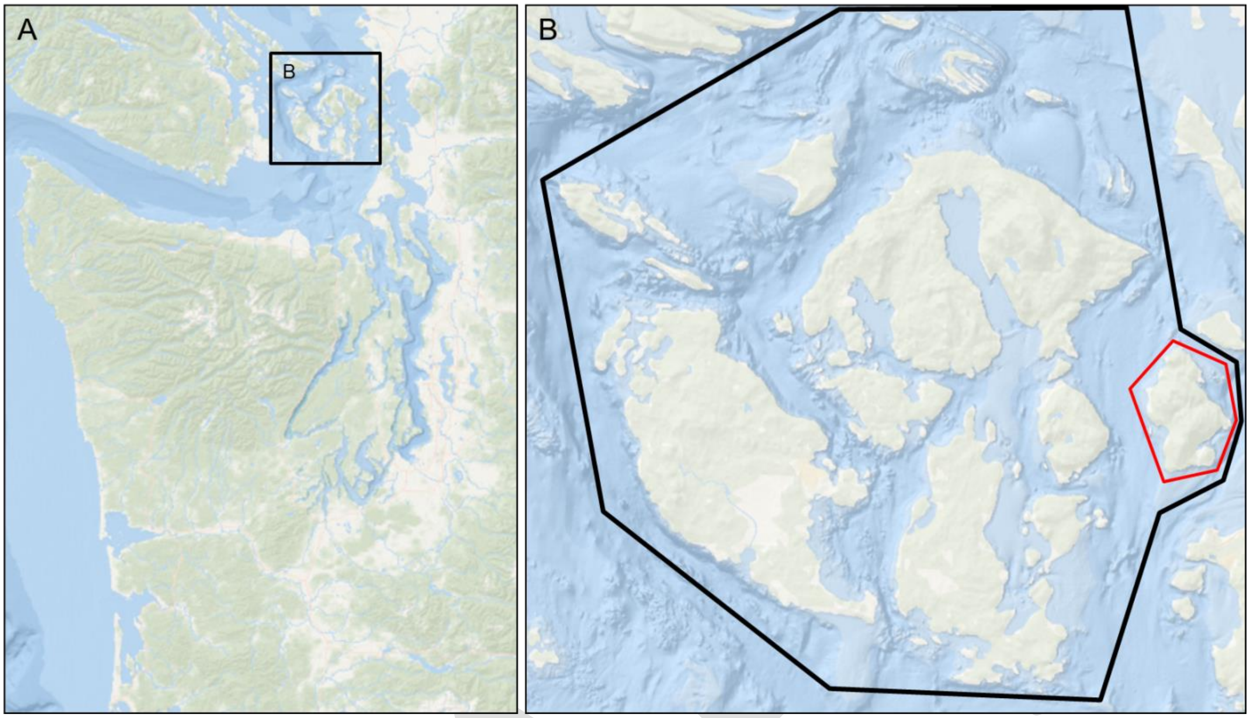


Figure 1: Western Washington State (A) with the San Juan Island sub-basin (B). Black polygon delineates San Juan Islands sub-basin. Samish Indian Nation aerial kelp data is collected along all shorelines in the sub-basin except those in the DNR Cypress Island aquatic reserve (red polygon).

2. Data, methods, and analyses

2.1 Overview

Data collection, summarization, and analysis followed general guidelines described in the floating kelp canopy area [guidelines and procedures document]. Below is a detailed description of how these guidelines were implemented for datasets in the San Juan Island Sub-basin.

2.2 Datasets analyzed for the indicator

Detailed dataset descriptions for the [Samish Indian Nation Aerial Kelp Survey Data] and [Washington Department of Natural Resources Cypress Island Aquatic Reserve aerial kelp surveys] are available on the Kelp Hub website. (Draft dataset descriptions can be found in Appendix 7 and Appendix 11.) Below is a summary of the datasets that are included in the San Juan Island Sub-basin.

Two data sources are used for indicator creation, the Samish Indian Nation Aerial Kelp Survey Data and Washington Department of Natural Resources Cypress Island Aquatic Reserve aerial kelp surveys.

1. Samish Indian Nation aerial kelp data includes surveys in 2004/2006, 2016 and 2019 and covers approximately 656.9 km (408.2 mi) or 95.5% of kelp area in the sub-basin.
2. DNR Cypress Island aquatic reserve aerial data data induces annual surveys from 2010 – 2019 and covers approximately 30.9 km (19.2 mi) or 4.5% of kelp area in the sub-basin.

2.3 Other datasets considered

In addition to the datasets above, we considered five additional datasets that include information on floating kelp canopy area.

- In 2019 the Samish Indian Nation collected and summarized Traditional Ecological Knowledge on the presence of floating kelp in their traditional territory including the San Juan Islands sub-basin. These data provide valuable insight into the past ecosystem state of the region.
- Neushul (1967) noted the presence of *Nereocystis* and understory kelp species near Brown Island in the late 1960s. This area was re-surveyed by WA DNR in 2018 (Christiaen B. personal communication).
- The San Juan County Marine Resources Committee conducted kayak monitoring of kelp beds in the sub-basin. However, these sites have not been surveyed since 2017.
- Erin Spencer (2006) explored changes in *Nereocystis* abundance on the eastern shores of San Juan Island, between Turn Rock and Point Caution.
- Berry and Mumford (2011) compared aerial photography-based surveys in 2004 and 2006 to historical Fertilizer Maps (Cameron 1915).

2.4 Time period designation

We followed the general guidelines for analysis time periods outlined in the floating kelp canopy area [guidelines and procedures document]. How these guidelines apply to the San Juan Islands sub-basin is described below.

Table 1: Definition of kelp status and trends analysis time periods for the San Juan Islands sub-basin.

Period	Duration
Recent	NA
Entire data record	NA
Overall	San Juan Islands: 2006, 2016, 2019 Cypress Island Aquatic Reserve: 2011 – 2021 Time periods encompassed in Other datasets considered

Following the general guidelines for kelp status time periods in the floating kelp canopy area [guidelines and procedures document] there is only sufficient data for an overall assessment of kelp condition. This is due to gaps in sampling frequency of existing Samish aerial and DNR Cypress datasets. Furthermore, the methods used on aerial photo flights in 2006, 2016, and 2019 surveys were inconsistent (see [Samish Indian Nation Kelp Aerial Survey] dataset description). The 2016 and 2019 surveys were not controlled for tides and currents. This precludes aerial comparisons, because tides and currents have been shown to have variable and large effects on the amount of visible kelp, ranging from 10% – 90% reduction in visible kelp (Britton-Simmons et al 2008).

2.5 Analysis

For both Samish Indian Nation aerial data and DNR Aquatic Reserve data from Cypress Island, GIS polygons of kelp bed area were obtained and plotted with GIS. For each year, kelp bed area was summed in 38 (Samish) and 9 (Cypress) unique nearshore zones. Zones were created following the guidelines used to create similar nearshore spatial units (also called "map-indecies") developed by DNR for the outer coast and Strait of Juan de Fuca. These units comprise approximately 5 to 15 km of shoreline and extend from the mean lower low water tide line (MLLW) to approximately 30m depth. Breaks between zones were created with consideration to overall size, consistency of physical parameters (e.g. shoreline type, substrate, exposure), and large geographical features such as bays, channels, and headlands. This created a single file for each dataset 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 whole dataset 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 2). Anomalies were calculated as the proportional difference in kelp bed area in a given year compared to the mean kelp bed area over the three 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 of the maximum proportional kelp bed area for the dataset (large circles are zones that have large kelp bed area). Circles are 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 gray. 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 over the all survey years for the Samish aerial data and for the recent time period (last 5 years: 2017 – 2021) and for the entire data record (10 years 2011 – 2021).

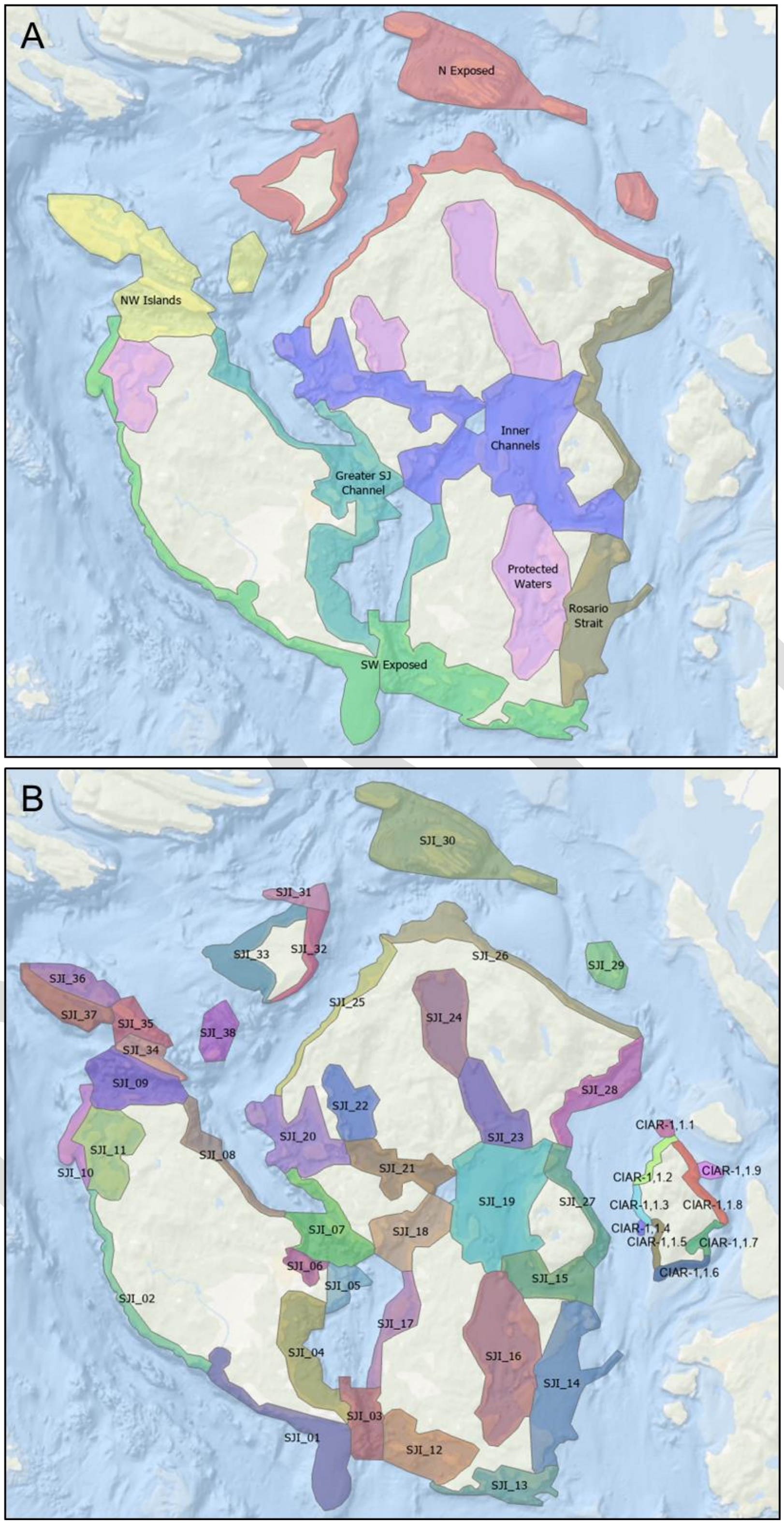


Figure 2: Reaches (A) and zones (B) of the San Juan Islands sub-basin. The protected waters reach (A) is composed of four smaller areas that are not spatially connected, but the kelp in these areas are summarized together. Note reaches are not defined for the DNR Cypress Island Aquatic Reserve.

3. Results

3.1 Abundance and distribution of floating kelp

3.1.1 Samish Indian Nation aerial data

The maximum amount of kelp detected in the San Juan Islands with the Samish Indian Nation aerial dataset was 324 hectares (800 acres) in 2006. Kelp detection in the sub-region decreased in 2016 and 2019, with the lowest kelp area detected in 2019 (Figure 3). Average kelp bed area per year was 233 +/- 86.9 sd hectares (575 acres +/- 214.6 sd). All Samish aerial data are presented as kelp bed area. The amount of kelp bed area varies greatly from survey-to-survey and at the reach and zone scale in Samish aerial data. Kelp bed area is most abundant in the SW Exposed reach which corresponds to zones SJI_01, SJI_02, SJI_03, SJI_12, and SJI_13. This is also where declines over the three surveys are most evident (Figure 4, 5).

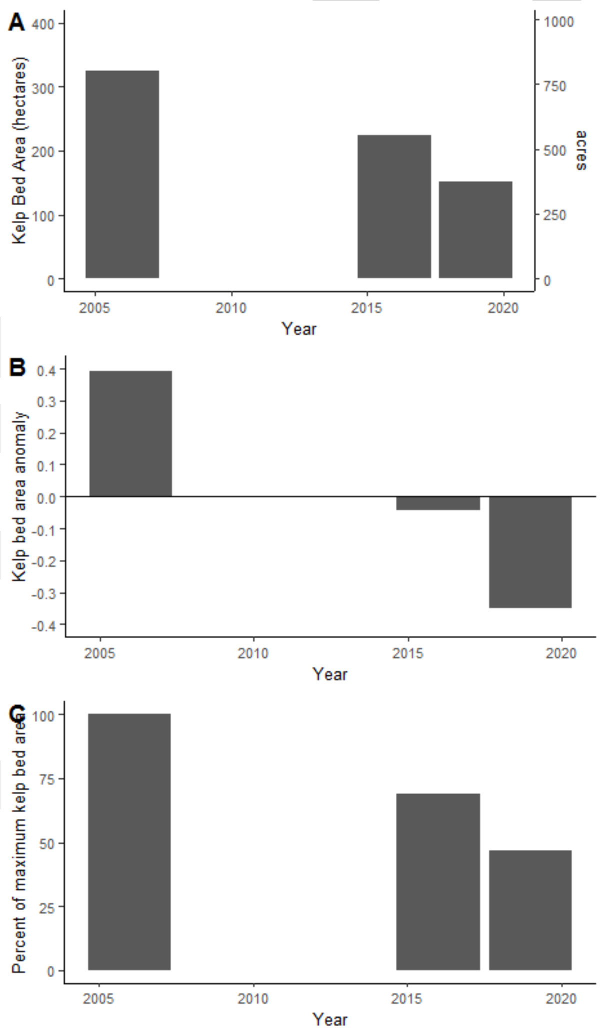


Figure 3: Kelp bed area (A), kelp bed area anomaly (B), and percent of maximum kelp bed area (C) summed in each year of the Samish Indian Nation aerial data collected in 2006, 2016, and 2019. Apparent changes should be interpreted with caution because the 2016 and 2019 aerial photography was not controlled for tides or currents, which are known to impact kelp detection.

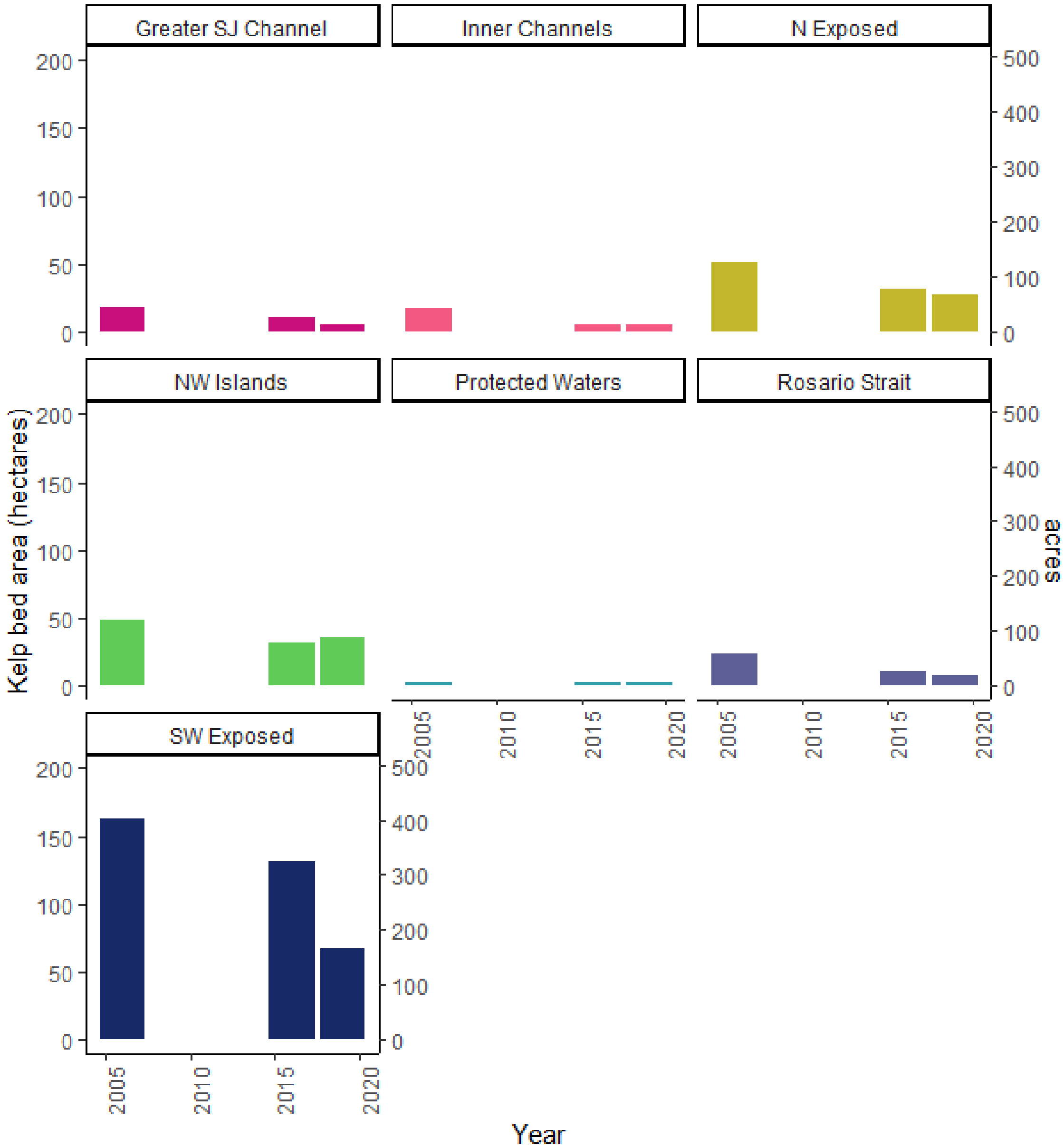


Figure 4: Kelp bed area summed by reach in the San Juan Islands sub-basin. Apparent changes should be interpreted with caution because the 2016 and 2019 aerial photography was not controlled for tides or currents, which are known to impact kelp detection.

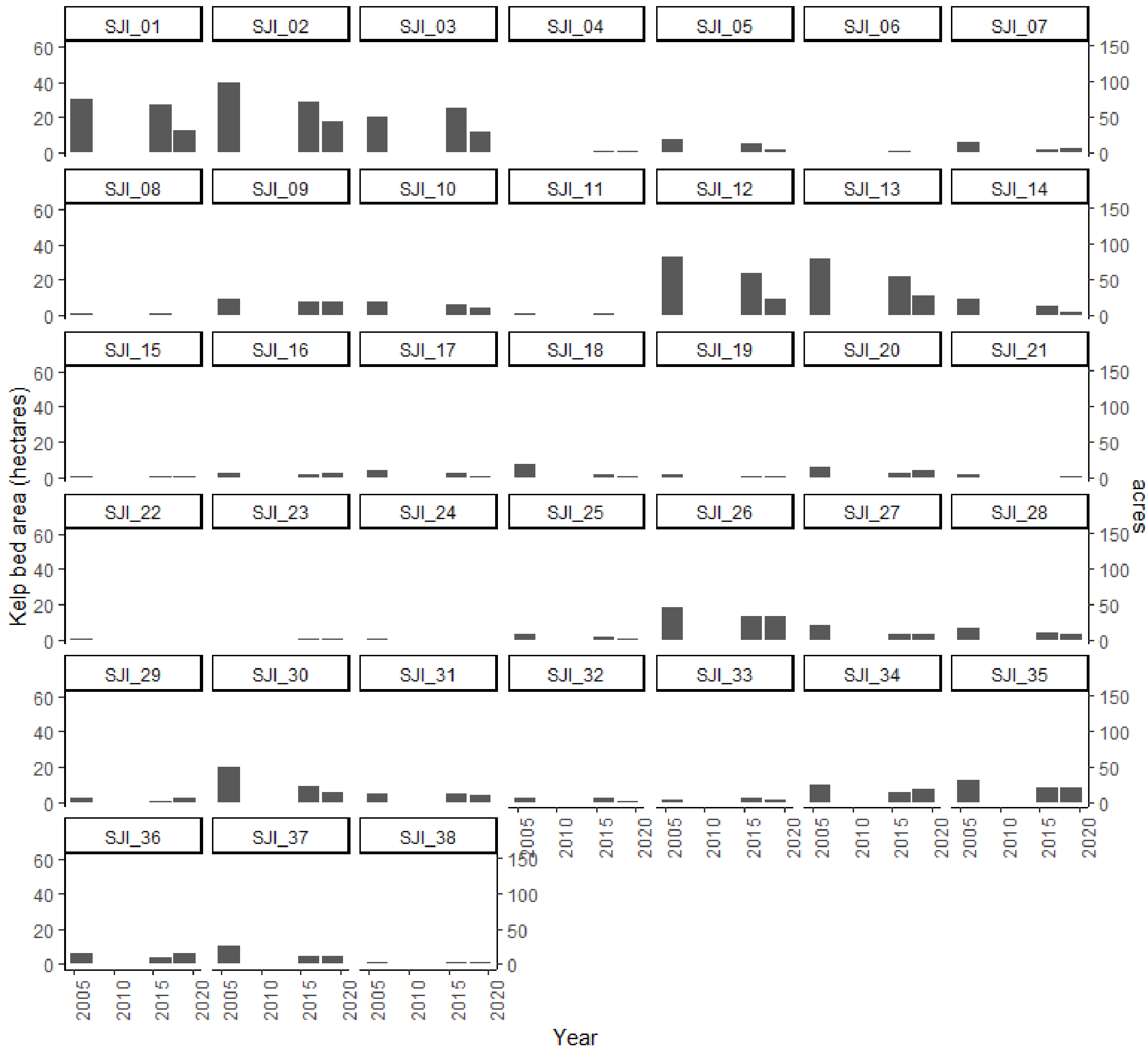


Figure 5: Kelp bed area summed by zone in the San Juan Islands sub-basin. Changes among years should be interpreted with caution because the 2016 and 2019 aerial photography was not controlled for tides or currents, which are known to impact kelp detection.

3.1.2 DNR Cypress Island Aquatic Reserve data

Kelp area in the Cypress Island Aquatic Reserve has varied year-to-year from 2010 to 2020 but has been largely consistent across the time span. In Cypress Island Aquatic Reserve, floating kelp area is reported in two ways: 1) As kelp *bed* area (comparable to the Samish Indian Nation aerial dataset), and 2) as kelp *canopy* area (comparable to COSTR data set which includes data for the Strait of Juan de Fuca [link]). We report both here. In summary, the canopy encompasses the area with bulbs, blades and stipes floating on the surface while the bed groups nearby plants and includes the gaps between them. All figures for this sub-basin are shown for bed area, to maintain comparability between the Samish Indian Nation aerial data set and the DNR Cypress Island Aquatic Reserve data set.

Cypress Island – Floating kelp bed area

The maximum floating kelp bed area detected in the Cypress Island Aquatic Reserve was 79.2 hectares (195.7 acres), which occurred in the year 2013 (Figure 6). The minimum kelp bed area detected in the Cypress Island Aquatic Reserve was 54.6 hectares (134.9 acres), which occurred in the year 2015. Average kelp bed area per year was 66.8 hectares [± 8.2 hectares s.d.].

Cypress Island – Kelp canopy area

The maximum kelp canopy area detected in Cypress Island Aquatic Reserve was 14.6 hectares (36.1 acres) in 2013. The minimum kelp canopy area detected in Cypress Island Aquatic reserve was 9.3 hectares (23.0 acres), which occurred in the year 2015. Average kelp canopy area per year was 12.7 hectares [± 1.9 hectares sd].

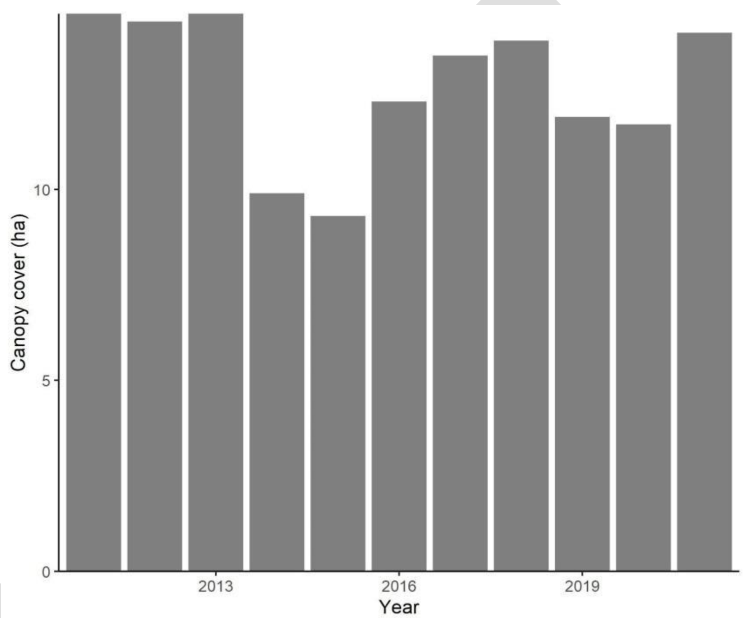


Figure 6: Kelp canopy area summed across all zones on the DNR Cypress Island Aquatic Reserve aerial data set from 2010 to 2021.

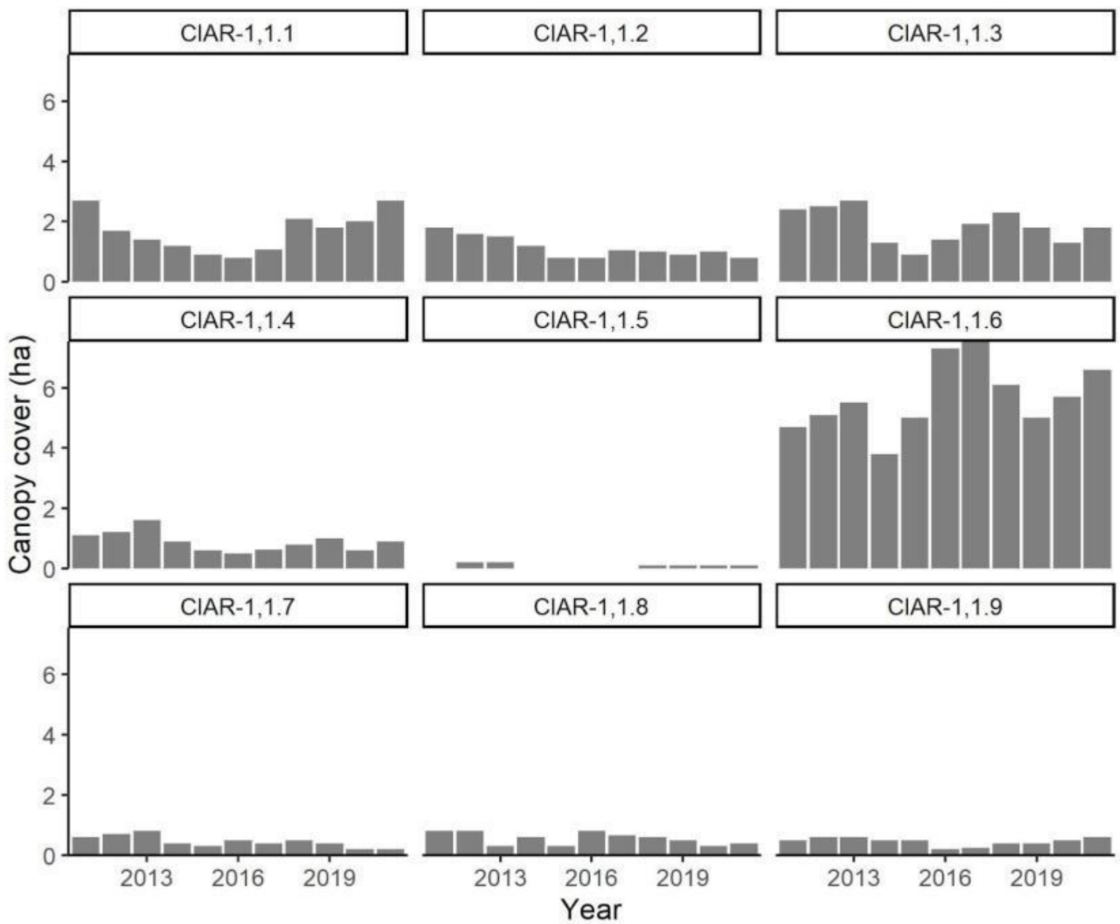


Figure 7: Kelp canopy area summed in zones on the DNR Cypress Island Aquatic Reserve aerial data set from 2010 to 2021.

3.2 Trends in floating kelp area

3.2.1 Samish Indian Nation aerial data

Six out of seven reaches and 32 out of 38 zones in the Samish aerial surveys showed no change in kelp abundance across all survey years. One each (SW Exposed) and 6 zones showed lower abundance in 2019, compared to 2006, however this difference could be due to sampling conditions (Figure 8 - 11). Kelp canopies in the most rapidly contracting zone (SJI_12, located near the western portion of southern Lopez Island) decreased at an average rate of 1.6 hectares (3.9 acres) per year (Fig. 13). These patterns are mirrored when kelp data are summarized at the reach level (Figure 8). These estimates of change must be interpreted with caution because the 2016 and 2019 estimates did not control for tides and currents, which are known to affect the canopy visibility.

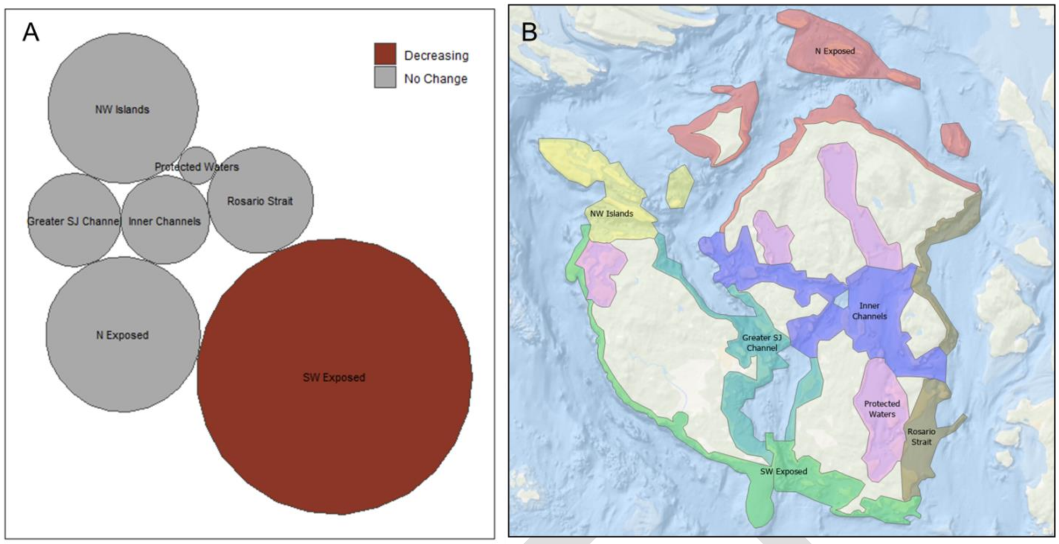


Figure 8: A: Bubble plot of reach level trends in kelp bed area from Samish aerial surveys across all survey years (2006, 2016, and 2019). These estimates of change must be interpreted with caution because the 2016 and 2019 estimates did not control for tides and currents, which are known to affect the canopy visibility. Circle size is the proportion of total kelp area of a given reach. B: Map of San Juan Island sub-basin with reaches of Samish aerial data. Same color polygons indicate the same reach.

