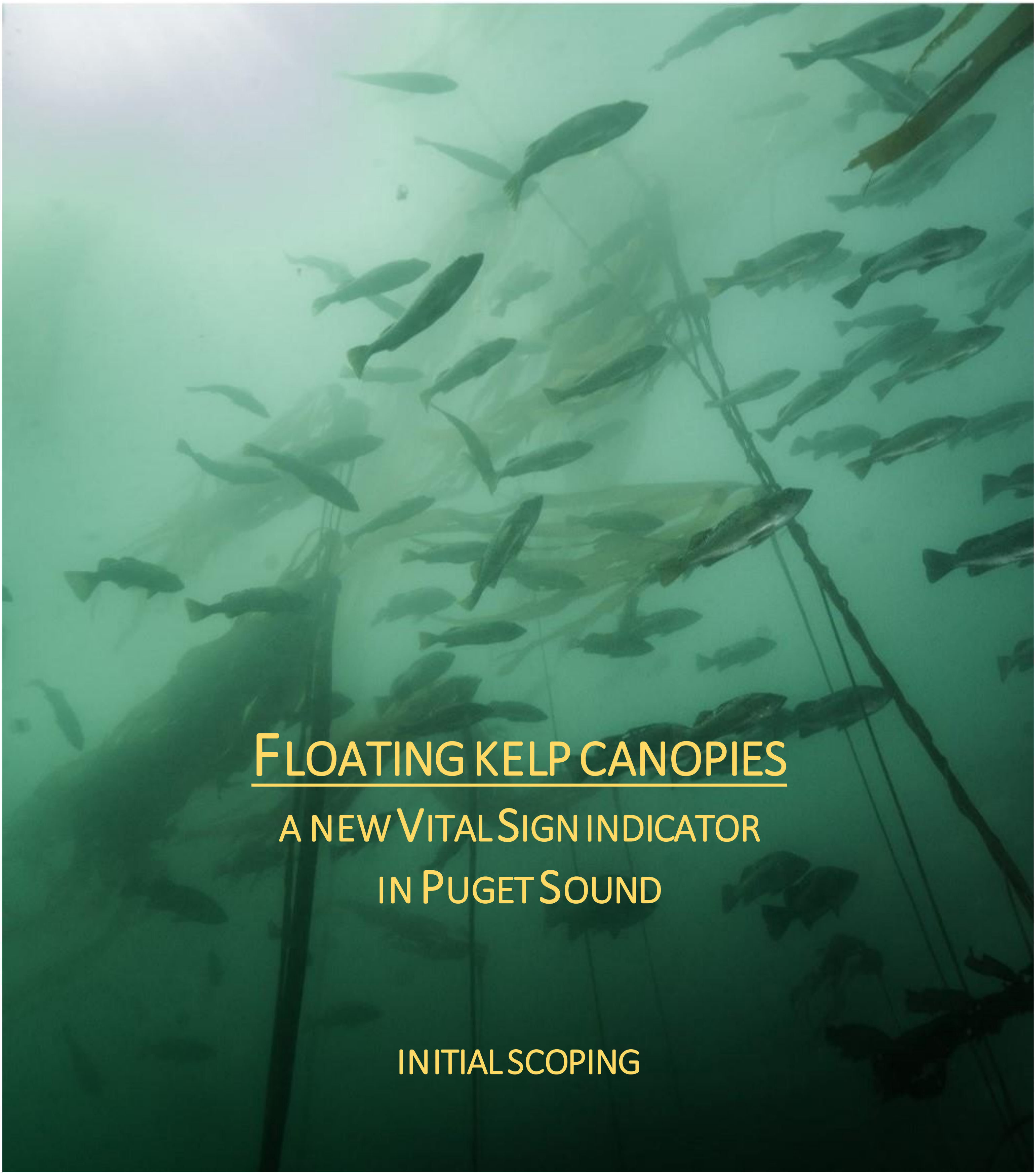

Floating kelp canopies

a new Vital Sign indicator in Puget Sound

Initial scoping

ACKNOWLEDGEMENTS

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

PROJECT TEAM

Sea Grant Washington
Nicole Naar

Samish Indian Nation
Todd Woodard
Casey Palmer-McGee

Northwest Straits Commission
Dana Oster
Suzanne Shull

Marine Agronomics
Tom Mumford

Washington Department of Natural Resources
Helen Berry
Pete Dowty
Elizabeth Spaulding
Bart Christiaen
Lisa Ferrier
Julia Ledbetter

University of Washington
Megan Dethier
Wendel Raymond

DISCLAIMER

The data and interpretations in this report were prepared by the authors based on ongoing research and investigations. They do not necessarily reflect the views or policies of the affiliated organizations. This document represents an initial scoping effort, produced rapidly in order to solicit early guidance from the Puget Sound community.

CITATION: Berry, H., N. Naar, T. Woodard, S. Shull, T. Mumford, W. Raymond, P. Dowty, B. Christiaen, L. Ferrier, J. Ledbetter, M. Dethier, E. Spaulding. 2022. Floating kelp canopies: a new Vital Sign indicator in Puget Sound, Initial Scoping.

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

Executive Summary

This report presents preliminary scoping information to support development of the *floating kelp canopy area* ecological indicator, a newly identified biophysical indicator for the Puget Sound Partnership's *Beaches and Marine Vegetation* Vital Sign. The report summarizes required and desirable attributes, along with candidate datasets. The purpose of the report is to make an initial plan available and to elicit feedback from the Puget Sound community. The *Project Team* will use the findings to guide future work. The project will culminate in May 2023 with posting of the newly developed indicator and associated results on PS Info, the Vital Sign reporting system.

The project is distinct from many other indicator development efforts because the *Project Team* represents a broad-based alliance of organizations and communities that value kelp. The principle driving this approach is that diverse engagement will both enrich the indicator and strengthen its connection to kelp conservation and restoration actions. The initial indicator will be developed from a synthesis of existing data from state agency monitoring, community science surveys, and Indigenous Scientific Knowledge. We anticipate that the indicator produced during this project will be incrementally improved over time. So, in addition to defining and constructing the indicator, the project will identify priorities for enhancing and expanding it in the future.

How to get involved:

Provide feedback on the Scoping Questions by participating in a workshop or submitting comments:

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

Consider how you want to participate. The Community Engagement section outlines ideas for inclusivity. Your contributions could be part of the indicator project or part of broader efforts associated with the *Puget Sound Kelp Conservation and Recovery Plan* (*Kelp Plan*):

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

Each phase of the project includes opportunities to provide feedback:

<u>Phase 1. Initial Scoping</u> *Identify indicator requirements, priorities, and candidate datasets*	• Report released: Jan. 11, 2022 • ***Online workshop: Jan. 13, 2022, 10 am – 12 pm*** • Public comments due: Mar. 1, 2022
<u>Phase 2. Indicator Options</u> *Explore indicator options through data visualization*	• Report released: May 30, 2022 • ***Online workshop: Jun. 7, 2022, 10 am – 12 pm*** • Public comments due: Aug. 1, 2022
<u>Phase 3. Proposed Indicator</u> *Select and refine indicator*	• Report released: December 20, 2022 • ***Online workshop: Jan. 4, 2023, 10 am – 12 pm*** • Public comments due: Feb. 15, 2023

As part of the initial scoping, the *Project Team* identified key considerations for feedback. Key considerations were framed in terms of the scoping questions:

Question	**Key Considerations**
Who is the indicator for? How will it be used?	- Diverse audiences. - Single simple figure for rapid communication. - Detailed metrics that drill down into the data.

The indicator is limited to describing status and trends in floating kelp canopies. What linkages are most important?	- Linkages to stressors, management actions, ecosystem components, human well-being.
	- Additional conceptual model development may be useful as part of indicator development or broader *Kelp Plan* work:
	  ○ A 'kelp canopy centric' model may provide insight.
	  ○ A simple model could communicate common understanding.
	  ○ Advanced models could target additional actions.

What time spans should the indicator consider? Why?	- Short-term (years). - Long-term (decades).
What geographic assessment areas are important? Why?	- Sub-basins within Puget Sound. - Include the open coast.
What metrics and data should be included in the initial indicator? The future indicator?	- Initial canopy area and bed perimeter area from DNR, MRC volunteers, Samish. What else? - Future: a plan for expanding metrics and data is needed. - Currently, resources for data collection and reporting are extremely limited. The program must be scaled to match available resources.

For more information on the project or to join the mailing list, visit the project web site or contact us at nearshore@dnr.wa.gov

Contents

1. Introduction 1
   1.1 Overall Project Goal and Approach 1
   1.2 Project Description 1
      1.2.1 Project Team and Contributors 1
      1.2.2 Project Phases and Schedule 2
      1.2.3 Outcomes 4
   1.3 Scoping Questions 5
2. Community Engagement 7
   2.1 Vision 7
   2.2 Challenges and Opportunities 8
3. The Indicator Framework 10
   3.1 The Role of Vital Signs and Indicators at the Puget Sound Partnership 10
   3.2 The Partnership's Conceptual Models and Causal Frameworks 12
   3.3 Other Models that Link Kelp to Stressors, Management and the Ecosystem 16
   3.4 Other regional efforts related to kelp in Puget Sound 17
4. Monitoring Techniques and Existing Data 18
   4.1 Monitoring Techniques 18
   4.2 Status and Trends 20
   4.3 Candidate datasets 23
      4.3.1 Geographic Assessment Units 23
      4.3.2 Floating Kelp Canopy Datasets 26
5. Conclusions: Key Considerations for Indicator Development 29
6. References 33

Appendix 1. Conceptual Models 40
Appendix 2. Examples of Geographic Assessment Areas 45
Appendix 3. Dataset Descriptions 53

Figures

Figure 1. Overview of project phases and timeline. 3

Figure 2. Framework for interdisciplinary and transdisciplinary co-creation of knowledge (from Mauser et al., 2013)... 8

Figure 3. A cartoon of a Driver-Pressure-State-Impact-Response (DPSIR) causal framework illustrating the links among indicators of ecosystem conditions (i.e., State and Impacts) with Pressures to ecosystem health and policy/strategy/management Responses (from O'Neill et al., 2018)...................................13

Figure 4. Integrated conceptual model for ecosystem recovery (from O'Neill et al., 2018). The integrated model includes three embedded frameworks: the Driver-Pressure-State-Impact-Response framework, the EPA's Essential Ecological Attribute Framework and the human wellbeing framework (from Harguth et al., 2015)..14

Figure 5. The conceptual model for the Marine Vegetation portion of the Beaches and Marine Vegetation Vital Sign, developed as part of the Vital Signs Revision (McManus et al., 2020). The *floating kelp canopy area* indicator falls within this Vital Sign. Zoom into the image to read text. 15

Figure 6. The Partnership's Progress Measures Framework. Progress measure types are shown with orange headings. Related types of information ad assessment are shown with black and gray headings. Zoom in to image to read text. (https://pspwa.app.box.com/s/3glesl2yknwzd5ydq9kentxd2svjecmp) 16

Figure 7. Multi-scale canopy monitoring approach from the Marine Plan Partnership (MaPP) in British Columbia (from Cavanaugh et al., 2021). 19

Figure 8. (A) understory and (B) floating kelp distribution in Washington State (Nearshore Habitat Program, 2001)...20

Figure 9. Comparison of the recent extent of bull kelp canopies to the cumulative maximum of all recorded observations in South Puget Sound and Central Puget Sound. The cumulative maximum extent was synthesized from historical data sources, including charts, surveys and (Berry et al., 2020, Berry et al., 2021)..22

Figure 10. Sub-basins defined by PSNERP (https://salishsearestoration.org/wiki/Puget_Sound_Sub-basins)...25

Figure 11. Candidate datasets that describe floating kelp canopy extent. Two statewide datasets are not included in this map: The ShoreZone Inventory and Fertilizer Investigations.....................................27

Figure 12. A cartoon of a Driver-Pressure-State-Impact-Response (DPSIR) causal framework illustrating the links among indicators of ecosystem conditions (i.e., State and Impacts) with Pressures to ecosystem health and policy/strategy/management Responses (from O'Neill et al. 2018). 40

Figure 13. Integrated conceptual model for ecosystem recovery (from O'Neill et al. 2018). The integrated model includes three embedded frameworks: the Driver-Pressure-State-Impact-Response framework, the Essential Ecological Attribute Framework (EPA 2002) and the human wellbeing framework (from Harguth et al. 2015)...41

Figure 14. The conceptual model for the Marine Vegetation portion of the Beaches and Marine Vegetation Vital Sign, developed as part of the Vital Signs Revision (McManus et al. 2020). The *floating kelp canopy area* indicator falls within this Vital Sign. Zoom into the image to read text.....................42

Figure 15. The process conceptual model of the nearshore developed by the Nearshore Science Team for the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) for assessing restoration of the nearshore system (Simenstad et al. 2006). Related models were also developed for domain, organizations, change/action scenario, and time variability. 43

Figure 16. Results of a literature search of kelp stressors based on a simplified conceptual diagram, including results for (A) broader coast literature and (B) Salish Sea literature. Color indicates the direction of the relationship (blue represents negative, dark gray – neutral, orange – positive, purple – no consensus, and light gray – no literature) while the texture of the line indicates the number of studies identified (dashed represents two or fewer studies, solid indicates > 2). .See also related figure below. From Hollarsmith et al., in press...44

Figure 17. Results of a literature search of the pressures impacting floating and non-floating kelp species in the Salish Sea and temperate costs wherever kelps are found. The numbers in each box represent the number of studies identified. See Figure 16 caption for a description of the colors. See also related figure above. From Hollarsmith et al., in press...44

Figure 18. Ecoregions of western North America, defined by the Nature Conservancy (Floberg et al. 2004)...45

Figure 19. Sub-basins defined by PSNERP (https://salishsearestoration.org/wiki/Puget_Sound_Sub-basins)..46

Figure 20. DNR's Submerged Vegetation Monitoring Program monitors eelgrass condition at soundwide, regional and site scales. Five regions were selected to capture distinct conditions in portions of Puget Sound. The number of regions was determined in part by the need for regions to be large enough to include a sufficient number of probabilistically samples for statistical extrapolation (Dowty et al., 2019). 47

Figure 21. Basin description in Live Ocean, a computer model simulating ocean water properties. The sub-areas are described as: "The 'basins' are generally deep with weak tidal currents. These are Main Basin, Whidbey Basin, Hood Canal, and South Sound. The 'straits' connecting them are generally shallower, narrower and have much stronger tidal currents, especially Admiralty Inlet and Tacoma Narrows." (Live Ocean https://faculty.washington.edu/pmacc/LO/long_term_trends.html)...................48

Figure 22. The Delineation of Puget Sound for the Rockfish Recovery Plan and the Kelp Conservation and Recovery Plan (Calloway et al., 2020)...49

Figure 23. Water Resource Inventory Area (WRIA) boundaries in the Puget Sound area. From https://www.eopugetsound.org/articles/water-resource-inventory-areas-puget-sound...........................50

Figure 24. Marine Areas for Harvest Management https://www.eregulations.com/washington/fishing/marine-area-rules-definitions. 51

Figure 25. The 12 regions monitored in the Marine Water Condition Index by the Washington Department of Ecology. Accessed January 5, 2022. https://www.epa.gov/salish-sea/marine-water-quality 52

Tables

Table 1. Opportunities for public feedback in the indicator development process. 4

Table 2. Summary of key considerations for each scoping question 29

Table 3. Volunteer Kayak Monitoring by Marine Resources Committees (MRC-kayak)......................53

Table 4. Kayak Monitoring by DNR in Central and South Puget Sound (DNR-kayak).........................54

Table 5. Samish Kelp Canopy Surveys in Traditional Territory (Samish-TT) 55

Table 6. Historical Kelp Forests in Samish Traditional Territory (Samish-TT)...................................55

Table 7. Synthesis of long-term floating kelp data in South Puget Sound and Central Puget Sound (DNR – synthesis) 56

Table 8. Shoreline survey of floating kelp presence (DNR-boat) 56

Table 9. Long-term monitoring of the Coast, Strait and Aquatic Reserves using Aerial Photography (DNR-COSTR and DNR AQRES) 57

Table 10. Fertilizer Investigations...58

Table 11. The Washington State ShoreZone Inventory...59

1. Introduction

1.1 Overall Project Goal and Approach

The overall goal of this project is to produce a *floating kelp canopy area* indicator for the Puget Sound Vital Signs. In 2020, the Puget Sound Partnership called for a new *floating kelp canopy area* indicator, in recognition that kelp forests are foundations for diverse and productive ecosystems. The indicator will fill a current gap in scientific information about the condition of floating kelp canopies. It will also serve as a communications tool for sharing information with the public.

Kelp is an ecosystem engineer that provides habitat and food web support for myriad species of invertebrates, fishes, birds and mammals. In Puget Sound, for example, kelp forests are critical habitat for juvenile rockfish (*Sebastes* spp.), forage fish (including Pacific herring and surf smelt), as well as out-migrating juvenile and returning adult salmon (Love et al., 1991; Doty et al., 1995; Johnson and Schindler, 2009; Essington et al., 2018; Shaffer et al., 2020). Changes in kelp abundance can have cascading effects (Sunday et al., 2016). For more information on the ecological role of kelp, see The Knowledge Review in The Kelp Conservation and Recovery Plan (Calloway et al., 2020).

1.2 Project Description

1.2.1 Project Team and Contributors

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

- The *Project Team* of 10-15 staff who primarily complete the project;
  - Washington State Department of Natural Resources (DNR) - Helen Berry, Pete Dowty, Lisa Ferrier, Bart Christiaen, Julia Ledbetter, Kelp Ecologist (Natural Resources Scientist 3 project position, to be hired), Elizabeth Spaulding
  - Samish Indian Nation - Todd Woodard (alternate: Casey Palmer-McGee)
  - Northwest Straits Commission - Dana Oster, Suzanne Shull
  - University of Washington - Megan Dethier, Wendel Raymond
  - Washington SeaGrant - Nicole Naar
  - Marine Agronomics - Tom Mumford
- *Contributors* who provide guidance through document review and meetings.

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

- The Washington State Department of Natural Resources (DNR) is the state steward for kelp, eelgrass and other aquatic vegetation. DNR's Nearshore Habitat Program has conducted kelp monitoring for 30 years. It is also the indicator lead for the *eelgrass area* component of the Beaches and Marine Vegetation Vital Sign.

- The Samish Indian Nation works to preserve, protect and enhance culturally significant natural resources in Samish Territory, which encompasses culturally important kelp habitats in the San Juan Islands and nearby shorelines. Through the tribe's strong connection with the natural world, they have observed kelp declines and species struggling to survive and adapt. They are incorporating local indigenous knowledge into their scientific monitoring program.
- The Northwest Strait Commission is a community-led collaboration working to protect and restore the marine environment of northwest Washington. It provides funding and technical coordination for 7 county-based Marine Resources Committees (MRCs). MRCs serve as advisors to local government 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) will provide ecological analysis expertise and link the indicator to ongoing kelp research. FHL is known worldwide for research and teaching in marine-related sciences. Visiting and resident scientists and their students conduct a wide array of research projects related to kelp. FHL is the academic home for one postdoctoral research fellow working on kelp ecophysiology and several other researchers with decades of experience related to kelp.
- Washington Sea Grant (WSG) funds and conducts marine research, outreach, and education to support the health and sustainability of Washington's vibrant communities and marine resources. WSG acts 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.

