Puget Sound Kelp Conservation and Recovery Plan

May 2020

Prepared by the Northwest Straits Commission, NOAA's National Marine Fisheries Service, Puget Sound Restoration Fund, Washington State Department of Natural Resources, and Marine Agronomics.

Our shared vision for thriving kelp forests in Puget Sound

Vibrant kelp forests are vital to the health of Puget Sound and Salish Sea. They provide critical refuge, feeding, and nursery grounds for forage fish, rockfish, and salmon, as well as fueling food webs that support healthy bird and marine mammal populations—including Southern Resident killer whales. Mounting evidence points to significant local declines of kelp forests throughout Puget Sound. In response to these widespread concerns, the Puget Sound Kelp Conservation and Recovery Plan provides a research and management framework for a coordinated and collaborative approach to protecting and restoring kelp forests of Puget Sound. We envision revitalized Puget Sound kelp forests stretching from Olympia to Vancouver, B.C. providing economic, recreational, and ecological benefits to all living things that call these shores and waters home.

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Want to join us in our shared vision for kelp? Sign on to the vision statement by adding your organization here: https://nwstraits.org/our-work/kelp/

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Illustration above used with permission of Claudia Makeyev.
Cover Photo: Bull kelp forest. Image courtesy of Eiko Jones Photography.

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A diverse group of local and regional experts contributed valuable perspectives to this Puget Sound Kelp Conservation and Recovery Plan. We would like to thank the many participants who took part in the kelp workshops in 2016, 2018, and 2019. Appendix C includes a full participant list and notes from the workshops. Workshop participants represented the following organizations:

Clallam Marine Resources Committee
Friends of the San Juan's
Island Marine Resources Committee
Jamestown S'Klallam Tribe
Jefferson Marine Resources Committee
King County Department of Natural Resources
Marine Agronomics LLC
Natural Resources Consultants
National Oceanic and Atmospheric Administration
Northwest Straits Commission
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Paua Marine Research Group
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Puget Sound Restoration Fund
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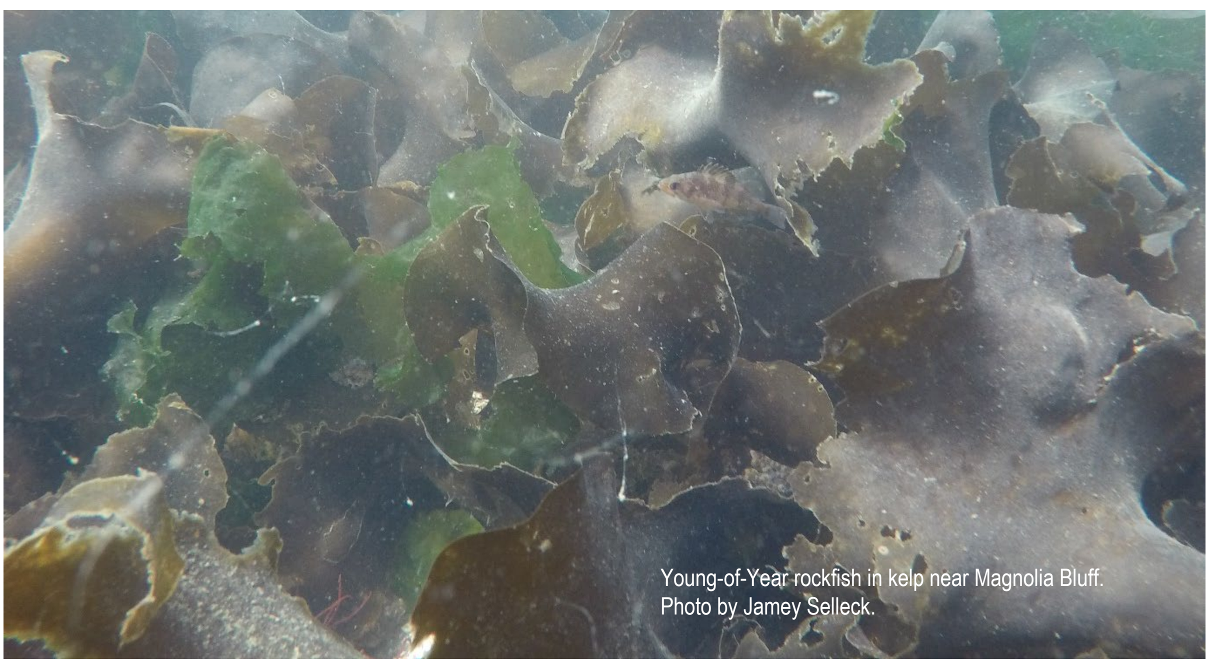
San Juan Marine Resources Committee
San Juan Salmon Recovery Lead Entity
Simon Fraser University
Skagit Marine Resources Committee
Snohomish Marine Resources Committee
Stillaguamish Tribe
Suquamish Tribe
Surfrider Foundation
Swinomish Indian Tribal Community
Tulalip Tribes
University of British Columbia
University of California, Davis
University of Chicago
University of Victoria
University of Washington
University of Wisconsin, Milwaukee
United States Army Corps of Engineers
United States Geological Survey
Washington Department of Ecology
Washington Department of Fish and Wildlife
Washington State Department of Natural Resources
Western Washington University
Whatcom Marine Resources Committee

The discussions in the workshops formed the framework for this Kelp Plan. Without the time and energy contributed by representatives from these organizations, this effort would have failed. We hope this plan provides our community with a framework for continued focus and momentum toward kelp conservation and recovery.

TABLE OF CONTENTS



Young-of-Year rockfish in kelp near Magnolia Bluff.
Photo by Jamey Selleck.

Table of Figures

Setchell's kelp (Laminaria setchellii), Ebey's Landing, Whidbey Island.

List of Acronyms

CWA	Clean Water Act
DNR	Washington State Department of Natural Resources
DOE	Washington State Department of Ecology
EPA	United States Environmental Protection Agency
EFH	Essential Fish Habitat
ESA	Endangered Species Act
GMA	Growth Management Act
HPA	Hydraulic Project Approval
MRC	Marine Resources Committee
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWS	Northwest Straits
PSP	Puget Sound Partnership
PSRF	Puget Sound Restoration Fund
RCW	Revised Code of Washington
SMA	Shoreline Management Act
SMP	Shoreline Master Program
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WWTP	Wastewater Treatment Plant

Glossary

Biogenic habitat: Habitat provided by living organisms (i.e., kelp, eelgrass, or terrestrial plants).

Blade or Lamina: The flattened and elongated portion of a kelp individual where most photosynthesis occurs.

Floating kelp: Species that are held aloft either in the water column or at the water surface by pneumatocysts (buoyant bulbs).

Gametophyte: The sexually differentiated, microscopic, haploid, reproductive kelp life stage that produces egg and sperm (gametes).

Grazer: Herbivorous species (usually invertebrates) that feed directly on fresh or detrital kelp material.

Holdfast: Structure at the terminal end of a kelp stipe used to anchor the individual onto substrate.

Kelp: Species of brown seaweed in the order Laminariales.

Kelp forest: The community and services provided by intact ecosystems dominated by kelp species composed of multiple species and strata (stories) that rise above the benthos (seafloor) and can extend up to 10 to 25 meters to the surface

Pneumatocyst: Bouyant, gas-filled float on some species of brown algae that lifts a portion of the individual off the benthos (bottom).

Sorus (pl. sori): Reproductive patches on kelp blades that undergo meiosis and produce zoospores.

Sporophyte: The conspicuous phase of the kelp life cycle. The macroscopic diploid life stage that produces reproductive zoospores.

Stipe: The stem of a kelp individual that connects the holdfast to the blades/lamina. Kelp stipes vary between species.

Stressor: Any of several physical or biological parameters known to affect long-term kelp health and persistence.

Turf algae: small filamentous and foliose green and red algae that provide fewer ecosystem services and lower biodiversity

Understory / non-floating kelp: Species lacking pneumatocysts. These species either lay along the seafloor or held aloft in the midstory by a rigid stipe.

Zoospore: A microscopic phase of the kelp life cycle. Single-celled structures produced through meiosis, usually motile. Once settled on substrate, they quickly germinate into male and female gametophytes.

I. Executive Summary

Kelp—some of the largest of all seaweeds—form extensive living structures that provide an array of valuable ecosystem goods and services to deep water and nearshore environments in Puget Sound. These underwater forests act as foundations for diverse and productive nearshore ecosystems, supporting food webs and providing critical habitat for a wide array of marine life.

Anecdotal observations and research suggest that Puget Sound is losing its kelp forests. Extensive losses of bull kelp have been documented in South and Central Puget Sound, and localized declines have been observed throughout Puget Sound. Concerns also exist about potential losses to other kelp species, yet trends are unknown due to data gaps. Although kelp distribution and drivers of declines in Puget Sound are not well understood, data from kelp ecosystems in other temperate coastal regions indicate that widespread loss of kelp habitats would be devastating to the Puget Sound ecosystem. There is a consensus in the scientific community that coordinated action is needed to reverse downward trends in kelp populations by addressing both longstanding and emerging stressors. Cumulative impacts from human stressors threaten kelp. These impacts include degraded water quality from pollution, nutrient loading, increased turbidity, and sediment deposition; introduction of invasive species; and alterations to food-web dynamics from commercial and recreational fishing. Additionally, warming ocean waters and other impacts from climate change pose new and intensifying threats to kelp resilience that often exacerbate the negative effects of other stressors.

This Puget Sound Kelp Conservation and Recovery Plan (Kelp Plan) provides a framework for coordinated research and management actions to protect these fundamental and iconic kelp species from a suite of global and local stressors. Successfully achieving kelp conservation and recovery will require a collaborative effort between our community of Tribes, managing entities, and stakeholders in Puget Sound. Additional collaboration with Canadian federal, provincial, and First Nation entities will support conservation and recovery efforts in the Puget Sound/Georgia Basin region.

Actions identified in this Kelp Plan address six strategic goals:

1. Understand and reduce kelp stressors;
2. Deepen understanding of the value of kelp to Puget Sound ecosystems and integrate into management;
3. Describe kelp distribution and trends;
4. Designate kelp protected areas;
5. Restore kelp forests; and
6. Promote awareness, engagement, and action from user groups, Tribes, the public, and decision-makers.

We propose the following research, communication, and conservation actions to achieve these strategic goals.

1. **Understand and reduce kelp stressors.** Water quality degradation, urbanization/development, invasive species, and warming ocean temperatures are cumulatively affecting kelp and likely driving regional declines in bull kelp populations. These stressors are likely to increase in magnitude with continuing population growth and climate change.

   Reduce human impacts on water quality and kelp habitats:

   - Inform future management actions through continued research into the impacts of current and historical human activities on kelp forests.
   - Identify priority stressors negatively affecting Puget Sound kelp on a sub-regional scale to target management actions.
   - Fully implement and enforce available protections for kelp through existing regulations, programs, and policies.
   - Increase protection for kelp populations by addressing key gaps in existing regulations and implementation programs.
   - Form interagency workgroups to increase collaboration and information sharing across management organizations to improve implementation and to address policy gaps.
   - Reduce human-caused nutrient and sediment loading.
   - Support sustainable kelp harvest by informing recreational harvesters about regulations and sustainable kelp harvest methods.

   Reduce impacts from biological stressors:

   - Strive to incorporate kelp and other trophic considerations into fisheries management planning.
   - Explore invasive macroalgae (*Sargassum muticum* and *Undaria pinnatifida*) control alternatives, ecological roles, and long-term management considerations with respect to climate change.

   Reduce impacts from climate change:

   - Investigate climate change impacts to improve management decisions, such as prioritizing locations for kelp protected areas, restoration sites, and mitigation activities.
   - Investigate the climate-related benefits of kelp, and develop management opportunities for these benefits.

- Investigate the development of temperature-tolerant strains of native kelp species for potential use in restoration and mitigation outplanting in regions where local stressors are reduced.

2. **Deepen understanding of the value of kelp to Puget Sound ecosystems and integrate into management.** Kelp provides critical habitat as well as food and foraging opportunities for associated nearshore species in Puget Sound. Quantifying services provided by kelp will support management actions, especially for pinto abalone, threatened and endangered species of rockfish, salmon, and Southern Resident killer whales.

   Improve understanding of kelp value:

   - Quantify functional roles of kelp habitats for associated species and provide guidance to managers on regulatory implementation, such as endangered species habitat conservation.
   - Calculate the value of kelp ecosystem services for use in developing mitigation guidance.

3. **Describe kelp distribution and trends.** Successful implementation of existing regulations relies on accurate information regarding the distribution and trends. Consistent and coordinated multi-year monitoring is essential for establishing accurate inventories and understanding natural variation.

   Gain accurate information on kelp distribution and trends:

   - Update and expand information on the current extent of canopy-forming and understory kelp.
   - Make distribution and trends data available to agencies and the public for use in spatial planning, project planning, and regulatory implementation.
   - Coordinate the strategic monitoring of canopy-forming and understory kelp throughout Puget Sound through expanding efforts and building collaborations between organizations.
   - Expand the understanding of historical distributions and trends by compiling historical information sources and exploring traditional ecological knowledge.
   - Identify the genetic structure of kelp populations, including connectivity, dispersal, and population dynamics.
   - Form a research and monitoring workgroup to increase collaboration and information sharing across organizations.

4. **Designate kelp protected areas.** Puget Sound kelp recovery begins with the conservation and protection of kelp forests.

   Protect kelp habitat:

- Protect kelp habitat in existing and new reserves, refuges, and protected areas.
- Assess the extent of recreational kelp harvest and its potential impacts. Develop spatial management plans and strategies for kelp harvest activities.

5. **Restore kelp forests.** Restoring historical kelp forests requires indirect habitat improvement through stressor reduction and direct kelp population enhancement in areas where natural recruitment is limited. In addition to reducing stressors responsible for declines, developing best practices will be critical for successful kelp restoration and mitigation projects.

   Restore kelp forests:

   - Develop a spatial plan identifying regions and sites for priority restoration actions and mitigation.
   - Continue the development of kelp restoration techniques for use in enhancement and mitigation projects.
   - Fund and implement restoration activities at priority sites.

6. **Promote awareness, engagement, and action from user groups, Tribes, the public, and decision-makers.** The success of the Kelp Plan and the conservation and recovery of kelp in Puget Sound depends on increased awareness, engagement, and support of actions to sustain kelp.

   Promote awareness, engagement, and support:

   - Share information on (1) the value and role of kelp ecosystems as critical nearshore habitat and food web support (for forage fish, rockfish, salmon, and killer whales) in Puget Sound; and (2) the growing concern regarding significant losses to bull kelp canopies.
   - Build research capacity through coordinated knowledge sharing of ongoing kelp recovery projects and research gaps.

At the heart of these strategic goals is the need for continued interagency coordination; communication between researchers and managers; and funding to support research, monitoring, education, outreach, implementation, and enforcement. The actions outlined in this Kelp Plan require a unified collaborative effort from federal and state management agencies, Washington State Tribes, Non-governmental organizations (NGOs), and local stakeholders. Raising awareness of the need to support kelp conservation and recovery will help further strengthen budding collaborative partnerships. This Kelp Plan is a call to action. It advocates that kelp be recognized as a necessary element of ecosystem-wide recovery planning, including the prioritization of funding to support the actions outlined in this Kelp Plan.

Black rockfish swimming in bull kelp forest near Keystone Jetty.
Photo by Adam Obaza- Paua Marine Research.

Sugar kelp (Saccharina latissima), Squaxin Island.
Photo by Helen Berry.

II. Introduction

Kelp—groups of brown algae that include some of the largest of all seaweeds—provide valuable ecosystem goods and services to deep water, terrestrial, and nearshore environments. Underwater kelp forests act as foundations for diverse and productive nearshore ecosystems, supporting food webs and providing critical habitat for a wide array of marine life (Steneck et al. 2002; Christie et al. 2009; von Biela et al. 2016).

Most available information on kelp in Puget Sound pertains to the floating canopy-forming bull kelp (*Nereocystis luetkeana)*. Despite a lack of systematic surveys, available data from multiple sources document long-term declines in canopy cover of bull kelp within several areas of Puget Sound (Berry et al. 2019, *in review*). While bull kelp forests are not declining everywhere, many historical Puget Sound bull kelp forests, especially in Central and South Puget Sound, have been entirely lost or reduced to vestiges of historical abundances. The consequences of these declines are not limited to the direct effects on kelp populations, but also influence, both directly and indirectly, the many species and ecosystem services that depend on the presence of kelp forests. Though the distribution and drivers of declines in Puget Sound are not well understood, data from kelp ecosystems in other temperate coastal regions indicate that a large-scale loss of kelp habitats would be devastating to the Puget Sound ecosystem (Steneck et al. 2002; Graham 2004; Rogers-Bennett and Catton 2019).

2.1 Purpose of the Conservation and Recovery Plan

The Puget Sound Kelp Conservation and Recovery Plan (herein referred to as "the Kelp Plan") provides a framework for research, conservation, recovery, and communication actions aimed at protecting and restoring Puget Sound kelp species and the goods and services provided by them. This document provides a synthesis of the most current information regarding kelp in Puget Sound and should be considered best available science by local governments and other state agencies.

This Kelp Plan is a call to action! Kelp is a critical element of ecosystem-wide recovery.

The overarching intent of the Kelp Plan is to strengthen the implementation and enforcement of existing regulatory and management policies, and to develop additional tools to conserve and restore Puget Sound kelp habitats. Successfully achieving kelp conservation and recovery will require collaboration between the community of scientists, Tribes, managing entities, and stakeholders in Puget Sound.

The Kelp Plan aims to address the following strategic goals:

1. Understand and reduce kelp stressors;

2. Deepen understanding of the value of kelp to Puget Sound ecosystems and integrate into management;
3. Describe kelp distribution and trends;
4. Designate kelp protected areas;
5. Restore kelp forests; and
6. Promote awareness, engagement, and action from user groups, Tribes, the public, and decision-makers.

Recommended management actions, particularly those focused on reducing stressors, support recovery plans for other species and issues of concern, including eelgrass (*Zostera marina*) (DNR 2015), salmon (*Oncorhynchus* spp.) (NMFS 2007), Southern Resident killer whales (*Orcinus orca*) (NMFS 2008), rockfish (*Sebastes* spp.) (NMFS 2017), and ocean acidification (Washington State Blue Ribbon Panel on Ocean Acidification 2012; Washington Marine Resources Advisory Council 2017). Actions identified in these plans, and other actions that protect and improve Puget Sound ecosystem health, benefit kelp, but kelp is often left out of local discussions pertaining to critical species that warrant protection and recovery measures. This Kelp Plan is a call to action. It advocates for recognizing that kelp is an integral element of ecosystem-wide recovery planning, including the prioritization of funding to support the actions outlined in the Kelp Plan.

2.2 Plan Development and Coordination

Efforts to develop a conservation and recovery plan for Puget Sound kelp began in 2016 after the need to conserve kelp habitats in Puget Sound arose as a priority during the development of the Rockfish Recovery Plan for Puget Sound and the Georgia Basin (NMFS 2017). Participants in the rockfish recovery planning process stressed the importance of kelp forests as critical habitat for many juvenile rockfish species, and as support for long-term rockfish recovery. Consequently, the rockfish recovery plan outlined the need for synthesizing available research on kelp, improving understanding of kelp distribution, and developing conservation and restoration approaches for kelp habitats (NMFS 2017 Appendix V). Following the completion of the rockfish recovery plan, NOAA's National Marine Fisheries Service (NMFS) allocated funds for the development of the Kelp Plan.

Development of the Kelp Plan began in September 2017. It proceeded during a two-year process led by the Northwest Straits Commission (NWS Commission) with invaluable guidance and support from the Puget Sound Restoration Fund (PSRF), Marine Agronomics LLC, Washington State Department of Natural Resources (DNR), NMFS, and Washington Department of Fish and Wildlife (WDFW). Activities included forming the Kelp Core Team to oversee plan development; synthesizing literature and current research on kelp in Puget Sound; holding workshops with researchers, agencies, tribes, and stakeholders; and facilitating peer review and public comment of the Kelp Plan.

Kelp Core Team

The Kelp Core Team provided technical expertise during Kelp Plan development and workshop planning and reviewed deliverables. The Kelp Core Team includes the following organizations:

Puget Sound Restoration Fund,

Washington State Department of Natural Resources,

Marine Agronomics LLC,

National Marine Fisheries Service, and

Northwest Straits Commission.

Knowledge Review and Data Gaps

Efforts in Year 1 of the Kelp Plan development focused on synthesizing and communicating available data and current research on kelp in Puget Sound through a literature review and two workshops. Year 2 efforts included surveying technical experts on needs for kelp recovery and using the results to create a prioritized list of the knowledge gaps. This list informed decisions for kelp conservation and recovery strategies. The survey results are provided in Appendix C.

Workshops

Four workshops were held during the Kelp Plan development process. These workshops brought together technical experts to share current research, review data gaps, prioritize actions to address data gaps, and discuss management opportunities and needs. Workshop participants and notes are available for review in Appendix C.

Workshops in 2018 focused on discussing kelp status and trends, stressors, and ecosystem linkages, and then identifying data gaps and associated research and monitoring needs. Workshops held in 2019 focused on outlining actions to address high-priority knowledge gaps and identifying management and policy tools, gaps, and opportunities for kelp conservation. Results from votes tallied at workshops revealed a consensus among workshop participants on research and monitoring needs that support specific management actions.

Puget Sound Conservation and Recovery Plan Area

Recommended conservation and recovery actions in the Kelp Plan are specific to Puget Sound[1] and adopt the area boundaries used in the Rockfish Recovery Plan (NMFS 2017). Figure 1 shows the Puget Sound Kelp Conservation and Recovery Plan area. Puget Sound—the southern arm of an inland sea located on the Pacific Coast of North America—can be subdivided into basins including South, South Central, and North Central Puget Sound, Whidbey basin, Hood Canal, the San Juan Islands and Georgia Strait, and the Strait of Juan de Fuca. The western boundary for the

[1] The Washington State Legislature defines Puget Sound as Water Resource Inventory Areas (WRIA) 1-19.

Kelp Plan is the Victoria Sill, a significant oceanographic feature in the Strait of Juan de Fuca. Patterns of circulation created by the Victoria Sill create discontinuities in temperature, salinity (Masson and Cummins 2000), nitrogen (Mackas and Harrison 1997), primary production (Foreman et al. 2008), and water column organic carbon (Johannessen et al. 2008). Together, these factors create habitat conditions within the basins of Puget Sound that are distinct from the exposed outer coast.

Stalked kelp (Pterygophora californica), Ebey's Landing, Whidbey Island.
Photo by Tom Mumford, Marine Agronomics LLC.

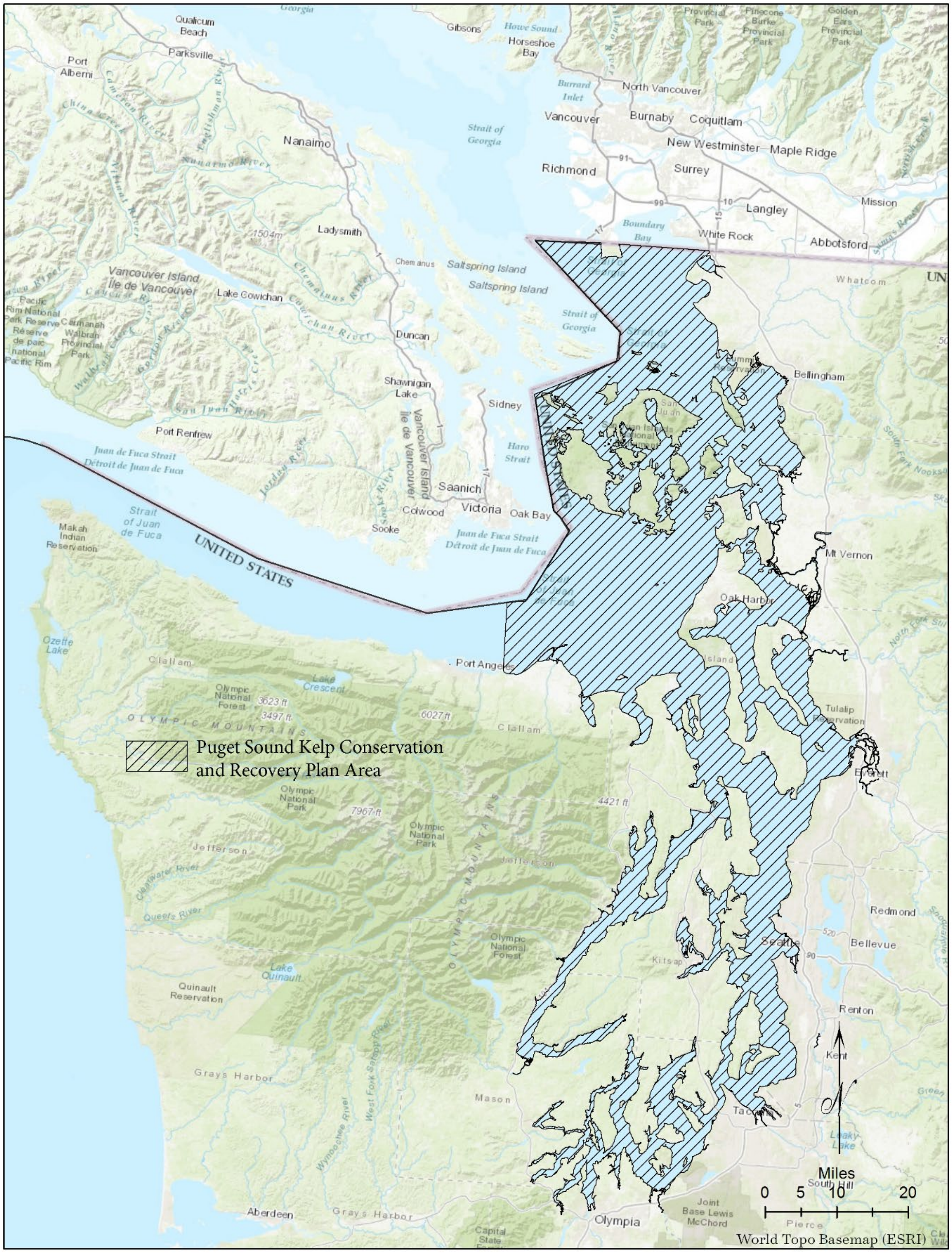


Figure 1. Map of Puget Sound Kelp Conservation and Recovery Plan Area. The area is indicated by the cross-hatched area.

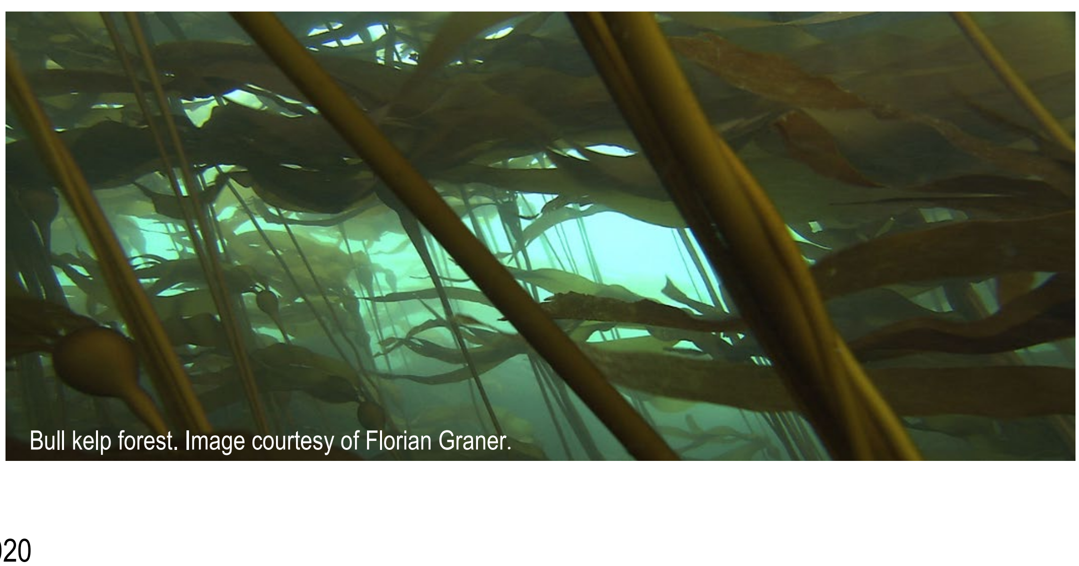
2.3 Precautionary Principle and Adaptive Management

A precautionary principle frames our approach to kelp conservation and recovery in Puget Sound. The precautionary principle stresses the implementation of conservation measures for critical habitats, even in the absence of scientific certainty (Harremoes et al. 2002; Brisman 2011). Available data document significant losses of bull kelp in several basins. The fact that other kelp species share similar environmental requirements with bull kelp raises concerns about losses to understory species as well (Dayton 1985; Bartsch et al. 2008). Additionally, research in British Columbia documents declines in multiple species of kelp, both floating and understory (Starko et al. 2019). In light of this evidence, and given the importance of these habitats to threatened and endangered species, a precautionary approach that includes monitoring, conservation, and restoration actions is critical.

The Precautionary Principle stresses the implementation of conservation measures for critical habitats even in the absence of scientific certainty.

Adaptive management is also central to our plan. Kelp conservation and recovery planning will need to be reviewed and updated as research and action implementation improve our understanding of kelp distribution, key stressors, and priority management actions. Scientific uncertainties in Puget Sound kelp distribution and trends, and the impact of global and local stressors, warrant adaptive management (Goetz et al., n.d.). Both the precautionary principle and adaptive management approaches are meant to be iterative processes, dynamically responding to the best available science as research improves our understanding of Puget Sound kelp ecosystems.

There is a rising concern across the research and management communities that without coordinated research and conservation actions, continued kelp declines may lead to significant impacts to broader Puget Sound ecosystem function. Adaptive management approaches, including restoration activities, could lead to improved habitat function for kelp ecosystems.



Bull kelp forest. Image courtesy of Florian Graner.