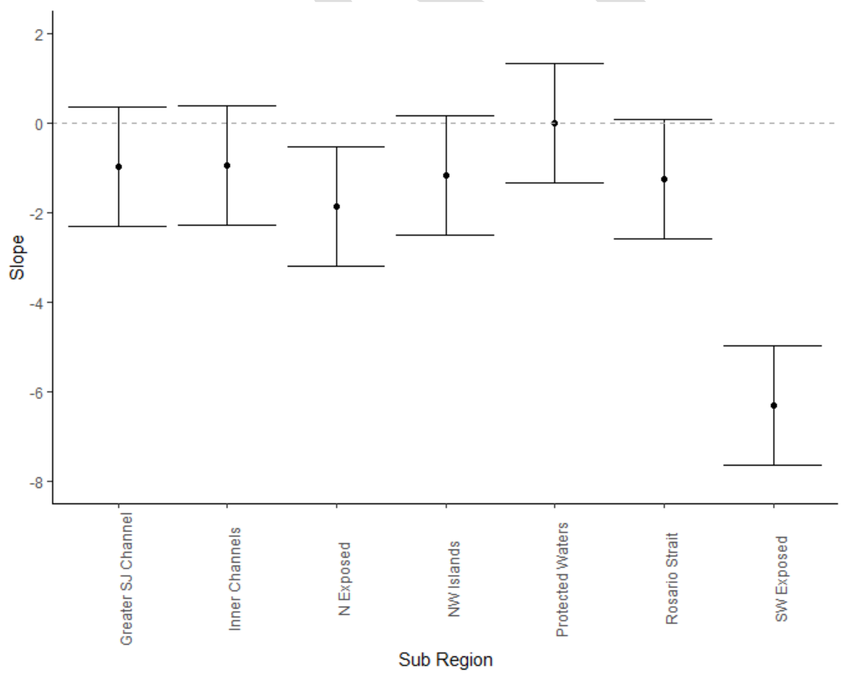


Figure 9: Slope plot of reach level trends in kelp bed area from Samish aerial surveys across all survey years (2006, 2016, and 2019). These estimates of change must be interpreted with caution because the 2016 and 2019 estimates did not control for tides and currents, which are known to affect the canopy visibility. Circle size is the proportion of total kelp area of a given zone.

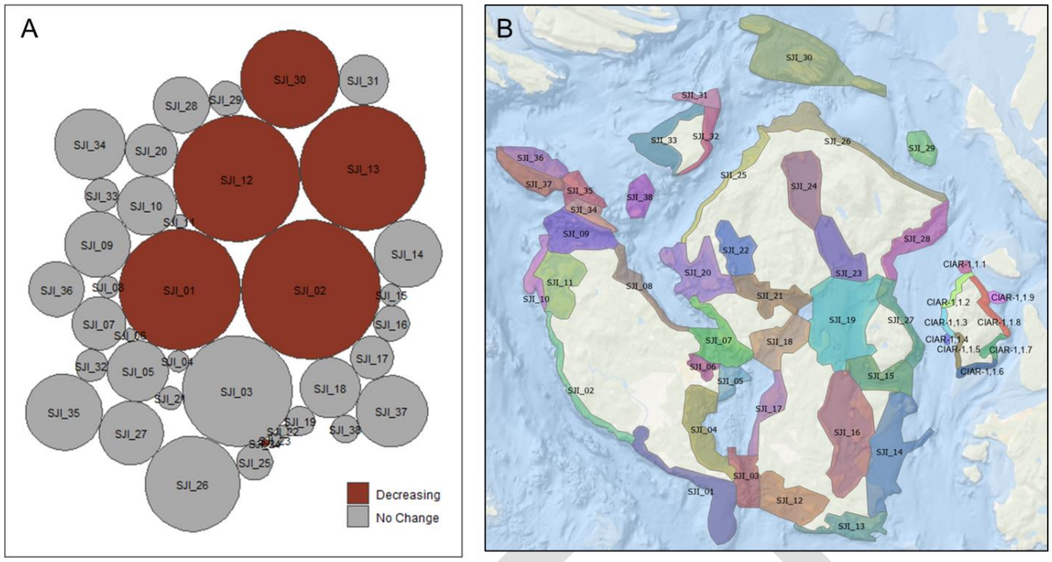


Figure 10: A: Bubble plot of zone level trends in kelp bed area from Samish aerial surveys across all survey years (2006, 2016, and 2019). These estimates of change must be interpreted with caution because the 2016 and 2019 estimates did not control for tides and currents, which are known to affect the canopy visibility. Circle size is the proportion of total kelp area of a given zone. B: Map of San Juan Island sub-basin with zones of Samish aerial data and Cypress Island. See Figure 12-14 for Cypress Island trends.

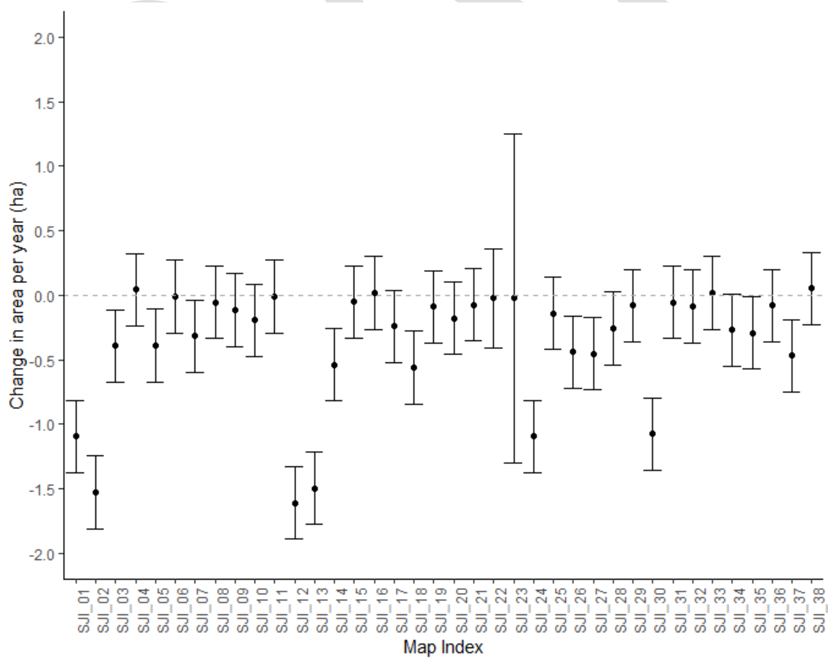


Figure 11: Slope plot of zone level trends in kelp bed area from Samish aerial surveys across all survey years (2006, 2016, and 2019). These estimates of change must be interpreted with caution because the 2016 and 2019 estimates did not control for tides and currents, which are known to affect the canopy visibility.

DNR Cypress Island Aquatic Reserve data

Seven out of nine zones (77%) in the Cypress Island Aquatic Reserve showed no evidence of a change in kelp bed area from 2010 to 2020, while two map indices showed evidence of decline (Figure 12). Kelp canopies in the most rapidly decreasing zone (CIAR1, 1.2) decreased at an average rate of 0.5 hectares (1.2 acres) per year across all survey years (Figure 13). However, trends across the last 5 years indicate increases in CIAR1 1.1 and CIAR1 1.5, with the remaining zones suggesting no trend (Figure 14 - 15).

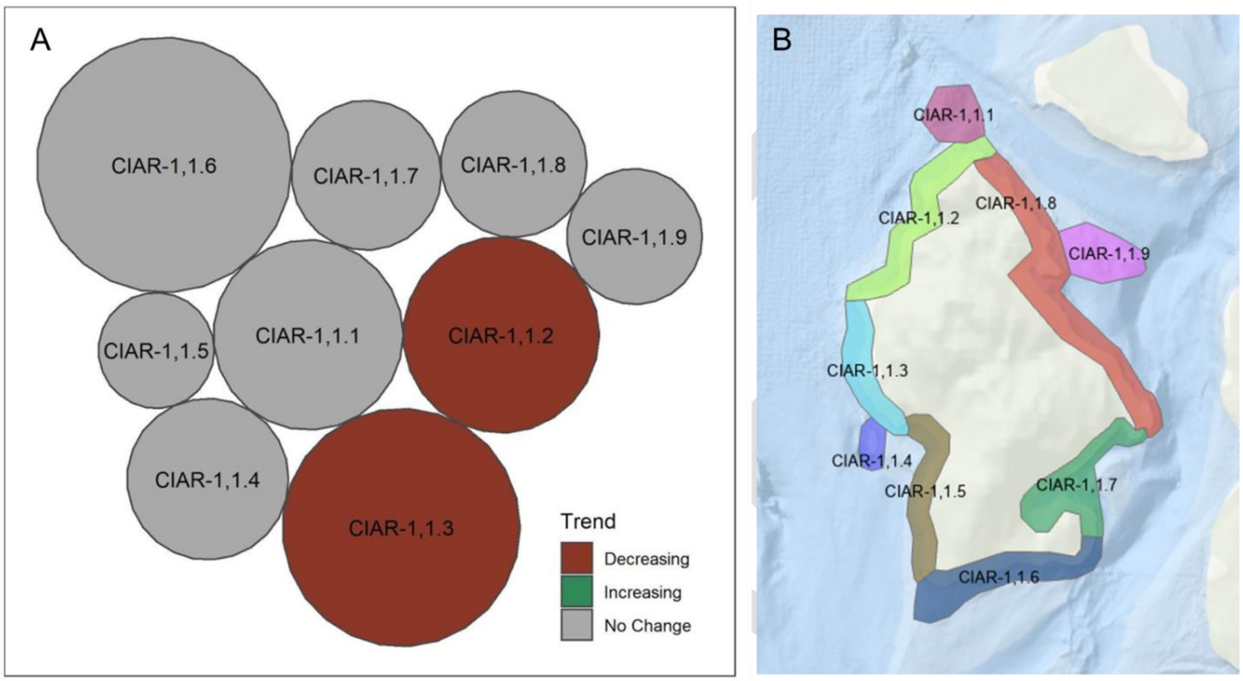


Figure 12: A: Bubble plot of zone level trends in kelp bed area from Cypress Island Aquatic Reserve across all survey years (2011 – 2021). B: Map of Cypress Island zones.

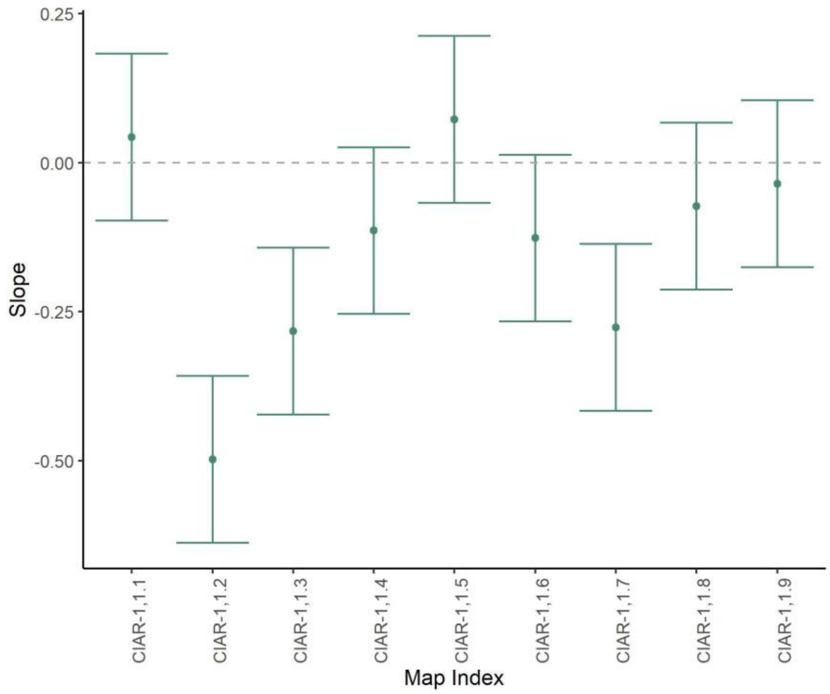


Figure 13: Slope plot of zone level trends in kelp bed area from Cypress Island Aquatic Reserve across all survey years (2011 – 2021).

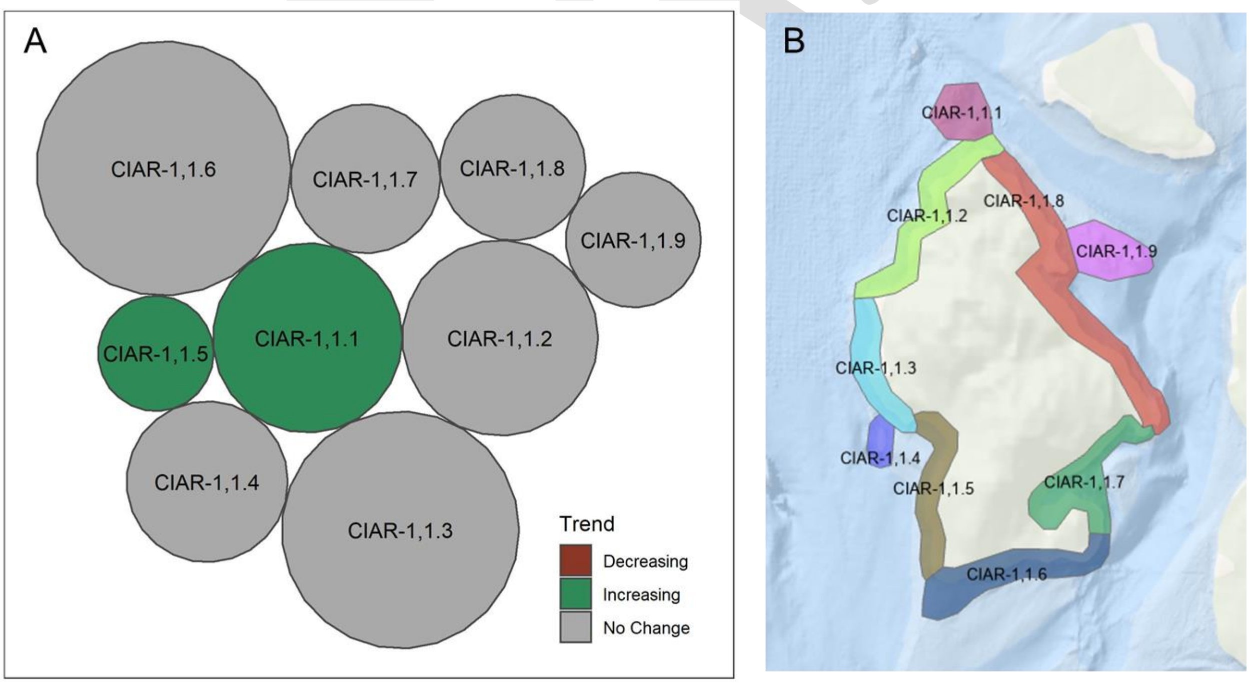


Figure 14: A: Bubble plot of zone level trends in kelp bed area from Cypress Island Aquatic Reserve from the last 5 years (2017 – 2021). B: Map of Cypress Island zones.

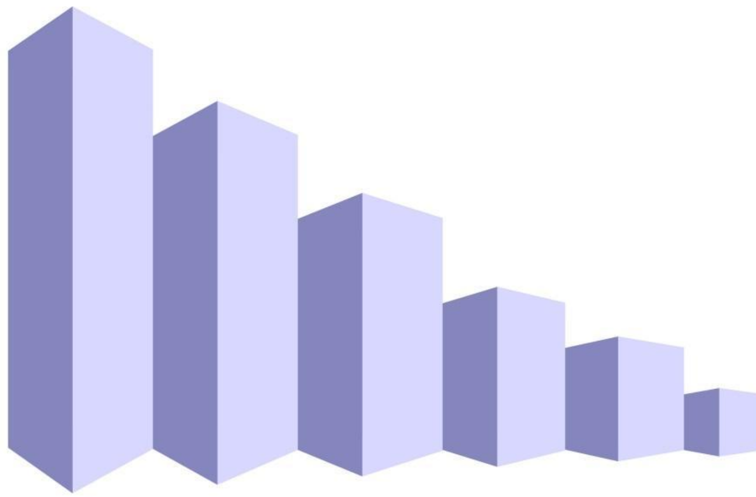


Figure 15: Slope plot of zone level trends in kelp bed area from Cypress Island Aquatic Reserve from the last 5 years (2017 – 2021). Currently not available.

3.3 Other datasets

- Mapping of Samish Indian Nation Indigenous Scientific Knowledge (ISK) identifies general areas within the sub-basin where Tribal fishermen fished near canopy-forming kelp beds (Figure 16). Multiple conspicuous differences existed between ISK and aerial survey data, suggesting both expansion and contraction at different sites. Notable areas where contemporary surveys observed substantially smaller floating kelp beds include the southeast portion of San Juan Island (Garrison Bay), east coast of Orcas Island (Deep Point to Lawrence Point), east Shaw Island (Picnic Cove to Hankin Point), and northwest Lopez Island (Flat Point to Upright Head). Notable areas of expansion are the shorelines around Stewart, Spieden Island, Patos, Sucia, and Matia Island, the outer shoreline of Henry Island (Kellett Bluff area), and southern shorelines of Cypress Island. However, given the methods by which ISK was collected, these maps likely reflect areas where elders had long-standing knowledge, rather than a comprehensive sub-basin assessment of where canopies occurred throughout the sub-basin. Areas with no kelp canopies mapped could indicate either that no kelp was present or that the elders did not use that area. No distinction between 'absent' and 'no data'' has been made. Note that Samish ISK data includes areas that are not a part of the San Juan sub-basin including Lummi Island, Guemes Island, shorelines near Anacortes, WA, Burrows and nearby islands, and Deception Pass. However, ISK data from these regions is useful for other sub-basins.
- DNR towed videography in the same vicinity as Neushul (1967) in addition to widespread anecdotal observations has noted that *Nereocystis* has been absent from Brown Island for at least a decade.
- The San Juan County Marine Resources Committee kayak monitoring sites are pending review, prior to inclusion in the dataset. Because the sites have not been surveyed since 2017, and major changes were not noted during the years they were surveyed, they are anticipated to be useful primarily for comparison to other datasets. A detailed dataset description of the Marine Resources Committee kelp surveys can be found [here].
- Erin Spencer (2006) noted disappearance of some beds of *Nereocystis* and changes in density relative to 1911-1912, but also noted substantial uncertainty related to methodological differences.

- Berry and Mumford (2011) identified the eastern shores of San Juan Island as an area with high probability of localized losses.

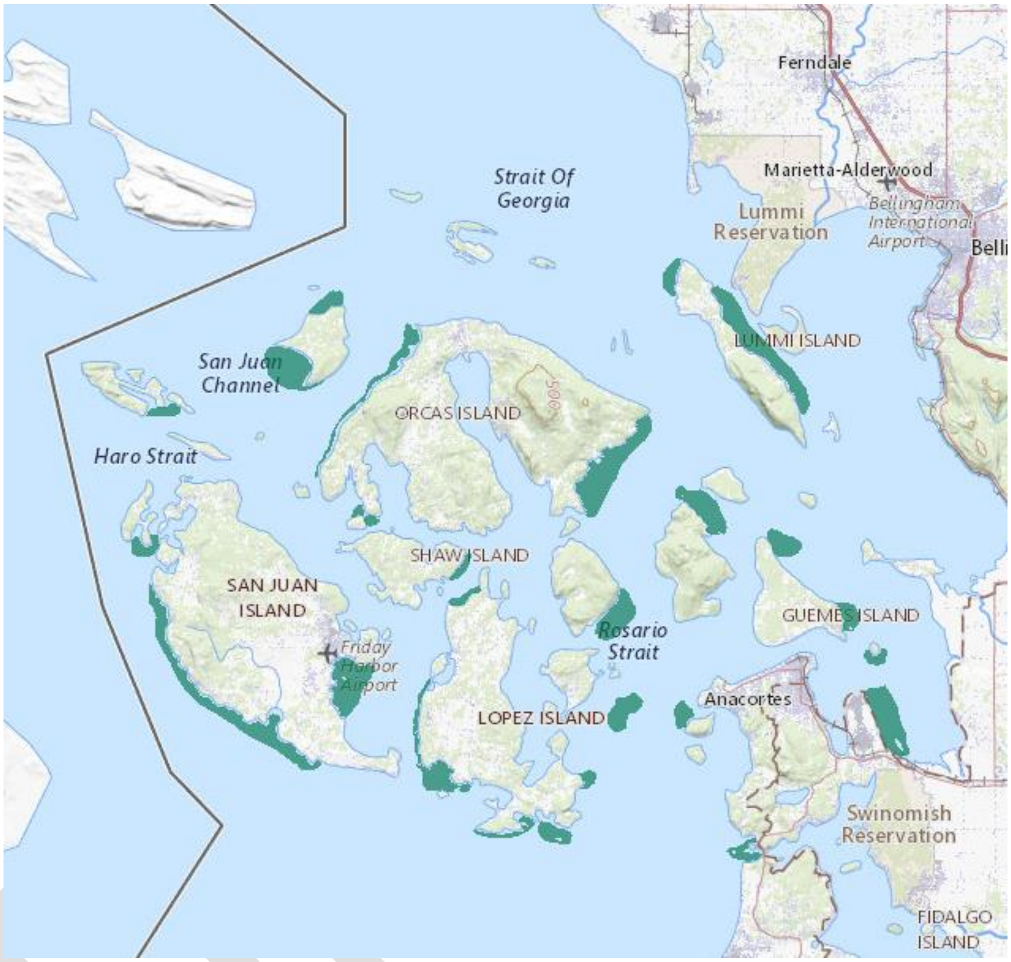


Figure 16: Indigenous Scientific Knowledge of kelp beds in the Samish Indian Nation traditional territory. Green shaded areas represent locations where two tribal fishermen drew where they remembered seeing Bull Kelp from their decades of fishing the waters surrounding the San Juan Islands. Elders denoted that kelp canopies were historically present.

3.4 Determination of sub-basin trend designation

Due to the substantial spatial and temporal data gaps, as well as methodological inconsistencies, it is not possible to conclusively assess floating kelp trends over the last 5 years or longer time spans in the San Juan sub-basin. Therefore, it is classified as *insufficient data* for recent and entire data record. The DNR Cypress Island data suggests stability based on annual surveys with consistent methods over the last 10 years, but this dataset comprises less than 5% of the sub-basin shorelines. Taking both aerial datasets into consideration in addition to results from other datasets there is the suggestion of loss of kelp canopy area over longer time periods. Therefore, the overall classification is *concern* for floating kelp canopies in the San Juan Islands 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	Insufficient data	
Entire data record	Insufficient data	
Overall	Concern	
Indicator Classification	**Concern**	

4. Discussion

4.1 Datasets used in sub-basin assessment

Samish aerial and DNR Cypress aerial data provide a comprehensive survey of floating kelp canopy area for the years surveyed in the sub-basin. While the 2006 Samish aerial data and Cypress aerial data is collected following procedures that account for tide and currents, the 2016 and 2019 survey years of the Samish aerial data is not. This introduces substantial unaccounted error in the 2016 and 2019 surveys as visible floating kelp canopy area can be greatly affected by tide and current (Britton-Simmons et al. 2008, Cavanaugh et al. 2021).

Samish Indian Nation ISK kelp canopy area data provides a unique view of past kelp bed state in the sub-basin. The apparent abundance of kelp from this data is in stark contrast to recent aerial surveys and suggests that kelp bed area has substantially declined over many decades. These apparent differences highlight a need for consistent monitoring of kelp bed area in the sub-basin.

4.2 Potential drivers of observed kelp trends and linkages to ecosystem components

The nature of available data kelp data in the sub-basin presents considerable challenges when trying to ascribe potential drivers to observed patterns. However, it is important to note that the sub-basin constitutes the greatest extent of floating kelp shoreline in Washington State. Therefore, floating kelps make up a major nearshore habitat in the sub-basin and changes in its abundance are likely to have wide-reaching effects.

Like other floating kelp populations in the region, floating kelp in the San Juan Islands are susceptible to large scale and local climatic and physical drivers including the Pacific Decadal Oscillation, the Oceanic El Niño Index, and the North Pacific Gyre Oscillation, regional surface temperatures, and salinity. Of particular note, there is a well-documented temperature and salinity gradient between the south and north of the sub-basin (Masson and Cummins 2000, Lowe et al. 2016). Southern areas (South and West San Juan Island, and South Lopez Island) are dominated by relatively cold and saline waters of the Strait of Juan de Fuca, whereas Northern areas (North Orcas Island, Sucia Island, Patos Island, Matia Island, Waldron Island, and Stuart Island) are dominated by warmer, fresher water from the Fraser River plume. This gradient connected with deep channels between islands, and strong tidal driven currents produce a dynamic physical environment that may influence floating kelp abundance. The apparent declines on the Southern margin of the sub-basin is surprising in that kelps should thrive in these waters compared to the Northern portion of the sub-basin where they may be more physiologically stressed. This further highlights that the observed decline in floating kelp in that reach may be a function of differences in sampling as the 2016 and 2019 data where not collected with regard to tide height and current.

Sea urchins are important grazers in kelp forest ecosystems (Watson and Estes, 2011) and are common in the sub-basin. However, direct grazing pressure by sea urchins on floating kelps is assumed to be low as sea urchins appear to rely on drift algae for consumption (Britton-Simmons et al. 2012). Other than records of commercial catch, there is little information on the population status and trends of sea urchins in the region. Other grazers including *Lacuna* sp. snails (Duggins et al. 2001), and kelp crabs (*Pugettia producta*) (Dobkowski 2017, Dobkowski et al. 2017) have been noted to consume kelp in the region. However the sub-basin scale impact of these grazers is unknown.

4.3 Priorities for future research and monitoring

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

- The highest priority is to continue to collect comprehensive aerial data in the Cypress Island Aquatic Reserve annually and process San Juan County Aerial imagery when conducted. Currently, County flights are planned to occur every three years.
- Upgrade San Juan County imagery to match methods used by Washington Department of Natural Resources. Priorities would be to conduct flights during low current and low tide conditions, use consistent image processing procedures, and conduct flights annually.
- Conduct additional research at locations that indicate losses such as the South and West shoreline of San Juan Island and South Lopez Island.
- Continue collaboration with Samish Indian Nation on aerial and Indigenous Scientific Knowledge
- Encourage re-sampling of Marine Resource Committee kayak kelp monitoring sites.

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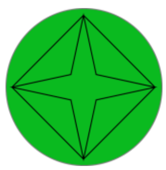
Appendix 4: Draft sub-basin report – Western Strait of Juan de Fuca

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).

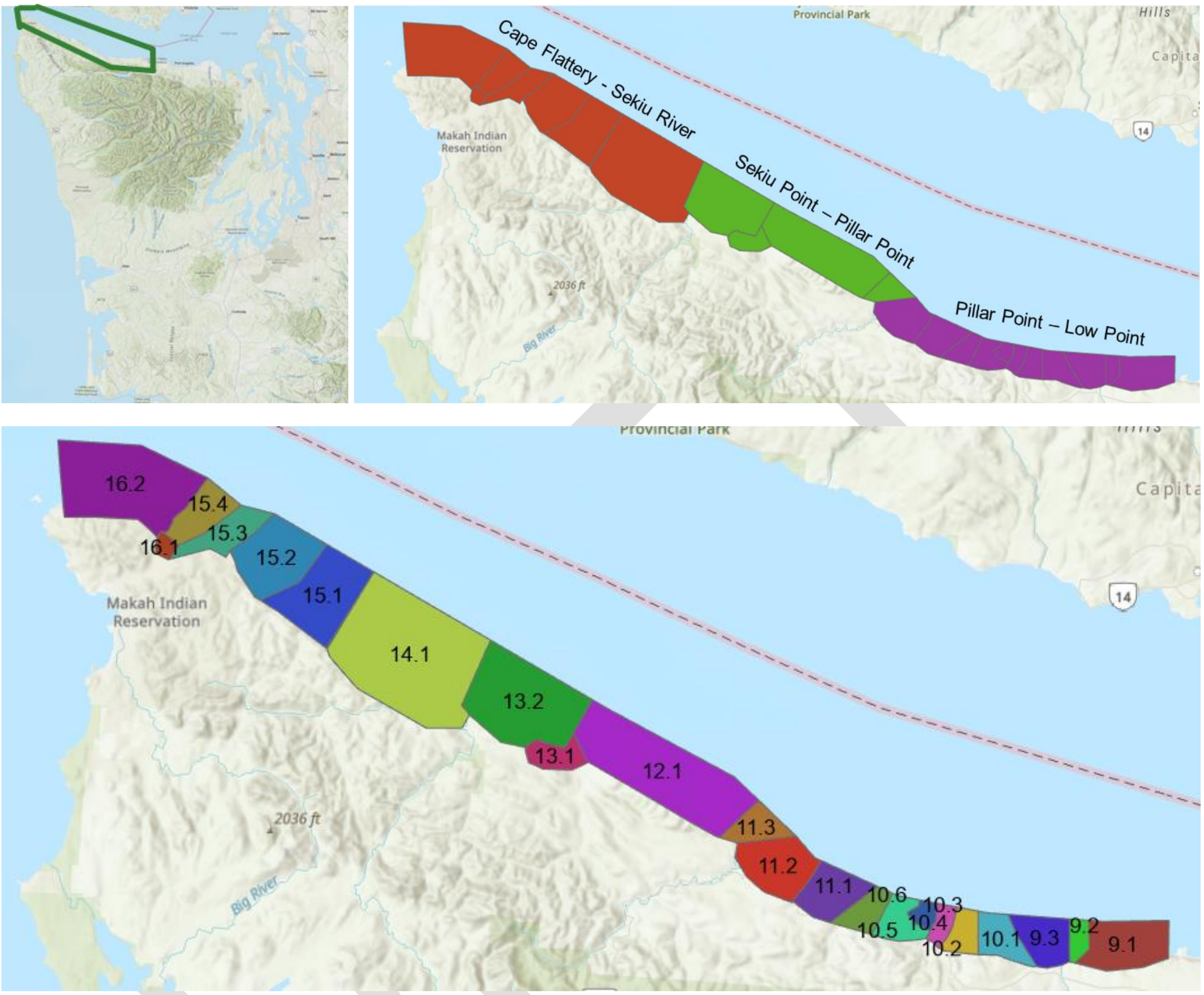


Figure 1. Maps of the Western Strait sub-basin.
Top left – map of western Washington State with a green polygon surrounding the Western Strait sub-region. Top right – close-up map of the Western Strait sub-region, labeled by reach. Bottom – close-up map of the Western Strait sub-region, labeled by zone (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 $p \le 0.05$ 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.].

