# Monitoring Program Design and Data Assessment Protocols for Floating Kelp Monitoring in Washington State

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Kelp Forest Monitoring Alliance of Washington State


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

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

DISCLAIMER

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

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# Executive Summary

This technical report describes the program design and data assessment protocols for statewide monitoring of floating kelp in Washington. The monitoring program is conducted by The Kelp Forest Monitoring Alliance of Washington State (KelpForestsWA), a diverse partnership of organizations that value kelp.

The Alliance monitors floating kelp because it is an important nearshore resource that provides food and habitat to a wide range of species. There is widespread concern about kelp losses, both globally and locally. In 2020, the Puget Sound Conservation and Recovery Plan (Kelp Plan) identified the need to expand monitoring and create an indicator that summarizes kelp status and trends in Washington State. Shortly thereafter, the Puget Sound Partnership expanded its regional Vital Signs to include floating kelp, pending indicator development. During the development process, the Project Team identified a broad need for a statewide monitoring program informed by the Kelp Plan, the Puget Sound Partnership Vital Signs Program, and community input. This led to the development of a diverse set of program products which include the PS Info indicator.

The monitoring program has been developed rapidly using existing data because there are time-sensitive needs for information about kelp status and trends. This document describes the current program implementation and areas for future program expansion (dependent on program resources). The framework for the monitoring program incorporates requirements from the PS (Puget Sound) Partnership Vital Signs, the Kelp Plan, and input provided by the broader community.

The main components of the monitoring program design protocol include geographic assessment areas, floating kelp parameters, data collection procedures, data analysis procedures, and metrics (defined here as variables derived from measured parameters). Two primary metrics are defined for reporting the statewide indicator and the PS Info indicator. Where available, secondary metrics assist in supplemental assessment of sampling locations and sub-basins.

In summary, the statewide indicator and PS Info indicator are composed of two metrics:

- Long-term trends in bed area, assessed at sampling locations. Trend results are based on linear regressions, supplemented by expert review, secondary metrics, and other data sources. Trend categories are: increasing, no trend, declining, total loss, limited data, and no floating kelp.
- Overall status, assessed in sub-basins. A summary classification for 11 areas within the state, based on all available information. The purpose of this metric is to provide an integrated evaluation of all data sources that informs research and management. Ideally, the baseline would represent a recovery target or historical distribution.

However, because these baselines are not known, the status categories describe overall understanding of changes in floating kelp (examples include stable, concern, declines, no floating kelp) with consideration of data completeness (limited or insufficient data). Status categories: stable, decreasing, concern of declines (but limited data), insufficient data, no floating kelp.

The spatial sampling framework incorporates a series of hierarchical geographic assessment areas. The study area is divided into 11 sub-basins, based on large-scale oceanographic features distinguished by their environmental conditions. Two types of sampling locations are included to maximize the use of available data:

- Zones - generally spanning 1-10 km of shoreline and surveyed by aerial photography
- Sites – generally at a scale of 1 km of shoreline, surveyed by kayak

Primary data collection methods include fixed-wing imagery and kayaks. The monitoring program synthesizes data collected by three organizations, using custom protocols:

- The Samish Indian Nation
- The Northwest Straits Commission and county Marine Resource Committees (MRCs)
- The Nearshore Habitat Program in the Washington State Department of Natural Resources

The WA floating kelp monitoring dataset is a synthesis of these existing datasets. The data producers retain stewardship over the complete datasets and their use. The data management section of the report describes the geospatial data structure.

Six types of products are defined:

- A statewide summary report
- Content for PS Info, the reporting platform for PS Partnership Vital Signs. (Content for PS Info is derived from the statewide summary and converted to the PS Info reporting format.)
- An interactive map that allows for spatial exploration of data
- Sub-basin information. Two options are being considered:
    - Single page summaries (implemented and made available in both the statewide summary report and interactive map)
    - In-depth reports. A sample report has been completed (San Juan Islands Sub-basin Report) (Not implemented in current version, no planned implementation at this time; dependent on future staff and resources).
- Dataset descriptions for all datasets included in the primary metrics.
- Monitoring program design and data assessment protocols (this report).

During assembly of these products, the Project Team identified priorities for enhancement of the monitoring program. Future enhancements will require additional funding; highlights include:

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

Cross-border collaboration with scientists and managers in British Columbia will also help to direct future enhancements. These collaborations are currently being developed by participation in the annual Kelp Mappers meetings (held in Victoria, BC), and in the BC-WA Kelp Node (a component of the Biodiversity Action Network, an endorsed UN Decade of the Ocean Science for Sustainable Development (UNDOS) project, under the MarineLife 2030 program.)

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# 1 Framework for program development

## 1.1 Overview

The framework for program development incorporates requirements scoped from three main sources: the PS Partnership Vital Signs, the Kelp Plan, and community input during the Floating Kelp Monitoring Program (the Program) development project. Each source is described below. During development, the Project Team (Section 1.2) identified a broad need for a statewide floating kelp monitoring program. The PS Info indicator constitutes a subset of the broader Program described here.

Community engagement is central to the Program and its development. Meaningful community engagement is more likely to lead to conservation success and to environmental justice. However, it is important to acknowledge that true co-creation of knowledge is challenged by existing institutions and social constructs. The Project Team incorporated community engagement to the greatest extent possible, given current structures, available resources, and time. We emphasize that true partnerships require time to grow. Moving forward, we envision community engagement will continue to be a central tenant of the Program.

Linkages to other programs will be critical to using monitoring data to inform management, research, and restoration. These considerations are discussed in Linkages (Section 1.5).

## 1.2 Project team

Participants in Floating Kelp Monitoring Program development project 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, Danielle Claar, Pete Dowty, Lisa Ferrier, Bart Christiaen, Julia Ledbetter, Elizabeth Spaulding, Tyler Cowdrey, Tim McClure
    - 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 morning program and its various products. 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 Straits 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 Program 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 monitoring program is envisioned as a connector between many organizations and communities that value kelp. To this end, the Project Team has created the Kelp Forest Monitoring Alliance of Washington State.

## The Kelp Forest Monitoring Alliance of Washington State:

### Mission and Scope

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

## 1.3 Scoping Requirements

### *1.3.1 Puget Sound Partnership Vital Signs program*

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, and
- 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 (see O'Neill et al., 2018).

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 directing regional strategies and specific actions needed to recover Puget Sound.
- Puget Sound Info (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 if 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. The conceptual model for the Beaches and Marine Vegetation Vital Sign that houses the *floating kelp canopies* indicator is available in McManus et al. 2020.

### *1.3.2 The Kelp Plan*

In 2020, the Puget Sound 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. Floating kelp monitoring is one component of many actions that address the six strategic goals identified in the Kelp Plan. The Kelp Plan implementers serve as the primary umbrella organization for coordinating kelp-related activities. The plan also supports widespread connections between floating kelp monitoring and related scientific and management work.

### *1.3.3 Community input*

During the program development project, a series of workshops and small meetings further identified priorities for data analysis, synthesis, and use. Five priority themes were identified and refined (Table 1).

*Table 1. Five priority themes and related key considerations reviewed in floating kelp monitoring program development workshops*

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

Participants confirmed that scientists, managers, and communities need the information that the floating kelp monitoring project will produce. Participants identified needs for multiple types of information that ranged from intuitive summaries to more nuanced and detailed results. They also expressed the need for information at multiple geographical scales, from statewide to ~1-km sites. Specific comments included:

- There was strong support for the project approach, which integrates information from diverse sources and knowledge types.
- There was broad support for including the open coast in the geographical extent from scientists, managers, and communities.
- Organizations who are not members of the Project Team expressed interest in monitoring floating kelp beds in their locales for potential inclusion. Future funding could make expansion possible.
- Comments from individual managerial programs identified specific applications of the monitoring results (i.e., the Habitat Strategic Initiative and the Kelp and Eelgrass Health and Conservation Plan). These programs provide additional valuable connections to management actions.

Taken together, comments strongly suggest that PS Info and the Partnership's Vital Sign Program represent a subset of all of the floating kelp monitoring and data synthesis needs. The project identified a broad need for a statewide monitoring program. The PS Info indicator thus constitutes a part of the broader floating kelp monitoring program. The Program strives to both develop the indicator for PS Info and fulfill the other distinct purposes that were identified by participants. In practice, we envision that Program products will be used as a broad-scale reference point for information on the status and trend of floating kelps throughout Washington State, and complement local programs.

## 1.4 Community engagement

The Floating Kelp Monitoring Program, including the PS Info indicator, 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 incorporated these values into the development process and encourages prioritizing these values in future work. However, The Project Team recognizes both the challenges and opportunities presented by this approach.

### *1.1.1. Long-term vision*

Diverse participation in conservation research is important for both ethical and practical reasons. Conservation is ultimately about values (Borgerhoff Mulder & 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). The long-term vision for floating kelp monitoring is to further increase participation by holding public workshops and other opportunities for public involvement.

However, 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 community scientists/volunteers and Tribes is a key element of the Project Team's community engagement strategy. Community scientists and volunteers serving on county Marine Resources Committees (MRCs) advise local county governments and can use monitoring 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 et al., 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 1). 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). 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 knowledge sources, such that the monitoring program synthesizes data from state agencies, community/citizen science, and indigenous science.

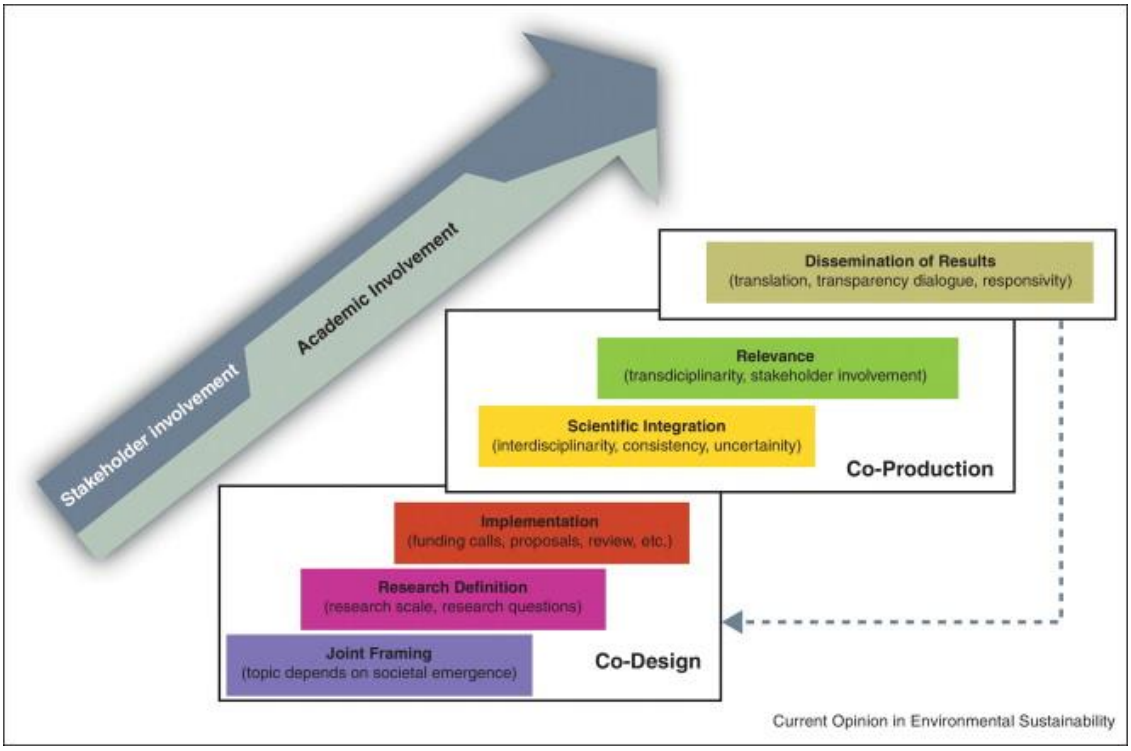


*Figure 1: Framework for interdisciplinary co-creation of knowledge (from Mauser et al., 2013).*

### *1.4.1 Challenges and opportunities*

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 Program. PS Info indicator development must fit within an existing framework with its own goals and objectives, process, standards, and requirements. The timeline for creating the first iteration of the PS Info indicator and the broader Program has been relatively brief, ~1.5 years, from the perspective of building trust between diverse partners, forging meaningful relationships, and reconciling differences between perspectives and approaches (Kotaska, 2019). Finally, the existing Puget Sound Vital Sign framework and many other monitoring frameworks are not defined according to the principles of co-design (shown in Figure 1).