III. Puget Sound Kelp Overview

The term "kelp" broadly refers to large (10 cm to 30 m) brown macroalgae (phylum Phaeophyta, class Phaeophyceae) in the order Laminariales. Washington State is home to a diverse community of canopy and understory kelp, with 22 kelp species found along the outer coast and within Puget Sound (Appendix A provides a full list of these species). Puget Sound, as defined by the Kelp Plan in Section 2.2, is home to 17 species of kelp (Appendix A). Giant kelp *(Macrocystis pyrifera*) is excluded from the Kelp Plan because its range is restricted to the western Strait of Juan de Fuca, which is outside the planning area.

Puget Sound is home to 17 species of kelp.

Communities of kelp species form extensive biogenic (living) structures that serve as critical habitat for many taxa, including several fish species listed as species of concern by Washington State and endangered or threatened under the federal Endangered Species Act (ESA). This Kelp Plan employs the term "kelp" to refer to multiple species in the order Laminariales, and common names to refer to individual species, such as bull kelp.

3.1 Kelp Biology

In the macroscopic phase, kelp can be annual or perennial, depending on the species (Dayton 1985; Bartsch et al. 2008). Kelp species in Puget Sound are adapted to cold temperate waters and grow optimally at 5 to 15 °C (Tera Corp. 1982; Maxell and Miller 1996; Bartsch et al. 2008). Many common kelp species, such as bull kelp and sugar kelp (*Saccharina latissima*), die back in the late fall and winter before appearing again as early as February (Druehl and Hsiao 1977; Allen 2018).

Kelp Life History

All kelp species have two distinct life phases, each with different environmental requirements and stress thresholds (Geange et al. 2014). In the macroscopic form, kelp sporophytes produce reproductive patches (sori) along their blades that release microscopic zoospores that germinate into male and female microscopic gametophytes (Schiel and Foster 2006; Hurd et al. 2014). The male and female gametophytes produce sperm and eggs, respectively, and eggs that are fertilized by sperm produce microscopic sporophytes that typically grow to adult size within one season. Figure 2 illustrates the kelp life stages for bull kelp. In Puget Sound, where kelp forests are mostly annual, the microscopic life stages overwinter until the spring (Carney and Edwards 2006). However, the ecology of the microscopic life stage(s) that overwinters is not well understood at this time.

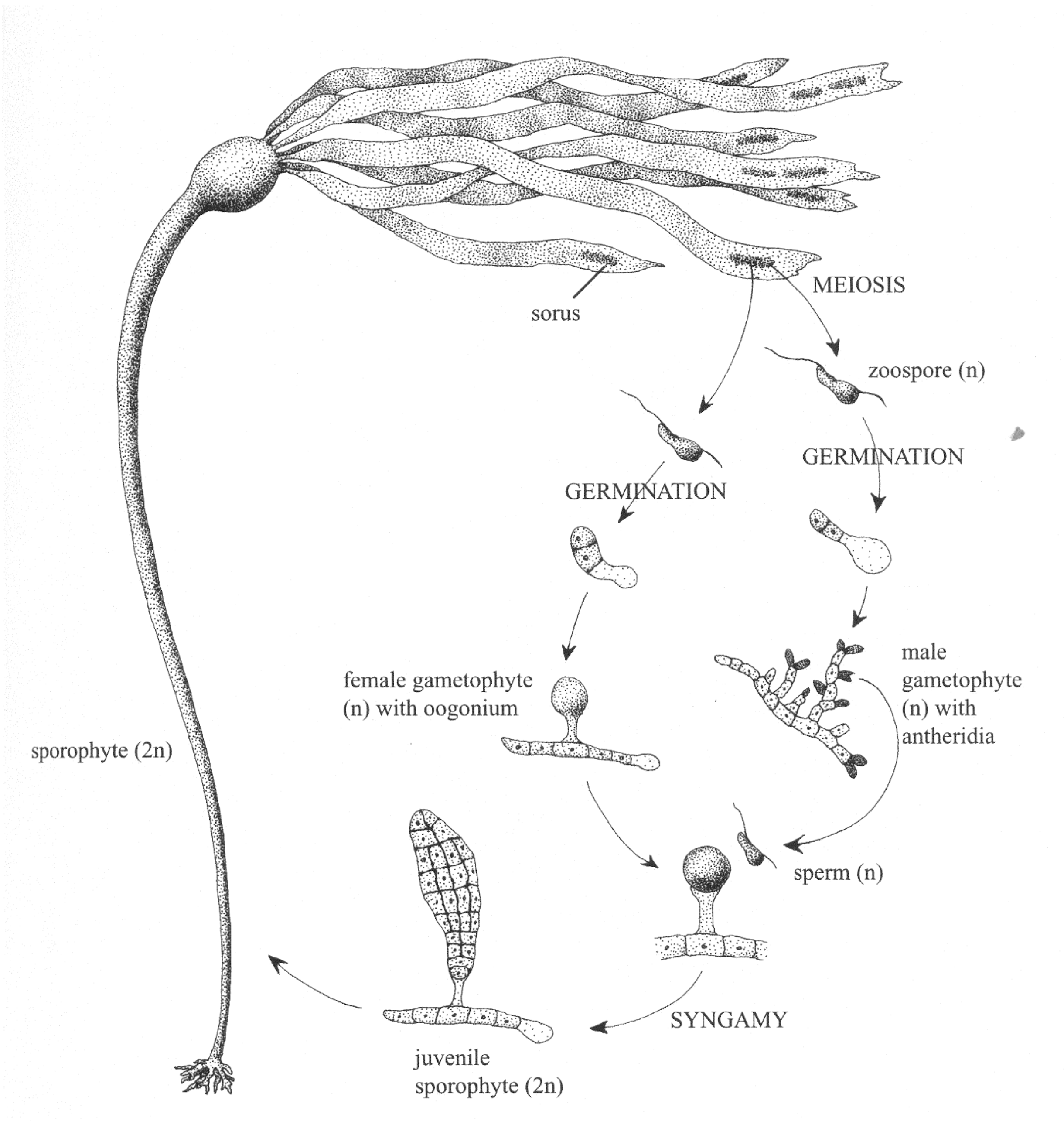


Figure 2. Diagram of kelp life stages. Illustration by Lisa (Scharf) Spitler. In: Mondragon J, and J. Mondragon (2003). Seaweeds of the Pacific Coast: Common Marine Algae from Alaska to Baja California. Sea Challengers, Monterey California, 97 pages.

Kelp Forest Structure

The term "kelp forest" encompasses the community and services provided by intact ecosystems dominated by kelp species. Kelp habitats are composed of multiple species and strata (stories) that rise above the benthos (seafloor) and can extend up to 10 to 25 meters to the surface (Steneck et al. 2002; Figure 3). Kelp sporophytes are organized into three types, shown in Figure 3, based on morphology:

- **Prostrate kelp** lack a rigid stipe or gas-filled buoy (pneumatocyst) and remain close to the seafloor, forming thick understories. For example, *Saccharina latissima, Costaria costata,* and *Agarum clathratum.*
- **Stipitate kelp** stand erect with the help of rigid stipes (stems), thus forming a midstory. For example, *Pterygophora californica.*
- **Floating kelp** rely on pneumatocysts to hold the plant up in the water column and can create large, floating surface canopies. For example, bull kelp (*Nereocystis luetkeana)* and giant kelp (*Macrocystis pyrifera*).

Kelp communities with all three morphological types form the most structurally complex forests, but assemblages of kelp species, regardless of morphology, provide large volumes of living habitat that provides critical foundations for nearshore ecosystems and food webs (Steneck et al. 2002; Teagle et al. 2017). In Puget Sound, prostrate kelp species are the most common (ShoreZone 2001) and provide crucial primary production, refuge, and habitat. Kelp species also host diverse microbial biofilms whose functional roles are not yet known and may play a role in future recovery efforts (Weigel and Pfister 2019).

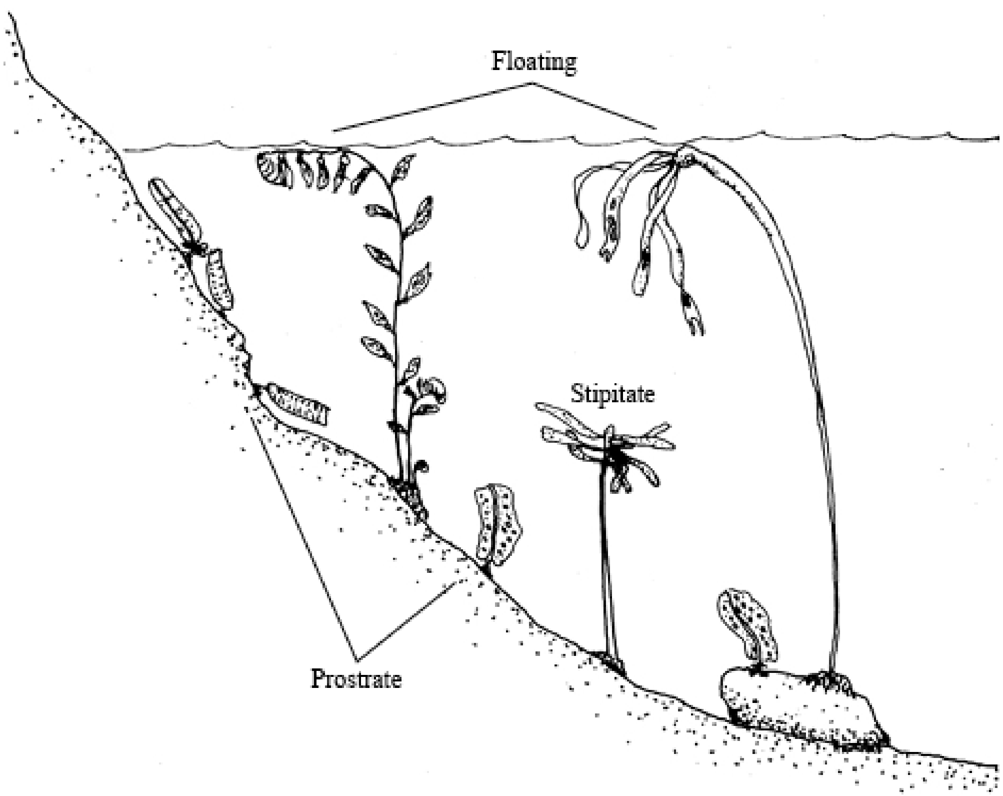


Figure 3. Kelp growth forms showing prostrate, stipitate, and floating kelp species. Illustration by Tom Mumford (2019).

3.2 Kelp Ecosystem Goods and Services

Kelp forests provide a variety of direct and indirect services for nearshore marine habitats and human coastal populations, such as:

- Habitat for ecologically and commercially important species;
- Food web support (primary production, forage habitat);
- Cultural value for Northwest Tribes and local communities;
- Recreation opportunities for harvest, diving, water sports, and fishing;
- Potential local water quality improvements through carbon and nutrient uptake; and
- Natural breakwaters that slow water motion.

In Washington State, kelp forests uptake 27 to 136 metric tons of carbon per day (Pfister et al. 2019). That is equivalent to the emissions of approximately 2,000 to 10,500 vehicles per year (EPA 2018).

Like eelgrass, kelp ecosystems provide critical habitat that increases overall biodiversity (Graham 2004; Altieri and van de Koppel 2014; Unsworth et al. 2018). The habitat is important for many economically valuable species, including threatened salmon and endangered rockfish (NMFS 2017; Shaffer et al. 2020). The large volume of primary production characteristics of kelp ecosystems provides an essential base for Puget Sound food webs, ultimately helping support marine mammals, including killer whale populations (Harvey et al. 2012; Southern Resident Orca Taskforce 2019). In addition to its role as foundation species, kelp is also an influential ecosystem engineer that, at high densities, can improve water quality by assimilating nitrogen (Kim et al. 2015) and slow the movement of water (Gaylord et al. 2007), potentially acting as natural breakwaters. This dampening of water motion increases the residence time of nutrients and particles (Eckman et al. 1989), potentially increasing larval densities of associated species and leading to higher food availability within kelp forests as compared to nearby vegetated and non-vegetated habitats. Finally, kelp forests offer diverse recreation opportunities to local residents, including productive fishing grounds and picturesque kayak and dive sites.

Kelp as Critical Habitat

Kelp forests provide critical habitat through two mechanisms:

1. Creating three-dimensional physical habitat that provides shelter and foraging opportunities, and
2. Acting as a direct food source (primary producer).

Kelp creates large volumes of high-quality habitat in areas with hard and rocky substrates unsuitable for eelgrass or saltmarsh vegetation. Eelgrass and kelp also grow intermixed in shallow areas with mixed substrates (Olsen 2019). Together, kelp forests, eelgrass meadows, and salt marshes can create contiguous marine vegetated habitats critical for associated species.

Primary production in kelp forests exceeds that of tropical rainforests per unit area (Krumhansl et al. 2016), and, in Washington waters, kelp biomass production is up to six times that of phytoplankton per unit volume (Pfister et al. 2019). This high productivity provides an important food source that supports food webs both inside kelp forests and in neighboring deep-water and shoreline habitats (Duggins et al. 2016; Filbee-Dexter and Scheibling 2016; Krause-Jensen and Duarte 2016; Olson et al. 2019; Schooler et al. 2019; Zuercher and Galloway 2019).

Losses in kelp populations result in losses to nearshore biodiversity and negatively impact fisheries, tourism, and coastal health.

The primary production in kelp forests is a foundation of nearshore food webs (Graham 2004; Krumhansl and Sheibling 2012; Koenigs et al. 2015; von Biela et al. 2016). Kelp forests in Norway harbor a greater abundance of marine invertebrates than other marine vegetated areas; in some cases, invertebrate abundances were five times higher than in eelgrass meadows (Christie et al. 2009). Similarly, invertebrate abundances—particularly of species known to be important forage fish, juvenile salmonid, and young-of-year rockfish prey species—are higher within kelp forests than adjacent open water and unvegetated benthic habitats (Siddon et al. 2008; Shaffer et al. 2020). The high volume of habitat provided by kelp, in combination with abundant food resources, makes kelp forests ideal refuges. The refuge and abundant food resource provided by kelp forests allow juvenile and mid-trophic species to feed in relative safety, helping lessen non-consumptive predator effects and leading to higher growth rates (O'Brien et al. 2018; Shaffer 2020). A study of kelp forests in the Strait of Juan de Fuca found that herring, surf smelt, and juvenile salmonids are more abundant inside kelp forests compared to adjacent open water sites (Shaffer et al. 2020). Kelp forests are also important foundations for adult finfish populations (Koenigs et al. 2015). Stable isotope data shows that adult coho salmon, chinook salmon remain reliant on nearshore food webs throughout their lives (see Appendix A for a more detailed discussion; Johnson and Schindler 2009). Healthy populations of finfish, particularly salmon, provide important prey for iconic Puget Sound predators, including killer whales (particularly Southern Resident killer whales), birds, and other marine mammals (Harvey et al. 2012; Southern Resident Orca Taskforce 2019).

The Cultural Importance of Kelp

The first human inhabitants of the Pacific Northwest likely followed a near-continuous band of floating kelp canopies dubbed "the kelp highway" that extended along the Pacific Rim from Asia to South America (Erlandson et al. 2007, 2015). Within the Pacific Northwest, bull kelp played a particularly prominent role in traditional subsistence knowledge and technology and in fishing, hunting, and food preparation and storage (Boas and Hunt 1921; Stewart 1977; Turner and Bell 1971; Turner 1995; Turner 2001) It was also put to more playful uses, as children and adults used the kelp for toys and target practice (Turner 1979, 2001). Finally, kelp played, and continues to play, a vital role in the symbolic and spiritual aspects of traditional Northwest Coast cultures. In some oral histories, kelp represents the interdependence between indigenous people and the sea and the reciprocal ties of kinship between humans and supernatural beings. In other stories, however, murderous kelp beings remind people of the potential dangers of the ocean. Appendix B provides more detail on the cultural importance of kelp for Pacific Northwest Tribes.

For many non-Tribal residents of Puget Sound, kelp forests have been and continue to be an essential food resource, particularly in the San Juan Islands. Bull kelp and other kelp species are harvested and dried for household consumption. Various groundfish species found in kelp forests, including rockfish and greenling, are also harvested for commercial, recreational, and subsistence purposes.

3.3 Kelp Distributions, Trends, and Regional Changes

Kelp forest persistence is highly dynamic over time, but evidence increasingly suggests that climate change stressors will lead to widespread and long-term declines in kelp populations (Connell et al. 2019; Smale 2019; Wernberg et al. 2019; Rogers-Bennet and Catton 2019). Kelp forests in many regions across the globe show decline. Persistent declines to kelp forests have been documented in North-Central California, Nova Scotia, the Gulf of Maine, Ireland, Norway, and South Australia (Wernberg et al. 2019). Recent kelp declines in Northern California (Rogers-Bennett and Catton 2019), Australia (Connell et al. 2019), and other locations (Airoldi and Beck 2007; Filbee-Dexter and Wernberg 2018; Wernberg et al. 2019) have been severe with little to no natural recovery. Causes of kelp loss vary by region, but generally reflect a combination of local and global stressors that interact additively or synergistically (Filbee-Dexter and Wernberg 2018; Rogers-Bennett and Catton 2019). Regardless of the cause, significant declines in kelp populations can result in substantial losses to nearshore biodiversity and negatively impact fisheries, tourism, and coastal health (Graham 2004; Bertocci et al. 2015; Koenigs et al. 2015).

Kelp Distributions and Trends in Puget Sound

Kelp exists in all of the basins of Puget Sound with appropriate habitat conditions, but is most abundant in exposed areas with hard substrate (ShoreZone 2001). While floating kelp canopies are the most conspicuous, they are only present along 11 percent of Washington shorelines while understory kelp is present along 31 percent shorelines. For comparison, eelgrass is present along 37 percent of Washington shorelines (ShoreZone 2001). However, these estimates are based on a compressive, one-time survey conducted in 2000 and may not accurately represent current distributions.

Along the outer coast and Western Strait of Juan de Fuca, floating canopy abundance, while highly variable, has remained stable in recent decades and over the last century (Krumhansl et al. 2016; Pfister et al. 2017). In contrast, traditional and local ecological knowledge from Tribes and residents, citizen-science surveys, and analysis of historical data suggest significant declines in the extent and density of bull kelp forests throughout Puget Sound (as defined in the Kelp Plan). Little information exists regarding changes in distribution or abundance among the 16 understory kelp species in Puget Sound (Mumford 2007).

Bull kelp forests in South Puget Sound have declined by 62 percent since the 1870s, with most losses occurring after 1980 (Berry et al. *in review*). A majority of the losses occurred in the inner reaches of South Puget Sound, with almost complete losses along all shorelines, except the Tacoma Narrows. These decreases include the loss of two bull kelp forests over the past decade and dramatic decreases in canopy area at several remaining forests (Berry et al. 2019, *in review*). In the Central Puget Sound, anecdotal reports document total bull kelp loss around Bainbridge Island and citizen-science data document kelp losses and decreases in canopy area around Edmonds and Mukilteo. Finally, analysis of aerial photography from the San Juan Islands raises concerns over significant losses in the North Puget Sound, especially to the more northern islands exposed to the warmer waters of the Strait of Georgia (Palmer-McGee 2019).

While evidence of kelp losses in Puget Sound is limited to bull kelp, recent research suggests that other kelp species are also vulnerable. Research in British Columbia found that multiple species of kelp declined in wave-sheltered areas compared to kelp in wave-exposed areas. The wave-sheltered environments of Puget Sound may be similarly vulnerable, with numerous species at risk, not just bull kelp (Starko et al. 2019).

3.4 Stressors

Environmental and biological conditions influence the abundance, persistence, and health of kelp populations (Dayton 1985; Steneck et al. 2002; Filbee-Dexter and Wernberg 2018; Pfister et al. 2019). Generally, kelp species in Puget Sound require hard substrates for attachment, and clear, cold water with sufficient nutrients to support growth (Wernberg et al. 2019). Sensitivity to changes in water quality makes kelp a potential sentinel or indicator species for nearshore environments, with losses often following the deterioration of local water quality and increased water temperatures (Reed et al. 2016; Filbee-Dexter and Wernberg 2018; Smale 2019). Biological controls in the form of competition with other seaweed species and grazing from herbivorous invertebrates also exert significant influence over kelp populations (Duggins 1980; Davenport and Anderson 2007; O'Brien and Scheibling 2016). These biological stressors can, and do, interact additively and synergistically with environmental stressors (Crain 2008). While there are areas of concern within Puget Sound, data are limited, and more research is needed to understand embayment-specific effects of local stress regimes (PSEMP Marine Waters Workgroup 2018; Berry et al. 2019; Calloway 2019).

The major stressors known to affect kelp populations are summarized below. Interactions among unidentified stressors not discussed explicitly here (e.g., disease introduction from restoration and commercial aquaculture, the introduction of new non-native species, effects of large oil spills, etc.) may also play an important role in future adaptive management strategies (see Appendix A for more detailed discussion of key kelp stressors).

Nutrient Loading

Kelp requires adequate nutrients for reproduction and growth. These minimum requirements can increase during periods of rapid growth and in the face of additional stressors (Bartsch et al. 2008; Stephens and Hepburn 2016; PSEMP Marine Waters Workgroup 2018). In field studies, nitrogen concentrations of 10 µmol/L resulted in increased giant kelp blade biomass and decreased blade erosion rates (Stephens and Hepburn 2016). Similarly, nitrogen concentrations of 10 µmol/L resulted in higher bull kelp recruitment success as compared to 1 and 5 µmol/L (Muth et al. 2019). Nutrient concentrations vary widely throughout Puget Sound; in some areas, concentrations remain consistently above these thresholds while they dip below these thresholds in others (Pfister et al. 2019; Berry et al. *in review*). Though the direct impacts of excess nutrients on kelp in Puget Sound are understudied, there is evidence that anthropogenic nutrient loading has altered nutrient dynamics and algal biomass in Puget Sound (Khangaonkar et al. 2018). In addition, excess nitrogen loading can indirectly affect kelp populations, promoting phytoplankton blooms that can quickly reduce available light (Burkholder et al. 2007; Mohamedali et al. 2011; Khangaonkar et al. 2018), and lend a competitive advantage to turf species that displace kelp (Russell et al. 2009; Falkenberg et al. 2013; Feehan et al. 2019). Turf algae include small filamentous and foliose green and red algae that provide fewer ecosystem services and lower biodiversity (Connell et al. 2014; Filbee-Dexter and Wernberg 2018; Appendix A). Because of these indirect impacts, anthropogenic nutrient loading from wastewater treatment plants, stormwater runoff, and other point and non-point sources of water pollution can have serious consequences for kelp forests (Benedetti-Cecchi et al. 2001; Falkenberg et al. 2013; Norderhaug et al. 2015).

Climate Change

Kelp forests are generally found in high latitudes and prefer cool water. Consequently, warming ocean temperatures threaten kelp forests across the globe (Smale 2019; Wernberg et al. 2019). The optimal temperature for many Puget Sound kelp species (for example, those in the genus *Laminaria sensu lato*, *Costaria costata,* and bull kelp) falls in the range of 5 to 15 °C (Tera Corp. 1982; Bartsch et al. 2008). Temperature stress makes kelp less tolerant and more vulnerable to other stressors, and marine heat waves have resulted in significant kelp forest losses in Northern California and Australia (Tera Corp. 1982; Rothäusler et al. 2009; Rogers-Bennett and Catton 2019; Wernberg et al. 2019). More discussion on this topic can be found in Appendix A. Due to the geomorphological complexity of Puget Sound, temperature stress will likely affect shallow and sheltered embayments more than deeper, well-mixed areas (e.g., sills separating major basins). Future management actions will benefit from identifying local temperature regimes and resulting impacts to kelp populations. While little can be done at the local level to reduce global stressors, such as rising ocean temperatures, actions taken to reduce local stressors can help decrease overall stress to kelp species in Puget Sound.

Fine Sediment Loading

Human activities in Puget Sound have both increased and blocked upland sediment loading (i.e., logging and dams, respectively) (Rubin et al. 2017) as well as the frequency of sediment resuspension from benthic and subtidal activities. Changes in fine sediment loading from river discharge, stormwater runoff, in-water construction activities, and coastal development can negatively impact kelp recruitment and microscopic life stage survival by burying suitable substrate and increasing turbidity (Airoldi 2003). However, the nature and severity of impacts depend on the timing of sediment deposition and the level of exposure at a given kelp forest (Geange et al. 2014). In the short term, increased sediment loads can increase mortality of dormant microscopic kelp life stages (Arakawa 2005; Deiman et al. 2012; Watanabe et al. 2016), while higher turbidity from sediment loading can significantly delay spring recruitment and reduce the maximum depth of kelp forests (Glover et al. 2019). Finally, sediment dynamics in Puget Sound have been altered by large-scale historical changes to upland and nearshore landscapes (Perkins and Collins 1997; Pearson et al. 2018). The effects of historical and current human-related alterations to nearshore sediment delivery on kelp habitat availability and population dynamics in Puget Sound are unknown and warrant further investigation.

Grazers

The loss of kelp forests due to uncontrolled grazing is well documented in the popular and scientific literature (Estes and Duggins 1995; Steneck et al. 2002; Ling 2008; Rogers-Bennett and Catton 2019). Generally, loss of mid- and high-level predators often results in expansions of grazers that negatively impact kelp populations (Davenport and Anderson 2007; Steneck et al. 2013: Rogers-Bennett and Catton 2019). However, decreases in grazing pressure can also lead to significant changes in kelp forest composition, allowing perennial species to displace annuals such as bull kelp (Duggins 1980; see Appendix A for a more detailed discussion).

Purple urchins have been responsible for recent large and persistent kelp losses in northern California (Rogers-Bennett and Catton 2019), and there is concern that urchin barrens may be expanding north into Oregon (Flaccus and Chea 2019). Puget Sound hosts three urchin species, but WDFW has not documented extensive urchin barrens during urchin population surveys (personal communication with Henry Carson, WDFW, November 14, 2019).

While herbivory from macrograzers, like urchins, is critical in understanding kelp forest dynamics (Steneck et al. 2002), smaller mesograzers—such as amphipods, small crustaceans, and small gastropods—may also negatively affect kelp populations (Davenport and Anderson 2007; O'Brien and Scheibling 2016; Pfister and Betcher 2017). Often, pressures from smaller grazers interact synergistically with environmental stress, resulting in more significant impacts than expected.

Fisheries Impacts

In Puget Sound, historical cod, pollock, hake, salmon, rockfish, urchin, sea cucumber, lingcod, cabazon, and abalone fisheries have significantly altered Puget Sound marine food webs (see Appendix A for more detail). The impacts of these changes on kelp population distributions and dynamics are unknown.

Harvest

Recreational harvest of kelp is allowed for individual use, and jointly managed by DNR and WDFW. Currently, DNR and WDFW only recommend sustainable harvest practices; best practices are codified for Washington State Parks only (WAC 325-32-350). A recent study on Whidbey Island found that unsustainable harvest practices (clipping kelp too close to the stipe) precluded regrowth post-harvest and negatively impacted kelp densities for up to a year after harvest (Kilgo 2019). Statewide regulations restrict harvest to 10 pounds of kelp (regardless of species) per person per day and recommend sustainable cutting (above the plant growth area, or meristem) (RCW 79.135.410). Currently, there is no formal, statewide monitoring of recreational kelp harvest to document harvest locations, species, methods, and quantities to assess the potential impacts of harvest on kelp populations. In Washington State parks, sustainable harvest is permitted in three parks during defined dates; all other parks are closed to recreational kelp harvest. In other areas, local regulations further limit or prohibit harvest.

Washington State does not allow commercial harvest of wild seaweed or kelp (RCW 79.135.410). There is one exception for giant kelp harvest for the traditional herring "spawn-on-kelp" fishery, but giant kelp does not occur within the boundaries of the study area of the Kelp Plan, and this fishery has been closed for decades.

Shoreline Development and Activities

Human activities and shoreline development generate a wide range of potential stressors affecting kelp species. Shoreline development and activities include, but are not limited to, overwater structures, outfalls, shoreline armoring, dredging, marinas, and navigation. The impacts on kelp can be both direct and indirect. Potential impacts include, but are not limited to dredging and construction in or near kelp forests, increased turbidity from increased sediment inputs (Rubin et al. 2017; Glover et al. 2019), shading from overwater structures (Szypulski 2018), anthropogenic nutrient loading (Falkenberg et al. 2013; Khangaonkar et al. 2018; Feehan et al. 2019), exposure to petroleum products from tanker spills (Antrim et al. 1995), and impacts from recreational and commercial boating activities. While existing regulations do consider kelp when permitting human activities and shoreline development, specific guidance for surveys (i.e., WDFW's interim macrovegetation survey guidelines) and mitigation measures are not clear and have different requirements than for other macrovegetation. Collaborative research, in partnership with regulators and policymakers, will better support the management of kelp impacts from human activities and shoreline development.

Invasive Species: *Sargassum muticum* and *Undaria pinnatifida*

The invasive seaweed *Sargassum muticum* is known to displace native kelp species in Puget Sound (Britton-Simmons 2004). *Sargassum* was estimated to span approximately 20 percent of the shoreline in Puget Sound in the late 1990s (ShoreZone 2001). In Barkley Sound along the outer coast of British Columbia, *Sargassum* distributions have increased in wave-sheltered areas in recent decades (Starko et al. 2019). There is a concern that the *Sargassum* range has also expanded in the wave-sheltered environment of Puget Sound since the late 1990s (personal communication with Brent Hughes, Sonoma State University, November 12, 2019). While little data exists on *Sargassum* distribution and trends in Puget Sound, existing data from previous vegetation surveys may provide better insight. The invasive kelp species *Undaria pinnatifida* (known more commonly as Wakame) has been encountered as far north as San Francisco along the California coast (Zabin et al. 2009), and there is concern regarding its potential presence in Washington State waters and Puget Sound. Currently, there is no evidence that *Undaria* has been introduced to Puget Sound, but in the absence of comprehensive understory kelp surveys, its presence is unknown. While *Undaria,* like *Sargassum*, is a common invasive species throughout the Pacific Coast, there is no consensus on its impacts on native kelp assemblages (Casas et al. 2004; South et al. 2017).

Kelp crabs on bull kelp, Squaxin Island.
Photo by Julia Ledbetter.

IV. Puget Sound Kelp Management Framework

Kelp and kelp-based ecosystems in Washington State are managed within a framework of ownership, regulations, and trust responsibilities. The management is split between Tribes, state and federal management agencies, and county and municipal governments.