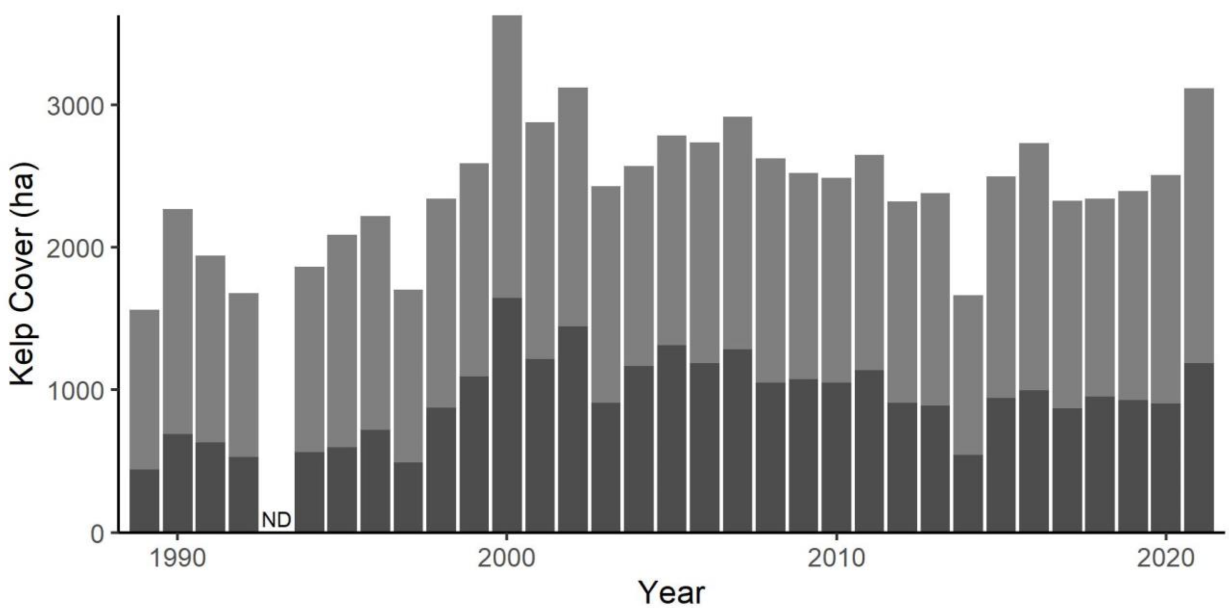


Figure 2. Total kelp canopy cover from 1989 to 2021.
Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area (includes both bull kelp, Nereocystis luetkeana, and giant kelp, Macrocystis pyrifera). Note that no data was collected in 1993. Data from COSTR (Western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

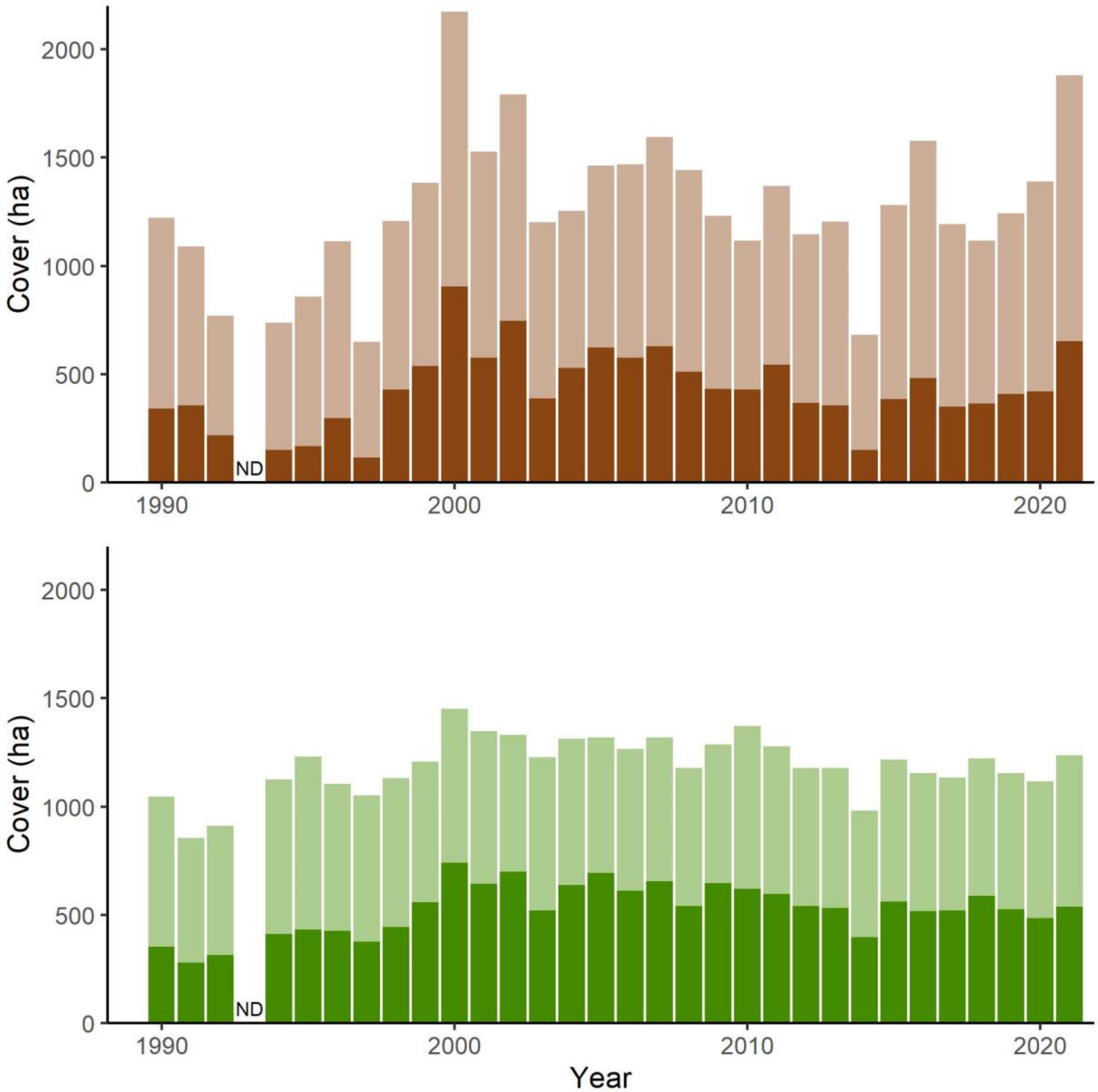


Figure 3. Total kelp cover (including both bull kelp, Nereocystis luetkeana [in brown], and giant kelp, Macrocystis pyrifera [in green]) from 1990 to 2021.
Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area. Note that no data was collected in 1993, and that 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).

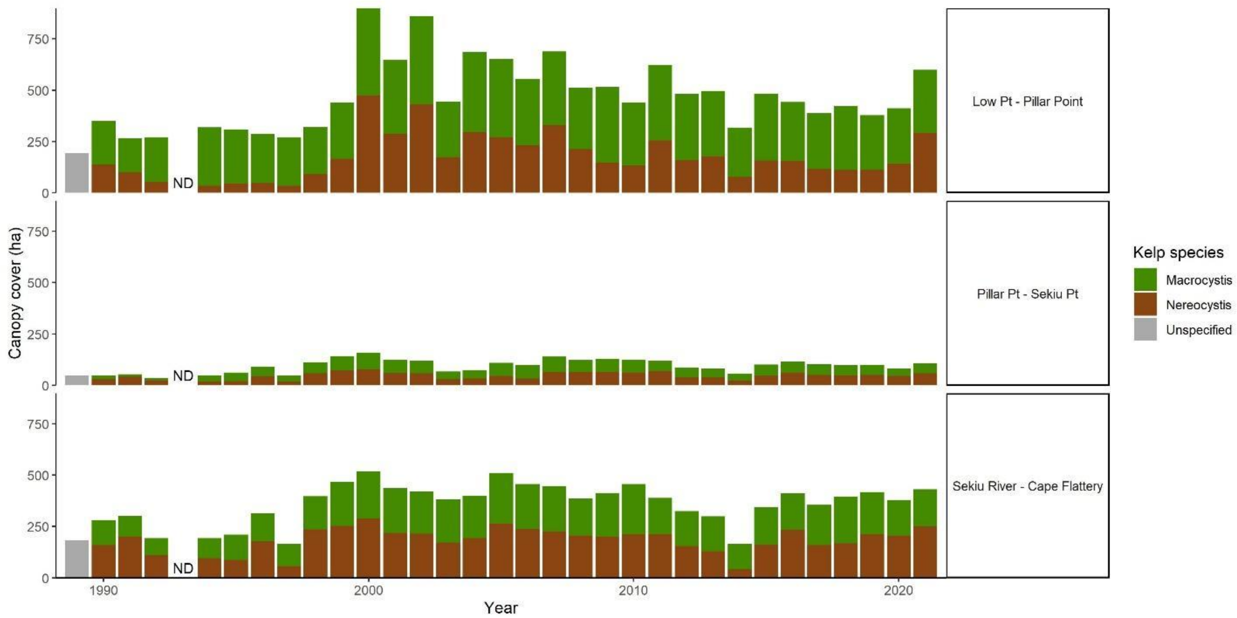


Figure 4. Total kelp cover (including both bull kelp, Nereocystis luetkeana [in brown], and giant kelp, Macrocystis pyrifera [in green]) from 1990 to 2021 for each reach in the Western Strait.
Note that no data was collected in 1993, and that kelp species was not specified during the 1989 surveys (indicated 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).

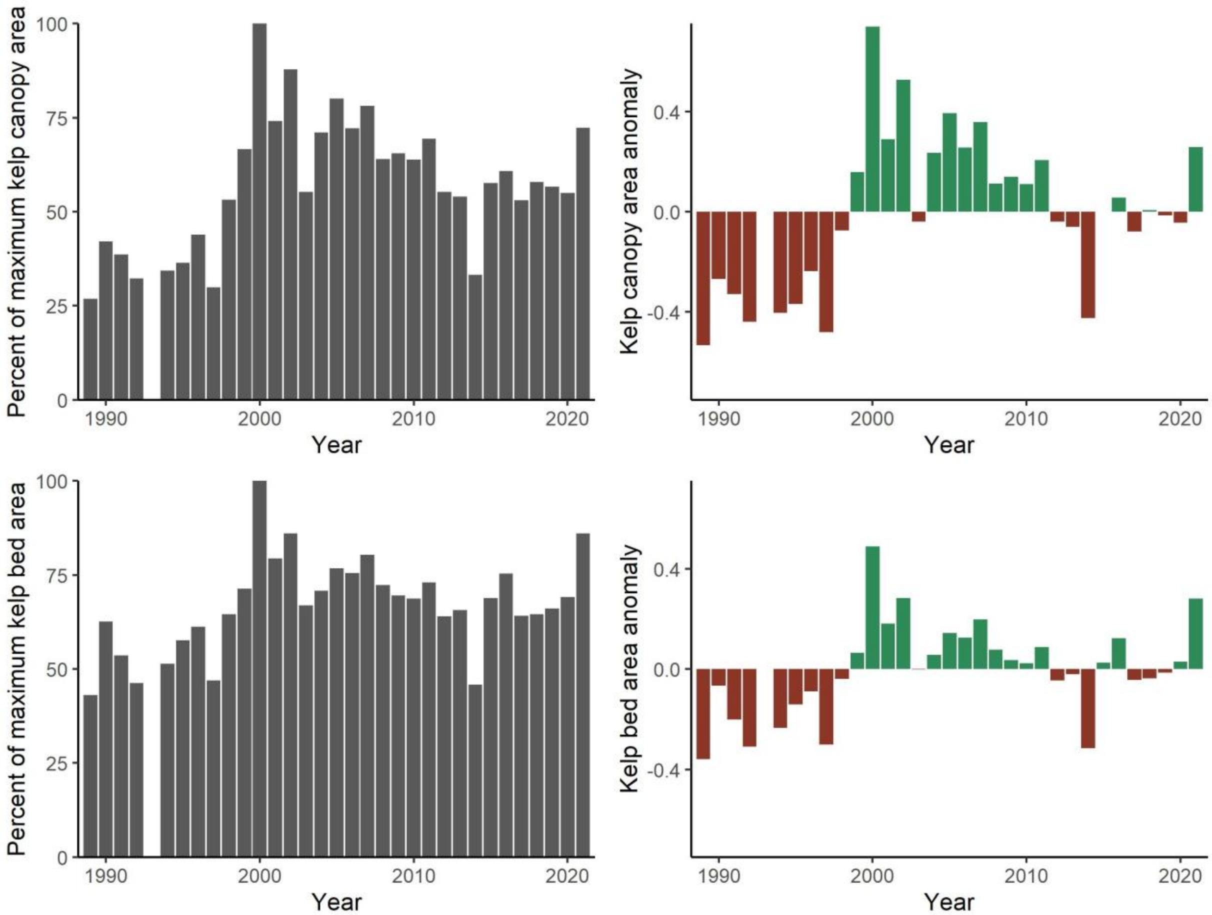


Figure 5. Kelp area anomalies for the Western Strait of Juan de Fuca.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean kelp 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).

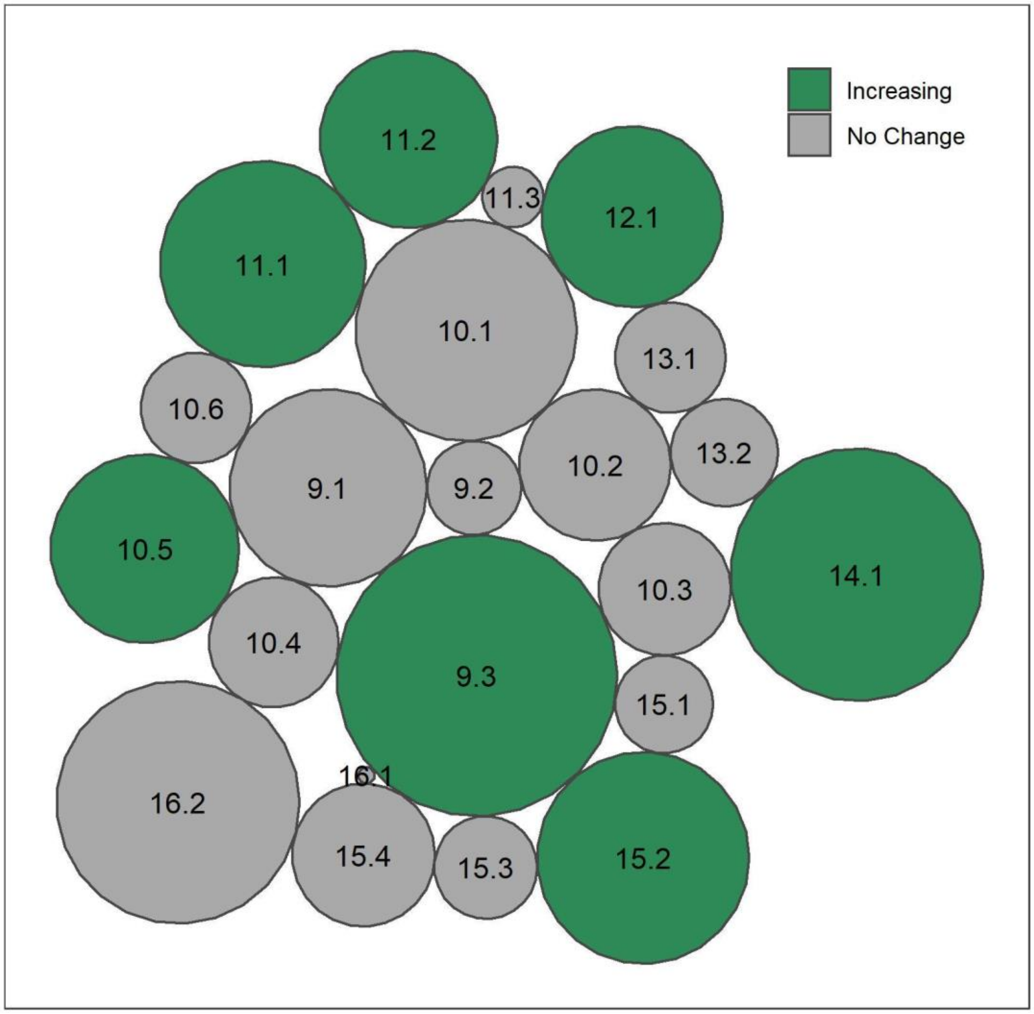


Figure 6. Kelp canopy area change over time (1989-2021) for each zone in the Western Strait of Juan de Fuca. Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent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

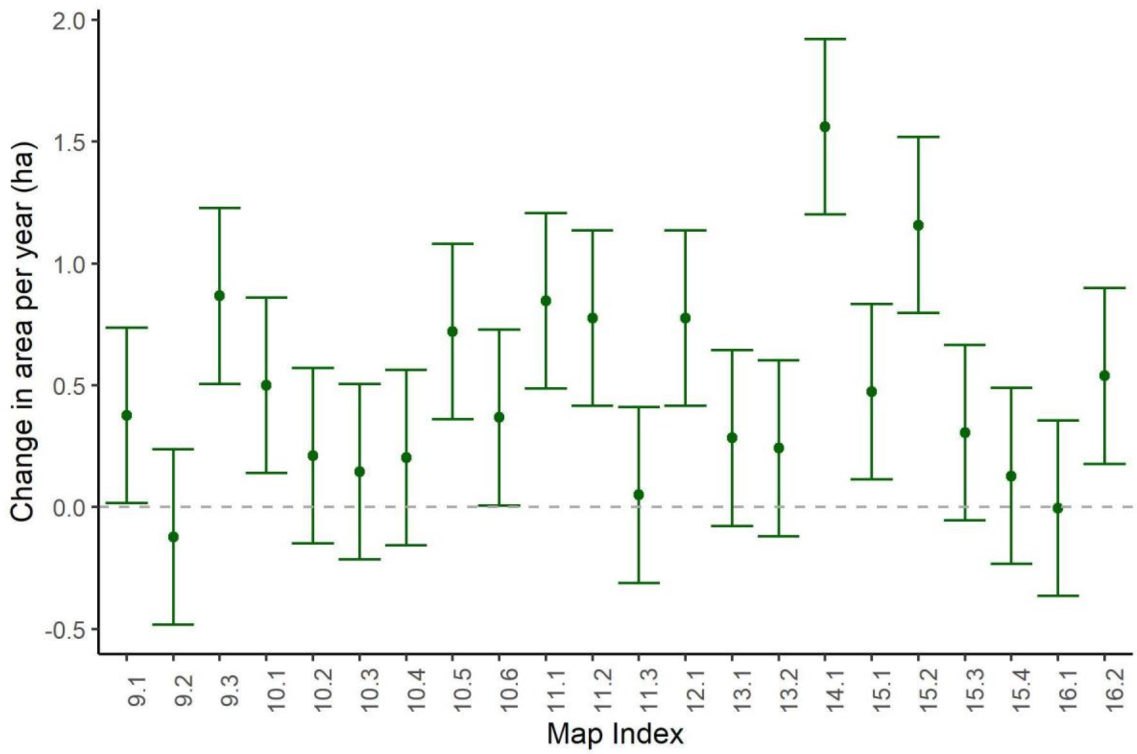


Figure 7. Kelp canopy area change over time of total kelp canopy, including both bull kelp and giant kelp, for each zone. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no change. Data from COSTR (Western Strait) 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).

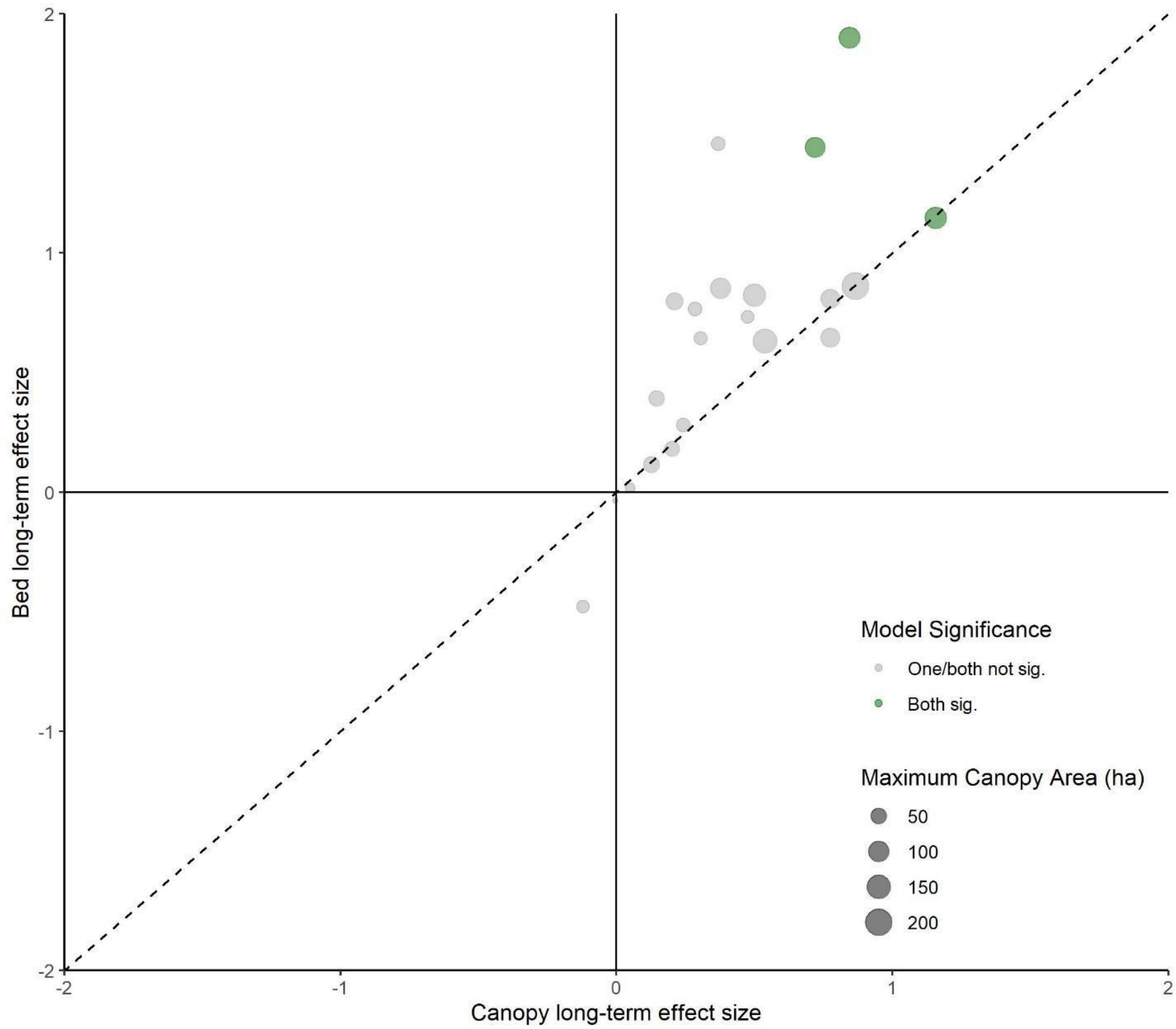


Figure 8. Comparison of rate of change in kelp area between canopy and bed measurements.
Each circle represents a zone, and they are scaled by the maximum canopy area detected in that zone. Data points in the top-right quadrant of the figure indicate increases in both bed and canopy area, and points 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).

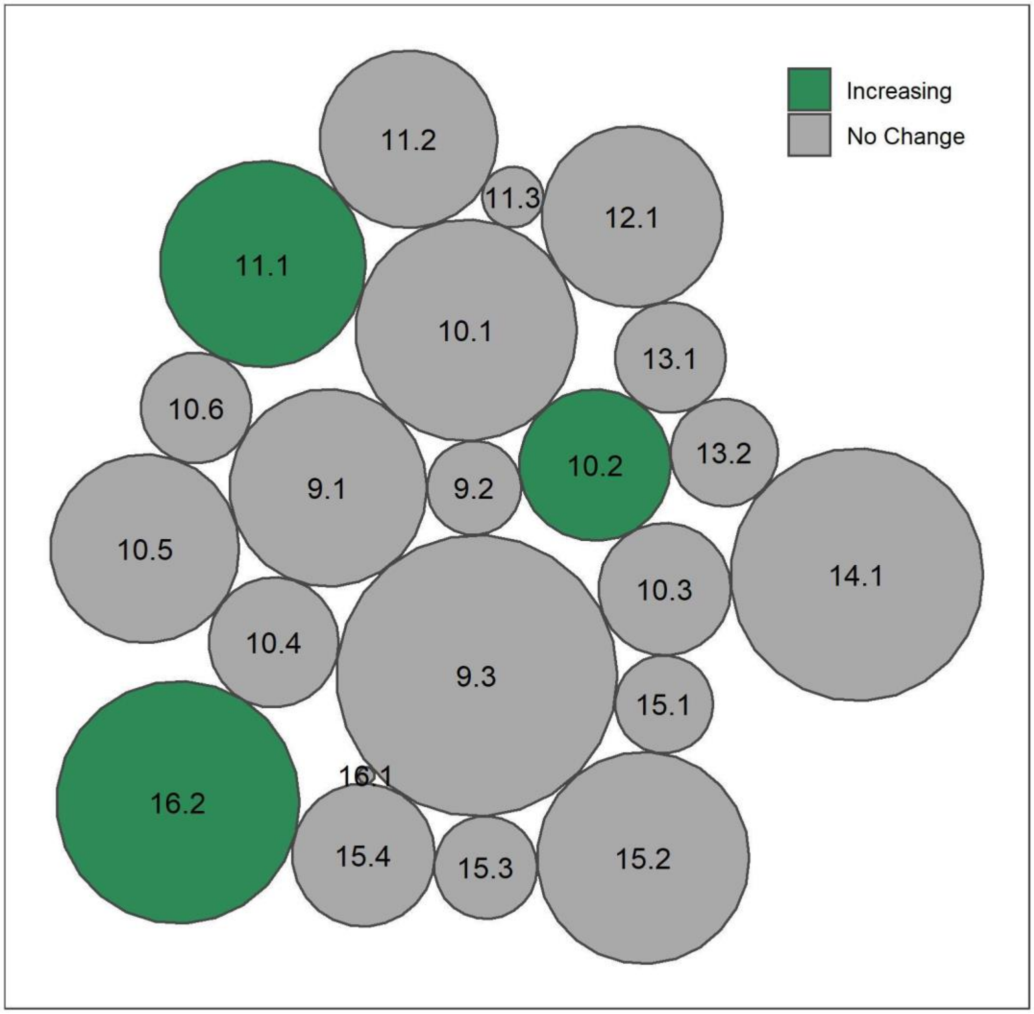


Figure 9. Kelp canopy area change over time for each zone in the Western Strait of Juan de Fuca during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each 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).

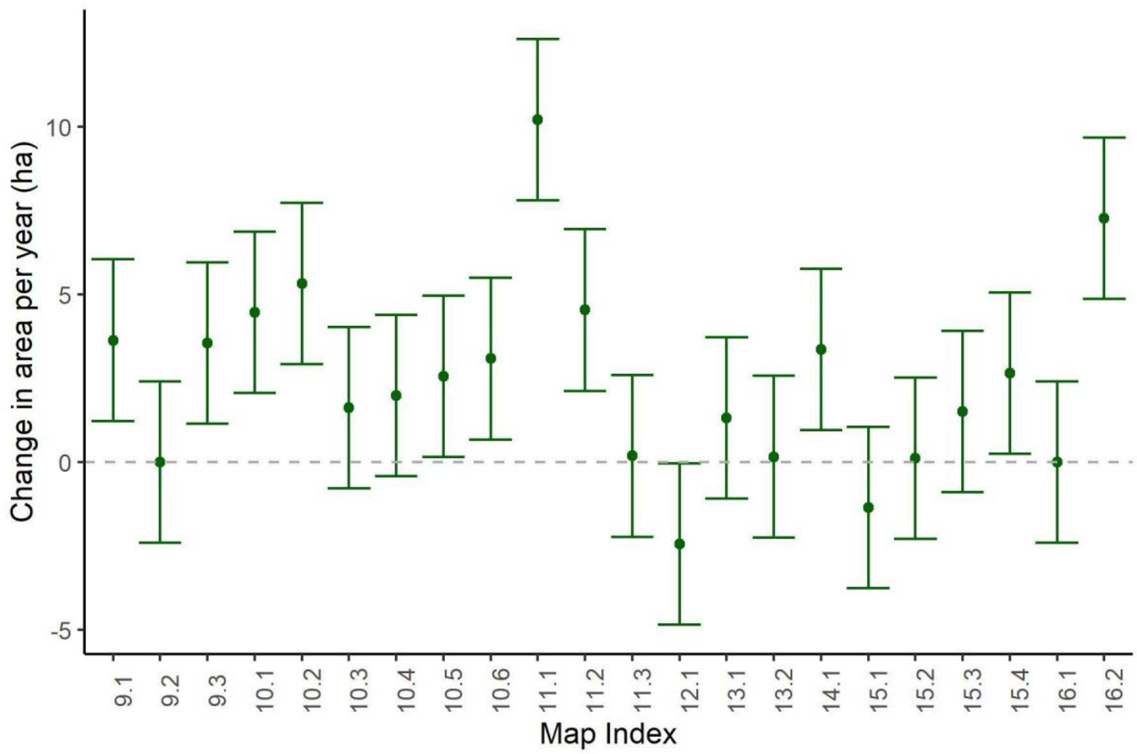


Figure 10. Kelp canopy area change over time of total kelp canopy during the past five years (2017-2021), including both bull kelp and giant kelp, for each zone.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates 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).