Despite these challenges, Program development and refinement provide many opportunities for enhancing community engagement around kelp conservation. Our ability to co-design the Program may be limited, but we can lay the groundwork for co-production (Figure 1) 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 1), 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 will necessarily be more narrowly defined to ensure consistency with the Puget Sound Partnership Vital Signs framework. Direct contributions to program development might include, but are not limited to:

- Sharing datasets to be included.
- Suggesting priorities for monitoring, such as the time spans considered (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 Program 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 the PS Info indicator development, but can be incorporated into the broader long-term goals 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 Program 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 Program 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 Monitoring Program contributes to making the Vital Sign program itself more inclusive, participatory, and transdisciplinary.

### *1.4.2 Current implementation*

For the first iteration of the Floating Kelp Monitoring Program products, including the PS Info indicator and Statewide Summary, community engagement was largely dictated by the members of the Project Team and by the timeline to produce the Program. 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 process.

## 1.5 Linkages

The Program is limited to describing status and trends in floating kelp canopies and bed area. 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 Program yet are critical to its overall success.

### *1.5.1 Management*

In order to drive conservation and recovery actions, it is important to link the Program 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), Statewide Kelp and Eelgrass Health and Conservation Plan, and the Habitat Strategic Initiative for Marine Vegetation.

### *1.5.2 Research and monitoring*

Like many other PS Info indicators, the strength of the floating kelp bed indicator and broader program is that it will summarize scientific understanding of conditions at a regional scale. This strength comes with limitations, including: 1) the indicator and broader Program does not explicitly examine stressors that might be driving observed trends; 2) the Program does not conduct intensive, high-resolution research. Connections are needed between the Program, Project Team, and other groups addressing 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 PS Info indicator work. These could be newly established or built on established at locations of substantial existing research, such as: Tatoosh Island, Elwha, and Friday Harbor Laboratories sites.

### *1.5.3 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 BC-WA 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
- Interested tribes

Formal or informal collaborations for research and monitoring could include:

- Ongoing Elwha shoreline research including: USGS (United States Geological Survey), Lower Elwha Klallam Tribe, and Washington Sea Grant
- University of Chicago
- Academic institutions, including University of Washington Friday Harbor Laboratories
- The Olympic National Marine Sanctuary
- Reef Check
- BC-WA Kelp Node
- Puget Sound Restoration Fund (restoration and sub-tidal monitoring)
- NOAA (National Oceanographic and Atmospheric Administration)
- WDFW (Washington Department of Fish & Wildlife)
- Interested tribes

# 2 Spatial framework and metrics

## 2.1 Overview

The main components of the Floating Kelp Monitoring Program include geographic assessment areas, floating kelp metrics, and procedures for data collection and analysis.

The Program has been developed rapidly using existing data because there are time-sensitive needs for information about floating kelp status and trends. This document describes the current implementation of the Program along with long-term plans for future program expansion (dependent on resources).

We use the following two terms in the description:

- Parameter – a measure that is collected (such as bed area).
- Metric – a value derived from a parameter (such as a trend result or classification).

Two primary metrics are defined for statewide monitoring and for reporting in PS Info. Where available, secondary metrics assist in supplemental assessment. The primary metrics are:

- Long-term trends in bed area, assessed at sampling locations. The program assesses trends in the bed extent of canopy-forming kelp forests at locations throughout Washington State by tracking the area of kelp forests floating on the water surface. Trend results are based on linear regressions, supplemented by expert review and secondary data sources. Categories: increasing, no trend, declining, total loss, limited data, and no floating kelp.
- Overall status, assessed at sub-basins. A summary classification for each sub-basin based on all available information, including other ways of knowing. The goal of this metric is to provide an integrated evaluation of data sources. Categories: stable, decreasing, concern of declines but limited data, insufficient data, and no floating kelp.

The primary metrics are based on floating kelp bed area because it has the most available data (see Sections 2.3.3 & 2.3.4 for additional detail). Canopy area is a secondary metric used at many locations (see Figure 6 for definitions of bed and canopy area).

The spatial sampling framework incorporates a series of hierarchical geographic assessment areas. For core statewide reporting, the study area is divided into 11 sub-basins, based on large-scale oceanographic features that are associated with environmental conditions. Two types of sampling methods and locations are included in order to maximize the use of available data:

- Zones - generally spanning 1-10 km of shoreline and surveyed by aerial photography.

- Sites – generally at a scale of 1 km of shoreline, surveyed by kayak.

The core dataset synthesizes data collected by three organizations:

- The Samish Indian Nation.
- The Northwest Straits Commission and county Marine Resources Committees (MRCs).
- The Nearshore Habitat Program in the Washington State Department of Natural Resources.

The data management section of the report describes the geospatial data structure. The floating kelp dataset is synthesized from multiple existing datasets. The data producers retain stewardship over the source datasets and their use.

Taken together, the spatial framework and metrics are a core element of the Floating Kelp Monitoring Program and highlight the integrated nature of the overall Program. Figure 2 is a conceptual diagram of the Program and how different internal and external pieces are connected. In summary, the Kelp Forest Monitoring Alliance of Washington State, comprised of the Project Team, developed the Program through consideration and consultation from community input, the Kelp Plan, and Puget Sound Partnership Vital Signs Program. This project created the first iteration of the Program which has six products which are detailed in Section 5. The Monitoring Program Design and Protocols document details geographic assessment areas, floating kelp parameters, data collection procedures, data analysis procedures, and metrics. These feed and guide the other Program products. Sub-basin Summaries provide descriptions of floating kelp data and observations. Dataset Descriptions provide a short description of data used in the Program and link to the ultimate data source. The Statewide Indicator, including the Statewide Summary Report, PS Info content, Interactive Map, and Web site serve as the accessible, front facing products that report kelp trends at locations and kelp status in sub-basins. These different forms of communication are tailored to a broad audience and range in detail and presentation mode. With an eye to future development of the Program, Program products are meant, in part, to inform associated kelp management, conservation, restoration, and research efforts. In turn, these efforts can inform the Alliance to further improve the Program.

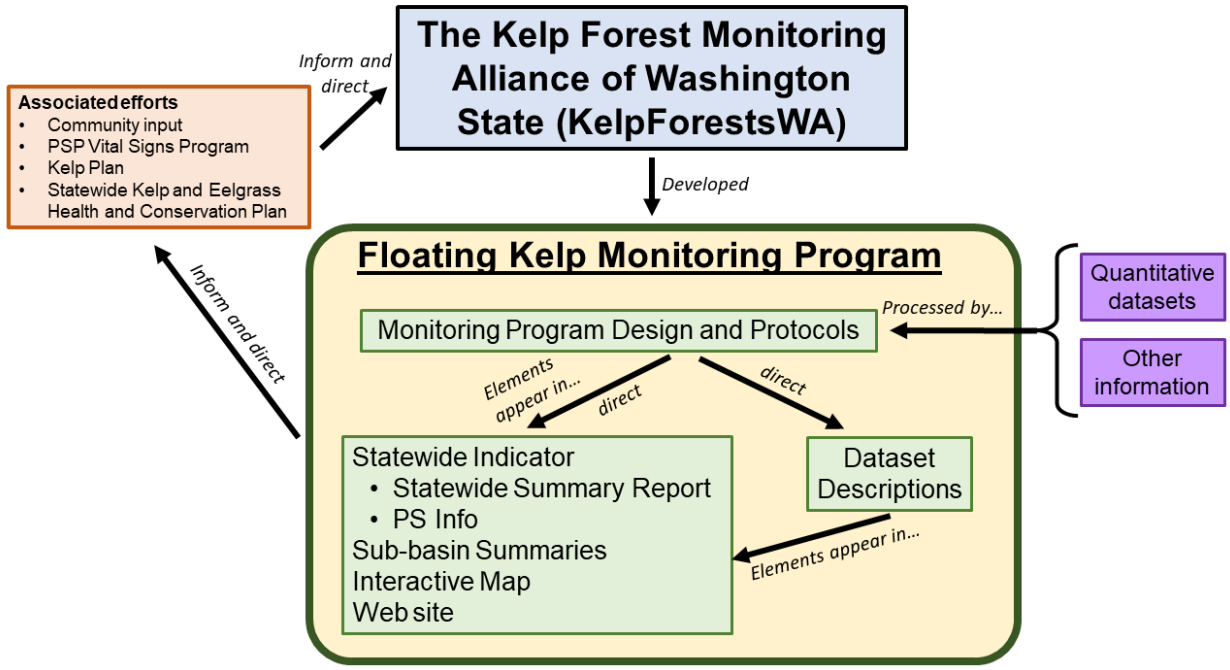


*Figure 2: Conceptual diagram of the Floating Kelp Monitoring Program, its components, and external inputs and influences. Relationships between elements (colored text boxes) can be inferred by reading the box, then the italic text the box is pointing to, then the box that is being pointed to. For example, the Monitoring Program Design Protocols direct what appears in Sub-basin Summaries.*

## 2.2 Geographic assessment areas

### *2.2.1 Overview of long-term plan and current implementation*

Many Puget Sound Vital Sign indicators are summarized throughout greater Puget Sound and tracked within spatial sub-divisions that capture meaningful variation in the indicator. For indicators that track species such as kelp, which have widespread distribution and are known to respond to local and regional conditions, sub-areas are generally defined by prioritized physical, biological, and/or management factors.

A series of hierarchical geographical assessment areas are defined for evaluating and reporting floating kelp results (Figure 4). The hierarchical structure and the levels within it consider related physical, chemical, biological, and management factors at a variety of scales (Table 2). The long-term goal is to use targeted studies to refine and implement this framework of geographical assessment scales for data synthesis and analysis.

In summary, the study area for the Program, including PS Info, includes all of Washington's saltwater areas. The study area is divided into 11 sub-basins, based on oceanographic factors (Figure 3). More detailed spatial scales (reaches, sites, zones, and 1-km segments; Table 2) have been implemented in portions of the study area. The extent of implementation was largely

dictated by available data. Table 3 summarizes the currently implemented spatial delineations in each sub-basin and the data present.

In order to maximize the use of existing data, the Program integrates data from two types of sampling locations: zones and sites.