Figure 4 shows the management framework for kelp in Washington State.


Rockfish in understory kelp.
Photo by Adam Obaza- Paua Marine Research.

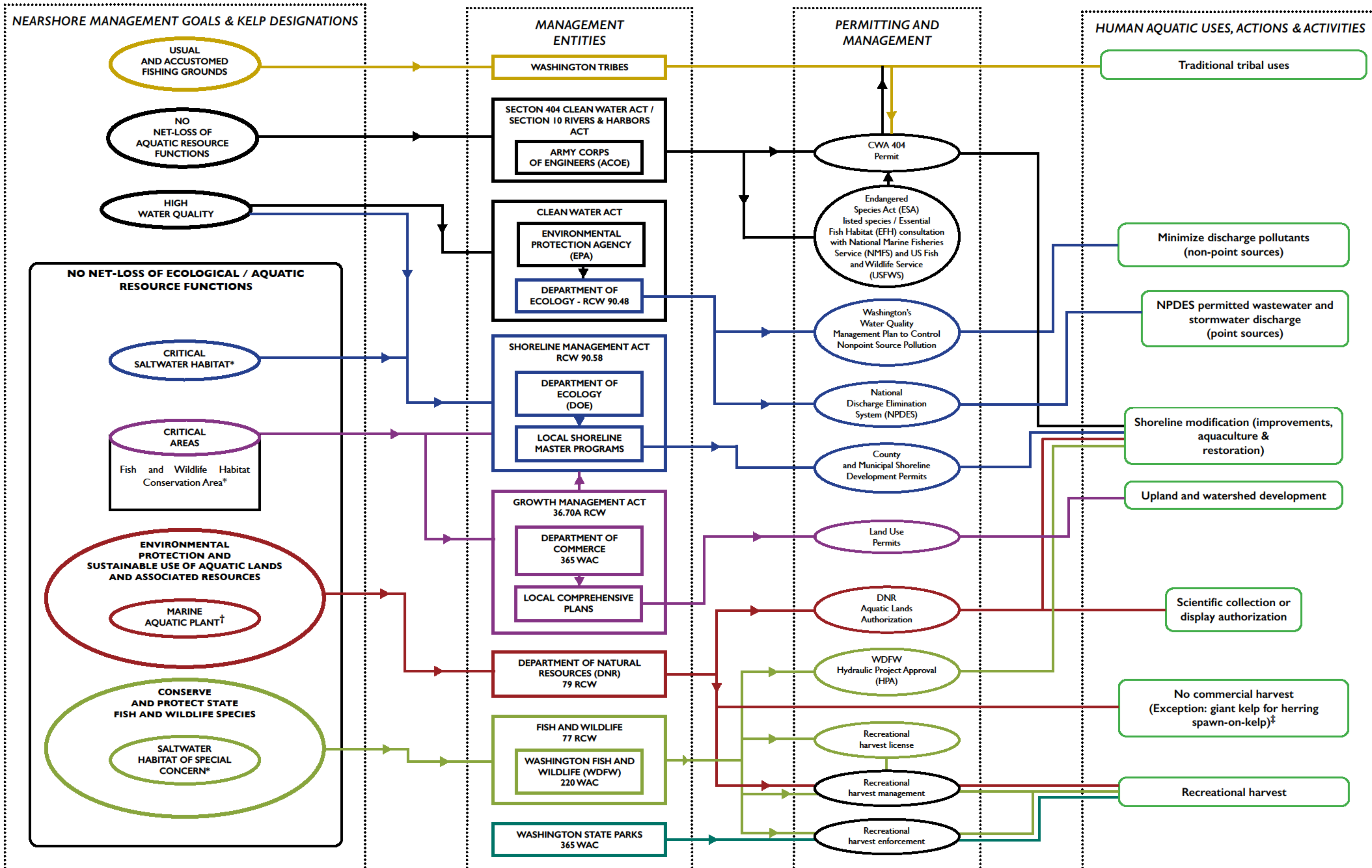


Figure 4. Diagram of the management framework for kelp in Washington State; * Designations that refer to "kelp" specifically and explicitly; † Designations that refer to macroalgae and/or species in the class Phaeophyta generally; ‡ Giant kelp does not occur within the geographic boundaries of this plan.

4.1 Kelp Management Responsibilities

Multiple Tribal and governmental agencies share responsibilities for managing Puget Sound kelp and their habitats.

Washington State Tribes

Washington Tribes have a reserved right to conserve and protect Puget Sound kelp habitats as critical habitat for several culturally and economically important species covered by treaty rights. Conserving and protecting critical fish habitat from environmental degradation was reaffirmed as a fundamental treaty right for all Washington Tribes under Phase II of the "Boldt Decision" (*U.S. v. Washington, 506 F. Supp. 187, 191*), and kelp restoration activities are now considered "fish habitat enhancement projects" by the WDFW (RCW 77.55.181). Kelp, in and of itself, also has significant historical and cultural value for Washington Tribes (Appendix B).

Washington State Department of Natural Resources

The Washington State Department of Natural Resources (DNR) manages and stewards 2.6 million acres of state-owned aquatic lands. The DNR manages aquatic lands in pursuit of five goals:

- Encourage direct public use and access;
- Foster water-dependent uses;
- Ensure environmental protection;
- Provide opportunities for utilization of renewable resources; and
- Generate income from the use of aquatic lands, when consistent with the previous goals.

State-owned aquatic lands include most subtidal areas (bedlands), nearly 30 percent of intertidal areas (tidelands), and unsold shorelands of rivers and lakes (shorelands). In general, bedlands below the extreme lower low water and within the three-mile state boundary are considered State-owned aquatic lands. Because kelp is generally found in subtidal waters and considered an attached resource, DNR manages the majority of Puget Sound kelp resources. Kelp harvest is also regulated under Washington State guidelines and regulations (RCW 79.135.410). State regulations prohibit the commercial collection of natural set kelp. Shellfish and seaweed aquaculture on State-owned aquatic lands requires a DNR use authorization, and DNR includes habitat stewardship measures to ensure the protection of kelp during construction and operations. DNR also has the authority to withdraw sites from leasing by Commissioner's order to promote native species conservation.

DNR established the Aquatic Reserve Program in 2002 to protect areas of "special educational or scientific interest, or of special environmental importance" (WAC 332-30-151). Eight Aquatic Reserves are currently managed by DNR (seven saltwater, one freshwater), and new aquatic reserves can be proposed according to DNR aquatic reserve implementation and designation guidelines. Kelp ecosystems are designated as priority marine habitats under DNR guidelines due to the critical functions and services they provide to associated marine species. Current aquatic reserves contain important areas of extensive and diverse kelp forests in the Strait of Juan de Fuca.

Shoreline Management Act: Department of Ecology and Local Shoreline Master Programs

The Shoreline Management Act of 1971 requires 41 coastal counties and municipalities in Washington State to draft and implement local shoreline management plans (SMPs) according to Department of Ecology (DOE) guidelines and regulations (WAC 173-26). SMPs, besides meeting other requirements, must delineate and afford protections to "critical areas," (RCW 36.70A)—which include kelp and eelgrass beds as "fish and wildlife habitat conservation areas"—using best available science (WAC 365-190-130).

DOE guidelines also require the protection of priority habitat areas, which include kelp as both a component of the Puget Sound Nearshore (WDFW 2008) and a "saltwater habitat of special concern," as defined by the WDFW (WAC 220-660-320). As a result, SMPs must "include policies and regulations to protect critical saltwater habitats and should implement planning policies and programs to restore such habitats" (WAC 173-26-221(2)(C). While these existing regulations provide significant protections for kelp habitats, effective conservation depends on local implementation and enforcement.

Clean Water Act: Washington Department of Ecology

The DOE implements water quality standards in fulfillment of the federal Clean Water Act (CWA), and the standards submitted by DOE must pass review from the EPA before being accepted. Water quality standards drafted by DOE are used in permitting both non-point sources of pollution from stormwater runoff, and point source pollution and waste discharge through the National Pollutant Discharge Elimination System (NPDES). The CWA requires states to develop a Total Maximum Daily Load (TMDL) plan for water bodies that exceed standards and are listed on the CWA Section 303(d) list. Current regulations do not include specific thresholds or pollution protections for kelp, but planned human-source nutrient load reductions aim to improve conditions for Puget Sound as a whole (RCW 90.40.010). It is unknown how effective such regulations are at protecting kelp specifically.

Hydraulic Project Approval: Washington Department of Fish and Wildlife

The WDFW Hydraulic Project Approval (HPA) program is intended to ensure "no net loss" of ecological functions within "saltwater habitats of special concern," specifically as they pertain to fish productivity (WAC 220-660-050). The objective is to minimize impacts of projects that "use, divert, obstruct, or change the natural flow or bed" of state waters. WDFW's HPA guidelines outline specific survey and mitigation requirements (avoid, minimize, compensate impacts) for all project applications, and reserve the right to deny any applications. Current WDFW HPA regulations provide exemptions for SMP development permits for fish habitat enhancement projects, which include kelp restoration activities (RCW 77.55.181).

Recreational Harvest and Scientific Collection Permits

DNR and WDFW share the management of recreational seaweed harvest statewide (RCW 79.135.410). No commercial harvest of naturally growing seaweed is permitted in Washington

State. WDFW issues recreational shellfish/seaweed collection licenses that allow for the harvest of up to 10 pounds (wet weight) of seaweed per day. This license does not require a catch record card, thus tracking seaweed harvests is left to on-the-ground enforcement and management officials from WDFW.

Kelp harvest for non-recreational uses is not well coordinated or tracked. DNR permits collection of kelp for scientific and display uses as a part of its "Aquatic Use Authorization" process on state-owned aquatic lands. The University of Washington's Friday Harbor Laboratories tracks the scientific collection of organisms in San Juan County, including seaweeds (RCW 28B.20.320). Responsibility for scientific and display collection on other lands resides with the local land manager.

Army Corps of Engineers: Clean Water Act, Rivers and Harbors Act Section 10, and Endangered Species Act

The United States Army Corps of Engineers (USACE) is responsible for permitting construction activities within U.S. waters. Section 404 of the CWA regulates dredged and fill material discharged into U.S. waters to "restore and maintain … the integrity of waters of the U.S." Section 10 of the Rivers and Harbors Act requires that construction activities do not interfere with navigable waters. In 1990, a memorandum added the goal of "no net loss" for aquatic resources to the USACE's responsibilities, requiring that any activities impacting aquatic resources include mitigation actions for "special aquatic sites," which include "vegetated shallows." However, "vegetated shallows" are defined as waters that support rooted vegetation, and interpretation differs on whether this category includes kelp and other seaweeds that do not form roots. As a result, kelp is often excluded from federal mitigation guidelines. CWA Section 404 does provide protections against impacts to critical habitat for ESA-listed species, however, and kelp is considered an endangered Puget Sound rockfish habitat.

National Marine Fisheries Service and United States Fish and Wildlife Service: Endangered Species Act

The NMFS and United States Fish and Wildlife Service (USFWS) designate critical habitat for ESA-listed species and require consultation under Section 7(a)(2) of the ESA with federal action agencies that propose actions that may affect listed species and their habitats. NMFS designated critical habitat in the nearshore for bocaccio, noting that "…substrates such as sand, rock and/or cobble compositions that also support kelp (families Chordaceae, Alariaceae, Lessoniacea, Costariaceae, and Laminaricea) are essential for conservation because these features enable forage opportunities and refuge from predators and enable behavioral and physiological changes needed for juveniles to occupy deeper adult habitats" (78 FR 47635).

National Marine Fisheries Service: Essential Fish Habitat

When a federal agency authorizes, funds, or undertakes an action that may adversely affect essential fish habitat (EFH), they must consult with NMFS on that action. An adverse effect on EFH is considered to be any direct or indirect effect that reduces the quality and/or quantity of the habitat and range from large-scale ocean uses to small-scale projects along the coast. NMFS provides advice and recommendations to federal agencies to avoid, reduce, or offset these adverse effects.

Canopy kelp is considered a "Habitat Areas of Particular Concern" (HAPC), which is a discrete subset of EFH. The canopy kelp HAPC includes those waters, substrate, and other biogenic (living) habitat associated with canopy-forming kelp species (e.g., Macrocystis spp. and Nereocystis spp.). The HAPCs are considered high-priority areas for conservation, management, or research because they are important to ecosystem function, sensitive to human activities, stressed by development, or are rare. These areas provide important ecological functions and/or are especially vulnerable to degradation and can be designated based on either specific habitat types or discrete areas. A HAPC designation does not automatically confer additional protections or restrictions upon an area, but it helps to prioritize and focus conservation efforts.

Kelp Aquaculture Regulations

Kelp aquaculture regulations and practices are not addressed in the Kelp Plan, as this document primarily focuses on the conservation and recovery of naturally occurring populations. There are potential future benefits from expanded seaweed aquaculture, but aquaculture should not be considered a replacement for naturally occurring kelp populations and should not negatively impact or displace them. A developed permitting framework for shellfish aquaculture in Puget Sound (RCW 19.135) is coordinated by the Shellfish Interagency Permitting Team, and kelp aquaculture generally falls within this framework. To date, only one site has been permitted in Washington State. Separate efforts spearheaded by NMFS and Washington SeaGrant are working to develop resources for seaweed aquaculture development in Washington State.

Bull kelp.
Photo courtesy of Eiko Jones Photography.

V. Kelp Conservation and Recovery Actions

The Kelp Plan defines six strategic goals and associated actions as a framework for coordinated research and management to support kelp conservation and recovery in Puget Sound. These goals and actions reflect the precautionary principle discussed in Section 2.3 and outline an approach that includes monitoring, conservation, and restoration actions. Adaptive management will play a key role, as our understanding of Puget Sound kelp populations, ecology, and biology grow. Furthermore, successful kelp conservation and recovery will require continued coordination between user groups, and additional funding and resources to support outlined actions. The Kelp Plan includes the formation of workgroups for ongoing coordination among management and science collaborators to continue this critical work.

While our understanding of kelp and its stressors is not yet sufficient to define a prioritized strategy or list, the broad suite of actions that are needed is clear. Strategic goals and related actions for kelp conservation and recovery are identified below, along with partner organizations that have expressed interest in contributing to these goals. If your organization is interested in joining this collaborative effort but is not listed below, please contact kelp@nwstraits.org.

1. Understand and Reduce Kelp Stressors

Regional- and local-scale stressors in Puget Sound affecting kelp likely differ between sub-regions and are not well understood. Reducing stressors will require research into the dynamics of kelp populations relative to both individual stressors and cumulative stressor impacts on a regional and local scale. Managers often look to reduce stressors on an individual basis by targeting priority key stressors to kelp. However, the spatial scale and potential cumulative and synergistic impacts of stressors on kelp may require a more holistic approach. Adaptive management is critical to support management needs to address stressors individually while incorporating the latest scientific understanding of how individual stressors fit into the bigger picture of kelp recovery. Consistent with the precautionary principle, even a partial understanding of the critical thresholds for individual stressors on kelp and the top priority stressors can be used to target management actions. Failure to reduce stressors that have caused kelp losses will impede successful restoration and recovery efforts.

Failure to reduce stressors that have caused kelp losses will impede successful restoration and recovery efforts.

Several existing tools and regulations direct diverse management entities to minimize kelp stressors (outlined in Section IV). Moreover, the scientific and management communities have expressed a need to strengthen enforcement and compliance of existing laws and regulations, close loopholes, increase interagency coordination, and prioritize kelp conservation. Finally, reducing environmental stressors will provide benefits for kelp and the overall health of Puget Sound.

Human Impacts on Water Quality and Kelp Habitats

Globally, kelp forests rely on clean, cool waters for persistence—and many of these waters are being lost to water quality degradation and warming ocean temperatures. Of specific concern are impacts to the nearshore environment from increased development, and growing populations, all of which can lead to excess nutrient loading, sediment delivery, and point and nonpoint sources of common pollutants and contaminants. Implementation of the following actions will help reduce human impacts on water quality and kelp habitats.

1.1. Form interagency workgroups to increase collaboration and information sharing across management organizations to improve implementation and to address policy gaps.

1.2. Inform future management actions through continued research on the impacts of current and historical human activities on kelp forests (e.g., nutrient and sediment loading thresholds and impacts, turbidity effects on kelp recruitment, substrate availability, and impacts from recreational and commercial boating activities).

1.3. Identify priority stressors that negatively affect Puget Sound kelp on a sub-regional scale to target management actions.

1.4. Fully implement and enforce available protections for kelp through existing regulations, programs, and policies (e.g., DOE SMA Guidance, Local SMPs, WDFW HPA, DNR Aquatic Use Authorizations, mitigation programs, NMFS ESA and EFH consultations).

- 1.4.1. Fully consider kelp in programs that respond to and prevent chemical and oil spills (e.g., DOE Geographic Response Planning).
- 1.4.2. Develop tools to support planners' ability to review/access policy regulations that assist in decision-making.
- 1.4.3. Develop and implement long-term research and monitoring actions using rigorous scientific and adaptive management principles to determine the effectiveness of current regulations and protection actions.

1.5. Increase protection by addressing key gaps in existing regulations and implementation programs.

- 1.5.1. Improve kelp-specific mitigation guidance and implementation.
- 1.5.2. Add an explicit reference to kelp in existing regulations that include kelp protection but do not reference kelp specifically. (e.g., CWA Section 404 definition of Vegetated Shallows, DNR's definition of submerged aquatic vegetation, and WDFW's Priority Habitats and Species list).

1.5.3. Update survey guidelines and foster coordination among the organizations that conduct site-level surveys, such as the WDFW Macroalgae Habitat Interim Survey Guidelines and the Coastal Zone Training Program.

1.5.4. Form an interagency workgroup to review the kelp aquaculture permitting process and develop best management practices, such as cultivating native species, avoiding the spread of pathogens, and avoiding the use of harmful pesticides and other chemicals.

1.6. Reduce anthropogenic nutrient and sediment loading (e.g., stormwater and WWTP permitting, and TMDL planning).

1.6.1. Coordinate and share research with the Nutrient Reduction Program planning and implementation program, led by the DOE.

1.7. Support sustainable kelp harvest by informing recreational harvesters about regulations and sustainable kelp harvest methods.

Biological Stressors

Human activity, historical and current, has altered the biological condition of Puget Sound. Fishing pressure has disrupted elements of the Puget Sound food web, impacting populations of cod, hake, pollock, salmon, rockfish, urchin, sea cucumber, abalone, lingcod, cabazon, and others (See Appendix A for more discussion). Fishing-related changes to marine food webs have the potential to impact kelp populations (See Section IV). Still, the connection between fishing pressure and status of kelp populations in Puget Sound is unknown. Additionally, human activities have introduced non-native macroalgal species, such as *Sargassum*, that compete with native kelp for space and light. Implementation of the following actions will help reduce biological stressors.

1.8. Strive to incorporate kelp and other trophic considerations into fisheries management planning.

1.9. Explore invasive macroalgae (including *Sargassum muticum* and *Undaria pinnatifida*) control alternatives, ecological roles, and long-term management considerations related to climate change.

Climate Change

Anthropogenic climate change poses a profound threat to marine environments all over the globe. For kelp in Puget Sound, increasing water temperatures are a major potential concern. Many of the inner basins naturally experience high water temperatures (Burns 1985; Bos et al. 2015) and the water temperatures are expected to rise with climate change. Additional stress associated with climate change-related impacts to water quality (increased turbidity from increased storm severity and frequency, increased flooding, and sea-level rise), increases in human development resulting from climate-related migration, and ocean acidification-related hypoxia also pose serious threats to Puget Sound kelp populations. Many of these climate-related stressors can be addressed by previously outlined actions in this Kelp Plan to better understand and reduce their impacts on Puget Sound kelp populations. While there is no Washington State or local policy action that can "lower the thermostat" on Puget Sound waters, it is important to note that temperature stress likely exacerbates the impacts of other stressors. Implementation of the following actions will help reduce impacts of climate change.

1.10. Investigate climate change impacts to improve management decisions, such as prioritizing locations for kelp protected areas, restoration sites, and mitigation activities.

1.10.1. Include kelp habitat in regional and local climate adaptation strategies and planning.

1.11. Investigate local effects within kelp beds on seawater chemistry (Pfister et al. 2019) and consider potential management opportunities for these benefits.

1.12. Investigate the development of temperature-tolerant strains of native kelp species for potential use in restoration and mitigation outplanting.

2. Deepen Understanding of the Value of Kelp to Puget Sound Ecosystems and Integrate into Management

Available information indicates that kelp forests provide important ecosystem services to Puget Sound. While we have a general understanding of these ecosystem goods and services from other kelp ecosystems from around the world, our understanding of the magnitude of those services in Puget Sound is incomplete. Improving our understanding of the role of kelp in Puget Sound food webs and the essential ecosystem services it provides will support regulatory actions to better protect kelp. Additional research and management guidance are needed to demonstrate the link between kelp forests and populations of species like salmon, rockfish, forage fish, and killer whales (particularly Southern Residents). A deeper understanding will enhance our ability to advocate for kelp conservation as a necessity for improving the health of Puget Sound as a whole. Implementation of the following actions will improve our understanding of kelp habitats and their values.

2.1. Determine and quantify functional roles of kelp habitats for associated species and provide guidance to managers for regulatory implementation, such as endangered species habitat conservation.

2.1.1. Monitor the use of kelp forests as nurseries, migration corridors, refuges, and high-quality forage grounds for salmonids, rockfish populations, forage fish, pinto abalone, and killer whales.

2.1.2. Utilize local ecological knowledge to assess the value of kelp forests as fishing areas.

2.1.3. Use isotopic and biochemical analysis of Puget Sound species and other tools to assess kelp contributions to nearshore, deep water, and terrestrial food webs.

2.2. Calculate the value of kelp ecosystem services for use in developing mitigation guidance.

3. Describe Kelp Distribution and Trends

Successful management relies on having accurate information regarding the distribution and trends of species and populations of management concern. Currently, synoptic data on kelp distribution throughout Washington State is limited to the 1990s-era ShoreZone Inventory (Berry et al. 2001). More detailed and recent information is needed on the distribution of both canopy-forming and understory species. Additionally, due to the dynamic nature of kelp forests, information on short- and long-term trends is needed to tease apart natural variation and response to stressors. Kelp monitoring is limited to surface canopy surveys by the DNR and NWS Commission, surveys by the Marine Resources Committee in some locations, and understory surveys by the United States Geological Survey (USGS).

Updated information on distribution and trends is essential to inform point-in-time surveys, link changes in distributions to stressors, and guide planning. Additionally, continued and regular monitoring will help managers detect where the loss of kelp forests is occurring. This information will allow policymakers and managers to effectively target sites with stable kelp forests for conservation and sites with measured losses for recovery efforts. Finally, it will allow for the regional tracking of kelp resources. Implementation of the following actions will provide new information on kelp distribution and trends.

- 3.1. Update and expand information on the current extent of canopy-forming and understory kelp.
- 3.2. Make distribution and trends data available to agencies and the public for use in spatial planning, project planning, and regulatory implementation.
- 3.3. Coordinate and expand efforts to strategically monitor canopy-forming and understory kelp throughout Puget Sound and build collaborations between organizations.
  - 3.3.1. Continue and expand surface monitoring of Puget Sound canopy-forming kelp.
  - 3.3.2. Develop Puget Sound-specific subtidal monitoring protocol, and establish a network of partners conducting subtidal kelp index site monitoring (e.g., REEFCheck, PSRF)
  - 3.3.3. Encourage compatibility among protocols to support data synthesis, linking ecological functions, and relationships to local stressors.
  - 3.3.4. Collaborate with the Puget Sound Partnership to expand the eelgrass Vital Sign to incorporate kelp indicators (such as kelp canopy area and understory kelp distributions).
- 3.4. Expand understanding of historical distributions and trends by compiling historical information sources and exploring traditional ecological knowledge.
- 3.5. Identify the genetic structure of kelp populations, including connectivity, dispersal, and population dynamics.

4. Designate Kelp Protected Areas

Puget Sound kelp recovery begins with the conservation and protection of kelp forests. Besides implementing and strengthening current regulations to conserve kelp, the establishment of priority kelp habitat areas will support local and regional conservation efforts. Given that stressors and available management tools vary by location, we anticipate that enhanced protections will be site-specific. Coordination among multiple management organizations could increase the span of protections at a site (for example, limitation of harvest and land use activities). Implementation of the following actions will increase kelp protection.

4.1. Protect kelp habitat in existing and new reserves, refuges, and protected areas.

4.1.1. Increase the protection of existing kelp forests through organizations like DNR and USFWS.

4.1.2. Use withdrawal letters and set standards for lease agreements to ensure the protection of kelp forests (DNR).

4.2. Assess the extent of recreational kelp harvest and its potential impacts, and develop spatial management plans and strategies to reduce potential impacts from projected kelp harvest activities.

4.2.1. If necessary, identify priority enforcement needs relating to permits and recreational harvest activities to support existing protections.

5. Restore Kelp Forests

Historical kelp forests can be restored through a combination of indirect habitat improvements to reduce stressors and direct kelp population enhancement. Reestablishment of persistent kelp forests relies on first eliminating or minimizing the stressors that contribute to current documented losses. Since restoration methods and best practices are still being developed, it is critical that we monitor restoration and mitigation sites following project completion and assess the success and efficacy of new methods. Restoration success could be increased by identifying places with the greatest potential to support kelp. Finally, we must work to shift current approaches to mitigation away from piecemeal actions and towards a more holistic, total-ecosystem approach that takes into account kelp forest connectivity and large-scale issues of nearshore habitat connectivity. Implementation of the following actions will help restore kelp forests.

5.1. Develop a spatial plan identifying regions and sites for priority restoration actions and mitigation.

5.1.1. Target management actions that reduce stressors at priority restoration sites.

5.1.2. Reintroduce kelp through outplanting at sites that are recruitment limited.

5.1.3. Develop a mitigation bank of priority locations for kelp enhancement and restoration projects, and for when *in-situ* mitigation is not viable.

5.2. Continue development of kelp restoration techniques for use in enhancement projects and mitigation.

5.2.1. Develop best management practices for designing, installing, and maintaining compensatory mitigation sites and restoration projects.

5.2.2. Define measurable project success standards to include ecosystem goods and services and long-term persistence of kelp forest.

5.2.3. Develop monitoring protocols to verify project success/compliance.

5.2.4. Support the development of local kelp seed banks for use in genetically appropriate restoration.

5.3. Fund and implement restoration activities at priority sites.

5.3.1. Target restoration-funding sources for stressor reduction and population enhancement projects.

5.3.2. Reach out to restoration funding sources to include funding for kelp restoration.

5.3.3. Use compensatory mitigation as a tool to restore goods and services provided by kelp forests.

6. Promote Awareness, Engagement, and Action from User Groups, the Public, and Decision-Makers

The success of this Kelp Plan and the conservation and recovery of kelp in Puget Sound depends on increased awareness and engagement in support of actions to sustain kelp. We must improve our understanding of the current status and ecological value of kelp in Puget Sound, implement the research and management needs identified in this Kelp Plan, and educate individuals on how they can help. Implementation of the following actions will help increase awareness and engagement in kelp recovery efforts.

6.1. Share information on (1) the value and role of kelp ecosystems as critical nearshore habitat and food web support (for forage fish, rockfish, salmon, and killer whales) in Puget Sound; and (2) the growing concern regarding significant losses to bull kelp canopies.

6.1.1. Educate decision-makers (federal, state, and local entities) regarding the value of kelp, local declines, and the needs articulated in the Kelp Plan.

6.1.2. Work with Tribal partners to elevate the prominence of traditional ecological knowledge regarding kelp.

6.1.3. Encourage partners (e.g., Tribes, anglers, commercial fishermen, Washington Public Port Association, industry, recreational harvesting groups, and NGOs) to help tell the story of kelp to local communities and decision-makers.

6.1.4. Develop curricula and other educational tools focused on Puget Sound kelp ecosystems for K-12 classrooms and other education forums (e.g., aquariums, science centers, reserves).

6.1.5. Carry out targeted outreach and advocacy to develop support for the implementation of the goals outlined in the Kelp Plan.

6.1.6. Develop public educational materials and maps on how boaters and outdoor recreation groups can minimize their impacts to kelp (e.g., parks, boat launches, marinas).

6.2. Build research capacity and coordinate knowledge sharing of ongoing kelp recovery projects and research gaps.

6.2.1. Create and maintain a regularly scheduled forum for information sharing and knowledge gathering between Tribal, federal, state, and local entities.

6.2.2. Coordinate kelp conservation actions and research activities with the Salish Sea International Kelp Alliance, British Columbia, and states of Oregon and California.

6.2.3. Coordinate knowledge sharing through regular participation in conferences, workshops, publications, social media, etc.

Partners in Kelp Conservation and Recovery

Partners committed to participating in actions at the time of Kelp Plan development include but are not limited to:

DNR
DOE Water Quality Program
Feiro Marine Life Center
Kwiáht
Marine Agronomics LLC
MRCs
NMFS
NWS Commission
NWS Foundation
The Pew Charitable Trusts
Port Gamble S'Klallam Tribe
Puget Sound Partnership
PSRF
REEFCheck
Salish Seaweeds
Samish Indian Nation
SeaDoc Society
Tulalip Tribes
University of Washington
USGS
WDFW
Washington State University
Western Washington University

MRC kayak-based survey of bull kelp forest at Ebey's Landing.
Photo by Rich Yukubousky.

Kayakers and bull kelp in Commencement Bay, Tacoma.
Photo by Washington State Legislative Support Services.

VI. Conclusions

Bull kelp forests have declined and disappeared from some areas of Puget Sound. There is a growing concern within the scientific community that this trend is not limited to bull kelp, and that threats to kelp species are intensifying. The development of this Kelp Plan brought together kelp scientists, ecosystem recovery experts, tribal resource managers, and local, state, and federal representatives. The parties discussed current research and data gaps, and identified key goals and actions that support science-based regulation and management to conserve and restore kelp. The Kelp Plan defines six strategic goals and related critical actions to initiate a regional response.

1. Understand and reduce kelp stressors;
2. Deepen understanding of the value of kelp to Puget Sound ecosystems and integrate into management;
3. Describe kelp distribution and trends;
4. Designate kelp protected areas;
5. Restore kelp forests; and
6. Promote awareness, engagement, and action from user groups, Tribes, the public, and decision-makers.