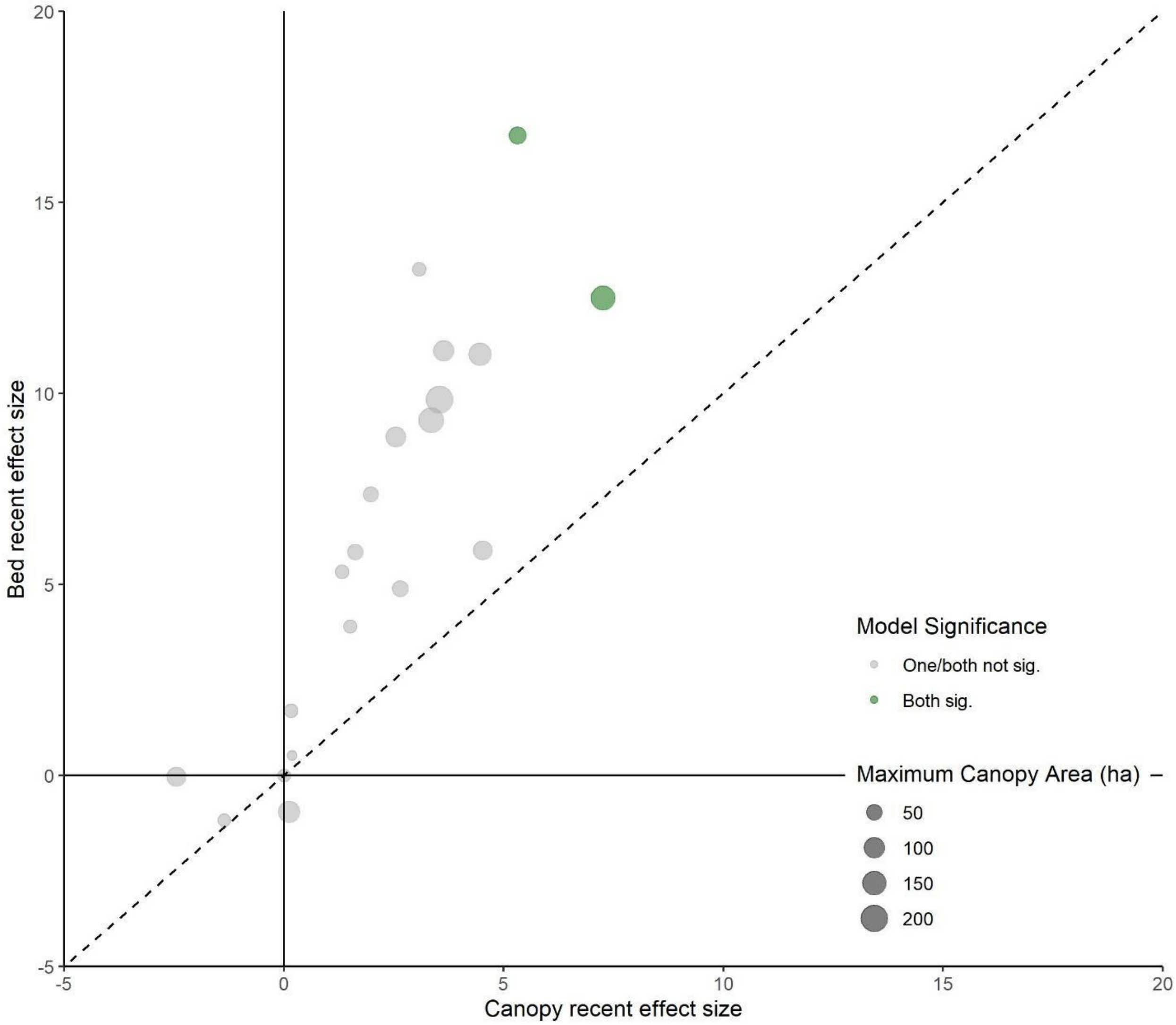


Figure 11. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021).
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases in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

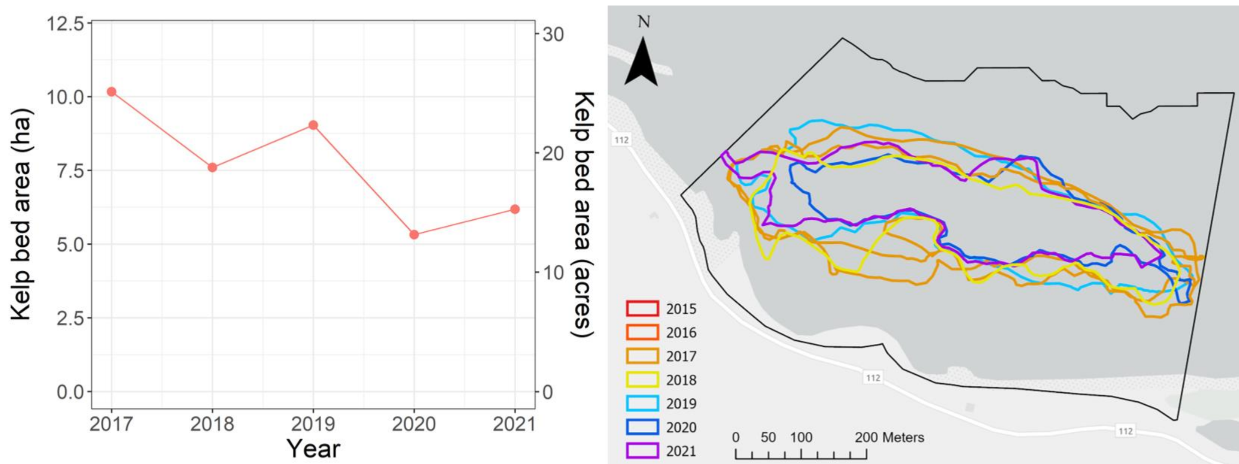


Figure 12. Changes in kelp bed area at the MRC monitoring site in Clallam Bay. Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey assessment extent.

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).

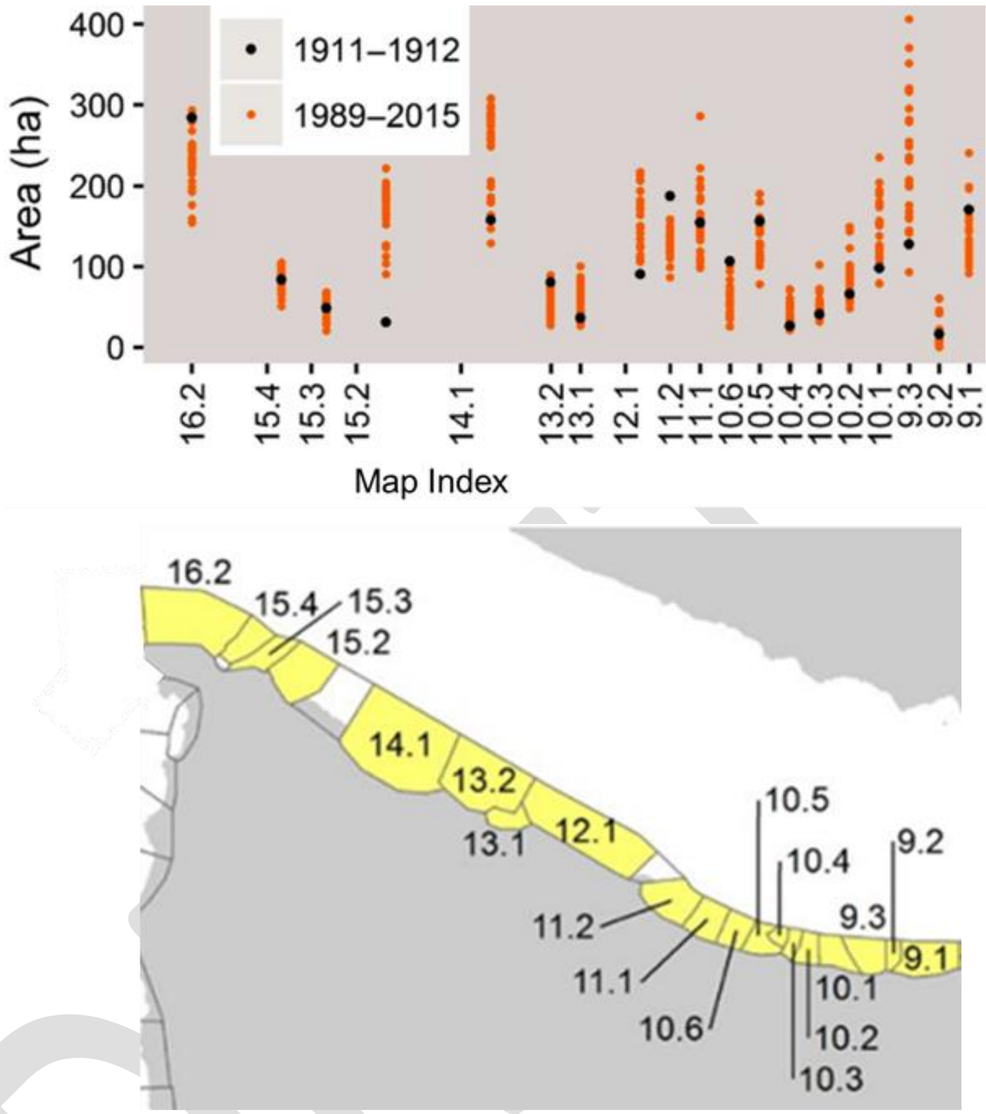
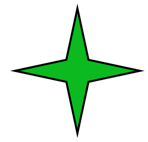
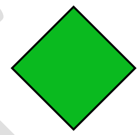
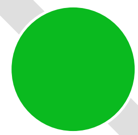
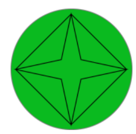


Figure 13. Comparison of Fertilizer Maps and COSTR data, from Pfister, Berry, and Mumford 2018.
Top panel shows historical kelp canopy area (collected in 1911-1912; black dots) and recent kelp canopy area (collected in 1989-2015; orange dots). Bottom panel shows the location of each zone (“map index”;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

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

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

Last updated: May 27, 2022

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

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

Executive summary

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

Data Summary

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

Key Findings

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

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

Priorities for Future Research and Monitoring

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

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

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

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 the third tier sub-basin reports, such as this document. The purpose of sub-basin reports is to provide detailed information on the data, analyses, and results of kelp status and trends that are synthesized in the floating kelp canopy area indicator, including rationale for sub-basin trend designation.

1.2 Sub-basin overview

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

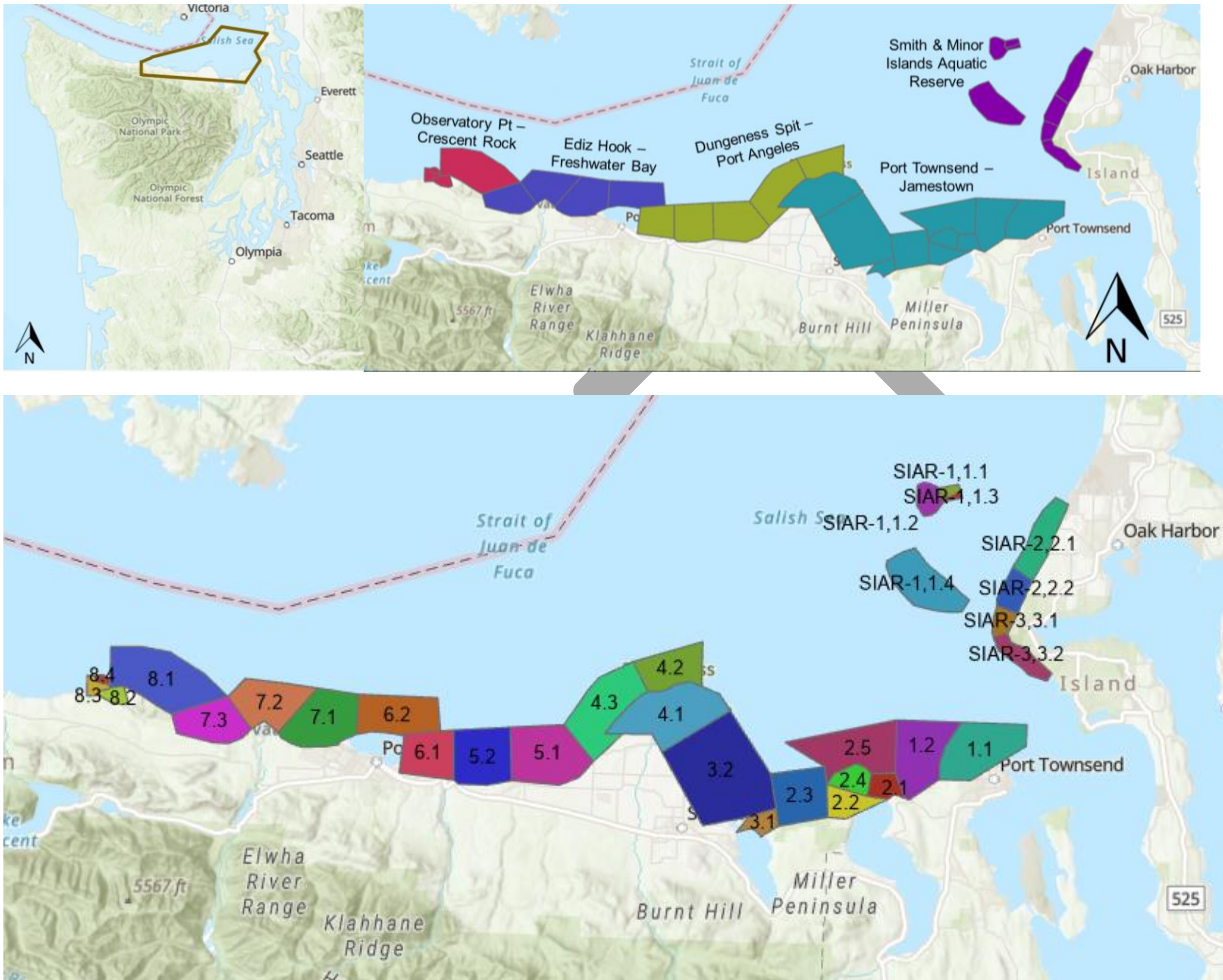


Figure 1. Maps of the Eastern Strait sub-basin.

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

2. Data, methods, and analyses

2.1 Overview

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

2.2 Datasets analyzed for the indicator

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

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

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

2.3 Other datasets and information considered

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

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

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

2.4 Time period designation

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

Table 1. Time period designation and corresponding data sets.

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

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

2.5 Analysis

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

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

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

3. Results

3.1 Abundance and distribution of floating kelp canopy area

3.1.1 Float kelp canopy extent

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

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

3.1.2 Float kelp bed extent

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

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

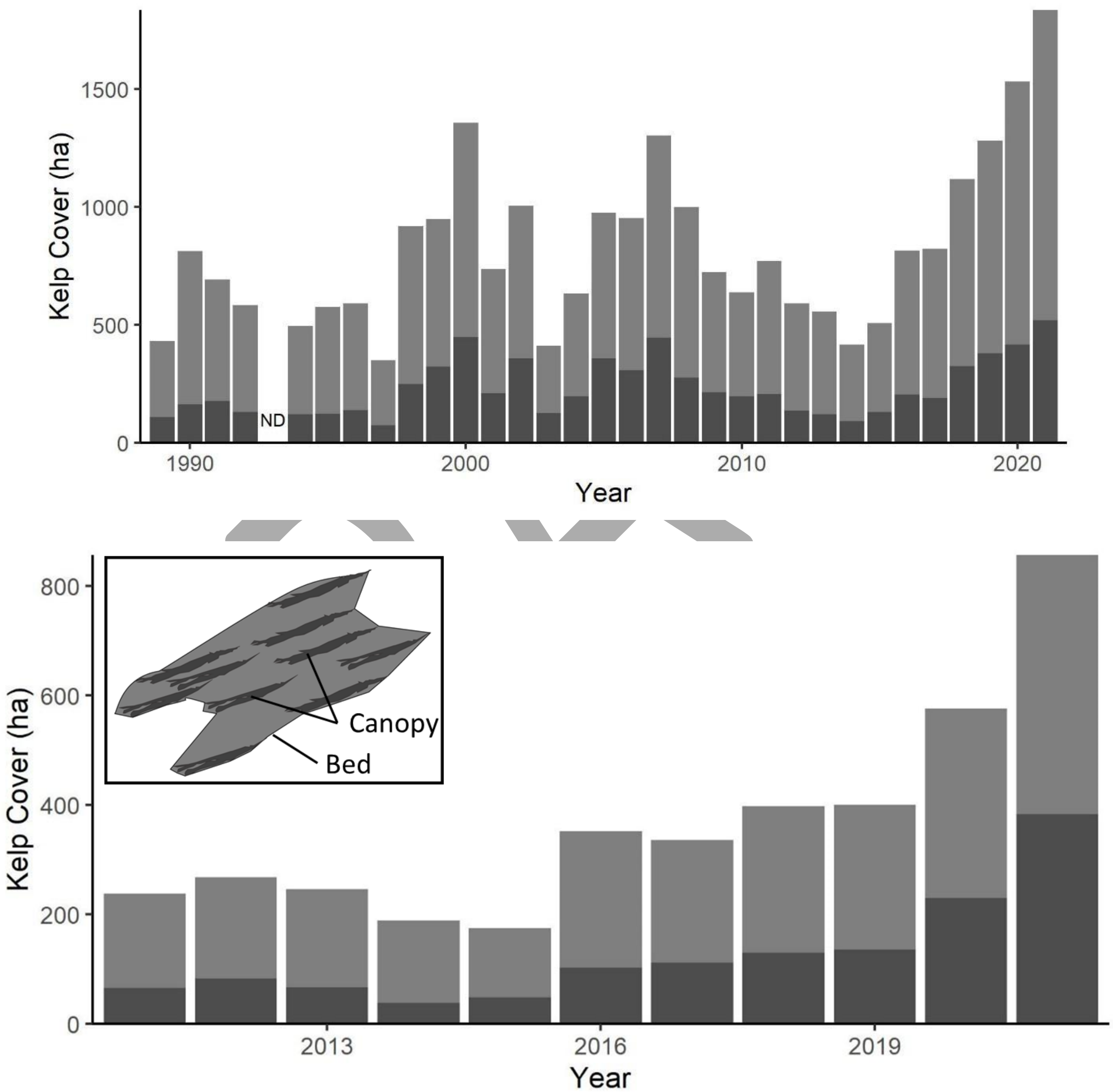


Figure 2. Kelp cover (canopy and bed) over time in the Eastern Strait.
Top - Total kelp cover from DNR COSTR (Eastern Strait) dataset from 1989 to 2021. Darker shaded area indicates kelp canopy area, and lighter shaded area indicates kelp bed area. Kelp cover was dominated by bull kelp (*Nereocystis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

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

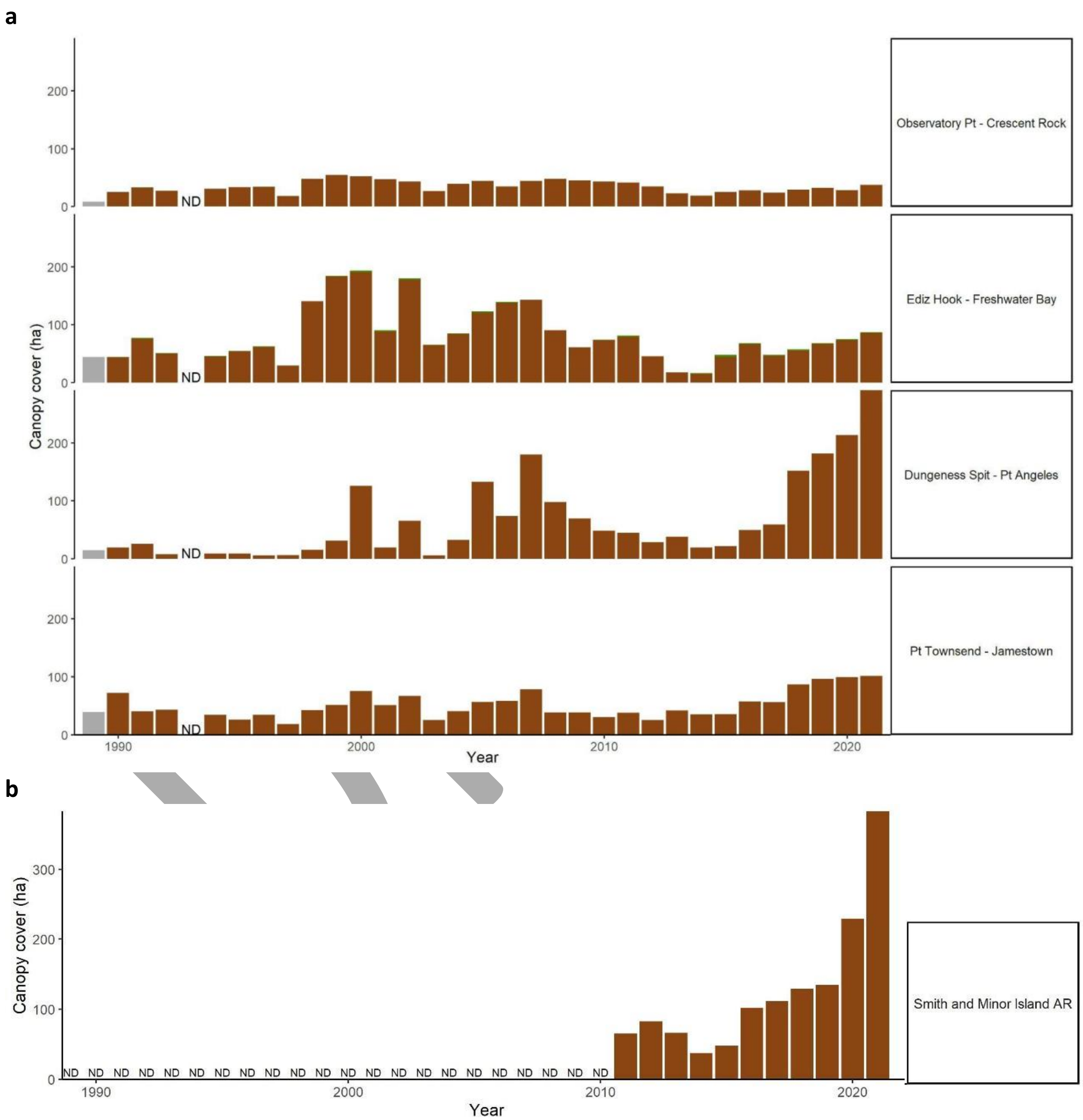


Figure 3. Total kelp canopy cover for each reach in the Eastern Strait.
a) Total kelp canopy cover from 1989 to 2021 for each reach in the Eastern Strait (COSTR dataset). Note that no data was collected in 1993, and that kelp species was not specified during the 1989 surveys (indicated as 'Unspecified'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

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

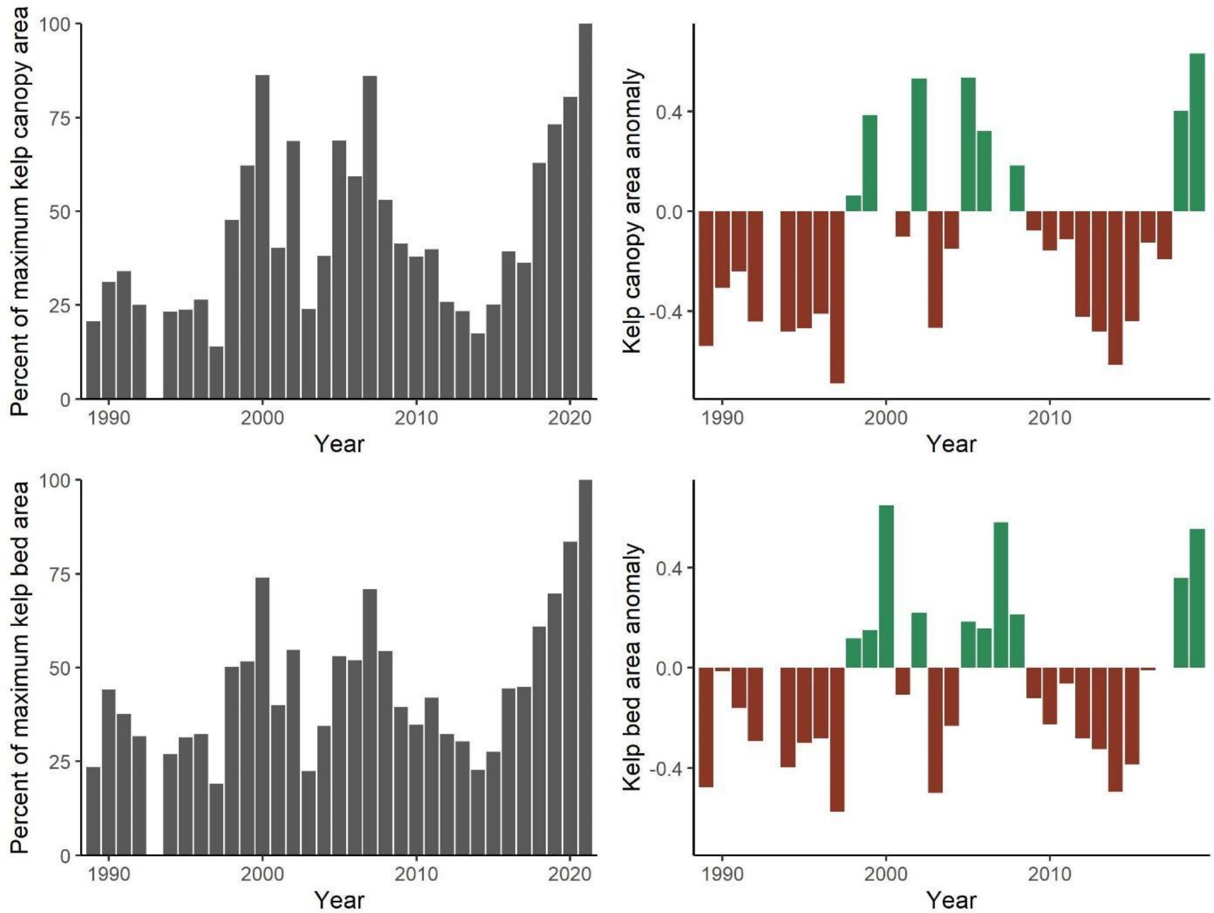


Figure 4. Kelp area anomalies for the Eastern Strait of Juan de Fuca.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean kelp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

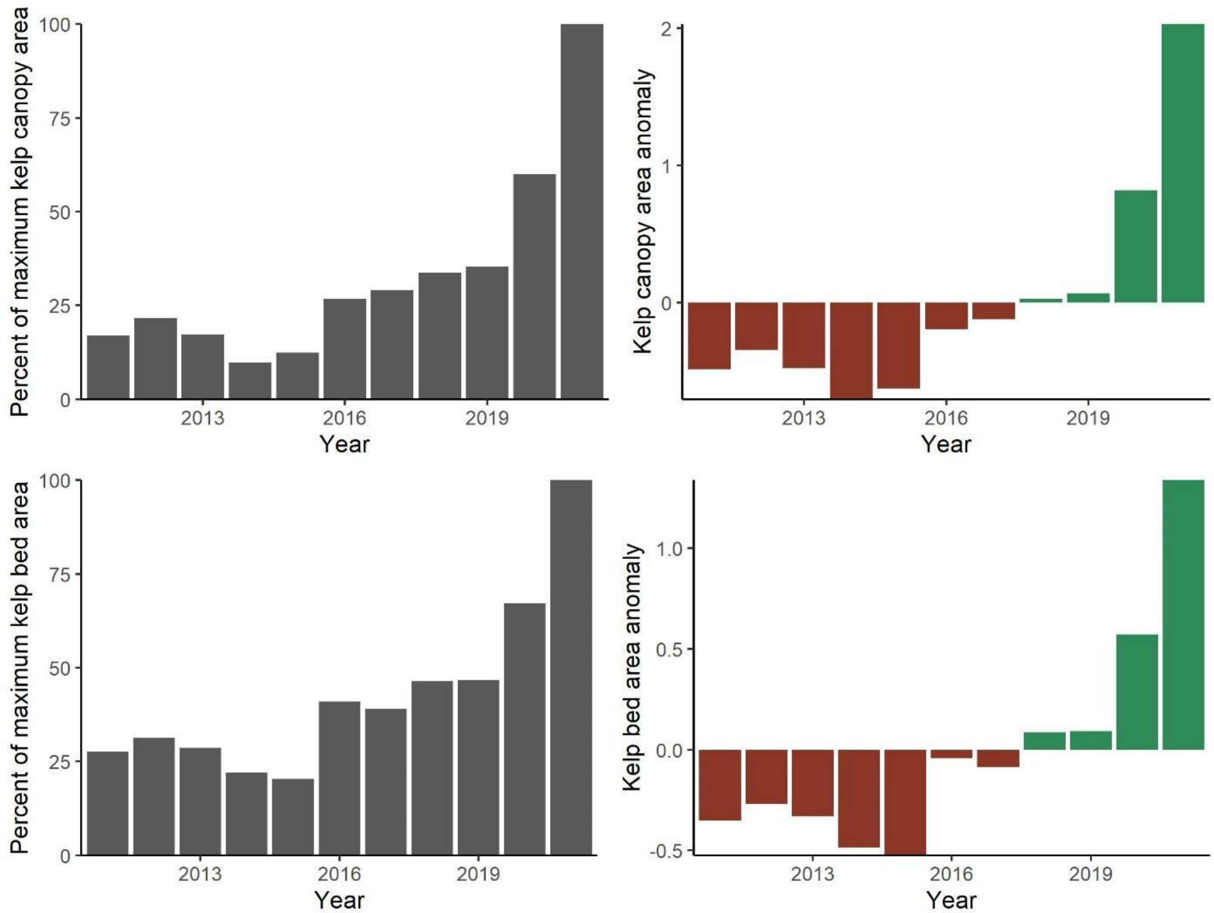


Figure 5. Kelp area anomalies for Smith and Minor Islands Aquatic Reserve.
Top row shows results for kelp canopy area, bottom row shows results or kelp bed area. Left column shows kelp area per year as a percentage of maximum area, and the right column shows kelp area as an anomaly from long-term mean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

3.2 Trends in floating kelp canopy area

Full data set - COSTR

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

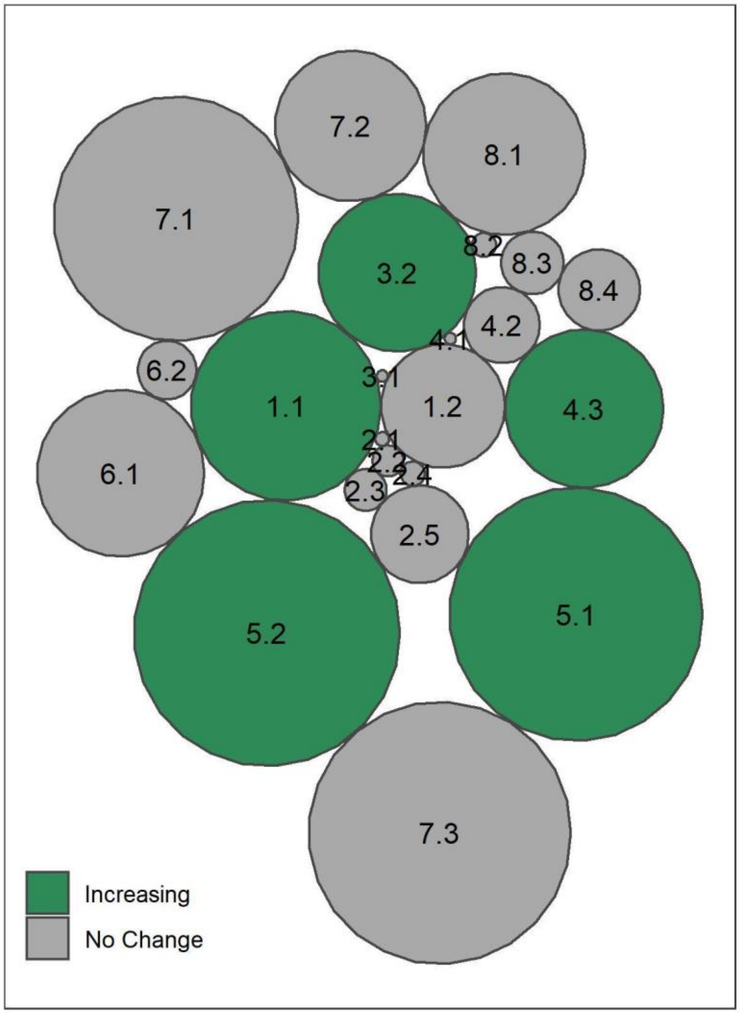


Figure 6. Kelp canopy area change over time for each zone in the full COSTR Eastern Strait dataset.
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled to represent the maximum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