1.2.2 Project Phases and Schedule

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

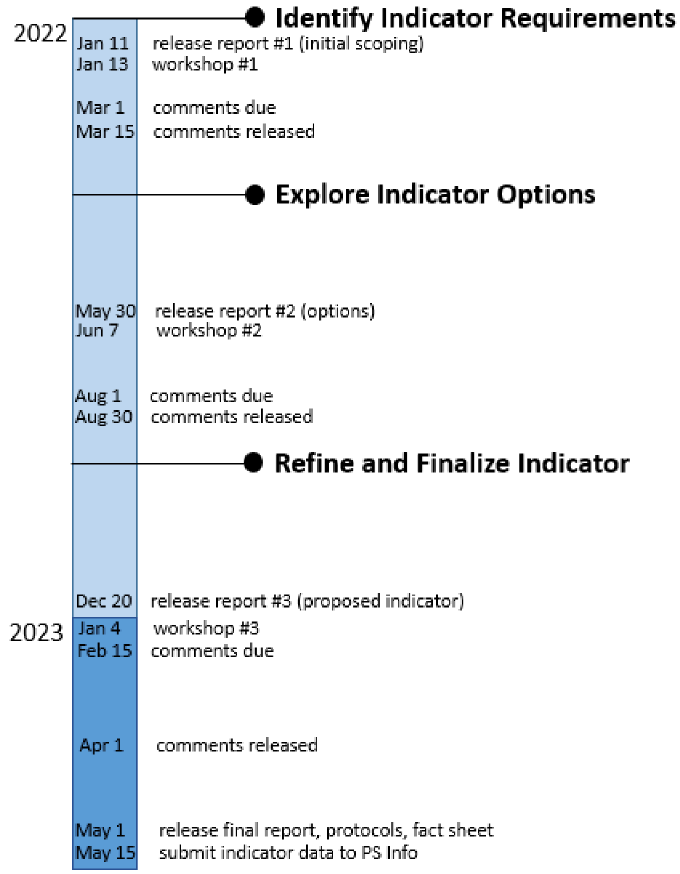

Figure 1. Overview of project phases and timeline.

Phase 1. Identify indicator requirements.

This report kicks off the initial scoping process to identify indicator requirements, priorities, and candidate datasets. The *Project Team* is soliciting input on key attributes to be incorporated into the kelp canopy area indicator based on the PS Partnership Vital Sign indicator requirements, ecological guidelines for indicator development, and specific considerations for canopy-forming kelp species in Puget Sound. The results will guide the subsequent phases of indicator development.

The *Project Team* is also identifying existing candidate datasets to be incorporated into the initial indicator. Candidate datasets will be drawn from DNR, the Samish Tribe, the NW Straits Commission, and other available sources.

The framework developed during initial scoping will be further developed in subsequent phases.

Phase 2. Explore indicator options through data analysis and visualization

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

Phase 3. Refine and finalize indicator

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

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

Phase 1. Initial Scoping *Identify indicator requirements, priorities, and candidate datasets*	• Report released: Jan. 11, 2022 • ***Online workshop: Jan. 13, 2022, 10 am – 12 pm*** • Public comments due: Mar. 1, 2022
Phase 2. Indicator Options *Explore indicator options through data visualization*	• Report released: May 30, 2022 • ***Online workshop: Jun. 7, 2022, 10 am – 12 pm*** • Public comments due: Aug. 1, 2022
Phase 3. Finalize Indicator *Select and refine indicator*	• Report released: December 20, 2022 • ***Online workshop: Jan. 4, 2023, 10 am – 12 pm*** • Public comments due: Feb. 15, 2023

1.2.3 Outcomes

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

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

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

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

1.3 Scoping Questions

We formulated 5 primary questions to consider during indicator development. Each primary question includes a list of related questions that continue to be articulated and added:

<u>Who is the indicator for? How will it be used?</u>
Examples of related questions:

- How do partners want to access data and results?

<u>The indicator is limited to describing status and trends in kelp canopy area. What linkages are most important?</u>
Examples of related questions:

- Is additional conceptual model development needed? If yes, what? For whom?
- What additional datasets and other kinds of information are top priorities for related analyses? Key topics likely include stressors, management actions, and linkages to valued species and human well-being.

<u>What time spans should the indicator consider? Why?</u>
Examples of related questions:

- What are the relative priorities and time periods for short-term and long-term assessment? Why?
- Are short-term time frames preferred for management feedback. If yes, what time periods?
- Are long-term time frames (decades and more) preferred for ecological studies and understanding conditions prior to widespread non-native settlement?
- How should effort be allocated to historical vs current studies?
- Can past reconstructions give us insight into interannual variation, response to marine heat waves and other conditions?

<u>What geographic assessment areas are important to consider? Why?</u>
Examples of related questions:

- What management boundaries are most important to consider?
- What ecological boundaries are most important to consider?

What metrics and data should be included in the initial indicator? The future indicator?

Examples of related questions:

- What monitoring techniques best meet indicator needs?
- When is it important to distinguish between the two primary canopy-forming kelp species, giant kelp and bull kelp?
- What are the relative tradeoffs of data quantity and quality? e.g. if there are broad datasets available but they have substantial uncertainty associated with them, how might they add value?

We welcome comments at workshops, individual meetings and emails (nearshore@dnr.wa.gov).

2. Community Engagement

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

2.1 Vision

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

We know, however, that simply marking an event as "open to the public" is insufficient for ensuring meaningful engagement, especially from groups typically excluded from region-wide monitoring efforts. Thus, intentional outreach to citizen scientists/volunteers and Tribes is a key element of the *Project Team*'s community engagement strategy for indicator development. Citizen scientists and volunteers serving on MRCs advise local county governments and can use indicator results as a communication tool to further expand engagement in coastal communities across Washington State. The Tribes are the original stewards of the Salish Sea and continue to steward their lands and waters. Evidence from prehistoric artifacts, historical sources, and contemporary practices suggests Pacific Northwest kelp forests have a long prehistory as sustainable social-ecological systems. Thus, the traditional ecological knowledge, subsistence practices, and symbolic culture of the Tribal are essential contributions to kelp conservation in Puget Sound (Naar, 2020).

Encouraging diverse participation and including diverse perspectives makes possible the last element of the *Project Team*'s vision for community engagement: transdisciplinary co-creation of knowledge (Mauser et al., 2013, Figure 2). Transdisciplinary integrated research represents a departure from the traditional "way of doing business," which tends to rely solely on Western science (Johnson et al., 2016) and encourages specialization and knowledge silos (Campbell, 2005[1969]). But this approach holds potential for addressing complex societal challenges that are beyond the scope of individual disciplines (Mauser et al., 2013; Kaiser et al., 2019). Our goal is for diverse participation to promote the weaving together of diverse knowledges, such that the indicator synthesizes data from state agencies, community/citizen science, and Indigenous science.

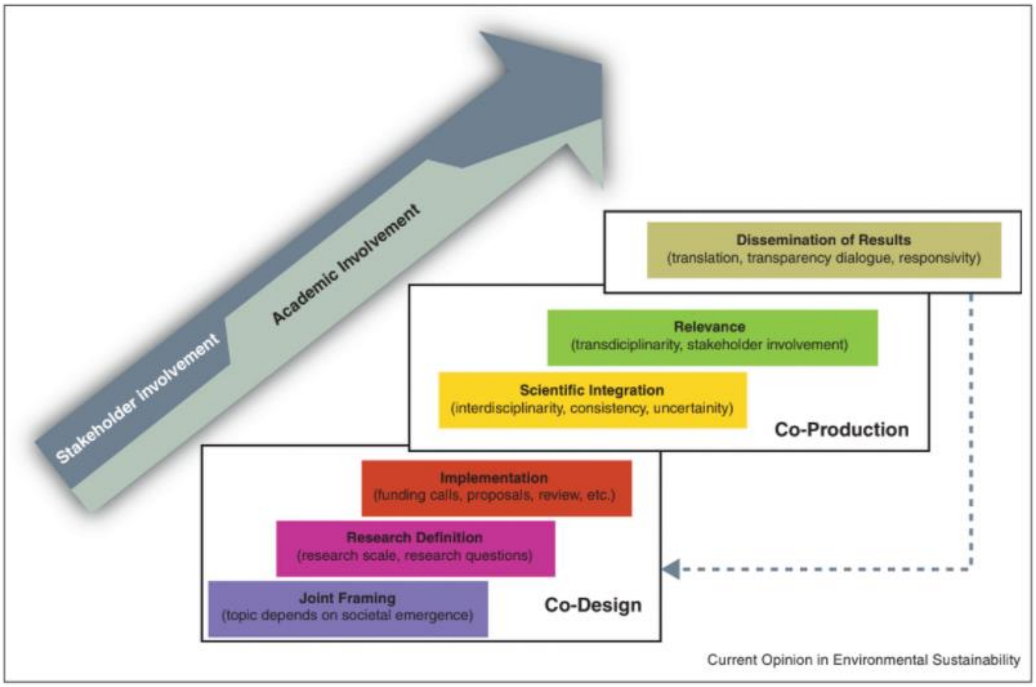

Figure 2. Framework for interdisciplinary and transdisciplinary co-creation of knowledge (from Mauser et al., 2013).

2.2 Challenges and Opportunities

We recognize, however, that transdisciplinary, integrated co-creation of knowledge is a long-term and challenging process. Given existing constraints, it is an aspiration that will more likely be realized at the longer timescale and broader scope of the *Kelp Plan*. Indicator development must fit within an existing framework with its own goals and objectives, process, and standards and requirements (see Chapter 3). The two-year project timeline is also relatively brief from the perspective of building trust between diverse partners, forging meaningful relationships, and reconciling differences between perspectives and approaches (Kotaska, 2019). Finally, contrary to the principles of co-design shown in Figure 2, the indicator project has already been designed (i.e., framed, defined, and funded) to be consistent with the Puget Sound Vital Sign framework.

Despite these challenges, we want to acknowledge the many opportunities for enhancing community engagement around kelp conservation that indicator development provides. Our ability to co-design the *floating kelp canopy area* indicator may be limited, but we can strive for co-production (Figure 2) 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 2) so that it includes both co-design and co-production and moves us closer to our vision of diverse participation, intentional outreach, and transdisciplinarity.

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

- Sharing datasets to be included in the indicator;
- Suggesting priorities for the indicator to address, such as the time spans that the indicator considers (for example, shorter time spans are often preferred for feedback to management while longer time spans are preferred for cultural and ecological perspectives).
- Providing guidance on how the indicator meets individual needs to understand how kelp is doing and how it is changing.

The *Project Team* also encourages contributions that might not neatly fit within the narrower boundaries of indicator development, but can be incorporated into the broader long-term project of the *Kelp Plan*. Potential ways to engage at this level include, but are not limited to:

- Contributing other information that enriches our understanding of indicator results and could be referenced as additional information (e.g., additional datasets, cultural or scientific studies, historical records, or other forms of knowledge);
- Defining measures of success to guide metric definition and later target setting (such as: total abundance, habitat usage by valued species, cultural uses).
- Linking the indicators to actions that conserve and protect kelp.
- Communicating why kelp is important to you, your community, and Puget Sound and articulating how floating kelp canopy area is linked to social-ecological well being.

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

3. The Indicator Framework

3.1 The Role of Vital Signs and Indicators at the Puget Sound Partnership

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

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

Like many other ecosystem management and recovery efforts, the Partnership uses ecological indicators to guide ecosystem management and recovery efforts. A series of projects have identified and refined the Vital Sign indicators of biophysical conditions and human wellbeing, with the following milestones:

- In 2010, the Indicators Action Team proposed portfolios of high-level Vital Signs and associated indicators. In 2011, the Leadership Council adopted a set of indicators, measures and 2020 recovery targets.
- In response to a request by the Science Panel, the Washington State Academy of Sciences (WSAS) conducted an independent review of the Vital Sign indicators and concluded that there were "significant flaws and inconsistencies in the process" (WSAS, 2012). Key weaknesses included: 1) the selection process lacked a conceptual model and framework, 2) a sufficient number of attributes were not measured; 3) the portfolio was skewed; and 4) insufficient attention was given to evaluating specific metrics.
- In 2014, the Partnership completed the Puget Sound Pressures Assessment (McManus et al., 2014). This study evaluated key biophysical vulnerabilities related to human behavior and generated conceptual models to link pressures to indicators and recovery objectives.
- To address the WSAS recommendations, the Science Panel and science program completed the Indicators Evolution Project (IEP) in collaboration with the Puget Sound Ecosystem Monitoring Program (PSEMP). This effort built on previous efforts to improve the scientific validity of the selection process and the portfolio of selected indicators (O'Neill et al., 2018).
- In 2020, the Partnership collaboratively revised the Vital Signs, adopting 13 Vital Signs and 34 indicators. Nineteen more indicators were flagged for future development. This effort established the *floating kelp canopy area* indicator and identified *understory kelp*

condition as a future indicator (McManus et al., 2020). These indicators were placed within the *Beaches and Marine Vegetation* Vital Sign. Additionally, the 2020 revision introduced the concept of *Intermediate Progress Measures* to link indicators to activities causing changes and collective actions in response (discussed in the next section).

- In 2021, The Leadership Council initiated the process of updating recovery targets for specific indicators when it approved new quantitative recovery targets for four indicators. A schedule has not yet been developed for defining recovery targets for the remaining indicators.

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

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

The basic requirements for Vital Sign indicators are that they must be scientifically sound, pertinent to regional ecosystem goals, reliable and practical to measure (O'Neill et al., 2018). These requirements are similar to other indicator programs (ie. 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.

Existing Vital Sign indicators and the reporting platform provide further insight into indicator requirements. Indicators are generally reported sound-wide, as well as within smaller geographic assessment units. The majority of indicators assess changes over time in a metric, while the minority, such as Toxics in Fish, compare levels of a metric to a threshold. For most indicators, *status* tracks movement in relation to the target that was defined through 2020, while *progress* tracks the direction of any trend.

The Vital Sign reporting platform prioritizes summaries. Each indicator is described in an introductory paragraph, a single data visualization, and limited bulleted results. Three 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.

3.2 The Partnership's Conceptual Models and Causal Frameworks

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. An example of a conceptual model is the Driver-Pressure-State-Impact-Response (DPSIR) model (Figure 3). In Puget Sound, DPSIR models have been used in many contexts to link biophysical indicators to factors considered in management.

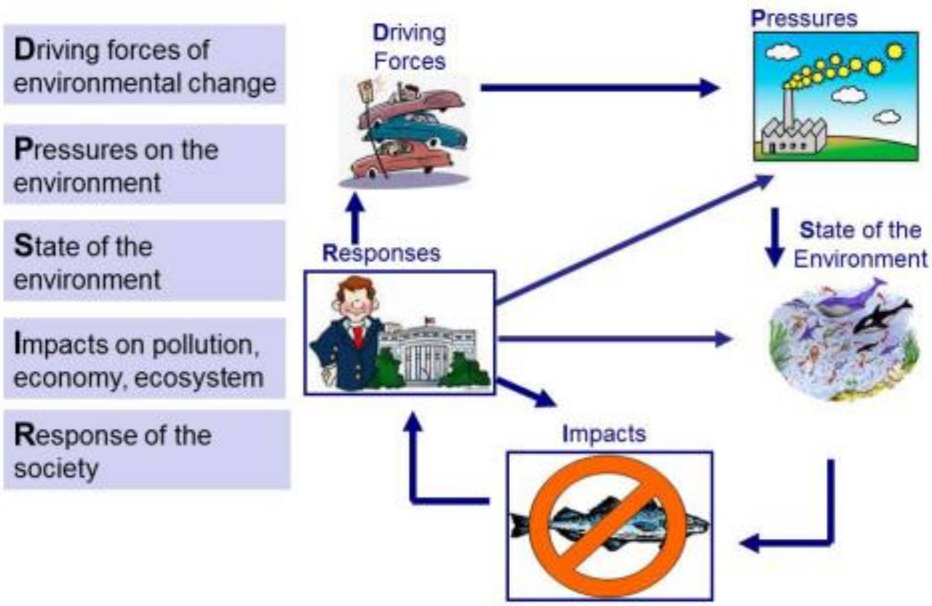

Figure 3. A cartoon of a Driver-Pressure-State-Impact-Response (DPSIR) causal framework illustrating the links among indicators of ecosystem conditions (i.e., State and Impacts) with Pressures to ecosystem health and policy/strategy/management Responses (from O'Neill et al., 2018).

The Partnership's use of conceptual models and causal frameworks has evolved over time. The most recent Indicators Evolution Project (IEP) developed an overarching ecosystem recovery model (Figure 4) that combined three independent frameworks in a generalized theoretical description of Puget Sound's social-ecological system (O'Neill et al., 2018). It also adopted conceptual models that were previously developed for individual indicators or workgroups. To address nearshore areas, the IEP included conceptual models (Simenstad et al., 2006) developed by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP).

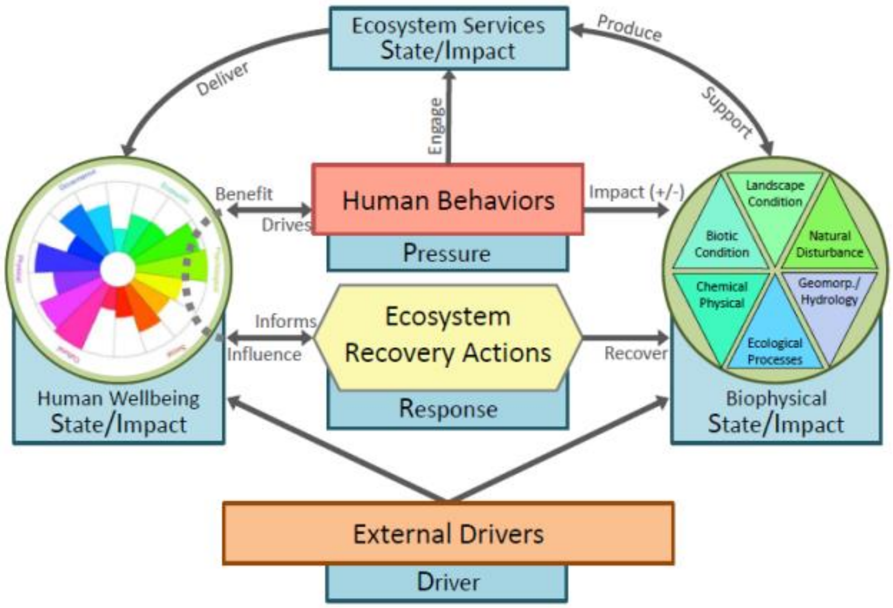

Figure 4. Integrated conceptual model for ecosystem recovery (from O'Neill et al., 2018). The integrated model includes three embedded frameworks: the Driver-Pressure-State-Impact-Response framework, the EPA's Essential Ecological Attribute Framework and the human wellbeing framework (from Harguth et al., 2015).

In 2020, the Vital Sign revision project developed conceptual models for each of the new Vital Signs using the Miradi Conservation Management framework (McManus et al., 2020). The *floating kelp canopy area* indicator falls within the *Beaches and Marine Vegetation* Vital Sign (Figure 5). The most up to date version can be viewed online here.