At the heart of the six strategic goals is a need for ongoing coordination of research and interagency efforts; improved communication between researchers and managers; and additional funding to support research, monitoring, education, outreach, implementation, and enforcement. The actions outlined in the Kelp Plan require a unified effort from many people and organizations to carry out the strategic goals. Raising awareness of the need to support kelp conservation and recovery will help further build this network. The Kelp Plan provides the framework to coordinate research and management actions to support the persistence of kelp in the face of global and local stressors, and ensure that these iconic native species continue to thrive in our local waters.

At the heart of kelp recovery efforts is a need for ongoing interagency coordination of research, better communication between researchers and managers; and additional funding to achieve the strategic goals.

Bull kelp forest at Ebey's Landing. Photo by Rich Yukubousky.

VII. References

Airoldi, L. 2003. The effects of sedimentation on rocky coast assemblages. Oceanography and Marine Biology: An Annual Review. Volume 41, pages 161 to 236.

Airoldi, L., and M. W. Beck. 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology Volume 45, pages 345 to 405.

Allen, Brian. 2018. Kelp canopy restoration; enhancement practice development in Puget Sound. Salish Sea Ecosystem Conference. April 6, 2018, Seattle, WA.

Altieri, A. H., and J. van de Koppel. 2014. Foundation species in marine ecosystems. Pages 37 to 57 *in* Marine Community Ecology and Conservation, J. F. Bruno, M. D. Bertness, B. R. Silliman, & J. J. Stachowicz editors. 2014. Sinauer Associates, Inc., Sunderland, MA.

Antrim, L. D., R. M. Thom, W. W. Gardiner, V. I. Cullinan, D. K. Shreffler and R. W. Bienert. 1995. Effects of petroleum products on bull kelp (*Nereocystis luetkeana*). Marine Biology. Volume 122, pages 23 to 31.

Arakawa, H. 2005. Lethal effects caused by suspended particles and sediment load on zoospores and gametophytes of the brown alga *eisenia bicyclis*. Fisheries Science. Volume 71(1), pages 133 to 140.

Bartsch, I., C. Wiencke, K. Bischof, C. M. Buchholz, B. H. Buck, A. Eggert, P. Feuerpfeil, et al. 2008. The genus *Laminaria Sensu Lato*: Recent insights and developments. European Journal of Phycology. Volume 43(1), pages 1 to 86.

Benedetti-Cecchi, L., F. Pannacciulli, F. Bulleri, P. S. Moschella, L. Airoldi, G. Relini, and F. Cinelli. 2001. Predicting the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. Marine Ecology Progress Series 214:137–150.

Berry, H. D., J. R. Harper, T. F. Mumford, B. E. Bookheim, A. T. Sewell and L. J. Tamayo. n.d. The Washington State ShoreZone inventory user's manual. 2001. Washington State Department of Natural Resources, Nearshore Habitat Program, Olympia, WA. 29 pages.

Berry, H. D., M. D. Calloway, and J. Ledbetter. 2019. Bull kelp monitoring in south Puget Sound in 2017 and 2018. Washington State Department of Natural Resources, Aquatic Resources Division, Nearshore Habitat Program, Olympia, WA. 72 pages.

Berry, H.D., T.F. Mumford, B. Christiaen, P. Dowty, M. Calloway, L. Ferrier, E.E. Grossman, and N.R. VanArendonk. *in review*. Long term changes in kelp forests in an inner basin of the Salish Sea. Preprint available at: https://www.biorxiv.org/content/10.1101/2020.02.13.947309v1. 52 pages.

Bertocci, I., R. Araújo, P. Oliveira, and I. Sousa-Pinto. 2015. Review: Potential effects of kelp species on local fisheries, Henrik Österblom, editor. Journal of Applied Ecology Volume 52(5), pages 1216 to 1226.

von Biela, V. R., S. D. Newsome, J. L. Bodkin, G. H. Kruse, and C. E. Zimmerman. 2016. Widespread kelp-derived carbon in pelagic and benthic nearshore fishes suggested by stable isotope analysis. Estuarine, Coastal and Shelf Science. Volume 181, pages 364 to 374.

Boas, F. and G. Hunt. 1921. Ethnology of the Kwakiutl, based on data collected by George Hunt. Thirty-Fifth Annual Report. Smithsonian Institution Bureau of American Ethnology Government Printing Office, Washington, DC.

Bos. J., M. Keyzers, L. Hermanson, C. Krembs, and S. Albertson. 2015. Quality assurance monitoring plan. Long-term marine waters monitoring, water column program. Publication No. 15-03-101. Washington State Department of Ecology. January 2019. Document available at: https://fortress.wa.gov/ecy/publications/documents/1503101.pdf.

Brisman, A. 2011. Rio Declaration. Pages 960 to 961 *in* Encyclopedia of Global Justice, D. K. Chatterjee editor. 2011. Springer Netherlands, Dordrecht, Netherlands.

Britton-Simmons, K. H. 2004. Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. Marine Ecology Progress Series. Volume 277, pages 61 to 78.

Burkholder, J. M., D. A. Tomasko and B. W. Touchette. 2007. Seagrasses and eutrophication. Journal of Experimental Marine Biology and Ecology. Volume 250, pages 56 to 72.

Calloway, M.D., Puget Sound Restoration Fund, November 14, 2019. Personal communication with Helen Berry, Washington State Department of Natural Resources Nearshore Habitat Program and Taylor Frierson, Washington Department of Fish and Wildlife, regarding presence of urchin barrens in Washington State waters.

Calloway, M. D., Puget Sound Restoration Fund, November 14, 2019. Personal communication, email to Henry Carson, Ph.D., Washington Department of Fish and Wildlife, regarding the presence of urchin barrens in Puget Sound.

Calloway, M. D. 2019. *Nereocystis luetkeana* (bull kelp) in South Puget Sound: Stressor impacts on the health of native floating kelp canopies. Master's Thesis, The Evergreen State College, Olympia, WA. 60 pages.

Carney, L. T., and M. S. Edwards. 2006. Cryptic processes in the sea: A review of delayed development in the microscopic life stages of marine macroalgae. Algae. Volume 21(2), pages 161 to 168.

Casas, G., R. Scrosati, and M. L. Piriz. 2004. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in nuevo gulf (Patagonia, Argentina). Biological Invasions. Volume 6(4), pages 411 to 16.

Christie, H., K. M. Norderhaug, and S. Fredriksen. 2009. Macrophytes as habitat for fauna. Marine Ecology Progress Series. Volume 396, pages 221 to 33.

Connell, S. D., M. S. Foster, and L. Airoldi. 2014. What are algal turfs? Towards a better description of turfs. Marine Ecology Progress Series. Volume 495, pages 299 to 307.

Connell, S. D., K. J. Kroeker, K. E. Fabricius, D. I. Kline, and B. D. Russell. 2013. The other ocean acidification problem: CO_2 as a resource among competitors for ecosystem dominance. Philosophical Transactions: Biological Sciences Volume 368(1627) pages 1 to 9.

Connell, S. D., A. Vergés, I. Nagelkerken, B. D. Russell, N. Shears, T. Wernberg, and M. A. Coleman. 2019. The past and future ecologies of Australasian kelp forests. Pages 414 to 430 *in* Interactions in the Marine Benthos, S. J. Hawkins, K. Bohn, L. B. Firth, and G. A. Williams, editors. 2019. Cambridge University Press, Cambridge, United Kingdom.

Crain, C. M., K. Kroeker, and B. S. Halpern. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters. Volume 11(12), pages 1304–15.

Dayton, P. K. 1985. The ecology of kelp communities. Annual Review of Ecological Systems. Volume 16, pages 215 to 245.

Deiman, M., K. Iken, and B. Konar. 2012. Susceptibility of *Nereocystis luetkeana* (Laminariales, Ochrophyta) and *Eualaria fistulosa* (Laminariales, Ochrophyta) spores to sedimentation. ALGAE. Volume 27(2), pages 115 to 23.

DNR. 2015. Puget Sound eelgrass (*Zostera marina*) recovery strategy. Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA. 47 pages.

Druehl, L. D., and S. I. C. Hsiao. 1977. Intertidal kelp response to seasonal environmental changes in a British Columbia inlet. Journal of Fisheries Research Board of Canada. Volume 34(8), pages 1207 to 1211.

Duggins, D. O., M. C. Gómez-Buckley, R. M. Buckley, A. T. Lowe, A. W. E. Galloway, and M. N. Dethier. 2016. Islands in the stream: kelp detritus as faunal magnets. Marine Biology Volume 163(17), 10 pages.

Duggins, David O. 1980. Kelp beds and sea otters: An experimental approach. Ecology. Volume 61(3), pages 447 to 53.

Eckman, J. E., D. O. Duggins, and A. T. Sewell. 1989. Ecology of under story kelp environments. I. Effects of kelps on flow and particle transport near the bottom. Journal of Experimental Marine Biology and Ecology. Volume 129(2), pages 173 to 187.

EPA. 2018. Greenhouse Gases Equivalencies Calculator - Calculations and References. 2018. Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references. Website accessed November 5, 2019.

Erlandson, J. M., M. H. Graham, B.J. Bourque, D. Corbett, J. A. Estes, and R. S. Steneck. 2007. The kelp highway hypothesis: marine ecology, the coastal migration theory, and the peopling of the Americas. The Journal of Island and Coastal Archaeology. Volume 2(2), pages 161 to 74.

Erlandson, J. M., T. J. Braje, K.M. Gill, and M. H. Graham. 2015. Ecology of the kelp highway: Did marine resources facilitate human dispersal from northeast Asia to the Americas? The Journal of Island and Coastal Archaeology. Volume 4894, pages 1 to 20.

Estes, J. A., and D.O. Duggins. 1995. Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm. Ecological Monographs. Volume 65, pages 75 to 100.

Everitt, R.D., C.H. Fiscus and R.L. DeLong. 1980. Northern Puget Sound Marine Mammals. Prepared for the MESA (Marine Ecosystems Analysis) Puget Sound Project. Seattle, WA. 155 pages.

Falkenberg, L. J., B. D. Russell, and S. D. Connell. 2013. Contrasting resource limitations of marine primary producers: implications for competitive interactions under enriched CO_2 and nutrient regimes. Oecologia. Volume 172(2), pages 575 to 83.

Feehan, C. J., S. P. Grace, and C. A. Narvaez. 2019. Ecological feedbacks stabilize a turf-dominated ecosystem at the southern extent of kelp forests in the northwest Atlantic. Scientific Reports. Volume 9(1), pages 70 to 78.

Filbee-Dexter, K., and R. E. Scheibling. 2016. Spatial patterns and predictors of drift algal subsidy in deep subtidal environments. Estuaries and Coasts. Volume 39(6), pages 1724 to 1734.

Filbee-Dexter, K., and T. Wernberg. 2018. Rise of turfs: A new battlefront for globally declining kelp forests. BioScience. 13 pages.

Flaccus, G, and T. Chea. The Oregonian. 2019. Sea urchins are chomping their way through Oregon Coast kelp, “uncharted territory” for marine ecosystem. Available at: https://www.oregonlive.com/news/2019/10/sea-urchins-are-devouring-oregon-coast-kelp-uncharted-territory-for-marine-ecosystem.html. Accessed November 11, 2019.

Foreman, M. G. G., W. Callendar, A. MacFadyen, B. M. Hickey, R. E. Thomson and E. Di Lorenzo. 2008. Modeling the generation of the Juan de Fuca eddy. Journal of Geophysical Research – Oceans. Volume 113, C03006.

Gaylord, B., J. H. Rosman, D. C. Reed, J. R. Koseff, J. Fram, S. MacIntyre, K. Arkema, et al. 2007. Spatial patterns of flow and their modification within and around a giant kelp forest. Limnology and Oceanography. Volume 52(5), pages 1838 to 1852.

Geange, S. W., A. Powell, K. Clemens-Seely, and C. A. Cárdenas. 2014. Sediment load and timing of sedimentation affect spore establishment in *Macrocystis pyrifera* and *Undaria pinnatifida*. Marine Biology. Volume 161(7), pages 1583 to 92.

Glover, H.E., A. S. Ogston, I. M. Miller, E. F. Eidam, S. P. Rubin, and H. D. Berry. 2019. Impacts of suspended sediment on nearshore benthic light availability following dam removal in a small mountainous river: *In situ* observations and statistical modeling. Estuaries and Coasts. Volume 42(7), pages 1804 to 1820.

Goetz, F, C. Tanner, C. Simenstad, K. Fresh, T. F. Mumford, and M. Logsdon. n.d. Guiding restoration principles. Technical Report 2004-03. Prepared in support of the Puget Sound Nearshore Partnership. 22 pages.

Graham, M. H. 2004. Effects of local deforestation on the diversity and structure of southern California giant kelp forest food webs. Ecosystems. Volume 7(4), pages 341 to 357.

Harremoes, P., D. Gee, M. MacGarvin, A. Stirling, J. Keys, B. Wynne, and S. Vaz, editors. 2002. The precautionary principle in the 20th. Routledge, London, United Kingdom.

Harvey, C. J., G. D. Williams and P. S. Levin. 2012. Food web structure and trophic control in Central Puget Sound. Estuaries and Coasts. Volume 35, pages 821 to 838.

Hurd, C.L., P.J. Harrison, K. Bischof, and C.S. Lobban. 2014. Seaweed ecology and physiology. Cambridge University Press, Cambridge, United Kingdom. 551 pages.

Johannessen, S. C., G. Potentier, C. A. Wright, D. Masson and R. W. Macdonald. 2011. Water column organic carbon in a Pacific marginal sea (Strait of Georgia, Canada). Elsevier. Volume 66, hal-00563045.

Johnson, S. P., and D. E. Schindler. 2009. Trophic ecology of Pacific salmon (*Oncorhynchus spp.*) in the ocean: A synthesis of stable isotope research. Ecological Research. Volume 24(4), pages 855 to 63.

Khangaonkar, T., A. Nugraha, W. Xu, W. Long, L. Bianucci, A. Ahmed, T. Mohamedali, and G. Pelletier. 2018. Analysis of hypoxia and sensitivity to nutrient pollution in Salish Sea. Journal of Geophysical Research: Oceans. Volume 123(7), pages 4735 to 61.

Kilgo, J., B. Bookheim, H. Berry and B. Christiaen. 2019. Recreational kelp harvest study at Libbey Beach: Smith and Minor Islands Aquatic Reserve. Washington State Department of Natural Resources, Olympia, WA. 33 pages.

Kim, J. K., G. P. Kraemer, and C. Yarish. 2015. Use of sugar kelp aquaculture in Long Island Sound and the Bronx River estuary for nutrient extraction. Marine Ecology Progress Series. Volume 531, pages 155 to 66.

Koenigs, C., R. J. Miller, and H. M. Page. 2015. Top predators rely on carbon derived from giant kelp *Macrocystis pyrifera*. Marine Ecology Progress Series. Volume 537, pages 1 to 8.

Krause-Jensen, D., and C. M. Duarte. 2016. Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience. Volume 9, pages 737 to 743.

Krumhansl, K. A and R. E. Sheibling. 2012. Production and fate of kelp detritus. Marine ecology progress series 467, pages 281 to 302.

Krumhansl, K. A., D. K. Okamoto, A. Rassweiler, M. Novak, J. J. Bolton, K. C. Cavanaugh, S.D. Connell, et al. 2016. Global patterns of kelp forest change over the past half-century. Proceedings of the National Academy of Sciences of the United States of America. Volume 113(48), pages 13785 to 13790.

Lemay, M.A., Martone, P.T., Keeling, P.J., Burt, J.M., Krumhansl, K.A., Sanders, R.D., Wegener Parfrey, L., 2018. Sympatric kelp species share a large portion of their surface bacterial communities: Kelp-associated bacterial diversity. Environmental Microbiology 20, 658–670. Available at: http://doi.org/10.1111/1462-2920.13993.

Ling, S. D. 2008. Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: A new and impoverished reef state. Oecologia. Volume 156(4), pages 883 to 894.

Mackas, D. L. and P. J. Harrison. 1997. Nitrogenous nutrient sources and sinks in the Juan de Fuca Strat/Strait of Georgia/Puget Sound estuarine system: Assessing the potential for eutrophication. Estuarine, Coastal and Shelf Science. Volume 44, pages 1 to 21.

Masson, D. and P. F. Cummins. 2000. Fortnightly modulation of the estuarine circulation in Juan de Fuca Strait. Journal of Marine Research. Volume 58, pages 439 to 463.

Maxell, B. A., and K. A. Miller. 1996. Demographic studies of the annual kelps *Nereocystis luetkeana* and *Costaria costata* (Laminariales, Phaeophyta) in Puget Sound, Washington. Botanica Marina. Volume 39, pages 479 to 489.

Mohamedali, T, M. Roberts, B. Sackmann, and A. Kolosseus. 2011. Puget Sound dissolved oxygen model nutrient load summary for 1999-2008. Publication No. 11-03-057, Washington State Department of Ecology, Olympia, WA.

Mumford, T. F., Marine Agronomics, LLC., November 12, 2019. Personal communication, email to Brent Hughes, Ph.D., Sonoma State University Assistant Professor of Biology, regarding the expansion of *Sargassum muticum* in Puget Sound.

Mumford, T. F. 2007. Kelp and eelgrass in Puget Sound. Technical Report 2007-5. Prepared in support of the Puget Sound Nearshore Partnership. 27 pages.

National Marine Fisheries Service. 2007. Puget Sound Salmon Recovery Plan. National Marine Fisheries Service, Seattle, WA. 550 pages.

National Marine Fisheries Service. 2008. Recovery plan for Southern Resident Killer Whales (*Orcinus orca*). National Marine Fisheries Service, Seattle, WA. 251 pages.

National Marine Fisheries Service. 2017. Rockfish recovery plan: Puget Sound / Georgia Basin yelloweye rockfish (*Sebastes ruberrimus*) and bocaccio (*Sebastes paucispinis*). National Marine Fisheries Service, Seattle, WA. 153 pages.

Nearshore Habitat Program. 2001 The Washington State ShoreZone Inventory. Washington State Department of Natural Resources, Olympia, WA. Available at: https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/nearshore-habitat-inventory. Accessed March 4, 2020

Norderhaug, K. M., H. Gundersen, A. Pedersen, F. Moy, N. Green, M. G. Walday, J. K Gitmark, et al. 2015. Effects of climate and eutrophication on the diversity of hard bottom communities on the Skagerrak coast 1990-2010. Marine Ecology Progress Series. Volume 530, pages 29 to 46.

O'Brien, J. M., and R. E. Sheibling. 2016. Nipped in the bud: mesograzer feeding preference contributes to kelp decline. Ecology 97(7), pages 1873 to 1886.

O'Brien, B. S., K. Mello, A. Litterer, and J. A. Dijkstra. 2018. Seaweed structure shapes trophic interactions: A case study using a mid-trophic level fish species. Journal of Experimental Marine Biology and Ecology. Volume 506, pages 1 to 8.

Olson, A. M., M. Hessing-Lewis, D. Haggarty, and F. Juanes. 2019. Nearshore seascape connectivity enhances seagrass meadow nursery function. Ecological Applications. Volume 29(5), e01897.

Palmer-McGee, C. 2019. A decade of disappearance: Kelp canopies in Samish traditional territory. ArcGIS online story map (https://www.arcgis.com/apps/MapJournal/index.html?appid=b9690e508ac74af7acb0d9)

Pearson, S. F., N. Hamel, S. Walters, and J. Marzluff, editors. 2018. Threats: Impacts of natural events and human activities on the ecosystem. Encyclopedia of Puget Sound. University of Washington, Puget Sound Institute, Tacoma, WA. Available at:

https://www.eopugetsound.org/science-review/threats-impacts-natural-events-and-human-activities-ecosystem. Accessed April, 30, 2018.

Perkins, S.J., and B.D. Collins. 1997. Landslide and channel response inventory for the Stillaguamish watershed. Unpublished report. Snohomish and Skagit Counties, Washington.

Pfister, C. A., H. D. Berry and T. Mumford. 2017. The dynamics of kelp forests in the northeast Pacific Ocean and the relationship with environmental drivers. Journal of Ecology. 14 pages. http://doi.org/10.1111/1365-2745.12908

Pfister, C. A., M.A. Altabet, and B. L. Weigel. 2019. Kelp beds and their local effects on seawater chemistry, productivity, and microbial communities. Ecology. Volume.100(10), e02798. Available at: http://doi.org/10.1002/ecy.2798

PSEMP Marine Waters Workgroup. 2018. Puget Sound marine waters: 2017 overview. S. K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, N. Hamel, S. Kim, A. Brown, C. Krembs, and J. Newton, editors. Prepared for the Puget Sound Ecosystem Monitoring Program, Marine Waters Workgroup. 72 pages.

Reed, D., L. Washburn, A. Rassweiler, R. Miller, T. Bell, and S. Harrer. 2016. Extreme warming challenges sentinel status of kelp forests as indicators of climate change. Nature Communications. Volume 7, 13757.

Rogers-Bennett, L., and C. A. Catton. 2019. Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. Scientific Reports. Volume 9(1), 15050.

Rothäusler, E., I. Gómez, I. A. Hinojosa, U. Karsten, F. Tala, and M. Thiel. 2009. Effect of temperature and grazing on growth of *Macrocystis spp.* (Phaeophyceae) along a latitudinal gradient. Journal of Phycology. Volume 45(3), pages 547 to 559.

Rubin, S. P., I. M. Miller, M. M. Foley, H. D. Berry, J. J. Duda, B. Hudson, N. E. Elder, et al. 2017. Increased sediment load during a large-scale dam removal changes nearshore subtidal communities, J. P. Meador, editor. PLOS ONE. Volume 12(12), e0187742.

Schiel, D. R., and M. S. Foster. 2006. The population biology of large brown seaweeds: Ecological consequences of multiphase life histories in dynamic coastal environments. Annu. Rev. Ecol. Evol. Syst. Volume 37, pages 343 to 372.

Schiel, D. R., and M. S. Foster. 2015. The biology and ecology of giant kelp forests. University of California Press, Oakland, California. 395 pages.

Schooler, N. K., J. E. Dugan, and D. M. Hubbard. 2019. No lines in the sand: Impacts of intense mechanized maintenance regimes on sandy beach ecosystems span the intertidal zone on urban coasts. Ecological Indicators. Volume 106, 105457.

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

Shaffer, S. 2004. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. Pages 1 to 11 *in* Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference; March 31 to April 3, 2003, Vancouver, British Columbia. CD-ROM or Online. Available: http://www.psat.wa.gov/03_proceedings/start.htm [February 2004] 31:pages 1 to 11

Siddon, E. C., C. E. Siddon, and M. S. Stekoll. 2008. Community level effects of *Nereocystis luetkeana* in southeastern Alaska. Journal of Experimental Marine Biology and Ecology 361:pages 8 to 15.

Smale, D. A. 2019. Impacts of ocean warming on kelp forest ecosystems. New Phytologist.

South, P. M., O. Floerl, B. M. Forrest, and M. S. Thomsen. 2017. A review of three decades of research on the invasive kelp *Undaria pinnatifida* in Australasia: An assessment of its success, impacts and status as one of the world's worst invaders. Marine Environmental Research Volume 131(October) pages 243 to 57.

Southern Resident Orca Task Force. 2019. Final report and recommendations. Olympia, WA. 196 pages

Starko, S., L. A. Bailey, E. Creviston, K. A. James, A. Warren, M. K. Brophy, A. Danasel, M.P. Fass, J. A. Townsend, and C. J. Neufeld. 2019. Environmental heterogeneity mediates scale-dependent declines in kelp diversity on intertidal rocky shores, J. Hewitt, editor. PLOS ONE. Volume 14(3), e0213191.

Steneck, R. S., M. H. Graham, B. J. Bourque, D. Corbett, J. M. Erlandson, J. A. Estes, and M. J. Tegner. 2002. Kelp forest ecosystems: Biodiversity, stability, resilience and future. Environmental Conservation. Volume 29(4), pages 436 to 459.

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

Stephens, T.A. and C.D. Hepburn. 2016. A kelp with integrity: *Macrocystis pyrifera* prioritizes tissue maintenance in response to nitrogen fertilization. Oecologia. Volume 182, pages 71 to 86.

Stewart, H. 1977. *Indian Fishing: Early Methods on the Northwest Coast*. University of Washington Press, Seattle, WA. 188 pages.

Szypulski, E. J. 2018. Ecological effects of overwater structures on subtidal kelp, northern Puget Sound, Washington. Master's Thesis. Central Washington University, Lakewood, WA. 159 pages.

Calloway, M. D. 2019. *Nereocystis luetkeana* (bull kelp) in South Puget Sound: Stressor impacts on the health of native floating kelp canopies. Master's Thesis, The Evergreen State College, Olympia, WA. 60 pages.

Tarquinio, F., Bourgoure, J., Koenders, A., Laverock, B., Säwström, C., Hyndes, G.A., 2018. Microorganisms facilitate uptake of dissolved organic nitrogen by seagrass leaves. The ISME Journal. Available: https://doi.org/10.1038/s41396-018-0218-6.

Teagle, H., S. J. Hawkins, P.J. Moore, and D. A. Smale. 2017. The role of kelp species as biogenic habitat formers in coastal marine ecosystems. Journal of Experimental Marine Biology and Ecology. Volume 492, pages 81 to 98.

Tera Corp. 1982. Compendium of thermal effects laboratory studies: Diablo Canyon power plant. Volume 2. Tera Corporation, Berkeley, CA.

Turner, N. C. and M. A. M. Bell. 1971. The ethnobotany of the Coast Salish Indians of Vancouver Island. Economic Botany. Volume 25(1), pages 63 to 104.

Turner, N. J. 1979. Plants in British Columbia Indian Technology. Royal British Columbia Museum, Victoria, BC. 304 pages.

Turner, N. J. 1995. Food Plants of Coastal First Peoples. 2nd Edition. University of British Columbia Press, Vancouver, BC. 180 pages.

Turner, N. J. 2001. Coastal peoples and marine plants on the northwest coast. Pages 69 to 76 *in* Proceedings of the 26th Annual Conference of the International Association of Aquatic and Marine Science Libraries and Information Centers; September 30 to October 5, 2000, Victoria, BC.

Unsworth, R. K. F., L. M. Nordlund, and L. C. Cullen-Unsworth. 2018. Seagrass meadows support global fisheries production. Conservation Letters. Volume 12, e12566.

Washington Department of Fish and Wildlife. 2008. Priority Habitat and Species List. Olympia, Washington. 292 pages.

Washington Marine Resources Advisory Council. 2017. Addendum to ocean acidification: From knowledge to action, Washington State's strategic response. EnviroIssues, editors. Seattle, WA.

Washington State Blue Ribbon Panel on Ocean Acidification. 2012. Ocean acidification: From knowledge to action, Washington State's strategic response. H. Adelsman and L. Whitely

Binder, editors. Washington Department of Ecology, Olympia, WA. Publication no. 12-01-015.

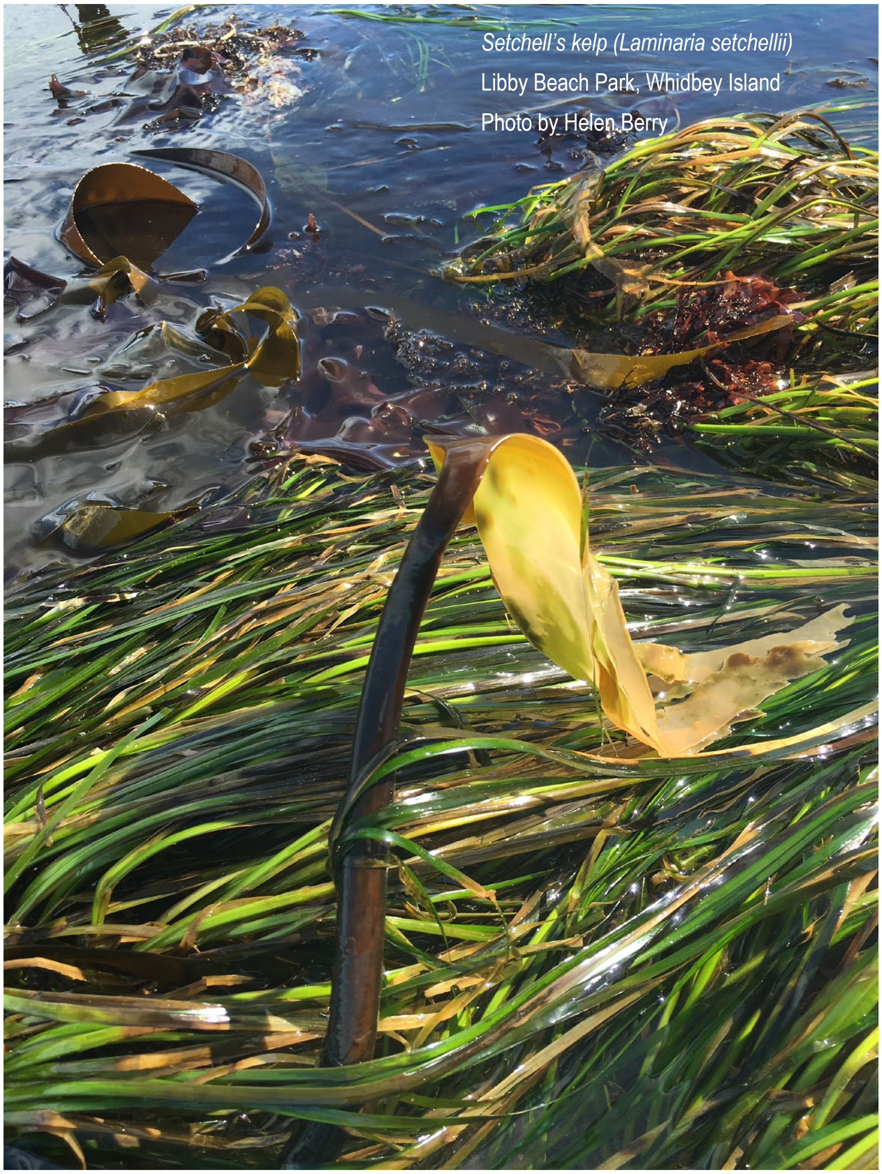
Watanabe, H., M. Ito, A. Matsumoto, and H. Arakawa. 2016. Effects of sediment influx on the settlement and survival of canopy-forming macrophytes. Scientific Reports. Volume 6, 18677.