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

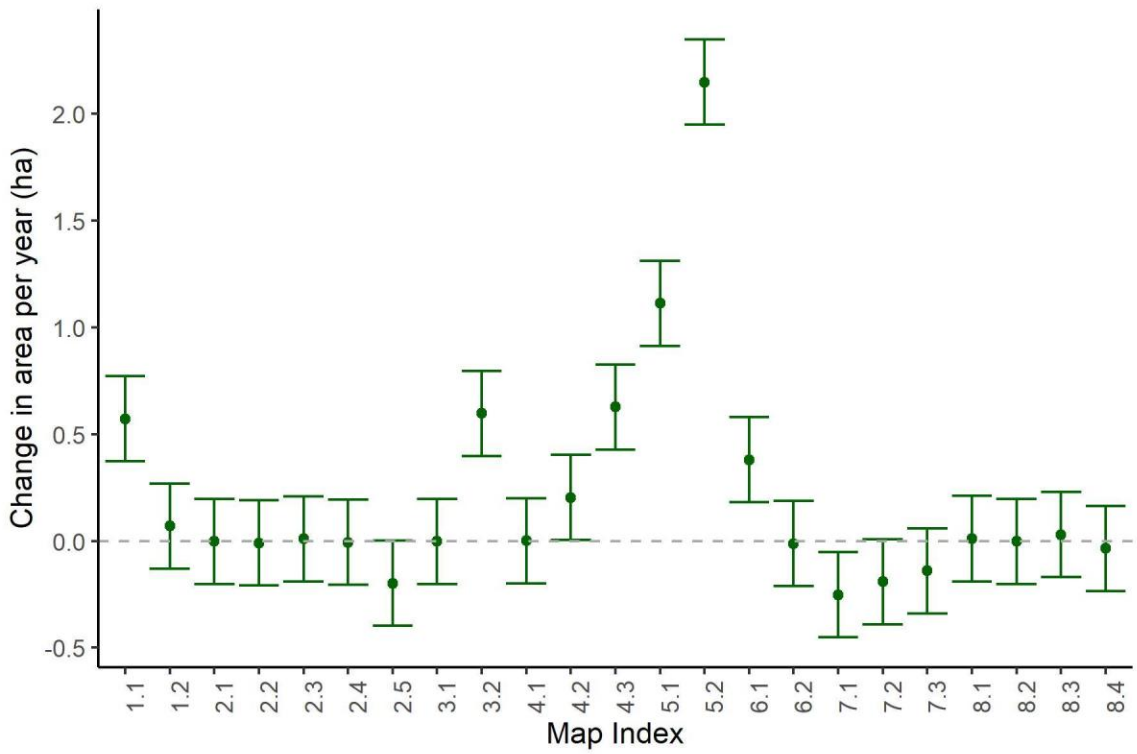


Figure 7. Kelp canopy area change over time of total kelp canopy, for each zone for the full COSTR Eastern Strait dataset. Zones corresponds to zones in Figure 1. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates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

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

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

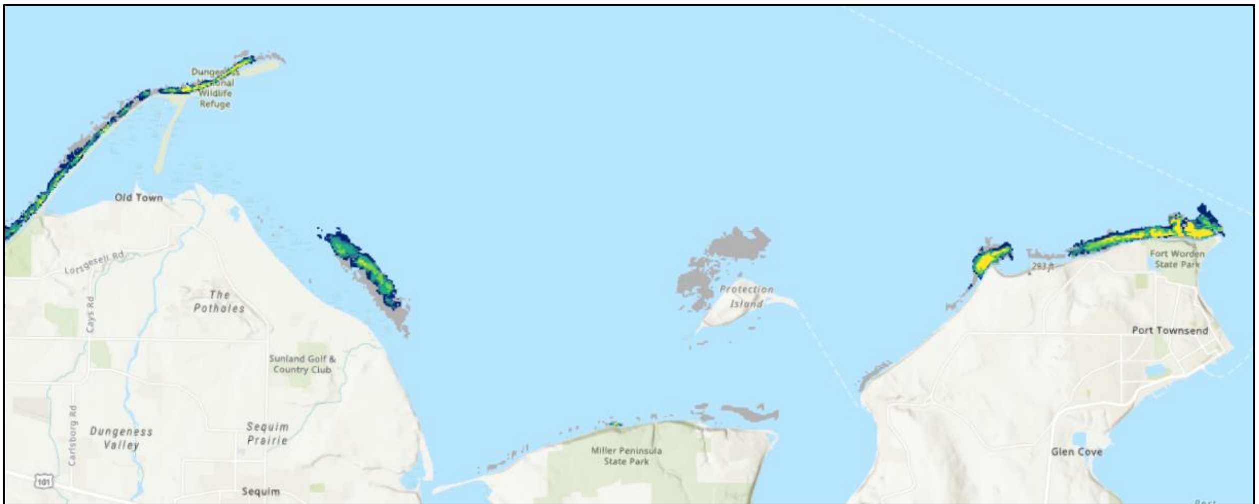


Figure 8. Heat map of kelp bed occurrence along the Jamestown to Port Townsend Reach.
Grey areas denote locations where kelp beds occurred historically but have been absent in recent years. The heat maps of shades from blue to yellow indicate increasing persistence (years of kelp presence). Losses within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

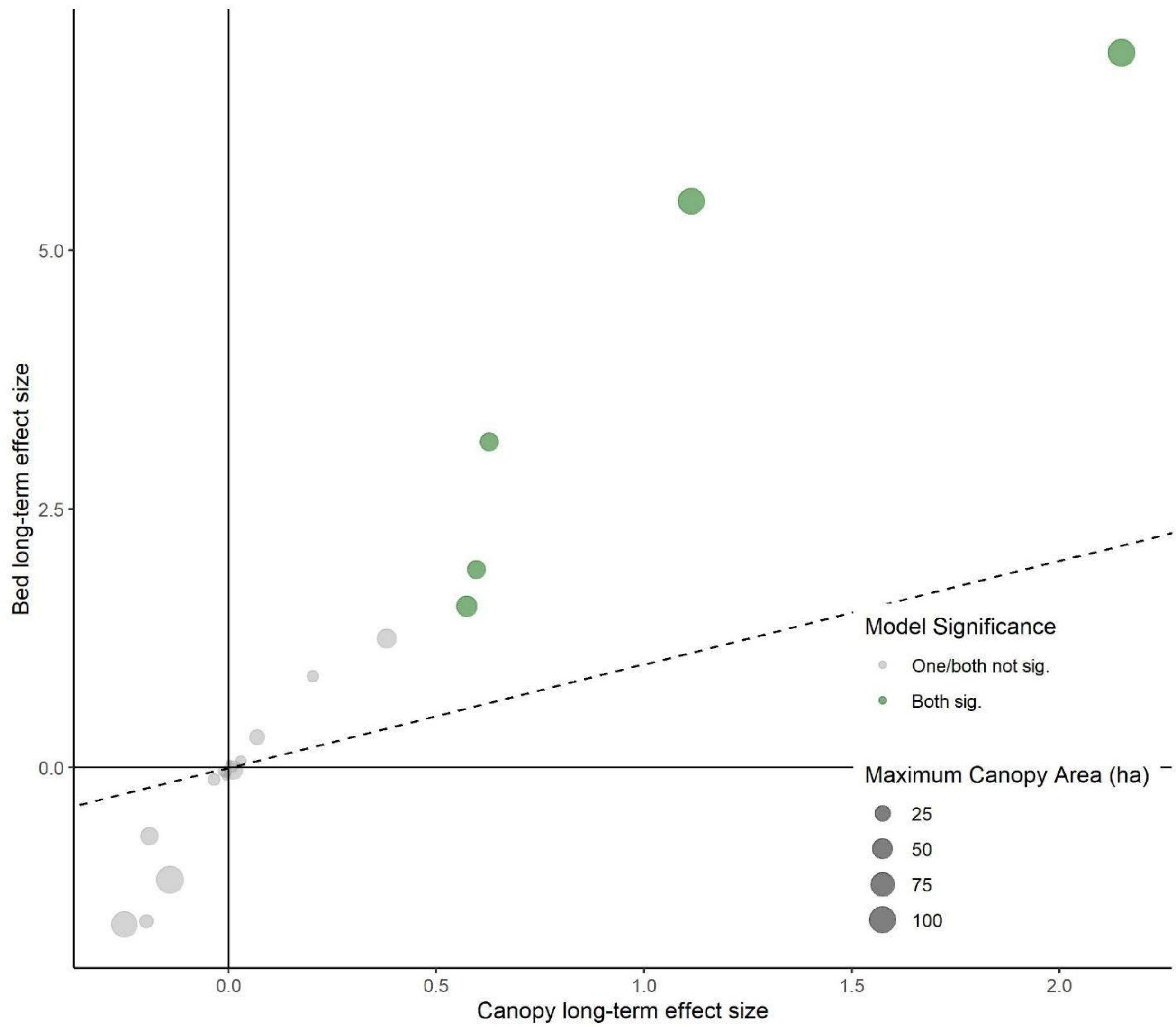


Figure 9. Comparison of rate of change in kelp area between canopy and bed measurements for the full COSTR Eastern Strait dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate increases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

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

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

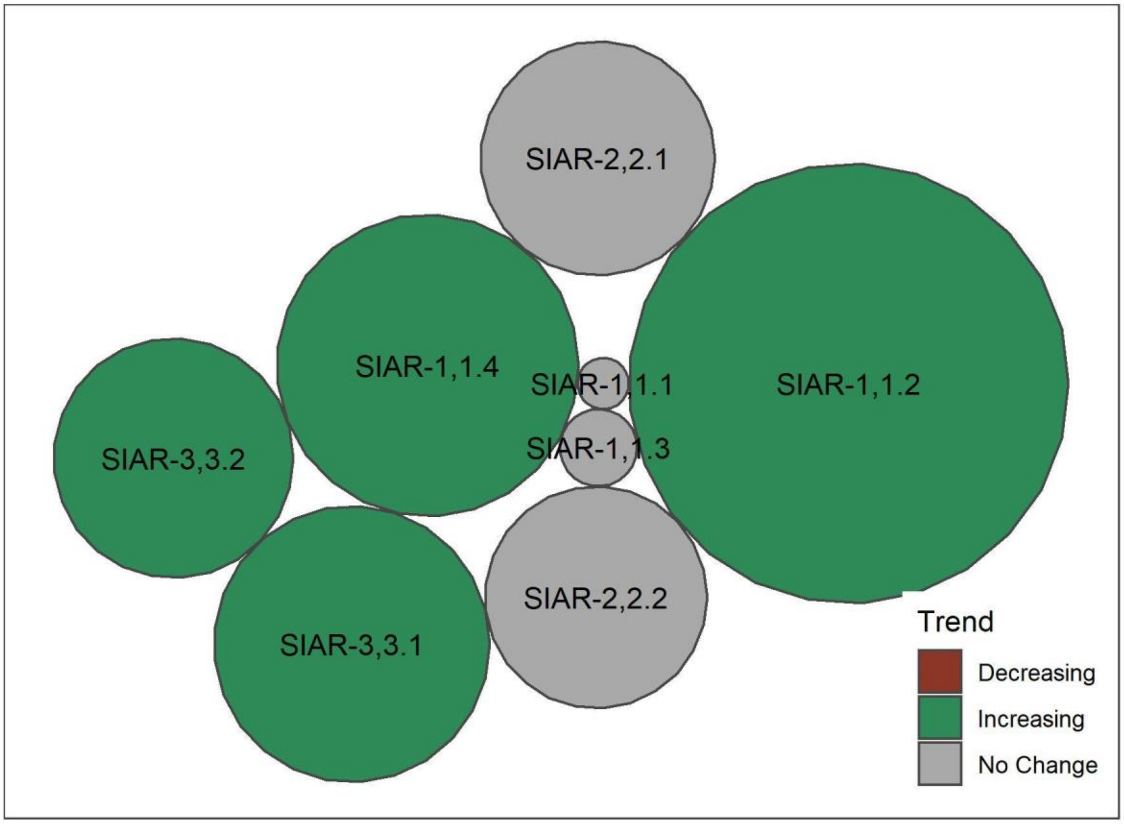


Figure 10. Kelp canopy area change over time for each zone in the Smith and Minor Islands Aquatic Reserve (2012-2021). Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each circle is scaled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

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

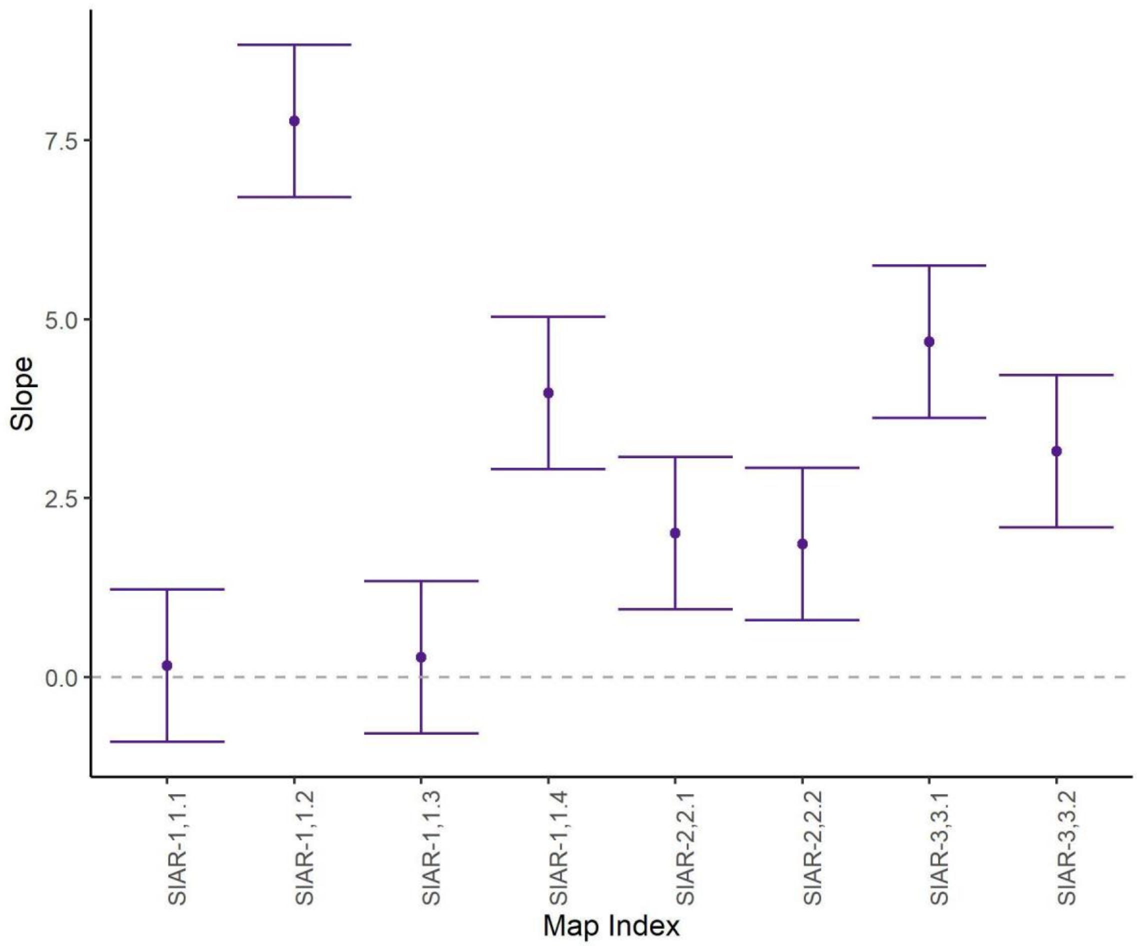


Figure 11. Kelp canopy area change over time of total kelp canopy in the Smith and Minor Aquatic Reserves (2012-2021), for each zone.
Zones correspond to zones in Figure 1. Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero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

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

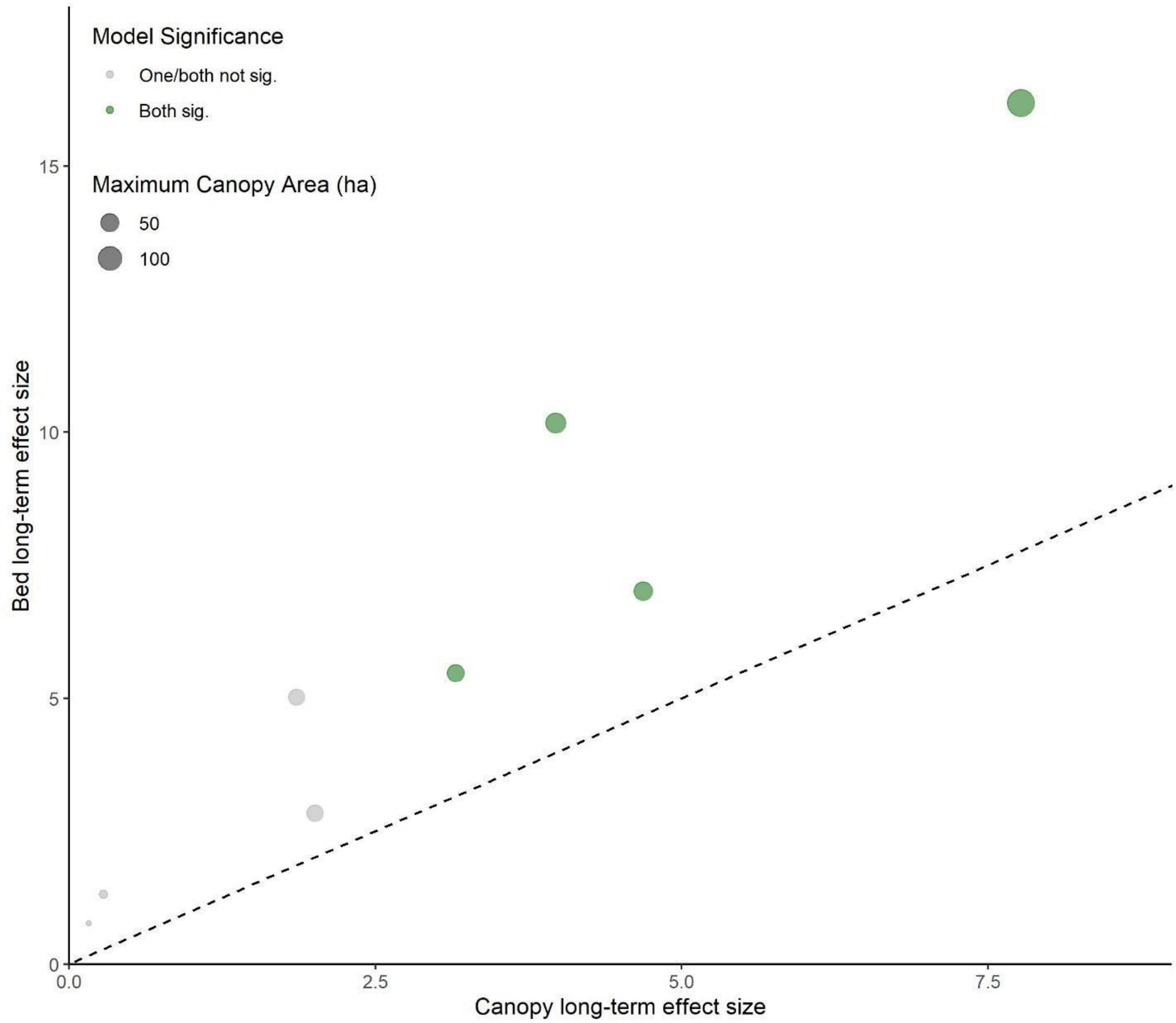


Figure 12. Comparison of rate of change in kelp area between canopy and bed measurements for Smith and Minor Islands Aquatic Reserve (2012-2021).
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right quadrant of the figure indicate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

Past five years (2017-2021) – COSTR dataset

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

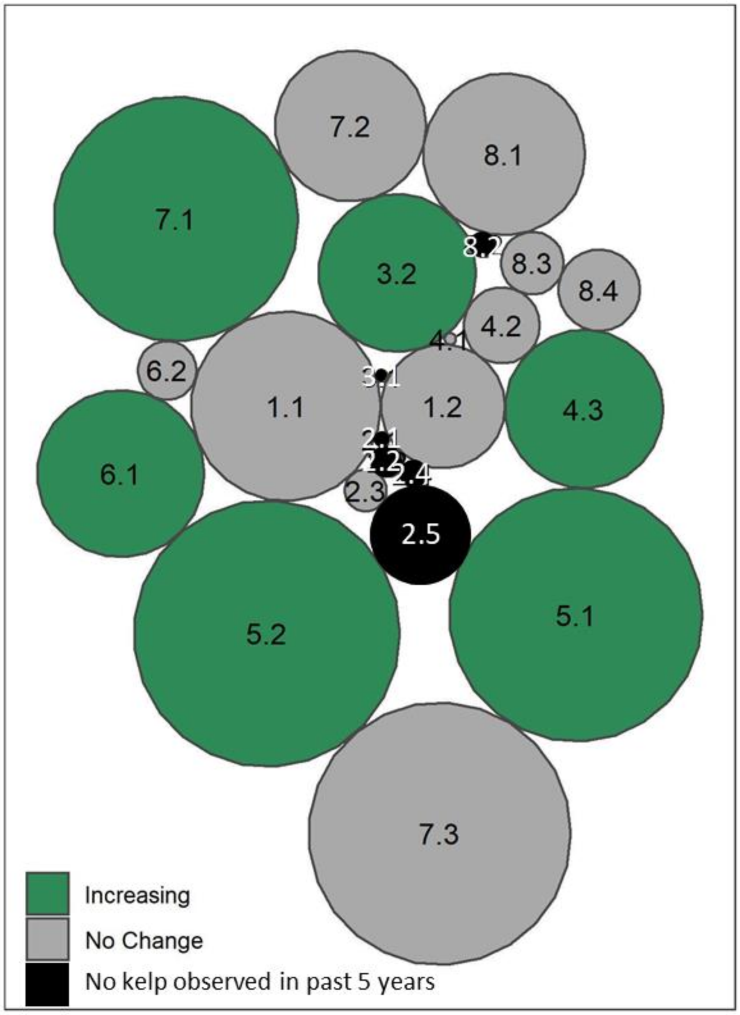


Figure 13. Kelp canopy area change over time for each zone in the COSTR Eastern Strait dataset during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size of each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

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

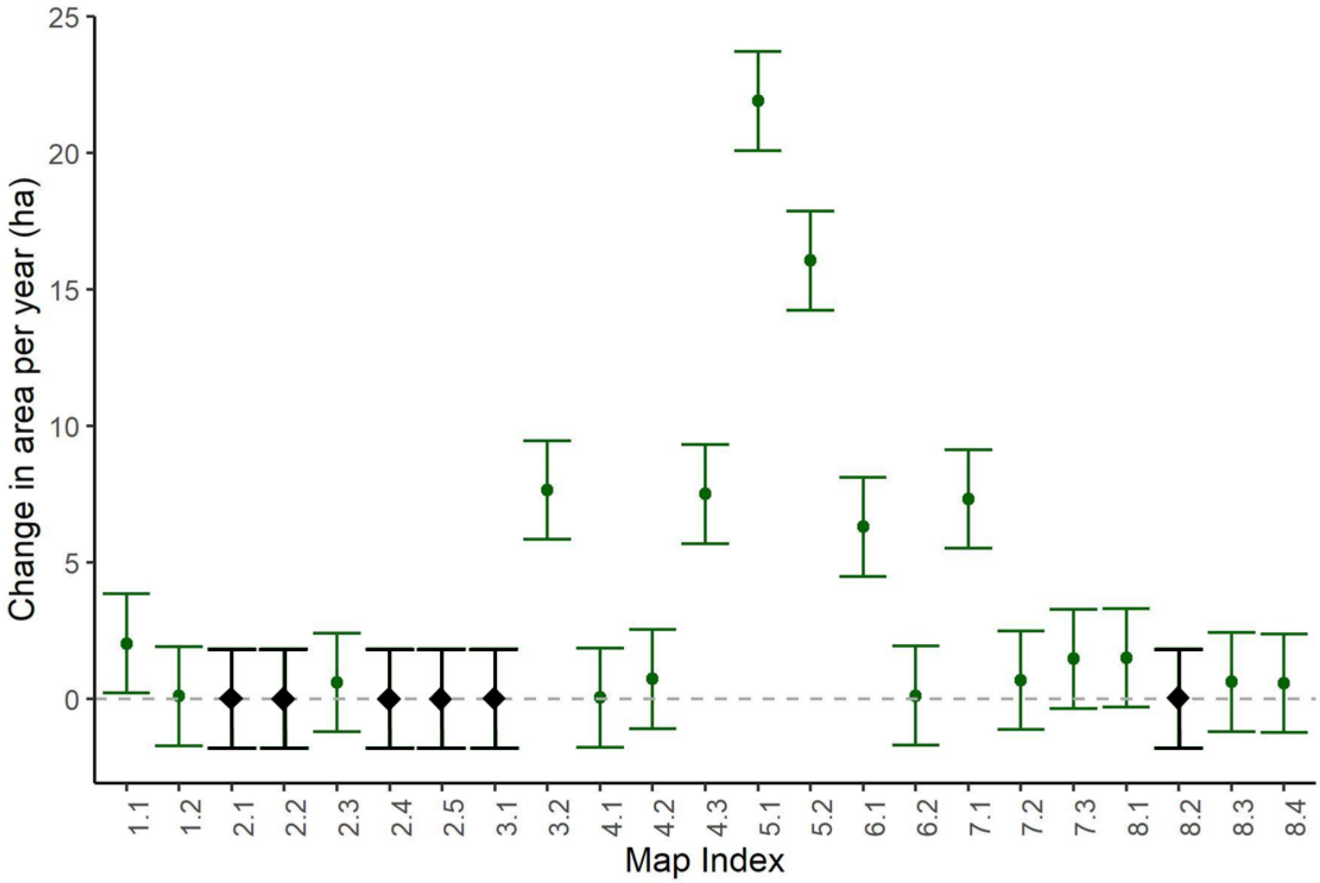


Figure 14. Kelp canopy area change over time of total kelp canopy during the past five years (2017-2021), for each zone in the COSTR Eastern Strait dataset.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates no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

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

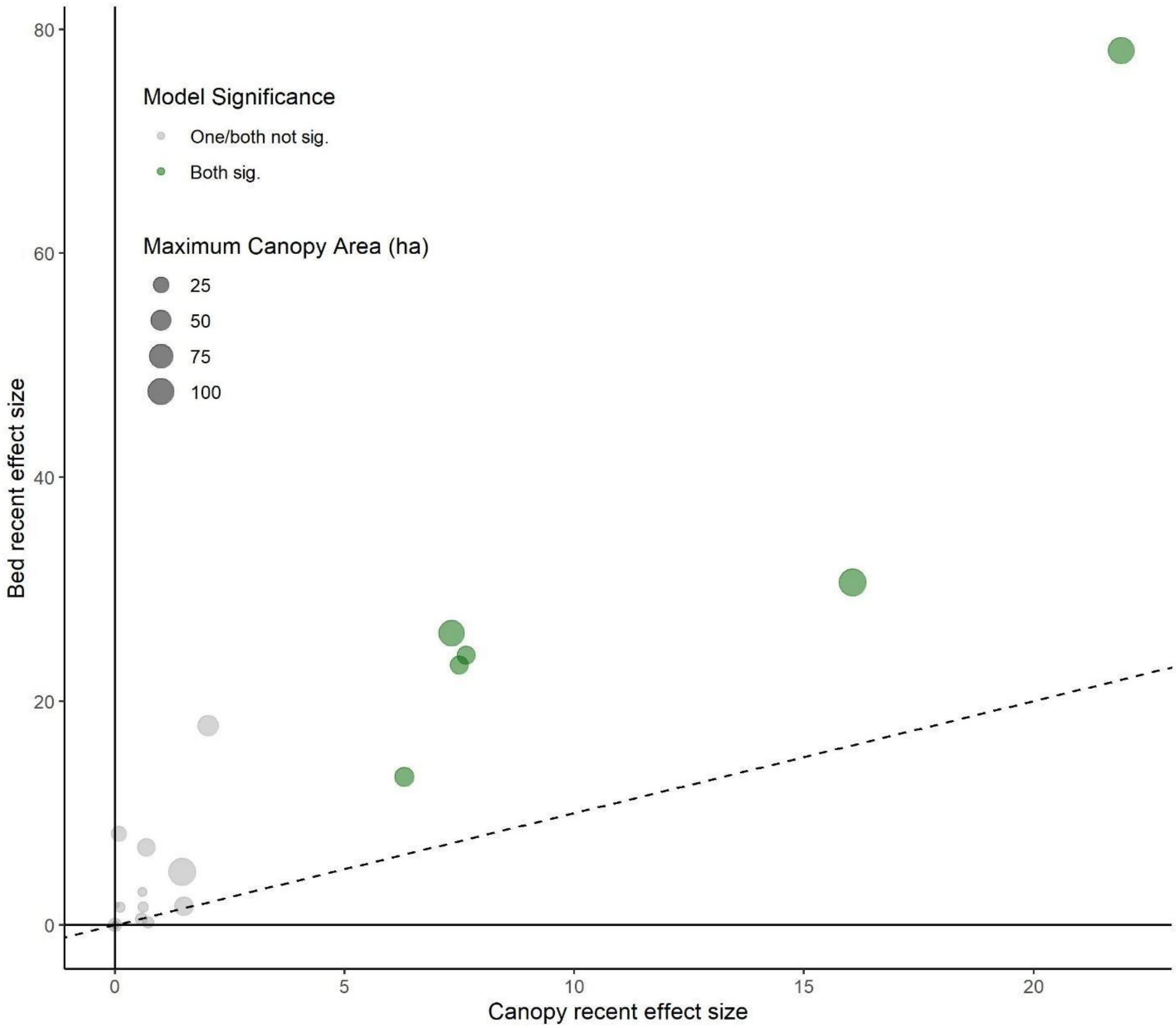


Figure 15. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021) for each zone in the COSTR Eastern Strait dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the top-right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

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

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

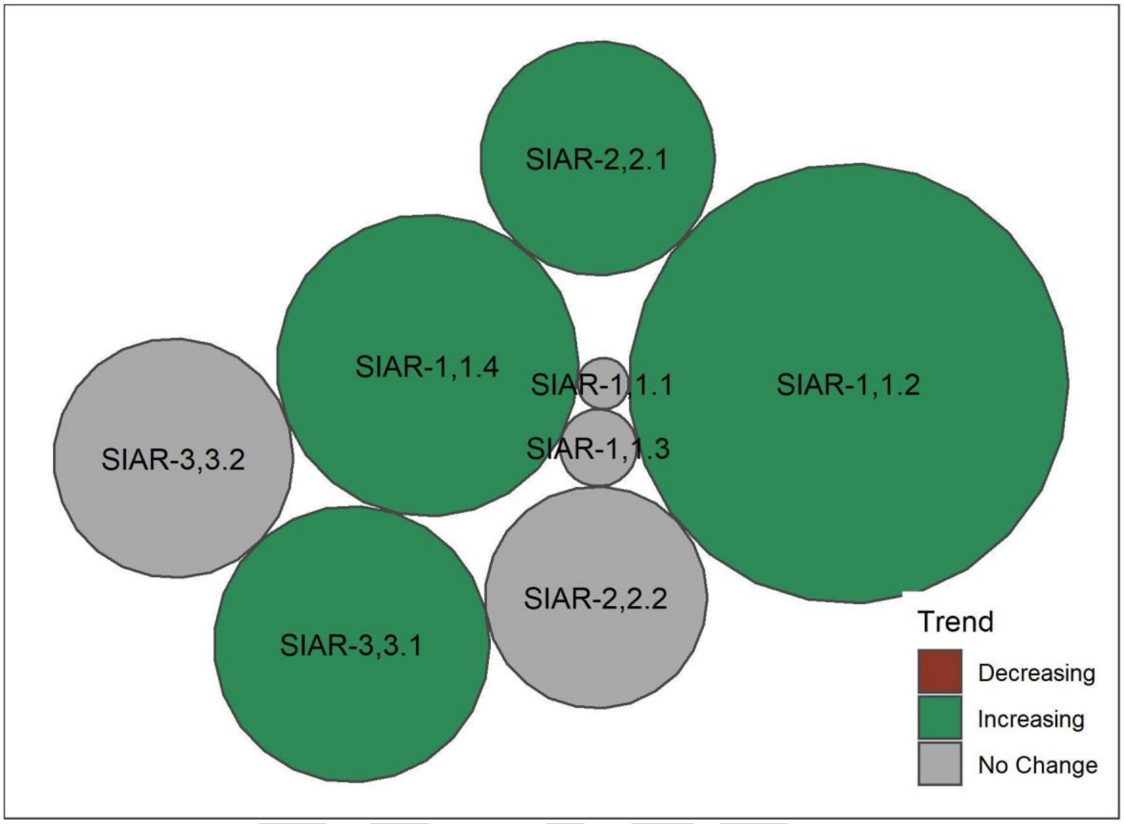


Figure 16. Kelp canopy area change over time for each zone in the Smith and Minor Islands Aquatic Reserve during the past five years (2017-2021).
Each circle represents a zone, and zone numbers are shown at the center of each circle. To show differences in trends among different sizes of beds, the size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