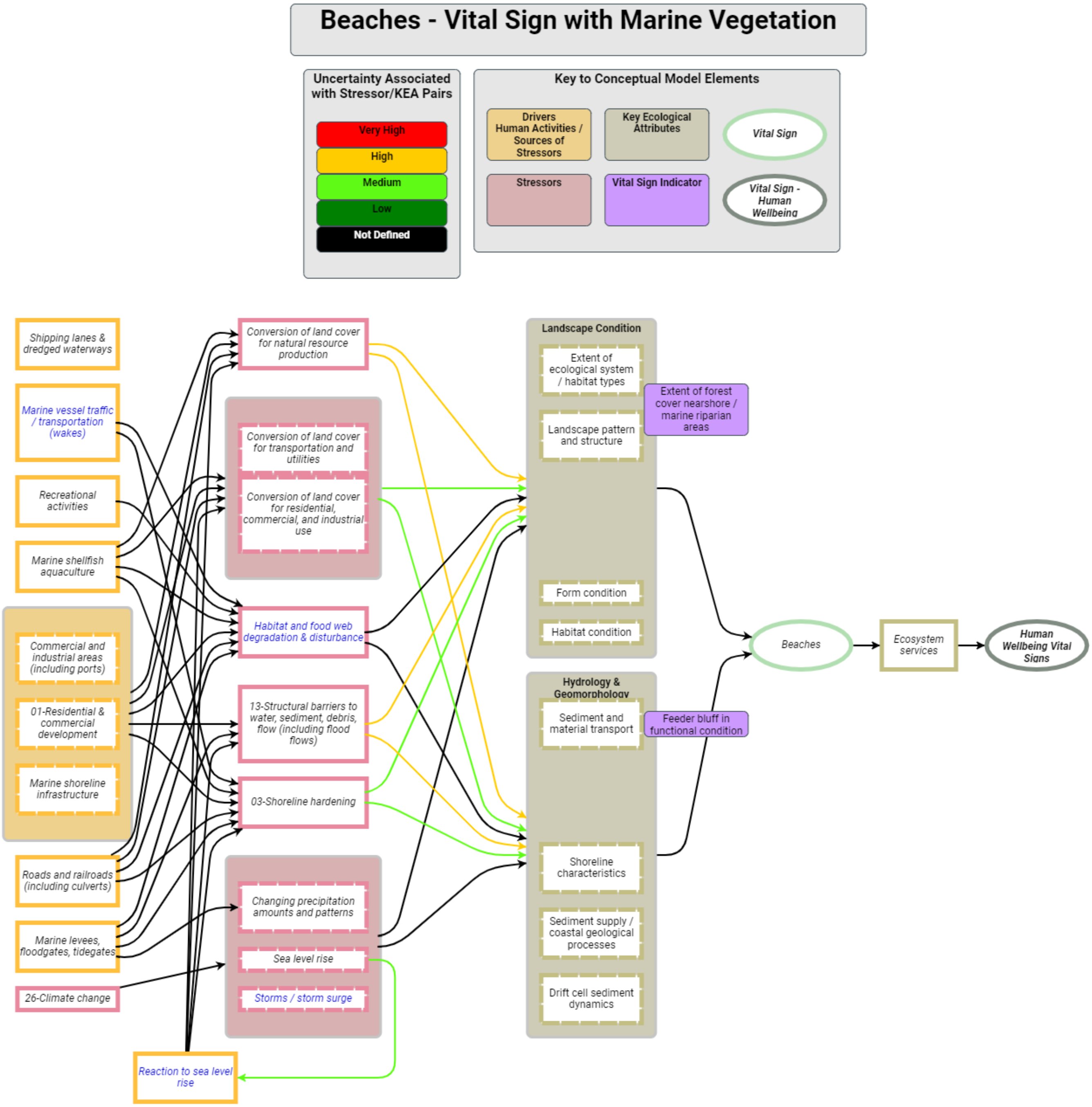

Figure 5. The conceptual model for the Marine Vegetation portion of the Beaches and Marine Vegetation Vital Sign, developed as part of the Vital Signs Revision (McManus et al., 2020). The *floating kelp canopy area* indicator falls within this Vital Sign. Zoom into the image to read text.

Related to conceptual models, in 2020 the Partnership structured indicators within a *Progress Measures Framework* (Figure 6). The purpose of the framework is to identify natural and social processes causing changes to the Vital Signs and the collective impact of multiple activities toward reducing or mitigating the impact of those pressures. There are three types of measures:

- *Activity Progress Measures* –outputs of activities and programs.
- *Intermediate Progress Measures* –the cumulative results of activities and programs.
- *Vital Signs* and *Indicators* –the ultimate desired outcomes.

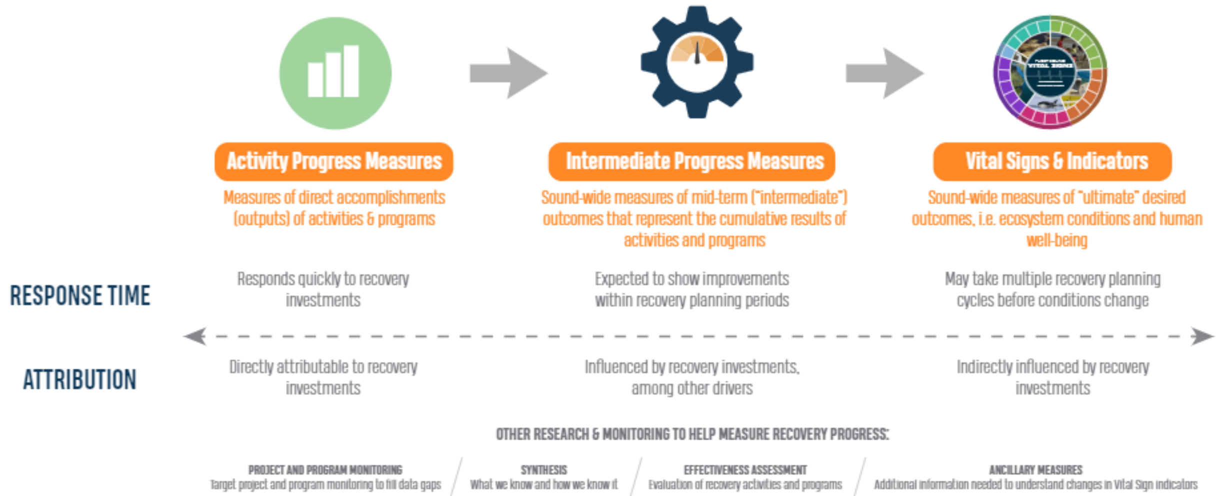

Figure 6. The Partnership's Progress Measures Framework. Progress measure types are shown with orange headings. Related types of information ad assessment are shown with black and gray headings. Zoom in to image to read text. (https://pspwa.app.box.com/s/3glesl2yknwzd5ydq9kentxd2svjecmp)

3.3 Other Models that Link Kelp to Stressors, Management and the Ecosystem

Independent from the Partnership efforts, several recently released kelp-specific conceptual models could provide additional insight into the ecosystem role of kelp, key stressors and potential management responses, either for the indicator itself or broader *Kelp Plan* efforts. Hollarsmith et al. (in press) defined a conceptual model for perceived direct and indirect stressors in the Salish Sea based on expert interviews and literature review (Appendix 2). They found variable consensus on the relationship between stressors and responses, and concluded that local ecological, oceanographic and anthropogenic contexts and threshold effects drive stressor-response relationships. They also identified priorities for future research. Hamilton et al. (2022) applied an Ecosystem-Based Management (EBM) approach to kelp forest management and identified 6 key principles for kelp forest EBM:

1. Monitoring at biologically relevant temporal and spatial scales;
2. Assessing and addressing cumulative impacts;
3. Managing across spatial and institutional scales;
4. Co-management with users;
5. Employing rapid adaptive management and/or the precautionary principle;
6. Managing food web connections.

3.4 Other regional efforts related to kelp in Puget Sound

In 2020, the *Kelp Conservation and Recovery Plan* (*Kelp Plan*) called for coordinated action to protect and restore kelp in the face of documented losses in some areas and widespread concerns (Calloway et al., 2020). The *Kelp Plan's* strategic goals generally align with the Partnership Vital Sign goals. The *Kelp Plan* called for the addition of kelp indicators to the Vital Signs. More broadly, it identified a widespread need to deepen understanding of the value of kelp to Puget Sound ecosystems, to identify trends, to prioritize stressors, and to mobilize management responses.

Some of the communication goals identified by the *Kelp Plan* could likely be addressed through the *floating kelp canopy area* indicator. However, many aspects of the *Kelp Plan* fall outside of the defined Vital Signs monitoring framework. Overlapping aspects of these related efforts could be addressed through coordination between the targeted work of *Vital Sign* implementers and the larger group of *Kelp Plan* implementers.

4. Monitoring Techniques and Existing Data

4.1 Monitoring Techniques

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

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

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

At the local scale, small boats and other ground-based techniques can be highly effective at capturing detailed observations. Boat-based and drone techniques have been employed successfully at sites in greater Puget Sound (discussed in next section). Generally, the techniques that have been most successful in greater Puget Sound fall into the regional scale and local scale categories (Figure 7). A multi-scale monitoring approach with an emphasis on tools at the regional and local scale is likely to be most effective in Washington State for monitoring kelp canopies in the near term.

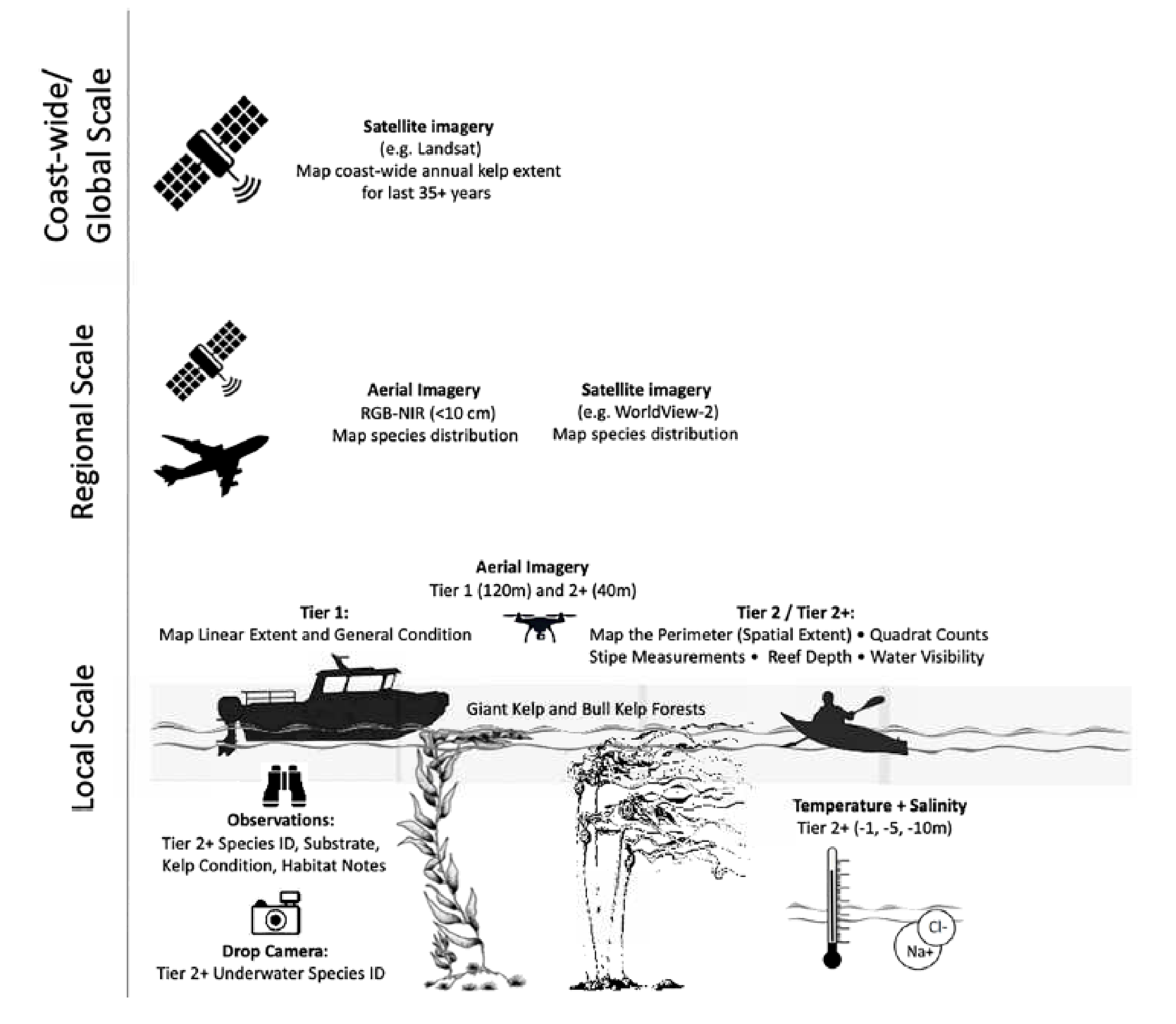

FIGURE 3 | Multi-scale canopy kelp monitoring approach taken by the Marine Plan Partnership. Local scale observations are separated into Tiers which represent increasing complexity of measurements.

Figure 7. Multi-scale canopy monitoring approach from the Marine Plan Partnership (MaPP) in British Columbia (from Cavanaugh et al., 2021).

4.2 Status and Trends

Washington State is home to 22 species of kelp (Mumford, 2007; Calloway et al., 2020). Two kelp species form extensive floating canopies, giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*). Giant kelp is limited to the open coast and the western Strait of Juan de Fuca. Bull kelp is broadly distributed; it occurs in all of the oceanographic sub-basins throughout greater Puget Sound, except Hood Canal. Floating kelp canopies grow along approximately 11% of Washington's shoreline, but are less widespread than understory kelp, which is found along 33% of the shoreline (Figure 8; Nearshore Habitat Program, 2001). Floating kelp canopies are generally more abundant in areas with strong waves and currents, proximate to oceanic influence.

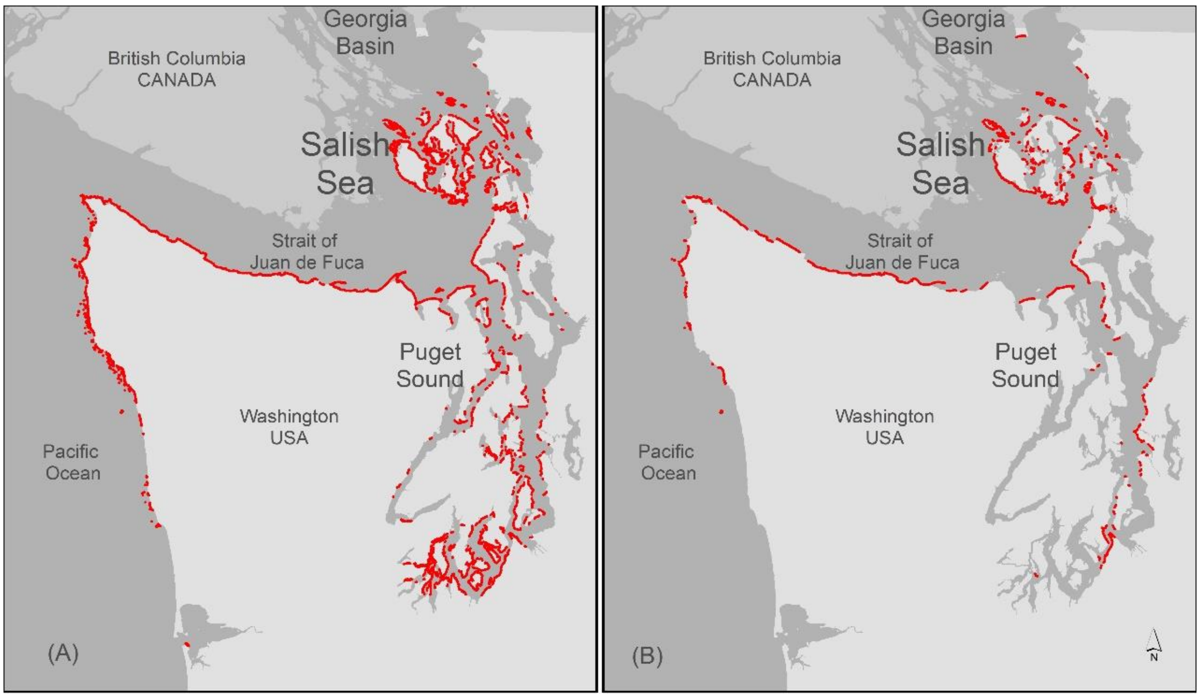

Figure 8. (A) understory and (B) floating kelp distribution in Washington State (Nearshore Habitat Program, 2001).

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

Among kelp species, abundance is positively related to relatively colder water temperatures and higher nutrient concentrations at multiple life stages, and is often linked to large-scale climate drivers (Dayton, 1985; Cavanaugh et al., 2012; Wernberg et al., 2012; Wernberg et al, 2016; Pfister et al., 2018; Muth et al., 2019; Hamilton et al., 2020). Because cold sea surface temperatures are often associated with increased nitrate, the separate role of each factor is difficult to separate. Local interactions such as herbivory and trophic cascades are also associated with patterns in kelp abundance (Graham, 2002; Watson and Estes, 2011; Smith et al., 2021). Variation in abundance has also been associated with other physical conditions, notably light, water motion, and substrate. Many human activities are known to impact kelp, including development, agriculture, and forestry (Wernberg et al., 2019). Researchers have identified factors including warming (Filbee-Dexter et al., 2016; Wernberg et al., 2019), eutrophication (Moy et al., 2012), acidification (Connell and Russell, 2010), changes to community structure (Steneck et al., 2013), and sedimentation (Rubin et al., 2017) as contributing factors that often interact. There is a pressing need to identify the extent to which human activities are impacting kelp forest condition.

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

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

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

Long-term studies in South Puget Sound and Central Puget Sound identified major declines over more than a century; recent floating kelp extent represented 20% of the extent of all historical observations (Figure 9). Many of the losses that were summarized in these studies were observed locally, including the disappearance of bull kelp from the shorelines of Bainbridge Island over the last 2 decades (observed by the Puget Sound Restoration Fund staff). Detailed temporal analysis within South Puget Sound showed that declines occurred throughout the time period, rather than abruptly (Berry et al., 2021). Floating kelp remains common in areas with intense currents and mixing, such as the Tacoma Narrows and Admiralty Inlet. Beds in other areas also persist. This spatial pattern suggests that areas with intense currents and mixing could be refugia from common kelp stressors. However, notable exceptions to this general spatial pattern underline the fact that other factors also determine floating kelp canopy distribution.