Weigel, B. L., C. A. Pfister. 2019. Successional dynamics and seascape-level patterns of microbial communities on the canopy-forming kelps *Nereocystis luetkeana* and *Macrocystis pyrifera*. Frontiers in Microbiology. Volume 10, 346. Available at: http://doi.org/10.3389/fmicb.2019.00346.

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

Zabin, C., G. Ashton, C. Brown, and G. Ruiz. 2009. Northern range expansion of the asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. Aquatic Invasions Volume 4(3) pages 429 to 34.

Zuercher, R., and A. W. E. Galloway. 2019. Coastal marine ecosystem connectivity: Pelagic ocean to kelp forest subsidies. Ecosphere. Volume 10(2), e02602.


Setchell's kelp (Laminaria setchellii)
Libby Beach Park, Whidbey Island
Photo by Helen Berry

Puget Sound Kelp Conservation and Recovery Plan

Appendix A - Kelp Knowledge Review

May 2020

Prepared by the Northwest Straits Commission, NOAA's National Marine Fisheries Service, Puget Sound Restoration Fund, Washington State Department of Natural Resources, and Marine Agronomics.

A.1 Kelp Biology and Ecology

The term "kelp" broadly refers to large (10 cm to 30 m) brown macroalgae (class Phaeophyceae) of the order Laminariales that form complex three-dimensional habitats in shallow, nearshore waters (Dayton 1985). Worldwide, the Laminariales consist of approximately 147 different species, including *Laminaria* spp., *Saccharina* spp., and iconic canopy-forming species such as *Nereocystis luetkeana* (hereafter *Nereocystis*) and *Macrocystis pyrifera* (hereafter *Macrocystis*) (Druehl and Clarkston 2016; Teagle et al. 2017). Kelp can be annual or perennial depending on the species.

Washington State is home to 22 species of kelp. These kelp species come in three different forms: *Prostrate kelp*, which lack a rigid stipe or gas-filled buoy, remain close to the seafloor, forming thick understories; *stipitate kelp*, which stand erect and form a subcanopy of kelp in the water column; and *floating kelp*, which rely on gas-filled pneumatocysts to suspend them in the water column and can create large, floating surface canopies. Prostrate kelp species are the most commonly distributed kelp species in Puget Sound. Table A-1 identifies the kelp species found in Washington State and provides associated taxonomic synonyms, common names, places of location, and forms.

Table A-1. Washington State Kelp Species.

Species Name	Taxonomic synonyms	Common name	Washington State Waters	Kelp Recovery plan study area	Form
Agarum clathratum Dumortier	*A. cribrosum*	-	X	X	prostrate
Costaria costata (C. Agardh) D.A. Saunders	-	-	X	X	prostrate
Dictyoneurum californicum Ruprecht	-	-	X	-	prostrate
Dictyoneurum reticulatum (D.A.Saunders) P.C.Silva	*Dictyoneuropsis reticulatum*	-	X	-	prostrate
Neoagarum fimbriatum (Harvey) H.Kawai & T.Hanyuda	*Agarum fimbriatum*	-	X	X	prostrate
Alaria marginata Postels et Ruprecht	*incl. Alaria nana*	-	X	X	prostrate
Lessoniopsis littoralis (Farlow et Setchell ex Tilden) Reinke	-	-	X	-	stipitate
Pleurophycus gardneri Setchell et D.A. Saunders ex Tilden	-	-	X	X	prostrate
Pterygophora californica Ruprecht	-	-	X	X	stipitate
Egregia menziesii (Turner) Areschoug	-	feather boa kelp	X	X	floating

Species Name	Taxonomic synonyms	Common name	Washington State Waters	Kelp Recovery plan study area	Form
Hedophyllum nigripes (Rosenvige) Starko, S.C.Lindstrom & Martone	*	-	X	X	prostrate
Hedophyllum sessile (C. Agardh) Setchell	*Saccharina sessilis*	sea cabbage	X	X	prostrate
Macrocystis pyrifera (Linnaeus) C. Agardh	*Macrocystis integrifolia*	giant kelp[1]	X	-	floating
Nereocystis luetkeana (Mertens) Postels et Ruprecht	-	bull kelp	X	X	floating
Postelsia palmaeformis Ruprecht	-	sea palm	X	-	stipitate
Saccharina complanata (Setchell & N.L.Gardner) P.W.Gabrielson, S.C.Lindstrom & O'Kelly	*Laminaria complanata*	-	X	X	prostrate
Saccharina latissima (Linnaeus) C.E.Lane, C.Mayes, Druehl & G.W.Saunders	*Laminaria saccharina*	sugar kelp	X	X	prostrate
Cymathaere triplicata (Postels et Ruprecht) J. Agardh	*Laminaria triplicata*	-	X	X	prostrate
Laminaria ephemera Setchell	-	-	X	X	prostrate
Laminaria longipes Bory	-	-	X	X	prostrate
Laminaria setchellii P.C Silva	*Incl. L. dentigera*	-	X	X	stipitate
Laminaria sinclairii (Harvey ex Hooker f.) Farlow, C.L. Anderson et D.C. Eaton	-	-	X	X	prostrate
Total	-	-	22	17	-

* *Saccharina nigripes, Saccharina groenlandica, Saccharina subsimplex, Laminaria groenlandica, Laminaria bongardiana, Laminaria bullata f. subsimplex.*

A.1.1 Kelp Life History

All kelp exhibit heteromorphic life histories of alternating generations (Hurd et al. 2014). Kelp alternate between a large, asexual, diploid, macroscopic form called a sporophyte and microscopic, sexual, haploid gametophytes. Once sporophytes mature, portions of the blades undergo meiosis to produce distinct patches known as sori that release billions of motile zoospores into the water

[1] Giant kelp (*Macrocystis pyrifera*) is present in the Strait of Juan de Fuca that extend the boundary to Cape Flattery, but this species is not present in the geographic area of this plan.

column (Bartsch et al. 2008; Schiel and Foster 2015). Other species, such as *Macrocystis* and the locally abundant *Alaria marginata*, produce specialized reproductive blades near the base of the plant called sporophylls that produce sori. Dispersal distances for kelp spores are relatively small compared to the larval stages of other marine biota (Gaylord et al. 2002; Suskiewicz 2010). Generally, kelp zoospores fall within several meters of the parent plant. However, zoospore dispersal distance is negatively related to depth, with spores released higher in the water column possibly traveling several kilometers before settling (Gaylord et al. 2002). Additionally, adult plants with pneumatocysts that break free from the benthos, such as *Macrocystis* and *Nereocystis*, can form floating rafts capable of traveling long distances while continuing to produce viable spores (Rothäusler et al. 2009).

Kelp requires solid substrates and will attach readily to both consolidated bedrock and unconsolidated gravel or cobble interspersed in muddy or sandy areas (Dayton 1985). Once attached, the spores germinate after approximately one week into male and female gametophytes that reproduce sexually to produce microscopic germling sporophytes in as little as three weeks. Following this initial recruitment, juvenile sporophytes grow rapidly throughout the entirety of the growing season. In the Salish Sea, macroalgal recruitment and growth occur during the spring and early summer (Druehl and Hsiao 1977; Maxell and Miller 1996).

A.1.2 Kelp Recruitment and Growth

Kelp species exhibit high growth rates, making them competitively dominant in subtidal algal assemblages (Dayton 1985). Persistence of any kelp species is limited by spore availability and the ability to recruit to the available substrate (Reed 1990). Recruitment also depends on species-specific life histories and ambient environmental conditions. Spore production in some perennial species is limited to certain dispersal windows, while annual species produce spores only as long as adult sporophytes are present. If a large disturbance (e.g., marine heatwaves, large storms, booms in grazer populations) results in the loss of most sporophytes before spore dispersal, recruitment may be severely impacted (Wernberg et al. 2010). However, if microscopic life stages are impacted by disturbance, the recruitment dynamic for perennial species can shift from a competition regime between adults and new recruits to one that is wholly dependent on adult sporophytes (Wernberg et al. 2010). In these instances, as is always the case for annual species, any disturbance that removes sporophytes may result in total forest loss.

A.1.3 Microscopic Life Stage Dormancy

For all annual and perennial species with seasonal spore production, there is growing evidence that microscopic forms remain dormant or overwinter until conditions are favorable for reproduction and growth (Carney and Edwards 2006). Evidence points to gametophytes being the most common life stage capable of overwintering, although there is some evidence that spores and germling sporophytes may overwinter as well (Hurd et al. 2014). Controlled laboratory experiments have produced the bulk of evidence for dormancy in microscopic life stages. While these studies are valuable, caution is prudent when generalizing results to *in situ* populations (Schiel and Foster 2015). The abiotic thresholds and biotic stressors for zoospores, gametophytes, and germling sporophytes can differ from those of mature sporophytes and between species. The cryptic nature of microscopic life stages and the logistical difficulties associated with conducting underwater ecological research continue to be the largest hurdles in increasing our understanding of these critical life stages in the field.

A.1.4 Light Availability and Timing of Kelp Recruitment

Kelp sporophytes and gametophytes occupy the photic zone, the area of the nearshore environment where light penetrates to the benthos at a rate where net photosynthesis exceeds respiration (Dayton 1985; Hurd et al. 2014). Generally, one percent of total irradiance is regarded as the boundary of the photic zone (Bertness et al. 2014). However, this boundary depends on the ambient irradiance, which is itself influenced by the timing of low tides, the amount of attenuation or scattering (dependent on suspended sediments and phytoplankton), day length, and the angle of the sun in relation to locale.

Irradiance in Puget Sound shows strong seasonal patterns, increasing ten-fold from approximately 127 $\mu mol/m^2/s$ in December to 1,348 $\mu mol/m^2/s$ in July (Knapp n.d.). The timing of the lowest daily tide (Lower Low Water), which occurs during the night in winter and during the day in summer, further influences total benthic light availability. The shift from night to day lower low tides occurs in February and March (late winter). Despite intermediate irradiances (300 to 515 $\mu mol/m^2/s$) during late winter, the daytime timing of low tides allows for greater light availability in the nearshore (Knapp n.d.; Druehl and Hsiao 1977). Several studies have observed that this late-winter period of increased light availability coincides with kelp recruitment in the Pacific Northwest (Druehl and Hsiao 1977; Maxell and Miller 1996; Allen 2018).

In a recent *Nereocystis* outplant experiment in the Central Basin conducted by the Puget Sound Restoration Fund (PSRF), Allen (2018) observed that winter transfers of spore, gametophyte, and germlings to the field produced juvenile sporophytes in February and March only. Interestingly, successful recruitment from spore and gametophyte treatments occurred only for treatments outplanted in December, January and February, while only the germling sporophyte treatments successfully produced juveniles in the March treatment. Results on the timing of initial macroalgal recruitment made by Allen (2018) echo similar observations made by Druehl and Hsiao (1977) in Barkley Sound, B.C. and Maxell and Miller (1996) at Titlow Beach in the South Basin of Puget Sound, and point toward the importance of seasonal cues for *Nereocystis* reproduction.

A.1.5 Photosynthetic Performance

Generally speaking, kelp species are light-flexible (shade-tolerant), making them uniquely adapted to the low-light environments created by dense canopies (Clark et al. 2004; Schiel and Foster 2015). Light in kelp forests also varies broadly along spatial and temporal scales because of the constant motion of canopy fronds. Many understory kelp and macroalgal species are specially adapted to capture the "flecks" of sunlight for photosynthesis (Wing et al. 1993).

Photosynthesis occurs at variable rates over a range of irradiances (Hurd et al. 2014). At compensation irradiances, photosynthetic rates match cellular respiration, resulting in increased biomass. Kelp sporophytes generally require 2 to 11 µmol/m^2/s to reach compensation (Hurd et al. 2014). Even though no biomass is lost at compensation irradiances, the ability of any kelp life stage to deal with additional stressors is compromised. In addition, sporophyte sorus production, spore germination, gametophyte reproduction, and germling saprophyte growth may be delayed or impeded at low irradiances (Vadas 1972; Carney and Edwards 2006). For example, germling *Macrocystis* sporophytes delay growth at 2 to 3 µmol/m^2/s (Carney and Edwards 2006). Similarly, Vadas (1972) found that only one percent of *Nereocystis* gametophytes exposed to irradiances of approximately 2 µmol/m^2/s for three weeks attained fertility.

Photosynthetic rates increase with increasing irradiance until maximum photosynthetic rates are attained under saturation irradiances. At this point, any increase in irradiance returns little to no increase in photosynthetic rates. Saturation irradiances for kelp sporophytes fall between 150 to 250 µmol/m^2/s (Hurd et al. 2014). However, there is evidence that saturation levels are significantly lower for microscopic life stages. In laboratory cultures, growth rates of Puget Sound *Nereocystis* gametophytes and germling sporophytes peaked between approximately 15 and 30 µmol/m^2/s at 10 to 15 °C, similar to the critical levels needed to induce germling sporophyte growth in *Macrocystis* (20 to 30 µmol/m^2/s) (Vadas 1972; Carney and Edwards 2006). However, laboratory investigations on the effect of temperature on California *Nereocystis* gametophyte growth rates observed peak gametophyte growth at 77 and 110 µmol/m^2/s in temperatures between13 and 17 °C (Tera Corp. 1982). Whether these discrepancies result from differences in methodology or local adaptations of source populations is unknown, but they highlight the difficulty of accurately describing the reproductive ecology of kelp microscopic life stages from laboratory trials alone. While light is essential for photosynthesis, photoinhibition occurs when high irradiances and UV exposure lead to cellular damage and tissue death. Photoinhibition for kelp generally occurs between 850 and 1000 µmol/m^2/s, with microscopic stages being especially susceptible to UV damage (Swanson and Druehl 2000). However, photo-tolerance, like many traits, is species-specific, with floating canopy species likely adapted to deal with higher ambient irradiances and UV exposure at the water surface.

A.1.6 Temperature Requirements

Individual kelp species have unique optimal temperature ranges that can differ between alternative life stages (Dayton 1985; Harley et al. 2012; Hurd et al. 2014). Temperature optima vary between species and can be difficult to fully describe because populations adapted to local conditions can acclimate to a wide range of temperatures (Lind and Konar 2017; Muth et al. 2019; Hollarsmith et al. 2020).

Cold-water *Laminaria* and *Saccharina* species can survive and reproduce at temperatures from zero to 18 °C but grow optimally in the range of 5 to 15 °C (Bartsch et al. 2008). Similarly, while *Nereocystis* sporophytes can survive at a range of -1.5 °C to 18 °C (Lüning and Freshwater 1988), Maxell and Miller (1996) found that Puget Sound *Nereocystis* stipe and blade growth rates peaked in concert with summer temperatures of 13.5 °C. *Nereocystis* is an annual species, and it is unclear whether temperature or season influenced the peak blade growth rates observed by Maxell and Miller (1996). However, laboratory studies of Puget Sound *Nereocystis* germling sporophytes and gametophytes showed similar optimal temperature ranges between 10 and 15 °C (Vadas 1972). Spore germination rates follow a similar trend, with 60 to 70 percent of Strait of Georgia *Nereocystis* spores germinating at 10 to 15 °C, but only 20 to 30 percent germinating at 17.5 °C (Schiltroth et al. 2018).

Outside of optimal ranges, photosynthetic performance in terms of rate and yield can be augmented by increasing pigment content, reaction centers, and protein complexes, as long as sufficient nutrients are available (Bartsch et al. 2008). Yet, maintaining positive growth in the face of temperature stress may leave adult sporophytes more susceptible to other disturbances (Rothäusler et al. 2009; Wernberg et al. 2010).

A.1.7 Kelp Nutrient Requirements and Regimes in Puget Sound

Seasonal and geographic variations in nutrient availability influence the productivity of kelp species (Dayton 1985; Schiel and Foster 2006). Kelp species, like other autotrophs, are carbon- and nitrogen-limited (Dayton 1985; Hurd et al. 2014). Nutrient availability often tracks negatively with temperature and season (Dayton 1985). While there is not a strong upwelling regime in Puget Sound, dissolved inorganic nitrogen (DIN) concentrations follow a distinct seasonal pattern, peaking during winter months and dropping to near zero in some areas during summer periods of peak algal growth (Khangaonkar et al. 2018). While a majority of DIN is transported into Puget Sound via deeper waters entering from the Strait of Juan de Fuca, anthropogenic nutrient inputs account for 73 percent of surface DIN loads (Khangaonkar et al. 2011; Mohamedali et al. 2011; see 'Section A.3.6 Human impacts in Puget Sound' for more discussion on anthropogenic nutrient loading).

Macroscopic kelp sporophytes require suitable nutrients to maintain high growth rates. In California, *Macrocystis* requires a minimum of 1 to 2 µmol inorganic nitrogen/L to support average increases of 4 percent wet weight per day (Schiel and Foster 2015), while nitrate levels of 10 µmol/L are associated with increased *Macrocystis* blade biomass and reductions in blade erosion in New Zealand (Stephens and Hepburn 2016). No information currently exists regarding optimal nutrient ranges for adult *Nereocystis* sporophytes. However, in laboratory studies, juvenile *Nereocystis* sporophyte densities increased significantly when cultivated in 10 µmol nitrate/L as compared to 1 and 5 µmol nitrate/L (Muth et al. 2019). During 2018 field sampling, *Nereocystis* blades at Squaxin Island in SPS were significantly shorter, shredded, and often missing in July when surface DIN concentrations dropped to 0.21 µmol/L—lower than at any other site in the study (Berry et al. 2019; Calloway 2020). There is some evidence that faster-growing annual algae (phytoplankton and ephemeral seaweeds such as *Ulva* spp.) are more susceptible to nutrient limitations than slower-growing perennial species, but this speaks more to their rate of nutrient assimilation than to inherent differences in nutrient requirements (Hurd et al. 2014).

A.1.8 Algal Competition

Seaweeds compete for available space, light, and nutrients (Dayton et al. 1992; Schiel and Foster 2006). Canopy-forming species that recruit to new available substrate first reduce light availability for understory species (Wing et al. 1993; Clark et al. 2004; Hurd et al. 2014). *Nereocystis*, for example, relies on early recruitment and fast growth rates to quickly attain dominance in the canopy, where its floating fronds influence light availability below (Springer et al. 2010; Dobkowski et al. 2019). Reduced light availability from floating canopies directly affects macroalgal and sessile invertebrate understory assemblages, exerting significant control over the structure and composition of kelp forests (Irving and Connell 2002; Clark et al. 2004). Competition between macroalgal species is not limited to the sporophyte stage. Female kelp gametophytes release pheromones to trigger the release and attraction of sperm from the male gametophyte. Species whose gametophytes mature faster may swamp the environment with pheromones thereby increasing recruitment success (Reed 1990). In a field investigation of competition between kelp microscopic life stages, both medium and high densities of *P. californica* gametophytes reduced *Macrocystis* recruitment. *Macrocystis* densities had no effect on *P. californica* recruitment (Reed 1990). While the authors suggest the possibility that such pheromone “chemical warfare” may explain their results, they stress that other confounding variables likely play a role in kelp recruitment success and call for more study on the ecology of kelp microscopic life stages.

A.2 Kelp Distribution and Trends

A.2.1 Global Kelp Trends

Accurately describing long-term trends in global kelp forests is difficult. Kelp generally show a high level of seasonal and inter-annual variability—even more so than is characteristic of other marine ecosystems (e.g., coral reefs) or terrestrial biomes (Krumhansl et al. 2016). Long-term (≥ 20 years) and regional-scale studies provide the best clarity when assessing historical trajectories of kelp forests (Krumhansl et al. 2016; Pfister and Betcher 2017). However, a lack of consistent long-term data sets for subtidal kelp distribution and trends make any global snapshot of kelp reliant on a small and scattered sample of short-term studies.

An analysis by Krumhansl et al. (2016) of long-term (≥ 2 years) kelp monitoring data shows declines in approximately 38 percent of global kelp ecosystems (Krumhansl et al. 2016). Changes in the nearshore environment have led to serious losses of kelp in Australia (Connell et al. 2019), California (Rogers-Bennett and Catton 2019), and Tasmania (Ling et al. 2009; Wernberg et al. 2019). Such localized losses can be severe and difficult to reverse (Wernberg et al. 2019; Filbee-Dexter and Wernberg 2018; Steneck et al. 2002). Despite regional losses, Krumhansl et al. (2016) also found that 35 percent of global kelp forests have shown no change over 50 years. They caution, however, that this could be due to their reliance on sporadic, short-term (< 20 year) studies that lack the power to detect long-term change. The authors also warn that kelp monitoring has declined in frequency and extent over the past five years, making a strong case for increasing long-term kelp monitoring projects.

A.2.2 Puget Sound Kelp Trends

Our current understanding of kelp resources in Puget Sound is largely restricted to canopies formed by bull kelp (and giant kelp elsewhere in Washington waters) since their large surface-floating fronds allow for surveying from boats, aircraft, and satellites. Traditional and local ecological knowledge from Tribes, residents, citizen-science surveys, and analysis of historical data all point to significant declines in the extent and density of bull kelp forests throughout Puget Sound. Little information exists regarding distributions of the other 16 kelp species in Puget Sound as defined by this plan (Mumford 2007).

Collaboration and communication among the different organizations currently monitoring bull kelp forests provide strong evidence for declines in floating canopies. However, no current data or monitoring activities focus on the distributions and trends of understory kelp species.

Local Observations of Loss

Anecdotal observations from residents, Tribes, NGOs, and management agencies consistently describe losses in the number and extent of bull kelp forests in Puget Sound. The Suquamish Tribe witnessed the loss of a large and persistent bull kelp forest near Jefferson Head on the Kitsap Peninsula. PSRF documented the loss of the last remaining Bainbridge Island bull kelp canopy at Tyee Shoal between 2010 and 2015. Similarly, traditional ecological knowledge interviews with Samish elders describe significant losses around the San Juan Islands (Palmer-McGee 2019).

Washington Department of Natural Resources Long-term Monitoring

Annual aerial surveys of the outer coast and Strait of Juan de Fuca by the Washington State Department of Natural Resources (DNR) represent the best long-term monitoring of floating bull kelp and giant kelp canopies for the state. However, these flights incorporate only a small portion of the geographic scope of this plan—the north Quimper Peninsula shoreline (Berry et al. 2005). Within this region, DNR documented significant losses in the canopy area around Protection Island. However, examination of historical records shows that this area exhibited high variability, and observed declines may reflect natural variation (Rigg 1915; Berry et al. 2005). Comparisons of long-term aerial photography of the north Olympic Peninsula to kelp surveys from 1911 to 1912 document declines along shorelines between Dungeness Spit and Port Townsend, in contrast to century-scale stability along the open coast and western Strait of Juan de Fuca (Pfister et al. 2017).

Washington Department of Natural Resources Boat Surveys

DNR compared current and historical bull kelp distribution at sites and identified areas of concern for losses in South Puget Sound, Bainbridge Island, and east San Juan Island, and apparent increases in Elliott Bay (Berry et al. 2014).

Berry et al. (2019) documented major recent declines in all four *Nereocystis* beds monitored in South Puget Sound between 2013 and 2019, a period of extremely warm water conditions. They noted that *Nereocystis* beds in the Tacoma Narrows sub-area were far more abundant and in a healthier condition, with higher numbers of blades and lower severity of physical damage and epiphyte fouling. The authors also observed distinct differences in water column properties known to affect kelp. Nitrogen concentrations were significantly higher in the Tacoma Narrows, with values above 10 µmol/L throughout the year, while they dropped to 1 to5 µmol/L at the innermost site within the basin. Summer water temperatures were consistently higher (Δ1 to 4 °C) in the innermost site, compared to the Tacoma Narrows, and exceeded thresholds known to be deleterious to bull kelp (up to 20 °C). These differences in water column properties could be attributed to the intense tidal mixing that occurs at the Tacoma Narrows.

To establish a complete historical baseline for assessing *Nereocystis* canopy trends, DNR is comparing on-the-water surveys to historical charts and survey data from state and federal agencies. A recently completed analysis of South Puget Sound documented a 62 percent loss in linear extent of *Nereocystis* canopies, with losses significantly more severe in the western and central portions of the basin (Berry et al. *in review*; Figure A-1). DNR is currently conducting similar analyses for Central Puget Sound.

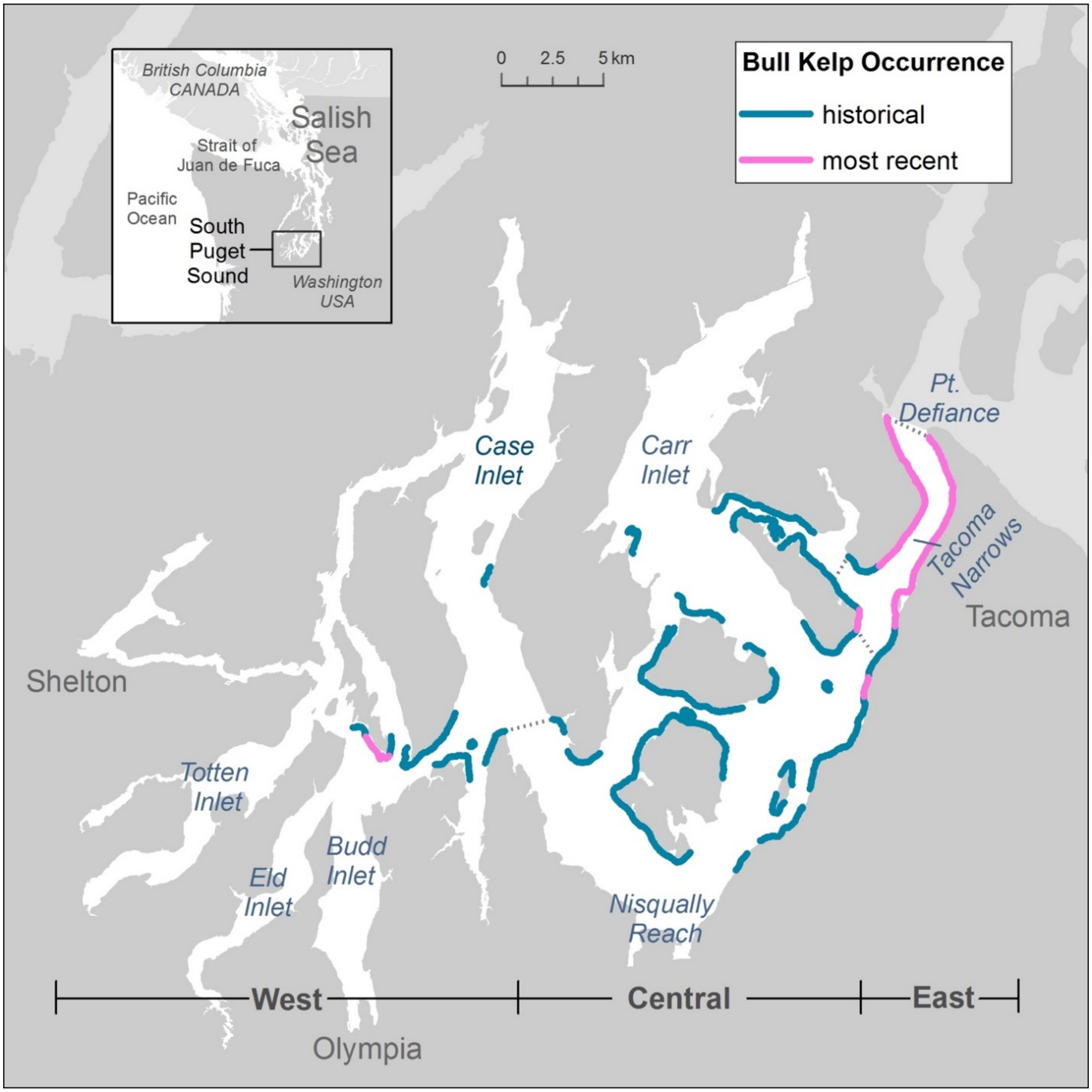


Figure A-1. Historical and recent bull kelp distribution in South Puget Sound. Blue lines delineate shorelines where bull kelp occurred historically but has not been observed recently (all records since 1870s). Pink lines delineate shorelines where bull kelp occurred historically and persisted in most recent surveys (2017-2018).

Northwest Straits Commission Marine Resources Committee Kayak Monitoring

In addition to efforts in the South and Main Basins, the Northwest Straits Commission and seven county marine resources committees (MRCs) conduct citizen-science kayak mapping of bull kelp canopies in the Whidbey Basin, Strait of Juan de Fuca, San Juan archipelago, and North Sound. Citizen-science kayak surveys focus on mapping the surface perimeter of *Nereocystis* canopies and collecting additional data on environmental conditions (e.g., water temperature). Bull kelp beds monitored by the MRCs have been relatively stable from 2015-2019, except for select sites in Snohomish County where the MRC has documented forest losses and declines near Mukilteo and Meadowdale.

A.3 Kelp Stressors

Kelp species thrive in clear, cool waters and their sensitivity to changes in water quality make them potential sentinel species for nearshore environments, with losses often following increases in temperature, nutrient loading, and turbidity (Steneck et al. 2002; Reed et al. 2016; Filbee-Dexter and Wernberg 2018). Development and urbanization are associated with predictable impacts on nearshore environments, including increases in runoff, sediment delivery, and effluent discharges that have the potential to severely affect kelp forests (Heery 2017).

A.3.1 Increased Ocean Temperatures

Global sea surface temperatures (SST) have increased an average of 0.44 °C (0.36 to 0.52 °C) since 1971, while extreme warming events—like the 2014-2016 "blob" that resulted in maximum SST anomalies five to seven degrees Celsius warmer than average in the northeastern Pacific—are likely to increase in severity and frequency (Gentemann et al. 2017; IPCC 2014). No long-term SST data exists for Puget Sound, but records from Race Rocks, Canada (close to Neah Bay, Washington) show a 0.7 °C increase in SST over the past century (Pfister et al. 2017). Warming ocean temperatures and marine heatwaves have, directly and indirectly, led to significant and persistent kelp losses at several locations across the globe (Wernberg et al. 2019; Connell et al. 2019; Feehan et al. 2019; Rogers-Bennett and Catton 2019).