*Table 2: Hierarchical geographic assessment levels including descriptions, approximate number statewide, and approximate size.*

| Name | Description | Approximate Number of Units Statewide | Size (shoreline km per feature) |
|---|---|---|---|
| study area | All saltwater areas throughout Washington State | 1 | 1000s km |
| sub-basin | Areas with similar oceanographic conditions, sub-divided at shallow sills or other large-scale features | 11 | 100s km |
| reach | Intermediate scales of consideration that group contiguous or geomorphologically similar sample locations (zones or sites). Delineations between reaches focus on geomorphological boundaries, taking into account features such as fetch, shoreline type, and aspect. | 10s-100s | ~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 have also been called “map indices” in some sub-basins) | 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 |

*Table 3: Spatial delineations for each sub-basin and the data present for the current implementation of the Floating Kelp Monitoring Program (sub-basins sorted from the open coast into Puget Sound).*

| Sub-basin | Abbreviation | Reach | Zone | Site | Segment | Data |
|---|---|---|---|---|---|---|
| South Coast | SCO | X | X | X | X | DNR COSTR |
| North Coast | NCO | X | X | X | X | DNR COSTR |
| Western Strait of Juan de Fuca | WST | X | X | X | X | DNR COSTR, NWSC/MRCs |
| Eastern Strait of Juan de Fuca | EST | X | X | X | X | DNR COSTR, DNR AQRES, NWSC/MRCs |
| San Juan Island | SJI | X | X | X | X | Samish, DNR AQRES |
| North Puget Sound | NPS | | | X | X | NWSC/MRCs |
| Admiralty Inlet | ADM | | | X | X | NWSC/MRCs |
| Saratoga/Whidbey | SWH | | | X | X | NWSC/MRCs |
| Central Puget Sound | CPS | | | X | X | DNR Kayak |
| South Puget Sound | SPS | | | X | X | DNR Kayak |
| Hood Canal | HDC | | | | X | No floating kelp |

#### *2.2.1.1 Study Area*

The Program study area spans all of Washington State's saltwater shorelines. While the open coast lies outside of the Puget Sound Partnership planning area, understanding status and trends of floating kelp in this distinct region is critical from an ecological perspective in order to compare conditions in the inland sea to the open coast. It is also critical for comparing observations within Washington State to adjacent regions and globally. Finally, it is critical to include the open coast in order to engage with communities that are often excluded from efforts that emphasize Puget Sound. The importance of including the open coast was a strong theme in feedback from a broad cross-section of scientists, federal and state managers, NGOs, citizens, and tribes (see scoping comments during Phase 1 and Phase 2 of Program development).

#### *2.2.1.2 Sub-basins*

Sub-basins are 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 have proven 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 program is based on integration of existing data rather than probabilistic sampling, sampling effort did not drive the determination of the number and size of sub-basins.

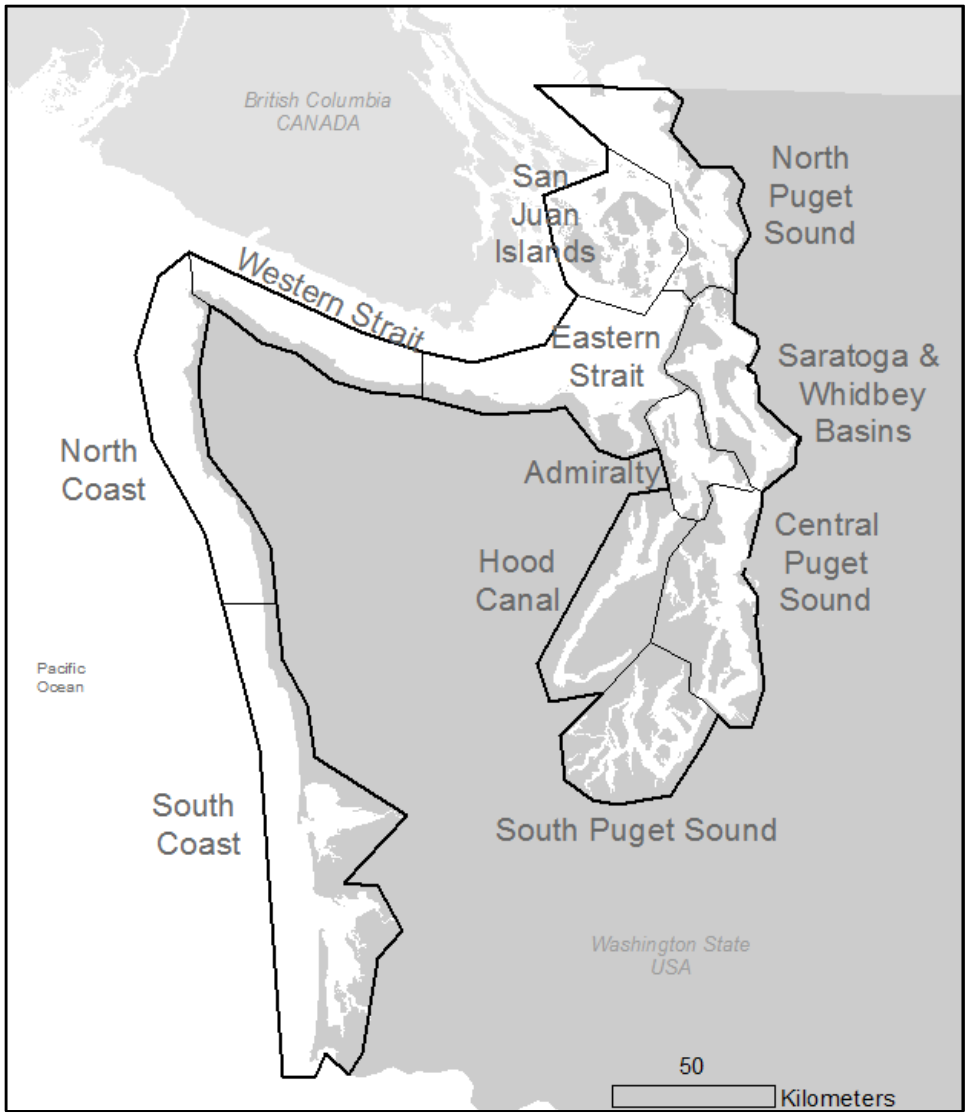


*Figure 3: Sub-basins for the Floating Kelp Monitoring Program including PS Info floating kelp bed area indicator.*

Eleven sub-basins are defined for the Floating Kelp Monitoring Program (Figure 3). Many sub-basin delineations exist, with clear commonalities and minor differences. The floating kelp sub-basin delineation adapted a widely used sub-basin delineation that was created by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), with some minor differences:

- The open coast is included in the study area. It is divided into northern and southern portions. The northern portion is dominated by rocky shorelines. The southern portion is dominated by sandy shorelines and two major estuaries (Grays Harbor and Willapa Bay).
- 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 (National Marine Fisheries Service, 2017) and WDFW's Marine Areas (used in 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 in conditions. For many attributes, the north and south portions are more similar to adjacent areas 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').

It is important to acknowledge that while sub-basins are useful for spatial summation, the precise placement of boundaries is somewhat arbitrary at small spatial scales.

#### *2.2.1.3 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. Reaches allow for rolling up of status and trends data for examination of differences within and among nearby locations. Reaches occur within a single sub-basin, with coincident boundaries.

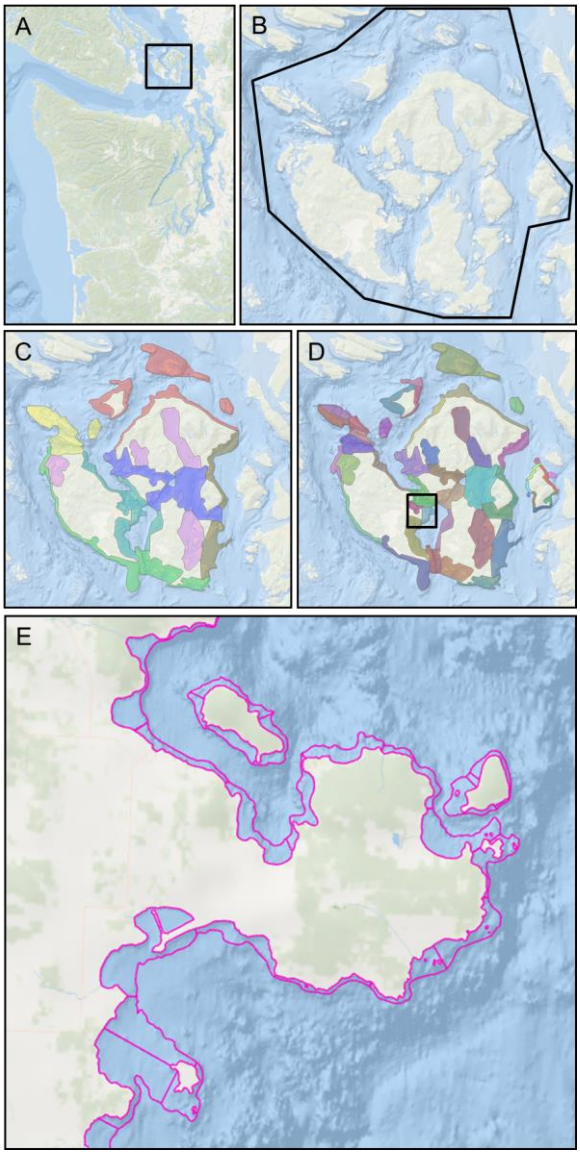


*Figure 4: Coastal Washington State (A) with San Juan Islands inset, San Juan Islands sub-basin (B), reaches within sub-basin (C), zones within reaches (D) with detailed inset, 1-km site polygons (E).*

#### *2.2.1.4 Zones, 1-km segments, and sites*

Three types of high-resolution units are defined based on existing data and preliminary discussion of spatial analysis approaches:

- Zones: Units spanning stretches of shoreline ranging from approximately 1 km to 10 km in shoreline length. Zones were originally defined in the context of aerial photography survey projects, including COSTR and AQRES (and referred to as 'map indexes'). 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 rapidly to encompass the depth range where kelp would occur. Zones have been used to analyze aerial photography in the

following sub-basins: north coast, south coast, Western Strait of Juan de Fuca, Eastern Strait of Juan de Fuca, and San Juan Islands.

- 1-km segments: DNR has delineated segments state-wide that each span 1 km of shoreline, measured at the -6 m bathymetry contour. Segments were defined by DNR throughout much of greater Puget Sound for the Submerged Vegetation Monitoring Program and then expanded statewide for the Marine Vegetation Atlas. In Central Puget Sound (CPS) and South Puget Sound (SPS), they were subsequently modified for floating kelp monitoring. 1-km segments have proven to be useful for summarizing kelp persistence and other environmental characteristics (see Berry et al., 2021), they have also been identified as useful analysis units in British Columbia (Costa 2021, personal communication). Additional work is needed in most regions to expand the depth range of the site polygons to encompass all 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 were created for specific small-scale research and or management activities. They generally span 1 km of shoreline or less and are surveyed by kayak, UAS (drone), and other high-resolution techniques.

In the 2021 field year implementation, two types of sampling locations are included in the data: zones and sites. Integration of existing data produced 171 sampling locations. Subsequent sections describe metrics and data collection procedures.