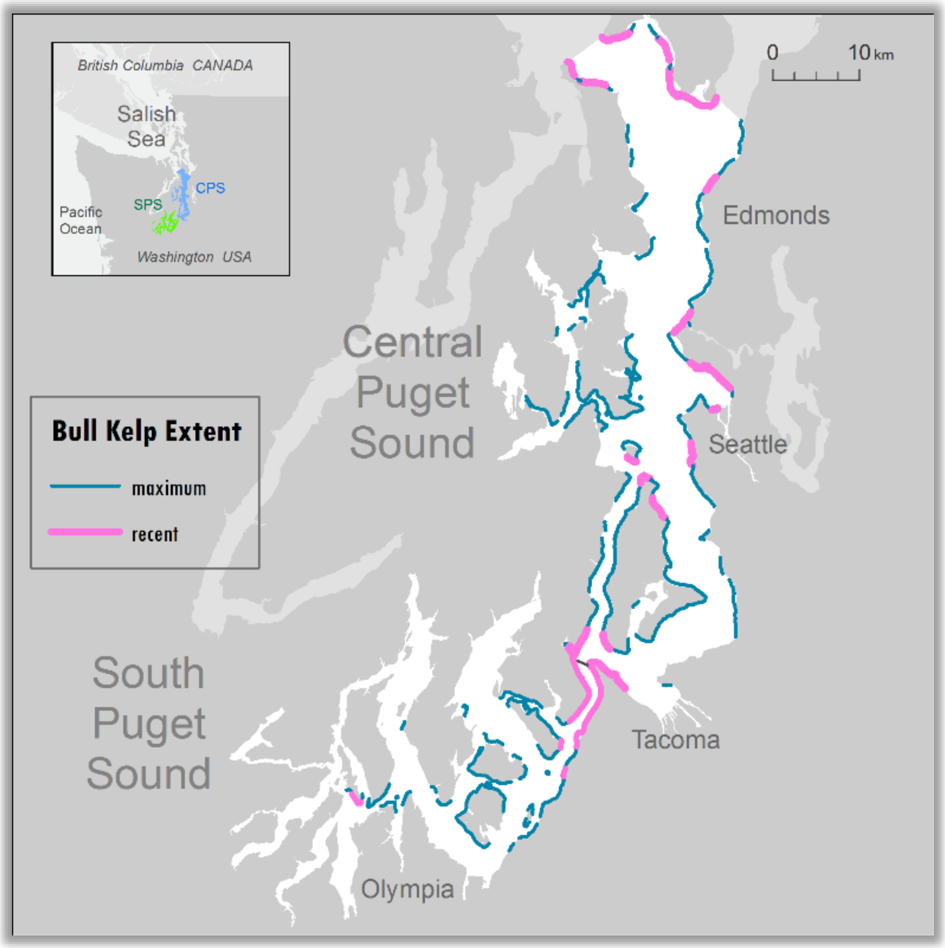

Figure 9. Comparison of the recent extent of bull kelp canopies to the cumulative maximum of all recorded observations in South Puget Sound and Central Puget Sound. The cumulative maximum extent was synthesized from historical data sources, including charts, surveys and (Berry et al., 2020, Berry et al., 2021).

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

- Within South Puget Sound, substantial declines occurred at all four of the beds monitored by DNR between 2013 and 2019. At two sites, bull kelp disappeared and has not returned (Berry et al., 2019; Calloway et al., 2020). Between 2018 and 2020, monitoring sites were added in the Tacoma Narrows and Central Puget Sound. The data records for these sites are not yet long enough to test for changes over time.
- Since 2015, citizen-science kayak surveys detected substantial kelp canopy losses at sites near Mukilteo and Meadowdale in Snohomish County, without subsequent recovery (more information available from Snohomish County MRC). Other areas monitored by the MRCs were relatively stable during this time period, or dropped and then rebounded.
- Along the open coast and Strait, total canopy area decreased to half of its long-term average in 2014, then rapidly rebounded in 2015 (DNR, unpublished data). The strong rebound contrasts with persistent losses in northern California during this time period (Rogers-Bennett and Catton, 2020).
- At DNR's northern aquatic reserves, floating kelp canopy declines were observed in 2014, followed by recovery. However, the timing of recovery was distinct; the sub-areas proximate to oceanic influence and mixing began to recover in 2015, while increased abundances at the Cherry Pt Aquatic Reserve were delayed until 2017 (DNR unpublished data).

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

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

4.3 Candidate datasets

As part of initial scoping for the *floating kelp canopy area* indicator, we identified two general types of data and existing datasets that could be used to assess condition:

- Geographic assessment units
- Floating kelp canopy datasets

4.3.1 Geographic Assessment Units

Most Vital Sign indicators are summarized throughout greater Puget Sound, and also tracked within spatial sub-divisions that capture meaningful differences in the indicator, such as 'spawning per river' for Chinook salmon. Selecting sub-areas for monitoring floating kelp will be important because floating kelp distribution and trends are known to be distinct within portions of Puget Sound. For indicators such as kelp, that have widespread distribution and are known to respond to local and regional conditions, sub-areas are generally based on prioritized physical, biological and/or management factors. The total number of sub-areas is often limited by sampling effort – a sufficient number of samples per sub-area are needed to characterize status and trends.

This section summarizes a series of sub-area classifications that could inform the delineation of floating kelp sub-areas. The challenge in defining sub-areas is to select a tractable number of sub-areas for sampling that capture the most important spatial differences. Increasing the resolution of the delineation allows for greater spatial discrimination, but usually also requires greater sampling effort. While many individual delineations exist, there are clear commonalities. One widely used sub-basin delineation (Figure 10) was created by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). We highlight commonalities and differences among a variety of sub-area classifications (Appendix 1):

- The outer coast and the inland sea are often divided to capture marine vs estuarine conditions (eg., TNC ecoregions). Two alternatives for the boundary are: 1) mid-way along the Strait of Juan de Fuca (TNC and rockfish); 2) Cape Flattery.
- PSNERP excluded the outer coast because it was outside the project area, a common approach for the Puget Sound Vital Signs. Based on species considerations, NOAA's Rockfish Recovery Plan placed the boundary of Puget Sound farther east, at the Victoria Sill, near Port Angeles.
- The *Kelp Plan* adopted the rockfish recovery boundary because it was motivated by rockfish recovery needs and concerns about kelp losses and stressors are lower along the western Strait.
- Within greater Puget Sound, basic oceanographic processes are commonly captured by sub-dividing the region into oceanographic basins at sills. In addition to capturing oceanographic characteristics, sub-basins divide the study area into areas with similar environmental characteristics and stressors.
- The classification of the San Juan Islands often varies among delineations, with three main alternatives: independent, lumped with Georgia Strait or lumped with the Strait of Juan de Fuca. The San Juan Islands have intermediate characteristics overall and strong gradients. The north and south portions are more similar to adjacent areas in many attributes than they are to each other.
- PSNERP differentiates a small sub-basin around North Central Puget Sound, a narrow waterway with high currents and intense mixing. Other classifications driven by physical oceanographic considerations, such as Live Ocean, further discriminate similar areas of high currents and intense mixing.
- Hood Canal, South Puget Sound and Central Puget Sound are frequently discriminated, although the precise location of the boundary varies. Whidbey sub-basin and Saratoga Passage are often lumped as a unit. Sometimes these areas are lumped due to sampling considerations.

- Watershed-based classifications like WRIA's are important for considering salmonid habitat. However, these classifications are less meaningful when extended into marine areas.
- Sampling programs often strive to select similarly sized sub-areas, or to avoid small sub-areas, in order to ensure a sufficient and balanced number of samples can be collected in each sub-area.

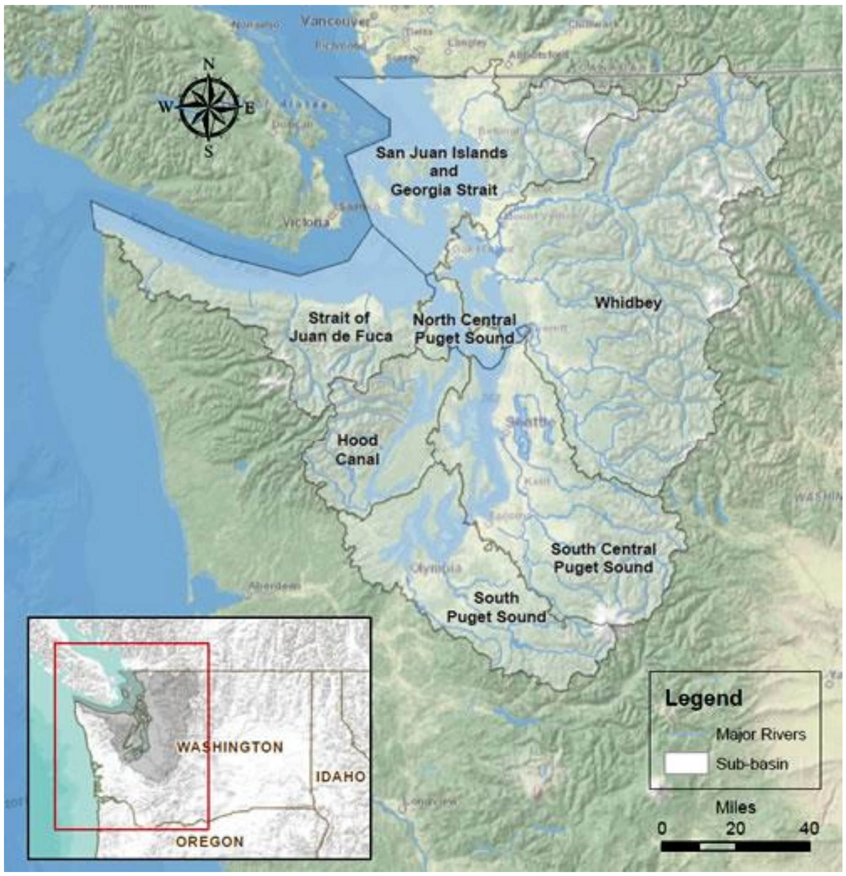

Figure 10. Sub-basins defined by PSNERP (https://salishsearestoration.org/wiki/Puget_Sound_Sub-basins).

In addition to sub-area classifications, some sampling programs employ site-scale spatial frameworks at the approximate scale of kilometers of shoreline for collecting and summarizing data. Some site-scale frameworks that exist in the study area and have been used for kelp inventory and monitoring:

- DNR divided nearshore areas within Puget Sound comprehensively into sites. These sites form the basis of eelgrass monitoring in the Submerged Vegetation Monitoring Program (Dowty et al., 2019, Figure 20). The initial delineation divided the -6 m bathymetry contour into 1 km sections has been used for the Marine Vegetation Atlas and historical studies of change in kelp over time (Berry et al., 2021). For eelgrass monitoring, sites within extensive embayments were grouped into 'flats'.

- The Washington State ShoreZone Inventory sub-divided the upper intertidal shoreline based on geomorphic characteristics.
- DNR's long-term monitoring along the open coast, Strait of Juan de Fuca and Aquatic Reserves divided the shoreline into map indexes that are defined by geographic features such as headlands (described in next section).
- Boat-based monitoring of floating kelp beds by the MRCs and DNR has defined sites for repeated surveys (described in next section).

4.3.2 Floating Kelp Canopy Datasets

Floating kelp extent has been described using a variety of methods in Washington State (Figure 11 and Appendix 3). Surveys generally included two species: giant kelp (*Macrocystis pyrifera*) and the bull kelp (*Nereocystis luetkeana*). Here, we identify a short-list of candidate datasets, with a focus on datasets that cover broad spatial extents and/or multiple years and differentiate floating kelp canopies from other kelp species. All of the datasets summarized here contain spatial features, some also include tabular data. The most common spatial features are:

- 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.
- Bed – the spatial extent of nearby canopies, aggregated to include small gaps between kelp floating tissues. Also called bed perimeter (MRCs) and bed planimeter (DNR). 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. applying a buffer around the canopy).

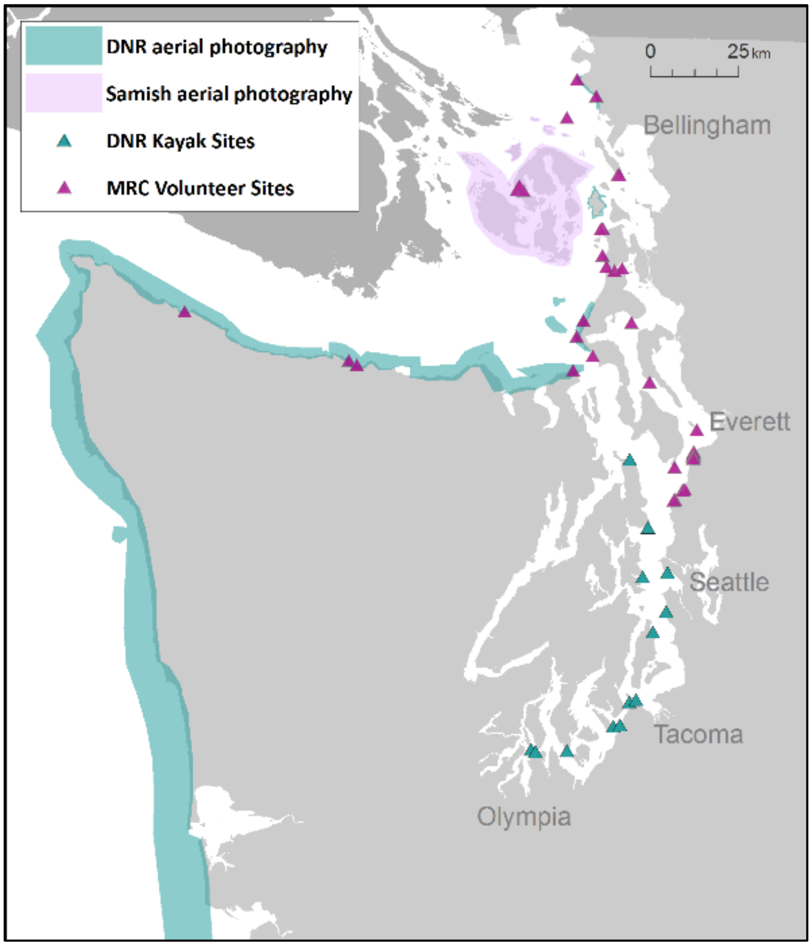

Figure 11. Candidate datasets that describe floating kelp canopy extent. Two statewide datasets are not included in this map: The ShoreZone Inventory and Fertilizer Investigations.

The only modern dataset that describes floating kelp statewide is the Washington State ShoreZone Inventory, which surveyed the shoreline comprehensively over 6 years (1994-2000). While the ShoreZone Inventory effectively characterized the presence of floating canopies over a large area, the abundance information is generalized, which limits its ability to detect changes over time. Within each ShoreZone shoreline unit, the proportion of the linear unit with alongshore floating canopies is categorized as absent (0%), patchy (<50%) or continuous (>50%). Small, low-density beds that were known to be present at the time of the survey in some areas were missed.

DNR's long-term monitoring along the Open Coast and Strait of Juan de Fuca (COSTR) represents the longest and most consistently collected floating kelp dataset. The program has conducted annual aerial photography-based surveys since 1989 (except 1993) during late summer, the season of maximum floating kelp extent in the study area. This dataset has two major strengths: 1) data collection and processing methods have been highly consistent throughout the temporal record; and 2) the aerial photography platform collected imagery during narrow temporal windows with calm sea-state, low-tide and slack currents. Starting in 2011, these methods were expanded to include DNR's Aquatic Reserves, which have also been surveyed annually. The most consistent and accurate data in these datasets are the tabular summaries of canopy area and bed area, summed at the scale of geomorphically-defined stretches of shoreline known as map indexes. The spatial data are less precise and accurate due to spatial data processing methods. The spatial data could be substantially improved by re-scanning the original hand-delineated maps. Annual survey data is processed through 2019, the years 2020 and 2021 are being processed.

The Samish Indian Nation delineated beds using aerial photography in San Juan County in 2004/2006, 2016 and 2019. They additionally classified Skagit County shorelines in 2019 using similar methods. To identify important fishing areas associated with kelp canopies over longer time periods, the Samish Indian Nation employed Traditional Ecological Knowledge (TEK) to delineate general areas with persistent beds by interviewing fishermen.

Two multiyear datasets have delineated floating kelp beds at sites using kayaks or small motorized boats. Volunteers with Marine Resources Committees (MRCs) have delineated beds since 2015 in the seven northern counties (Clallam, Island, Skagit, Jefferson, San Juan, Snohomish, Whatcom). DNR scientists have delineated beds in South Puget Sound and Central Puget Sound since 2013. For both programs, many of the sites have been monitored for a subset of all years.

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

One historical dataset comprehensively delineated floating kelp beds in 1911-12 for harvest as fertilizer (Crandall, 1915). While this data source provides useful information on the location of beds, studies by Pfister et al. (2018) and Berry et al. (2021) suggest that data completeness may vary by region, and the surveys may have targeted large, accessible beds.

5. Conclusions: Key Considerations for Indicator Development

This section summarizes the key considerations that the *Project Team* compiled to begin the process of indicator development (Table 2). Considerations are framed in terms of the broad scoping questions outlined in Section 1.3.

Table 2. Summary of key considerations for each scoping question

Question	Key Considerations
Who is the indicator for? How will it be used?	- Diverse audiences. - Single simple figure for rapid communication. - Detailed metrics that drill down into the data.
The indicator is limited to describing status and trends in floating kelp canopies. What linkages are most important?	- Linkages to stressors, management actions, ecosystem components, human well-being. - Additional conceptual model development may be useful as part of indicator development or broader *Kelp Plan* work: o A 'kelp canopy centric' model may provide insight. o A simple model could communicate common understanding. o Advanced models could target additional actions.
What time spans should the indicator consider? Why?	- Short-term (years) - Long-term (decades).
What geographic assessment areas are important? Why?	- Sub-basins within Puget Sound. - Include the open coast.
What metrics and data should be included in the initial indicator? The future indicator?	- Initial canopy area and bed perimeter area from DNR, MRC volunteers, Samish. What else? - Future: a plan for expanding metrics and data is needed. - Currently, resources for data collection and reporting are extremely limited. The program must be scaled to match available resources.

<u>Who is the indicator for? How will it be used?</u>

- Diverse audiences are interested in kelp condition, status, and trends. A single simple figure would achieve rapid communication to a wide audiences. A single simple figure is ideal for the indicator reporting platform. The PS Info reporting platform prioritizes executive-level summaries of each indicator with a single visualization. The system is optimized for rapid reporting to a broad audience, with provisions to link to additional information sources.

- In addition to producing a summary indicator visualization, additional metrics and detailed visualizations could drill down into the kelp data with increasing temporal, geographic and numerical detail.
- Links to the independent web sites of the *Project Team* members would directly communicate the work and perspectives of the contributing organizations and encourage further collaborations.
- In addition to reporting results, distribution of data could support further indicator use. Because spatial data maintenance and distribution requires substantial resources, it will be important to prioritize products and articulate the benefits of data distribution.
- A quantitative recovery target for the *floating kelp canopy area* indicator is not required at this time. We anticipate that the Partnership will develop targets for all indicators in the future.
- The *Project Team* will seek out broad participation by requesting guidance during this project and exploring interest in development of a framework for future engagement.

<u>The indicator is limited to describing status and trends in floating kelp canopies. What linkages are most important?</u>

- In order to drive conservation and recovery actions, it is important to link the kelp indicator to stressors and management responses. This is a major undertaking that is part of broader *Kelp Plan* work. It may be possible to identify and complete targeted tasks in these areas within the *floating kelp canopy area* indicator development project.
- Conceptual models exist for the PSEMP program, and the *Beaches and Marine Vegetation* Vital Sign. Further development of conceptual models or other tools may be needed to: 1) direct research and monitoring; 2) prioritize management actions; 3) deepen public understanding. Is a 'canopy kelp centric' model needed?
- The PS Info reporting platform provides information on the condition of the indicator. The platforms also allows for text summaries on key stressors/pressures and management actions.
- The *floating kelp canopy area* indicator will be one component of many actions that address the six strategic goals identified in the *Kelp Plan* (Calloway et al. 2020). Coordination with the *Kelp Plan* implementers will be important.
- A simple conceptual model could be a useful communications tool to simply convey collective understanding of the system. More advanced models could drive research and actions. The *Project Team* is looking for further input on the relative priority of further developing a conceptual model. The *Project Team* proposed addressing these topics in the context of the needs of the *Kelp Plan*.