While species-specific temperature tolerances differ, most kelp species in our region are predicted to respond negatively to warming ocean temperatures with lower spore production, germination rates, and recruitment (Muth et al. 2019). Kelp species, especially at the warm edges of their natural distributions, can and have quickly adapted to changes in temperature regimes in the past; but there is a concern that the current rate of SST increase may be too rapid for kelp to adapt naturally (Muth et al. 2019; Feehan et al. 2019; Hollarsmith et al. 2020).

A.3.2 Shifts to Turf-Dominated Assemblages

Turf algae include small filamentous and foliose green and red algae associated with lower community biodiversity and fewer ecosystem services than healthy kelp forests (Connell et al. 2014). Shifts to communities dominated by turf-forming algae are increasing across the globe. They have been recently documented in North Sea *S. latissima* forests (Moy and Christie 2012), southern Australian *E. radiata* stands (Connell and Russell 2010), along developed coasts in the Mediterranean (Benedetti-Cecchi et al. 2001), and the northeastern United States (Feehan et al. 2019). Potentially similar shifts have also been noted in Washington State in proximity to Seattle (Heery 2017).

Shifts to turf-dominated assemblages are a new phenomenon, and researchers are working to pinpoint causes in order to recover lost kelp forests (Filbee-Dexter and Wernberg 2018). Both increased water temperature and anthropogenic nutrient loading seem to lend competitive advantages to turf species, allowing them to quickly monopolize available substrates and block kelp recruitment (Russell et al. 2009; Feehan et al. 2019). In laboratory experiments conducted in

Australia, higher temperatures resulted in significant increases in turf cover on experimental substrates (Falkenberg et al. 2013). Falkenberg et al. (2013) also found that higher temperatures combined with increased CO_2 lead to faster expansion of turf assemblages than would be predicted from either parameter acting alone. Experiments by Falkenberg, Russell, and Connell (2013) show that increased nitrogen availability allows for faster turf expansion, raising concerns about increased anthropogenic nutrient loading in areas experiencing increased coastal development. However, recent research from Rhode Island in the northwest Atlantic documents conversion of kelp habitats to turf assemblages during a period of time when anthropogenic nutrient loads decreased (Feehan et al. 2019). This finding raises serious concerns that increased water temperature alone, more than excess nutrient loading, may explain the recent the rise of turf barrens.

A.3.3 Grazing Pressure

The effects of herbivory on kelp forest systems are well documented in the popular and scientific literature (see Steneck et al. 2002 for a review). While sea otter reintroduction led to some kelp recovery in southeastern Alaska (Estes and Duggins 1995), there is no historical evidence for sea otters in the inland waters of Puget Sound (Everitt et al. 1980). Urchins left unchecked by predators can quickly “clear cut” entire kelp forests, creating barrens devoid of macroalgae and crowded by sickly urchins. Puget Sound hosts three urchin species (*Strongylocentrotus purpuratus*, *S. droebachiensis*, and *Mesocentrotus franciscanus*), but WDFW has not documented extensive urchin barrens during population surveys (personal communication with Henry Carson, WDFW, November 14, 2019). Limited areas characterized by low macroalgae cover and high purple urchin (*S. purpuratus*) densities, however, have been documented along the outer coast of Vancouver Island, the western Strait of Juan de Fuca, and the San Juan Islands (personal communication with Helen Berry and Taylor Frierson, WDFW, November 14, 2019). Purple urchins have been responsible for recent large and persistent kelp losses in northern California, and there is a concern that urchin barrens may be expanding north into Oregon (Flaccus and Chea 2019; Rogers-Bennett and Catton 2019).

While the importance of herbivory from conspicuous macrograzers, like urchins, is critical in understanding kelp forest dynamics (Steneck et al. 2002), smaller mesograzers—such as amphipods, small crustaceans, and small gastropods—may exert a similar negative influence (Duggins et al. 2001; Davenport and Anderson 2007; O’Brien and Scheibling 2016; Pfister and Betcher 2017). Often, pressures from smaller grazers interact synergistically with environmental stress, resulting in greater impacts than expected.

Duggins et al. (2001) investigated the role of current flow on the abundance of the grazing gastropod *Lacuna vincta* and mortality of *Nereocystis* in the San Juan Islands of Washington State. *Nereocystis* mortality was highest in areas that experienced the largest tidal exchanges, despite low *L. vincta* abundances. This mortality was in contrast to low mortality rates found in both low current areas with high *L. vincta* densities and high current areas with low *L. vincta* densities that experienced less dramatic tidal exchanges. This counterintuitive result stems from the interactive effect of current velocity and grazer damage. Duggins et al. (2001) found that even minor damage to *Nereocystis* stipes significantly reduced their breaking strength. During periods of low tidal current velocity, *Lacuna* snails were able to damage *Nereocystsis* stipes enough that high currents during large tidal exchanges resulted in significant sporophyte mortality. Pfister and Betcher (2017) observed similar patterns of mortality associated with wave action and grazer damage to stipes for the upper subtidal species *Pleurophycus gardneri* along the Tatoosh Island coast.

Within Puget Sound, there is concern that grazing from the locally abundant northern kelp crab (*Pugettia producta*) may have similar detrimental effects when acting in concert with above-average water temperatures and high current velocities (Rothäusler et al. 2009). While *P. producta* prefers *Macrocystis* in California, a strong preference for *Nereocystis* has been demonstrated in Puget Sound (Dobkowski 2017; Dobkowski et al. 2019). In subtidal experiments, Dobkowski (2017) found that only *Nereocystis* sporophytes fully protected from *P. producta* grazing increased in wet mass and tissue length. Anecdotal accounts from local recreational boaters in the Bainbridge Island and Olympia areas often attribute kelp losses to increases in *P. producta* abundance (personal observation). There is no current information regarding the large-scale impacts of locally abundant herbivores on Puget Sound kelp distribution and persistence.

It is important to note that grazing, when checked, acts as an influential intermediate and ongoing disturbance that may promote increased macroalgal diversity. In Alaskan *Saccharina groenlandica* and *Nereocystis* forests, Duggins (1980) found that kelp diversity decreased over the long term following the experimental removal of urchins. In the absence of regular disturbance, the large perennial *S. groenlandica* quickly monopolized the benthos, excluding most other macroalgae, including *Nereocystis*.

A.3.4 Sediment Effects on Microscopic Life stages and Turbidity

Changes in sediment transport, deposition rates, and particle size can have significant impacts on kelp recruitment and persistence. While sediment does not generally induce mortality in large sporophytes, increases in water turbidity can starve kelp of light and cause significant mortality to kelp spores, gametophytes, and germling sporophytes (Deiman et al. 2012; Geange et al. 2014; Watanabe et al. 2016).

Mortality of microscopic life stages results from suffocation by suspended or smothering sediments or through the prevention of attachment to substrates by settled sediment. In laboratory experiments on the effect of suspended and settled sediments on *Nereocystis* and dragon kelp (*Eualaria fistulosa*, closely related to *Alaria marginata* found in Puget Sound), suspended sediment loads of 420 mg/L resulted in only six percent average spore attachment, while settled sediment reduced spore attachment by nearly 99 percent (Deiman et al. 2012). A similar study on *Macrocystis* and *Undaria pinatifidia* (an introduced cousin of *A. marginata*) spore germination suggests that sediment loads greater than 100 mg/L may be enough to severely impact gametophyte densities (Geange et al. 2014). Studies on the Japanese canopy species *Eisenia* *bicyclis* show that loads as low as 30 mg/L led to 100 percent mortality in laboratory-grown gametophytes (Arakawa 2005).

Whether sediment is an issue for Puget Sound kelp is currently unknown. Observed suspended sediment concentrations (SSC) for South Puget Sound rarely exceed 2 mg/L (Berry et al. 2019). However, wave action and tidal currents complicate efforts to measure *in situ* benthic sediment accumulation and SSC (Storlazzi et al. 2011). Furthermore, sediment-associated pollutants from urban and agricultural runoff may lead to higher mortality, even when accumulation rates and SSC are below known mortality thresholds. Unfortunately, little data exists on adult sporophyte or microscopic life stage response to common runoff-associated pollutants.

Increased sediment transport to the nearshore can also negatively affect kelp populations by increasing turbidity. Kelp beds at the mouth of the Elwha River completely disappeared for several years following the removal of two large dams (Rubin et al. 2017; Glover et al. 2019). Total sediment flux during the six months of April through September in the three years (2012-2014) following dam removal was more than 0.65 Mt, 2.4 Mt, and 0.1 Mt, respectively. Kelp and other macroalgae were abundant at all study sites before dam removal but declined dramatically in the first two years afterward (Rubin et al. 2017). Kelp and macroalgae cover remained sparse during the spring of 2014 but recovered significantly following a surprise recruitment event in late summer. While such large sediment loads can lead to significant mortality for microscopic life stages (Deiman et al. 2012; Watanabe et al. 2016), Rubin et al. (2017) attributed the late-season recruitment event to the low sediment fluxes recorded in late summer of 2014 (<500 tonnes/day), which resulted in greater light availability for dormant microscopic life stages. Subsequent analysis by Glover et al. (2019) identified the primary driver of light attenuation to be suspended sediment, with measured chlorophyll-a and colored dissolved organic matter (CDOM) concentrations contributing < 15 percent to observed attenuation values. Modeling showed that total daily benthic light availability was below 1 to 2 $\mu mol/m^2/day$ in 2013 and seasonally in 2012 and 2014, supporting the hypothesis that reduced light availability caused the mortality event. Light availability increased in 2016 and 2017 as the annual sediment load decreased in tandem with the reestablishment of the macroalgal community.

A.3.5 Invasive Seaweed: *Sargassum muticum* and *Undaria pinnatifida*

There is concern that the invasive *Sargassum muticum* may disrupt native algal succession in Puget Sound by altering light availability (Britton-Simmons 2004). In experiments conducted in the San Juan Islands, Britton-Simmons (2004) documented a 75 percent reduction in the abundance of native prostrate kelp species in shallow waters. The authors attributed these declines to *S. muticum*'s early growth, which blocked light for native species that recruit slightly later. The authors also demonstrated in feeding trials that *Sargassum* is less palatable to local invertebrates. Considering the significant contribution of kelp-derived biomass to nearshore ecosystems (von Biela et al. 2016), large-scale shifts to *Sargassum*-dominated habitat may potentially have negative effects that cascade up Puget Sound food webs. Additionally, *Sargassum* is more temperature tolerant than native kelp species, and may persist and expand in tandem with increasing SST.

Undaria pinnatifida has been encountered as far north as San Francisco along the California coast (Zabin et al. 2009), and there is concern over its potential presence in Washington State waters and Puget Sound. There is no evidence for *Undaria* in Puget Sound, but in the absence of comprehensive understory kelp surveys, its presence is currently unknown. While *Undaria*, like *Sargassum*, is a common invasive species throughout the Pacific, there is no consensus regarding its impacts on native kelp assemblages (Casas et al. 2004; South et al. 2017).

A.3.6 Human Impacts in Puget Sound

As of 2017, the Washington State population has increased over 300 percent since 2010, with considerable growth in coastal areas ("Population Trends, Washington State," n.d.). From 2000 to 2017, the Puget Sound region saw a 26 percent increase in new housing units (Washington Department of Commerce 2017). Most of this growth occurred in and around the cities of Seattle, Bellevue, Everett, and Tacoma, but above average rural and urban development occurred in Whatcom, Skagit, Kitsap, and Thurston counties as well.

Urbanization and development are associated with predictable changes to the nearshore environment. Nutrient pollution from increased wastewater treatment plant (WWTP) effluent, increased water temperatures, and decreased salinity and increased sediment and contaminant delivery caused byrunoff all interact to create different conditions in urban nearshore environments (Howarth et al. 2002; Heery 2017). Of particular concern for nearshore kelp beds are increased point source WWTP discharge and non-point sources of pollution from runoff.

Modeling from 2011 estimates for DIN loading from all human point and non-point sources accounted for 73 percent of total DIN loads (Mohamedali et al. 2011). Annual average WWTP DIN loads were 1.4 times greater than river inputs, but were 4.3 times higher in summer months, a time when excess anthropogenic nutrients inputs can have greater impacts to Puget Sound dissolved oxygen and phytoplankton blooms (Mohamedali et al. 2011). While large-scale eutrophication has not been a concern in Puget Sound, the Washington State Department of Ecology (DOE) has identified excessive levels of nutrients from human sources as a major threat to water quality in Puget Sound (DOE 2019). Additionally, DOE has listed many water bodies with degraded water quality on the federally mandated 303d list. Studies from Australia and Europe documented increases in turf algae and decreases to kelp canopies even in non-eutrophic waters (Airoldi and Beck 2007; Falkenberg et al. 2013). Potentially similar shifts have been documented in proximity to urban areas in the Main Basin of Puget Sound (Heery 2017).

Toxic Contaminants

While there is serious concern about the toxic effects of common pollutants on Puget Sound kelp populations, there is little available information. Eklund and Kautsky (2003) found 82 studies on macroalgae toxicity published from 1959 to 2003, with relatively few substances being tested on more than one species. Out of 65 species included in the surveyed literature only 12 were

Laminariales species and only *S. latissima* and *Macrocystis* had more than 2 published toxicity studies—10 and 4 respectively (Eklund and Kautsky 2003).

Copper toxicity on kelp is fairly well understood and accounted for 41 percent of the studies compiled by Eklund and Kautsky (2003). Studies showed exposure often reduced spore release, and inhibited or delayed gametophyte germination and reproduction, and juvenile sporophyte growth (Eklund and Kautsky 2003; Leal et al. 2018). In addition to contaminants from point and non-point sources, there is particular concern in the Salish Sea over impacts of oil spills (Niu et al 2016). Unfortunately, only one study to date investigates the effects of petroleum exposure on Puget Sound kelp species. Laboratory studies conducted after the 1991 “Tenyo Maru” oil spill in the western Strait of Juan de Fuca found that exposure to diesel and crude oil bleached *Nereocystis* blades and stipes, severely impacting photosynthetic performance (Antrim et al. 1995). The authors note that petroleum products, which tend to float, may have a greater impact on floating species than understory populations. Regardless, more research is needed to fully understand the impacts large petroleum spills and exposure to common contaminants may have on kelp populations.

Landscape-Scale Changes

Human activity has fundamentally altered the shores and catchments of Puget Sound. Coastal development has altered the structure and function of 99.8 percent of Puget Sound shorelines, while broad-scale land use changes in the catchments that empty into Puget Sound have impounded 37 percent of the total drainage area and converted or harvested roughly 50 percent of all lowland forests and wetlands (Pearson et al. 2018). Together, these changes significantly alter terrestrial-nearshore linkages by negatively impacting the ability of the landscape to retain water, sediments, and nutrients.

Changes to catchment-scale processes may affect kelp, as Puget Sound has considerable freshwater inputs from the Skagit, Stillaguamish, Snohomish, Duwamish, Puyallup, Nisqually, and Deschutes rivers (Ebbesmeyer et al. 1988). Of particular concern is the potential for land use changes to increase sediment delivery to estuarine environments. For example, 1,080 landslides occurred in the Stillaguamish watershed between the 1940s and 1990s (Perkins and Collins 1997). While such landslides are a natural part of watershed disturbance regimes, subsequent analysis revealed that road construction and clearcutting practices were responsible for 75 percent of these slides.

Increased sediment loads can have significant impacts on overwintering microscopic forms of kelp. However, the implications depend on the timing of landslide-related sediment deposition, as well as the level of exposure at a given kelp bed (Spurkland and Iken 2011). Winter sediment pulses could potentially smother overwintering kelp gametophytes and sporophytes, while spring sediment pulses could significantly delay recruitment due to increased turbidity. Whether changes in estuarine sediment dynamics affect nearby kelp beds is a concern in Alaska, where increased glacial melt due to climate change heavily influences river sediment loads. While Puget Sound is less affected by glacial melt, residential, commercial, and industrial development increases runoff and hardens shorelines, significantly influencing nearshore processes.

Shoreline armoring dominates nearshore development, accounting for 74 percent of artificial shorelines (Pearson et al. 2018). A long-term study of sediment grain-size along armored and unarmored beaches showed clear relationships between beach sediments and armoring, but no clear connections between lower-intertidal sediments and armoring (Dethier et al. 2016). While no causal link has been identified, it is generally recognized that armoring simplifies shorelines and interferes with natural processes that maintain shoreform structures (Pearson et al. 2018). Such interference may potentially alter substrate availability for kelp recruitment in Puget Sound, but more research is needed to understand these links.

Historic Impacts of Fisheries

Increased commercial and recreational fishery landings in the 1970s and 1980s significantly altered Puget Sound's trophic structure (Harvey et al. 2012). The abundance of Puget Sound rockfishes as a group has declined by about 70 percent over the last 40 years, and overfishing is considered a primary reason for this decline (Williams et al. 2010). Fishing pressure also historically focused on finfish, urchin, sea cucumber, pinto abalone, and geoduck for export markets. The diversity of species targeted for commercial and recreational harvest encompasses nearly the entire range of Puget Sound trophic levels, from suspension-filter feeders to apex predators, suggesting the possibility for severe impacts on trophic functionality (Steneck et al. 2004). This trend of "fishing down the food web" is not unique to Puget Sound, and can negatively affect ecosystem resilience by removing entire functional groups from trophic systems.

Fishery landings for most Puget Sound finfish species peaked and plateaued in the 1970s and 1980s before significantly declining (Essington et al. 2018). Assessments following observed declines led to the closure of Puget Sound commercial cod (*G. maccrocephalus*) and hake (*Merluccius productus*) fisheries, as well as the closure of the recreational walleye pollock (*G. chalcogrammus*) fishery (Gustafson et al. 2000). Of eight salmonids found in the Puget Sound, four—Chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), bull trout (*Salvelinus confluentus*) and steelhead (*O. mykiss*)—are listed as threatened under the ESA, and two populations of Puget Sound rockfish—yelloweye (*S. ruberrimus*) and Bocaccio (*S. paucispinis*)—were recently listed (64 Fed. Reg. 14308, March 24, 1999; 64 Fed. Reg. 14508, March 25, 1999; 72 Fed. Reg. 26722, May 11, 2007; 75 Fed. Reg. 63898, October 18 2010; National Marine Fisheries Service 2017). Since the adult finfish stocks occupy intermediate to top trophic levels, they play an essential role in maintaining healthy linkages within Puget Sound's trophic system (Steneck et al. 2004; Davenport and Anderson 2007). For instance, various rockfish species feed on kelp crab and other invertebrates that eat kelp (Washington et al. 1978). Grazer abundances are likely to increase in the absence of top-down controls, possibly causing serious harm to Puget Sound kelp resources. Invertebrate fisheries—specifically for urchin and sea cucumber—are still open for harvest, but the impacts of these activities on kelp populations are unknown.

A.4 Kelp as Foundational Species

Like eelgrass, kelp is a critical foundation species that structures broader community assemblages and promotes increased biodiversity by increasing food web complexity and providing critical habitat (Caro 2010; Altieri and van de Koppel 2014). All marine vegetation form living habitats, but kelp provides 25 times more habitat biomass per unit area than seagrass (Teagle et al. 2017). This abundance of biomass creates large volumes of high-quality habitat, much in the same way that high-rise apartment complexes allow for increased population densities in urban areas. The food and shelter provided by kelp cascades up the food chain, ultimately helping to support high-level predators such as birds and marine mammals (von Biela et al. 2016).

A.4.1 Kelp Forests as Critical Finfish Habitat

On large scales, kelp distribution explains variation in fish communities (Pérez-Matus and Shima 2010, 2010). Initial larval settlement often occurs at the first patch of suitable kelp habitat encountered, regardless of quality, as a refuge from predation (Munsch et al. 2016). For many fish species, juvenile survival is linked to growth rate (Duffy et al. 2010; O'Brien et al. 2018). The combination of high-quality refuge and ample foraging opportunities characteristic of kelp forests may help ameliorate stress responses associated with non-consumptive predator effects, further enhancing juvenile survival (Donelan et al. 2017).

In Puget Sound, kelp forests are critical habitat for juvenile rockfish (*Sebastes* spp.), forage fish (including Pacific herring and surf smelt), Pacific cod (*Gadus microcephalus*), and out-migrating juvenile and returning adult salmon (*Oncorhynchus* spp.) (Doty et al. 1995; Shaffer 2000; Duffy et al. 2010).

Increased Invertebrate Abundances

At the individual level, a single kelp provides two to three distinct microhabitats for small invertebrates: the holdfast, the stipe, and the lamina (blade) (Teagle et al. 2017). While holdfast morphology, size, and volume of interstitial space vary widely between species, these structures can host approximately 30 to 70 unique species, with assemblages dominated by amphipods, copepods, and polychaetes (Christie et al. 2009; Teagle et al. 2017). Stipes and blades, on average, harbor fewer distinct taxa but support higher abundances of associated fauna. In California, Miller et al. (2018) observed abundances of shrimp and amphipods exceeding 8,000 individuals per kilogram of giant kelp frond wet weight. *Macrocystis* forests often contain 2.5 to five kg/m^2 of fronds, translating to shrimp and amphipod densities of between 20,000 and 40,000 per square meter. Similarly, structure-associated harpacticoid copepods and decapods (important forage fish and juvenile salmonid prey species) were significantly more abundant inside of Strait of Juan de Fuca kelp forests than in adjacent open water (Shaffer et al. 2020). As a result, invertebrate abundances in kelp forests can be five times greater than in seagrass and other (non-kelp) seaweed habitats and include important fish prey including copepods, amphipods, and shrimp and crab larvae (Penttila 2007; Christie et al. 2009; Duffy et al. 2010; Shaffer et al. 2020).

Forage Fish

Kelp forests, like eelgrass, provide important spawning and rearing habitats for forage fish (Johnson n.d.; Essington et al. 2018). In Puget Sound, forage fish rely on shallow nearshore environments and kelp forests for spawning and foraging success (Shaffer et al. 2020; Shaffer 2000). Large blades provide prey-dense refuges where mid-trophic species like forage fish can feed in relative safety (O'Brien et al. 2018). Pacific herring (*Clupea pallasii*) spawn directly onto submerged aquatic vegetation and, along with surf smelt (*H. pretiosus*) are more abundant in Salish Sea kelp forests than adjacent open water habitats (Shaffer et al. 2020). In addition, sand lance (*Ammodytes hexapterus*) and surf smelt will preferentially aggregate along the edges of kelp beds close to the shore to balance foraging opportunities with refuge from predation (Shaffer 2004). This is not a surprise, as forage fish are generally planktivorous, and kelp beds harbor greater diversity and abundance of marine invertebrates than kelp-free areas (Shaffer et al. 2020; Siddon et al. 2008; Christie et al. 2009).

Rockfish

Juvenile rockfish, like forage fish, preferentially recruit to floating kelp canopies to take advantage of copepods, amphipods, and other abundant zooplankton (Singer 1985; Love et al. 1991). During 1995 surveys of nearshore vegetated habitats, Puget Sound young-of-year (YOY) rockfish were found in 56 percent of all *Nereocystis* stands surveyed, but only 19 percent of eelgrass beds and 15 percent of seaweed forests without a floating canopy (Doty et al. 1995). As juvenile rockfish grow, they seek out deeper water and larger prey items, moving from the floating canopy to kelp understories before maturing and moving to deeper water (Love et al. 1991). Exported kelp wrack and detritus transported to deep-water habitats are an important food subsidy for deep-water invertebrates and likely help indirectly support deep-water groundfish and finfish populations (Britton-Simmons et al. 2012; Krumhansl and Scheibling 2012; Filbee-Dexter and Scheibling 2016). Recent WDFW underwater video surveys observed adult rockfish aggregating in proximity to kelp mats that had drifted to waters deeper than the photic zone where kelp originates, suggesting exported kelp biomass may be important for adult rockfish populations.

Salmon

Together with eelgrass meadows and saltmarshes, kelp forests are a critical part of juvenile salmon outmigration corridors. Juvenile salmon exhibit similar strategies to YOY rockfish, showing a preference for shallow nearshore environments and overwater structures, including kelp canopies (Shaffer 2004; Toft et al. 2007; Shaffer et al. 2020). Stable isotope analysis of native Salish Sea salmon species shows that nearshore kelp food webs remain important for Chinook and coho salmon throughout adulthood (Johnson and Schindler 2009). As a result, recreational fishers and others often search the edges of bull kelp forests when looking for Chinook salmon (personal communication with Dan Tonnes, NOAA, July 17, 2019; WDFW 2020). Researchers in Alaska and Washington have also documented preferential associations between juvenile salmon and submerged and floating kelp forests (Johnson n.d.; Shaffer 2004).

A.4.2 Kelp in the Food Web

Primary production in kelp forests is greater per unit area than in tropical rainforests (Krumhansl et al. 2016), and, in Washington State waters, kelp biomass production is up to six times that of phytoplankton per unit volume (Pfister et al. 2019). This high productivity helps support complex food webs both inside kelp forests and in neighboring deep-water and shoreline habitats (Duggins et al. 1989; Krumhansl et al. 2014). Deep-sea mats of kelp detritus and heaps of kelp wrack on sandy and rocky coasts act as temporary oases, supporting booms in invertebrate populations that, in turn, help support adjacent food webs (Krumhansl and Scheibling 2012).

It is possible to trace kelp-derived carbon through food webs using carbon (∂^{13}C) isotopes because kelp detritus generally has a higher carbon isotopic value than associated phytoplankton (Fredriksen 2003; Miller and Page 2012; von Biela et al. 2016). As shown in Table A-2, such analyses consistently demonstrate the significant role that kelp-derived carbon plays in subsidizing kelp forest food webs (Table A-2). Small invertebrate grazers in Norwegian kelp beds had carbon isotopic signatures very similar to those of associated kelp species, with kelp-derived carbon consistently accounting for 50 percent to nearly 100 percent of the biomass in some gastropod species (Fredriksen 2003). In Alaskan kelp beds, kelp-derived carbon constitutes 57 percent of the muscle biomass in black rockfish *(Sebastes melanops)* and kelp greenling *(Hexagrammos decagrammus)* (von Biela et al. 2016). While these numbers are impressive, a recent review suggests the contribution of kelp-derived carbon may be overstated due to the reliance on offshore phytoplankton for comparative carbon values (Miller and Page 2012). However, the authors noted that this should not be taken to mean that the contribution of kelp-derived carbon to nearshore food webs is inconsequential, simply that more research is required to accurately assess contributions.

Table A-2. Kelp-derived carbon in common Puget Sound fauna, modified from von Biela et al. 2016.

Common Name	Species	Location	Kelp Carbon Contribution
Herring	*Clupea pallasi* (juv.)	Vancouver Island, BC, Canada	35–45 percent
Cod*	*Gadus morhua* (open sea) *	Finnøy, Norway	40 percent
	Gadus morhua (kelp forest) *	Finnøy, Norway	59 percent
Kelp Greenling	*Hexagrammos decagrammus*	northeast Pacific Ocean	39–99 percent
Rock Greenling	*Hexagrammos lagocephalus*	Aleutian Islands, AK, USA	15–75 percent
Kelp Rockfish	*Sebastes atrovirens*	Santa Barbara, CA, USA	35–45 percent
Copper Rockfish	*Sebastes caurinus*	Vancouver Island, BC, Canada	55–65 percent
Black Rockfish	*Sebastes melanops*	Vancouver Island, BC, Canada	50–60 percent
	Sebastes melanops (juv.)	Vancouver Island, BC, Canada	35–45 percent
	Sebastes melanops	northeast Pacific Ocean	35–81 percent
Blue Rockfish	*Sebastes mystinus*	Santa Barbara, CA, USA	10–25 percent
Cormorant	*Phalacrocorax pelagicus*	Aleutian Islands, AK, USA	30–70 percent
Harp Seal*	*Phoca groenlandica* *	Baffin Island, Canada	20 percent
Ringed Seal*	*Phoca hispidia* *	Baffin Island, Canada	9 percent
*Proxies for similar Puget Sound species, all other listings represent species present in Puget Sound.			

A.5 Ecosystem Engineering

Kelp forests also create conditions for increased community diversity by altering physical conditions within forests (Altieri and van de Koppel 2014; Miller et al. 2018). The structural complexity, size, and area that large kelp forests occupy influences the aquatic environment by attenuating water and particle flow within and around beds (Eckman et al. 1989; Duggins et al. 1990; Gaylord et al. 2007). This dampening of water motion increases the residence time of nutrients and particles within *Macrocystis* forests, allowing associated seaweeds and filter-feeders to take full advantage of nutrients and food that would otherwise be swept quickly over the reef. Beneath canopies, understory kelps simultaneously retain particulate matter, block sediment accumulation on the benthos (Eckman et al. 1989; Duggins et al. 1990), and help sweep sediment from the benthos, maintaining access to hard substrates for sessile invertebrate larvae and kelp spores (Kennelly 1989; Arkema et al. 2009).

Furthermore, rapid growth makes kelp species some of the most productive autotrophs in the world, with primary productivity exceeding that of cultivated agricultural fields and tropical rain forests per unit area (Krumhansl et al. 2016). The result is an estimated primary productivity above 1,200 g/cm^2/year (Christie et al. 2009). Such an efficient transformation of nutrients and carbon into new biomass may have important implications for the global carbon budget, ocean acidification, and nutrient pollution,

A.5.1 Kelp Carbon Sequestration

Recent estimations by Krause-Jensen and Duarte (2016) suggest that deep-sea deposition and burial of seaweed biomass in nearshore sediments effectively sequesters 173 TgC per year. This estimate exceeds that of carbon sequestration from salt marshes, mangrove forests, and seagrass beds combined. While impressive, these are rough estimates based on data from the available literature, and the authors acknowledge the need for a more detailed analysis of the role of macroalgae in long-term global carbon sequestration. Furthermore, kelp carbon is extremely labile and quickly respired back into the environment, meaning long-term kelp carbon sequestration relies heavily on deep-water deposition and burial.