## 2.3 Floating kelp parameters and metrics

### *2.3.1 Overview*

For the purpose of this document, we define parameters as values that are measured and metrics as assessment variables derived from parameters. For example:

- Bed area – a parameter that measures the areal extent of a floating kelp bed (Figure 6).
- Long-term trends in bed area – a metric that assesses multiple annual measures of the bed area parameter.

Our long-term plan is to statistically evaluate multiple floating kelp parameters at multiple spatial scales, and to collaboratively link floating kelp data to other environmental datasets. Implementation of this long-term plan throughout Washington State with high spatial and temporal resolution will depend on program capacity. The current implementation defines two metrics at explicit spatial scales:

- Trends in bed area at sampling locations
- Sub-basin status

Data collection and processing methods vary with program (described below).

### *2.3.2 Long-term plan for data collection techniques, parameters, and metrics*

Floating kelp species are distinct from other kelp species because they have buoyant bulbs and blades that float on the water surface. Because floating kelp is 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.

Remote sensing is an established tool for surveying and monitoring floating kelp 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 floating kelp, 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 floating kelp 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 uncrewed aerial systems (UAS; also called drones) (Fig. 5). 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, UAS provide a promising new platform for collecting high resolution imagery in Puget Sound, with the ability to capture approximately 1 km of shoreline per low tide sampling event (Berry and Cowdrey, 2021).

At the local scale, small boats and other water-based techniques can be highly effective at capturing detailed observations. Boat-based and UAS techniques have been employed successfully at sites in greater Puget Sound. 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 floating kelp in the near term.

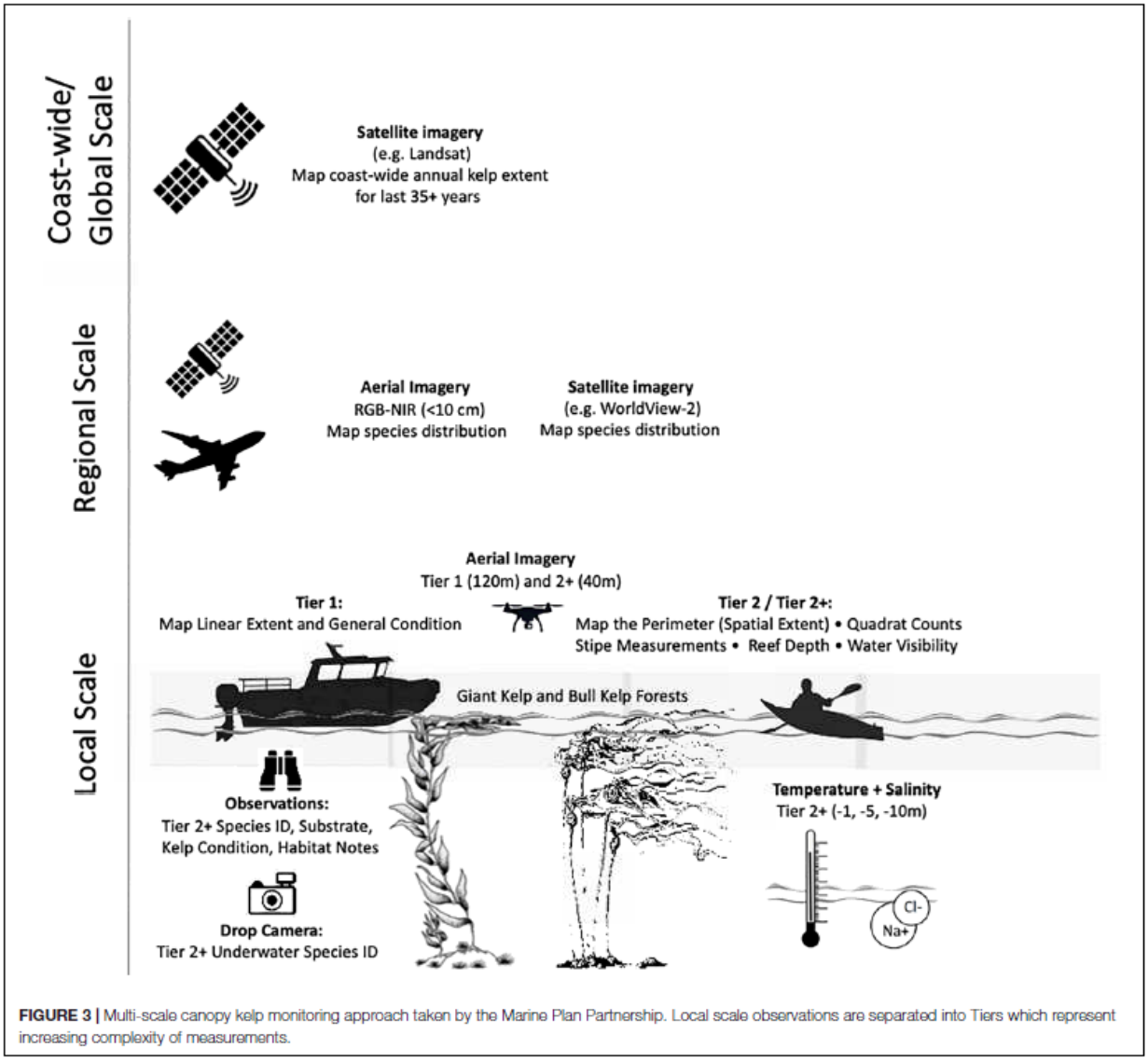


**FIGURE 3 |** Multi-scale canopy kelp monitoring approach taken by the Marine Plan Partnership. Local scale observations are separated into Tiers which represent increasing complexity of measurements.

*Figure 5. Multi-scale canopy monitoring approach from the Marine Plan Partnership (MaPP) in British Columbia (from Cavanaugh et al., 2021).*

Floating kelp extent is described with a variety of parameters and metrics, some of which are closely linked to particular data collection techniques. The most common parameters describing extent are (Figure 6):

- Bed – the spatial extent of nearby canopies, aggregated to include small gaps between floating kelp individuals. Minimum thresholds for defining a bed vary among datasets. Additionally, rules vary for inclusion of other features within the bed (i.e., rocks and other non-kelp features) and for perimeter location (i.e., whether a buffer is applied around the canopy).
- Canopy – the spatial extent of giant kelp or bull kelp stipes, bulbs, and blades that are floating on the water surface. Datasets vary in resolution and in the degree to which they include kelp tissue floating on the water surface or just below the surface.

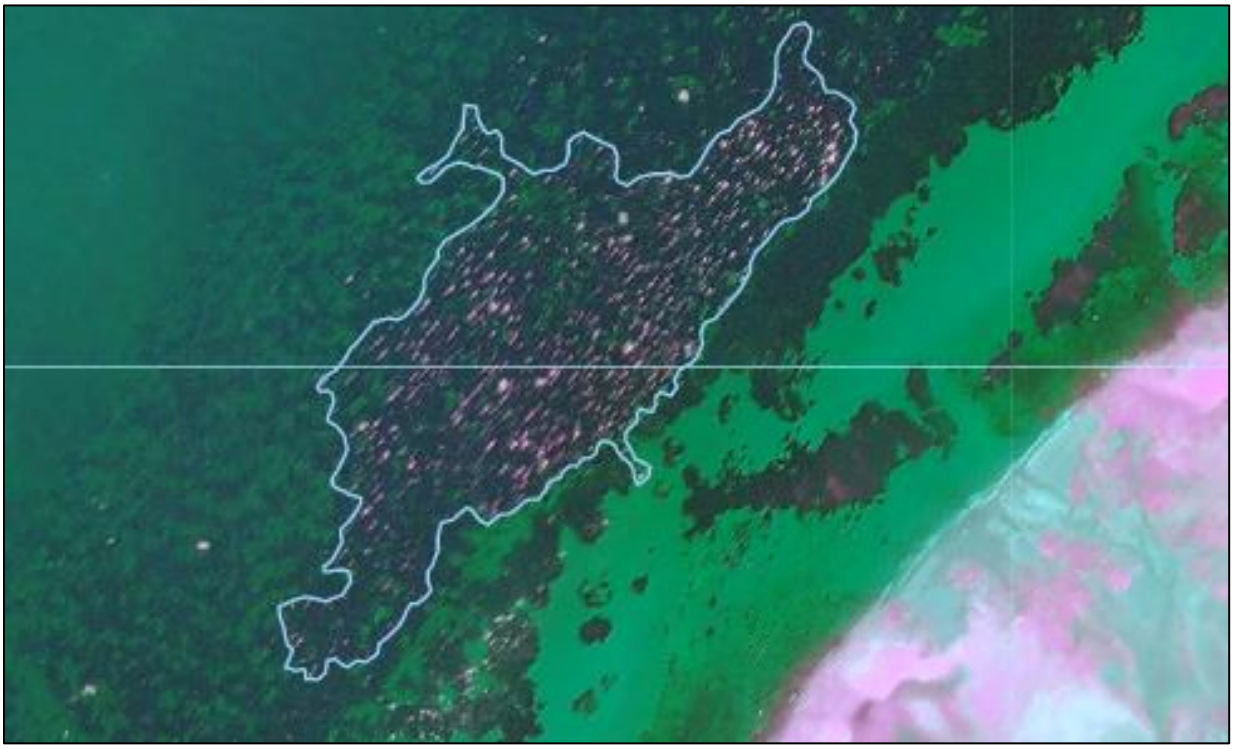

*Figure 6. Example of floating kelp metrics, illustrated in aerial imagery. Bed area (the blue perimeter polygon) includes the total extent of floating kelp and gaps between individuals. Canopy area (the red features within the polygon in the near infrared imagery are the floating surface canopy), excludes gaps between individuals. The floating kelp monitoring program also tracks canopy area at many locations, and considers this metric (where available) during long-term trend assessment.*

Bed area serves at the primary parameter for the statewide indicator because it has the most available data. Canopy area is a secondary parameter used at many locations.

Bed and canopy area metrics can be aggregated and evaluated in different ways:

- Area estimates can be assessed within each sampling location, then groups of locations can be compared as frequency counts or proportions of sites over a larger spatial area. For example, the proportion of locations with long-term declines in bed area can be compared to the proportion with no trends or increases.
- Where comprehensive data exists, area estimates can be summed over larger geographical scales. Examples include total bed area or total canopy area, reported for an entire reach or sub-basin (if sufficient data exist).

Other commonly used parameters (generally assessed at the sampling location scale) include

- Density,
- Percent cover,
- Biomass,
- Minimum and maximum depth (or depth range),
- Morphometrics, and
- Assessments of condition.

### *2.3.3 Current implementation: two metrics*

#### *2.3.3.1 Trends in bed area at sampling locations*

Trend in bed area is the primary metric tracked at sampling locations. Bed area describes the spatial extent of floating kelp visible on the surface, including small gaps between adjacent floating kelp individuals. Delineation rules and minimum thresholds for defining a bed vary among datasets (see next section).

Statistical trends tests are used to identify patterns of change in bed area over time, and statistical test results drive classification into one of seven categories (Table 4). Trends are assessed over two time periods: the last 5 years (recent) or over the entire data record (Table 5). Because floating kelp is known to experiences high natural year-to-year variability and to be sensitive to changes in environmental conditions. Assessing trends at multiple time scales is useful for understanding dynamics. Summary PS Info indicator results rely on the long-term trend result. However, it is important to note that many sites have extremely limited temporal records, which limit their interpretive power.