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

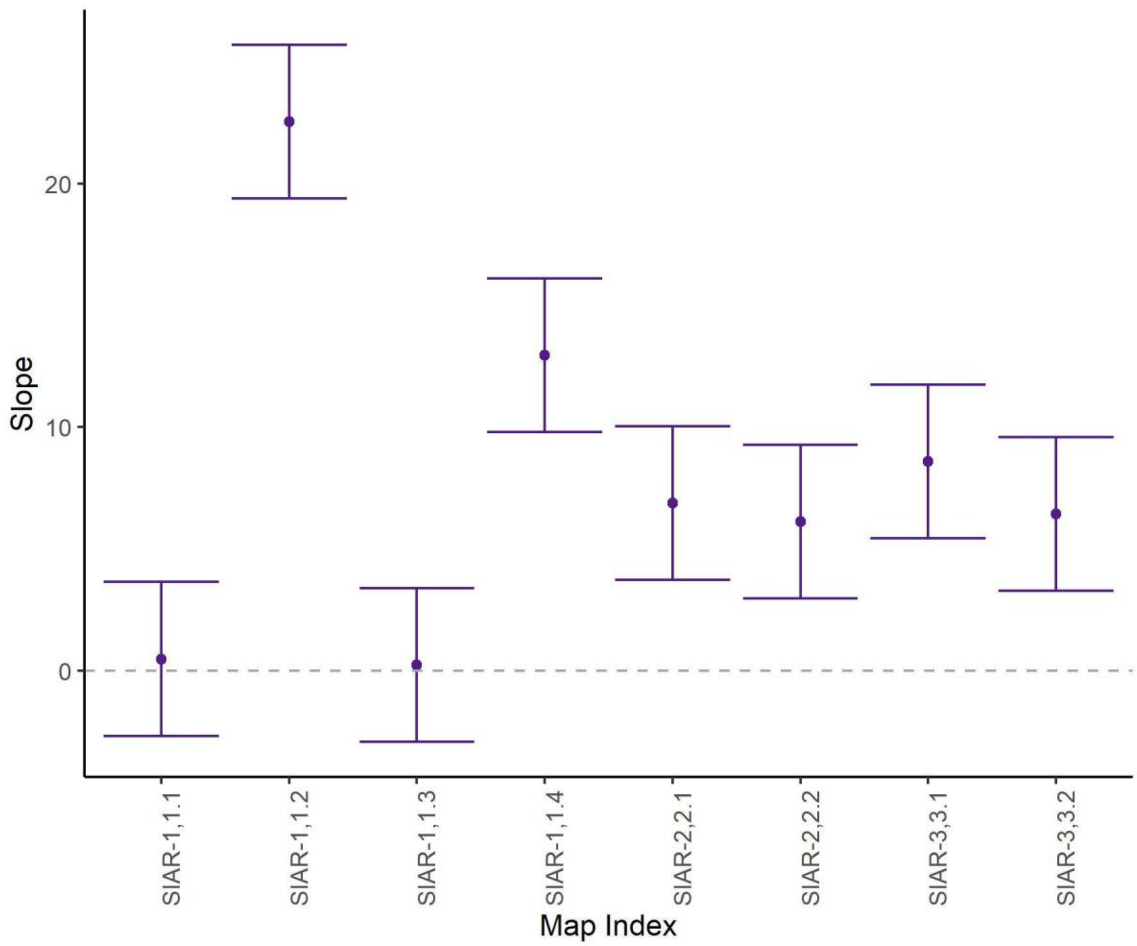


Figure 17. Kelp canopy area change over time of total kelp canopy in each zone during the past five years (2017-2021) in the Smith and Minor Islands Aquatic Reserve.
Positive numbers indicate increases in kelp canopy, and negative numbers indicate decreases in kelp canopy; the dashed line at zero indicates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

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

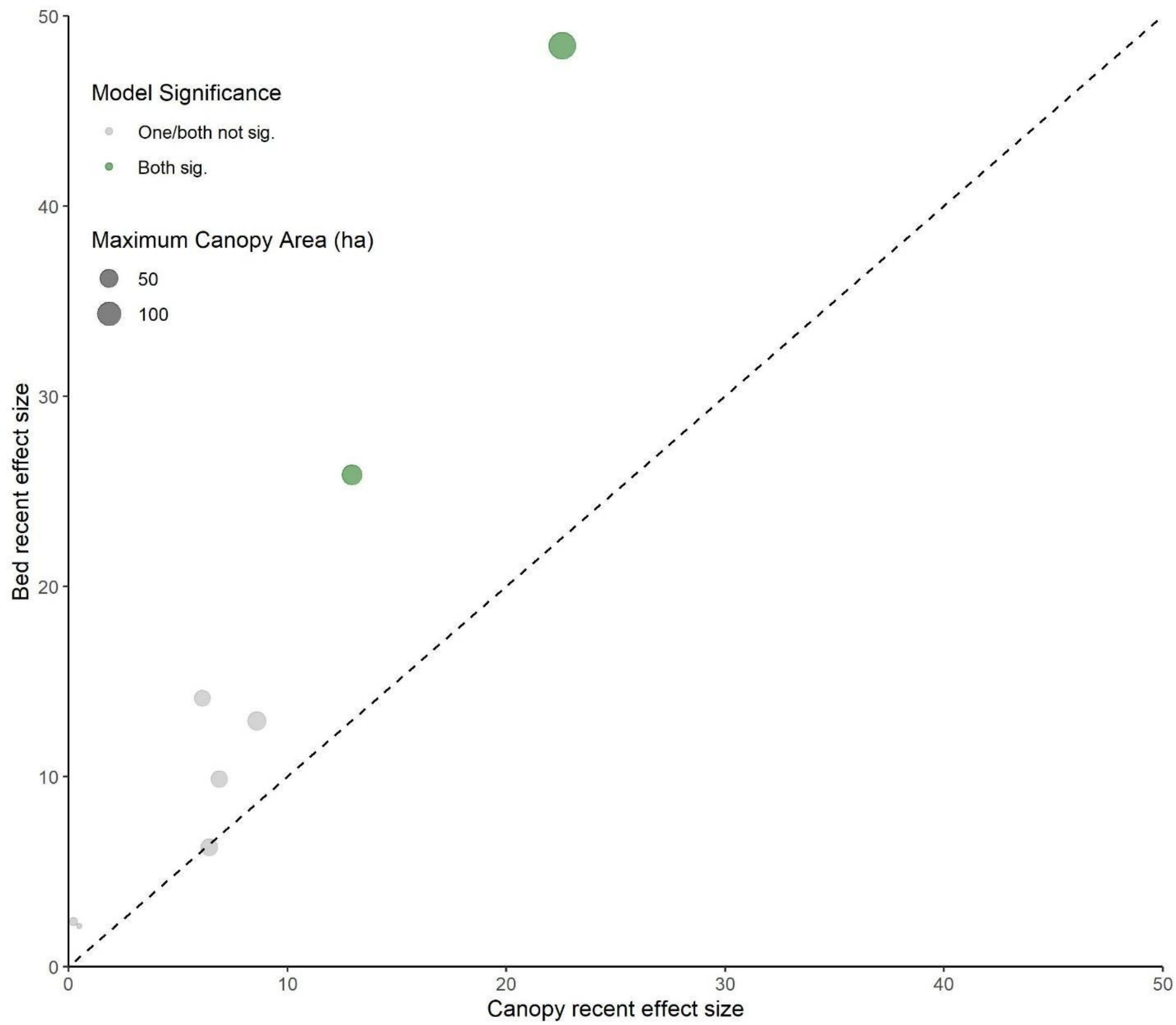


Figure 18. Comparison of rate of change in kelp area between canopy and bed measurements from the past five years (2017-2021) for the Smith and Minor Islands Aquatic Reserve dataset.
Each circle represents a zone, and they are scaled by the maximum canopy area detected at that zone. Data points in the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

Marine Resources Committee kayak-based survey data

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

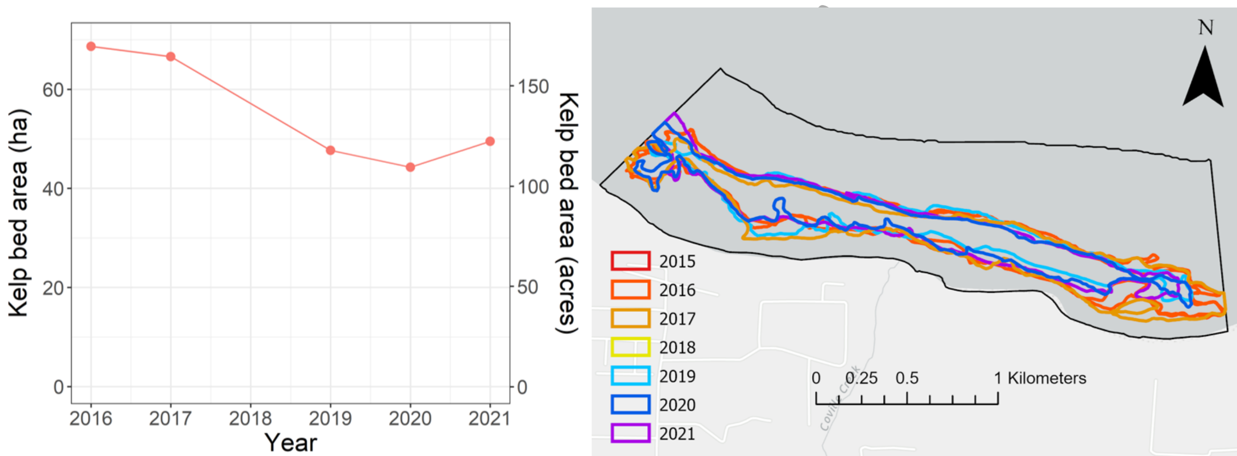


Figure 19. Changes in kelp bed area at the MRC monitoring site in Freshwater Bay.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

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

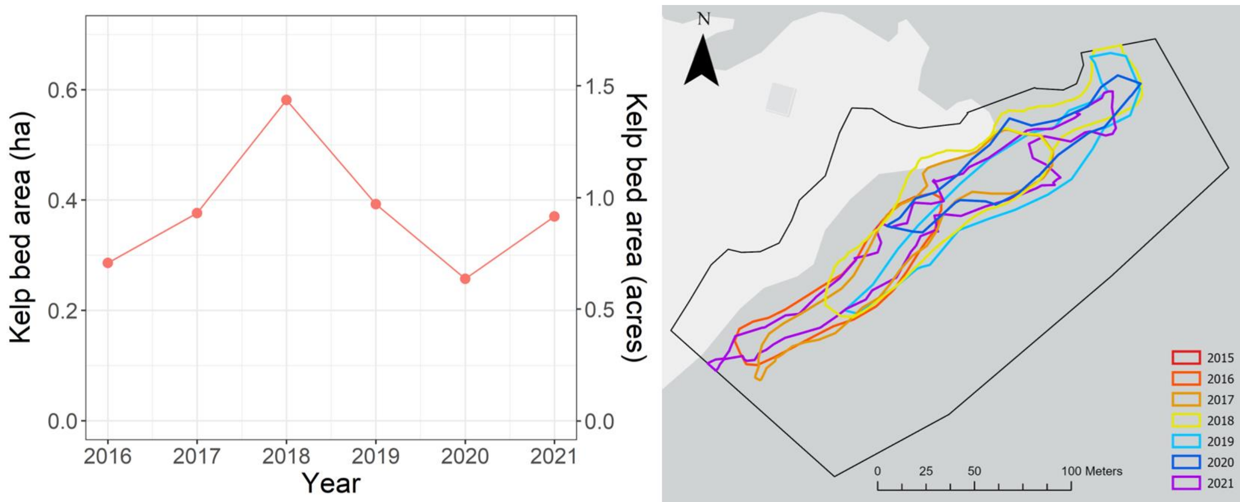


Figure 20. Changes in kelp bed area at the MRC monitoring site at Observatory Point.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

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

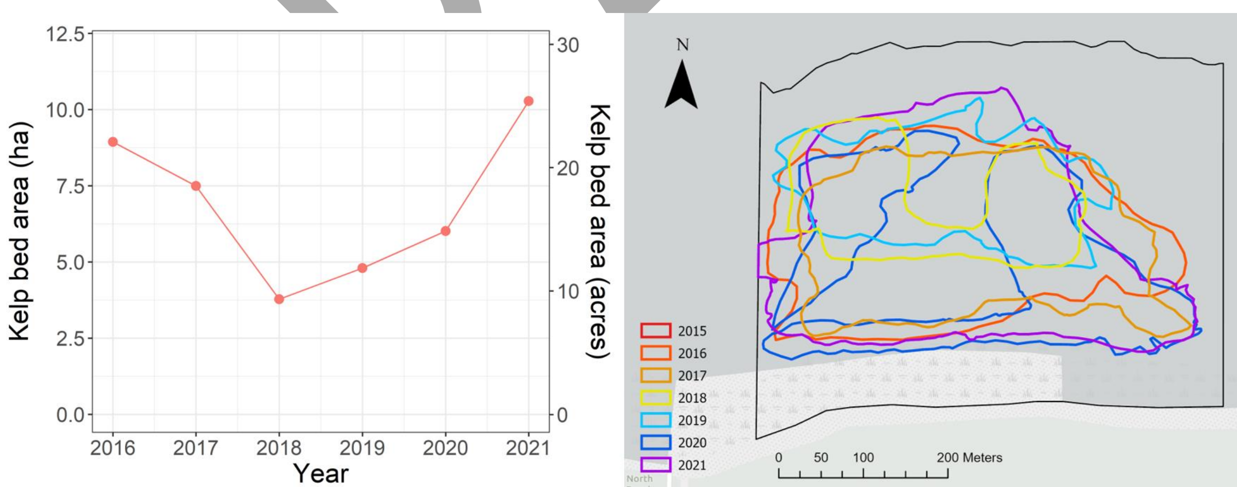


Figure 21. Changes in kelp bed area at the MRC monitoring site at North Beach.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the multi-year survey extent.

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

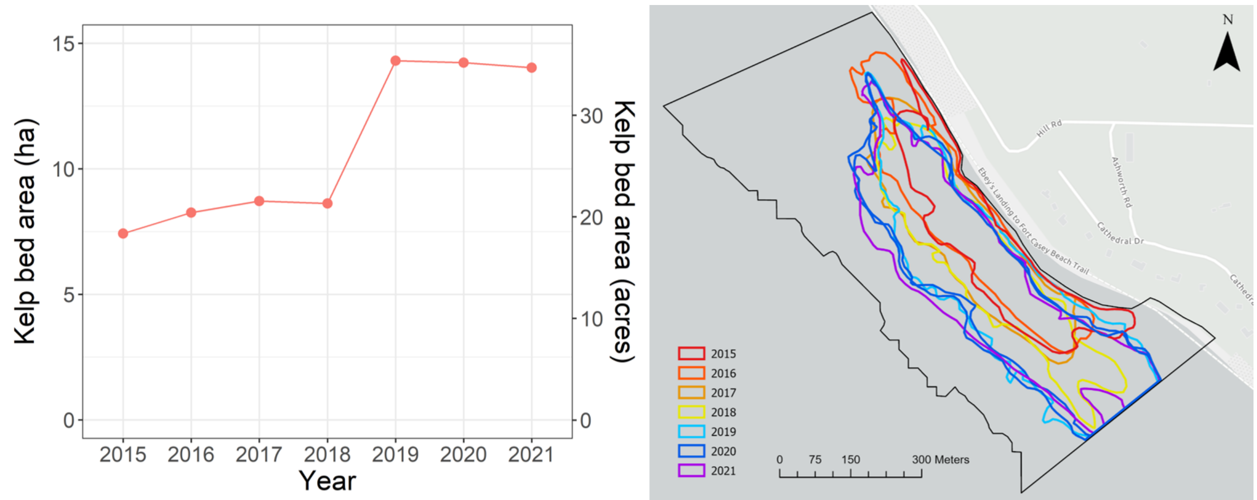


Figure 22. Changes in kelp bed area at the MRC monitoring site at Ebey's Landing.
Graph on left shows the maximum extent of kelp area each year surveyed in acres. Map on the right shows the kelp bed perimeters collected each year, the black polygon represents the survey area

3.3 Other datasets

Comparison of COSTR data to Fertilizer Maps

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

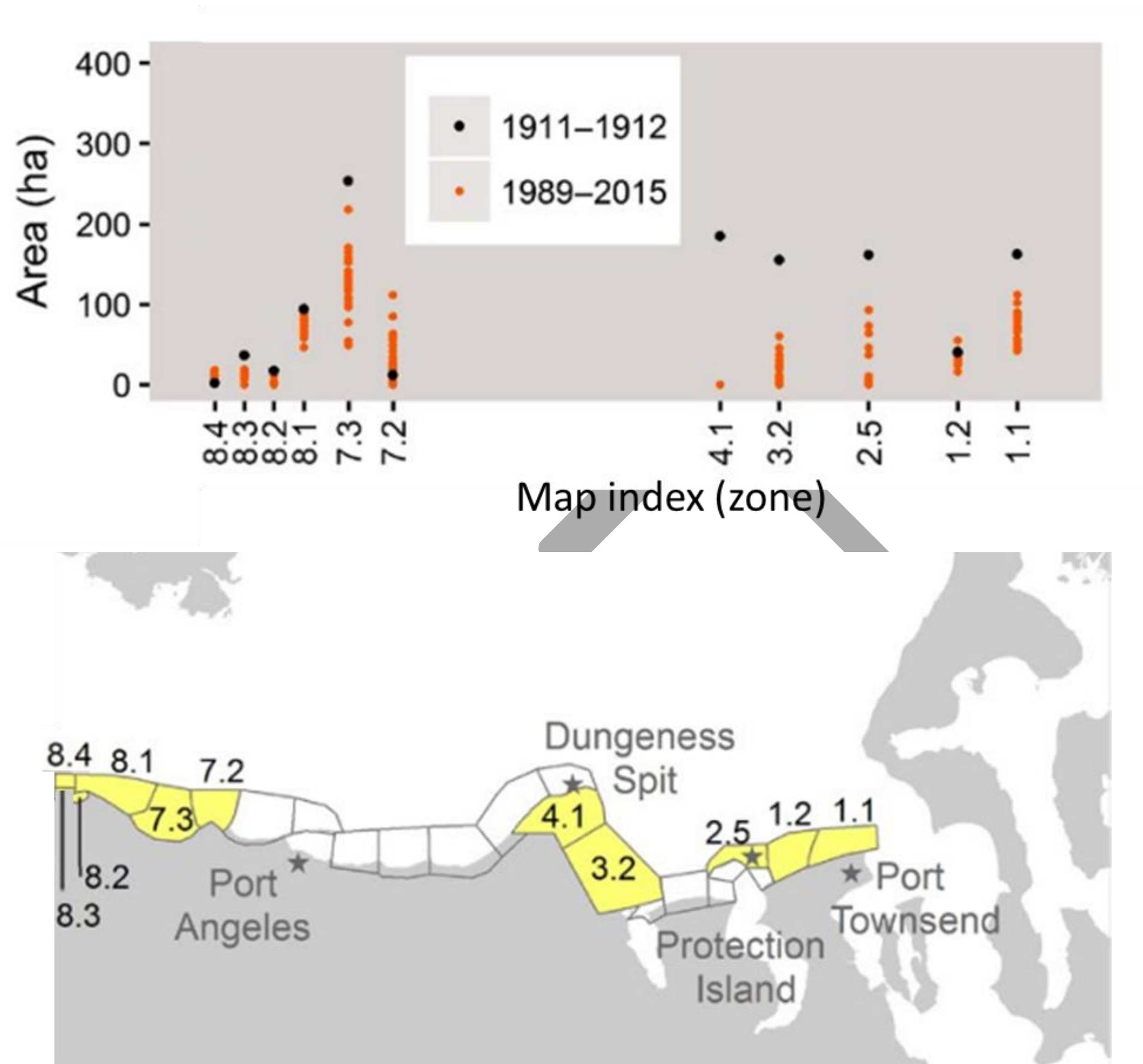


Figure 23. Comparison of Fertilizer Maps and COSTR data, from Pfister, Berry, and Mumford 2018.
Top panel shows historical kelp canopy area (collected in 1911-1912; black dots) and recent kelp canopy area (collected in 1989-2015; orange dots). Bottom panel shows the location of each zone (highlighted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

Observations by the Beckett Point Kelp Group

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

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

3.4 Determination of sub-basin trend designation

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

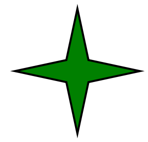
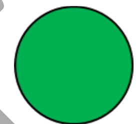
Analysis of recent trends within the AQRES Smith and Minor Islands dataset (2017-2021) showed a yearly increase of 8 hectares (19.8 acres) of floating kelp canopy area, and four out of eight zones had significant increases in floating canopy area, so this dataset is classified as increasing in the short-term.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

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

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

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

Table 2. Determination of sub-basin trend designation

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

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

4. Discussion

4.1 Datasets used in sub-basin assessment

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.3 Priorities for future research and monitoring

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

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

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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.

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

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.

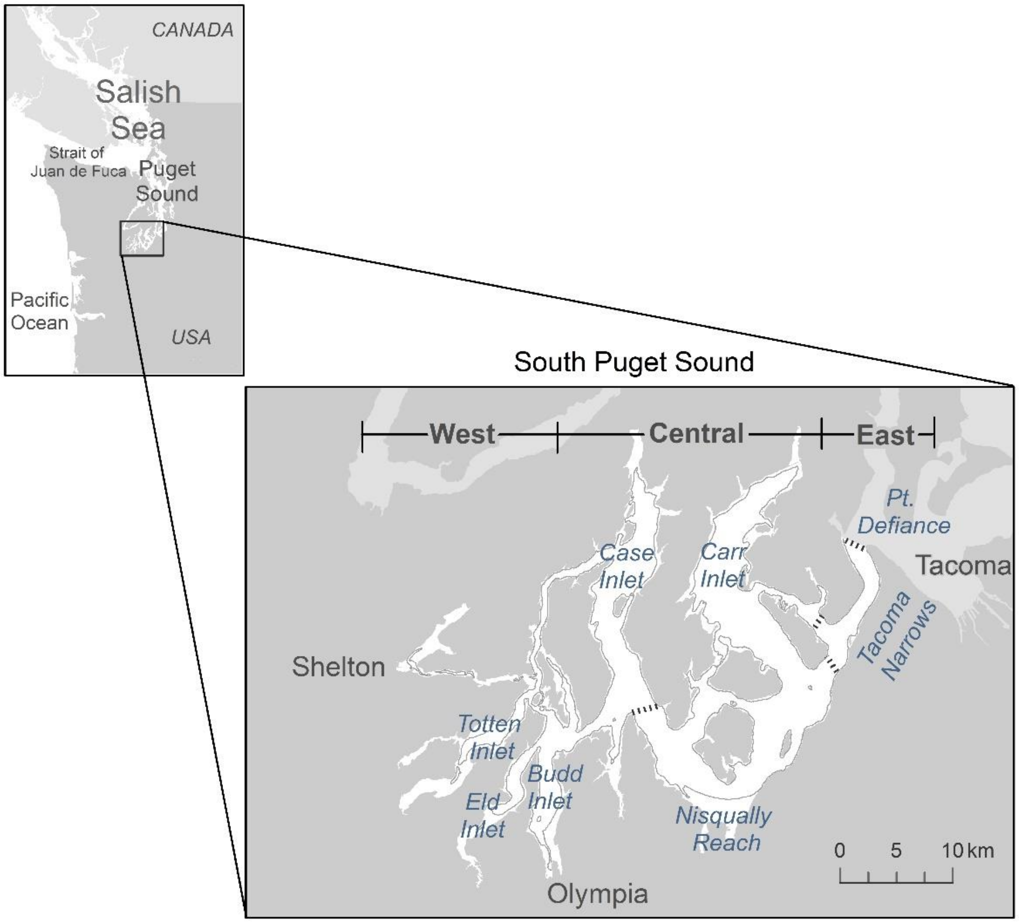


Figure 1. Western Washington State showing the location of South Puget Sound (A) and the South Puget Sound sub-basin (B).
The locations of the three reaches are described generally along the upper portion of the map, and precise boundaries are demarcated on the map with hash marks.

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.)

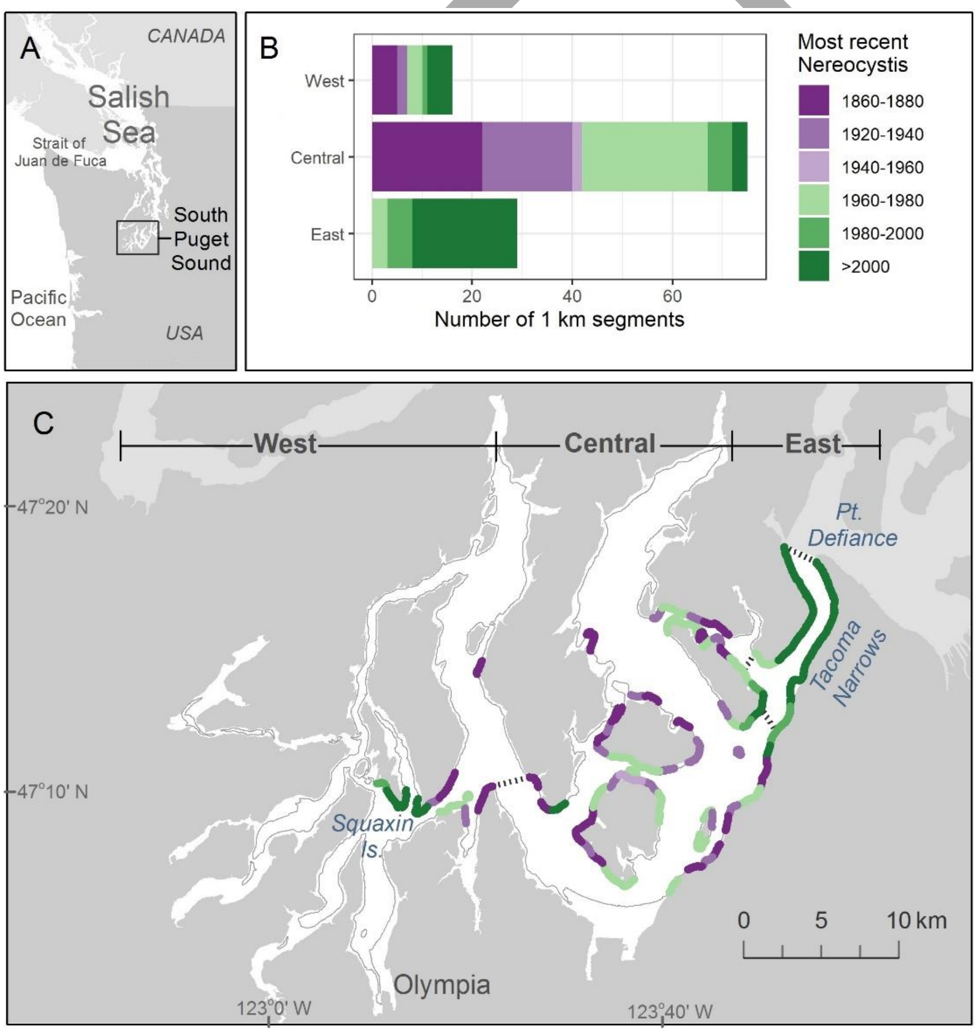
At four long-term monitoring sites, we assessed changes over time by testing for significant trends in annual bed area.

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.

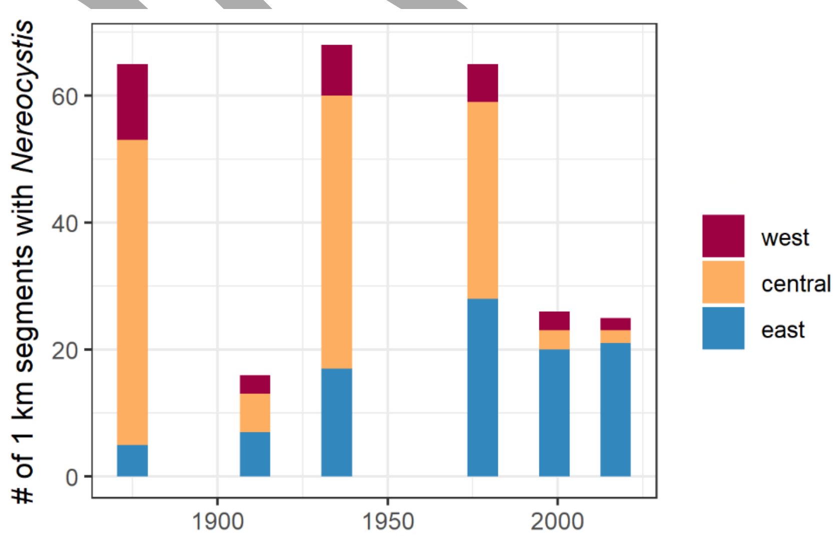


Figure 3. Number of 1-km segments with *Nereocystis* present between 1876 and 2017, based on six comprehensive snapshot surveys, summarized over three reaches.

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.

