PUGET SOUND KELP FORESTS:

A REVIEW OF NATURAL HISTORY AND POTENTIAL IMPACTS FROM SMALL OVERWATER STRUCTURES (SOWS)

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Cover Photo: A school of rockfish gather in a floating *Nereocystis* forest **(**Clark Anderson/Aquaimages, Wikimedia Commons)

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EXECUTIVE SUMMARY

- Kelp refers to any macroalgae species in the order Phaeophyta and family Laminariales.
- All kelp species share similar environmental requirements and thresholds. Individual populations and life stages – rather than individual species - are the most important considerations for understanding environmental impacts to kelp.
- There is concern over the potential impacts of small overwater structures (SOWS), like residential docks, on kelp species and habitats in Washington state waters.
- Available information and expert opinion identify multiple potential positive and negative SOWS-related impacts to Washington kelp species.
- Kelp productivity is influenced by multiple factors including, but not limited to light, temperature, and nutrient availability, making it difficult to pinpoint specific environmental causes for the persistence, expansion, or decline of kelp populations.
- The following, non-exhaustive list summarizes the potential effects of SOWS on kelp species based on the available literature and expert opinion:
    - **Shading:** <u>Unknown</u>. Potential negative impact to kelp if light levels are reduced to below required thresholds for persistence.
        - *Only one study in WA waters suggested a negative correlation between shading from SOWS and non-floating kelp abundance but was also confounded by other potential non-shading disturbances.* Requires more study.
    - **Physical disturbance:** <u>Unknown</u>. Potentially temporary negative impact from SOWS construction and installation activities.
        - *No available information in our region.*
    - **Additional hard substrates:** <u>Unknown</u>. Potentially positive over the long term by providing additional substrate for all Washington kelp species. SOWS-attached kelp, like natural populations, may provide additional fish habitat.
        - *There are no formal data on kelp attached to SOWS, interactions with natural populations, or its use by native fish species. However, anecdotal reports from experts and survey respondents document kelp attached to SOWS artificial structures.*

  - **Changes to water motion, adjacent benthic substrates, and nearshore sediment processes:** Unknown and likely site-specific. Will vary based on regional SOWS density, tides, currents, shoreline geomorphology, and other physical oceanographic processes.
    - *No available information in our region.*
- Significant data gaps surrounding impacts and interactions of SOWS to and with nearshore physical and biological processes and the impacts of common human-associated stressors to Washington kelp resources hinder ongoing efforts at protection and recovery.
- There is no understanding of the cumulative, long-term impacts of SOWS and human activities associated with residential SOWS. Complicating this understanding are potential interactions with additional environmental variables such as ambient water clarity and nutrient availability that may compound or alleviate SOWS-related impacts.

INTRODUCTION

Kelp forests create high volumes of habitat in temperate, nearshore waters across the world (Steneck et al. 2013; Wernberg et al. 2019). Over the last two decades, kelp forests have been under increasing stress from human activity and increased temperatures due to anthropogenic climate change, with largescale losses documented in western and southern Australia, northern California, Puget Sound, north-eastern US, and northern Europe (Steneck et al. 2013; Wernberg et al. 2016; Christie et al. 2019; Rogers-Bennett and Catton 2019; Wernberg et al. 2019; Berry et al. 2020). Anecdotal accounts of floating kelp forest losses, in combination with designation as critical habitat for federally listed Puget Sound endangered rockfish species jumpstarted Washington kelp conservation and recovery planning in 2017. Published in 2020, the Puget Sound Kelp Conservation and Recovery Plan (Kelp Plan) outlines six strategic goals and supporting action items and identifies specific management and policy tools for potential use in advancing Puget Sound kelp conservation and recovery efforts (Calloway et al. 2020a). One such existing tool mentioned explicitly in the Kelp Plan is the Washington Department of Fish and Wildlife (WDFW) Hydraulic Project Approval (HPA) process.

Through the HPA process applications for proposed hydraulic projects in state-managed waters are reviewed, conditioned, and issued to ensure that construction or performance of work as part of the project is done in a manner that protects fish life, including their habitats [(77.55 Revised Code of Washington (RCW)]. WDFW reviews permit applications on an individual basis and approves and provisions the HPA to address site and project-specific impacts [Washington Administrative Code (WAC) 220-660-020]. Construction work authorized by the HPA must achieve no net loss through a sequence of mitigation actions to avoid, minimize, and compensate for impacts. Habitat biologists evaluate the impact caused by a hydraulic project by comparing the condition of the habitat before project construction or the performance of work to the anticipated condition of the habitat after project completion based on available information. The technical provisions of the HPA include mitigation measures used to protect fish life (WAC 220-660-090) which must relate to the project, cannot maximize conditions for habitat, and must be proportional to the impact of the project (WAC 220-660-070). Habitats of submerged aquatic vegetation (SAV) in Washington waters include both seagrass (most often *Zostera marina* or eelgrass), and macroalgae (including all kelp species) dominated areas. WDFW lists kelp species as both a saltwater habitat of special concern and a priority habitat (under the umbrella of macroalgae) (WAC 220-660-320; WDFW 2008). The presence of saltwater habitats of special concern or adjacent areas with similar characteristics may restrict project type, design, location, and timing of construction work. WDFW does not have the authority to regulate the ongoing use of SOWS.

A survey of WDFW staff and local consultants involved in the HPA process (see below) demonstrated high variation among these groups in their familiarity and certainty around kelp biology and potential impacts from SOWS. The purpose of this document is to review the current state of biological and ecological knowledge of Washington kelps and their observed and potential responses to stressors associated with residential SOWS in marine environments. Impacts to kelp species and habitats are limited to discussion of stressors associated with the permitting and construction of new SOWS with special consideration to impacts from structural shading. Data gaps specific to our region are discussed to identify important priority topics for future study and monitoring.

The goals of this document align with three priority actions under the Kelp Plan strategic goal to "Understand and Reduce Stressors" (Calloway et al. 2020). Specifically:

> **1.4.2.** Develop tools to support planners' ability to review and 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.
>
> **1.5.1.** Improve kelp-specific mitigation guidance and implementation

Finally, this document expands on Lambert et al. (2021) which reviewed the general ecological impacts of SOWS to nearshore marine habitats used by juvenile and adult salmonids. Most of the research in Washington to date has focused on shade-related impacts of large overwater structures (LOWS) such as ferry terminals to eelgrass beds and juvenile salmonid behavior (Simenstad, Thom and Olson 1997; Toft et al. 2007). Some insights from LOWS studies help inform potential shading impacts on kelp, but only one study (Szypulski 2018) investigates the impacts of SOWS-related shade on kelp in Washington waters.

METHODS

Literature Review

This review builds on reviews conducted by Calloway et al. (2020b), Lambert et al. (2021), and Hollarsmith et al. (2022) in identifying kelp stress thresholds and effects, and regional data gaps through exhaustive and systematic searches of scientific literature databases. Environmental thresholds reported by Bartsch et al. (2008) are used as accepted generalizations for all species currently and formerly a part of the genus *Laminaria* (*Laminaria sensu lato*). For all other Washington kelp species, this review relies on region-specific data when considering the potential impacts of SOWS-related stressors, with general examples of the plasticity and resiliency of kelp species from the available global literature.

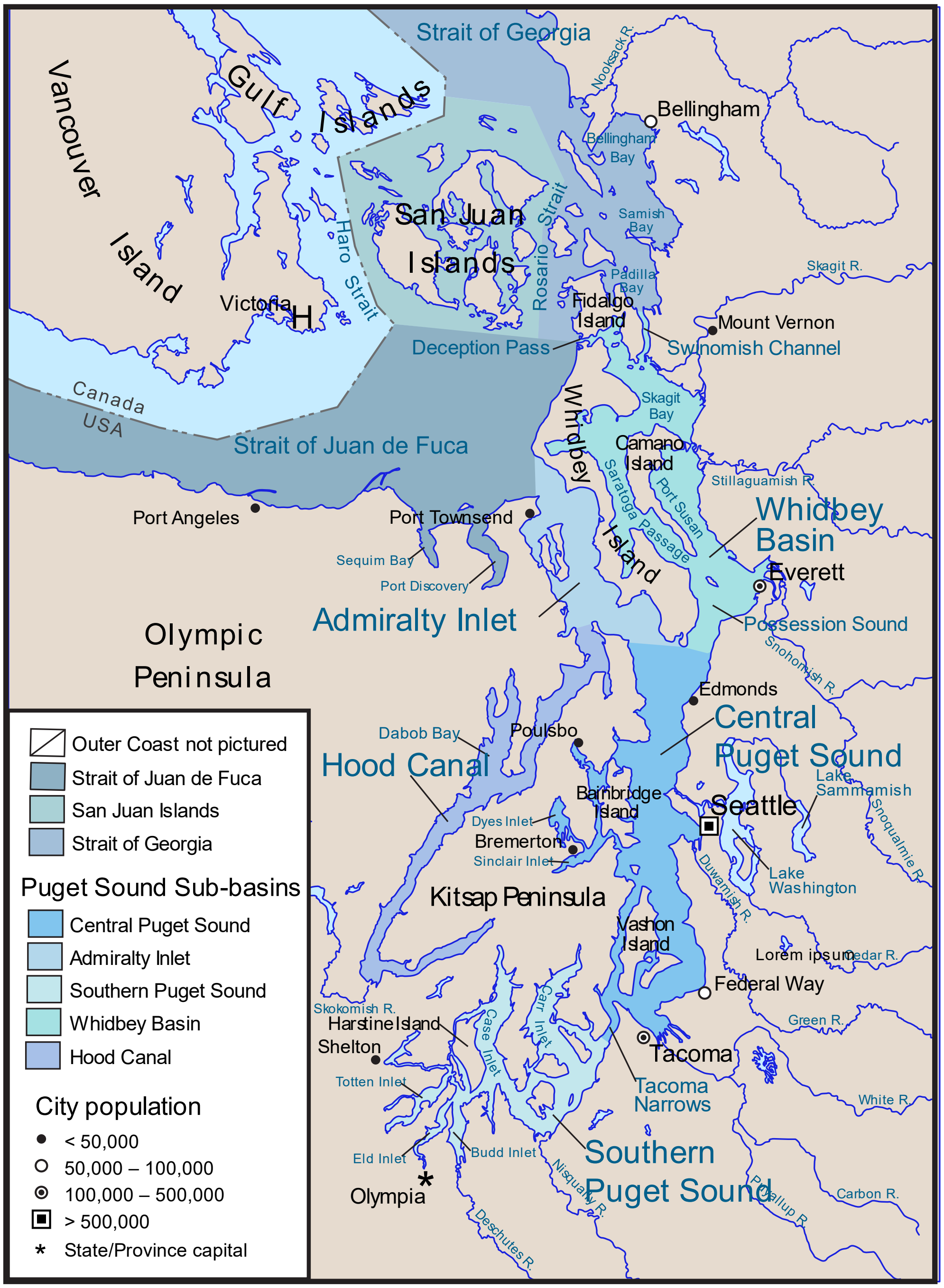
Geographic boundaries

For this document, Washington waters are divided into six main basins with Puget Sound further subdivided into five subbasins (Figure 1). The geographic areas are as follows:

- Outer coast (Coast)
- Strait of Juan de Fuca (Strait)
- San Juan Islands (SJI), southern Strait of Georgia (SoG)
- Puget Sound
    - Hood Canal
    - Admiralty Inlet
    - Whidbey Basin
    - Central Puget Sound (CPS)
    - Southern Puget Sound (SPS)

This document also references Salish Sea, which includes all Washington and Canadian waters in the Strait, SJI, SoG, and Puget Sound. The Salish Sea does not include Washington or Canadian waters outside of the Strait.

Figure 1. Map of Washington state waters showing the six geographic areas used in this document.



WDFW staff, county planner, and consultant survey

A 10-question survey was sent to a group of 11 potential respondents that included WDFW staff, county planners, and consultants involved directly or indirectly with HPA-related activities. Nine of the 11 contacted responded to the survey and included six WDFW staff (including three regional habitat biologists), two consultants [Jen-Jay, Inc. and Marine Surveys & Assessments (MSA)], and one county planner (Pierce County). Four of the nine respondents reported working in all geographic regions and five in Puget Sound (two CPS, one SPS, one Whidbey Basin, and one in CPS, Hood Canal, and the Strait). The outer coast was not included as a choice in the geographic region portion of the survey. The survey questions aimed to understand the degree of knowledge of non-floating kelp species distributions and assess potential impacts and associated degrees of certainty or uncertainty of SOWS-related stress effects to Washington kelp forests. See *Appendix B: WDFW staff, county planner, and consultant survey results* for a summary of responses.