*Table 4: Floating kelp bed area trend categories.*

| Trend category | Definition |
|---|---|
| Increasing | positive (statistically significant, $p < 0.05$) change in area over time |
| No trend | no statistically significant ($p > 0.05$) change in area over time |
| Decreasing | negative (statistically significant, $p < 0.05$) change in area over time |
| Total loss | floating kelp was present in the data record but absent in the most recent year |
| Limited data | quantitative data is available but is not sufficient to perform regression or assess long-term changes using alternative methods. |
| No floating kelp | all surveys show absence of floating kelp |
| No data | no surveys available |

*Table 5: Definition of time spans considered in the Floating Kelp Monitoring Program.*

| Time span | Definition |
|---|---|
| Recent | The most recent 5-year period.<br>Recent trends address responses to management actions and ongoing observations but they are often driven by weather and climate conditions. |
| Long-term | The time span of the existing record varies by sub-basin and dataset. The initial PS Info and Statewide Summary presents results for all available time spans and then documents the final result. |

Trends in bed area are assessed at all locations using simple linear regression. Provisional trend categories are assigned automatically following Table 4. Criteria for regression analysis:

- Data must measure bed area, summarized annually at the zone or site scale.
- To be eligible for long-term trend testing, data must include at least 5 years of floating kelp bed area (either 5 continuous years or a dataset that spans 5 years).
- To be eligible for short-term trend testing, data must include floating kelp bed observations from at least 3 of the past 5 years.

If data meet these criteria, the below regression analysis is performed.

Equation 1: $$kelp\ area = \alpha + \beta\ year + \beta\ location + \beta\ (year * location) + \varepsilon$$

Where *kelp area* is the bed area, *year* is the calendar year in which the kelp area was surveyed, and *location* is a categorical variable of the zone or site in which the kelp area is summarized.

Below is an example of how equation 1 is parameterized in the R programming language.

```
lm(kelp.area ~ year * location, data = kelp.data)
```

Regression output including coefficient estimates, error, and p-values for each zone or site are extracted using the 'emtrends' function in the 'emmeans' package in R (Lenth 2022).

Experts review the provisional trend assignment ("auto_trend") and either confirm or override it based on considering the potential effect of statistical artifacts which may skew analysis and other datasets which may further inform the bed area trend result. For example, an expert may override the automatic assignment if the data violate statistical assumptions, or if the result fails to consider known kelp dynamics at particular locations or the time period of analysis. Datasets that do not meet assumptions for quantitative analysis are used to qualitatively inform and reinforce quantitative data in reports.

Where canopy area data exists, similar regression analyses are conducted and the canopy results are compared to the bed result during data review.

#### *2.3.3.2 Sub-basin status*

The purpose of the status assessment is to integrate all available data and ways of knowing into a single, summary classification of floating kelp abundance and distribution relative to an expected baseline. Ideally, the baseline would represent a recovery target or historical distribution. Because these baselines are not known, the status categories describe overall understanding of changes in floating kelp (examples include stable, concern, declines, no floating kelp) with consideration of data completeness (limited or insufficient data). Status classification categories will be updated as more data are integrated into the Program. There are five classification categories (Table 6).

*Table 6: Floating kelp status classifications and definitions.*

| Status classification | Definition |
|---|---|
| Stable | no long-term change in extent over time |
| Concern of losses but limited data | data sources suggest losses but quantitative data lack sufficient spatial or temporal detail (low signal-to-noise ratio) |
| Substantial documented declines | data sources demonstrate major losses (high signal-to-noise ratio) |
| Insufficient information | data sources do not provide sufficient spatial or temporal certainty to classify the sub-basin as stable, concern or declines |
| No floating kelp | all data sources show floating kelp has been absent historically and is currently absent |

Sub-basin floating kelp status is built from a synthesis of (1) counts of trend results at all sampling locations within the sub-basin and (2) other information in a given sub-basin. First, counts of trend categories from all available locations are summed and converted to a proportion. This proportional breakdown sets the context to interpret any other floating kelp information available in the sub-basin. In the best-case scenario, clear trends in kelp area for a given time span will be evident from visual (plots) and regression analysis for all datasets in a sub-basin. However, given the paucity of existing datasets, the diversity of datasets included in the Program development 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. Therefore, we outline guidelines for synthesizing patterns, results, and information from these potential sources below, with specific 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. We aim to include as much information as possible (Section 3). Therefore, to not exclude data, we employ the following considerations in making final kelp status and trend designations at all time spans. 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 do 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?

The Program defines status in all 11 sub-basins, however, data richness varies greatly among sub-basins. Sub-basins range from having multi-decadal comprehensive surveys with multiple other data sources to sub-basins with data from only a few locations. Due to the uneven nature of available data, status classifications should be interpreted in the context of the amount and type of available data in each sub-basin. Since trends can be assessed on canopy or bed extent and at recent or entire data record, some locations have multiple trend results to consider.

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. Sub-basin summaries provide highlights of the data sets assessed for each sub-basin.

### *2.3.4 Current implementation: data collection methods*

The following data collection methods are considered for inclusion:

- Airborne imagery collected from a fixed-wing aircraft, UAS, or satellite. 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 (red-green-blue-near infrared) sensors or multispectral sensors preferred.
        - Digital georeferenced imagery.
- Water-based surveys from small boats, such as kayaks or skiffs. Spatial extent of kelp beds are 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 that document the occurrence of floating canopy kelps.

Quantitative data in five distinct datasets represent three different organizations. Data have a range of types and spatial and temporal coverage (Table 7). These data are synthesized into a single dataset (described in a subsequent section). The floating kelp monitoring program synthesizes existing datasets. Therefore, methods for data collection and processing are

defined independently for each dataset. Individual dataset descriptions summarize each of the methodologies (accessible in Table 7), as well as procedures and considerations for integrating each dataset into the Program.

*Table 7: Summary of quantitative data currently implemented in the Floating Kelp Monitoring Program. (Click on the link in the dataset name to access detailed descriptions of data collection, processing and integration methods).*

| Dataset | Owner/ Originator | Years | Frequency | Methods | Coverage |
|---|---|---|---|---|---|
| Long-term monitoring of the Coast & Strait of Juan de Fuca 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 | 18 sites |
| Kayak Monitoring by DNR in Central and South Puget Sound (DNR-kayak) | Washington Department of Natural Resources | 2013, 2014, 2016-2021 | Annual depending on location | kayak bed perimeter | 13 sites |

Other datasets could potentially be included in future versions of the Program. Two candidate datasets include shoreline surveys completed by DNR in South and Central Puget Sound (Table 8). These datasets were instrumental in the sub-basin status assessments in CPS and SPS because they capture extensive, multi-decadal losses. They are referenced in the sub-basin reports but they are not integrated into the current Program dataset.

*Table 8: Summary of quantitative data currently under consideration for integration into the Floating Kelp Monitoring Program.*

| Dataset | Owner/ Originator | Years | Frequency | Methods | Coverage |
|---|---|---|---|---|---|
| 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 |
| Samish Kelp Canopy Kayak Surveys in Traditional Territory (Samish) | Samish Indian Nation | 2018, 2019, 2021, 2022 | annual | kayak bed perimeter | two 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 |
| Volunteer Kayak Monitoring by Marine Resources Committees (MRC-kayak) | Northwest Straits Commission | 2016-2022 | annual depending on location | kayak bed perimeter | 3 sites |

# 3 Supporting datasets

A series of datasets from other sources are being used in concert with the geodatabase in order to characterize the spatial extent and nature of nearshore areas. These include:

Linear extent of shallow sub-tidal shoreline is characterized along the -6.1 m isobath (-20 ft), relative to Mean Lower Low Water (MLLW). While the maximum depth of floating kelp beds varies with location, this depth provides a general reference for deriving broad-scale estimates of habitat extent. The -6.1 m isobath was derived from the gridded bathymetric data produced by the Washington Department of Fish and Wildlife (Nysewander et al. 2005).

Linear extent of upper intertidal shoreline is characterized along approximate Ordinary High Water. This line is represented by a spatial data layer maintained by DNR in a GIS and derived from 1:12,000 orthorectified aerial photographs. Inclusion of this line allows for comparison to the Washington State ShoreZone Inventory (Berry et al. 2001), the most complete inventory of state-wide saltwater shoreline habitats.

Areal extent of nearshore habitat is estimated using the USGS CoNED Topobathymetric Models of Puget Sound (OCM Partners, 2022b) and the Strait of Juan de Fuca (OCM Partners, 2022a), the NCEI CUDEM 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles (Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado, Boulder. 2014), and the NCEI Coastal Relief Model (CRM) (National Geophysical Data Center, 2003). CoNED topobathymetric tiles were bulk downloaded in GeoTIFF format using the program uGet (uGet Download Manager, https://ugetdm.com/) and transformed from NAVD88 to MLLW using NOAA's vertical datum transformation tool (VDatum 4.4, https://vdatum.noaa.gov/). CUDEM bathymetric tiles were downloaded in GeoTIFF format in MLLW from the NOAA Digital Coast: Data Access Viewer (NOAA Digital Coast: DAV, https://coast.noaa.gov/dataviewer/#/). CRM Volume 8, Northwest Pacific was downloaded from the NCEI website in NetCDF format and converted to GeoTIFF format in ArcGIS Pro (ArcGIS Pro 3.0.2, ESRI). Finally, all datasets were projected on to NAD 1983 HARN StatePlane Washington South FIPS 4602 prior to area analyses. The four topobathymetric datasets were prioritized by resolution, such that CRM was used for the south open coast, CUDEM for the north open coast, and CoNED used for all others. For the purposes of this project nearshore floating kelp habitat was defined as being between -15 meters and -1 meter MLLW, irrespective of other geologic or oceanographic features such as substrate type, wave exposure, aspect, etc. Future refinements of these estimates will aim to take more of those nearshore features into account. Given these bathymetric contour bounds, nearshore floating kelp habitat area was calculated for each sub-basin in two meter bins (i.e., -15 m to -13 m, -13 m to -11 m, … , -3 m to -1 m) using the *Zonal Histogram* tool in ArcGIS Pro and tabulated to calculate percent of area sampled by current kelp monitoring efforts.

Bathymetric data sources:

CoNED Topobathymetric Model of Puget Sound, Washington, 1887 to 2017
https://www.fisheries.noaa.gov/inport/item/59971
Bulk download url:
https://coast.noaa.gov/htdata/raster2/elevation/Puget_Sound_CoNED_DEM_2020_9112/

2021 USGS CoNED Topobathymetric Model (1891 - 2016): Strait of Juan de Fuca
https://www.fisheries.noaa.gov/inport/item/65169
Bulk download url:
https://coast.noaa.gov/htdata/raster5/elevation/CoNED_Juan_de_Fuca_DEM_2021_9347/

NCEI Coastal Relief Model
https://www.ncei.noaa.gov/products/coastal-relief-model

NCEI Continuously Updated Digital Elevation Model (CUDEM) - 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles
https://www.ncei.noaa.gov/metadata/geoportal/rest/metadata/item/gov.noaa.ngdc.mgg.dem:999919/html

VDatum full package (vdatum_all_20220315.zip):
https://vdatum.noaa.gov/download.php

# 4 Program dataset description

## 4.1 Data ownership and management

A goal of the Floating Kelp Monitoring Program is to increase access to information on floating kelps in Washington State. This goal is balanced with the respect for individual organizations to retain the rights to their data and how it is disseminated. Therefore, the Program is envisioned as a data node that synthesizes distinct data sources and provides links/contacts for access to the original data sources.