There is also a growing interest in using kelp aquaculture as one part of broader climate mitigation portfolios, specifically to offset carbon emissions from global aquaculture and regional agriculture sectors (Froehlich et al. 2019). However, kelp aquaculture carbon mitigation requires the development of suitable technologies to transport large volumes of biomass to deep ocean areas where the carbon is most likely to remain sequestered for significant amounts of time—technology that is still in development. Froehlich et al. (2019) estimate that 14 to 25 percent of current global seaweed production would be required to offset total emissions from the global aquaculture industry, suggesting that co-culture of seaweed with other commercial aquaculture species could present a viable way for sustainable, zero-emissions growth of the global aquaculture sector. While seaweed aquaculture may be impractical for offsetting global agricultural emissions, it may be a viable way for regional agricultural sectors to neutralize carbon emissions. California's agricultural sector, for example, could be carbon neutral by utilizing 3.8 percent of the West Coast Exclusive Economic Zones (EEZs) or 0.065 percent of total suitable global waters (Froehlich et al. 2019) for seaweed aquaculture.

A.5.2 Ocean Acidification Amelioration

Carbon uptake and oxygen respiration during photosynthesis may allow kelp species to ameliorate ocean acidification (OA) conditions (Nielsen et al. 2018). However, kelp forests do not export associated increases in water pH levels, and changes in pH are marked by significant depth and diel variation. During daytime photosynthesis, kelp—like other autotrophs—draw up carbon and release oxygen before releasing carbon back into the water during nighttime respiration. Measurement of pH within kelp forests reflect this diel cycle, increasing during the day and decreasing to ambient levels during the night. Despite this diel cycle, the pH in kelp forests along the Strait of Juan de Fuca was, on average, 0.08 points higher than adjacent waters with total diel variation ranging from 0.17 to 0.35 pH units (Pfister et al. 2019). While increases in pH and aragonite saturation are largely restricted to daylight hours, there is evidence that calcifying organisms may time growth to take advantage of this daily amelioration of OA conditions (Wahl et al. 2018). In addition, filter-feeding organisms grow more quickly in kelp forests due to the entrainment of particulate matter characteristic of these habitats (Duggins et al. 1989). This combination of temporary increases in pH and aragonite saturation and increases in food availability makes kelp forests potential "phytorefugia" from OA conditions. While kelp may provide limited local benefits for calcifying organisms, kelp forests are by no means a "silver bullet" for OA conditions.

A.5.3 Nutrient Bioextraction

Nutrient bio-extraction refers specifically to the use of kelp to extract excess nutrients from eutrophic coastal waters (Kim et al. 2017). A handful of studies have focused on the potential for commercial kelp aquaculture to reverse eutrophic conditions, and results from China and the eastern United States show promise (Fei 2004; Kim et al. 2015). Using the nitrogen content of cultivated seaweed tissue as a proxy, Fei et al. (2004) estimated that seaweed aquaculture has the potential to remove 6,600 mg/m^3 of nitrogen from the first two meters of surface waters in a one hectare farm (or roughly up to 528,000 mg/m^2). This number far exceeds the level (400 mg/m^3) used as a benchmark for nitrogen eutrophication. Similarly, Kim et al. (2015) determined that sugar kelp cultivation could potentially remove up to 274,000 mg/m^2 of nitrogen per year from waters in New York's Long Island Sound.

A.6 References

Ahn, O., R. J. Petrell, and P. J. Harrison. 1998. Ammonium and nitrate uptake by *Laminaria saccharina* and *Nereocystis luetkeana* originating from a salmon sea cage farm. Journal of Applied Phycology 10:333–340.

Allen, B. 2016. Sampling for kelp production and biomass at the Hood Head mariculture (HCM) kelp farm: Methods for estimating net productivity in sugar kelp at Hood Head. Puget Sound Restoration Fund.

Allen, B. 2018. Bull kelp early life history study; Final Report to NOAA Northwest Fisheries Science Center. Award# RA133F16SE1508. Puget Sound Restoration Fund.

Altieri, A. H., and J. van de Koppel. 2014. Foundation species in marine ecosystems. Pages 37–57 in J. F. Bruno, M. D. Bertness, B. R. Silliman, and J. J. Stachowicz, editors. Marine Community Ecology and Conservation. Sinauer Associates, Inc., Sunderland, Massachusetts.

Antrim, L. D., R. M. Thom, W. W. Gardiner, V. I. Cullinan, D. K. Shreffler and R. W. Bienert. 1995. Effects of petroleum products on bull kelp (*Nereocystis luetkeana*). Marine Biology 10:23–31.

Arakawa, H. 2005. Lethal effects caused by suspended particles and sediment load on zoospores and gametophytes of the brown alga *Eisenia bicyclis*. Fisheries Science 71:133–140.

Arkema, K. K., D. C. Reed, and S. C. Schroeter. 2009. Direct and indirect effects of giant kelp determine benthic community structure and dynamics. Ecology 90:3126–3137.

Bartsch, I., C. Wiencke, K. Bischof, C. M. Buchholz, B. H. Buck, A. Eggert, P. Feuerpfeil, D. Hanelt, S. Jacobsen, R. Karez, U. Karsten, M. Molis, M. Y. Roleda, H. Schubert, R. Schumann, K. Valentin, F. Weinberger, and J. Wiese. 2008. The genus *Laminaria* Sensu Lato: Recent insights and developments. European Journal of Phycology 43:1–86.

Benedetti-Cecchi, L., F. Pannacciulli, F. Bulleri, P. S. Moschella, L. Airoldi, G. Relini, and F. Cinelli. 2001. Predicting the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. Marine Ecology Progress Series 214:137–150.

Berry, H. D., T. F. Mumford Jr, and P. Dowty. 2005. Using historical data to estimate changes in floating kelp (*Nereocystis luetkeana* and *Macrocystis integrifolia*) in Puget Sound, Washington. Page proceedings of the 2005 Puget Sound George Basin research conference. Puget Sound Action Team, Olympia, Washington.

Berry, H. D., T. F. Mumford and K. Sherman. An historical study of changes in floating kelp breds in Puget Sound and the Strait of Juan de Fuca *in* Salish Sea Ecosystem Conference, April 30, 2014, Seattle, WA.

Berry, Helen D., M. Calloway, and J. Ledbetter. 2019. Bull kelp monitoring in South Puget Sound in 2017 and 2018. Page 41. Washington Department of Natural Resources, Aquatic Resources Division, Nearshore Habitat Program.

Berry, H.D., T.F. Mumford, B. Christiaen, P. Dowty, M. Calloway, L. Ferrier, E.E. Grossman, and N.R. VanArendonk. *in review*. Long term changes in kelp forests in an inner basin of the Salish Sea. Preprint available at: https://www.biorxiv.org/content/10.1101/2020.02.13.947309v1. 52 pages.

Bertness, M. D., J. F. Bruno, B. R. Silliman, and J. J. Stachowicz, editors. 2014. Marine community ecology and conservation. Sinauer Associates, Inc.

von Biela, V. R., S. D. Newsome, J. L. Bodkin, G. H. Kruse, and C. E. Zimmerman. 2016. Widespread kelp-derived carbon in pelagic and benthic nearshore fishes suggested by stable isotope analysis. Estuarine, Coastal and Shelf Science 181:364–374.

Britton-Simmons, K. H. 2004. Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. Marine Ecology Progress Series 277:61–78.

Britton-Simmons, K. H., A. L. Rhoades, R. E. Pacunski, A. W. E. Galloway, A. T. Lowe, E. A. Sosik, M. N. Dethier, and D. O. Duggins. 2012. Habitat and bathymetry influence the landscape-scale distribution and abundance of drift macrophytes and associated invertebrates. Limnology and Oceanography 57:176–184.

Calloway, M. D., Puget Sound Restoration Fund, July 17, 2019. Personal communication, email to Dan Tonnes, Ph.D., NOAA, regarding recreational fishing for chinook salmon in proximity to bull kelp canopies.

Carney, L. T., and M. S. Edwards. 2006. Cryptic processes in the sea: A review of delayed development in the microscopic life stages of marine macroalgae. Algae 21:161–168.

Caro, T. 2010. Conservation by proxy: Indicator, umbrella, keystone, flagship and other surrogate species. Island Press, Washington.

Casas, G., R. Scrosati, and M. Luz Piriz. 2004. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). Biological Invasions 6:411–416.

Christie, H., K. Norderhaug, and S. Fredriksen. 2009. Macrophytes as habitat for fauna. Marine Ecology Progress Series 396:221–233.

Clark, R., M. Edwards, and M. Foster. 2004. Effects of shade from multiple kelp canopies on an understory algal assemblage. Marine Ecology Progress Series 267:107–119.

Connell, S. D., and B. D. Russell. 2010. The direct effects of increasing CO_2 and temperature on non-calcifying organisms: increasing the potential for phase shifts in kelp forests. Proceedings: Biological Sciences 277:1409–1415.

Connell, S. D., A. Vergés, I. Nagelkerken, B. D. Russell, N. Shears, T. Wernberg, and M. A. Coleman. 2019. The past and future ecologies of Australasian kelp forests. Pages 414–430 in S. J. Hawkins, K. Bohn, L. B. Firth, and G. A. Williams, editors. Interactions in the Marine Benthos. First edition. Cambridge University Press.

Connell, S., M. Foster, and L. Airoldi. 2014. What are algal turfs? Towards a better description of turfs. Marine Ecology Progress Series 495:299–307.

Davenport, A. C., and T. W. Anderson. 2007. Positive indirect effects of reef fishes on kelp performance: the importance of mesograzers. Ecology 88:1548–1561.

Dayton, P. K. 1985. Ecology of kelp communities. Annual review of ecology and systematics 16:215–245.

Dayton, P. K., M. J. Tegner, P. E. Parnell, and P. B. Edwards. 1992. Temporal and spatial patterns of disturbance and recovery in a kelp forest community. Ecological Monographs 62:421–445.

Deiman, M., K. Iken, and B. Konar. 2012. Susceptibility of *Nereocystis luetkeana* (Laminariales, Ochrophyta) and *Eualaria fistulosa* (Laminariales, Ochrophyta) spores to sedimentation. ALGAE 27:115–123.

Department of Ecology. 2019. Reducing nutrients in Puget Sound. https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients.

Dobkowski, K. A., K. D. Flanagan, and J. R. Nordstrom. 2019. Factors influencing recruitment and appearance of bull kelp, *Nereocystis luetkeana* (Phylum Ochrophyta). Journal of Phycology 55:236–244.

Donelan, S. C., J. H. Grabowski, and G. C. Trussell. 2017. Refuge quality impacts the strength of nonconsumptive effects on prey. Ecology 98:403–411.

Doty, D. C., R. M. Buckley, and J. E. West. 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.

Druehl, L. D., and B. E. Clarkston. 2016. Pacifc Seaweeds: A guide to common seaweeds of the West Coast. Second. Harbour Publishing, BC Canada.

Druehl, L. D., and S. I. C. Hsiao. 1977. Intertidal kelp resonse to seasonal environmental changes in a British Columbia inlet. Journal of Fisheries Research Board of Canada 34:1207–1211.

Duffy, E. J., D. A. Beauchamp, R. M. Sweeting, R. J. Beamish, and J. S. Brennan. 2010. Ontogenetic diet shifts of juvenile Chinook salmon in nearshore and offshore habitats of Puget Sound. Transactions of the American Fisheries Society 139:803–823.

Duggins, D., J. E. Eckman, C. E. Siddon, and T. Klinger. 2001. Interactive roles of mesograzers and current flow in survival of kelps. Marine Ecology Progress Series 223:143–155.

Duggins, D. O. 1980. Kelp beds and sea otters: An experimental approach. Ecology 61:447–453.

Duggins, D. O., J. E. Eckman, and A. T. Sewell. 1990. Ecology of understory kelp environments. II. Effects of kelps on recruitment of benthic invertebrates. Journal of Experimental Marine Biology and Ecology 143:27–45.

Duggins, D. O., C. A. Simenstad, and J. A. Estes. 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. Science 245:170–173.

Eckman, J. E., D. O. Duggins, and A. T. Sewell. 1989. Ecology of under story kelp environments. I. Effects of kelps on flow and particle transport near the bottom. Journal of Experimental Marine Biology and Ecology 129:173–187.

Eklund, B. T. and L. Kautsky. 2003. Review on toxicity testing with marine macroalgae and the need for method standardization—exemplified with copper and phenol. Marine Pollution Bulletin 46:171–181.

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

Estes, J. A., and D. O. Duggins. 1995. Sea otters and kelp forests in Alaska: Generality and variation in a community ecological paradigm. Ecological Monographs 65:75–100.

Everitt, R.D., C.H. Fiscus and R.L. DeLong. 1980. Northern Puget Sound Marine Mammals. Prepared for the MESA (Marine Ecosystems Analysis) Puget Sound Project. Seattle, WA. 155 pages.

Falkenberg, L. J., B. D. Russell, and S. D. Connell. 2013. Contrasting resource limitations of marine primary producers: implications for competitive interactions under enriched CO 2 and nutrient regimes. Oecologia 172:575–583.

Federal Register, Volume 64, No.14308. March 24, 1999. Final rule: Endangered and Threatened Species; Threatened Status for Three Chinook Salmon Evolutionarily Significant Units (ESUs) in Washington and Oregon, and Endangered Status for One Chinook Salmon ESU in Washington.

Federal Register, Volume 64, 14508. March 25, 1999. Final rule, notice of determination: Endangered and Threatened Species: Threatened Status for Two ESUs of Chum Salmon in Washington and Oregon.

Federal Register, Volume 72, No. 26722. May 11, 2007. Final rule: Endangered and Threatened Species: Final Listing Determination for Puget Sound Steelhead.

Federal Register, Volume 75, No. 63898. October 18, 2010. Final rule: Endangered and Threatened Wildlife and Plants; Revised Designation of Critical Habitat for Bull Trout in the Coterminous United States.

Feehan, C. J., S. P. Grace, and C. A. Narvaez. 2019. Ecological feedbacks stabilize a turf-dominated ecosystem at the southern extent of kelp forests in the Northwest Atlantic. Scientific Reports 9:7078.

Fei, X. 2004. Solving the coastal eutrophication problem by large scale seaweed cultivation. Pages 145–151 Asian Pacific Phycology in the 21st Century: Prospects and Challenges. Springer.

Filbee-Dexter, K., and R. E. Scheibling. 2016. Spatial patterns and predictors of drift algal subsidy in deep subtidal environments. Estuaries and Coasts 39:1724–1734.

Filbee-Dexter, K., and T. Wernberg. 2018. Rise of turfs: A new battlefront for globally declining kelp forests. BioScience.

Flaccus, G., and T. Chea. 2019, October 24. Sea urchins are chomping their way through Oregon coast kelp, ‘uncharted territory’ for marine ecosystem. The Oregonian.

Froehlich, H. E., J. C. Afflerbach, M. Frazier, and B. S. Halpern. 2019. Blue growth potential to mitigate climate change through seaweed offsetting. Current Biology: S0960982219308863.

Gaylord, B., D. C. Reed, P. T. Raimondi, L. Washburn, and S. R. McLean. 2002. A physically based model of macroalgal spore dispersal in the wave and current-dominated nearshore. Ecology 83:1239–1251.

Gaylord, B., J. H. Rosman, D. C. Reed, J. R. Koseff, J. Fram, S. MacIntyre, K. Arkema, C. McDonald, M. A. Brzezinski, J. L. Largier, and others. 2007. Spatial patterns of flow and their modification within and around a giant kelp forest. Limnology and Oceanography 52:1838–1852.

Geange, S. W., A. Powell, K. Clemens-Seely, and C. A. Cárdenas. 2014. Sediment load and timing of sedimentation affect spore establishment in *Macrocystis pyrifera* and *Undaria pinnatifida*. Marine Biology 161:1583–1592.

Gentemann, C. L., M. R. Fewings, and M. García-Reyes. 2017. Satellite sea surface temperatures along the West Coast of the United States during the 2014-2016 northeast Pacific marine heat wave: Coastal SSTs During “the Blob.” Geophysical Research Letters 44:312–319.

Glover, H. E., A. S. Ogston, I. M. Miller, E. F. Eidam, S. P. Rubin, and H. D. Berry. 2019. Impacts of suspended sediment on nearshore benthic light availability following dam removal in a small mountainous river: In situ observations and statistical modeling. Estuaries and Coasts 42:1804–1820.

Graham, M. H. 2004. Effects of local deforestation on the diversity and structure of Southern California giant kelp forest food webs. Ecosystems 7.

Greene, C., L. Kuehne, C. Rice, K. Fresh, and D. Penttila. 2015. Forty years of change in forage fish and jellyfish abundance across greater Puget Sound, Washington (USA): anthropogenic and climate associations. Marine Ecology Progress Series 525:153–170.

Harley, C. D. G., K. M. Anderson, K. W. Demes, J. P. Jorve, R. L. Kordas, T. A. Coyle, and M. H. Graham. 2012. Effects of climate change on global seaweed communities. Journal of Phycology 48:1064–1078.

Harvey, C. J., G. D. Williams and P. S. Levin. 2012. Food web structure and trophic control in Central Puget Sound. Estuaries and Coasts. Volume 35(3), pages 821 to 838.

Heery, E. C. 2017. Benthic subtidal assemblages and ecological processes in urbanized seascapes of Puget Sound, Washington, USA.

Hollarsmith, J. A., A. H. Buschmann, C. Camus, E. D. Grosholz. 2020. Varying reproductive success under ocean warming and acidification across giant kelp (*Macrocystis pyrifera*) populations. Journal of Experimental Marine Biology and Ecology 522:151247.

Howarth, R. W., A. Sharpley and D. Walker. 2002. Source of nutrient pollution to coastal waters in the United States: Implications for achieving coastal water quality goals. Estuaries 25(4):656-676.

Hurd, C. L., P. J. Harrison, K. Bischof, and C. S. Lobban. 2014. Seaweed ecology and physiology. Second. Cambridge University Press.

Irving, A. D., and S. D. Connell. 2002. Sedimentation and light penetration interact to maintain heterogeneity of subtidal habitats: algal versus invertebrate dominated assemblages. Marine Ecology Progress Series 245:83–91.

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

Johnson, S. W. (n.d.). A survey of fish assemblages in eelgrass and kelp habitats of southeastern Alaska:48.

Kennelly, S. 1989. Effects of kelp canopies on understory species due to shade and scour. Marine Ecology Progress Series 50:215–224.

Khangaonkar, T., A. Nugraha, W. Xu, W. Long, L. Bianucci, A. Ahmed, T. Mohamedali, and G. Pelletier. 2018. Analysis of hypoxia and sensitivity to nutrient pollution in Salish Sea. Journal of Geophysical Research: Oceans 123:4735–4761.

Kim, J., G. Kraemer, and C. Yarish. 2015. Use of sugar kelp aquaculture in Long Island Sound and the Bronx River Estuary for nutrient extraction. Marine Ecology Progress Series 531:155–166.

Knapp, C L, Stoffel, T L, and Whitaker, S D. 1980. Insolation data manual: long-term monthly averages of solar radiation, temperature, degree-days and global anti K/sub T/ for 248 national weather service stations. United States: N. p., 1980. Web. doi:10.2172/6749901.

Krause-Jensen, D., and C. M. Duarte. 2016. Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9:737.

Krumhansl, K. A., J.-S. Lauzon-Guay, and R. E. Scheibling. 2014. Modeling effects of climate change and phase shifts on detrital production of a kelp bed. Ecology 95:763–774.

Krumhansl, K. A., D. K. Okamoto, A. Rassweiler, M. Novak, J. J. Bolton, K. C. Cavanaugh, S. D. Connell, C. R. Johnson, B. Konar, S. D. Ling, F. Micheli, K. M. Norderhaug, A. Pérez-Matus, I. Sousa-Pinto, D. C. Reed, A. K. Salomon, N. T. Shears, T. Wernberg, R. J. Anderson, N. S. Barrett, A. H. Buschmann, M. H. Carr, J. E. Caselle, S. Derrien-Courtel, G. J. Edgar, M. Edwards, J. A. Estes, C. Goodwin, M. C. Kenner, D. J. Kushner, F. E. Moy, J. Nunn, R. S. Steneck, J. Vásquez, J. Watson, J. D. Witman, and J. E. K. Byrnes. 2016. Global patterns of kelp forest change over the past half-century. Proceedings of the National Academy of Sciences of the United States of America 113:13785–13790.

Krumhansl, K., and R. Scheibling. 2012. Production and fate of kelp detritus. Marine Ecology Progress Series 467:281–302.

Leal, P. P., C. L. Hurd, S. G. Sander, E. Armstrong, P. A. Fernández, T. J. Suhrhoff and M. Y. Roleda. Copper pollution exacerbates the effects of ocean acidificatoin and warming on kelp microscopic early life stages. Nature Scientific Reports 8:14753.

Lind, A. C., and B. Konar. 2017. Effects of abiotic stressors on kelp early life-history stages. Algae 32:223–233.

Ling, S. D. 2008. Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. Oecologia 156:883–894.

Ling, S. D., C. R. Johnson, S. D. Frusher, K. R. Ridgway, and J. C. Castilla. 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proceedings of the National Academy of Sciences of the United States of America 106:22341–22345.

Love, M. S., M. H. Carr, and L. J. Haldorson. 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.

Lüning, K., and W. Freshwater. 1988. Temperature tolerance of Northeast Pacific marine algae. Journal of Phycology 24:310–515.

Maxell, B. A., and K. A. Miller. 1996. Demographic studies of the annual kelps *Nereocystis luetkeana* and *Costaria costata* (Laminariales, Phaeophyta) in Puget Sound, Washington. Botanica Marina 39:479-489.

Miller, R. J., K. D. Lafferty, T. Lamy, L. Kui, A. Rassweiler, and D. C. Reed. 2018. Giant kelp, *Macrocystis pyrifera*, increases faunal diversity through physical engineering. Proceedings of the Royal Society B: Biological Sciences 285:20172571.

Mohamedali, T, M. Roberts, B. Sackmann, and A. Kolosseus. 2011. Puget Sound dissolved oxygen model nutrient load summary for 1999-2008. Publication No. 11-03-057, Washington State Department of Ecology, Olympia, WA.

Moy, F. E., and H. Christie. 2012. Large-scale shift from sugar kelp (*Saccharina latissima*) to ephemeral algae along the south and west coast of Norway. Marine Biology Research 8:309–321.

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 pages.

Munsch, S., J. Cordell, and J. Toft. 2016. Fine-scale habitat use and behavior of a nearshore fish community: nursery functions, predation avoidance, and spatiotemporal habitat partitioning. Marine Ecology Progress Series 557:1–15.

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

Nielsen, K., J. Stachowicz, H. Carter, K. Boyer, M. Bracken, F. Chan, F. Chavez, K. Hovel, M. Kent, K. Nickols, J. Ruesink, J. Tyburczy, and S. Wheeler. 2018. Emerging understanding of the potential role of seagrass and kelp as an ocean acidification management tool in California. California Ocean Science Trust, Oak.

Niu, H., S. Li, T. King and K. Lee. 2016. Stochastic modeling of oil spill in the Salish Sea. Proceedings of the Twenty-sixth (2016) International Ocean and Polar Engineering Conference. June 26 - July 1, 2016, Rhodes, Greece.

O'Brien, B. S., K. Mello, A. Litterer, and J. A. Dijkstra. 2018. Seaweed structure shapes trophic interactions: A case study using a mid-trophic level fish species. Journal of Experimental Marine Biology and Ecology 506:1–8.

O'Brien, J. M., and R. E. Scheibling. 2016. Nipped in the bud: mesograzer feeding preference contributes to kelp decline. Ecology 97:1873–1886.

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

Pearson, S. F., N. Hamel, S. Walters and J. Marzluff. 2018. Threats: Impacts of natural events and human activities on the ecosystem in Encyclopedia of Puget Sound. https://www.eopugetsound.org/science-review/threats-impacts-natural-events-and-human-activities-ecosystem. Accessed April 30, 2018.

Penttila, D. 2007. Marine forage fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.W. Army Corps of Engineers, Seattle, Available from: http://www.pugetsoundnearshore.org/technical_papers/marine_fish.pdf (December 4, 2019).

Pérez-Matus, A., and J. S. Shima. 2010. Disentangling the effects of macroalgae on the abundance of temperate reef fishes. Journal of Experimental Marine Biology and Ecology 388:1–10.

Pfister, C. A., M. A. Altabet, and B. L. Weigel. 2019. Kelp beds and their local effects on seawater chemistry, productivity, and microbial communities. Ecology: e02798.

Pfister, C. A., H. D. Berry, and T. Mumford. 2018. The dynamics of kelp forests in the Northeast Pacific Ocean and the relationship with environmental drivers. Journal of Ecology. 106:1520-1533.

Pfister, C. A., and S. P. Betcher. 2017. Climate drivers and animal host use determine kelp performance over decadal scales in the kelp *Pleurophycus gardneri* (Laminariales, Phaeophyceae). Journal of Phycology. 54(1): 1-11.

Reed, D. C. 1990. The effects of variable settlement and early competition on patterns of kelp recruitment. Ecology 71:776–787.

Reed, D., L. Washburn, A. Rassweiler, R. Miller, T. Bell, and S. Harrer. 2016. Extreme warming challenges sentinel status of kelp forests as indicators of climate change. Nature Communications. Volume 7, 13757.

Riggs, G. B. 1915. The beds of Puget Sound. Cameron, F.K., editor. U.S.D.A., Washington, D.C. 9 pages.

Rogers-Bennett, L., and C. A. Catton. 2019. Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. Scientific Reports 9:15050.

Rothäusler, E., I. Gómez, I. A. Hinojosa, U. Karsten, F. Tala, and M. Thiel. 2009. Effect of temperature and grazing on growth of *Macrocystis* spp. (Phaeophyceae) along a latitudinal gradient. Journal of Phycology 45:547–559.

Rubin, S. P., I. M. Miller, M. M. Foley, H. D. Berry, J. J. Duda, B. Hudson, N. E. Elder, M. M. Beirne, J. A. Warrick, M. L. McHenry, A. W. Stevens, E. F. Eidam, A. S. Ogston, G. Gelfenbaum, and R. Pedersen. 2017. Increased sediment load during a large-scale dam removal changes nearshore subtidal communities. PLOS ONE 12:e0187742.

Russell, B. D., J.-A. I. Thompson, L. J. Falkenberg, and S. D. Connell. 2009. Synergistic effects of climate change and local stressors: CO2 and nutrient-driven change in subtidal rocky habitats. Global Change Biology 15:2153–2162.

Schiel, D. R., and M. S. Foster. 2006. The population biology of large brown seaweeds: ecological consequences of multiphase life histories in dynamic coastal environments. Annu. Rev. Ecol. Evol. Syst. 37:343–372.

Schiel, D. R., and M. S. Foster. 2015. The biology and ecology of giant kelp forests. University of California Press, Oakland, California.

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

Shaffer, A.J.., D. Parks, E. Schoen, and D. Beauchamp. 2019. Salmon, forage fish, and kelp. Frontiers in Ecology and the Environment 17:258–258.

Shaffer, A.J.. 2004. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. Pages 1–11 Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference.

Shaffer, A.J. 2000. Seasonal variation in understory kelp bed habitats of the Strait of Juan de Fuca. Journal of Coastal Research 16:768–775.

Schiltroth, B., S. Bisgrove; and B. Heath, Effects of warm ocean temperatures on bull kelp forests in the Salish Sea in Puget Sound. Salish Sea Ecosystem Conference. April 6, 2018, Seattle, WA. Document available at: https://cedar.wwu.edu/ssec/2018ssec/allsessions/515

Siddon, E. C., C. E. Siddon, and M. S. Stekoll. 2008. Community level effects of *Nereocystis luetkeana* in southeastern Alaska. Journal of Experimental Marine Biology and Ecology 361:8–15.

Singer, M. M. 1985. Food habits of juvenile rockfishes (*Sebastes*) in a central California kelp forest. Fishery Bulletin 83:531–541.

South, P. M., O. Floerl, B. M. Forrest, and M. S. Thomsen. 2017. A review of three decades of research on the invasive kelp *Undaria pinnatifida* in Australasia: An assessment of its success, impacts and status as one of the world’s worst invaders. Marine Environmental Research 131:243–257.

Springer, Y. P., C. G. Hays, M. H. Carr, and M. R. Mackey. 2010. Toward ecosystem-based management of marine macroalgae—The bull kelp, *Nereocystis luetkeana*. Oceanography and marine biology. An Annual Review. 48:1-42.

Spurkland, T., and K. Iken. 2011. Kelp bed dynamics in estuarine environments in Subarctic Alaska. Journal of Coastal Research 27:133–143.

Steneck, R. S., M. H. Graham, B. J. Bourque, D. Corbett, J. M. Erlandson, J. A. Estes, and M. J. Tegner. 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation 29.

Steneck, R. S., J. Vavrinec and A. V. Leland. 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. Ecosystems 7(4):323-332.

Storlazzi, C. D., M. E. Field, and M. H. Bothner. 2011. The use (and misuse) of sediment traps in coral reef environments: theory, observations, and suggested protocols. Coral Reefs 30:23–38.

Suskiewicz, M. S. 2010. Effects of competition and dispersal on the recruitment of the annual kelp *Nereocystis luetkeana*. Masters Thesis, San José State University, San José, California, U.S.A.

Swanson, A. K., and L. D. Druehl. 2000. Differential meiospore size and tolerance of ultraviolet light stress within and among kelp species along a depth gradient. Marine Biology 136:657–664.

Teagle, H., S. J. Hawkins, P. J. Moore, and D. A. Smale. 2017. The role of kelp species as biogenic habitat formers in coastal marine ecosystems. Journal of Experimental Marine Biology and Ecology 492:81–98.

Tera Corp. 1982. Compendium of thermal effects laboratory studies: Diablo Canyon Power Plant. Vol 1 and 2. Tera Corporation, Berkelely, California, Report B-81-403 submitted to the Pacific Gas and electric Company.

Toft, J. D., J. R. Cordell, C. A. Simenstad, and L. A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management 27:465–480.

Vadas, R. L. 1972. Ecological implications of culture studies on *Nereocystis luetkeana*. Journal of Phycology: 8(2):196–203.

Wahl, M., S. Schneider Covachã, V. Saderne, C. Hiebenthal, J. D. Müller, C. Pansch, and Y. Sawall. 2018. Macroalgae may mitigate ocean acidification effects on mussel calcification by increasing pH and its fluctuations: Biogenic fluctuations mitigate OA effects. Limnology and Oceanography 63:3–21.

Washington Department of Fish and Wildlife (WDFW). 2020. Salmon fishing in marine areas. Document available at: https://wdfw.wa.gov/fishing/basics/salmon/marine-areas. Website accessed March 16, 2020.