Regional expert interviews

To supplement the survey, a short questionnaire of nine questions was sent to seven regional kelp experts and three forage fish experts. Four kelp experts responded to the email questionnaire and follow-up phone interviews were scheduled with three. Two of the three forage fish experts responded to the email questionnaire only and no follow-up interviews were scheduled. See *Appendix C: Summary of regional kelp expert questionnaire / follow-up interview response*s for individual responses from experts.

WASHINGTON KELP NATURAL HISTORY REVIEW

Regional kelp forests

Kelp species in Washington waters provide essential ecosystem services as foundation species and ecosystem engineers whose high productivity supports diverse marine food webs, both inside of kelp forests and in adjacent habitats (Steneck et al. 2002; Wernberg et al. 2020). The overall native seaweed diversity in the Pacific Northwest is some of the highest in the world and includes 22 species of kelp (Gabrielson et al 2012; see Calloway et al. 2020a for a detailed list of all 22 species). Kelp are brown macroalgae (class Phaeophyceae) of the order Laminariales that form critical nearshore habitat for numerous protected and endangered species in Washington waters (Calloway et al. 2020b; Hurd et al. 2014). All kelp species consist of a single or multiple blades (lamina) and a single or multiple stipe (stalk) secured to hard substrates by a holdfast. By relying on common morphological features, kelps can be organized into three broad categories: floating, stalked (stipitate), and prostrate.

Prostrate species generally consist of a single, wide blade and a single short (generally less than approximately 15 cm) stipe. Stalked species consist of single or multiple blades, held above the benthos by a single or multiple rigid, woody stipes. Floating species have multiple blades, attached to single or multiple stipes held afloat by gas-filled buoys (pneumatocysts). Other morphological features, such as holdfast and blade structure, can be used for species identification and, in our area, are most helpful for morphologically similar prostrate species (for species identification see Druehl and Clarkston 2000 and Gabrielson 2012 for a more detailed taxonomic key). Holdfasts are made up of individual, tangled branches (haptera) that resemble typical plant roots, or a single suction cup-like disc and serve only to attach the kelp to an available substrate.

Prostrate (also called non-floating along with stalked species) kelps are by far the most species diverse, abundant, and widely distributed in Washington state waters (Table 1; Table 2). In the expert interviews and survey conducted for this document, all respondents reported encountering one or multiple prostrate species in HPA project areas regardless of geography. Of prostrate species, the most abundant recorded in the literature and reported by experts and survey respondents are kelps of the *Saccharina/Hedophyllum* complex (hereafter *Saccharina* complex), named for sugar kelp *S. latissima,* (formerly *Laminaria saccharina*), a common kelp species found across temperate marine areas throughout the northern hemisphere. In addition to sugar kelp (*S. latissima*), this complex includes *S. complanata,* and *H. nigripes* all of which are genetically similar and difficult, if not impossible, to differentiate in the field (Gabrielson et al. 2012). Other common prostrate species <u>not included</u> in the *Saccharina* complex include *Costaria costata* (five-ribbed or seer-sucker kelp, hereafter *Costaria*), *Alaria marginata* (winged kelp, here after *Alaria*), *Pleurophycus gardneri* (broad-ribbed kelp), *Agarum/Neoagarum* species (sieve kelp), and *Cymathaere triplicata* (three-ribbed kelp).

Only three species of stalked and three species of floating kelps are found in Washington waters. The floating species *Egregia menziesii* (feather-boa kelp, hereafter *Egregia*), which can form dense canopies with *Alaria* along the inshore edges of floating *Nereocystis luetkeana* (bull kelp, hereafter *Nereocystis*) and

Macrocystis pyrifera (giant kelp, hereafter *Macrocystis*) forests (Shaffer 2003). The stalked kelp *Pterygophora californica* (walking kelp or stalked kelp, hereafter *Pterygophora*) can be the dominant canopy species in shallow subtidal areas, and the dominant understory species of floating kelp forests but also occurs in deeper waters in high-energy areas, and is found in association with *Agarum/Neoagarum* species (Matthews 1990; Shaffer 2000; Hilary Hayford, PSRF, personal communication, June 6, 2022; M. Calloway, personal observation, Tacoma Narrows, February 2019; M. Calloway, personal observation, Admiralty Inlet, summer 2019). *Egregia menziesii* along with *Laminaria setchelli* have been seen to co-occur with surf grass along the outer coast and Strait of Juan de Fuca (M. Calloway, personal observation, Olympic National Park, summer 2016-2017). The small, stout, stalked *Postelsia palmiformis* occurs only in extremely wave-exposed areas. Overall, there is very little information regarding prostrate and stalked kelp distributions, trends, faunal associations, and response to environmental stressors stemming from human activity and development in the Salish Sea (see Hollarsmith et al. 2020 for review).

The remaining two floating species, *Macrocystis* and *Nereocystis* form mixed, floating surface canopies along the outer coast and the Strait of Juan de Fuca. Most of our understanding of kelp biology in general and kelp forest ecology comes from research on the large, perennial *Macrocystis* forests along the California coast. Inside Puget Sound, *Nereocystis* is the only floating canopy-forming species and has been the focus of recent conservation and research prioritization since the publishing of the Puget Sound Kelp Conservation and Recovery Plan in 2020. Puget Sound *Nereocystis* forests have sustained documented losses in both south and central Puget Sound (Berry et al. 2021; Berry unpublished).

Table 1. From WA-DNR, nd. Summary of ShoreZone inventory (2000) submerged aquatic vegetation data by county.

County Name	Total Miles	Percent of Shoreline with Aquatic Vegetation			
		Eelgrass	Floating Kelp	Non-floating kelp	Sargassum
Clallum	254	20%	40%	80%	1%
Grays Harbor	187	5%	> 1%	6%	> 1%
Island	214	63%	10%	18%	8%
Jefferson	254	58%	7%	33%	18%
King	123	62%	13%	27%	25%
Kitsap	254	48%	> 1%	21%	21%
Mason	232	28%	> 1%	24%	33%
Pacific	276	22%	> 1%	1%	> 1%
Pierce	239	26%	7%	44%	19%
San Juan	408	41%	31%	63%	47%
Skagit	229	51%	12%	26%	15%
Snohomish	133	22%	1%	1%	3%
Thurston	118	4%	> 1%	24%	4%
Whatcom	147	55%	7%	18%	34%
Total	**3067**	**37%**	**11%**	**31%**	**18%**

Habitats dominated by kelp species are commonly referred to as kelp forests or kelp beds depending on the morphology of the most abundant species. It has been common practice to reserve "kelp forest" only for those habitats with canopies of stalked or floating species, while populations of prostrate species are described as "kelp beds" (Wernberg and Filbee-Dexter 2019). The designation "understory" is common for both stipitate species growing under floating canopies, and for prostrate species in general. These designations do not consider the fact that all kelp creates structure that provides refuge and abundant forage to associated species, shades the benthos, and requires similar environmental conditions (Teagle et al. 2017; Wernberg et al. 2019). This document will refer to all kelp habitats as kelp forests, but provide descriptive distinctions when necessary (e.g., non-floating kelp forest, prostrate kelp forest, kelp forest dominated by *S. latissima,* etc.).

There is no agreed-upon minimum density of kelps for a given population to be considered a forest or a bed. As Wernberg and Filbee-Dexter (2020) point out, "determining exactly when a group of individual seaweeds becomes a marine forest would be akin to asking how many corals it takes to make a coral reef or the number of oysters required to form an oyster bed." Instead, the authors stress that a kelp forest is any collection of kelp species that form a distinct subcanopy environment (floating or otherwise) that provides shelter and forage opportunities for associated species not found in non-vegetated habitats. While there are no concrete kelp density criteria for what makes a kelp forest, limited data from our region can provide some insight into commonly encountered densities in kelp forest habitats.

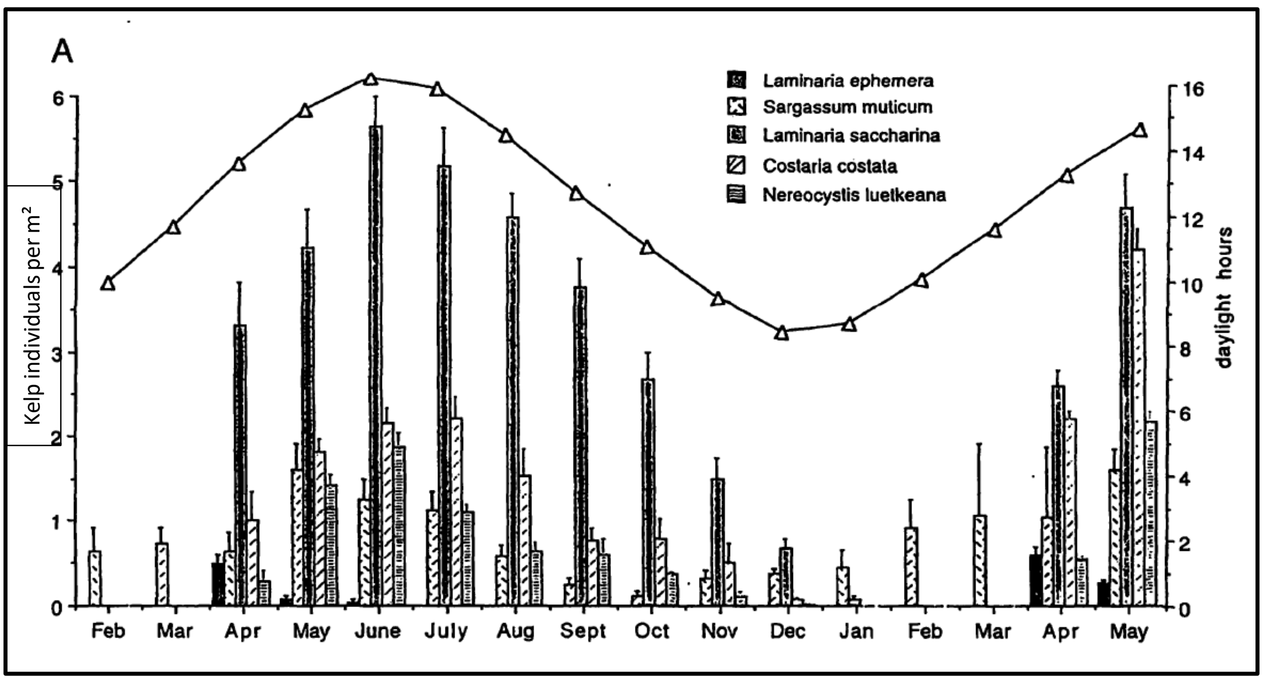
Kelp seasonal patterns: abundance

Kelp abundances can vary seasonally and with geographic location (Table 2). Shaffer (2000) tracked the average seasonal variation of *Nereocystis, Macrocystis,* and *Pterygophora* along the Strait of Juan de Fuca. They observed variation in understory densities based on floating canopy species, geographic location, and season with densities as high as 60 kelp per m² in the summer. In a different study on the Strait of Juan de Fuca, Rubin et al. (n.d.) conducted transect swath surveys of kelp species east and west of the Elwha River mouth in 2008, finding 10 kelp species, with an average kelp density of 3.1 individuals per m² across all sites and taxa? sampled. However, monitoring sites were distributed across several km of coast, spanned multiple substrates, and did not target kelp populations specifically. At Titlow Beach in SPS, Maxell and Miller (1996) tracked individual species densities of *Nereocystis, S. latissima, Costaria,* and *Laminaria ephemera* from February 1993 to May 1994. Kelp (excluding the non-native, non-kelp *S. muticum*) density peaked in June 1996 at approximately 9 kelp individuals per m² and was reduced to 0.5 kelp individuals per m² by December 1996 (Maxell and Miller 1995; Figure 2). *S. latissima* (formerly *L. saccharina*) was by far the most abundant kelp species present, reaching peak densities of approximately 5.5 individuals per m² in June 1996 (Maxell and Miller 1996; Figure 2). *Costaria,* the second most abundant species over the study period, attained densities of close to 2 individuals per m². *Nereocystis* density in May was also close to 2 individuals per m².