Floating kelp monitoring program data are drawn from multiple organizations. The organizations that collect and curate these data sets retain the rights to these data and serve as the long-term stewards. The program uses these data with permission through cooperation and collaboration with organizational partners. As a part of the Program communication products, the project has produced dataset descriptions which summarize each dataset, along with additional processing or interpretation related to inclusion in the Program. The dataset descriptions also link to detailed metadata and other documentation that is provided by the data owner.

## 4.2 Inclusion of new datasets in the Indicator

The Project Team has been approached by many parties interested in contributing to the Program. Our long-term goal is to be as inclusive as possible with the datasets that are included in the Indicator. Every case is unique, but in an effort to clarify how new data could be incorporated into the Indicator, please see the following guidelines. The criteria for including a new dataset in the indicator include:

- The data originator/steward/analyst must discuss the dataset, as well as inclusion requirements, with the Indicator Lead and/or a member of the Project Team.
- The dataset must be cleaned up and quality checked (i.e., ready for use in the Indicator without additional processing).
- The dataset must have been collected with consistent methods that follow fieldwork standards (e.g., tidal height, current, ocean conditions). Contact the Indicator Lead or a member of the Project Team to discuss how these standards apply to your data collection/synthesis.
- Before inclusion of a dataset, a complete metadata document must be prepared, including field methods, quality assurance standards, and data processing steps.

## 4.3 Geospatial database

Data synthesized in the Floating Kelp Monitoring Program is housed in an ArcGIS version 10 file geodatabase. It includes spatial and tabular data elements (Table 9) that are populated from the datasets listed in Table 7. Spatial data are in State Plan projection, Washington South zone, with a NAD83 HARN datum in US Survey feet.

*Table 9: Data elements in the Floating Kelp Monitoring Program.*

| Data element name | Type | Description |
|---|---|---|
| polys_all_units | Polygon feature class | Polygon features that describe the spatial boundaries of all locations (site and zone unit types). |
| pts_all_units | Point feature class | Point features for all locations (site and zone unit types) reported in the Program. |
| bed_recent_extent | Polygon feature class | Polygon features that encompass floating kelp bed area for the most recent year. |
| bed_max_extent | Polygon feature class | Polygon features that encompass cumulative floating kelp bed area from all monitoring years. |
| study_area | Polygon feature class | A polygon feature that encompasses the study area, used for visualization purposes. |
| sub_basins | Polygon feature class | Polygon features that describe the extent of 11 sub-basins within the study area. |
| sites_zones_results | non-spatial table | Table with attributes for all locations (site and zone unit types). |
| sub_basin_results | non-spatial table | Table with attributes for all sub-basins. |

Two tabular files contain the fields used in Program data analysis. At the scale of locations, the sites_zones_results.csv includes all identifying information as well as results (Table 10). At the scale of sub-basins, the sub_basin_results table includes all identifying information as well as results (Table 11).

*Table 10. Attributes of the sites_zones_results table.*

| Attribute | Data type | Description |
|---|---|---|
| unit_id | Text | Unique alphanumeric code identifying each location (site or zone), generated in the source dataset and maintained unchanged. |
| location | Text | Geographic name description. |
| unit_type | Text | Code for sampling location. Domain:<br>zone<br>site |
| mgmt_unit | Text | Optional field to note management affiliation |
| sub_basin | Text | Code for the sub-basin that the location is within. Domain:<br>ADM – Admiralty Inlet<br>EST – Eastern Strait of Juan de Fuca<br>SJI – San Juan Islands<br>SCO – Southern Open Coast<br>NCO – Northern Open Coast<br>NPS – North Puget Sound<br>SPS – South Puget Sound<br>CPS – Central Puget Sound<br>WST – Western Strait of Juan de Fuca<br>SWH – Saratoga and Whidbey |
| first_yr | Integer | First year of monitoring |
| last_yr | Integer | Most recent year of monitoring |
| nyears | Integer | Number of years with survey data |
| species | Text | Description of floating kelp species. Domain:<br>nereo – *Nereocystis luetkeana*<br>macro – *Macrocystis pyrifera*<br>nereo_macro – *Nereocystis luetkeana* & *Macrocystis pyrifera*<br>no_fk – no floating kelp |
| last_kelp_yr | Integer | The last year the floating kelp was observed. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| dataset | Text | The source dataset. Domain:<br>AQRES<br>COSTR<br>DNRkayak<br>MRC<br>Samish aerial |

| Attribute | Data type | Description |
|---|---|---|
| source_org | Text | The name of the organization the produced the data. Domain:<br>DNR Nearshore Habitat Program<br>NWStraits & Island MRC<br>NWStraits & Whatcom MRC<br>NWStraits & Clallam MRC<br>NWStraits & Snohomish MRC<br>NWStraits & Jefferson MRC<br>NWStraits & Skagit MRC<br>Samish Indian Nation |
| source_url | Text | url for source organization |
| data_desc_url | Text | url for data description |
| unit_area_ha | Double | The area of each location, extracted from the polys_all_units feature class and converted to hectares. |
| unit_area_min1min15_ha | Double | The area within the location (site or zone) between -15 m and -1 m (MLLW), extracted from CoNED or other bathymetry dataset. |
| depth_max_m | Double | The maximum depth at the site, currently populated with dummy values (-99) |
| year_trend_bed_long | Double | Annual rate of change in bed area over entire data record, estimated by regression. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| year_trend_bed_recent | Double | Annual change in bed area over most recent 5 years, estimated by regression. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| year_trend_canopy_long | Double | Annual rate of change in bed area over entire data record, estimated by regression. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| year_trend_canopy_recent | Double | Annual change in canopy area over most recent 5 years, estimated by regression. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |

| Attribute | Data type | Description |
|---|---|---|
| SE_bed_long | Double | Standard error from regression test for bed area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| SE_bed_recent | Double | Standard error from regression test for bed area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| SE_canopy_long | Double | Standard error from regression test for canopy area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| SE_canopy_recent | Double | Standard error from regression test for canopy area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| df_bed_long | Double | Degrees of freedom from regression test for bed area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| df_bed_recent | Double | Degrees of freedom from regression test for bed area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| df_canopy_long | Double | Degrees of freedom from regression test for canopy area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |

| Attribute | Data type | Description |
|---|---|---|
| df_canopy_recent | Double | Degrees of freedom from regression test for canopy area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| t_ratio_bed_long | Double | T-ratio from regression test for bed area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| t_ratio_bed_recent | Double | T-ratio from regression test for bed area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| t_ratio_canopy_long | Double | T-ratio from regression test for canopy area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| t_ratio_canopy_recent | Double | T-ratio from regression test for canopy area over last 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| p_value_bed_long | Double | P-value from regression test for bed area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| p_value_bed_recent | Double | P-value from regression test for bed area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |

| Attribute | Data type | Description |
|---|---|---|
| p_value_canopy_long | Double | P-value from regression test for canopy area over entire data record. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| p_value_canopy_recent | Double | P-value from regression test for canopy area over most recent 5 years. NA indicates that trend calculation was not possible (i.e., no floating kelp has been observed during the entire monitoring period or too few years of kelp data were available). |
| max_kelp_bed_long | Double | Maximum bed area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| max_kelp_bed_recent | Double | Maximum bed area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| max_kelp_canopy_long | Double | Maximum canopy area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| max_kelp_canopy_recent | Double | Maximum canopy area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| mean_kelp_bed_long | Double | Mean bed area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| mean_kelp_bed_recent | Double | Mean bed area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| mean_kelp_canopy_long | Double | Mean canopy area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| mean_kelp_canopy_recent | Double | Mean canopy area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| sd_kelp_bed_long | Double | Standard deviation in bed area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| sd_kelp_bed_recent | Double | Standard deviation in bed area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |

| Attribute | Data type | Description |
|---|---|---|
| sd_kelp_canopy_long | Double | Standard deviation in canopy area over entire data record. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| sd_kelp_canopy_recent | Double | Standard deviation in canopy area over most recent 5 years. NA indicates that no floating kelp has been observed during the entire monitoring period. |
| auto_trend_bed_long | Double | Text category stating regression result for bed area over entire data record. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data; <5 years of data)<br>no_fk (No Floating Kelp) |
| auto_trend_bed_recent | Double | Text category stating regression result for bed area over most recent 5 years. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data; <3 years of data)<br>no_fk (No Floating Kelp) |
| auto_trend_canopy_long | Double | Text category stating regression result for canopy area over entire data record. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data; <5 years of data)<br>no_data (No canopy data available for this unit)<br>no_fk (No Floating Kelp) |
| auto_trend_canopy_recent | Double | Text category stating regression result for canopy area over most recent 5 years. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data)<br>no_data (No canopy data available for this unit)<br>no_fk (No Floating Kelp) |

| Attribute | Data type | Description |
|---|---|---|
| final_trend_bed_long | Double | Text category stating final regression result after expert review for bed area over entire data record. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data)<br>no_fk (No Floating Kelp) |
| final_trend_bed_recent | Double | Text category stating final regression result after expert review for bed area over most recent 5 years. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>limited_data (Limited Data)<br>no_fk (No Floating Kelp) |
| final_trend_canopy_long | Double | Text category stating final regression result after expert review for canopy area over entire data record. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>no_data (No canopy data available for this unit)<br>no_fk (No Floating Kelp) |
| final_trend_canopy_recent | Double | Text category stating final regression result after expert review for canopy area over most recent 5 years. Domain:<br>inc (Increasing)<br>no_trend (No Trend)<br>dec (Declining)<br>total_loss (Total Loss)<br>no_data (No canopy data available for this unit)<br>no_fk (No Floating Kelp) |
| final_trend_notes_bed_long | Text | Notes related to bed area trend determination over entire data record. |
| final_trend_notes_bed_recent | Text | Notes related to bed area trend determination over most recent 5 years. |
| final_trend_notes_canopy_long | Text | Notes related to canopy area trend determination over entire data record. |
| final_trend_notes_canopy_recent | Text | Notes related to canopy area trend determination over most recent 5 years. |
| figure_name_sm | Text | Name of popup figure |

| Attribute | Data type | Description |
|---|---|---|
| figure_name_lg | Text | Name of clickthrough figure |
| figure_url_sm | Text | URL for popup figure |
| figure_url_lg | Text | URL for clickthrough figure |
| trend_version | Alphanumeric | Date of most recent expert review of trends, in numeric text Format: YYYY_MM_DD |