Washington, P.M., R. Gowan and D. H. Ito. 1978. A biological report on eight species of rockfish (*Sebastes spp.*) from Puget Sound, Washington. In NWAFC processed report, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle.

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

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

Wernberg, T., M. S. Thomsen, F. Tuya, G. A. Kendrick, P. A. Staehr, and B. D. Toohey. 2010. Decreasing resilience of kelp beds along a latitudinal temperature gradient: potential implications for a warmer future: Climate and resilience of kelp beds. Ecology Letters 13:685–694.

Wernberg, T., M. A. Vanderklift, J. How, and P. S. Lavery. 2006. Export of detached macroalgae from reefs to adjacent seagrass beds. Oecologia 147:692–701.

Wiencke, C., M. Y. Roleda, A. Gruber, M. N. Clayton, and K. Bischof. 2006. Susceptibility of zoospores to UV radiation determines upper depth distribution limit of Arctic kelps: evidence through field experiments. Journal of Ecology 94:455–463.

Williams, G. D.,P. S. Levin, and W. A. Palsson. 2010. Rockfish in Puget Sound: An ecological history of exploitation. Marine Policy 34:1010–1020.

Wing, S. R., J. J. Leichter, and M. W. Denny. 1993. A dynamic model for wave-induced light fluctuations in a kelp forest. Limnology and Oceanography 38:396–407.

Zabin, C., G. Ashton, C. Brown, and G. Ruiz. 2009. Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. Aquatic Invasions 4:429–434.

Puget Sound Kelp Conservation and Recovery Plan

Appendix B - The Cultural Importance of Kelp for Pacific Northwest Tribes

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B. Cultural Importance of Kelp for Pacific Northwest Tribes

This cultural appendix covers some of the cultural importance and uses of kelp to indigenous peoples of the broader Pacific Northwest region. However, it does not cover in full detail the specific use of this resource within and among the Coast Salish peoples, whose traditional territories are within the geographic scope of this conservation and recovery plan. Cultural significance and uses can best be understood by contacting and communicating with the tribe(s) in a given area.

B.1 A Link between Worlds

With its holdfast clinging firmly to the seafloor and a long stipe reaching up to bulb and blades in the waves, bull kelp provides a physical link between the surface and undersea worlds. But kelp is also a link between continents, a link between land and sea, and a link between the human and supernatural worlds (Turner 2005a; Pringle 2017). Many of these links between realms are formed — materially and/or symbolically — by bull kelp (*Nereocystis luetkeana*). For example, the Haida people, whose homelands include the coastal islands of southeastern Alaska and northwest British Columbia, tell the story of Sounding-Gambling-Sticks, who lost his father's town in a gambling game. He floated in his canoe for many nights, trying to think of how to regain what he had lost, when he came upon a two-headed kelp (Figure B-1). He followed the kelp down to the bottom of the sea and realized that it was a housepole leading to the home of his supernatural grandfather. His grandfather gave him the power to regain all that he had lost (Turner 2005b).

Figure B-1. A couple of examples of two-headed bull kelp, provided by Tom Mumford (left) and Helen Berry (right).

The close relationship between kelp-based coastal ecosystems and Pacific Northwest indigenous cultural systems is reflected in a wide range of evidence, including prehistoric artifacts, historical sources, and contemporary practices. The first human inhabitants of the Pacific Northwest likely followed "the kelp highway" that extends along the Pacific Rim from Asia to South America. Kelp forests provide habitat and primary production, supporting diverse marine resources that have sustained and inspired traditional indigenous lifeways across continents and over generations. Within the Pacific Northwest, bull kelp played a particularly prominent role in traditional subsistence knowledge and technology and was used in fishing, hunting, and food preparation and storage. It was also put to more playful uses by both children and adults, who used kelp for toys, target practice, and musical instruments.

Kelp also plays an important role in symbolic and spiritual aspects of traditional Northwest Coast cultures. Some groups used kelp for cranial modification, an important sign of status and nobility throughout the Pacific Northwest. Kelp also appears in various Coast Salish myths and stories, where it represents the interdependence between indigenous people and the sea, the reciprocal ties of kinship between humans and supernatural beings, and the potential perils of marine livelihoods.

B.2 An Ecological and Cultural Foundation Species

B.2.1 “May Contain Traces of Kelp”

Healthy kelp forests provide habitat and primary production that support diverse marine food webs (Klinger 2015), as well as economically and culturally important protected resources. In his satirical Breakfast Series, Kwakwa̲ka̲’wakw artist Sonny Assu (Gwa’gwa’da’ka) mentions that the Salmon Loops and Salmon Crisps “may contain traces of kelp” (Assu 2006), a fact confirmed by isotopic analyses of salmon species (Johnson and Schindler 2009). Kelp has relatively more carbon-13, while phytoplankton has relatively more carbon-14. Therefore, scientists can estimate how much of an organism’s diet comes from nearshore (kelp-based) versus pelagic (phytoplankton-based) food chains. Kelp accounts for 36-89 percent of the carbon in kelp greenlings and 32-65 percent of the carbon in black rockfish along the Pacific Coast (von Biela et al. 2016). However, kelp signatures in rockfish samples have declined since European contact (Szpak et al. 2013), likely in tandem with local declines in kelp forest cover. Given the importance of kelp to Puget Sound’s nearshore food webs, these declines may be cause for alarm.

B.2.2 The Kelp Highway

Archaeological evidence suggests that the Americas may have first been settled by maritime peoples following the rich assemblage of marine resources found in the kelp forests that extend along the Pacific Rim from Japan all the way down to Chile (Erlandson et al. 2007; Erlandson et al. 2015). The “Kelp Highway Hypothesis” suggests that ancient Americans may have arrived and dispersed far earlier by sea rather than by land. By fishing, hunting, and sheltering among the kelp forests, the first peoples may have followed kelp like a road map to find new land and resources. The close relationship between kelp-based coastal ecosystems and Pacific Northwest indigenous cultural systems is conveyed by the Coast Salish through stories of a girl who married a man of the sea. In the Samish version of the story (Figure B-2), Ko-kwahl-alwoot’s marriage ensures that her people have access to the sea’s bounty. Her own gradual transformation into a sea-being prevents Ko-kwahl-alwoot from visiting her family, but when the Samish see her hair — blades of bull kelp — moving with the tides near Rosario Beach, they know she still provides for them (Rector and Karsen 2015; Samish Indian Nation Elders, pers. comm., June 5, 2017). The maiden in the Chimakum/Klallam/Skokomish version of the story is Kaka’ntu’ or KᴇkanᴇTu, and her hair forms the kelp beds near Port Townsend and Port Crescent, Washington (Gunther 1925; Elmendorf 1961).

Figure B-2. The story of Ko-kwahl-alwoot, the Maiden of Deception Pass, is commemorated in a story pole carved by Tracy Powell on behalf of the Samish people. Powell's rendering clearly depicts the large bulbs characteristic of bull kelp (*Nereocystis luetkeana*). The story pole was raised near Rosario Beach at Deception Pass State Park in 1983. Photo by Cameron Lothrop Johnson.

B.2.3 The Role of Kelp in Traditional Ecological Knowledge

Traditional ecological knowledge (TEK) is knowledge about living organisms and their interactions with each other and their environment gained through generations of experience, adaptation, and cultural transmission (Berkes 1999). We know based on European explorer travelogues, early ethnography, myths, and contemporary subsistence activities that kelp was and continues to be an important part of Pacific Northwest indigenous TEK.[1] Declining kelp beds are, therefore, a sign of ecological disruption as well as an impending cultural loss since the two are so intricately intertwined in indigenous lifeways.

Much of kelp-related TEK highlights its role as a foundational habitat-forming species while also revealing sophisticated traditional ethological knowledge. Nuu-chah-nulth hunters knew that sea otters often rested on kelp beds and that females left their pups floating atop kelp beds while they foraged (Drucker 1965). Kwakwaka’wakw hunters tried to keep harpooned seals from swimming into patches of kelp, where they had a better chance of breaking the kelp harpoon line or dislodging the harpoon point (Boas and Hunt 1921). One Samish elder described how her family would search for crabs in kelp beds during low tide, when the crabs would hide underneath the kelp to stay cool and moist (Leslie Eastwood, Samish Indian Nation Elder, pers. comm., June 5, 2017). Once it washed ashore, salt-laden kelp attracted browsing deer that could easily be taken by Lummi hunters (Tacoma News Tribune 1972). Links between kelp and the harvesting of important traditional foods are also expressed in Pacific Northwest mythology. In various Tlingit myths, for example, Raven instructs the people to harvest particular species, such as halibut and sea urchins, in or near kelp forests (Swanton 1909).

Finally, persistent kelp forests were also part of the navigational knowledge of coastal groups. For example, names of marine landmarks reference the presence of kelp beds in various Tlingit legends (Swanton 1909). The Makah people sometimes used kelp beds as overnight anchorage when venturing far from home. Nuu-chah-nulth warriors famously did this in 1852 when they intimidated the U.S. Pacific Survey at Cape Flattery (Reid 2015).

B.3 The Role of Kelp in Traditional Subsistence Practices

B.3.1 Reef Net Fishing

Reef net fishing was practiced by the Lummi, Samish, and other Straits Salish groups to harvest salmon. This ingenious method took advantage of the tides and kelp-covered rocky reefs and was one of the few traditional fishing techniques that persisted many years after Euro-American settler colonialism (Lane 1973). The Samish, for example, continued reef net fishing for subsistence until

[1] A brief, but necessary note about sources: Many archival sources, including explorer travelogues and early ethnographies, offer a very colonialist and Eurocentric perspective on Pacific Northwest indigenous cultures. As part of the colonialist “exploration” and salvage ethnography eras, these descriptions and depictions often simultaneously reinforced Euro-American notions of “primitive Indians” and fueled false narratives about “vanishing” peoples and cultures. I urge readers to keep this important limitation in mind, and to critically evaluate their own assumptions. I also welcome any feedback from Tribal and First Nations communities on the accuracy and appropriateness of the information from these sources.

around 1875 and resumed the practice in the 1890s to sell salmon to local canneries (Lane 1975). Reef net fishing has persisted up to the present, and the practice has been observed as recently as 2014 near Shaw Island, and 2018 near Lummi Island (Thom Mumford, pers. comm., September 29, 2019).

Reef net fishing requires two canoes and six to twelve crewmen (Figure B-3). Preferably, reef nets are placed above natural kelp-covered reefs. In their absence, lead lines covered in strands of eelgrass can be added to the reef net anchor lines to mimic the appearance of kelp (Easton 1990). In either case, the large rocks anchoring reef nets often provide substrate for the formation of future kelp-covered rocky reefs. Nets are placed perpendicular in the path of migrating salmon during the tidal ebb or flow, where the kelp (real or fake) forces the salmon to rise closer to the surface and into the net. To facilitate this, a channel is cut through the kelp to funnel the salmon toward the reef net. Once the salmon are visible directly above the net, the slack in the anchor line is released to allow the net to be lifted and the canoes to come together, thereby trapping the salmon (Stewart 1977).

Figure B-3. Lummi Native American reef netters (ca. 1930), photographed by Eugene H. Field. Six to twelve fishermen and two canoes were needed for reef net fishing. Source: Item waRN0084, Lummi Island Heritage, Reef Net Fishing Collection, held at Island Library (Whatcom County Library System) and published by the Washington State Library.

B.3.2 Herring Spawn on Kelp

Many groups, including the Nuxalk, Haida, Heiltsuk, Nuu-chah-nulth, Tsimshian, and Kwakwa̲ka̲’wakw, also used kelp to harvest herring roe. Pacific herring deposit their eggs on seaweeds and seagrasses during spawning, and some groups augmented this process by setting up stalks of giant kelp (*Macrocystis pyrifera*) or cedar boughs in spawning areas near river mouths. After spawning, the kelp was gathered by boat and then left to dry in the sun (Stewart 1977). When prepared, the kelp pieces were soaked overnight then broken into small pieces and eaten with eulachon oil (Turner 1995; Turner 2001). Pacific herring roe remains an important traditional food for Salish Sea First Nations, and they continue harvesting herring spawn using kelp (Pawsey 2015).

However, according to Chris Morganroth III of the Quileute Tribe, increased sedimentation from logging has led to the loss of giant kelp beds where Pacific herring spawned on the Olympic Coast (Wunsch and Lepofsky 2014-2015). To maintain the traditional herring roe on kelp fishery despite declining kelp beds, in the 1990s the Makah Tribe harvested large quantities of *Macrocystis* and transported it by truck to the Lummi Reservation (Tom Mumford, pers. comm., September 29, 2019). For more information about the ecological and cultural importance of Pacific herring, including interviews with elders and videos of the spawn on kelp harvest, visit the Herring School's website: www.pacificherring.org.

B.3.3 Traditional Subsistence Technology

"Without doubt, the most valued marine plant material in traditional Northwest Coast technology is bull kelp" (Turner 2001). In particular, bull kelp figured prominently in traditional fishing and hunting technology. The Coast Salish made halibut and cod bentwood fishing hooks by placing fir and hemlock knots inside of bull kelp bulbs (Turner and Bell 1971). Branches were cut to size and shaved to the right thickness and shape before being placed inside of a kelp stipe. The stipe was then filled with water, plugged up at the end. The kelp stipes and bulbs were buried in hot ashes and left to steam overnight. By morning, the wood was supple and flexible and could be bent into shape or placed into wooden molds and left to harden and cool (Stewart 1977; Turner 2001; Turner 2005). A similar method was used to soften the ends of hardwoods and bend them into bows (Turner 1979; Turner 2001; Turner 2005a), and to straighten harpoon shafts (Waterman 1920). The Makah and Quileute tribes also steamed cedar bark in bull kelp stipes to soften it before making rope and baskets (Kirk 2015).

Bull kelp was also frequently used by the Quileute, Quinault, Makah, and other tribes to create fishing, anchor, and harpoon lines (Waterman 1920; Turner and Bell 1971; Gunther 1973). To make these lines, the stipe was tightly twisted and cured by alternatingly soaking it in freshwater and oil. The resulting line was brittle when dry, but strong and flexible once wet (Stewart 1977; Turner 2001; Turner 2005a).

B.3.4 Household Uses of Kelp

The technological uses of bull kelp also extended into many aspects of household daily life. Kelp bulbs and stipes facilitated the long-term storage and long-distance trade of eulachon, seal, dogfish, and whale oils (Boas and Hunt 1921; Turner 2001), and later molasses and spirits (Wood 1882; Gunther 1973). Bulbs were cut to make a convenient funnel, and liquids were poured into stipes and coiled up for storage in bentwood boxes (Stewart 1977). The Nuu-chah-nulth used bull kelp bulbs to store deer suet and healing skin salves. The liquid fat would harden inside the bulb, which could be pulled off after the fat solidified (Turner 2001).

In other household contexts, bull kelp also served as a garden hose, refrigerator, steamer, fuel, and even fertilizer. The Nuxalk often used the stipes as water conduits, and their modern word for hose literally means kelp (Turner 2001). Harvested fish were kept fresh and cool in canoes and on land with a protective layer of kelp (Turner 1979). To prepare fish and other foods, steam pits were lined with kelp and other seaweeds to add moisture and flavor (Boas and Hunt 1921; Stewart 1977; Turner 1995). And, in the absence of dry wood, dried kelp was used as fuel for the cooking fire

(Elmendorf 1961). Post-European contact, dried kelp and other seaweeds served as fertilizer for potato and vegetable gardens (Turner 2001).

Finally, kelp and other seaweeds had medicinal importance. They were often traded inland to treat iodine deficiency and goiter, and included in medicinal steam baths (Turner 1995). The Saanich also shaved off pieces of bull kelp holdfasts to make a medicinal tea that helped with internal ailments (Turner and Hebda 2012).

B.3.5 Playful Uses of Kelp

In addition to its prominent role in hunting and household technology, bull kelp was also put to more playful uses. “Children up and down the [Pacific Northwest] coast played many different games with seaweeds” (Turner 2001). Bulbs from various species of kelp were deployed as squirt guns, targets for spear throwing, and poppers when stomped on or thrown in the fire (Turner 1979; Turner 2001). Coast Salish and Kwakwa̱ka̱’wakw children fashioned toy blowguns and ammunition out of kelp (Turner 1979), while Nuu-Chah-Nulth children played a hockey-like game on the beach with sticks made from kelp stipes and a puck made out of holdfasts (Turner 2001). Makah children cut up kelp to make miniature wagons and wagon wheels and frequently dragged the stems along the beach. They would also use kelp stipes to pretend they were harpooning whales (Gunther 1973).

Playing with kelp is not just for children. During a recent cultural event, the Samish made toy rattles (not to be confused with sacred ceremonial rattles) out of dried bull kelp bulbs filled with pebbles (Leslie Eastwood, Samish Indian Nation Elder, pers. comm., June 5, 2017). Early ethnographers also described a Haida Nation throwing game played with kelp stalks (Turner 2005b). Bull kelp stalks were cut into foot-long pieces and placed upright in the ground about 20 feet apart, and two teams of two players positioned themselves on opposite sides. Using sharpened salmonberry sticks as spears, players took turns trying to hit and split open the opposing team’s kelp stalks. If any player hit the smallest kelp stalk, his/her team won the game immediately.

B.4 Symbolic Uses of Kelp

B.4.1 Status and Ceremony

Among many Pacific Northwest Tribes, various types of body modification — including pierced lips for labrets, facial tattoos, and cranial modification — were linked to regional systems of acknowledged status and marriageability (Suttles 1990). Cranial modification, in particular, was used to distinguish high-status individuals (Turner 2001), and, given its visibility in the archaeological record, we know the practice began at least 2,500 years ago (Cybulski 1990). If done incorrectly, a cranial modification could result in death, so this was indeed a reliable signal of the status and cultural knowledge of a child’s parents and relatives.

Kelp was specifically used by the Koskimo (Gusgimukw) — a Kwak’wala-speaking Tribe from Quatsino Sound on northwestern Vancouver Island — to bind the heads of infants and achieve the desired shape (Boas and Hunt 1921; Turner 2001). Kelp blades saturated with perch oil were wrapped around the infant’s head just above the ears and replaced at periodic intervals for a specific number of months. Different Tribes varied the replacement interval or the overall length of binding, resulting in observable differences in head shape (Boas and Hunt 1921).

Kelp was also used in ingenious ways during dramas performed at winter ceremonials and potlatches to create various special effects (Boas 1916; Turner 1979; Turner 2001). The Tsimshian and Kwakwa̱ka̱'wakw created sound effects, such as the illusion of voices or snoring, by having people speak through kelp stipes hidden under the stage. Other uses included using kelp as hoses to pump smoke onto the stage or to pump in water to put out fires quickly. Kelp and other seaweeds were also used in steam baths for spiritual purposes (Turner 1979).

B.4.2 Mythical Marriages Made in Kelp

In various Pacific Northwest myths and stories, kelp plays a prominent role in marriages linking land and sea. As mentioned above, multiple Coast Salish groups tell a common story about a girl who marries a man of the sea and ensures that her people have access to the sea's bountiful resources (Gunther 1925; Elmendorf 1961; Rector & Karsen 2015). Some versions of the story emphasize reciprocal ties of kinship and interdependence between indigenous people and the ocean. In the Samish telling of the story, the maiden's gradual transformation into a sea-being prevents her from visiting her people, but her hair — blades of bull kelp moving with the tides (Figure 2) — reminds the Samish of her presence and protection (Rector & Karsen 2015; Samish Indian Nation Elders, pers. comm., June 5, 2017).

However, in one Klallam version, the maiden becomes a fearful kelp-haired being who drowns people (Gunther 1925), highlighting one of the potential dangers of the Coast Salish reliance on the sea for subsistence. Similarly, the Kwakwa̱ka̱'wakw Mink Legend conveys some of the fundamental incompatibilities between land and sea through an ill-suited marriage between Mink and Kelp (Boas 2002 [1895]). Mink tries various times (unsuccessfully) to marry. On his second attempt, he marries long-haired Kelp despite his mother's warnings that she will submerge with the high tides. He tries to overcome this obstacle by plugging his nose and holding his breath when the tide comes in. He tells his new wife to let him go if he runs out of breath and pinches her. But when the tide comes in, Kelp ignores his increasingly desperate pinches and holds on to him until he drowns. Instead of the old "ball and chain," we might say that Mink was held down by the old "bulb and stipe."

B.4.3 Tangled Up in Murderous Mythical Kelp

The supernatural realm of the indigenous Pacific Northwest is inhabited by a wide array of powerful beings, both benevolent and nefarious. Within this mythos are multiple examples of murderous kelp. KEkanEtu, the Klallam maiden who married a sea-being, eventually transformed into a kelp-covered creature who drowns passersby (Gunther 1925). According to Quileute Tribal legend, high tides are caused by Duskiya (Dask'iya), a kelp-haired supernatural being who snatches away children (Powell 1990). In the Tlingit Raven myth, after they kill their evil father, the sons of ŁAkîtcîne' pursue and vanquish other monsters, including a deadly patch of kelp. This kelp bed, called Kelps-washed-up-against-one-another-by-the-waves (WūcxkAdutī't-gīc), would close in on and drown all who tried to pass. However, the brothers managed to dart through and then kill the kelp. They piled the dead kelp in one place, and it became a kelp-covered rock that is still visible today (Swanton 1909).

B.5 Conclusion

In conclusion, the close relationship between kelp-based coastal ecosystems and Pacific Northwest indigenous cultural systems links not only ecology and culture, but also joins land and sea and the human and supernatural. This connection highlights the role of kelp as both ecological and cultural foundation species, such that the loss of kelp species and habitats leads to the simultaneous loss of essential ecosystem function and important cultural knowledge (Garibaldi and Turner 2004). Although many of the stressors associated with kelp decline are associated with recent human impacts, the evidence presented here 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 our Tribal co-managers are essential contributions to the recovery and conservation of kelp within Puget Sound.

B.6 References

Assu, S. Ligwilda'x̱w of the Kwakwa̱ka̱'wakw Nations. Interdisciplinary Artist. 2006. Breakfast Series, available at: https://www.sonnyassus.com/gallery/breakfast-series. Website accessed July 1, 2017.

Berkes, F. 1999. Sacred Ecology: Traditional ecological knowledge and resource management. Taylor and Francis, Philadelphia, PA. 236 pages.

Boas, F. 2002 [1895]. The Mink legend of the Kwakiutl. Pages 354 to 355 *in* Bouchard, R. and D. Kennedy, editors. Bertz, D., translator. 2002 [1895]. Indian myths and legends from the North Pacific Coast of America: A translation of Franz Boas'1895 edition of Indianische Sagen von der Nord-Pacifischen Küste Amerikas. Talon Books, Vancouver, BC.

Boas, F. 1916. Tsimshian Mythology. Thirty-first annual report. Smithsonian Institution Bureau of American Ethnology, Government Printing Office, Washington, DC.

Boas, F. and G. Hunt. 1921. Ethnology of the Kwakiutl, based on data collected by George Hunt. Thirty-Fifth Annual Report. Smithsonian Institution Bureau of American Ethnology Government Printing Office, Washington, DC.

Cybulski, J. S. 1990. Human Biology. Pages 52 to 59 *in* Suttles, W., editor. 1990. Handbook of North American Indians. Volume 7, Northwest Coast. Smithsonian Institution, Washington, DC.

Drucker, P. 1965. Cultures of the North Pacific Coast. Chandler Publishing Company, San Francisco, CA. 243 pages.

Easton, N. A. 1990. The archaeology of Straits Salish reef netting: past and future research strategies. Northwest Anthropological Research Notes. Volume 24(2), pages 161 to 177.

Eastwood, Leslie, Bill Bailey, and Jackie Ferry. Samish Indian Nation elders. Samish Indian national conference room, Anacortes, WA. June 5, 2017. Personal communication during a meeting with Nicole Naar regarding traditional uses of kelp.

Elmendorf, W. W. 1961. Skokomish and other Coast Salish tales, Part II. Research Studies. Volume 2(24), pages 84 to 117.

Elmendorf, W. W. 1961. Skokomish and other Coast Salish tales, Part III. Research Studies. Volume 24(3), pages 119 to 150.

Erlandson, J. M., T. J. Braje, K. M. Gill, and M. H. Graham. 2015. Ecology of the kelp highway: did marine resources facilitate human dispersal from northeast Asia to the Americas? Journal of Island and Coastal Archaeology. Volume 4894(November), pages 1 to 20.

Erlandson, J. M., M. H. Graham, B. J. Bourque, D. Corbett, J. A. Estes, and R. S. Steneck. 2007. The kelp highway hypothesis: Marine ecology, the coastal migration theory, and the peopling of the Americas. Journal of Island and Coastal Archaeology. Volume 2(2), pages 161 to 174.

Garibaldi, A. and N. J. Turner. 2004. Cultural keystone species: implications for ecological conservation and restoration. Ecology and Society. Volume 9(3), pages 1 to 18.

Gunther, E. 1925. Klallam folk tales. University of Washington Publications in Anthropology. Volume 1(4), pages 113 to 170.

Gunther, E. 1973. Ethnobotany of Western Washington: The knowledge and use of indigenous plants by Native Americans. University of Washington Press, Seattle, WA. 74 pages.

Johnson, S.P. and D. E. Schindler. 2009. Trophic ecology of Pacific salmon (*Oncorhynchus spp*.) in the ocean: a synthesis of stable isotope research. Ecological Research. Volume 24(4), pages 855 to 863.

Kirk, R. 2015. Ozette: Excavating a Makah whaling village. University of Washington Press, Seattle, WA. 120 pages.

Klinger, T. 2015. The role of seaweeds in the modern ocean. Perspectives in Phycology. Volume 2(1), pages 31 to 39.

Lane, B. 1973. Anthropological report on the identity, treaty status and fisheries of the Lummi Tribe of Indians. Archival material accessed from the Northwest Ethnohistory Collection, Center for Pacific Northwest Studies, Western Washington University, Bellingham, WA.

Lane, B. 1975. Identity, treaty status and fisheries of the Samish Indian Tribe. Archival material accessed from the Northwest Ethnohistory Collection, Center for Pacific Northwest Studies, Western Washington University, Bellingham, WA.

Mumford, Tom. Natural resource scientist (retired), Washington Department of Natural Resources, Olympia, WA. September 29, 2019. Personal communication with Nicole Naar regarding traditional uses of kelp.

Pawsey, T. 2015. Herring spawn on kelp. Montecristo Magazine. August 24, 2015. Retrieved from http://montecristomagazine.com/magazine/summer-2015/herring-spawn-on-kelp.

Powell, J. V. 1990. Quileute. Pages 431 to 437 *in* Suttles, W., editor. 1990. Handbook of North American Indians. Volume 7, Northwest Coast. Smithsonian Institution, Washington, DC.

Pringle, H. 2017. In the land of lost gardens. Hakai Magazine. June 6, 2017. Retrieved from http://wws.hakaimagazine.com/features/land-lost-gardens/

Rector, T. and L. Karsen, directors. 2015. The maiden of Deception Pass: Guardian of her Samish People [video recording]. Longhouse Media, Seattle, WA.

Reid, J. L. 2015. The sea is my country: The maritime world of the Makahs. Yale University Press, New Haven, CT. 416 pages.

Stewart, H. 1977. Indian fishing: Early methods on the Northwest Coast. University of Washington Press, Seattle, WA. 188 pages.

Suttles, W. 1990. Introduction. Pages 1 to 15 *in* Suttles, W., editor. 1990. Handbook of North American Indians. Volume 7, Northwest Coast. Smithsonian Institution, Washington, DC.

Swanton, J. R. 1909. Tlingit myths and texts. Bulletin 39. Smithsonian Institution Bureau of American Ethnology. Government Printing Office, Washington, DC. 451 pages.

Szpak, P., T. J. Orchard, A. K. Salomon, and D. R. Gröcke. 2013. Regional ecological variability and impact of the maritime fur trade on nearshore ecosystems in southern Haida Gwaii (British Columbia, Canada): evidence from stable isotope analysis of rockfish (Sebastes spp.) bone collagen. Archaeological and Anthropological Sciences. Volume 5(2), pages 159 to 182.

Tacoma News Tribune. 1972. "Listen to the elders," Indian tells students. Tacoma News Tribune. January 12, 1972. 1 page.

Turner, N. C. and M. A. M. Bell. 1971. The ethnobotany of the Coast Salish Indians of Vancouver Island. Economic Botany. Volume 25(1), pages 63 to 104.

Turner, N. J. 1979. Plants in British Columbia Indian technology. Royal British Columbia Museum, Victoria, BC. 304 pages.

Turner, N. J. 1995. Food plants of Coastal First Peoples. 2nd Edition. University of British Columbia Press, Vancouver, BC. 180 pages.

Turner, N. J. 2001. Coastal peoples and marine plants on the northwest coast. Pages 69 to 76 *in* Proceedings of the 26th Annual Conference of the International Association of Aquatic and Marine Science Libraries and Information Centers; September 30 to October 5, 2000, Victoria, BC.

Turner, N. J. 2005a. The earth's blanket: Traditional teachings for sustainable living. University of Washington Press, Seattle, WA. 306 pages.

Turner, N. J. 2005b. Plants of Haida Gwaii. Sono Nis Press, Winlaw, BC. 264 pages.

Turner, N. J. and R. J. Hebda. (2012). Saanich ethnobotany: Culturally important plants of the Wsánec People. Royal British Columbia Museum, Victoria, BC. 192 pages.

von Biela, V. R., S.D. Newsome, J. L. Bodkin, G. H. Kruse, and C. E. Zimmerman. 2016. Widespread kelp-derived carbon in pelagic and benthic nearshore fishes suggested by stable isotope analysis. Estuarine, Coastal and Shelf Science. Volume 181, pages 364 to 374.

Waterman, T. T. 1920. The whaling equipment of the Makah Indians. University of Washington Press, Seattle, WA. 67 pages.

Wood, C. E. S. 1882. Among the Thlinkits in Alaska. The Century Magazine. Volume 24(3), pages 323 to 339.

Wunsch, M. and D. Lepofsky. 2014-2015. Pacific herring: Past, present and future. Retrieve from: http://www.pacificherring.org/home. Interview with Chris Morganroth III, available at: https://vimeo.com/117964214. Website accessed September 26, 2017.