What time spans should the indicator consider? Why?

- Separate metrics for short-term and long-term trends would allow us to track known differences in the response of floating kelp over time within portions of Puget Sound.
- Short-term metrics are often useful to assess management actions and short-term conditions, such as weather events.
- Long-term metrics can provide insight into changes from long-term baselines and ecosystem impacts.
- Data availability will likely drive differences in the construction of short and long-term metrics. While recent data exist for an ongoing data stream, long-term trends assessments are currently limited to several focus studies.

What geographic assessment areas are important? Why?

- Vital Sign indicators track metrics related to condition, and most often consider changes over time. Optimally, results are reported sound-wide, as well as within smaller geographic assessment units.
- Geographic assessment units are needed to capture known differences in kelp status and trends among sub-areas in Puget Sound. Oceanographic sub-basins provide a commonly used framework that reflects physical properties. The number of sub-areas and precise boundaries differ in various classifications. Precise sub-area boundaries for the floating kelp canopy indicator should be placed based on environmental considerations and properties of the monitoring data.
- Because trends in floating kelp may be distinct in areas with strong currents and mixing, considering these areas independently would be desirable if resources permit.
- Although the open coast is outside of the Vital Sign study area, inclusion of the open coast in the floating kelp canopy monitoring data set is important for understanding differential responses to environmental conditions and kelp trends across the landscape. Compatible data exist along the open coast.
- Should data collection approaches be prioritized that allow for analysis using different area designations? Examples include ecological considerations and jurisdictional boundaries.

What data should be included in the initial indicator? The future indicator?

- A variety of metrics have been used globally to describe canopy abundance. Commonly, canopy area assessments are implemented in two closely related, yet subtly different, ways: canopy area (the surface area of water covered by all kelp tissues - stipes, bulbs and blades), and bed area (an expansion of canopy area metric to encompass both the individual plants and small gaps between individuals). We propose that the initial indicator accommodate data describing either plant area or bed area yet require consistency in the measure used for analyses of changes over time, to maximize the geographic and temporal scope of analyses using available datasets.

- Common approaches to summarizing data to consider in the short-term include: 1) area, based on summaries of comprehensive data or extrapolation from sites; 2) frequency of stable, increasing, and declining sites.
- In the longer term, metrics that more fully describe abundance, density, biomass, depth range, condition and other factors should be identified and prioritized.
- The major challenge for this project will be to synthesize the distinct existing datasets into a scientifically rigorous indicator. While the existing datasets provide partial coverage of many locations within the study area, individual methods and sampling years vary. These differences make it challenging to develop methods for reliably assessing change over time. This will be particularly challenging because kelp is known to have high interannual variability and time series data are limited.
- The Partnership requires indicators to be scientifically sound, pertinent to regional ecosystems goals, reliable and practical to measure. Some of these requirements may not be fully met in the Phase 1 indicator that is developed using existing data. As part of indicator development, the project will identify limitations and prioritize future enhancements.
- To guide future work, the project will identify key data gaps related to 1) spatial coverage; 2) short- and long-term temporal coverage; 3) metrics; and 4) data collection protocols.
- Synthesis, update, and distribution of data require substantial resources, yet resources for continuing work on the *floating kelp canopy area* indicator are extremely limited. An important factor will be to develop an indicator that can be maintained with available resources.

6. References

Berry, H. D., Harper, J. R., Mumford Jr., T. F., Bookheim, B. E., Sewell, A. T., Tamayo, L. J. 2001. The Washington State ShoreZone Inventory User's Manual. Olympia, WA: Nearshore Habitat Program, Washington State Department of Natural Resources. Available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-publications.

Berry, H. D., Calloway, M., Mumford, T. F. 2020. Long-term changes in bull kelp in South and Central Puget Sound. Salish Sea Ecosystem Conference. https://cedar.wwu.edu/ssec/2020ssec/allsessions/51/

Berry, H. D., Mumford, T. F., Christiaen, B., Dowty, P., Calloway, M., Ferrier, L., Grossman, E. E., VanArendonk, N. R. 2021. Long-term changes in kelp forests in an inner basin of the Salish Sea. PLoS ONE 16: e0229703. doi: 10.1371/journal.pone.0229703 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0229703

Berry, H., Calloway, M., Ledbetter, J. 2019. Bull kelp monitoring in South Puget Sound in 2017 and 2018. Olympia, WA: Washington State Department of Natural Resources Nearshore Habitat Program. p. 72. Available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-publications.

Berry, H., and Cowdrey, T. 2021. Kelp forest canopy surveys with unmanned aerial vehicles (UAVs) and fixed-wing aircraft: a demonstration project at volunteer monitoring sites in northern Puget Sound. Final report to the Northwest Straits Commission. December 31, 2021. 57 pp.

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

Borgerhoff Mulder, M., and Coppolillo, P. 2005. Conservation: Linking ecology, economics and culture. Princeton University Press.

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

Calloway, M., Oster, D., Berry, H., Mumford, T., Naar, N., Peabody, B., Hart, L., Tonnes, D., Copps, S., Selleck, J., Allen, B., Toft, J. 2020. Puget Sound kelp conservation and recovery plan. Prepared for NOAA-NMFS, Seattle, WA. 52 pages plus appendices. Available at: https://nwstraits.org/our-work/kelp/.

Calloway, M., Berry, H., Ledbetter, J. 2020. Bull kelp in South Puget Sound: differences in stressor intensity and plant condition in South Puget Sound bull kelp forests. ESRI ArcGIS StoryMap available at: https://storymaps.arcgis.com/stories/96fc7e27353c4cc3872a0610881331dd

Campbell, D. T. 2005 [1969]. Ethnocentrism of Disciplines and the Fish-Scale Model of Omniscience. In S. J. Derry, C. D. Schunn, & M. A. Gernsbacher (Eds.), Interdisciplinary collaboration: An emerging cognitive science (pp. 3–21). Lawrence Erlbaum Associates Publishers.

Cavanaugh, K. C., Siegel, D. A., Reed, D. C., Dennison, P. E. 2011. Environmental controls of giant-kelp biomass in the Santa Barbara Channel, California. Marine Ecology Progress Series 429: 1-17. https://doi.org/10.3354/meps09141.

Cavanaugh, K. C., Bell, T., Costa, M., Eddy, N. E., Gendall, L., Gleason, M. G., Hessing-Lewis, M., Martone, R., McPherson, M., Pontier, O., Reshitnyk, L., Beas-Luna, R., Carr, M., Caselle, J. E., Cavanaugh, K. C., Flores Miller, R., Hamilton, S., Heady, W. N., Hirsh, H. K., Hohman, R., Lee, L. C., Lorda, J., Ray, J., Reed, D. C., Saccomanno, V. R., Schroeder. S. B. 2021. A Review of the Opportunities and Challenges for Using Remote Sensing for Management of Surface-Canopy Forming Kelps. Frontiers in Marine Science, 8: 753531., https://www.frontiersin.org/article/10.3389/fmars.2021.753531, DOI=10.3389/fmars.2021.753531

Cavanaugh, K. C., Cavanaugh, K. C., Bell, T. W., Hockridge, E. G. 2021. An automated method for mapping giant kelp canopy dynamics from UAV. Frontiers in Environmental Science 8: 587354. doi: 10.3389/fenvs.2020.58735

Connell, S. D., Russell, B. D. 2010. The direct effects of increasing CO2 and temperature on non-calcifying organisms: increasing the potential for phase shifts in kelp forests. Proceedings of the Royal Society B: Biological Sciences 277(1686): 1409–15. pmid:20053651

Dayton, P. K. 1985. The ecology of kelp communities. Annual Review of Ecology and Systematics 16: 215-45. https://doi.org/10.1146/annurev.es.16.110185.001243.

Dethier, M. N. 1990. A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Dept. Natural Resources. 56 pp. Olympia, Wash. https://www.dnr.wa.gov/publications/aqr_nrsh_marine_class.pdf

DNR Marine Vegetation Atlas https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/washington-marine-vegetation-atlas

Doty, D. C., Buckley, R. M., West, J. E. 1995. Identification and protection of nursery habitats for juvenile rockfish in Puget Sound, Washington. Pages 181–190 Puget Sound Research '95 Proceedings. Puget Sound Water Quality Authority, Olympia, WA

Dowty, P., Ferrier, L., Christiaen, B., Gaeckle, J., Berry, H.. 2019. Submerged Vegetation Monitoring Program 2000-2019 Geospatial Database User Manual. https://www.dnr.wa.gov/publications/aqr_nrsh_svmp_databse_user_manual.pdf

Dowty, P. and Berry, H. 2018. Kelp Forests Along Washington State's Strait Over A Century. ESRI ArcGIS StoryMap available at: https://wadnr.maps.arcgis.com/apps/MapSeries/index.html?appid=6b32b37740a443cb8e8848a8614879a2

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

Filbee-Dexter, K., Feehan, C. J., Scheibling, R. E. 2016. Large-scale degradation of a kelp ecosystem in an ocean warming hotspot. Marine Ecology Progress Series 543: 141–52.

Floberg, J., Goering, M., Wilhere, G., MacDonald, C., Chappell, C., Rumsey, C., Ferdana, Z., Holt, A., Skidmore, P., Horsman, T., Alverson, E., Tanner, C., Bryer, M., Iachetti, P., Harcombe, A., McDonald, B., Cook, T., Summers, M., Rolph, D.. 2004. Willamette Valley – Puget Trough – Georgia Basin Ecoregional Assessment Volume One: Report. https://www.eopugetsound.org/sites/default/files/features/resources/WPG_Ecoregional_Assessment.pdf

Graham, M. H. 2002. Prolonged reproductive consequences of short-term biomass loss in seaweeds. Marine Biology 140: 901–911.

Hamilton, S. L., Bell, T. W., Watson, J. R., Grorud-Colvert, K. A., Menge, B. A. 2020. Remote sensing: generation of long-term kelp bed data sets for evaluation of impacts of climatic variation. Ecology 101(7): e03031. 10.1002/ecy.3031

Hamilton, S., Gleason, M., Godoy, N., Eddy, N., Grorud-Colvert, K. 2022. Ecosystem-based management for kelp forest ecosystems. Marine Policy 136: 104919. 10.1016/j.marpol.2021.104919.

Harguth, H., Stiles, K., Biedenweg, K., Redman, S., O'Neill, S. 2015. Integrated Conceptual Model for Ecosystem Recovery. April 2015. A Technical Memorandum to the Puget Sound Partnership.

Hollarsmith, J. A., Andrews, K., Naar, N., Starko, S., Calloway, M., Obaza, A., Buckner, E., Tonnes, D., Selleck, J., Therriault, T.W. *in press*. Towards a conceptual framework for managing and conserving marine habitats: a case study of kelp forests in the Salish Sea. Ecology and Evolution.

Jensen, J. R., Estes, J. E., Tinney, L. 1980. Remote sensing techniques for kelp surveys. Photogrammetric Engineering and Remote Sensing 46, 743–755.

Johnson, J. T., Howitt, R., Cajete, G., Berkes, F., Pualani Louis, R., Kliskey, A.. 2016. Weaving Indigenous and sustainability sciences to diversify our methods. Sustainability Science 11: 1–11. https://doi.org/10.1007/s11625-015-0349-x

Johnson, S. P., and Schindler, D. E. 2009. Trophic ecology of Pacific salmon (Oncorhynchus spp.) in the ocean: a synthesis of stable isotope research. Ecological Research 24: 855–863.

Kaiser, B. A., Hoeberechts, M., Maxwell, K. H., Eerkes-Medrano, L., Hilmi, N., Safa, A., Horbel, C., Juniper, S. K., Roughan, M., Theux Lowen, N., Short, K., Paruru, D. 2019. The importance of connected ocean monitoring knowledge systems and communities. Frontiers in Marine Science 6: 309. https://doi.org/10.3389/fmars.2019.00309

Kotaska, J. 2019. Reconsidering Collaboration: What Constitutes Good Research with Indigenous Communities? Collaborative Anthropologies 11(2): 26–54. https://doi.org/10.1353/cla.2019.0005

LeFlore, M., Bunn, D., Sebastian, P., Gaydos, J. K. 2021. Improving the probability that small-scale science will benefit conservation. Conservation Science and Practice 4(1): e571. https://doi.org/10.1111/csp2.571

Love, M. S., M. H. Carr, Haldorson, L. J. 1991. The ecology of substrate-associated juveniles of the genus Sebastes. Rockfishes of The Genus Sebastes : Their Reproduction And Early Life History. Environmental Biology of Fishes 30 (1-2): 225–243.

Mauser, W., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., Moore, H. 2013. Transdisciplinary global change research: the co-creation of knowledge for sustainability. Current Opinion in Environmental Sustainability 5(3–4): 420-431, ISSN 1877-3435, https://doi.org/10.1016/j.cosust.2013.07.001.

McManus, E., Jenni, K., Clancy, M., Ghalambour, K., Langdon, J., Redman, S., Labiosa, B., Currens, K., Landis, W., Stiles, K., Quinn, T., Burke, J. 2014. The 2014 Puget Sound Pressures Assessment. December 2014. Puget Sound Partnership Technical Report 2014-04. 53 pp. with Appendices (278pp.) https://www.eopugetsound.org/sites/default/files/features/resources/2014-PSPA-Main-Report-Final.pdf

McManus, E., DuranceK., Khan, S. 2020. Revisions to Puget Sound Vital Signs and Indicators. A Collaboration of Ross Strategic and Puget Sound Partnership. Olympia, WA. 87pp. https://salishsearestoration.org/images/b/b8/McManus_et_al_2020_vital_sign_evaluation.pdf

Moy, F. E. and Christie, H. 2012. Large-scale shift from sugar kelp (Saccharina latissima) to ephemeral algae along the south and west coast of Norway. Marine Biology Research 8(4): 309–21.

Mumford, T. F. 2007. Kelp and eelgrass in Puget Sound, Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at: http://www.pugetsoundnearshore.org. 27 pp.

Muth, A. F., Graham, M. H., Lane, C. E., Harley, C. D. G. 2019. Recruitment tolerance to increased temperature present across multiple kelp clades. Ecology 100: e02594.

Nearshore Habitat Program. The Washington State ShoreZone Inventory. Olympia, WA.: Washington State Department of Natural Resources; 2001. Available from: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory.

NRC (National Research Council). 2000. Ecological Indicators for the Nation. Washington D.C, National Academy Press.

Nature Conservancy, 2004. Willamette Valley-Puget Tough-Georgia Basin Ecoregional Assessment. https://www.eopugetsound.org/articles/willamette-valley-puget-trough-georgia-basin-ecoregional-assessment

Naar, Ne. 2020. Appendix B: The cultural importance of kelp for Pacific Northwest Tribes. In: Calloway, M., Oster, D., Berry, H., Mumford, T., Naar, N., Peabody, B., Hart, L., Tonnes, D., Copps, S., Selleck, J., Allen, B., Toft, J. 2020. Puget Sound kelp conservation and recovery plan. Prepared for NOAA-NMFS, Seattle, WA. 52 pp plus appendices. Available at: https://nwstraits.org/media/2957/appendix_b_the-cultural-importance-of-kelp-for-pacific-northwest-tribes.pdf

Niemeijer, D. and de Groot, R. S. 2008. A conceptual framework for selecting environmental indicator sets. Ecological Indicators 8: 14-25.

O'Neill, S., Redman, S., Sullivan, C., Stiles, K., Harguth, H., Collier, T. 2018. Evolving the Portfolio of Indicators to Assess and Report on the Condition and Recovery of the Puget Sound Ecosystem: Moving from Theory to Practice. Puget Sound Partnership. Available at: https://pspwa.app.box.com/s/d22kacx5ibwq6r1efh9mtld1d65ltyro

Palmer-McGee, C. 2019. A decade of disappearance: Kelp canopies in Samish traditional territory. ArcGIS online story map. https://storymaps.arcgis.com/stories/b9f979a547004c32a616b5319a6410c0

Pfister, C. A., Berry, H. D., Mumford, T. 2018. The dynamics of Kelp Forests in the Northeast Pacific Ocean and the relationship with environmental drivers. Journal of Ecology 106: 1520-33. https://doi.org/10.1111/1365-2745.12908.

Rubin, S.P., Miller, I.M., Foley, M.M., Berry, H.D., Duda, J.J., Hudson, B.,Elder, N. E., Beirne, M. M., Warrick, J. A., McHenry, M. L., Stevens, A. W., Eidam, E. F., Ogston, A. S., Gelfenbaum, G., Pedersen, R. 2017. Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. PLoS ONE 12(12): e0187742. https://doi.org/10.1371/journal.pone.0187742. PubMed PMID: WOS:000417469900006.

Schiel, D. R., and Foster, M. S. 2006. The population biology of large brown seaweeds: Ecological consequences of multiphase life histories in dynamic coastal environments. Annual Review of Ecology, Evolution, and Systematics 37: 343-372.

Schomaker, M. 1997. Development of environmental indicators in UNEP. In: Paper Presented at the Land Quality Indicators and their Use in Sustainable Agriculture and Rural Development, January 25-26, 1996. Rome, FAO, pp. 35-36.

Schroeder, S. B., Dupont, C., Boyer, L., Juanes, F., Costa, M. 2019. Passive remote sensing technology for mapping bull kelp (Nereocystis luetkeana): a review of techniques and regional case study. Global Ecology and Conservation 19: e00683. doi: 10.1016/j.gecco.2019.e00683

Shaffer, A. J., Munsch, S. H., Cordell, J. R. 2020. Kelp forest zooplankton, forage fishes, and juvenile salmonids of the northeast Pacific nearshore. Marine and Coastal Fisheries 12(4): 4-20.

Simenstad, C., Logsdon, M., Fresh, K., Shipman, H., Dethier, M., Newton, J. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Puget Sound Nearshore Partnership Report No. 2006-03. Seattle: Washington Sea Grant Program, University of Washington. Available at http://pugetsoundnearshore.org.

Smith, J. G., Tomoleoni, J., Staedler, M., Lyon, S., Fujii, J., Tinker, M. T. 2021. Behavioral responses across a mosaic of ecosystem states restructure a sea otter–urchin trophic cascade Proceedings of the National Academy of Sciences Mar 2021, 118(11): e2012493118, DOI: 10.1073/pnas.2012493118

Steneck, R. S., Leland, A., McNaught, D. C., Vavrinec, J. 2013. Ecosystem flips, locks, and feedbacks: the lasting effects of fisheries on Maine's kelp forest ecosystem. Bulletin of Marine Science 89(1): 31–55.

Sunday, J. M., Fabricius, K. E., Kroeker, K. J., Anderson, K. M., Brown, N. E., Barry, J. P., Connell, S. D., Dupont, S., Gaylord, B., Hall-Spencer, J. M., Klinger, T., Milazzo, M., Munday, P. L., Russell, B. D., Sanford, E., Thiyagarajan, V., Vaughan, M. L. H., Widdecombe, S., Harley, C. D. G. 2016. Ocean acidification can mediate biodiversity shifts by changing biogenic habitat. Nature Climate Change 7: 81–85. https://doi.org/10.1038/nclimate3161

Uffman-Kirsch, L. B., B. J. Richardson, van Putten, E. I. 2020. A New Paradigm for Social License as a Path to Marine Sustainability. Frontiers in Marine Science 7: 1–6. https://www.frontiersin.org/articles/10.3389/fmars.2020.571373/full

Vander Schaaf, D., G. Wilhere, Z. Ferdaña, K. Popper, M. Schindel, P. Skidmore, D. Rolph, P. Iachetti, G. Kittel, R. Crawford, D. Pickering, Christy, J. 2006. Pacific Northwest Coast Ecoregion Assessment. Prepared by The Nature Conservancy, the Nature Conservancy of Canada, and the Washington Department of Fish and Wildlife. The Nature Conservancy, Portland, Oregon.