Siddon et al. (2008) observed similar seasonal trends but higher densities of prostrate kelps in Alaskan kelp forests where combined densities of the prostrate kelps *C. triplicata, H. nigripes, Costaria,* and *Agarum/Neoagarum* species ranged from almost 18 kelp per m² in the summer to nearly 8 per m² in winter. Juvenile kelps (< 30 cm in this study) accounted for nearly all kelp encountered in the winter, ranging from about 6 to 12 kelp per m². In areas with a floating canopy, *Nereocystis* summer densities of nearly 2 per m² were completely absent during the winter.

Floating kelp densities also vary seasonally and can be lower than those of prostrate kelps. Peak *Nereocystis* densities recorded during SCUBA surveys by Siddon et al. (2008) of 2 individuals per m² in the summer, and Maxell and Miller (1996) of 2 individuals per m² in May were similar to average surface density observations of *Nereocystis* reported by Calloway (2019) from forests in SPS. The average summer (August to September) surface canopy density in the Tacoma Narrows was 1.96 individuals per m² in the Tacoma Narrows, and 2.26 individuals per m² at Day Island, south of Titlow Beach (Calloway 2019). At the southern, innermost *Nereocystis* forest in Puget Sound at Squaxin Island, average summer (May to August) *Nereocystis* densities were only 0.57 individuals per m² (Calloway 2019). This site is unique in that, of *Nereocystis* forests studied in Washington state, it is exposed to the most stressful (warmest) temperature environments yet remains persistent even while other forests in South Puget Sound have been lost (Berry et al. 2021). In July 2022, the Washington Department of Natural Resources (DNR) Nearshore Habitat Program counted fewer than 100 *Nereocystis* individuals and noted an alarming decrease in overall canopy area compared to data from 2021, leading to concern from local experts that it may be the next floating canopy population lost in Puget Sound (Ledbetter 2022).

Figure 2. From Maxell and Miller 1994. Monthly kelp densities at Titlow Beach between February 1993 to May 1994. Left axis and bars represent monthly kelp species densities per m². Right axis, triangles, and lines represent daylight hours.



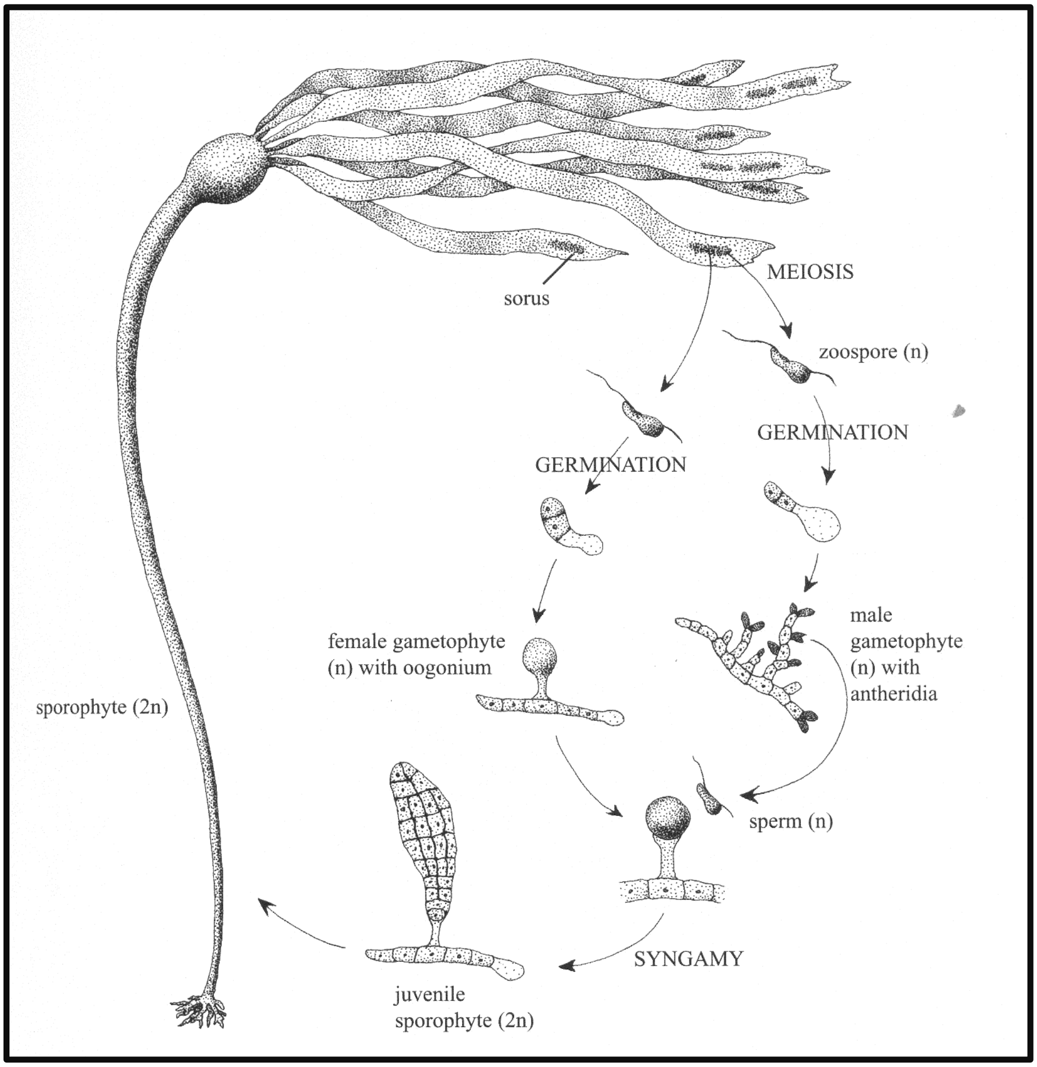
Kelp seasonal patterns: reproduction and persistence

The kelp lifecycle consists of an alternation of adult sporophytes (macroscopic and visible reproductive individuals, hereafter adults), and a series of microscopic forms (Druehl and Clarkston 2016; Figure 3).

Microscopic kelp life stages are difficult to study in the field. Almost all of our understanding of the biology and ecology of these stages is inferred from controlled experiments and observations (Schoenrock et al. 2021). The cultivation of kelp is a well-established practice and timeframes for germination, reproduction, and germling sporophyte growth are based on insights from l kelp aquaculture (Redmond et al. 2014).

Adult kelps produce and release billions of microscopic male and female spores from specialized blade structures (sorus, plural sori) either on the main blades or on specialized blades known as sporophylls (Druehl and Clarkston 2000). The timing of sorus production varies by species. Some species, like *Nereocystis* continuously produce sori once mature (Springer et al. 2010; Mohrig et al. 2013). Other species limit spore production to specific times in the season and are often tied to environmental cues (Reed 1990). For example, sugar kelp in Puget Sound, like populations on the east coast, begin sorus production once water temperatures cool in late autumn (Redmond et al. 2014). Within 24 hours of settling, spores germinate into male and female gametophytes, that mature and sexually reproduce over the course of one to two weeks (Steneck et al. 2002; Redmond et al. 2014; Wernberg et al. 2020). Once fertilized, the microscopic, juvenile sporophytes grow quickly, becoming visible to the naked eye as a fine fuzz after three to four weeks (Redmond et al. 2014; Max Calloway, personal observations).

Figure 3. Diagram of kelp life stages showing the juvenile and adult sporophyte phases and microscopic zoospore and gametophyte phases. 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 seasonality differs depending on species composition and can even differ from population to population of the same species. Perennial species, such as *Pterygophora* and giant kelp persist year-round, while annual species like *Costaria* appear anew each spring and disappear in the winter (Matthews 1990; Druehl and Clarkston 2000; Shaffer 2000). Annual species can sometimes persist longer, and perennial species may follow annual cycles. In Washington, kelp populations inside Puget Sound, and in the Strait of Georgia are largely annual, with perennial species, including those of the *Saccharina* complex, following the annual cycles of *Nereocystis* and *Costaria* (Matthews 1990; Maxell and Miller 1994). In the Strait of Juan de Fuca, *Nereocystis* canopies often persist year-round (Shaffer 2003).

Table 2. WA state kelp species and general information on habitat preference and seasonality.

Form	Species Name	Taxonomic synonyms	Common name	WA State Waters	Puget Sound**	Tidal Zonation[1]	Habitat Details[1]	Seasonality[1]
Floating	*Egregia menziesii*	-	feather boa kelp	Y	Y	Lower intertidal, shallow subtidal	x	x
	Macrocystis pyrifera	*Macrocystis integrifolia*	giant kelp	Y	N	Lower intertidal, shallow subtidal	Moderate wave exposure	Perennial
	Nereocystis luetkeana	-	bull kelp	Y	Y	Subtidal	Wave exposed to sheltered with significant water movement	Annual; some individuals persisting for two years
Stalked (Stipitate)	*Lessoniopsis littoralis*	-	-	Y	N	Lower intertidal	Wave exposed	x
	Postelsia palmaeformis	-	sea palm	Y	N	Upper intertidal	Wave exposed	x
	Pterygophora californica	-	stalked kelp, walking kelp	Y	Y	Subtidal	x	Perennial, persisting up to 25 years
Prostrate	*Agarum clathratum*	*A. cribrosum*	-	Y	Y	x	x	x
	Alaria marginata Postels et	*incl. Alaria nana*	winged kelp	Y	Y	Middle to lower intertidal, subtidal	x	x
	Costaria costata	-	seer sucker / five ribbed kelp	Y	Y	Lower intertidal, shallow upper subtidal	x	x
	Dictyoneurum californicum	-	-	Y	N	Lower intertidal, subtidal	Wave exposed	x
	Dictyoneurum reticulatum	*Dictyoneuropsis reticulatum*	-	Y	N	x	x	x
	Neoagarum fimbriatum	*Agarum fimbriatum*	-	Y	Y	x	x	Perennial
	Pleurophycus gardneri	-	-	Y	Y	Lower intertidal, shallow subtidal	Significant water flow	Perennial
Genus *Laminaria sensu lato*	*Saccharina complanata* ***	*Laminaria complanata*	-	Y	Y	x	x	x
	Saccharina latissima ***	*Laminaria saccharina*	sugar kelp	Y	Y	Lower intertidal, subtidal	Wave sheltered	x
	Hedophyllum nigripes ***	*	-	Y	Y	Lower intertidal, subtidal	x	x
	Hedophyllum sessile	*Saccharina sessilis*	sea cabbage	Y	Y	Middle intertidal	Moderately to fully wave exposed	
	Cymathaere triplicata	*Laminaria triplicata*	-	Y	Y	Lower intertidal, subtidal	x	Annual
	Laminaria ephemer	-	-	Y	Y	Lower intertidal, shallow subtidal	x	Annual
	Laminaria longipes	-	-	Y	Y	Subtidal	Wave exposed	Perennial
	Laminaria setchellii	*Incl. L. dentigera*	-	Y	Y	Lower intertidal, shallow subtidal	Wave exposed	Perennial
	Laminaria sinclairii	-	-	Y	Y	Lower intertidal	Often associated with sand	Perennial
Total				22	17			

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

** As defined in the Puget Sound Kelp Conservation and Recovery Plan (Calloway et al. 2020b), all waters east of the Victoria Sill (Victoria, BC / Sequim, WA) including Puget Sound, eastern Strait of Juan de Fuca, San Juan Islands, and Strait of Georgia.

*** Saccharina/Hedophyllum species. Difficult to impossible to differentiate in the field. Commonly known as "sugar kelp", despite the name being more accurately used to describe only Saccharina species.

Kelp ecosystem services: nearshore foundation species

Kelps are important foundation species, creating some of the most productive ecosystems on the planet, and supporting diverse and productive nearshore food webs (Graham et al. 2004; Altieri and van de Koppel 2014; Krumhansl et al. 2016). Kelp forests serve as important nurseries, refuges, and productive forage grounds for all life stages of associated finfish and invertebrates (Graham 2004; Koenigs et al. 2015; Teagle et al. 2017; Shaffer et al. 2020). Reflecting this, WDFW lists kelp species as both a saltwater habitat of special concern and a priority habitat (under the umbrella of macroalgae) (WAC 220-660-320; WDFW 2008). The incredible productivity of kelp forests is often exported to nearby habitats, with kelp detritus and entire dislodged kelp individuals providing important nutrients to low-productivity environments like sand or cobble beaches, and deep-water marine habitats (Krumhansl and Scheibling 2012). Regardless of species composition, all kelp forests increase nearshore biodiversity and species abundance (Steneck et al. 2002; Graham 2004; Siddon et al. 2008; Teagle et al. 2017; Shaffer et al. 2020).