*Table 11. Attributes of the sub_basin_results table.*

| Attribute | Data type | Description |
|---|---|---|
| sub_basin_code | Text | Unique alphanumeric code identifying the sub-basin. |
| sub_basin_name | Text | Unique geographic name identifying the sub-basin. |
| status | Text | Classification of sub-basin status. Domain:<br>insufficient_data<br>declines<br>stable<br>no_floating_kelp<br>concern |
| tot_units_samp | Integer | Total number of locations (zones or units) sampled within sub-basin. |
| lt_totloss | Integer | Total number of locations (zones or units) with total loss of floating kelp bed area over entire data record. |
| lt_inc | Integer | Total number of locations (zones or units) with increasing floating kelp bed area over entire data record. |
| lt_dec | Integer | Total number of locations (zones or units) with declining floating kelp bed area over entire data record. |
| lt_nofk | Integer | Total number of locations (zones or units) with no floating kelp bed area over entire data record. |
| lt_lim | Integer | Total number of locations (zones or units) with limited floating kelp bed area data over entire data record. |
| lt_notrend | Integer | Total number of locations (zones or units) with no trend in floating kelp bed area over entire data record. |
| rec_totloss | Integer | Total number of locations (zones or units) with total loss of floating kelp bed area over entire data record. |

| Attribute | Data type | Description |
|---|---|---|
| rec_inc | Integer | Total number of locations (zones or units) with increasing floating kelp bed area over entire data record. |
| rec_dec | Integer | Total number of locations (zones or units) with declining floating kelp bed area over entire data record. |
| rec_nofk | Integer | Total number of locations (zones or units) with no floating kelp bed area over entire data record. |
| rec_lim | Integer | Total number of locations (zones or units) with limited floating kelp bed area data over entire data record. |
| rec_notrend | Integer | Total number of locations (zones or units) with no trend in floating kelp bed area over entire data record. |
| fk_ha_prop | Integer | Estimated proportion of the total statewide floating kelp bed extent that is contained within the sub-basin. Based on extrapolation of existing survey data and expert knowledge. |
| nsh_min6_km | Double | Linear extent of shallow subtidal habitat within the sub-basin, estimated along the -6 m (MLLW) bathymetry contour, using data from Nysewander. Measured in kilometers. |
| shore_mhw_km | Double | Linear extent of upper intertidal habitat within the sub-basin, estimated along Ordinary High Water line using data from the Washington State ShoreZone Inventory. Measured in kilometers. |
| sub_poly_ha | Double | Areal extent of each sub-basin, including terrestrial and aquatic areas, measured in hectares. |
| sub_min151_ha | Double | Areal extent of nearshore habitat within each sub-basin, defined along the bathymetric contour of -15 m to -1 m (MLLW), measured in hectares. Bathymetric data sources: CoNED for most areas, CUDEM for the north coast sub-basin (NCO), CRM for the south coast sub-basin (SCO). Last updated based on bathymetric data compiled on 2022_11_23. |
| loc_poly_ha | Double | Areal extent of each location (site or zone) that is included in the monitoring program. Areas are not strictly comparable because delineation rules vary among datasets. See loc_min151_ha field for more comparable areal estimates. |

| Attribute | Data type | Description |
|---|---|---|
| loc_min151_ha | Double | Total areal extent of all locations (sites and zones) sampled, limited to depths between -15 m and –1 m (MLLW), measured in hectares. Bathymetric data sources: CoNED for most areas, CUDEM for the north coast sub-basin (NCO), CRM for the south coast sub-basin (SCO). Last updated based on bathymetric data compiled on 2022_11_23. |
| url_sm | Text | URL for small image in webmap popup. |
| url_lg | Text | URL for large sub-basin image, accessed in webmap via the popup. |
| url_report | Text | URL for the sub-basin report. |

# 5 Program products

## 5.1 Statewide Indicator

### *5.1.1 Statewide Summary Report*

A statewide summary report provides a high-level look at the floating kelp monitoring program methods and findings in a narrative format. Annual versions of this report will be maintained to provide an ongoing record of results at distinct time periods. The Statewide Summary Report for each year will be published by the end of the next calendar year (e.g., the summary including data through 2022 will be published in December 2023). In contrast, the majority of the other products will be updated as needed with new data and interpretations (described below).

### *5.1.2 Puget Sound Info*

Puget Sound Info (PS Info) is the Partnership's online platform for monitoring ecosystem health, including progress on the Vital Signs and Action Agenda implementation tracking. PS Info reports summary information for all indicators in the Vital Signs portfolio. The PS Info site is built from a template form.

## 5.2 Interactive Map

An interactive browser-based map presents the Statewide Indicator key results including trends at sites and zones, and sub-basin status. For each site and zone (Figure 7 points), clickable point features link to plots of kelp data, summary statistics, and links to further documentation. For each sub-basin, clickable polygon features link to a narrative explanation of sub-basin classification, summary statistics; including number of sampling locations, total nearshore area, and the number of locations in each trend category, and links to other documentation.

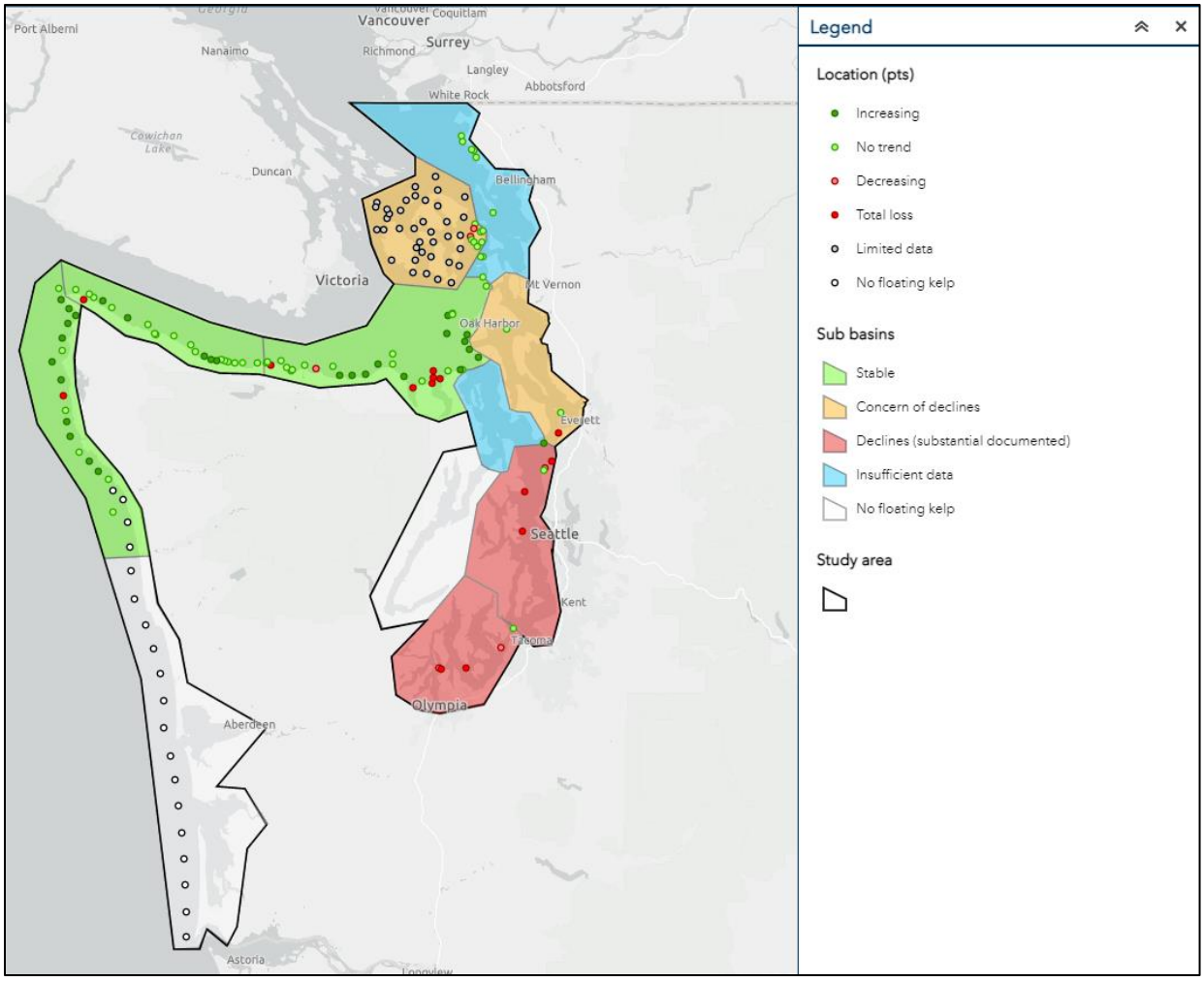


*Figure 7: Static image of interactive webmap. Features in the map link to detailed documentation, plots, and project partners.*

## 5.3 Sub-basin reports and summaries

We anticipate that additional information will be provided at the sub-basin scale. The Project Team is considering a series of potential products and assessing which options are most beneficial and also feasible from a staff capacity perspective. Sub-basin summaries are currently implemented, and we provide two additional potential approaches:

- Sub-basin summaries – single page summaries that are included in the statewide summary report and the interactive map. (This option has been implemented for all sub-basins.)
- In-depth sub-basin reports – in-depth reports could provide extensive information on the monitoring location results and other types of information. These reports could

expand on the general procedures as they pertain to the specific sub-basin. They could also serve as a repository for plots and tables of floating kelp bed area, and describe the rationale for trend designation in detail. These reports could be updated when new data for a sub-basin becomes available, or on a priority basis. One example of a sub-basin report has been completed (San Juan Islands Sub-basin Report). (Sub-basin reports are not currently implemented. Future implementation possibility and scope would be dependent on resource availability and staff time.)

- Individual summaries of additional datasets – individual dataset descriptions could be completed by organizations that produce information or by the Project Team. This approach would allow organizations to submit their datasets for inclusion. (Not implemented in current protocol).

## 5.4 Dataset descriptions

Each dataset that is used in the Floating Kelp Monitoring Program is documented in a short 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 Program and specific data products, 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. Draft dataset descriptions:

- Long-term monitoring of the Coast, Strait using Aerial Photography (COSTR)
- Long-term monitoring of the Aquatic Reserves using Aerial Photography (AQRES)
- Samish Kelp Canopy Surveys in Traditional Territory (Samish)
- Volunteer Kayak Monitoring by Marine Resources Committees (MRC-kayak)
- Kayak Monitoring by DNR in Central and South Puget Sound (DNR-kayak)

## 5.5 Monitoring Program Design and Data Assessment Protocols

This document serves as the technical documentation of the strategic framework, definition, and methods for producing the Floating Kelp Monitoring Program and its products.

## 5.6 Web site

The project website hosts Program products. It will be further developed after initial Program development is completed in June 2023.

# 6 Priorities for program enhancement

As discussed in the strategic framework, the floating kelp monitoring program was developed rapidly using existing data to address fundamental information needs. The initial program and associated products (Section 5) begins to address information gaps, yet substantial development is needed to produce a robust dataset with reduced uncertainty. In this report, individual sections discuss the current implementation and the long-term plan. Here, we propose a short list of enhancement priorities.

## 6.1 Fill gaps in ongoing monitoring coverage by expanding existing programs and incorporating other external datasets.

The most basic need is to increase ongoing monitoring coverage, with an emphasis on sub-basins with limited data (Table 12 and sub-basin status assessment results). Preferred methods vary by area because the effectiveness of particular platforms depend on local geomorphology, oceanography, floating kelp canopy characteristics.

Sub-basins with data gaps where fixed-wing aerial imagery could prove to be effective at capturing larger beds include SJI (which lacks low-tide and slack current imagery), SWH (less than 5% monitored and concern of losses, NPS (less than 5% monitored) and ADM (less than 5% monitored). This platform can rapidly collect high-resolution data, and be deployed during short time windows when conditions are acceptable. However, narrow and low-density beds often challenge the detection limits fixed-wing imagery, as do floating kelp beds that abut seagrass meadows or other algal beds. Targeted studies are needed to further assess the utility of fixed-wing imagery.