Watanabe, H., M. Ito, A. Matsumoto, Arakawa, H. 2016. Effects of sediment influx on the settlement and survival of canopy-forming macrophytes. Scientific Reports 6: 18677.

Watson, J., & Estes, J. A. 2011. Stability, resilience, and phase shifts in rocky subtidal communities along the west coast of Vancouver Island, Canada. Ecological Monographs 81: 215–239. https://doi.org/10.1890/10-0262.1

Wernberg, T., Bennett, S., Babcock, R. C., de Bettignies, T., Cure, K., Depczynski, M., Dufois, F., Fromont, J., Fulton, C. J., Hovey, R. K., Harvey, E. S., Holmes, T. H., Kendrick, G. A., Radford, B., Santana-Garcon, J., Saunders, B. J., Smale, D. A., Thomsen, M. S., Tuckett, C. A., Tuya, F., Vanderklift, M. A., Wilson, S. 2016. Climate-driven regime shift of a temperate marine ecosystem. Science 353: 169–172. https://doi.org/10.1126/science.aad8745

Wernberg, T., Smale, D. A., Tuya, F., Thomsen, M. S., Langlois, T. J., de Bettignies, T., Bennett, S., Rousseaux, C. S. 2012. An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. Nature Climate Change 3: 78–82. https://doi.org/10.1038/nclimate1627

Wernberg, T., K. Krumhansl, K. Filbee-Dexter, Pedersen, M. F. 2019. Status and trends for the world's kelp forests. Pp. 57-78 in World Seas: An Environmental Evaluation, Elsevier, Oxford, United Kingdom.

WSAS (Washington State Academy of Sciences). 2012. Washington State Academy of Sciences Committee on Puget Sound Indicators, Sound Indicators: A Review for the Puget Sound Partnership. Olympia, WA. 101pp. Available at: https://www.eopugetsound.org/articles/sound-indicators-review-puget-sound-partnership

Appendix 1. Conceptual Models

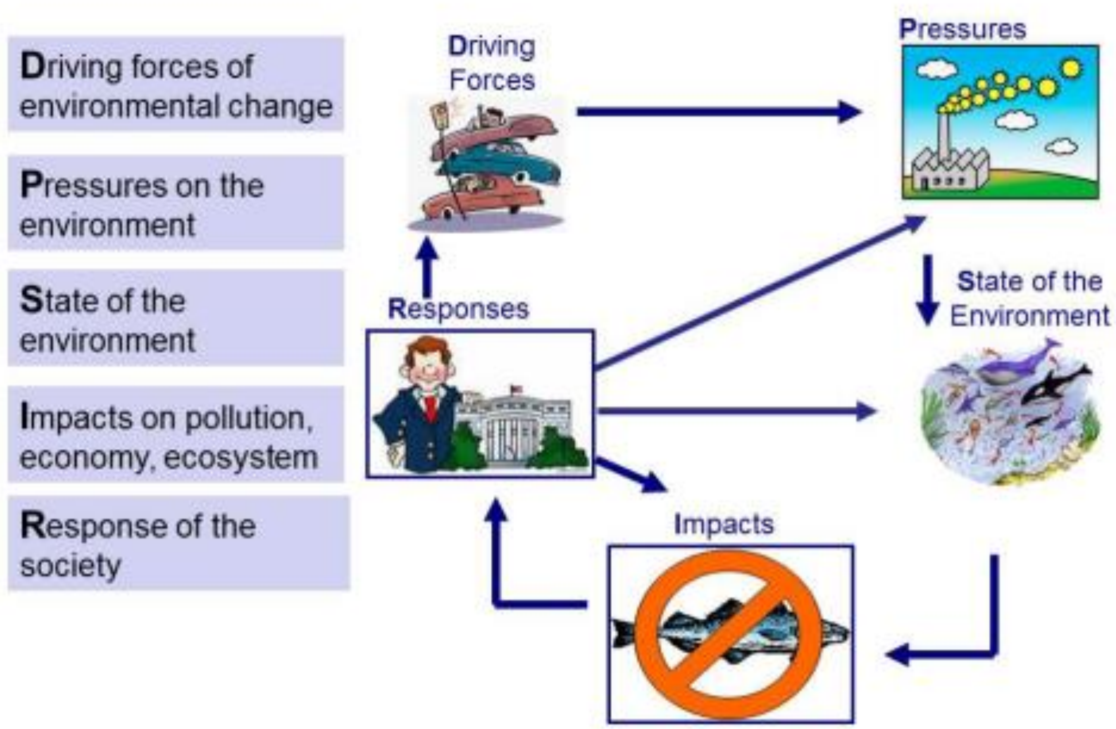

Figure 12. A cartoon of a Driver-Pressure-State-Impact-Response (DPSIR) causal framework illustrating the links among indicators of ecosystem conditions (i.e., State and Impacts) with Pressures to ecosystem health and policy/strategy/management Responses (from O'Neill et al. 2018).

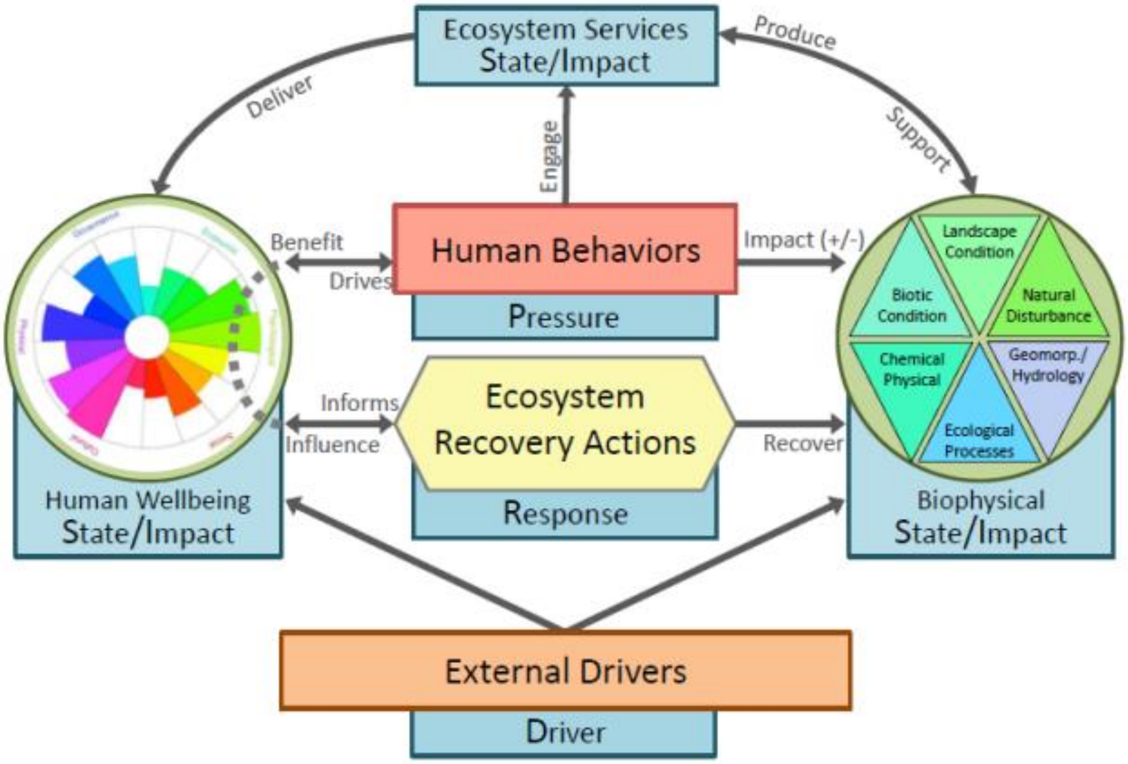

Figure 13. Integrated conceptual model for ecosystem recovery (from O'Neill et al. 2018). The integrated model includes three embedded frameworks: the Driver-Pressure-State-Impact-Response framework, the Essential Ecological Attribute Framework (EPA 2002) and the human wellbeing framework (from Harguth et al. 2015).

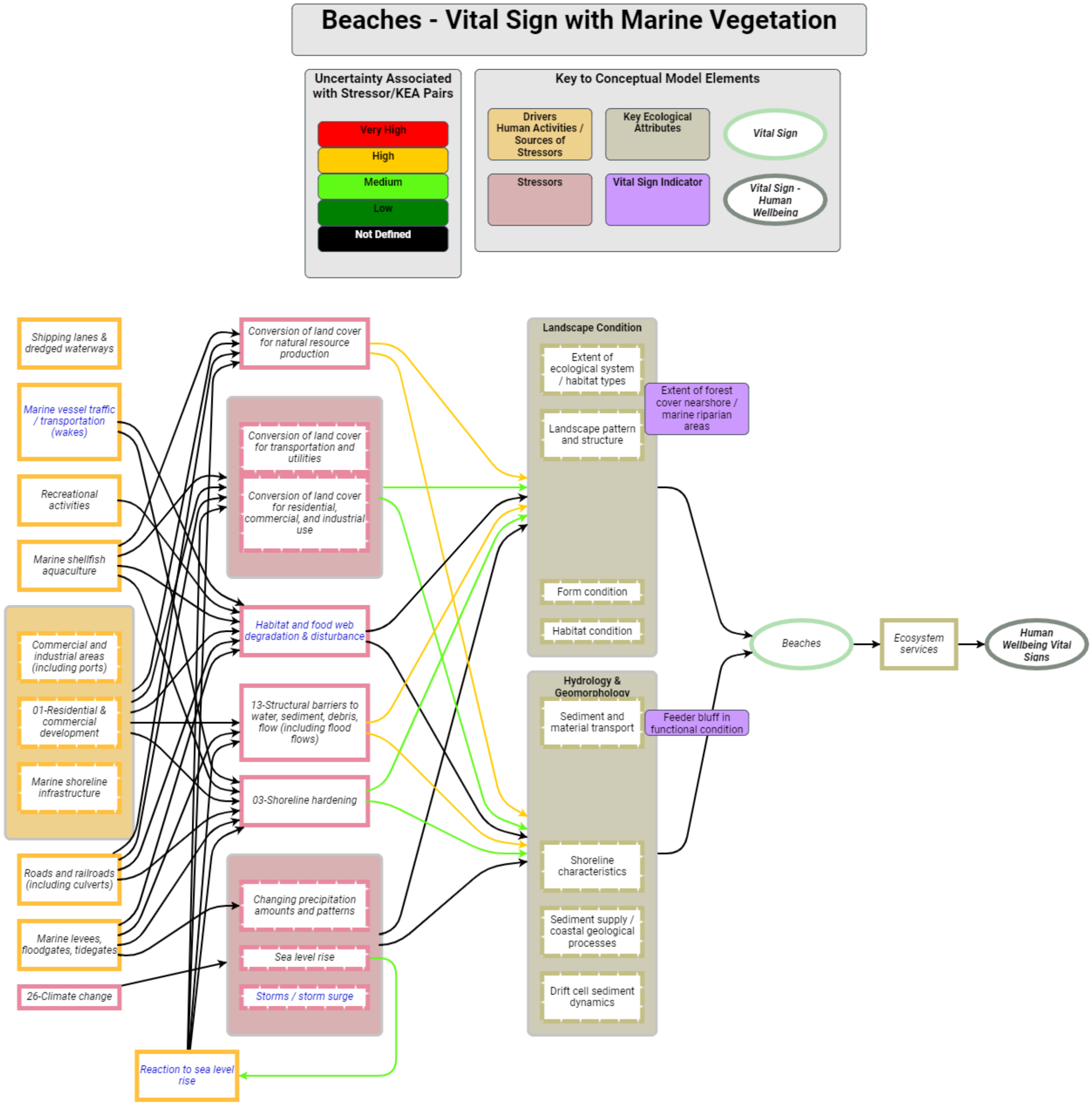

Figure 14. The conceptual model for the Marine Vegetation portion of the Beaches and Marine Vegetation Vital Sign, developed as part of the Vital Signs Revision (McManus et al. 2020). The *floating kelp canopy area* indicator falls within this Vital Sign. Zoom into the image to read text.

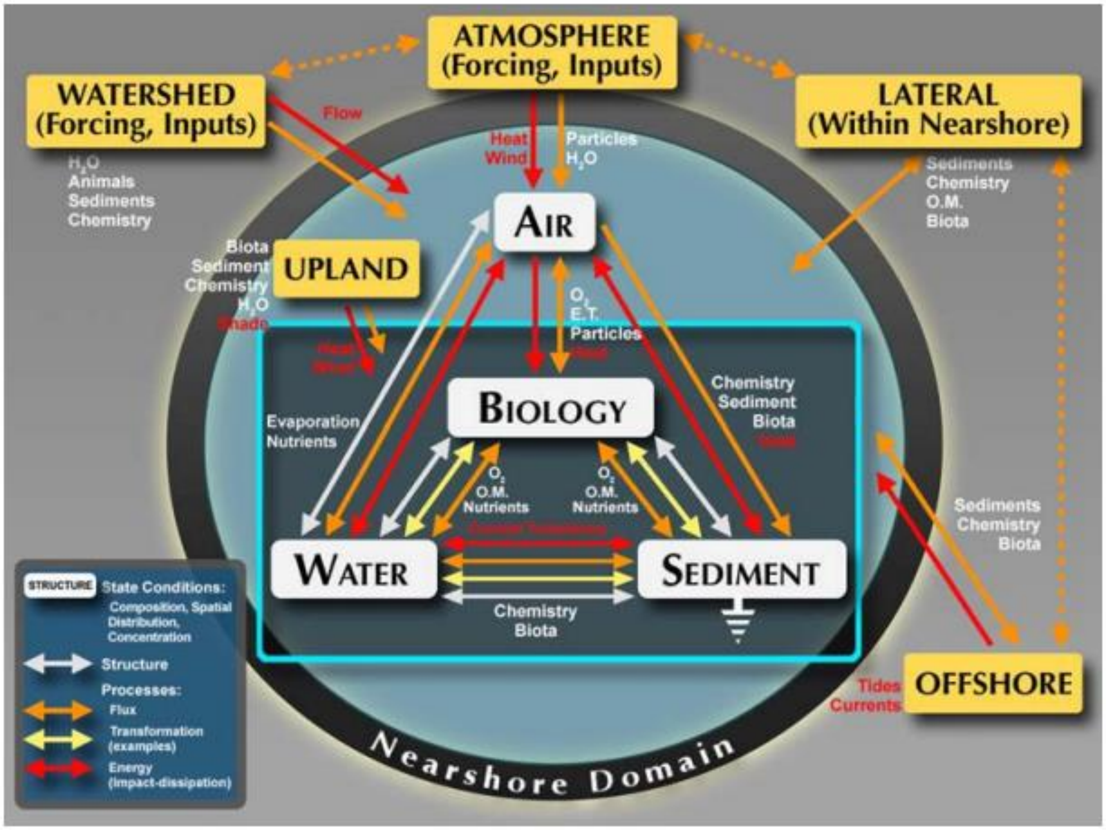

FIGURE B-11. PROCESSES AFFECTING THE STRUCTURE OF AIR, BIOLOGY, WATER AND SEDIMENT COMPONENTS, WITH EXAMPLES OF FLUXES, TRANSFORMATIONS, AND ENERGY INTERACTIONS AMONG THESE PRIMARY COMPONENTS OF THE NEARSHORE. THE OVAL SHADED AREA REPRESENTS THE SUITE OF INTERACTIONS BETWEEN SEDIMENT AND BIOLOGY COMPONENTS. ET = EVAPOTRANSPIRATION; OM = ORGANIC MATTER. (FROM SIMENSTAD ET AL. 2006)

Figure 15. The process conceptual model of the nearshore developed by the Nearshore Science Team for the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) for assessing restoration of the nearshore system (Simenstad et al. 2006). Related models were also developed for domain, organizations, change/action scenario, and time variability.

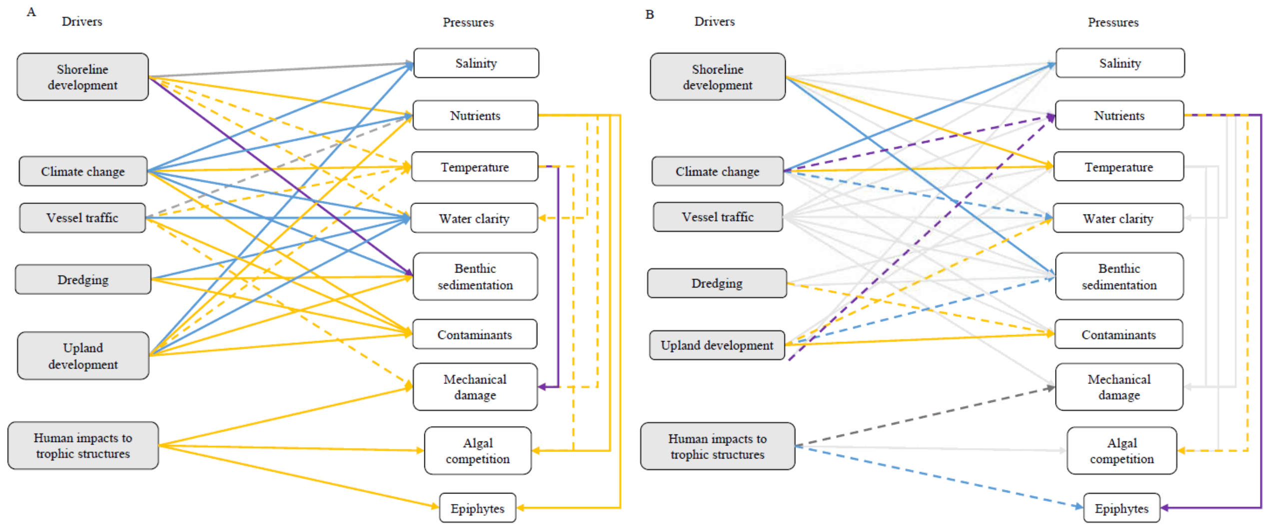

Figure 16. Results of a literature search of kelp stressors based on a simplified conceptual diagram, including results for (A) broader coast literature and (B) Salish Sea literature. Color indicates the direction of the relationship (blue represents negative, dark gray – neutral, orange – positive, purple – no consensus, and light gray – no literature) while the texture of the line indicates the number of studies identified (dashed represents two or fewer studies, solid indicates > 2). .See also related figure below. From Hollarsmith et al., in press.

Negative: 60-79% | >80% · Neutral: 60-79% · Positive: 60-79% | >80% · No consensus: <60% · No literature

Floating Kelps – Global	Floating Kelps – Salish Sea	ENVIRONMENTAL PRESSURES	Non-floating Kelps – Global	Non-floating Kelps – Salish Sea
2		Algal competition	6	1
4	1	Benthic sedimentation	3	1
8		Contaminants	9	
4		Epiphytes	28	
15	2	Nutrients	33	
5	1	Salinity	18	
37	4	Temperature	156	
19	3	Tissue damage	45	
9	1	Water clarity	12	1

Figure 17. Results of a literature search of the pressures impacting floating and non-floating kelp species in the Salish Sea and temperate costs wherever kelps are found. The numbers in each box represent the number of studies identified. See Figure 16 caption for a description of the colors. See also related figure above. From Hollarsmith et al., in press.