Kelp forests and eelgrass beds serve similar roles and provide similar benefits to nearshore species, but prostrate kelp forests can provide 25 times more biomass per m^2 than seagrass (Teagle et al. 2017). The total volume of habitat created by a kelp forest is influenced by species makeup, kelp density, substrate availability, and season (Maxell and Miller 1996; Siddon et al. 2008; Shaffer 2000). Kelp forests are not necessarily higher quality habitat than eelgrass or salt marshes, nor is the relationship between these different nearshore habitats antagonistic (Sheaves et al. 2015). Instead, kelp forests are often one piece of larger-scale habitat mosaics made up of patches of kelp forests, eelgrass meadows, and saltmarshes, all of whose seascape connectivity increases nearshore habitat quality and function as critical nurseries (Olson et al. 2019). This is important to consider, as kelp and eelgrass require opposite substrates, with eelgrass requiring soft mud or sand in which to lay roots, and kelps largely relying on hard substrates including artificial structures, bedrock, boulders, gravel, and cobble. Despite these differences in habitat requirements, seven of nine survey respondents, as well as the author, have encountered mixed habitats of kelp and eelgrass.

Kelps are characterized by rapid growth, making kelp forests more productive than rainforests or industrial agriculture fields (Krumhansl et al. 2016). The structure provided by kelp serves as a potentially edible habitat for invertebrates whose densities can be two to five times greater in kelp forests than in seagrass and other (non-kelp) seaweed habitats (Siddon et al. 2008; Christie et al. 2009). Additionally, a single kelp may provide three distinct microhabitats (the holdfast, stipe, and blade) that can each attract unique invertebrate populations (Teagle et al. 2017). In Alaska, increased invertebrate abundances are associated with prostrate kelp, even when occurring below a floating *Nereocystis* canopy (Siddon et al. 2008). Invertebrate communities in kelp forests commonly include copepods, amphipods, and decapod larvae, all of which are important Salish Sea finfish prey, as well as the endangered Pinto Abalone (Penttila 2007; Duffy et al. 2010; Rogers-Bennett et al. 2011; Olson et al. 2019; Shaffer et al. 2020).

The shelter provided by kelp canopies creates foraging refuges, allowing juvenile and smaller (forage, bait, and mid-trophic) fish to focus more energy on foraging and less on avoiding predators, potentially leading to reduced mortality and greater growth rates (Sheaves et al. 2015; O'Brien et al. 2018; Olson et al. 2019). Copper rockfish in SoG initially recruit to floating canopies, with young-of-year (YOY) rockfish eventually settling into deeper and adjacent eelgrass and *Agarum* (prostrate kelp) habitats (Love et al. 1991). Inside eelgrass beds along the coast of Calvert Island, British Columbia, Olsen et al. (2019) found that YOY copper and quillback rock fish inhabiting eelgrass bordering *Nereocystis* canopies had higher body conditions than those inhabiting the core of eelgrass beds or eelgrass bordering unvegetated substrates. Within the Strait and Puget Sound, available information suggests preferential associations of Pacific sand lance, surf smelt, YOY rockfish, and juvenile salmonids with floating kelp forests compared to adjacent open-water habitats and macroalgal habitats without a floating canopy (Doty et al. 1995; Shaffer et al. 2004; Shaffer et al. 2020; Love et al. 1991).

Anecdotal accounts suggest herring do not preferentially seek out kelp forests as spawning habitat in Washington, with only four of nine survey respondents reporting herring spawn on kelp, the same as reported spawn on bare substrate. Instead, herring are thought to return to the same spawning grounds year after year, regardless of changes to SAV populations (Dayv Lowry, NOAA personal communication June 6, 2022). Peak herring spawning activity occurs in February and March, coinciding with low kelp biomass at the beginning of seasonal kelp recruitment (Druehl and Hsiao 1977; Maxell and Miller 1996; Penttila 2007; Allen 2018). However, when kelps are used as herring substrate, their large surface area as compared to other common SAV allows for large abundances of eggs (Dayv Lowry, NOAA personal communication June 6, 2022). Therefore, while kelp is a suitable substrate for herring spawning, factors beyond vegetation type likely drive herring spawning abundance and egg survival.

Kelp provide habitat to juvenile fish, which vary in their associations with canopy or prostrate forming taxa. During visual surveys in Alaskan kelp forests, Siddon et al. (2008) reported six times more juvenile

Gadidae (cod and pollock) in prostrate kelp patches compared to areas with a floating canopy. Juvenile benthic fish (predominantly gunnels (Pholidae), lumpfish (Cyclopteridae), and sea ravens (Hemitripteridae) were twice as abundant in areas with a floating canopy compared to areas with only prostrate species yet were more common in the prostrate subcanopies of floating forests than in their surface canopies. In *S. latissima* kelp forests in the Gulf of Maine, O'Brien et al. (2018) observed that cunner fish preferentially sought refuge in *S. latissima* blades as compared to other available macroalgae, suggesting the possibility that individual fish species may preferentially associate with specific seaweed species. Little is known about the kelp habitat preferences for individual Salish Sea kelp species, except for juvenile and YOY copper, quillback, and bocaccios preference for kelp forests, especially those with a floating *Nereocystis* canopy (Doty et al. 1995; NOAA NMFS 2017).

Adult finfish and other predatory species are also found in higher abundances in and near Salish Sea kelp forests relative to other habitats, having either matured from juvenile populations or been attracted by the abundance of prey (Graham et al. 2004; Olson et al. 2019; Shaffer et al. 2020). In British Columbia, the highest abundances of adult copper rockfish, black rockfish, and kelp greenling occurred inside *Nereocystis* forests as compared to nearby eelgrass beds (Olson et al. 2019). Rockfish are known to preferentially recruit to floating kelp canopies and adjacent prostrate kelp populations suggesting that some portion of the predator population could be lifelong residents (Love et al. 1991; NOAA NMFS 2017). Returning adult salmonids, in contrast, are likely drawn to kelp forests thanks to the abundant prey. Investigations into the diets of adult salmonids in Washington waters found that Chinook and coho salmon continue to rely on nearshore food webs throughout adulthood, while pink and chum salmon rely on open-water prey (Johnson and Schindler 2009). While few formal studies have been conducted on adult salmon use of kelp habitats, kelp forests are regularly targeted by recreational fishing guides and anglers for Chinook in particular (personal communication with Dan Tonnes, NOAA July 17, 2019; WDFW 2020).

The importance of kelp forests for nearshore food webs can be tangibly measured by assessing the contribution of kelp-derived carbon in the biomass of nearshore species using carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes (Frediriksen 2003; Miller and Page 2012; von Biela et al. 2016; Olson et al. 2019; Chittaro 2020). Recent sampling in the Salish Sea by Chittaro (2020) found that kelp-derived carbon is the second most important carbon source for nearshore species after eelgrass-associated epiphytes and Particulate Organic Matter (POM), with eelgrass itself contributing the least. The percent kelp carbon in the biomass of Puget Sound finfish and invertebrates accounted for, on average, 17.3% of salmon and 25.4% of rockfish biomass (Chittaro 2020). When these results were limited to rockfish sampled from kelp-dominated sites, the percent of kelp carbon increased to 38% (Chittaro 2020). An earlier review of kelp-derived carbon in fish populations echoes the findings of Chittaro (2020) consistently reporting values of over 30% for rockfish and herring around Vancouver Island, BC (von Biela et al. 2016). The same review found significant contributions of kelp carbon to demersal fish populations both around Vancouver Island, BC and in other temperate marine environments. Thus, kelp in the Salish Sea represent a critical base of the food chain for culturally- and ecologically important fishes.

Kelp trends and distributions

Kelp forests are dynamic in their persistence, with regional conditions driving local changes (Krumhansl et al. 2016; Pfister et al. 2018). In Washington, documented historic losses (over 50% loss) of floating *Nereocystis* canopies in SPS are contrasted with largely stable floating canopies of *Nereocystis* and *Macrocystis* along the Strait and Coast (Pfister et al. 2018; Berry et al. 2020). The only statewide information on kelp distribution is limited to a single, comprehensive dataset from aerial flight surveys conducted in 2000 (ShoreZone 2001). ShoreZone data can be viewed and downloaded from two web-based GIS databases: the Washington Department of Ecology's (Ecology) Coastal Atlas, and the DNR Nearshore Habitat Program's Coastal Vegetation Atlas.

The DNR Nearshore Habitat Program regularly reports on floating kelp canopy area in the Strait, SJI, and Puget Sound (WA DNR 2022). The newly adopted f*loating canopy kelp area* indicator for the Puget Sound Partnership's (PSP) *Beaches and Marine Vegetation* Vital Sign will provide Sound-wide estimates of floating kelp canopies beginning in May 2023 (Raymond et al. 2022). The indicator is the first of its kind and will use a hybrid data approach, synthesizing data from DNR fixed-wing aerial surveys, DNR kayak-based surface canopy area surveys, Northwest Straits Commission kayak-based surface canopy area surveys, and aerial imagery analysis from the Samish Indian Nation (Raymond et al. 2022). Additionally, the Washington State Legislature recently passed Senate Bill 5619, the Kelp Forest and Eelgrass Meadow Conservation Initiative, in part to increase funding and research opportunities pertaining to kelp and eelgrass stressors, conservation planning, and restoration projects.

Distributions of non-floating kelp species are known from ShoreZone data alone and are likely outdated (Calloway et al. 2020b). In 2022, DNR's Nearshore Habitat Team conducted comprehensive SAV monitoring in the intertidal and shallow subtidal water of Snohomish County using towed underwater video footage and has plans to expand this monitoring in the future (Christiaen et al. 2022). Recently documented declines of multiple intertidal and shallow subtidal kelp species in British Columbia in sheltered waters (as compared to wave-exposed areas) have raised concerns for kelp forests in our region, due to the prevalence of similar wave-sheltered environments, especially in Puget Sound, SJI, and SoG (Starko et al. 2019; Berry et al. 2022).

KELP ENVIRONMENTAL REQUIREMENTS AND POTENTIAL IMPACTS FROM HPA-RELATED ACTIVITIES

The high productivity of kelp forests is directly tied to environmental conditions (Hurd et al. 2014). Habitat availability in the form of free hard substrates on which to recruit is a base requirement for kelp presence (Geange et al. 2014). However, light, temperature, and nutrient availability all influence overall forest productivity, making it difficult to pinpoint specific environmental causes for the persistence, expansion, or decline of kelp populations (Hurd et al. 2014; Berry et al. 2020). Kelp forests are also incredibly dynamic, varying in overall area and density from year to year (Pfister et al. 2017).

There is little research or observational study on the environmental thresholds for Salish Sea and Puget Sound-specific kelp populations (Calloway et al. 2020; Hollarsmith et al. 2022). The global kelp literature suggests that *among-population* variation is larger than *among-species* variation in abiotic requirements and optimum growth conditions (Berry et al. 2019; Muth et al. 2019; Table 3; Appendix A). Within a given kelp population, environmental requirements and thresholds will further differ between kelp life stages (Mumford 2007; Table 3). This means that different kelp species, growing under similar environmental conditions, will likely have more similar environmental requirements and tolerances, regardless of geographic location, than populations of the same kelp species growing under different environmental conditions (e.g., warm vs cool temperatures) in the same geographic region. This is due to the high degree of developmental and physiological plasticity of kelps and local genetic adaptations various populations may experience over several generations at a particular site (Bartsch et al. 2008; Muth et al. 2019).

Table 3. General environmental thresholds including light [photosynthetically active radiation (PAR)], nutrients and temperature for kelp species life history stage. Generalized thresholds are estimates based on aggregated values from the available scientific literature. For a summary of species-specific environmental thresholds used in these estimates, see *Appendix A: WA Kelp Species Environmental Thresholds*.