Near term actions to address these limitations:

- Fixed-wing imagery collection by DNR during summer 2022 in areas throughout the state will help to further define costs and areas where this survey technique is appropriate. Analysis of this imagery is currently underway.
- Explore incorporating external datasets through additional partnerships. Funding will be needed to process these datasets and incorporate them into the Program dataset. Funding will also be needed for protocol development and training.

*Table 12***.** Number of sampling locations and percent of total nearshore habitat (between -15 m and -1 m, MLLW depth) monitored for floating kelp, summarized by sub-basin.

| Sub-basin | Number of locations monitored | Percent of nearshore extent monitored | Considerations |
|---|---|---|---|
| Admiralty Inlet (ADM) | 2 | <1% | Sampling locations span low percentage of sub-basin and limited time period. |
| Central Puget Sound (CPS) | 9 | 2% | Sampling locations span low percentage of sub-basin and limited time period. Comprehensive studies have identified floating kelp extent and long-term changes |
| Eastern Strait of Juan de Fuca (EST) | 37 | 80% | More than 30 years of annual data for majority of sub-basin. Historical study provides century-scale comparison. |
| Hood Canal (HDC) | 0 | 0% | No floating kelp observations known in the sub-basin (south of Lofall). |
| North Coast (NCO) | 20 | 100% | More than 30 years of annual data for majority of sub-basin. |
| North Puget Sound (NPS) | 8 | 3% | Sampling locations span extremely low percentage of sub-basin and extremely limited time period. |
| South Coast (SCO) | 17 | 75% | No floating kelp observed along the southern portion of open coast. Data absent in embayments, but generally not potential floating kelp habitat. |
| San Juan Islands (SJI) | 47 | 100% | Comprehensive monitoring using aerial photography. However, limited time span in most areas (< 3 years). Strong currents and narrow beds challenge aerial photography methods. |
| South Puget Sound (SPS) | 6 | <1 % | Sampling locations span low percentage of sub-basin and limited time period. Comprehensive studies have identified floating kelp extent and long-term changes. |
| Saratoga / Whidbey Basin (SWH) | 3 | 2% | Sampling locations span extremely low percentage of sub-basin and extremely limited time period. |
| Western Strait of Juan de Fuca (WST) | 23 | 100% | More than 30 years of annual data for majority of sub-basin. Historical study provides century-scale comparison. |

Higher-resolution UAS (drone) and boat survey techniques are needed to effectively detect floating kelp in areas with small, low density beds, strong currents, and other environmental challenges. These types of beds are found in all sub-basins, but are typical in CPS, SPS, SWH and NPS. Near-term actions to address these limitations include:

- Exploring expansion of existing UAS and boat surveys.
- Exploring partnerships and external datasets. If external datasets are identified, funding needs will also be identified to process these datasets and incorporate them into the Program dataset.

In areas where floating kelp is uncommon, targeted surveys are needed to identify potential floating kelp habitats for monitoring. Boat surveys identified shorelines with floating kelp in CPS and SPS. Boat surveys could be repeated over defined time periods to evaluate changes in overall distribution. In HDC, surveys are needed to confirm presence/absence. Surveys in SWH and NPS would enable the program to target areas for more detailed surveys.

Data gaps could be filled by increasing the number of external partners. More resources would be needed to expand the number of datasets integrated into the indicator. The Project Team proposes the following approach to integrating data:

- Indicator datasets - Datasets with 5 or more years of monitoring data that track bed area could be considered for inclusion. Each dataset must have a defined methodology and procedures for maintaining consistency in data collection and processing. Geospatial data describing sampling location boundary and bed extent for each monitoring event are required. Additionally, consultation with the Project Team on data structure, results, and interpretation are required. DNR, the Northwest Straits Commission, and the Samish Indian Nation have developed procedures for integration of diverse datasets (see dataset descriptions). These methods will be further developed to incorporate other external datasets (dependent on funds).
- Additional datasets – Information in other formats will be considered during data synthesis.

## 6.2 Implement methodological improvements and expand metrics

There is uncertainty in floating kelp bed area estimates in all methods. The magnitude of uncertainty is not well understood, but future efforts will focus on maximizing repeatability and quantifying uncertainty.

New survey methods are expected to become available with advances in technology. For example, while satellite imagery has been challenged to detect beds in many areas of Washington State, technology improvements show potential to augment or replace fixed-wing aerial imagery in the future (with lower costs).

In NCO, SCO, WST, EST, and portions of NPS and SJI, the longest monitoring datasets do not use the latest technology for surveying, with a key limitation being that the aerial imagery is not true-vertical or high resolution. This methodology could be advanced, but it is critical to maintain backward compatibility with the more than 30-year monitoring record. High-resolution photography was collected in these areas in 2022 and will be compared to results from long-standing methods.

Metrics beyond bed area can be tracked with many methods. Many sampling locations evaluate additional metrics. Targeted studies are needed to assess the usefulness of additional metrics to enhance our understanding of bed changes and kelp condition. This work can be completed through collaborations with other researchers, such as the BC-WA Kelp Node. We anticipate this work to be ongoing, and advance incrementally with new technologies and understanding.

It is clear that optimal methods vary among locations. In the long term, we envision that the monitoring program will incorporate a network of locations that are surveyed with methods that are optimized based on environmental and kelp forest conditions at each location (see Section 6.1 for examples).

## 6.3 Determine resources available for annual monitoring and identify core annual monitoring areas

If comprehensive monitoring is not feasible, a statistically valid sampling approach will be needed. There are two general options to reduce costs for floating kelp canopy monitoring, with associated tradeoffs (Figure 8). The first alternative (Alt A) would identify core areas for annual monitoring. The benefit of this approach is that those locations would have regular surveys, allowing for fine-scale detection of trends and change. The second alternative (Alt B) is to monitor all shorelines, 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. Given the high year-to-year variability in kelp, we prefer Alternative A. Alternative B can be preferred for organisms with lower year-to-year variability, an approach adopted for eelgrass in DNR's Submerged Vegetation Monitoring Program.

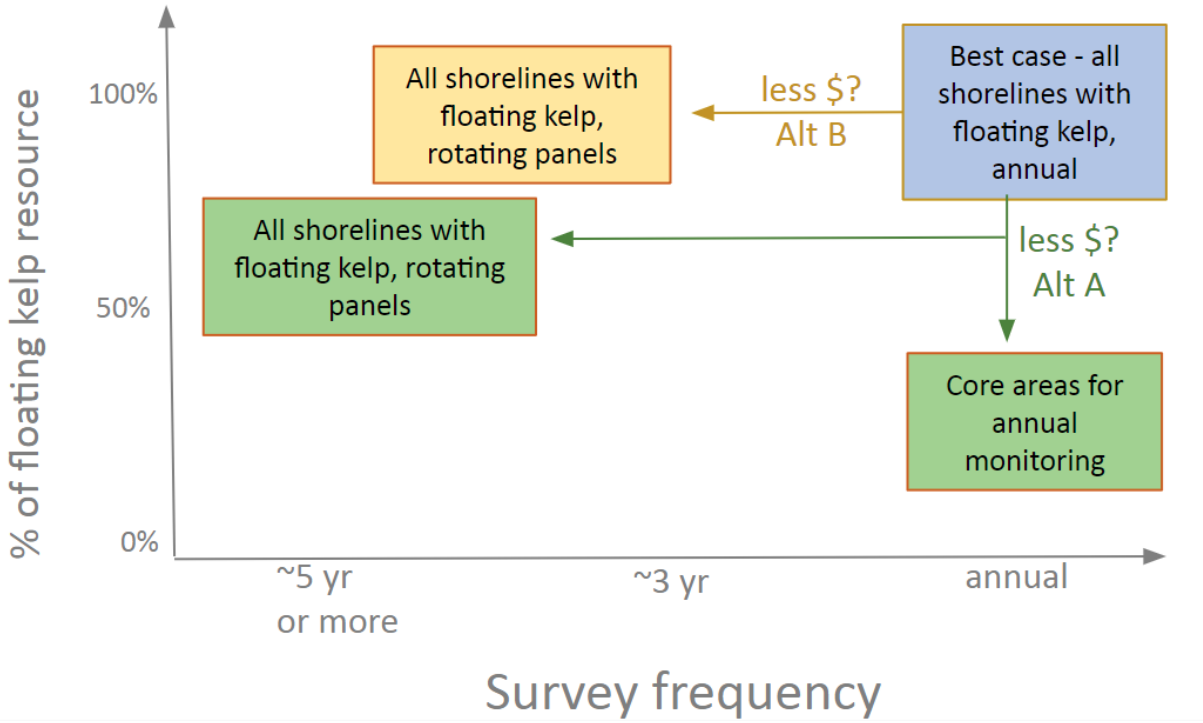


*Figure 8. Conceptual alternatives for survey frequency of floating kelp canopies in Washington State. At the top right corner (blue), all kelp in the state would be monitored annually (ideal from a data-collection perspective, but feasibility is dependent on funding). Moving down or to the left in the figure, operating cost decreases, with associated tradeoffs in the frequency and extent of monitoring.*

## 6.4 Integrate historical datasets to increase the time span of the monitoring record.

The time span of the monitoring record could be extended into the past by analyzing and integrating existing imagery and other information sources. The Project Team has begun to identify potential data sources and would welcome external input and involvement.

## 6.5 Partner with Tribes to expand information sources based on Indigenous Scientific Knowledge.

Indigenous Scientific Knowledge provides an important perspective and a deep source of information on floating kelp resources. This could include continuing current partnerships, developing partnerships with additional Tribes, and collaboration with the Northwest Indian College and other groups.

## 6.6 Incorporate community science datasets and other sources of local knowledge

Local knowledge of the nearshore environment is rich, and could be further gathered and synthesized by partner organizations. Potential opportunities include:

- The use of iNaturalist and/or MyCoast for reporting and collection of individual observations, and
- NOAA's Voices: Oral History Archives.

## 6.7 Enhance delineation of geographic assessment area delineation.

A hierarchical set of geographic assessment areas have been defined. However, ongoing work is needed to refine these categories and their implementation (the least defined levels are reaches, zones, and 1-kilometer segments). Following the 2022 field seasons, zone delineations will be added to many areas as part of 2022 fixed-wing imagery analysis and reporting.

Identification of potential floating kelp habitat would greatly improve our understanding and allow for targeted sampling. For example, in the current Program data products, estimates of nearshore extent are based solely on depth (-1 to -15 m, MLLW) and do not include other habitat characteristics that are associated with kelp presence or absence. While this estimate is useful, it could be honed into a more precise estimate by considering other habitat attributes such as substrate and local depth ranges for floating kelp.

## 6.8 Build linkages to environmental data.

Physical and biological datasets could help to inform interpretation of monitoring results, through integrating using existing datasets or collecting new data:

- Existing datasets could be linked spatially and summarized over geographical assessment areas. For example, a study in SPS identified that kelp persistence was highest in areas with strong currents through linking wave and current model data to kelp persistence patterns at 1-km segments (Berry et al., 2021).
- Environmental sensors could be deployed at subset of sites. Some deployments exist, maintained by the United States Geological Survey (USGS), Washington Department of Natural Resources (DNR), Puget Sound Restoration Fund (PSRF), University of Washington, and others.

## 6.9 Build linkages to management.

The Program collects and synthesizes data that can inform management goals and actions. Moving forward, we will continue to collaborate with managers to ensure that the Program provides information that is needed for planning and decision-making.

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