Appendix 2. Examples of Geographic Assessment Areas

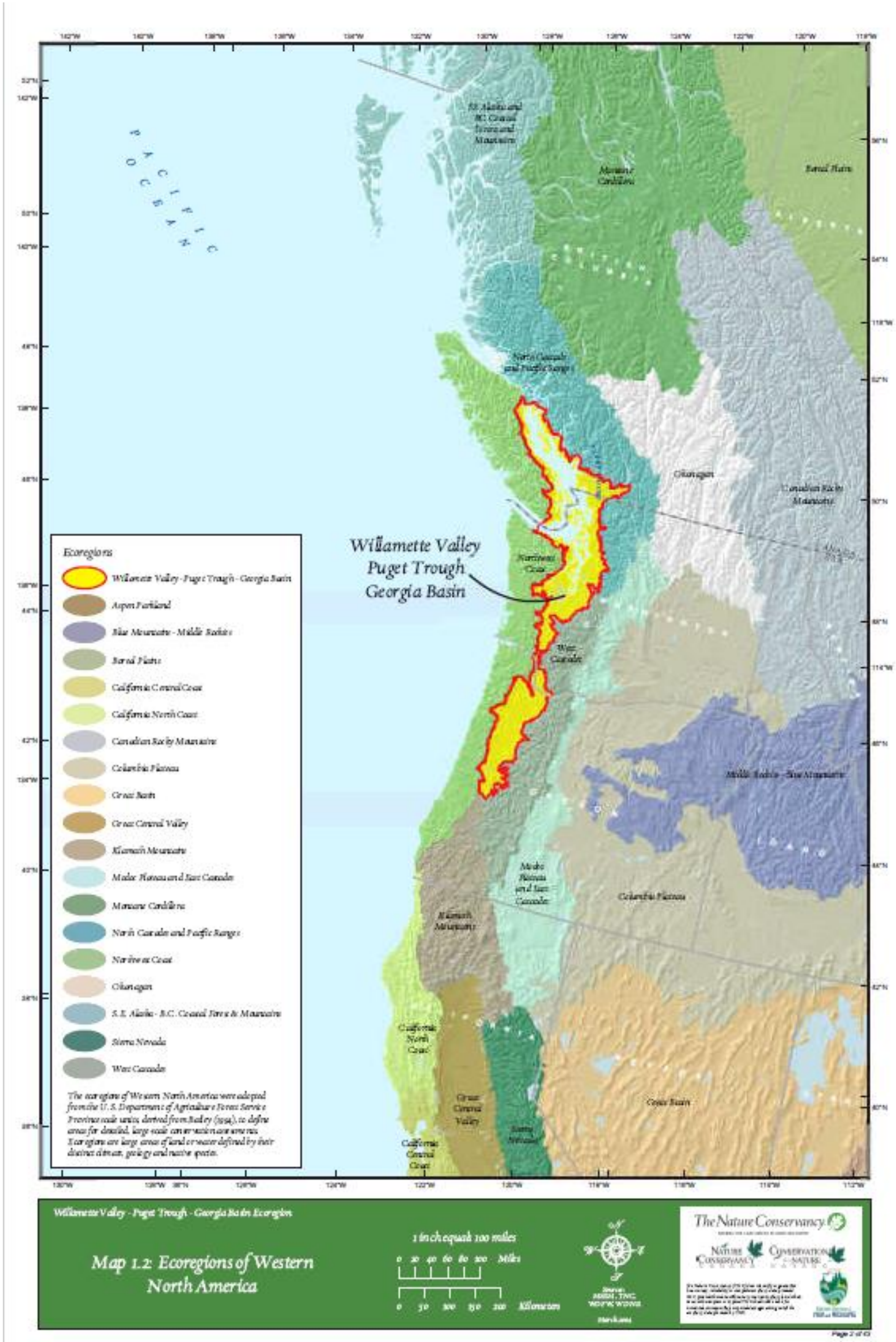

Figure 18. Ecoregions of western North America, defined by the Nature Conservancy (Floberg et al. 2004).

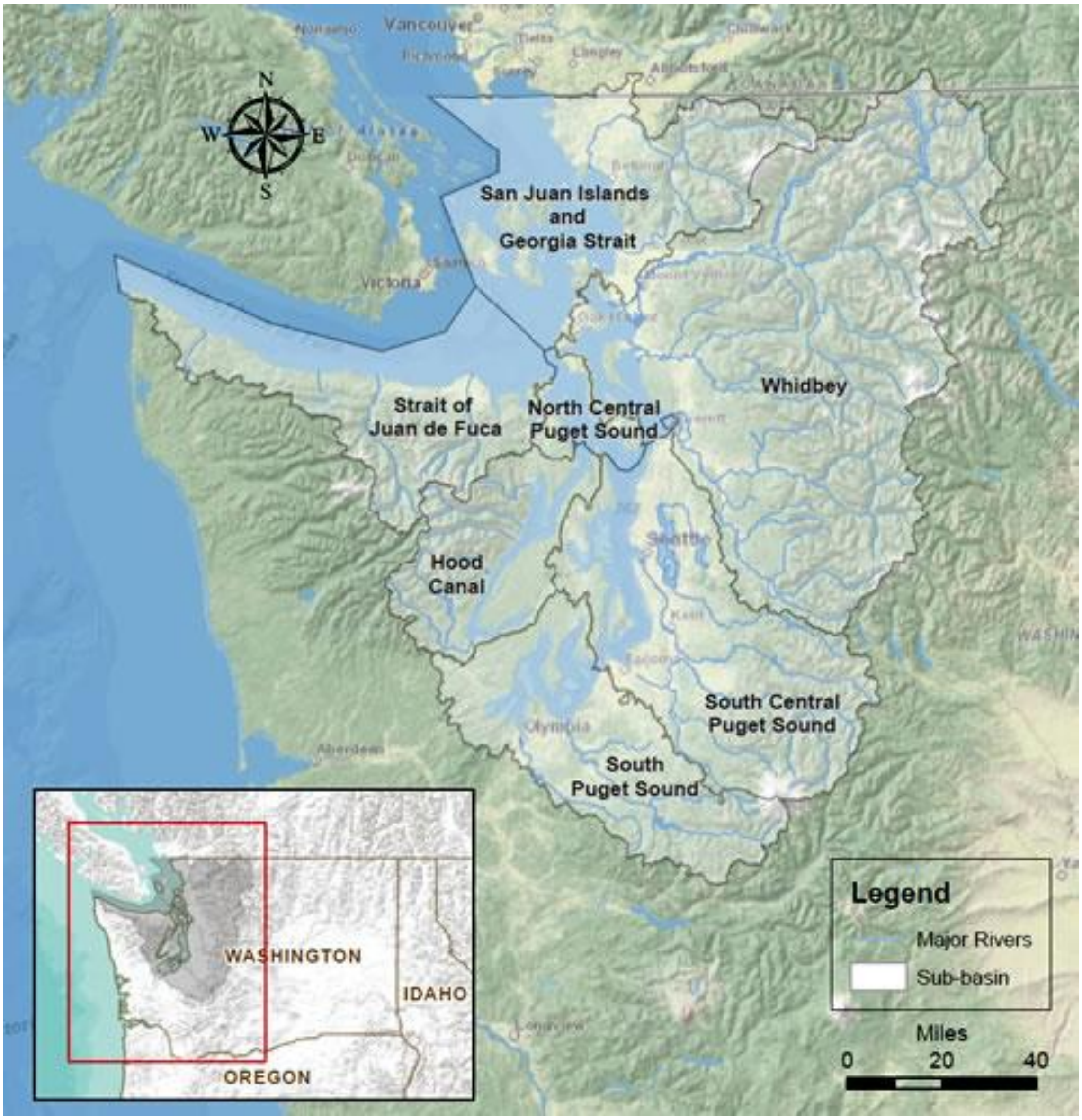

Figure 19. Sub-basins defined by PSNERP (https://salishsearestoration.org/wiki/Puget_Sound_Sub-basins).

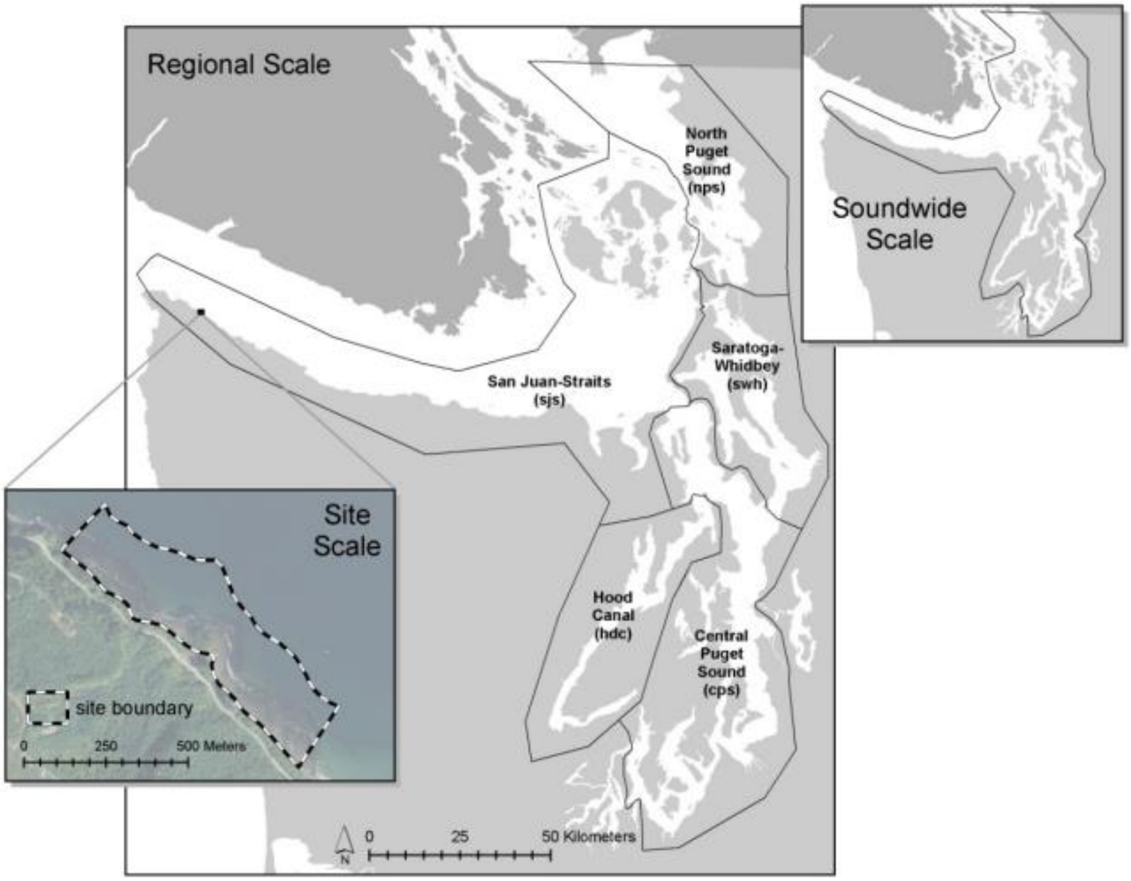

Figure 20. DNR's Submerged Vegetation Monitoring Program monitors eelgrass condition at soundwide, regional and site scales. Five regions were selected to capture distinct conditions in portions of Puget Sound. The number of regions was determined in part by the need for regions to be large enough to include a sufficient number of probabilistically samples for statistical extrapolation (Dowty et al., 2019).

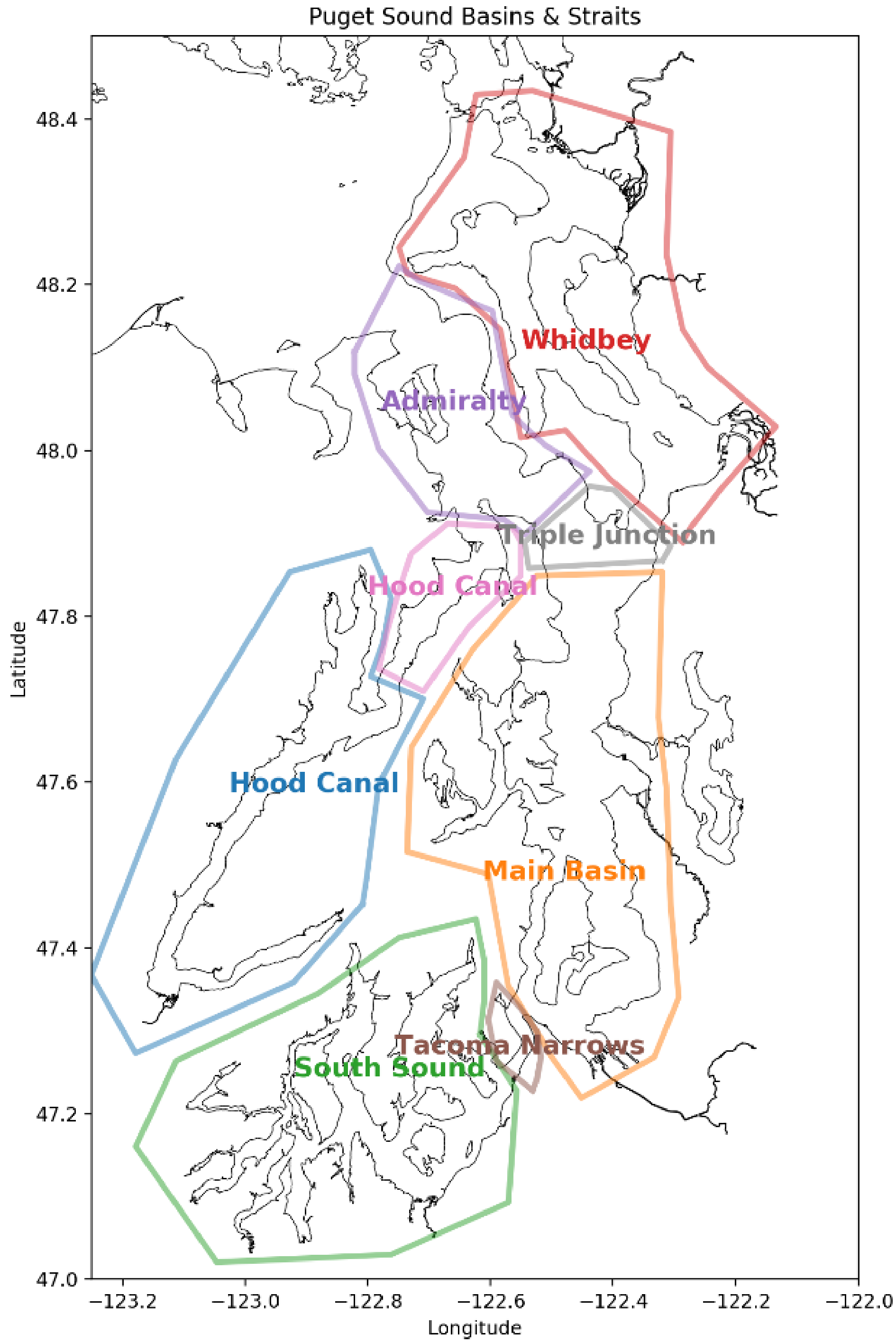

Figure 21. Basin description in Live Ocean, a computer model simulating ocean water properties. The sub-areas are described as: "The 'basins' are generally deep with weak tidal currents. These are Main Basin, Whidbey Basin, Hood Canal, and South Sound. The 'straits' connecting them are generally shallower, narrower and have much stronger tidal currents, especially Admiralty Inlet and Tacoma Narrows." (Live Ocean https://faculty.washington.edu/pmacc/LO/long_term_trends.html)

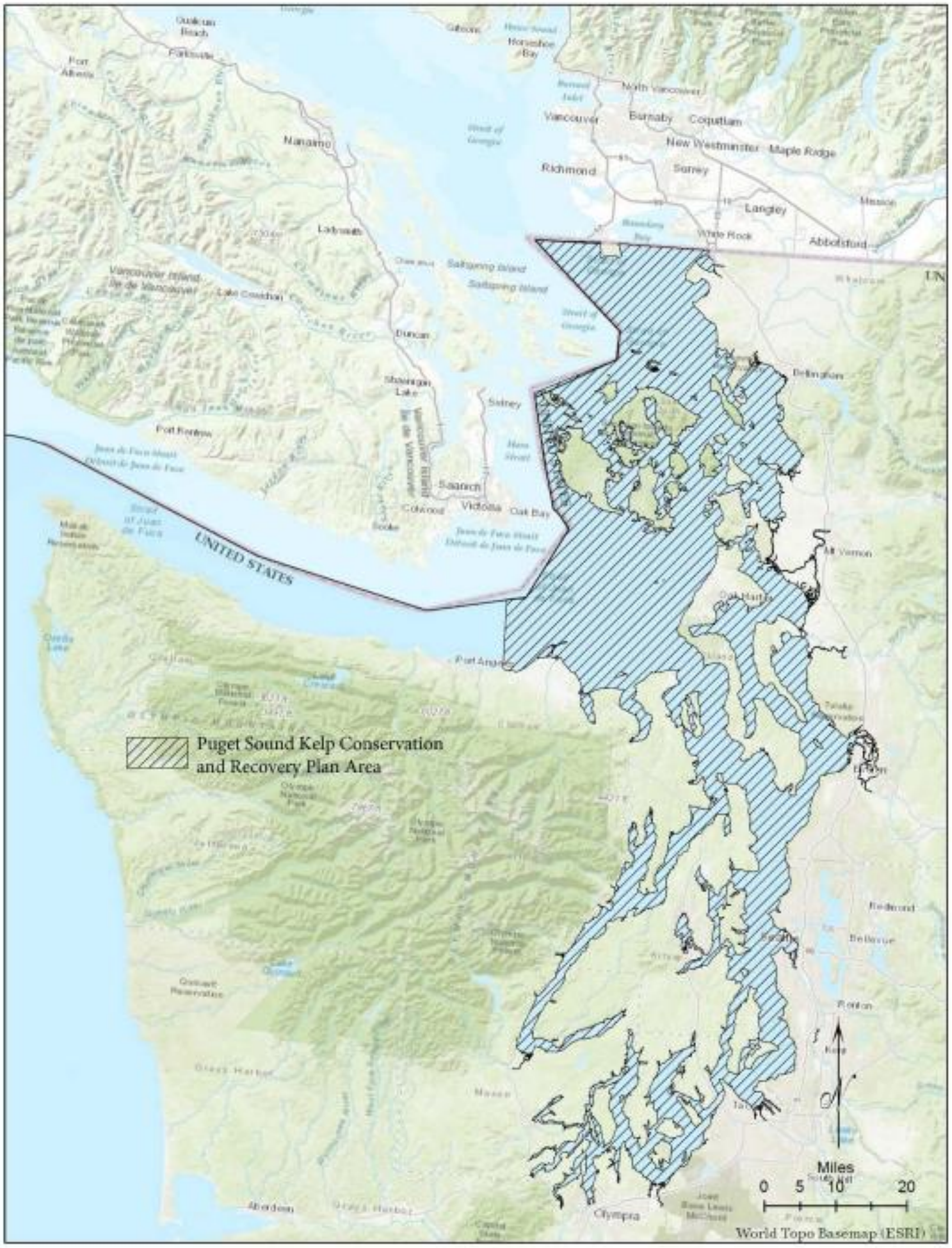

Figure 22. The Delineation of Puget Sound for the Rockfish Recovery Plan and the Kelp Conservation and Recovery Plan (Calloway et al., 2020).