Life stage	Light (PAR)			Nutrients (µM dissolved inorganic nitrogen - DIN)			Temperature (°C)	
	Minimum daily irradiance (M/m²/day)	Biological minimum (µmol/m²/s)	Growth optimum (µmol/m²/s)	Minimum nitrogen	Optimal	Observed impacts	Optimal range	Hazardous
Spore	1 – 2	2 – 3	20 – 60	1 – 2	> 10	–	5 – 15	17 – 20
Gametophyte	1 – 2	2 – 3	20 – 60	1 – 2	> 10	–	5 – 15	
Juvenile Sporophyte	1 – 2	20 – 100	60 – 100	1 – 2	> 10	–	5 – 15	17 – 20
Adult Sporophyte	1 – 2	20 – 100	150 – 250	1 – 2	> 10	> 10 associated with more robust blade tissue	5 – 15	17 – 20

Temperature

The negative effects of elevated temperatures on kelp populations are well documented and can exacerbate the effects of additional stressors such as nutrient depletion and others (Muth et al. 2019; Wernberg et al. 2019). While there is little potential for SOWS to influence water temperature, predicted continued increases in SST due to global climate change could exacerbate other SOWS-related stressors. Temperature requirements can differ between individual kelp species, different life stages of the same species, and populations of kelp inhabiting areas with different environmental conditions. Nonetheless, local experts recognize some general optimal ranges for growth and reproduction.

Laminaria and *Saccharina* species can persist at temperatures from 0 to 18°C, with optimum growth (regardless of life stage) occurring between 5 to 15 °C (Bartsch 2008). Adult *Nereocystis* can survive between -1.5 and 18 °C, with a physiological stress threshold of 14.5 to 16 °C (Lüning and Freshwater 1988; Hamilton et al. 2020). An observational study in South Puget Sound noted peak stipe and blade growth rates occurring during the summer at 13.5 °C (Maxell and Miller 1996). Research into *Nereocystis* spore germination, gametophyte maturation, and germling sporophyte growth report similar temperature optimums between 10 to 15 °C, with significant impacts to spore germination rates at 17.5 °C (Vadas 1972; Shiltroth et al. 2018).

Temperatures above 18 °C are generally associated with increased kelp physical damage and mortality in our region and other temperate marine regions with similar environmental conditions (Berry et al. 2020; Wernberg 2010). Long-term, mid-channel temperature data in South Puget Sound never exceeds 15 °C but nearshore sampling at Squaxin Island observed temperatures of 16 to 20 °C along a gradient from the seaward edge of the *Nereocystis* forest to the shore (Berry et al. 2021). Kelp photosynthetic rates increase with increasing temperatures, requiring increased nutrient uptake, potentially leading to nutrient-related stress during periods of low nitrate availability (Vadas et al. 1972; Hurd et al. 2011). Finer grain temperature monitoring is required to better understand temperature trends within Washington SAV populations and whether heat stress may exacerbate nearshore development impacts to kelps.

Nutrients

Along with light for photosynthesis, nutrients in the form of inorganic nitrogen are critical for high kelp productivity while elevated levels can lead to an increase in abundance of other algae such as phytoplankton or ulvoids. Kelp forest productivity on the west coast of North America is closely tied to nutrient availability driven by seasonal cycles in deep water upwelling (Schiel and Foster 2015). As a result, it is often common in the kelp literature to use seasonal water temperature as a proxy for nitrogen availability, with peak nutrient availability in the winter (Dayton 1985; Berry et al. 2021). While not driven directly by upwelling, nutrient availability in the interior waters of Puget Sound follow seasonal trends as significant amounts of dissolved inorganic nitrogen (DIN) make their way, via deep waters of the Strait, into Puget Sound and the SoG (Khangoankar et al. 2011). Average winter nitrogen levels vary by Salish Sea basin with DIN concentrations of between 2 to 3.5 µmol/L in the Strait, while most of Puget Sound, SJI, and SoG are characterized by higher winter concentrations (around 14 µmol DIN/L) followed by summer declines (between roughly 3.5 to 7 µmol DIN/L) (Mohamedali et al. 2011). In some areas, oceanic nutrients are supplemented heavily by human nutrient inputs. For example, human nutrient inputs account for 73% of surface DIN loads in Puget Sound (Mohamedali et al. 2011).

In California, a minimum of 1 to 2 µmol DIN/L is required to support “normal” daily growth rates of *Macrocystis* (Schiel and Foster 2015). Inorganic nitrogen concentrations of 10 µmol/L and greater are associated with both increased *Macrocystis* blade biomass in New Zealand, and with higher juvenile *Nereocystis* sporophyte densities in laboratory studies (Stephens and Hepburn 2016, Muth et al. 2019). Little study has been conducted on common stalked or prostrate kelp nutrient requirements in the Salish Sea.

Water motion also plays an important role in facilitating the transfer of nutrients from surrounding water into kelp tissues (Stevens et al. 2014; Kregting et al. 2016). Decreases in water flow may potentially have impacts on kelp nutrient uptake, but data are lacking on the effects of SOWS impacts to natural flow and associated kelp nutrient dynamics (Hilary Hayford, personal communication, June 6, 2022).

Light requirements and thresholds

As photosynthetic organisms, all kelp species are dependent on light for growth and long-term persistence. However, not all wavelengths of visible light are suitable for photosynthesis. Photosynthetically active radiation (PAR) refers to the range of visible light wavelengths between 400 and 700 nm used for photosynthesis (Nightengale and Simenstad 2001). PAR levels are commonly expressed as either instantaneous measurements ($\mu mol/m^2/s$) or summed over a period (e.g., per day) and reported as integrated irradiance (M/m^2/time period) (Simenstad et al. 1997). *Integrated* irradiance is a more useful metric when considering the ecological and biological effects of different light levels, including kelp persistence. *Instantaneous* measurements are often reported for laboratory studies and are useful for understanding the precise thresholds associated with photosynthetic rates and yields that trigger important biological functions. This makes generalizing daily PAR requirements for kelp persistence from instantaneously measured biological thresholds difficult, as instantaneous measurements are dynamic – changing with the relative angle of the sun (influenced by time of day and season), weather, water clarity, and depth.

Kelp photosynthetic performance is a gradient, not a binary switch where kelp either exists or not. Primary productivity decreases as a function of decreasing irradiance (Hurd et al. 2014). Two photosynthetic rates are important for considering biological impacts to kelp species: compensation irradiance and saturation irradiance (Simenstad et al. 1997). Compensation irradiances are the minimum threshold for growth. At irradiances lower than compensation levels, cellular respiration exceeds primary productivity leading to net losses to overall biomass (Bartsch et al. 2008). Saturation irradiance refers to the threshold at which photosynthetic performance plateaus. However, absolute maximum photosynthetic rates may occur at slightly higher irradiances and can be influenced by other environmental factors like temperature, nutrient availability, and water movement (Hurd et al. 2014, Bartsch et al. 2008). Complicating matters, there is evidence that irradiance thresholds are dynamic, changing in response to total available light. *S. latissima* in France has been documented to alter irradiance threshold by manipulating biological photosynthetic processes in response to changing irradiance due to tidal fluctuations in water depth

(Gévaert et al. 2003). No information exists on Washington kelp photosynthetic performance in response to natural alterations in light availability.

Kelps, regardless of morphology or species, are shade-tolerant, requiring only integrated irradiance of 1 to 2 $M/m^2/day$ for persistence, with microscopic life stages generally requiring lower light levels than adult sporophytes (Hurd et al. 2014, Bartsch 2008, Table 3). While specific requirements can vary within and between species, compensation irradiances (i.e., minimum for biological function) generally range from 3 to 100 $\mu mol/m^2/s$ and saturation irradiances from 150 to 250 $\mu mol/m^2/s$. and is generally lower for deeper water species and populations (Appendix A). For comparison, eelgrass requires more light than all kelps, becoming light limited below 300 $\mu mol/m^2/s$ and requiring a daily minimum of 3 $M/m^2/day$ PAR for long-term persistence (Simenstad et al. 1997).

In laboratory cultures, growth rates of Puget Sound *Nereocystis* gametophytes and germling sporophytes peaked between 15 and 30 $\mu mol/m^2/s$ at 10 to 15 °C when cultivated under long-day conditions of 16 hours of light (Vadas 1972). This is similar to the critical levels needed to induce germling sporophyte growth in *Macrocystis* (20 to 30 $\mu mol/m^2/s$) (Carney and Edwards 2006). However, laboratory investigations on *Nereocystis* gametophyte growth rates observed peak gametophyte growth at much higher light levels (77 and 110 $\mu mol/m^2/s$) in water temperatures between 13 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 and from drawing inferences from other geographic regions to the Salish Sea and potentially across regions within the Salish Sea.

Shading from SOWS can significantly impact populations of SAV – especially seagrasses - but data regarding impacts to kelp populations are limited (Nightengale and Simenstad 2001). In a study conducted in the San Juan Islands, SOWS reduced light to 163 $\mu mol/m^2/s$ (9.6% of ambient levels at -1.3 m mean lower low water (MLLW) and 68 $\mu mol/m^2/s$ (4% at -2.4 m MLLW (Fairbanks 2010 in Lambert et al. 2021). Similar measurements of less than <100 $\mu mol/m^2/s$ (<10%) ambient summertime PAR levels were also observed at depths of -5 m MLLW between 2 and 5 m beneath a ferry terminal (a LOWS) (Simenstad, Thom and Olson 1997). In the same study, researchers observed 10% to 70% declines in PAR availability due to propellor wash from regular ferry operations. The lack of integrated daily values in many of these studies makes determining the effects of shading on kelp persistence difficult but instantaneous measurements under OWS suggest that light levels can fall below biologically significant thresholds for kelp growth.

Daily, integrated PAR values from directly under public docks at three sites around Whidbey Island during the early and late summer rarely exceeded 2 M/m²/day – which is equal to the daily minimum found by Hurd et al. (2014) and Bartsch (2008), Table 3) - and were associated with lower kelp cover than dock perimeters and control sites (Szypulski 2018). While light levels at individual sampling stations directly below docks at all three sites either hovered around or dropped below the minimum for kelp persistence, all study dock sites were located at state parks and exposed to additional stressors. Two of the sites, Cornet Bay and Camano Island, were docks specifically intended for use as a public boat launch, subjecting the kelp populations there to increased turbidity and potential scour from propeller wash, and exposure to chemical pollution, among other stressors associated with regular vehicle and recreational vessel use. The third dock studied, while not a direct part of boat launch facilities, was adjacent to a less developed boat launch at a popular public kayak beach and campground. Differences in kelp percent cover may have been influenced by a combination of shade and recreational water-dependent activities. As such, the direct effects to kelp from shading at these docks cannot be determined because of the confounding impact of human use.

Light reductions from increases in turbidity can also delay or prevent kelp recruitment, leading to significant losses in kelp persistence (Glover et al. 2019, Rubin et al. 2017). Large sediment plumes following the removal of two hydroelectric dams on the Elwha River reduced total daily irradiance to below biological thresholds for persistence (< 1 to 2 M/m²) (Glover et al. 2019). Persistent, low irradiance from 2012 to 2014 resulted in total mortality to all seaweeds, including kelps. Kelp recovery did not occur until 2016 and 2017 when daily irradiances were above growth thresholds for more than 50% of the days between April and June – the critical period for kelp reproduction and recruitment (Glover et al. 2019). Whereas dam removals at a given site should be rare occurrences, human use at public docks is more common and widespread and may have ongoing impacts to kelp recruitment and persistence.

Kelp substrates and effect of sediments

Kelp species require sediment-free, hard substrates on which to recruit (Gabary et al. 1999; Hurd et al. 2011). Substrates suitable for kelp recruitment include everything from pea gravel to large boulders, shell hash, consolidated rocky reefs, and artificial structures. This contrasts with eelgrass, which requires mud or sand in which to root. In areas with mixed substrate types, it is not uncommon to find kelp and eelgrass growing together (Olson et al. 2019).

Kelp is known to regularly recruit to artificial structures throughout Washington (Szypulski et al. 2018; Lambert et al. 2021; Max Calloway, personal observation; Berry, unpublished data). Local consultants have reported kelp recruitment on accumulations of shell hash at the base of pilings (Max Lambert, personal communication, June 10, 2022). The overall consequences of SOWS structure on kelp dynamics are unclear – while artificial structures could provide additional kelp habitat in regions with predominantly soft benthic substrates, high densities of over- and in-water structures may affect sediment transport, deposition, and accumulation that result in long-term or indirect impacts to kelp (Szypulski 2018; Lambert 2021; Dayv Lowry, NOAA, personal communication, June 6, 2022).