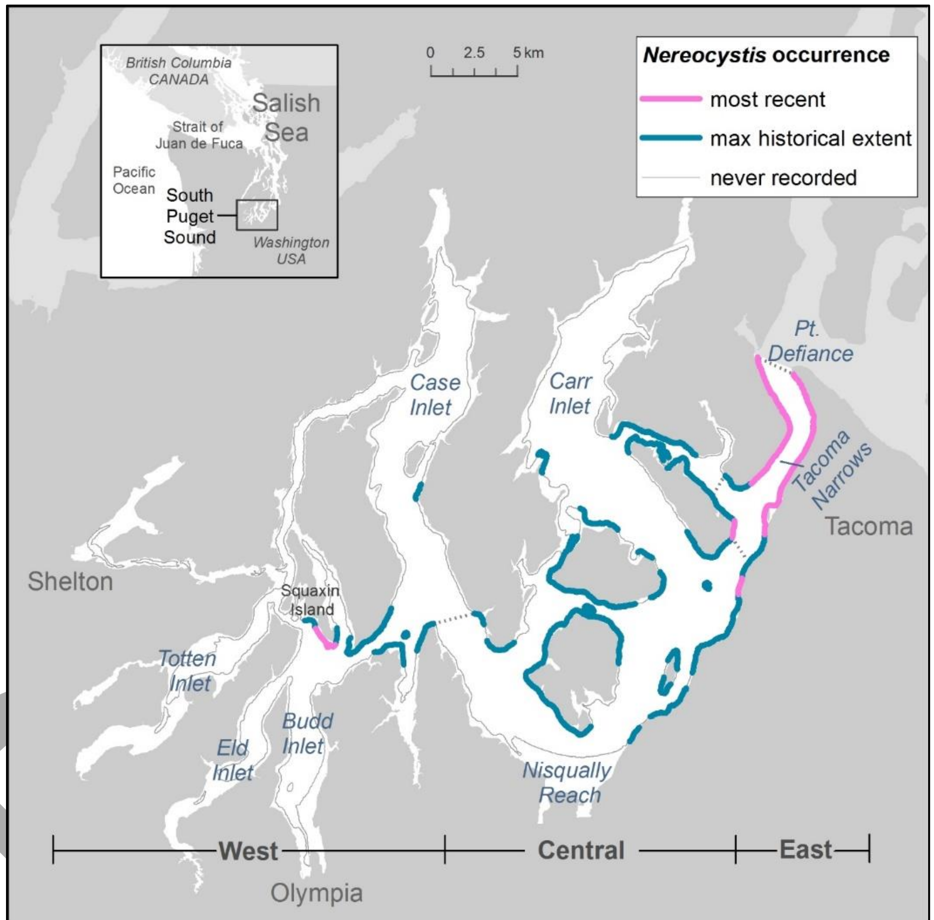
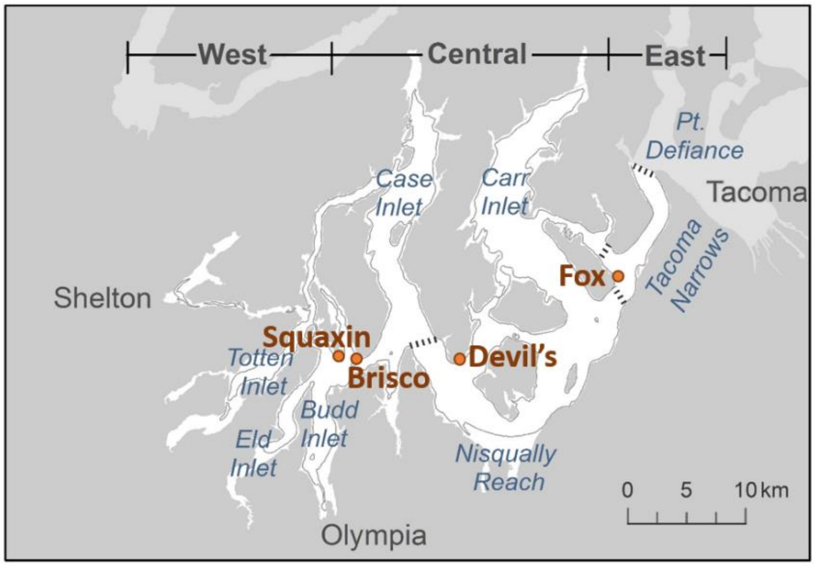


Figure 4. Distribution of floating kelp in 2018 compared to the maximum cumulative recorded extent between 1873 and 2018.
Presence/absence data are summarized in 1-km linear shoreline segments.

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.



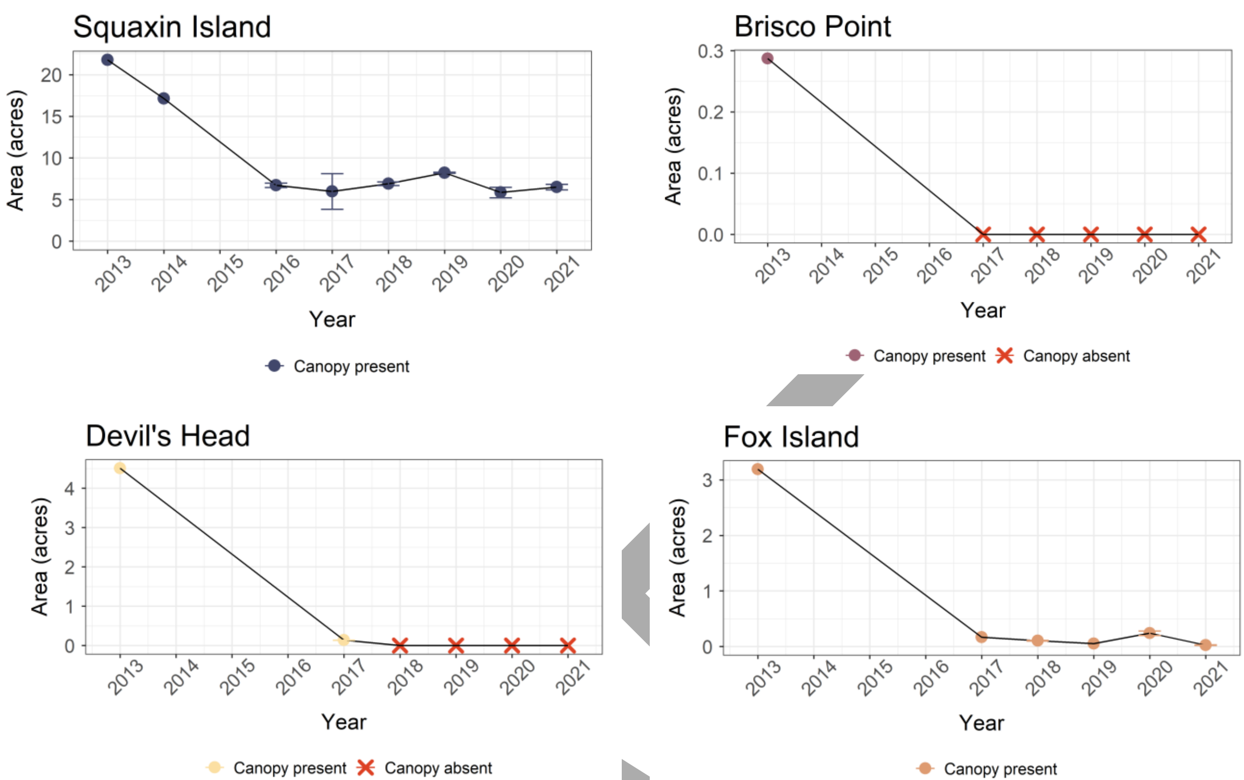


Figure 5. Map of site locations, and bed area at each site with sufficient data records for recent trends assessment (Squaxin Island, Brisco Pt, Devils Head, Fox Island.)

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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Appendix 7: Draft Dataset description – DNR COSTR and AQRES

Puget Sound Vital Signs
Floating kelp canopy area indicator:
dataset description

Department of Natural Resources' air photo-based monitoring of the open coast, Strait of Juan de Fuca and Aquatic Reserves (DNR-COSTR and AQRES)

Last updated: May 23, 2022

1. Introduction

In 2020, the Puget Sound Partnership added a new *floating kelp canopy area* indicator to the Puget Sound Vital Signs, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator fills gaps in scientific information about the condition of floating kelp canopies. It also serves 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 which can be found on the Puget Sound Floating Kelp Hub Site.

The purpose of dataset descriptions is to provide key information about datasets that are synthesized in the floating kelp canopy area indicator, including considerations related to dataset integration. Dataset descriptions are not meant to replace detailed metadata, which is available directly from the data owners/maintainers (links below).

This document describes the Washington Department of Natural Resources long-term monitoring of floating kelp canopies along Washington's open coast, Strait of Juan de Fuca and Aquatic Reserves using aerial photography (Fig. 1).

2. Dataset description

2.1 Summary

DNR's long-term monitoring along the Open Coast and Strait of Juan de Fuca (COSTR) has conducted annual aerial photography-based surveys since 1989 (except 1993) during late summer, the season of maximum floating kelp extent in the study area. Starting in 2011, these methods were expanded to include annual surveys of DNR's Aquatic Reserves with substantial floating kelp resources: Smith and Minor Island, Cypress Island and Cherry Point. (The Protection Island Aquatic Reserve is included in the COSTR monitoring area).

2.2 Description

Spatial Extent:	Open coast and the Strait of Juan de Fuca to Point Wilson, Port Townsend (COSTR). DNR's northern Aquatic Reserves (AR): Smith and Minor Island AR, Cypress Island AR, Cherry Point AR (AQRES). Note: Protection Island AR is included in the COSTR dataset.
Metric(s)	Bed (polygons), tabular data summarizing canopy area, bed area, relative density. In COSTR, estimates are sub-divided into giant kelp and bull kelp. In AQRES, only bull kelp is present.
Assessment Units	Comprehensive within study area
Survey years	1989-2021 (COSTR), 2011-2021 (AQRES)
Frequency	annual
Methods summary	Near-vertical low-tide color-infrared imagery is collected from a fixed wing platform during late summer. Imagery is projected onto 1:12,000 paper maps and kelp canopies are hand-delineated. Bed area is estimated by buffering canopy data with a 20 m radius of association. The hand-delineated paper canopy maps are scanned. Then tabular estimates of canopy area and bed area are produced and summarized at the scale of map indices (stretches of shoreline defined by geomorphic features such as headlands).
Access	All survey data is maintained by the Nearshore Habitat Program, in the Washington Department of Natural Resources (nearshore@dnr.wa.gov). Kelp monitoring results and spatial/tabular data are available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/kelp-monitoring

2.3 Considerations for integration in the Floating Kelp Canopy indicator

A primary strength of the COSTR and AQRES datasets the methodological consistency over a long time period. A related weakness is that the methods have not been updated with technological advances in spatial data collection and processing. In the currently distributed dataset, the most accurate and precise data are the tabular estimates of canopy area, bed area and relative density index (RDI), summarized by zone (also called map index). The spatial data (bed polygons) are generalized features, and some differences in the spatial features among years reflect changes in spatial processing technology over the past 3 decades rather than real changes.

Two major enhancements to the dataset are recommended, if funding permits:

- Upgrade imagery collection procedures to use a large format photogrammetric mapping camera system and 4- band imagery. Process imagery to orthomosaics.
- Explore ability to re-process existing survey data so that floating kelp abundance can be assessed at spatial scales finer than zones (also called map indexes).

2.4 References

Van Wagenen, R.F. (2015). *Washington Coastal Kelp Resources: Port Townsend to the Columbia River. Summer 2014.* Nearshore Habitat Program, Washington State Department of Natural Resources.
https://www.dnr.wa.gov/publications/aqr_nrsh_vanwagenen_2015_kelp_tables.pdf

Appendix 8: Draft Dataset description – DNR Boat

Puget Sound Vital Signs
Floating kelp canopy area indicator: dataset description

Department of Natural Resources floating kelp presence surveys (DNR-Boat)
Last updated: April 14, 2022

1. Introduction

In 2020, the Puget Sound Partnership added a new *floating kelp canopy area* indicator to the Puget Sound Vital Signs, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator fills gaps in scientific information about the condition of floating kelp canopies. It also serves 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 which can be found on the Puget Sound Floating Kelp Hub Site.

The purpose of dataset descriptions is to provide key information about datasets that are synthesized in the floating kelp canopy area indicator, including considerations related to dataset integration. Dataset descriptions are not meant to replace detailed metadata, which is available directly from the data owners/maintainers (links below).

This document describes the Washington Department of Natural Resources central and south Puget Sound floating kelp presence data (Fig. 1).

2. Dataset description

2.1 Summary

In South Puget Sound (SPS) and Central Puget Sound (CPS), recent comprehensive surveys identified shorelines with floating kelp, which are uncommon in these basins (in 2013 and 2017 in SPS, and 2019 in CPS). Both surveys recorded floating kelp presence along the -6 m subtidal bathymetry line, with a minimum threshold of a single individual. Both studies were paired with a multi-decadal synthesis of diverse data sources to summarize the presence/absence of floating kelp within 1 km shoreline segments. In SPS, the study noted presence, while in CPS presence was further categorized into abundance classes, ranging from isolated individuals to wide beds.

2.2 Description

Spatial Extent:	Central Puget Sound and South Puget Sound
Parameters	Floating kelp presence (linear data). Abundance classes (Central Puget Sound only).
Metric(s)	Comprehensive within study area
Survey years	2013 and 2017 (South Puget Sound), 2019 (Central Puget Sound)
Frequency	Infrequent
Methods summary	Collected field observations of floating kelp presence by motoring along the shoreline in a small boat, in shallow water during low tide and slack currents. Summarized presence/absence by segmenting -6 m bathymetry contour. Minimum threshold for detection: a single individual. In Central Puget Sound, observations were further sub-divided to describe abundance, ranging from isolated individuals to wide, conspicuous beds.
Access	All survey data is maintained by the Nearshore Habitat Program, in the Washington Department of Natural Resources (nearshore@dnr.wa.gov). Information: SPS (report), CPS (presentation)

2.3 Considerations for integration in the Floating Kelp Canopy indicator

For the South Puget Sound sub-basin assessment, data from this survey was considered as part of the long-term analysis in Berry et al. 2021. The Central Puget Sound sub-basin assessment is not yet complete.

2.4 References

Berry, H., Calloway, M., & Ledbetter, J. (2019). *Bull Kelp Monitoring in South Puget Sound in 2017 and 2018.* Nearshore Habitat Program, Washington State Department of Natural Resources. https://www.dnr.wa.gov/publications/aqr_nrsh_bullkelp_sps_2019.pdf

Berry HD, Mumford TF, Christiaen B, Dowty P, Calloway M, Ferrier L, et al. (2021) Long-term changes in kelp forests in an inner basin of the Salish Sea. PLoS ONE 16(2): e0229703. https://doi.org/10.1371/journal.pone.0229703

Appendix 9: Draft Dataset description – DNR Kayak

Puget Sound Vital Signs
Floating kelp canopy area indicator: dataset description

Department of Natural Resources central and south Puget Sound kayak monitoring (DNR-Kayak)
Last updated: April 14, 2022

1. Introduction

In 2020, the Puget Sound Partnership added a new *floating kelp canopy area* indicator to the Puget Sound Vital Signs, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator fills gaps in scientific information about the condition of floating kelp canopies. It also serves 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 which can be found on the Puget Sound Floating Kelp Hub Site.

The purpose of dataset descriptions is to provide key information about datasets that are synthesized in the floating kelp canopy area indicator, including considerations related to dataset integration. Dataset descriptions are not meant to replace detailed metadata, which is available directly from the data owners/maintainers (links below).

This document describes the Washington Department of Natural Resources central and south Puget Sound kayak monitoring (Fig. 1).

2. Dataset description

2.1 Summary

DNR scientists conduct annual monitoring of floating kelp beds at 13 sites in South Puget Sound and Central Puget Sound using kayaks and handheld GPS units. Surveys assess bed area, depth range, density, morphometrics and other parameters. Surveys began in 2013 at the oldest monitoring sites..

2.2 Description

Spatial Extent:	Sites within Central Puget Sound and South Puget Sound
Metric(s)	bed (polygons), minimum/maximum depth
Assessment Units	13 sites with historical or current floating kelp, sites span approximately 0.5 – 1.0 km of shoreline each.
Survey years	2013, 2017-2021 (South Puget Sound), 2018-2021 (Salmon Beach), 2020-2021 (Central Puget Sound)
Frequency	annual
Methods summary	Kayak based delineation of bed perimeter with handheld GPS. Minimum abundance for inclusion: single bulb. Maximum distance among individuals for inclusion in a single bed: 20 m. At a subset of sites, assessed: - density, percent cover and morphometrics at grid of points along regularly placed across-shore transects, - drone or fixed-wing canopy mapping. Information: - 2019 story map - 2017 and 2018 monitoring report - 2013, 2014 and 2016 monitoring report
Access	All survey data is maintained by the Nearshore Habitat Program, in the Washington Department of Natural Resources (nearshore@dnr.wa.gov). Kelp monitoring results and spatial/tabular data are available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/kelp-monitoring

2.3 Considerations for integration in the Floating Kelp Canopy indicator

Kayak based kelp area surveys provide relatively high resolution data on kelp bed area at sites. The bed area estimate is the primary parameter considered in indicator analysis.

Research has shown that environmental factors affect the extent of visible floating kelp canopies (Britton Simmons et al, 2008). So, sea-state, tide height, and current stage are considered during data interpretation.

References

Berry, H. (2017). *Assessment of Bull Kelp at Squaxin Island in 2013, 2014 and 2016.* Nearshore Habitat Program, Washington State Department of Natural Resources. https://www.dnr.wa.gov/publications/aqr_nrsh_squaxin_bullkelp_1217.pdf

Berry, H., Calloway, M., & Ledbetter, J. (2019). *Bull Kelp Monitoring in South Puget Sound in 2017 and 2018.* Nearshore Habitat Program, Washington State Department of Natural Resources. https://www.dnr.wa.gov/publications/aqr_nrsh_bullkelp_sps_2019.pdf

Britton-Simmons, K., Eckman, J.E., & Duggins, D.O. (2008). Effect of tidal currents and tidal stage on estimates of bed size in the kelp *Nereocystis leutkeana*. *Marine Ecology Progress Series, 355*, 95-105.

Appendix 10: Draft Dataset description – MRC Kayak

Puget Sound Vital Signs
Floating kelp canopy area indicator: dataset description

Marine Resource Committees volunteer kayak monitoring (MRC-Kayak)
Last updated: May 23, 2022

1. Introduction

In 2020, the Puget Sound Partnership added a new *floating kelp canopy area* indicator to the Puget Sound Vital Signs, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator fills gaps in scientific information about the condition of floating kelp canopies. It also serves 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 (Chapter 2 of the Phase 2 report), (2) sub-basin reports, (3) dataset descriptions which can be found on the Puget Sound Floating Kelp Hub Site.

The purpose of dataset descriptions is to provide key information about datasets that are synthesized in the floating kelp canopy area indicator, including considerations related to dataset integration. Dataset descriptions are not meant to replace detailed metadata, which is available directly from the data owners/maintainers (links below).

This document describes the Marine Resource Committees volunteer kayak monitoring (Figure 1).

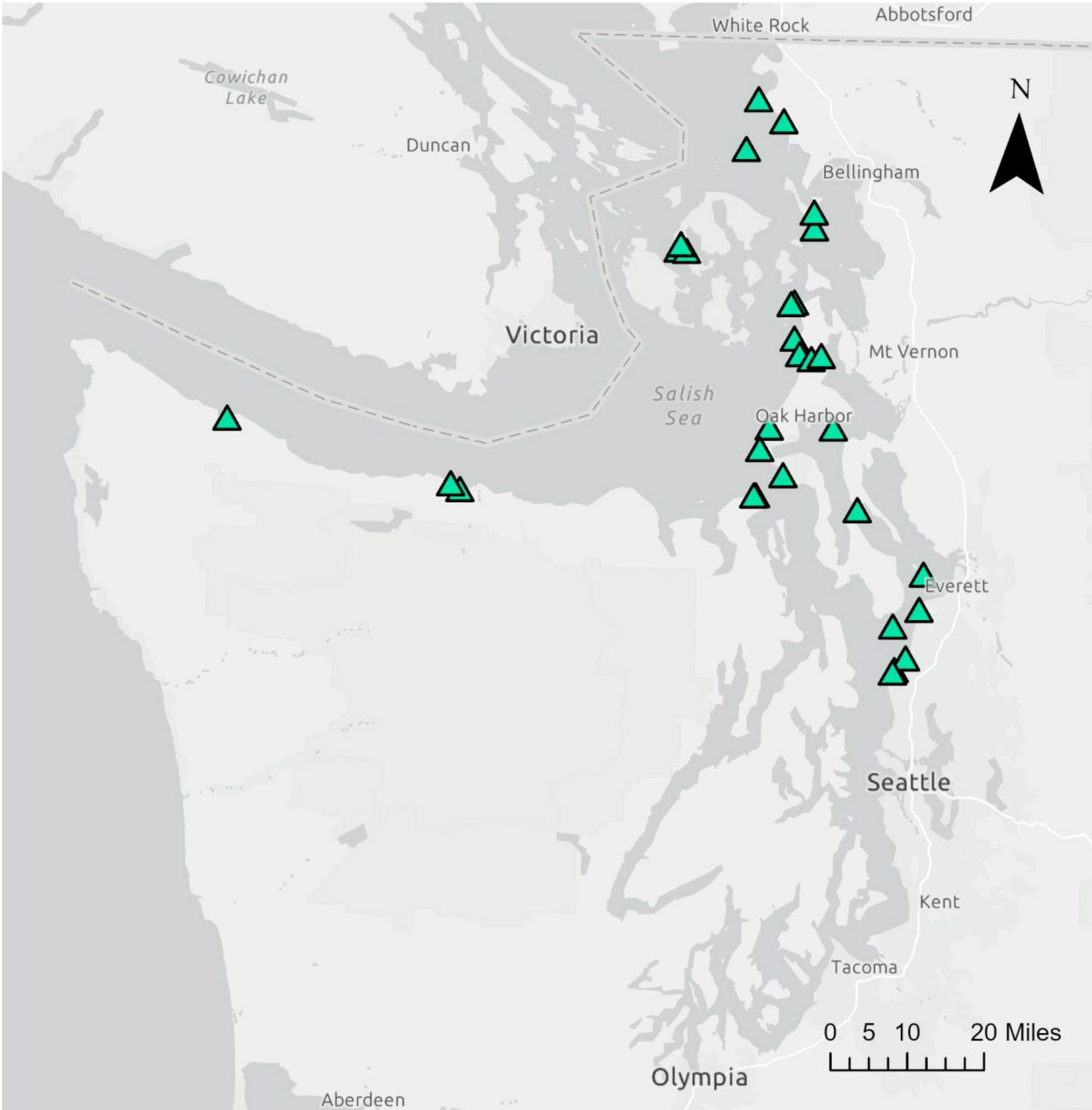

Figure 1. Map of Puget Sound with the MRC kayak monitoring sites represented as green triangles.

2. Dataset description

2.1 Summary

Volunteers with Marine Resources Committees (MRCs) and Northwest Straits Commission (NWSC) began surveying floating kelp beds in 2015 and in subsequent years have now surveyed beds in all seven counties in northern Washington (Clallam, Island, Skagit, Jefferson, San Juan, Snohomish, Whatcom).

Volunteers follow a kayak-based survey protocol to record the perimeter of floating kelp canopies with handheld GPS units at select sites.

The MRC site surveys range in temporal coverage. For this analysis we selected survey sites that had at least five years of data. Notably, some locations have multiple kelp "sites" that are surveyed. At some sites, volunteers survey kelp beds multiple times in a season, so only maximum observed extent per year is used in our analyses.Using these criteria, 17 sites were selected for use in indicator development.

2.2 Description

Spatial Extent:	Seven northern counties in Puget Sound that are within the Northwest Straits Initiative (Clallam, Island, Skagit, Jefferson, San Juan, Snohomish, Whatcom).
Metric(s)	Initial: bed perimeter (polygons) from locations with five or more years of surveys
Assessment Units	Multi-year monitoring sites, most sites are at the approximate scale of 1 km of shoreline (17 locations have been identified as of May 2022, a consolidation of 42 locations where volunteers have conducted kayak surveys)
Survey years	2015 – 2021 total, many sites span a subset of years.
Frequency	Annual
Methods summary	Kayak-based delineation of bed perimeter with handheld GPS. Minimum thresholds for inclusion: canopy width > 5 m. Maximum distance among individuals (fronds or bulbs) for inclusion: 8 m between individuals (Bishop 2014, updated 2020). Volunteers collect data on additional parameters such as water temperature and kelp bed depth as well as visual observations and photo documentation following the monitoring protocol developed by the Northwest Straits

	Commission (NWSC) with guidance from scientists. The data are collected by volunteer kayakers and members of the Marine Resources Committees (MRCs). Datasets are available through the NWSC and individual MRCs. NWSC and MRC web sites: - NWSC Kelp Monitoring - Clallam County - Island County - Jefferson County - San Juan County - Skagit County - Snohomish County - Whatcom County
Access	All survey data are maintained by the Northwest Straits Commission and visible on SoundIQ. GPS data is available for download through SoundIQ or directly contacting the NWSC. The ArcGIS Online feature service is available at: https://www.arcgis.com/home/item.html?id=762bb0b250a64b519d67f0f6b123dba6 Please contact the NWSC GIS Specialist (Suzanne Shull; sshull@padillabay.gov) or the Marine Program Manager (Dana Oster; oster@nwstraits.org) for questions or data inquires. MRC kayak protocol is available at: https://www.nwstraits.org/media/2937/kelp-protocol-may-2020-revised.pdf

2.3 Considerations for integration in the Floating Kelp Canopy indicator

Kayak based kelp area surveys provide relatively high resolution data on kelp bed area at sites. The bed area estimate is the primary parameter considered in indicator analysis.

Research has shown that environmental factors affect the extent of visible floating kelp canopies (Britton Simmons et al, 2008). So, sea-state, tide height, and current stage are considered during data interpretation.

2.3.1 Determining data to include in VS

The MRC kelp dataset includes data from a variety of sites with varying years of data so sites were evaluated for inclusion in the vital sign on a case by case basis. To determine the MRC kelp data to use for the vital sign indicator, several factors were considered, including (1) data collection protocols were consistent between surveys and (2) the multiyear site survey extent was confirmed with MRC volunteers (Table 1).

For an initial review, DNR assessed each individual survey polygon at 17 priority sites and developed review questions, on both the individual surveys and the sites in general. DNR then met with small groups of volunteers from each MRC to discuss each survey and site to gain insights into site and survey conditions, methods and uncertainties about the data. There were also discussions about surveys that seemed anomalous compared to the other surveys collected and whether to exclude the surveys from inclusion in the vital sign and analyses. In each meeting, MRC volunteers and DNR worked to delineate a “site extent” for each site, defined as the area that had been consistently surveyed for floating kelp each year.

After the meetings, the site extents were refined and sent to the volunteers for final confirmation of the accuracy of the alongshore extent. The site extents were used to create a polygon feature class in ArcGIS Pro, and the features were added to the DNR working database and used to clip comparable data out of the full MRC dataset to include in the Vital Sign dataset (see database structure section below). After the 2022 field season, each site extent will be reassessed and adjusted as necessary.

Table 1. Complete list of MRC kayak survey sites with the years surveyed, whether the site has been reviewed for the Vital Sign and the inclusion status.

Bed Name	2015	2016	2017	2018	2019	2020	2021	Reviewed?	VS Status
Ebey's Landing	x	x	x	x	x	x	x	Yes	Included
Edmonds	x	x	x	x	x	x	x	Yes	Included
Meadowdale	x	x	x	x	x	x	x	Yes	Included
Mukilteo	x	x	x	x	x	x	x	Yes	Included
North Beach Main	x	x	x	x	x	x	x	Yes	Included
Polnell Point		x	x	x	x	x	x	Yes	Included
Lummi SW		x	x	x	x	x	x	Yes	Included
Coffin Rocks		x	x	x	x	x	x	Yes	Included
Freshwater Bay		x	x	x	x	x	x	Yes	Included
Observatory Point		x	x	x	x	x	x	Yes	Included
Biz Point			x	x	x	x	x	Yes	Included
Cherry Pt-Gulf Rd			x	x	x	x	x	Yes	Included
Hat Island			x	x	x	x	x	Yes	Included
Possession Point			x	x	x	x	x	Yes	Included
Shannon Point East			x	x	x	x	x	Yes	Included
Shannon Point West			x	x	x	x	x	Yes	Included
Clallam Bay			x	x	x	x	x	Yes	Included
Aiston Preserve				x	x	x	x	No	Pending
Camano Island SP - Lowell		x	x			x	x	No	Pending
Hoypus Point		x	x	x			x	No	Pending
Point Whitehorn		x			x	x	x	No	Pending
Alden Bank				x	x	x		No	Pending
Ben Ure		x	x	x				No	Pending
Pole Pass	x	x	x					No	Pending
North Beach West	x				x		x	Yes	Excluded
Fawn Island		x	x					No	Pending
Reef Island		x	x					No	Pending
Camano Island 2		x						No	Pending
Freshwater Bay 3				x				Yes	Excluded
Hastie Lake	x							Yes	Excluded
Libbey Beach	x							Yes	Excluded
North Beach 2					x			Yes	Excluded

Years of data:	7 years	6 years	5 years	4 years	3 years	2 years	1 year

2.3.2 Site extent polygon descriptions

Biz Point: The polygon extends from the standardized shoreline created by the NWSC to the 60ft bathymetry line and runs from the northern guide points provided by NWSC into Telegraph Bight. The south end of the polygon extends beyond the southern guide points because kelp is expanding into Telegraph Bight.

Cherry Point: The polygon extends from the mean high tide line to the 30ft bathymetry line, The northern boundary is the NWSC's northern guideline and the southern end of the polygon ends just past the maximum extent of the 2019 survey.

Clallam Bay: The polygon extends from the mean high tide line to the 30ft bathymetry line and the NWSC guidelines are used as the east and west polygon boundaries.

Coffin Rocks: Unlike site extent polygons at other sites, the polygon at Coffin Rocks does not follow any bathymetry lines or shorelines but is a large circle around the kelp bed incorporating the rock outcrop at the center.

Ebey's Landing: The polygon extends along the shoreline from the northern guideline to the maximum extent of the 2018 survey on the southern side of the bed. In 2019, 2020 and 2021, the bed grew farther to the south than in previous years and merged with another bed. For that reason, the southern end of the polygon stops at the maximum extent of the 2018 survey. The shoreward edge of the polygon closely follows the survey lines on the northern portion of the site because there are rocks and kelp in the shallows that they surveyors avoid. On the south end of the site, the shoreward polygon edge extends to the mean high tide line. The deep edge of the polygon follows the 40ft bathymetry line.

Edmonds North: The polygon extends from the mean high tide line to the 30ft bathymetry line. The length (north-south) of the polygon was determined by the largest extent of the kelp beds.

Edmonds Dive Park: The polygon runs shoreward from the breakwater to the Edmonds North polygon and extends from the mean high tide line to the 30ft bathymetry line. This kelp bed has a separate polygon than the two beds to the north because the Edmonds Dive Park bed has been surveyed since 2017 and the other beds have been surveyed since 2015.

Freshwater Bay: The polygon extends from the mean high tide line to the 30ft bathymetry line and the west boundary aligns with the west NWSC guideline and the east polygon boundary is just east of the west guideline. The 2018 survey will be excluded from the multiyear dataset because volunteers were not confident the kelp was fully mapped on the east side of the site and is therefore incomplete.

Hat Island: The polygon extends from the mean high tide line to the 30ft bathymetry line. The polygon extends up the NE side of the island to a sandy point and extends to the west just around the southern point of the island.

Lummi SW: Due to shallow rocks, the polygon follows the shoreward side of the survey lines and extends to the 20ft bathymetry line. The polygon uses the guidelines provided by the NWSC as the east and west boundaries. The 2016 survey will be excluded because volunteers are uncertain of the full survey extent and are not confident it can be accurately compared to subsequent years.

Meadowdale: The polygon extends from the mean high tide line to the 30ft bathymetry line. The north end of the polygon is at the south end of Meadowdale Beach Park and the polygon extends south along the shoreline all the way to the north boundary of the Edmonds North polygon.

Mukilteo: The polygon extends from the mean high tide line to the 30ft bathymetry line and runs north-south from the Mukilteo boat launch in the north end to the first house on the beach in the south.

North Beach Main: The polygon extends along the shoreline from the east guideline to the west guideline of the main bed and from the mean high tide line to the 40ft bathymetry line. The 2015 survey will be excluded from analysis because it was surveyed at high tide and is not comparable to subsequent surveys.