Figure 23. Water Resource Inventory Area (WRIA) boundaries in the Puget Sound area. From https://www.eopugetsound.org/articles/water-resource-inventory-areas-puget-sound

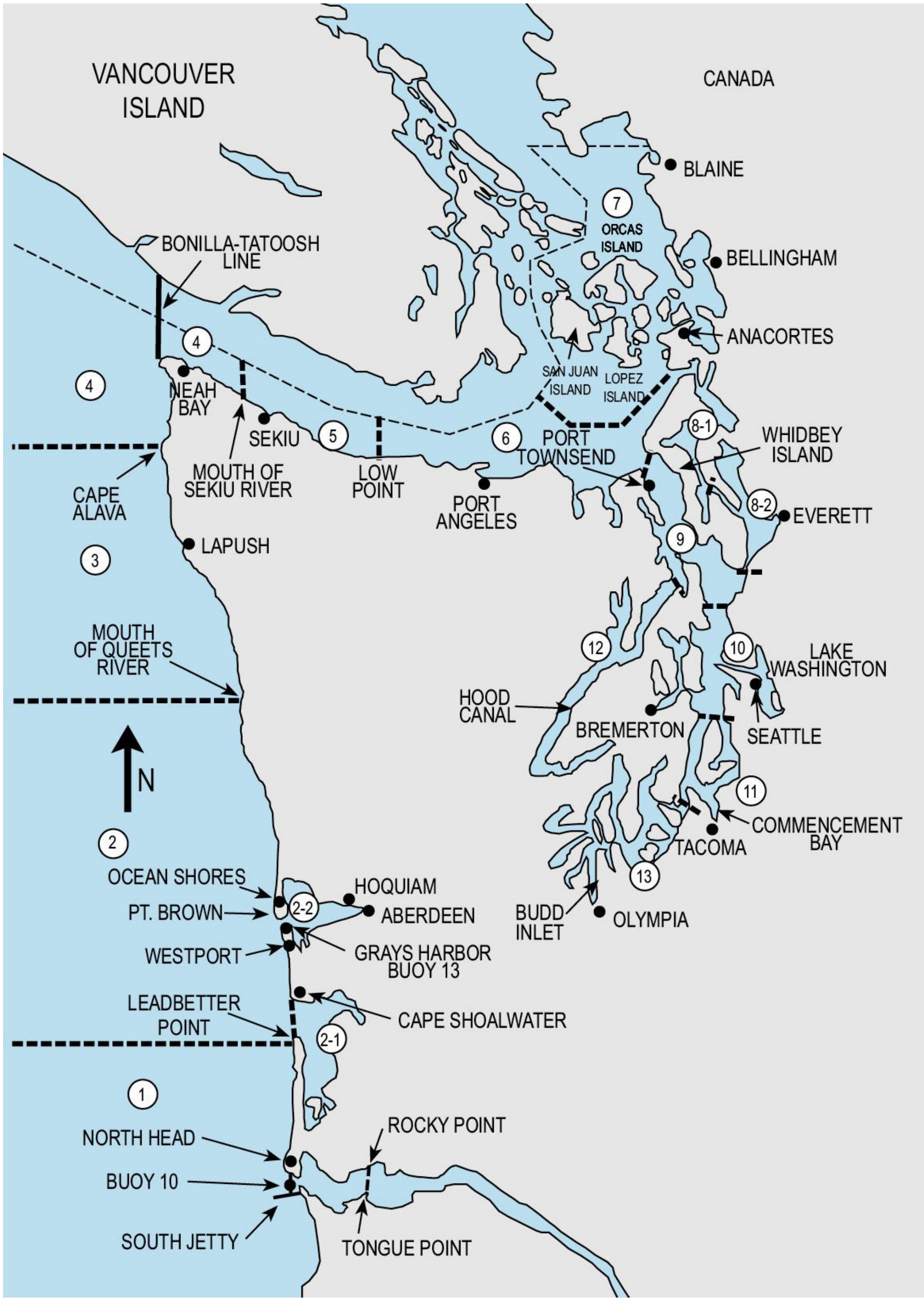

Figure 24. Marine Areas for Harvest Management https://www.eregulations.com/washington/fishing/marine-area-rules-definitions.

Marine Water Condition Index Scores for 12 Regions of Puget Sound

1999-2018

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Admiralty Reach	20	13	8	4	0	-5	-3	-5	4	0	-3	-2	14	12	8	4	-9	-1	1	3
Georgia Basin	-2	14	13	1	-2	10	-2	-7	1	9	-9	7	16	-7	3	-6	-4	-11	-6	-9
South Hood Canal	16	7	9	3	-4	-9	-1	-11	6	10	-1	-14	-11	1	4	4	-10	-1	4	1
Central Basin	15	14	12	8	-1	-6	-8	-3	4	1	-7	-10	7	0	1	-1	-5	-5	2	3
Bellingham Bay	10	13	23	-3	1	6	-12	-8	7	2	-12	-14	7	-9	0	-20	-3	-1	-8	-12
Sinclair Inlet	8	16	13	1	-3	-6	-5	-11	4	1	3	-13	3	-4	-3	-6	-8	-7	-18	-2
Oakland Bay	16	13	14	-4	-7	-9	-5	1	4	-3	1	-6	1	-3	1	-12	-9	-1	-2	3
South Sound	19	14	14	-2	2	0	-4	-2	3	0	-8	-12	9	6	8	-2	-4	-1	8	-1
Elliott Bay	28	19	5	-3	-9	3	-15	-9	3	4	-8	-5	5	5	8	-2	-7	0	7	-1
Commencement Bay	17	8	13	-3	-5	0	-3	-1	7	-5	-8	-8	2	2	8	4	-6	-6	2	-7
Whidbey Basin	11	8	8	-5	-2	-10	-1	1	9	7	-9	-14	-3	-3	-2	-6	-1	-14	-11	-4
Budd Inlet	8	14	17	1	-13	-9	-7	-1	8	5	3	-8	-1	-6	0	-12	-6	-10	-2	-5

Score
25 to 28
20 to 24
16 to 19
11 to 15
7 to 10
3 to 6
-2 to 2
-3 to 1
-7 to -4
-12 to -8
-16 to -13
-20 to -17

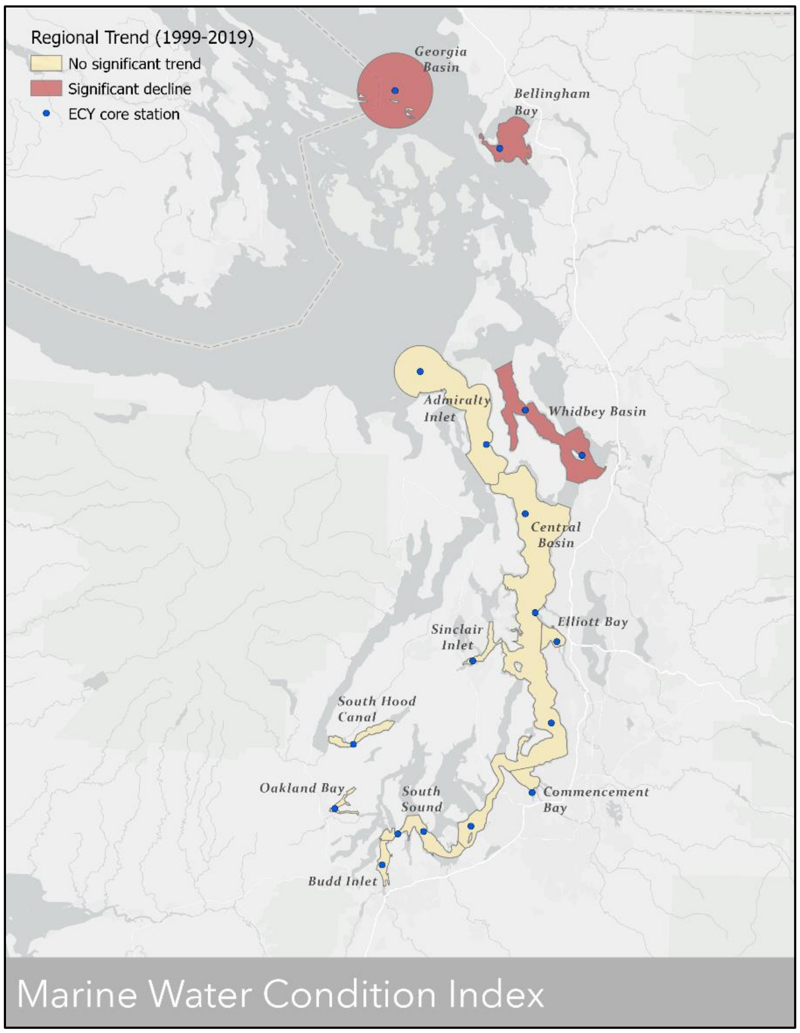

Figure 25. The 12 regions monitored in the Marine Water Condition Index by the Washington Department of Ecology. Accessed January 5, 2022. https://www.epa.gov/salish-sea/marine-water-quality

Appendix 3. Dataset Descriptions

Table 3. Volunteer Kayak Monitoring by Marine Resources Committees (MRC-kayak)

Spatial Extent:	Seven northern counties in Puget Sound that are within the Northwest Straits Initiative (Clallam, Island, Skagit, Jefferson, San Juan, Snohomish, Whatcom).
Candidate metrics for initial VS	Initial: bed perimeter (polygons). Additional multiyear metrics could be included.
Assessment Units	Multi-year monitoring sites, most sites are at the approximate scale of 1 km of shoreline (18 provisional locations have been identified as of January 2022, a consolidation of 42 locations where volunteers have conducted kayak surveys)
Survey years	2015 – 2020 total, subset of all years at most sites. (2021 being processed)
Frequency	Annual
Methods	Kayak-based delineation of bed perimeter, with minimum thresholds for inclusion of > 5 m wide and <8 m between individuals (Bishop 2014, updated 2020). Volunteers collected data on other parameters recorded observations following the monitoring protocol developed by the Northwest Straits Commission (NWSC). The data is collected by volunteers through the Marine Resources Committees (MRCs). Datasets are available through the NWSC and individual MRCs. NWSC and MRC web sites: - NWSC Kelp Monitoring - Clallam County - Island County - Jefferson County - San Juan County - Skagit County - Snohomish County - Whatcom County
Methods and Usage Considerations	The *Project Team* is working with the MRCs to identify appropriate multi-year monitoring data, led by NW Straits and DNR. The initial dataset considered for inclusion within the Vital Sign will be bed perimeter/area data from sites with consistent multi-year surveys. It will be possible to expand the number of sites and metrics over time.

Table 4. Kayak Monitoring by DNR in Central and South Puget Sound (DNR-kayak)

Spatial Extent:	Sites within Central Puget Sound and South Puget Sound
Candidate metrics for initial VS	bed (polygons), minimum/maximum depth
Assessment Units	13 sites with historical or current floating kelp, sites span approximately 0.5 – 1.0 km of shoreline.
Survey years	2013, 2017-2021 (South Puget Sound), 2018-2021 (Salmon Beach), 2020-2021 (Central Puget Sound)
Frequency	annual
Methods and Usage Considerations	Kayak based delineation of bed perimeter with handheld GPS. Minimum abundance for inclusion: single bulb. Maximum distance among individuals for inclusion in a single bed: 7 m. At a subset of sites, assessed: - density, percent cover and morphometrics at grid of points along regularly placed across-shore transects, - drone or fixed-wing canopy mapping. Information: - 2019 story map - 2017 and 2018 monitoring report - 2013, 2014 and 2016 monitroing report

Table 5. Samish Kelp Canopy Surveys in Traditional Territory (Samish-TT)

Spatial Extent:	San Juan County (SJC), Skagit County (SC)
Candidate metrics for initial VS	bed (polygons)
Assessment Units	Comprehensive delineation within the study area
Survey years	2004/2006 (SJC only, Western portion in 2004 and eastern portion in 2006), 2016 (SJC only), 2019
Frequency	Infrequent annual
Methods and Usage Considerations	Beds were delineated to encompass areas with floating kelp canopies (including gaps within the canopy and rocks) using on-screen digitizing of aerial photography. Aerial imagery sources: - 2004-2006 aerial photography: low-tide, color-infrared 9" x 9" negatives collected during joint DNR-Friends of the San Juans project. (Berry 2007). These photographs were originally used for surface canopy delination using semi-automated classification of spectral band data. - 2016 aerial photography: 6" resolution color imagery collected by Pictometry for San Juan County during May/June 2016. Variable tide and current levels. Information: Palmer-McGee 2021.

Table 6. Historical Kelp Forests in Samish Traditional Territory (Samish-TT)

Spatial Extent:	San Juan County (SJC)
Candidate metrics for initial VS	Generalized locations of persistent kelp beds
Assessment Units	Comprehensive delineation within the study area
Survey years	Generalized from approximately the past 50-75 years.
Frequency	One time
Methods and Usage Considerations	Used Traditional Ecological Knowledge (TEK) to delineate areas with persistent floating kelp beds. A nautical chart was delineated based on interviews with two tribal fisherman who have fished in the area for decades and have nearly 100 years of combined knowledge of the waters surrounding the San Juan Islands. Chart delineations were used to create ArcMap polygons. Information: Palmer-McGee 2021.

Table 7. Synthesis of long-term floating kelp data in South Puget Sound and Central Puget Sound (DNR – synthesis)

Spatial Extent:	Central Puget Sound and South Puget Sound
Candidate metrics for initial VS	Floating kelp presence (tabular data related to linear shoreline units)
Assessment Units	Comprehensive delineation within 1 km shoreline segments
Survey years	Late 1800s to 2019.
Frequency	Synthesis of multiyear data
Methods and Usage Considerations	Synthesized information on floating kelp presence from diverse data sources, including charts, harvest maps, habitat maps and scientific studies. Summarized presence/absence observations within 1-km linear shoreline units. In South Puget Sound, analyzed changes over time. In Central Puget Sound, summarized recent presence vs maximum recorded extent. Information: SPS (publication, storymap), CPS (presentation)

Table 8. Shoreline survey of floating kelp presence (DNR-boat)

Spatial Extent:	Central Puget Sound and South Puget Sound
Parameters	Floating kelp presence (linear data). Abundance classes (Central Puget Sound only).
Candidate metrics for initial VS	Comprehensive within study area
Survey years	2013 and 2017 (South Puget Sound), 2019 (Central Puget Sound)
Frequency	Infrequent
Methods and Usage Considerations	Collected field observations of floating kelp presence by motoring along the shoreline in a small boat, in shallow water during low tide and slack currents. Summarized presence/absence by segmenting -6 m bathymetry contour. Minimum threshold for detection: a single individual. In Central Puget Sound, observations were further sub-divided to describe abundance, ranging from isolated individuals to wide, conspicuous beds. Information: SPS (report), CPS (presentation)

Table 9. Long-term monitoring of the Coast, Strait and Aquatic Reserves using Aerial Photography (DNR-COSTR and DNR AQRES)

Spatial Extent:	Open coast and the Strait of Juan de Fuca to Point Wilson, Port Townsend (COSTR). DNR's northern Aquatic Reserves (AR): Smith and Minor Island AR, Cypress Island AR, Cherry Point AR (AQRES). Note: Protection Island AR is included in the COSTR dataset.
Candidate metrics for initial VS	Bed (polygons), tabular data summarizing canopy area, bed area, relative density. In COSTR, estimates are sub-divided into giant kelp and bull kelp. In AQRES, only bull kelp is present.
Assessment Units	Comprehensive within study area
Survey years	1989-2019 (COSTR), 2011-2019 (AQRES) Surveys from 2020 and 2021 being processed.
Frequency	annual
Methods and Usage Considerations	Near-vertical low-tide color-infrared imagery is collected from a fixed wing platform during late summer. Imagery is projected onto 1:12,000 paper maps and kelp canopies are hand-delineated. Bed area is estimated by buffering canopy data with a 20 m radius of association. The hand-delineated paper canopy maps are scanned. Then tabular estimates of canopy area and bed area are produced and summarized at the scale of map indices (stretches of shoreline defined by geomorphic features such as headlands). A primary strength of this dataset is its consistency over a long time period: the same person has collected and processed the imagery using the same methods throughout the data record (Bob VanWagenen, Ecoscan Resources). A related weakness is that the methods have not been updated with advances in spatial data collection and processing. In the currently distributed dataset, the most accurate and precise data are the tabular estimates of canopy area, bed area and RDI, summarized by map index. The spatial data (bed polygons) are generalized features, and processing techniques have changed with spatial processing technology over the past 3 decades. The spatial data (canopy and bed polygons) could be substantially improved by re-scanning the original paper maps and re-constructing the multiyear data.

Table 10. Fertilizer Investigations

Spatial Extent:	Statewide
Parameters	Bed (polygons)
Candidate metrics for initial VS	Comprehensive
Survey years	1911 or 1912
Frequency	One time
Methods and Usage Considerations	Boat-based surveys delineated floating kelp beds for potential harvest. Features were buffered to be visible on 1:100,000 charts (noted in Rigg's interim maps, Rigg 1912). Two different observers led surveys in Washington. G.C. Rigg completed the surveys in greater Puget Sound (east of Cape Flattery), with field work noted during 1911 and 1912. W.C. Crandell noted beds during an August-September survey on a 50-foot ketch from San Diego to Neah Bay. While the investigation was state-wide, it is unlikely that the observers comprehensively surveyed the entire shoreline, given the limited time available and logistical considerations. Additionally, many areas may not have been surveyed during optimal conditions. Comparison to other data sources suggests that the observers likely targeted beds with harvest potential (ie. large, accessible beds). The open coast data appears to be more generalized than the Puget Sound data, which has led to excluding it from analysis (Pfister et al., 2018). In South Puget Sound, a basin where floating kelp is uncommon, the Fertilizer Investigation surveys appear to be substantially generalized relative to other datasets, with fewer overall kelp bed features and larger individual features (Berry et al., 2021).

Table 11. The Washington State ShoreZone Inventory

Spatial Extent:	Saltwater shorelines throughout Washington state
Parameters	Presence of bull kelp, giant kelp and other kelp species within geomorphically-defined shoreline units (mean length 0.5 km) represented as line features. Described as patchy (<50%) or continuous (>50%) along shore.
Candidate metrics for initial VS	Geomorphically-defined shoreline segments,. mean segment length 0.5 km.
Survey years	All shorelines surveyed once between 1994-2000
Frequency	one-time
Methods and Usage Considerations	Physical and biological shoreline characteristics were summarized in tabular format along the Mean High Water (MHW) shoreline, using imagery and observations collected during low tide helicopter surveys. ShoreZone is the only modern dataset that describes floating kelp statewide. While the ShoreZone Inventory effectively characterized the presence of floating canopies over a large area, the abundance information is generalized, which limits its ability to detect changes over time. Within each ShoreZone shoreline unit, the proportion of the linear unit with alongshore floating canopies is categorized as absent (0%), patchy (<50%) or continuous (>50%). Small, low-density beds that were known to be present at the time of the survey in some areas were missed.