Fine sediment, whether suspended or settled, can block the recruitment of microscopic kelp life stages, block spore settlement, and smother spores, gametophytes, and germling sporophytes (Deiman et al. 2012; Geange et al. 2014). In laboratory studies on *Nereocystis* and *Eularia fistulosa* (a close relative of Puget Sound's *A. marginata*), suspended and settled sediment loads of 420 mg/L reduced spore attachment rates to 6% and 1%, respectively (Deiman et al. 2012). Similar trials conducted with *Macrocystis* resulted in reduced gametophyte densities from loads greater than 100 mg/L. (Geange et al. 2014). Average suspended sediment concentrations from kelp forest sites in South Puget Sound never exceeded 3 mg/L from December 2017 to September 2018, but regional variation in sediment dynamics and oceanographic processes in Washington waters may mean that sediment could be an issue at local sites (Berry et al. 2019). Construction activities associated with the installation of new overwater or in-water structures add further complexity to sediment and kelp dynamics due to the unknowns surrounding the concentration and duration of sediment resuspension events.

Sediment can also serve as a vector for pollutants from urban and agricultural runoff that may lead to higher mortality due to toxicity, even when accumulation rates and suspended sediment concentrations are below known mortality thresholds. Unfortunately, little data exists on adult sporophyte or microscopic life stage response to common terrestrial runoff-associated pollutants. More research is needed to fully understand the interaction between sediment-related pollutants and kelp species in Washington waters.

Both SOWS construction activities, water-dependent uses, and potential changes to water flow may impact Washington kelp populations. Construction activities and boat propellors are associated with benthic scour and sediment resuspension; however, the short duration of these activities may limit persistent negative impacts, especially if kelp is abundant in the immediate vicinity. However, cumulative impacts from boat propellor scour or sediment resuspension may cause long-term reductions into kelp persistence in the immediate vicinity. The temporary nature of physical disturbance-related stressors will depend in part on the availability of spores from local source populations. If no nearby populations of kelp are available to help recovery from temporary disturbances, all species effects, whether annual or perennial may be permanently lost. Potential construction-related kelp losses may be offset by newly available hard substrates provided by newly installed SOWS. While new substrate could function as suitable kelp habitat, the physical structure may also alter water flow, thereby altering nearshore sediment dynamics and resulting in increased scour or sediment deposition (Logan et al. 2021). Additional scour could provide ample substrates for new kelp populations, while increased sediment deposition could smother microscopic life stages, potentially impacting kelp persistence. The lack of data on these subjects makes predicting impacts difficult if not impossible.

Expert Opinion Interviews Synopsis

Summarized from Appendix C

- There was strong agreement among all experts that *Saccharina* complex species (*S. latissima, S. complanata, and H. nigripes)* as the most common non-floating kelp species in Washington waters.
- Species diversity and distribution differ geographically, with the greatest kelp diversity in the Strait and SJI.
- *Agarum/Neoagarum* species were identified as the deepest distributed kelp species and most shade tolerant.
- Maximum kelp depth distribution is tied to visibility (i.e., light penetration) which is correlated with geography: -10 m (-30 ft) MLLW in Puget Sound, and -20 m (-60 ft) MLLW in areas with better visibility: Hood Canal, Strait, SJI, and SoG.
- There was no consensus among experts regarding whether SOWS-related impacts to kelp are species-specific.

- There was no consensus on the potential negative impacts of SOWS-related stressors to kelp populations.
    - Most agreed that the overall effects of SOWS impacts vary by region and any negative impacts, while likely during construction activities, may be temporary due to the resilient nature of kelp species, particularly adult sporophytes.
    - Experts noted that negative impacts may be more severe for early kelp life stages (spores, gametophytes, juvenile sporophytes) and kelp species with annual (as opposed to perennial) life histories.
    - Two experts suggested that kelp populations may be more tolerant of shade than eelgrass populations, but that this resilience may only be over short (weeks to months) timespans.
    - Only one expert reported directly observing negative SOWS-related impacts to kelp populations.
    - Nearly all experts believed the additional hard substrates provided by SOWS may have positive benefits, especially in areas naturally lacking suitable kelp substrates.
- Experts often expressed the need for observational studies of all potential SOWS-associated impacts to kelp populations discussed in this document.

CONCLUSIONS AND RESEARCH NEEDS

Understanding the potential impacts of SOWS to Washington's kelp populations is hampered by a combination of data gaps regarding both kelp populations in the state and impacts of human development and activities to nearshore habitats in general (Calloway et al. 2020; Lambert et al. 2021; Hollarsmith et al. 2022). Current and planned actions by regional management agencies, Tribes, and non-governmental organizations are helping to increase our understanding of kelp species distribution and trends, and kelp forest ecological services, but there has been little research to date on specific stressor impacts on Washington kelp habitats.

The lack of a comprehensive baseline for non-floating kelp forests in Washington waters makes assessing the impacts of human-related stressors, such as those associated with SOWS even more difficult, as floating kelp forests are immediately apparent and avoided during HPA permitting when possible. The current focus on floating canopies, while critical for broader Washington kelp conservation and recovery efforts, may result in further delays to the development of comprehensive, baseline information on non-floating kelp forests. This may continue to present a challenge for understanding impacts from SOWS given non-floating kelps are more commonly seen relative to floating kelps around permitted hydraulic project sites.

Despite these gaps, available data and expert opinion suggest that SOWS have the potential to influence environmental conditions that are important to Washington kelp forests over both the short- and long-term. Even so, the regional kelp experts interviewed here suggest high uncertainty about the potential impacts of SOWS both at the site scale and cumulatively in the region relative to other stressors (Appendix B, Appendix C). Further, there is little information available to understand the effects of reduced kelp productivity on both long-term forest persistence and potential cascading effects to nearshore habitat quality and food webs. Even if shading does not result in kelp losses, decreases in productivity resulting from suboptimal light availability may have impacts on nearshore habitat quality and ecosystem service provisioning; however, more research is needed to understand both the extent of impact and the potential consequences of reduced kelp productivity on nearshore habitats and ecosystem services. Similarly, additional hard substrates provided by SOWS may result in kelp habitats providing different albeit similar habitat benefits to Washington marine species. Further, it remains unclear how impactful SOWS are to kelp relative to other stressors like shoreline armoring, chemical pollution, increased water temperatures, etc., and how SOWS impacts may interact with additional stressors. Regardless of the specific mechanisms and directions of SOWS-related impacts, among- species differences for kelp may be less significant than among-population or lifestage differences.

A 2021 review of SOWS effect on nearshore habitats by Lambert et al. (2021), compiled a non-exhaustive list of priority research needs and questions to assess the impacts of SOWS to nearshore marine habitat in Washington waters. Most of the questions developed during that review align with many data gaps identified in this document, and the opinion of regional experts. As Lambert et al. (2021) discuss, future research should give special consideration to study designs aimed at the functional links between SOWS impacts and responses from kelp and other SAV populations. Furthermore, multiple types of studies (observational, experimental, etc.) will be required to understand these functional links (Lambert et al. 2021). Agencies that permit the constructin of SOWS could use this information and future research to update their best management practices within the bounds of their respective authorities.

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APPENDIX A: WA KELP SPECIES ENVIRONMENTAL THRESHOLDS

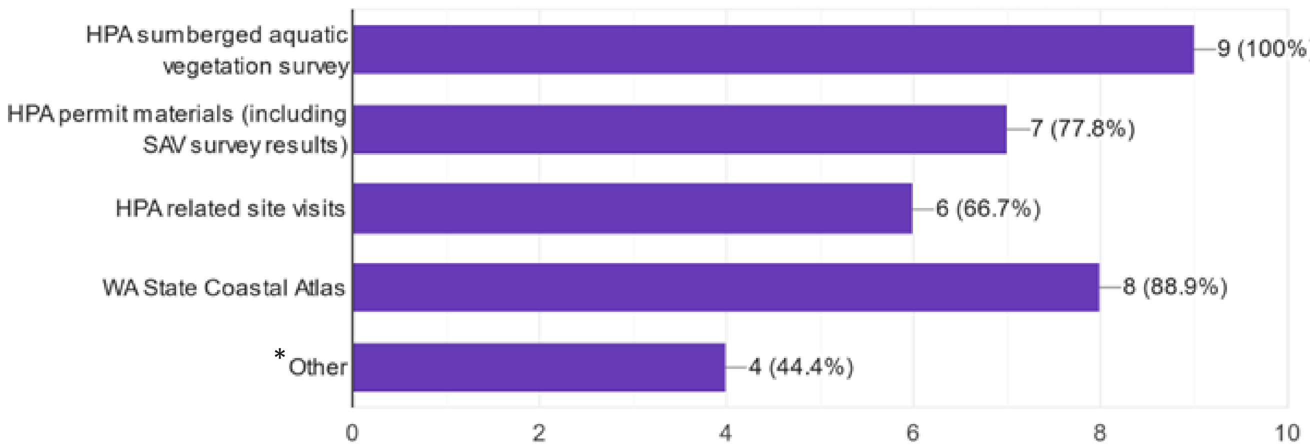
Published light, nutrient, and temperature thresholds and associated observed impacts for individual, WA kelp species adult sporophytes. X = No data found during this exercise; 1. Druehl and Clarkston 2000; 2. Bartsch et al 2008; 3. Cabello-Pasin and Alberte 1997; 4. Luning 1979; 5. Luning 1981; 6. Schiel and Foster 2004; 7. Stephens and Hepburn 2016; 8. Carney and edwards 2006; 9. Muth et al. 2019; 10. Schiltroth and Bisgrove 2018; 11. Vadas 1972; 12. Graham 2006; 13. Luning and Neushul 1978; 14. Mathews 1990.

Form	Species Name[1]	Taxonomic synonyms	Common name[1]	Light				Nutrients		Temperature	
				Minimum for biological function	Growth optimum	Damaging	Observed impacts	Minimum nitrate (µmol/L)	Optimal nitrate (µmol/L)	Hazardous temperature (°C)	Observed impacts
Floating	*Egregia menziesii* (Turner) Areschoug	-	feather boa kelp	x	x	x	x	x	x	18[9]	Failed spore germination[9]
Floating	*Macrocystis pyrifera* (Linnaeus) C. Agardh	*Macrocystis integrifolia*	giant kelp	30 to 70 µmol/m^2/sec[8]; 0.5 to 0.7 M/m^2/day[6]	220 µmol/m^2/sec[5]; 2 to 3 mol/m^2/day[6]	850 µmol/m^2/sec[12]	Delayed sporophyte growth at 2 to 3 µmol/m^2/sec[8]	1 to 2 needed for average growth[6]	9[8]; >10 associated with more robust blade tissue[7]	x	x
Floating	*Nereocystis luetkeana* (Mertens) Postels et Ruprecht	-	bull kelp	see observed impacts[11]	x	x	Severely reduced ♀ gametophyte fertility at 2 µM/m^2/s[11]; 50% greater ♀ gametophyte fertility at 29 µmol/m2/s (1.6 M/m2/day) vs. 14 µmol/m2/s (0.8 M/m2/Day)[11]	x	10 results in higher sporophyte densities than 1 or 5[9]	18[9]; 17.5[10]	Failed spore germination[9]; 70% to 80% failed spore germination[10]
Stalked (Stipitate)	*Lessoniopsis littoralis* (Farlow et Setchell ex Tilden) Reinke	-	-	x	x	x	x	x	x	18[9]	x
Stalked (Stipitate)	*Postelsia palmaeformis* Ruprecht	-	sea palm	x	x	x	x	x	x	18[9]	Failed gametophyte maturation[9]
Stalked (Stipitate)	*Pterygophora californica* Ruprecht	-	-	x	x	x	x	x	x	18[9]	Failed gametophyte reproduction[9]
Prostrate	*Agarum clathratum* Dumortier	*A. cribrosum*	-	x	x	x	x	x	x	x	x
Prostrate	*Alaria marginata* Postels et Ruprecht	*incl. Alaria nana*	-	x	x	x	x	x	x	18[9]	x
Prostrate	*Costaria costata* (C. Agardh) D.A. Saunders	-	-	x	x	x	x	x	x	x	x
Prostrate	*Dictyoneurum californicum* Ruprecht	-	-	x	< 50[3]	x	x	x	x	18[9]	Failed spore germination[9]
Prostrate	*Dictyoneurum reticulatum* (D.A.Saunders) P.C.Silva	*Dictyoneuropsis reticulatum*	-	x	x	x	x	x	x	x	x
Prostrate	*Neoagarum fimbriatum* (Harvey) H.Kawai & T.Hanyuda	*Agarum fimbriatum*	-	x	x	x	x	x	x	x	x
Prostrate	*Pleurophycus gardneri* Setchell et D.A. Saunders ex Tilden	-	-	x	x	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Saccharina complanata* ** (Setchell & N.L.Gardner) P.W.Gabrielson, S.C.Lindstrom &	*Laminaria complanata*	sugar kelp	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Saccharina latissima* ** (Linnaeus) C.E.Lane, C.Mayes, Druehl & G.W.Saunders	*Laminaria saccharina*	sugar kelp	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Hedophyllum nigripes* ** (Rosenvige) Starko, S.C.Lindstrom & Martone	*	sugar kelp	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Hedophyllum sessile* (C. Agardh) Setchell	*Saccharina sessilis*	sea cabbage	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Cymathaere triplicata* (Postels et Ruprecht) J. Agardh	*Laminaria triplicata*	-	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Laminaria ephemera* Setchell	-	-	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	18[9]	Failed spore germination[9]
Prostrate – Genus Laminaria sensu lato	*Laminaria longipes* Bory	-	-	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x
Prostrate – Genus Laminaria sensu lato	*Laminaria setchellii* P.C Silva	*Incl. L. dentigera*	-	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	18[9]	Failed gametophyte reproduction[9]
Prostrate – Genus Laminaria sensu lato	*Laminaria sinclairii* (Harvey ex Hooker f.) Farlow, C.L. Anderson et D.C. Eaton	-	-	20 to 100 µmol/m^2/sec[2]	150 to 200 µmol/m^2/sec[2]	x	x	x	x	x	x