Observatory Point: The polygon runs from the guideline inside Freshwater Bay to the outer rock on Observatory Point and extends from the mean high tide line to offshore of the survey lines. Bathymetry lines were not used to determine the deep side of the polygon because the bathymetry lines do not come into the bay.

Polnell Point: The northwest end of the polygon extends from the mean high tide line to the 30ft bathymetry line and cuts off the largest survey extents because the north end of the bed cannot be surveyed consistently every year. Near the point, the shoreward edge of the polygon follows the survey lines due to rocks and seals that the surveyors avoid, and extends to the 40ft bathymetry line. The polygon extends to the northeast to a small shoal.

Possession Point: On the northeast side of the site, the polygon starts at the eastern guideline and extends from the mean high tide line to the 40ft bathymetry line. At the main bed, the shoreward side of the polygon follows the survey lines and the deep edge extends to the 40ft bathymetry line. On the west side of the site, the polygon ends at the maximum extent of the 2018 survey. 2018 was the last year before the east and west kelp beds merged and surveyors only mapped the east bed prior to 2019.

Shannon Point East: The polygon runs east from the Shannon Point navigation marker to the guideline at the west end of the ferry parking lot and extends from the mean high tide line to the 30ft bathymetry line.

Shannon Point West: The polygon runs west from the Shannon Point navigation marker to the boat launch at Washington Park and extends from the mean high tide line to the 30ft bathymetry line.

2.3.3 MRC sites that are pending or excluded from Vital Sign

Aiston Preserve: This is a pending vital sign site. The site has four years of data (2018-2021) and there are plans to survey the site in 2022. It is being considered for inclusion in the vital sign dataset because of the limited data available in North Puget Sound sub-basin and the recent removal of an overwater structure that could benefit kelp growth.

Alden Bank: This is a pending vital sign site. There is some uncertainty in the bed footprint and in methods used to collect the perimeter. In 2018 and 2019, perimeters were collected by kayak and in 2020 the perimeter collected by tugboat. Aerial imagery is also collected for this site but the kayak/boat-collected perimeter do not match well to the imagery collected by volunteer pilot, Gregg Ridder. The blue water (site is not along a shoreline) conditions at this large isolated bed may make it difficult to collect accurate perimeters by kayak or boat.

Ben Ure: This is a pending vital sign site. The site was last surveyed in 2018 and has three years of data (2016-2018). However, it is being considered for inclusion in the vital sign dataset because there is limited kelp data in the Saratoga/Whidbey sub-basin.

Camano Island: This is a pending vital sign site. The site was last surveyed in 2021 and has four years of data (2016-2017, 2020-2021). There are plans to survey the site in 2022. It is being considered for inclusion in the vital sign dataset because there is limited kelp data in the Saratoga/Whidbey sub-basin.

Fawn Island: This site was last surveyed in 2017 and likely won't be surveyed again. It has two years of data (2016-2017), which is often insufficient for determining change but may be helpful to support other datasets.

Hastie Lake: This site was surveyed in 2015 and it was decided that the conditions were not good for kayak surveys. Surveyors did not return to the site.

Hoypus Point: This is a pending vital sign site. The site was last surveyed in 2021 and has four years of data (2016-2018, 2021) and there are plans to survey the site in 2022. It is being considered for inclusion in the vital sign dataset because there is limited kelp data in the Saratoga/Whidbey sub-basin.

Libbey Beach: This site was surveyed in 2015 and it was decided that the conditions were not good for kayak surveys. Surveyors did not return to the site.

North Beach West: This site was surveyed twice (2016 and 2019) and the area surveyed differs between years. This area was mainly surveyed in response to a proposal to move an outflow pipe. It would be best to use the North Beach Main site for long-term data.

Pole Pass: This site was last surveyed in 2017 and likely won't be surveyed again. There are three years of data (2015-2017), which is often insufficient for determining change but may be helpful to support other datasets.

Point Whitehorn: This is a pending vital sign site. It has an inconsistent bed footprint, some years the bed mapped is larger and other years it is much smaller. This could be in part due to the challenging conditions (swell, wind, changing substrate) the surveyors encounter. There is some uncertainty in what would be a consistently mapped area (smaller to be very confident the area has been mapped every year or slightly larger to capture a little of the variability seen on the deeper edge of the bed.

Reef Island: This site was last surveyed in 2017 and likely won't be surveyed again. It has two years of data (2016-2017), which is often insufficient for determining change but may be helpful to support other datasets.

2.3.4 Description of database structures

Figure 1 provides a visual of how data flows from collection by MRC volunteers, ingestion to the online webform KoboToolBox, to NWSC data processing, and on to DNRs working database, and finally to the vital sign database process. Not captured in the visual, but critical to this community science effort is the iterative process of data cleaning and verification with volunteers each survey season to confirm data cleaning reflects field observations.

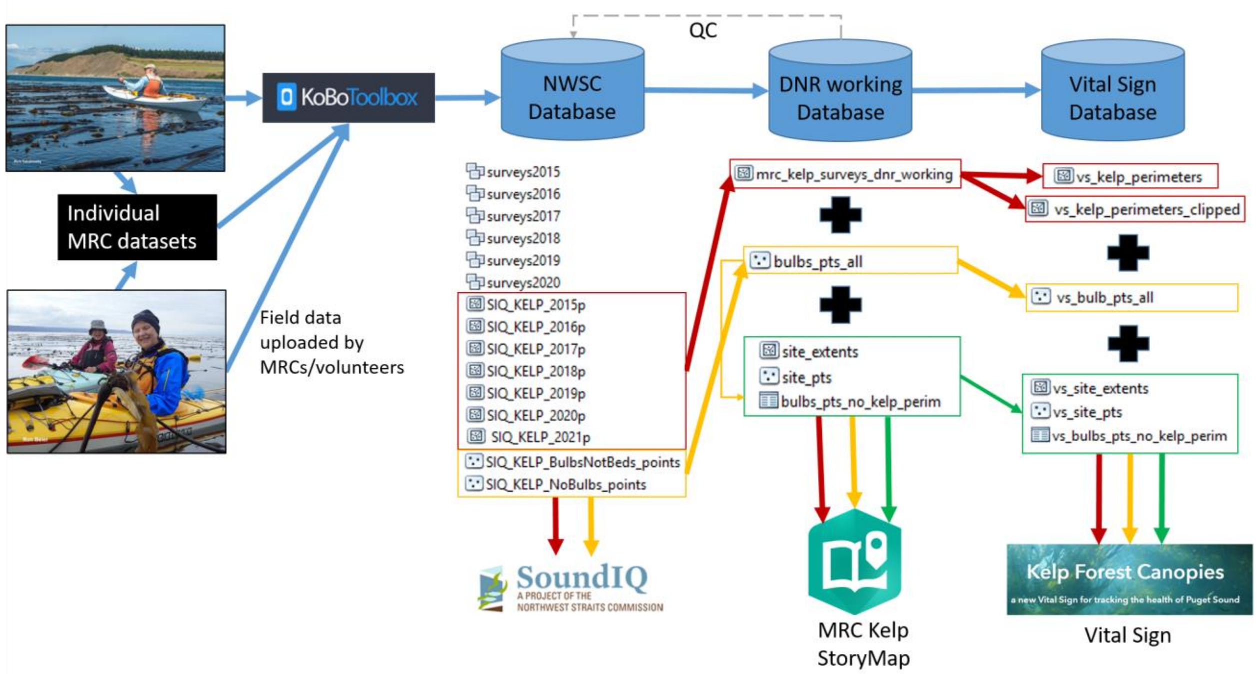

Figure 1. Flow chart of MRC kelp dataset from field collection to Vital Sign database

2.3.5 Northwest Straits Commission Database

The data collected by MRC volunteers includes: floating kelp perimeter data, field datasheet information and photos . Volunteers upload data to a KoboToolbox database. Data are downloaded from KoboToolbox, cleaned, converted from track points to polygons, attributed with the field data and formatted by the Northwest Straits Commission (NWSC) to create a geodatabase for publishing to NWSC mapping application SoundIQ. The NWSC geodatabase includes:

1. A feature dataset for each year (e.g. surveys2015). Each feature dataset contains a set of kelp perimeters (polygon feature classes) that include a polygon feature for each location and survey date (e.g. Ebeys_Landing_Aug_15_2015).

2. Annual polygon features that include all kelp perimeter features merged by year (e.g. SIQ_KELP_2015p).

3. Two point feature classes:
    a. SIQ_KELP_BulbsNotBeds_points includes point features where no conspicuous bed was present but individual bulbs were found.
    b. SIQ_KELP_NoBulbs includes point features where kelp was absent (no bulbs or beds present).

2.3.6 DNR Working Database

In the DNR working database, the NWSC database was restructured, edited and merged for manipulation, analysis and visualization. New feature classes were also added in the DNR database to better define sites and survey areas.

From the NWSC database, all the annual polygon features (e.g. SIQ_KELP_2015p) were merged into a single feature class (i.e. mrc_kelp_surveys_dnr_working) and all the existing fields were retained (Table 2). After 2021, the annual features should be appended to the master mrc_kelp_surveys_dnr_working feature class. Additional fields were added to standardize the formatting and allow for easy grouping (Table 3).

The two point feature classes in the NWSC database, SIQ_KELP_BulbsNotBed and SIQ_KELP_NoBulbs, had attribute tables with different formats so the attribute tables for each were exported to .csv files and read into R. Using R, the two attribute tables were reformatted to match each other and subsequently merged to create a single table, bulb_pts_all. A new field was added (kelp_obs) to distinguish points with no kelp from points with bulbs. The bulb_pts_all table is a record of every waypoint taken for bulbs and no bulbs and includes instances with duplicate site_code/svy_date when multiple points were taken (Table 4). The table was imported into ArcGIS Pro to create a point feature class.

A second bulb point table was created by filtering the bulb_pts_all table in R (using anti-join with the kelp perimeter table) to include only surveys with no kelp perimeters recorded at the site (Table 5). This second table, bulb_pts_no_kelp_perim, is exclusive from the kelp perimeter data and contains one record for each site and survey date that had either no kelp or only bulbs present without any corresponding perimeter, representing zero acres of kelp. It can be merged with the attribute table of the kelp perimeter feature class to produce a full dataset for analysis. The table was imported in ArcGIS Pro as a table with no spatial component.

There are two feature classes in the DNR geodatabase that were created by DNR and are not part of the NWSC database. The first is a point feature class called site_pts. Broad polygons were created around each site and converted to point features on the polygon centroid (Table 6). These points are used to identify each site location surveyed by the MRC volunteers and a field was included to indicate if a site is considered a vital sign site or not.

The second feature class created by DNR is site_extents, which consists of polygons that denote the area of each site that was consistently surveyed each year (Table 7). The polygons were defined and made in consultation with MRC volunteers that have knowledge of survey methods and site characteristics. The site_extents feature class is used to clip comparable survey data for inclusion in vital sign analyses.

2.3.7 Vital Sign Database

The vital sign database was populated by referencing the DNR working database and executing a python script. The only feature class that underwent structural changes to the tabular data was vs_kelp_perimeters. All other tables and feature classes were copied to the vital sign database and renamed (vs_survey_extents, vs_site_pts, vs_bulb_pts_all, vs_bulb_pts_no_kelp_perim).

To create the vs_kelp_perimeters feature class the python script copied the features from the dnr_working_db and then formatted and tidied the survey data in the following ways: (1) executed a spatial join to site_pts to relate site_code to each perimeter, (2) executed a spatial join to site_extents to relate site_extent value to each perimeter, (3) deleted nonessential fields to streamline dataset, (4) added and populated a kelp_acreage field, and (5) reordered fields. The output of this script was the vs_kelp_perimeters polygon feature class (Table 8). To isolate only the surveys suitable for inclusion in the vital sign, the vs_kelp_perimeters feature class was then clipped using the vs_site_extents feature class to create vs_kelp_perimeters_clipped feature class. Only perimeters within the vs_site_extent polygons and suitable for analysis were used to populate the vs_kelp_perimeters_clipped feature class.

2.3.8 Tables

Table 2. Fields retained from NWSC data in mrc_kelp_survey_dnr_working

Field name	Field type	Field description
BedName	Text	Name given to kelp bed by MRC volunteers
SurveyDate	Text	Date of survey
Acres	Double	Bed area in acres
Miles	Double	Perimeter of polygon in miles
County	Text	County survey occurred in
Location	Text	Location of kelp bed
Bulb_m2	Double	Density of bulbs per meter squared
WaTemp	Double	Water temperature (°C)
Wx	Text	Weather during survey
TideStation	Text	Tide station used to get tidal height
Obs	Text	Observations
Notes	Text	Notes
ToBe	Text	URL for photo taken of kelp bed towards the shore
ToWa	Text	URL for photo taken of kelp bed towards the water
BeL	Text	URL for photo taken of kelp bed with beach to the left
BeR	Text	URL for photo taken of kelp bed with beach to the right
CorrDepShor	Double	Corrected depth on the shore edge of the bed (m, MLLW)
CorrDepShore	Double	Corrected depth on the shore edge of the bed (m, MLLW)
CorrDepWa	Double	Corrected depth on the water edge of the bed (m, MLLW)
TidalHt_meters	Double	Tidal height in meters
TidalHt_meter	Double	Tidal height in meters
Obs2	Text	Additional observations
URL	Text	URL
WaTemp1	Double	Water Temperature (°C)
WaTemp2	Double	Water Temperature (°C)

Table 3. Standardized fields added by DNR in mrc_kelp_surveys_dnr_working

Field name	Field type	Field description
site_name	Text, Length: 20	Site name (derived from mrc bed name field)
svy_day	Short	Day of survey (derived from survey date)
svy_mon	Short	Month of survey (derived from survey date)
svy_yr	Short	Year of survey (derived from survey date)
svy_date	Text, Length: 8	Date of survey (concat DDMMYYYY)
visit_num+	Short	Site visit number (incrementing integer, starts at 1 year

		year)
svy_num+	Short	Survey number (incrementing integer, starts at 1 each visit)
analyze+	Short	Flag field used by DNR to track perimeters suitable for inclusion in analyses (0 = no, 1 = yes)
notes_dnr+	Text, Length: 100	Note field used by DNR

+ = populated by DNR

Table 4. Fields in bulb_pts_all and vs_bulb_pts_all

Field name	Field type	Field description
BedNameMRC	Text, Length: 25	MRC Bed Name
site_code+	Text, Length: 8	Unique code used to identify sites (DNR)
svy_date	Text, Length: 8	Day of survey (derived from survey date)
svy_yr	Short	Year of survey (derived from survey date)
svy_mon	Short	Month of survey (derived from survey date)
svy_day	Short	Day of survey (derived from survey date)
County	Text, Length: 25	County survey occurred in
kelp_obs+	Text, Length: 25	Note associated with pt: either no bulbs or bulbs not bed
Lat	Double	Latitude
Lon	Double	Longitude

+ = populated by DNR

Table 5. Fields in bulb_pts_no_kelp_perim and vs_bulb_pts_no_kelp_perim

Field name	Field type	Field description
site_code	Text, Length: 8	Unique code used to identify sites (DNR)
svy_date	Text, Length: 8	Date of survey (concat DDMMYYYY)
svy_day	Short	Day of survey (derived from survey date)
svy_mon	Short	Month of survey (derived from survey date
svy_yr	Short	Year of survey (derived from survey date
visit_num+	Short	Site visit number (incrementing integer, starts at 1 year year)
svy_num+	Short	Survey number (incrementing integer, starts at 1 each visit)
kelp_obs+	Text, Length: 25	Note associated with pt: either no bulbs or bulbs not bed
svy_area_ac	Float	Survey area in acres
site_extent+	Text, Length: 15	Concatenation of site_code and extent_num used to relate survey_extents to kelp_perimeters

analyze+	Short	Flag field used by DNR to track perimeters suitable for inclusion in analyses (0 = no, 1 = yes)
notes_dnr+	Text, Length: 100	Note field used by DNR

+ = populated by DNR

Table 6. Fields in site_pts and vs_site_pts

Field name	Field type	Field description
site_code+	Text, Length: 8	Unique code used to identify sites (DNR)
site_location+	Text, Length: 25	Site location, used to provide a detailed description of site_code (DNR)
vital_sign+	Short	Flag field used to indicate whether or not site is a 'vital sign' site (0 = no, 1 = yes)
lat	Double	Latitude
lon	Double	Longitude

+ = populated by DNR

Table 7. Fields in site_extent and vs_site_extent

Field name	Field type	Field description
site_code+	Text, Length: 8	Unique code used to identify sites (DNR)
site_location+	Text, Length: 25	Site location, used to provide a detailed description of site_code (DNR)
extent_num+	Short	Incrementing integer used to track and relate site_extents to a site (site_code) and survey (kelp_perimeter)
site_extent	Text, Length: 15	Concatenation of site_code and extent_num used to relate survey_extents to kelp_perimeters

+ = populated by DNR

Table 8. Fields in vs_kelp_perimeters and vs_kelp_perimeters_clipped.

Field name	Field type	Field description
site_code	Text, Length: 20	Unique code used to identify sites (DNR)
svy_date	Text, Length: 8	Date of survey (concat DDMMYYYY)
svy_day	Short	Day of survey (derived from survey date)
svy_mon	Short	Month of survey (derived from survey date
svy_yr	Short	Year of survey (derived from survey date
visit_num	Short	Site visit number (incrementing integer, starts at 1 year year)
svy_num	Short	Survey number (incrementing integer, starts at 1 each visit)
svy_area_ac	Float	Survey area in acres

site_extent	Text, Length: 15	Concatenation of site_code and extent_num used to relate survey_extents to kelp_perimeters
analyze	Short	Flag field used by DNR to track perimeters suitable for inclusion in analyses (0 = no, 1 = yes)
notes_dnr	Text, Length: 100	Note field used by DNR

2.4 References

Bishop, E. (2014). *A kayak-based survey protocol for Bull Kelp in Puget Sound*. Updated 2020. Northwest Straits Commission. https://www.nwstraits.org/media/2937/kelp-protocol-may-2020-revised.pdf

Britton-Simmons, K., Eckman, J.E., & Duggins, D.O. (2008). Effect of tidal currents and tidal stage on estimates of bed size in the kelp *Nereocystis leutkeana*. *Marine Ecology Progress Series, 355,* 95-105.

Appendix 11: Draft Dataset description – Samish

Puget Sound Vital Signs
Floating kelp canopy area indicator: dataset description

Samish Indian Nation kelp canopy aerial surveys
Last updated: May 13, 2022

1. Introduction

In 2020, the Puget Sound Partnership added a new *floating kelp canopy area* indicator to the Puget Sound Vital Signs, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator fills gaps in scientific information about the condition of floating kelp canopies. It also serves 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 which can be found on the Puget Sound Floating Kelp Hub Site.

The purpose of dataset descriptions is to provide key information about datasets that are synthesized in the floating kelp canopy area indicator, including considerations related to dataset integration. Dataset descriptions are not meant to replace detailed metadata, which is available directly from the data owners/maintainers (links below).

This document describes the Samish Indian Nation kelp canopy aerial surveys (Fig. 1).

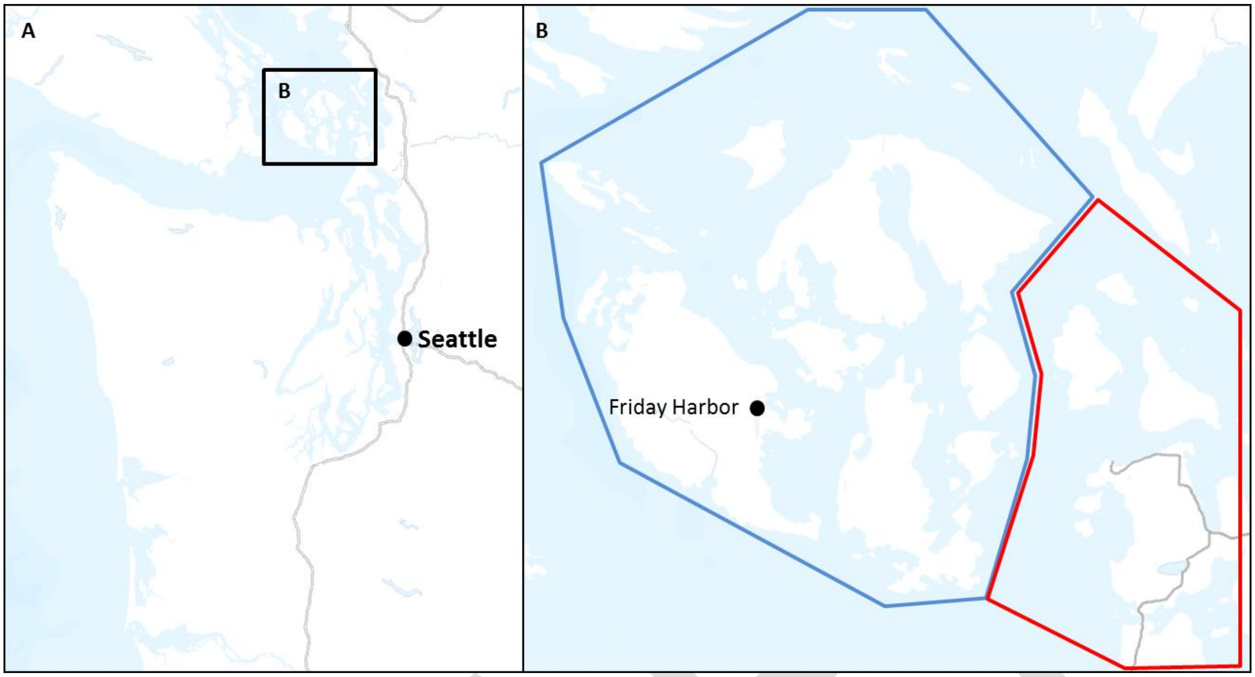

Fig. 1: Location of Samish Indian Nation kelp canopy aerial surveys. Blue polygon in panel B represents the approximate 2004/2006 and 2016 survey area. Red polygon in panel A represents the approximate additional survey area in 2019.

2. Dataset description

2.1 Summary

The Samish Indian Nation delineated floating kelp beds using aerial photography in San Juan County in 2004/2006, 2016 and 2019. In addition, they classified Skagit County and shorelines in 2019 using similar processing methods.

2.2 Description

Spatial extent	San Juan County (SJC), Skagit County (SC). Figure 1.
Metric(s)	Kelp bed area (GIS polygons)
Assessment Units	Comprehensive delineation within the study area
Survey years	2004/2006 (SJC only, Western portion in 2004 and eastern portion in 2006), 2016 (SJC only), 2019.
Frequency	Infrequent annual
Methods summary	Beds were delineated to encompass areas with floating kelp canopies (including gaps within the canopy and rocks) using on-screen digitizing of aerial photography. Detailed methods are available from the Samish Indian Nation. Aerial imagery sources: - 2004-2006 aerial photography: low-tide, color-infrared 9" x 9" negatives collected during joint DNR-Friends of the San Juans project. (Berry 2007). These photographs were originally used for surface canopy delineation using semi-automated classification of spectral band data. - 2016 and 2019 aerial photography: 6" resolution color imagery collected by Pictometry for San Juan County during May/June 2016. Variable tide and current levels. - 2019 photography from SC was collected at a different time than SJC photography
Accessibility	The 2006, 2016, and 2019 Samish aerial kelp surveys are generated and maintained by the Samish Indian Nation and are used here with permission. Access to raw data (including GIS files) can be done with a request to the Samish Indian Nation (contact). Samish Indian Nation kelp Story Map: Palmer-McGee 2021

2.3 Considerations for integration in the Floating Kelp Canopy indicator

The 2006, 2016, and 2019 Samish aerial kelp surveys provide a valuable comprehensive dataset of canopy kelp distribution in the region. However, the 2016 and 2019 surveys were not controlled for tides and currents. Tides and currents are known to have a large effect on amount of viable/detectable kelp (Britton-Simmons et al. 2008). Therefore, interpretation among years were interpreted with caution.

3. References

Britton-Simmons, K., Eckman, J. E., Duggins, D. O. 2008. Effect of tidal currents and tidal stage on estimates of bed size in the kelp *Nereocystis luetkeana*. Marine Ecology Progress Series 355: 95–105. doi: 10.3354/meps07209

Appendix 12: Puget Sound Partnership Vital Signs program conceptual models

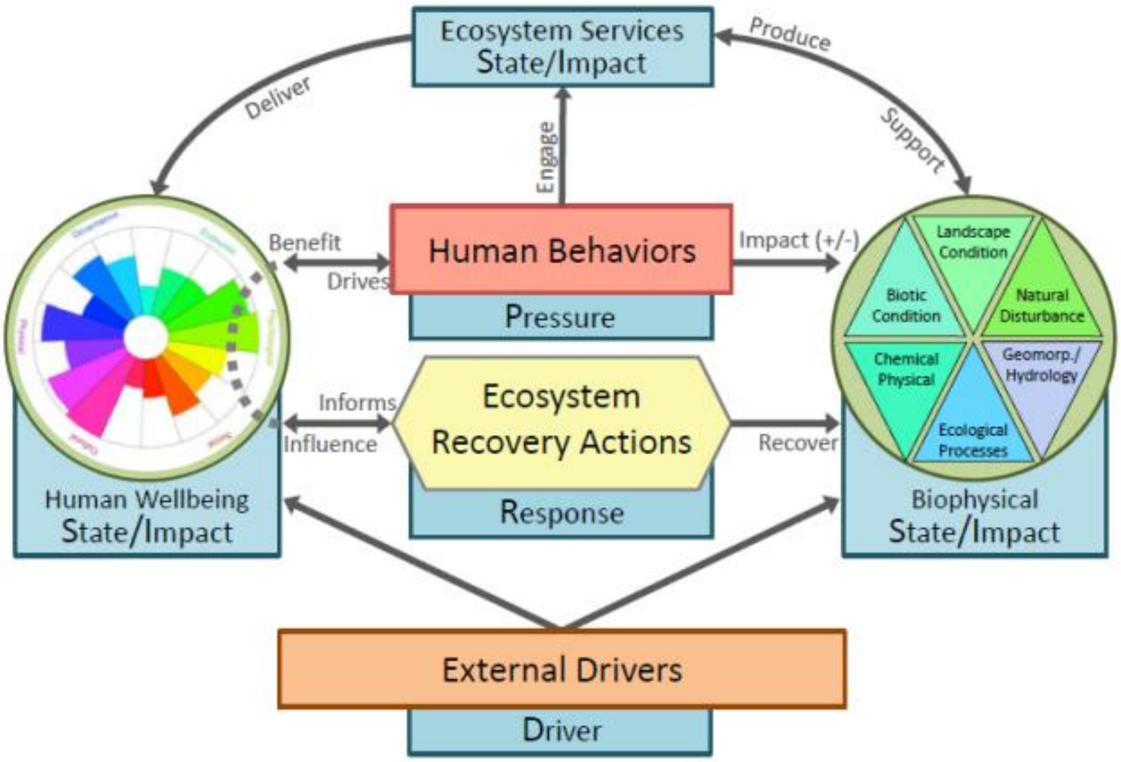

Figure A12-1: Integrated conceptual model for ecosystem recovery (from O'Neill et al. 2018). The integrated model includes three embedded frameworks: the Driver-Pressure-State-Impact-Response framework, the Essential Ecological Attribute Framework (EPA 2002) and the human wellbeing framework (from Harguth et al. 2015).

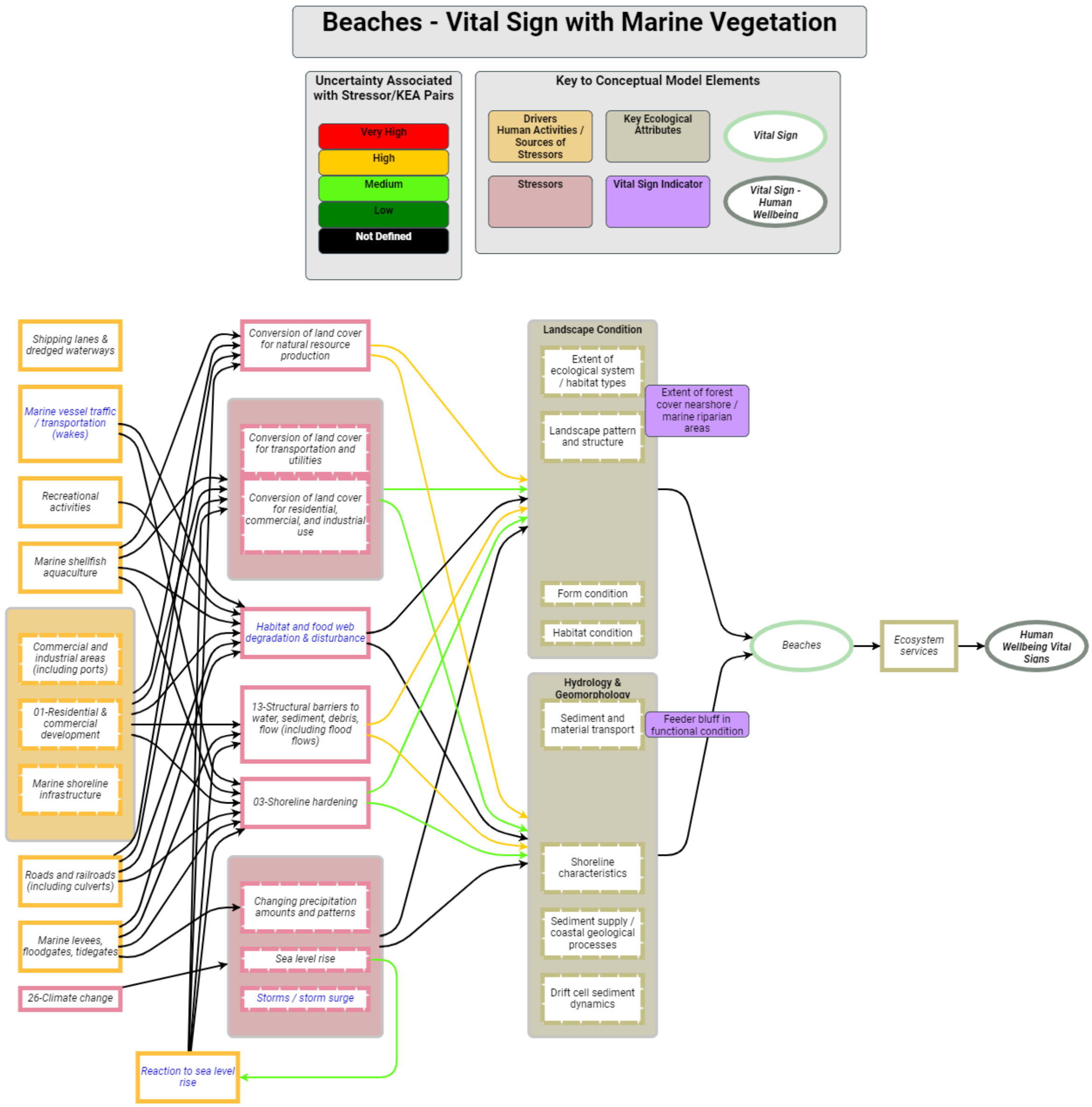

Figure A12-2: The conceptual model for the Marine Vegetation portion of the Beaches and Marine Vegetation Vital Sign, developed as part of the Vital Signs Revision (McManus et al. 2020). The *floating kelp canopy area* indicator falls within this Vital Sign. Zoom into the image to