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

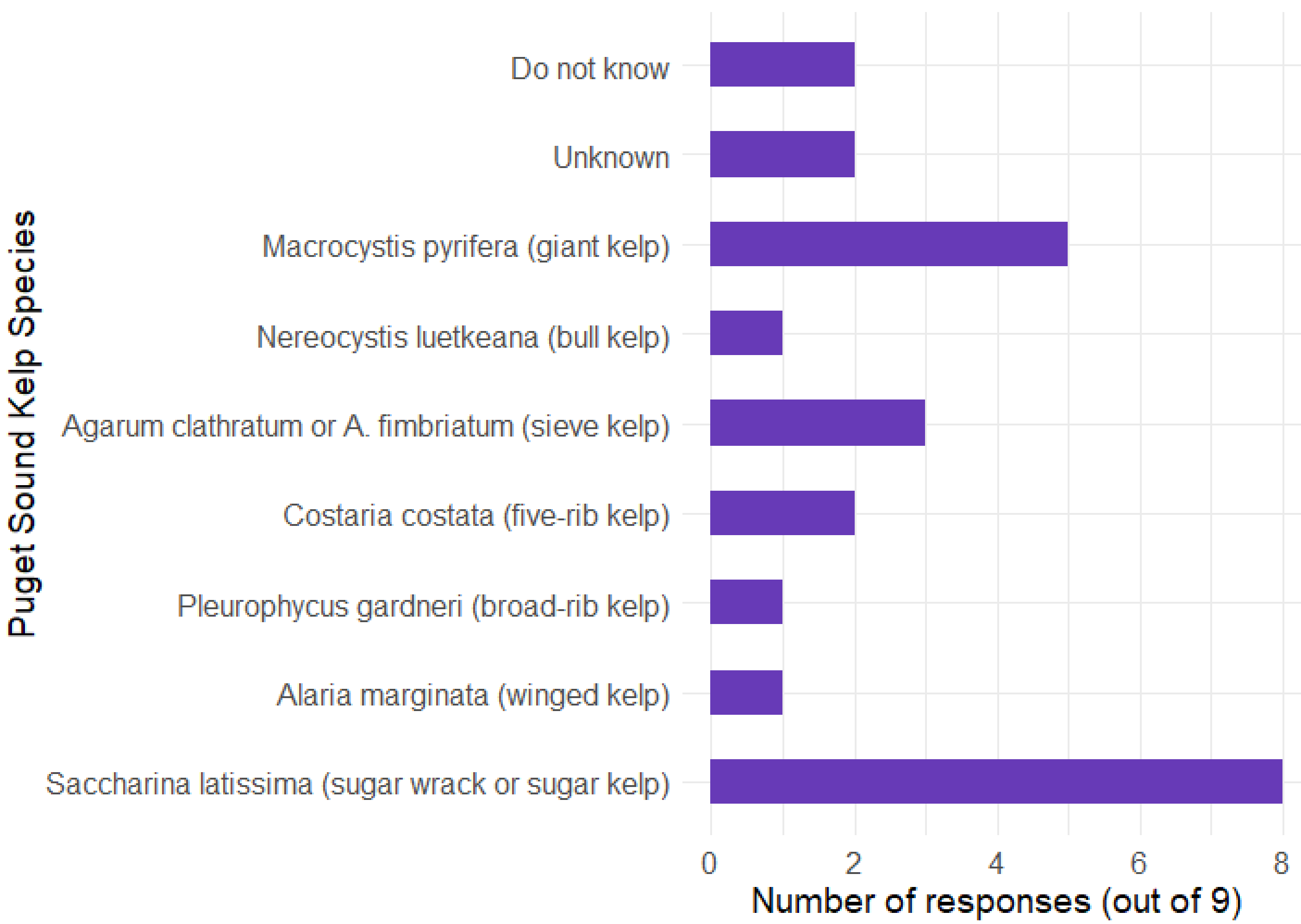
** *Saccharina/Hedophyllum* complex species. Difficult to impossible to differentiate in the field. Commonly known as “sugar kelp”, despite the name being more accurately used to describe only Saccharina species.

1. What sources of information inform your knowledge of common kelp species in your area?
9 responses

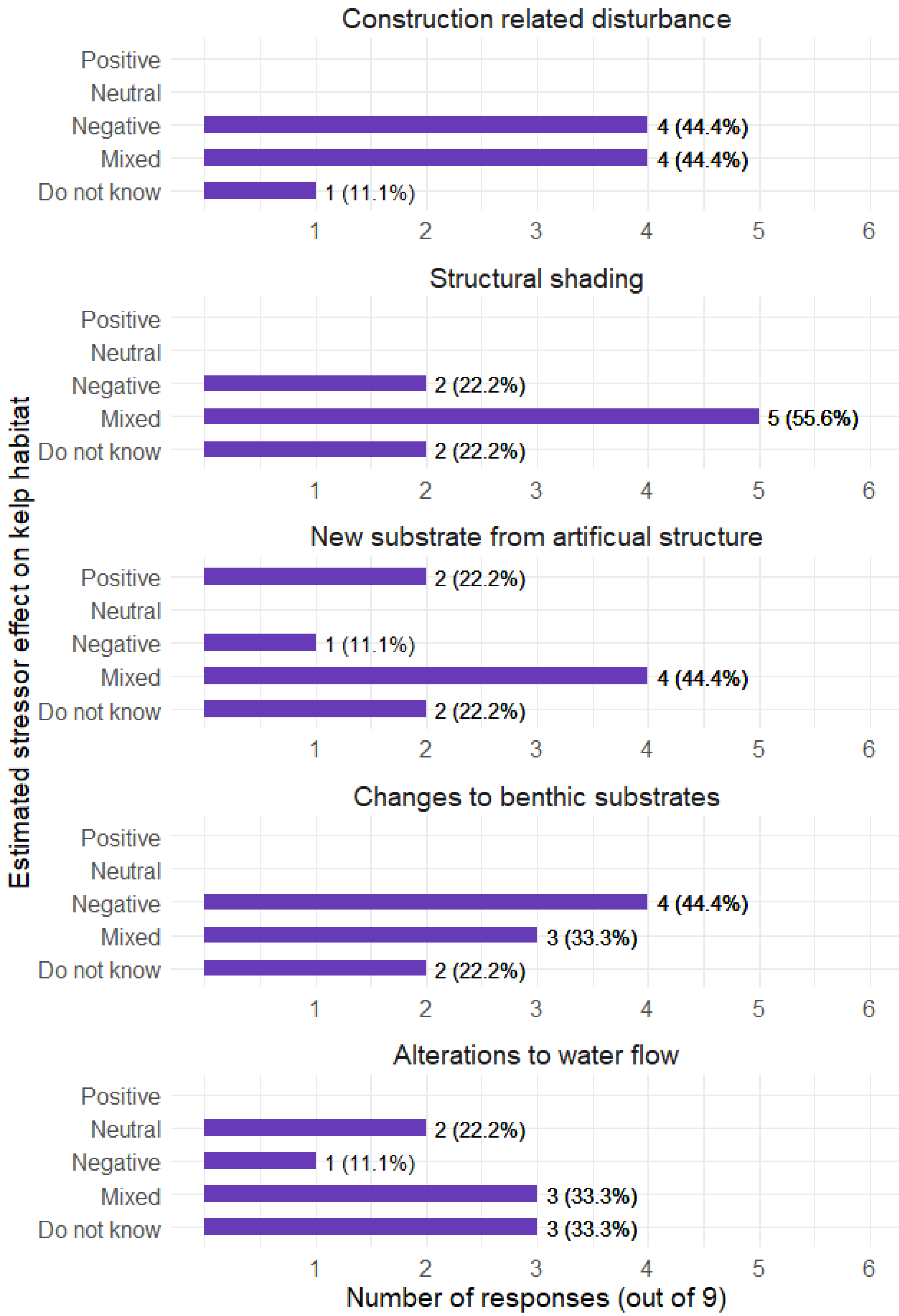


*All four "other" responses refrenced the DNR Coastal Vegetation Atlas

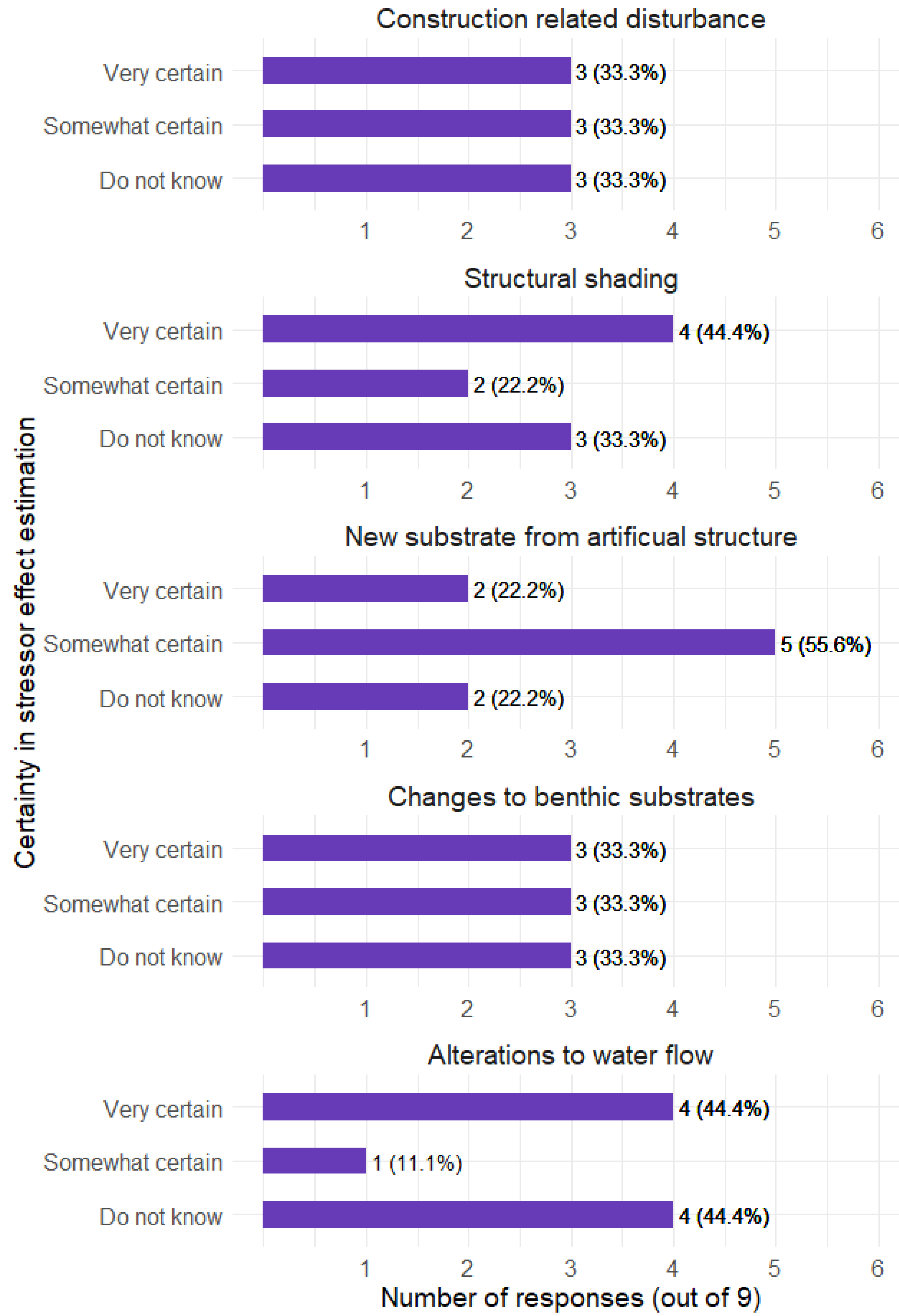
2. Select the most common kelp species encountered during HPA permit review process:



4.Please indicate direction of impact on kelp populations for the following SOWS related effects:

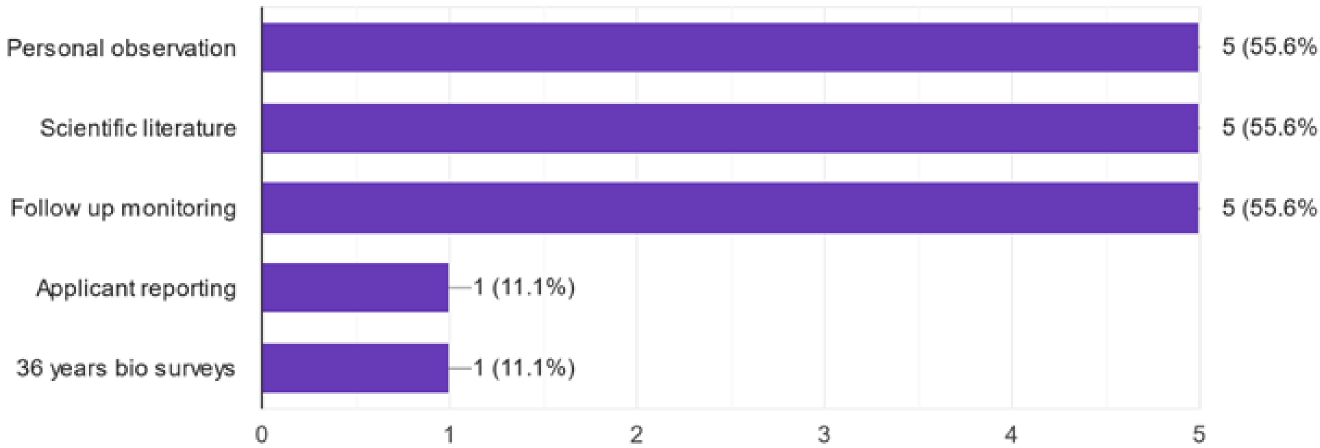


5. Rank your level of certainty regarding potential SOWS impacts to kelp populations:



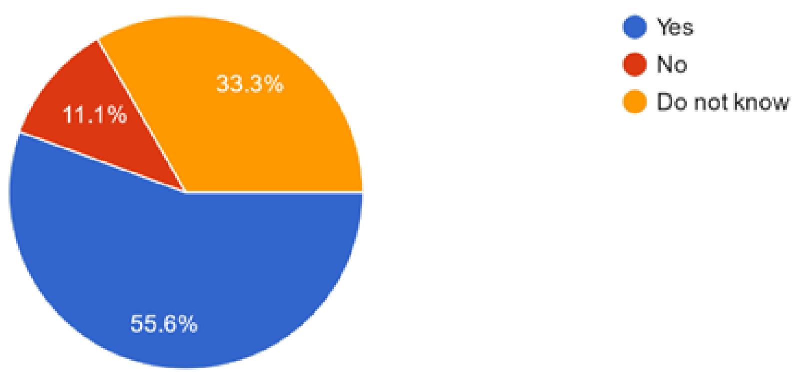
6. What evidence do you have of impacts to kelp populations?

9 responses



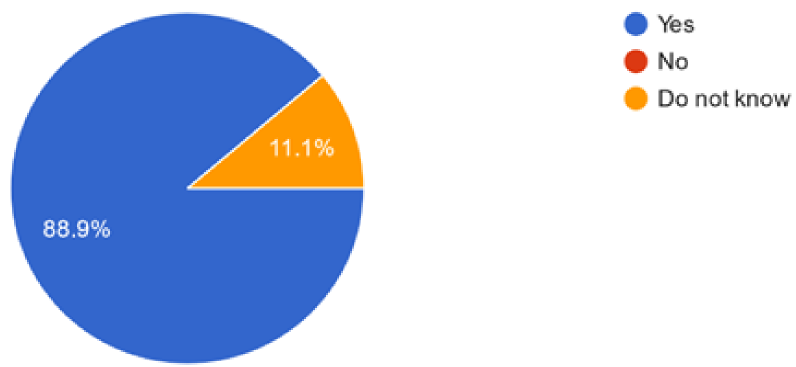
7. Of observed impacts to kelp from SOWS, have you noticed a difference in response between kelp population and eelgrass populations?

9 responses



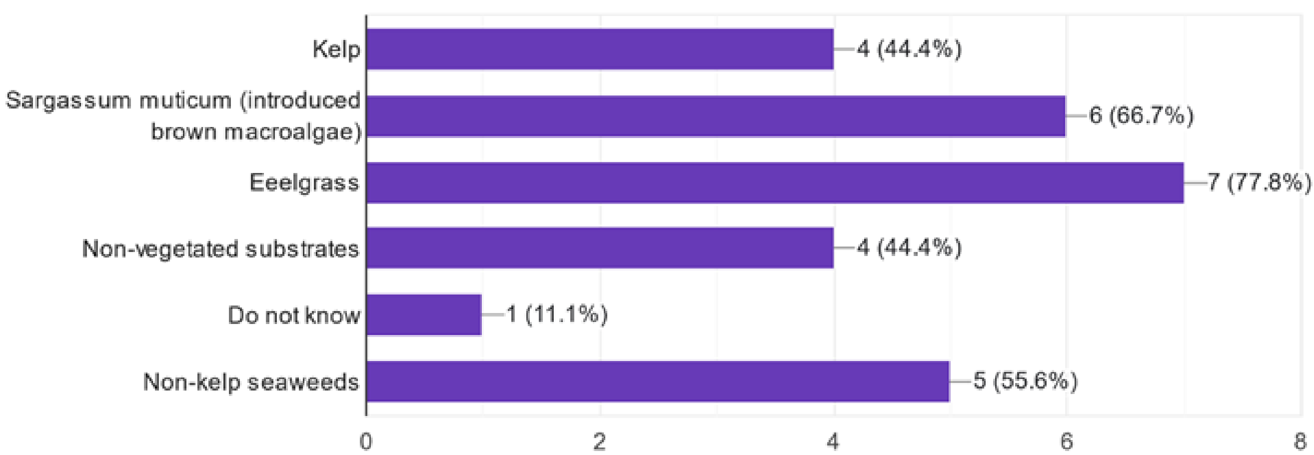
8. In your area, do you encounter proposed SOWS in herring spawning areas?

9 responses



8b. If you answered "yes" to question 8, which of the following substrates are associated with herring spawn?

9 responses



APPENDIX C: SUMMARY OF REGIONAL KELP EXPERT QUESTIONNAIRE / FOLLOW-UP INTERVIEW RESPONSES

During this review, a series of nine questions was sent to seven regional kelp experts and three forage fish experts. Four kelp experts responded to the email questionnaire and follow up phone interviews were scheduled with three:

- Tom Mumford, PhD. – MarineAgronomics, LLC., former Washington Department of Natural Resources (DNR) Nearshore Habitat Program Director
- Megan Dethier, PhD. – Director, University of Washington (UW) Friday Harbor Labs (FHL)
- Hilary Hayford, PhD. – Habitat Research Director, Puget Sound Restoration Fund (PSRF)
- Gray McKenna – Kelp and Oyster Program Specialist, PSRF (was not available for follow-up interview)

Two of the three forage fish experts responded to email questionnaire only and no follow up interviews were schedule:

- Dayv Lowry, PhD – NOAA Rockfish Recovery Coordinator
- Todd Sandell – Senior Forage Fish Biologist

Some respondents only replied to questions that fell inside of their individual areas of expertise. If an individual expert's response indicated the specific question fell outside of their area of expertise, or if no answer was given, their response was not included in this summary.

All respondents suggested additional experts for potential inclusion in future, formalized, expert elicitation. The full list of recommended experts for expert elicitation can be found at the end of this appendix.

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1. What are the most encountered and broadly distributed understory kelp species in Puget Sound?

Tom Mumford: Species can differ by sub-basin. Most common in Washington state waters are *Saccharina latissima, Hedophyllum nigripes, Costaria costata* (hereafter *Costaria*), *Alaria marginata* (hereafter *Alaria*; often on floats), and, in deeper waters, *Agarum* species.

Megan Detheir: *S. latissima, Laminaria complanata, Agarum* species (very abundant in the San Juan Islands), and *Costaria.*

Dayv Lowry: Sugar kelps (*S. latissima, H. nigripes, S. complanata)* and feather boa kelp (*Egregia menziesii,* hereafter *Egregia)* are the two most encountered during dive and herring rake surveys.

Todd Sandell: Eelgrass is predominant in most of Puget Sound (PS). In areas with high tidal flows and/or rocky shorelines (which often go together), red macroalgae is most common (*Gracilariopsis* and *Aghardiella* species). More diverse macroalgae assemblages are found in the Strait of Juan de Fuca (Strait), SJI and southern Strait of Georgia (SoG). Most common kelp species include *Saccharina/Laminaria* species, *Nereocystis luetkeana* (hereafter *Nereocystis*). Two non-kelp brown seaweeds are also common: the introduced *Sargassum muticum* (hereafter *Sargassum*) and *Desmarestia* species. Oddly, the macroalgae populations south of Alki Point in west Seattle (central Puget Sound, CPS) are also very diverse.

Hilary Hayford: *Saccharina/Hedophyllum* complex (hereafter sugar kelps or *Saccharina* complex) species are the most common overall. This group consists of *S. latissima, H. nigripes* (formerly *Saccharina nigripies/ Laminaria groenlandica*), and *L. complanata*); *H. nigripes* may overwinter much better than *S. latissima*. *L. complanata* really known only from SJI.

Diversity is greatest in the Strait, SJI, and SoG. *Pterygophora californica* (hereafter *Pterygophora*) often forms surface canopies in shallow waters in the western Strait. Other common species include *Cymathaere triplicata, Costaria, Alaria Pleurophycus gardneri, and Agarum* species.

Intertidally common species include *Hedophyllum sessile, Egregia, and S. latissima. Sargassum* is abundant in shallow & intertidal areas.

Gray McKenna: *Saccharina* complex species seem to be by far the most abundant understory kelp species. I also see *Costaria*, *Alaria,* and *Agarum* species at many sites in PS.

2. What are the general depth ranges for kelp forests and species in Puget Sound?

Tom Mumford: Max depth depends on species and location. For example, in Southern Puget Sound kelp is rarely found deeper than -10 m (-30 ft) MLLW.

Megan Dethier: *Agarum* species are deepest distributed.

Dayv Lowry: From approximately MLLW down to about -18 m (-60 ft) MLLW or so, on average. I think it is controlled by light more than anything, and I haven't noticed species-specific patterns. The maximum depth is deeper in Hood Canal than in SPS or CPS.

Todd Sandell**:** Typical maximum depth of submerged aquatic vegetation (SAV) in WA waters is approximately -6 m (-20 ft) MLLW. In areas with very clear water, like Hood Canal and interior SJI, maximum depth is as deep as -12 m (-40 ft) MLLW.

Hilary Hayford: Intertidal kelps: MLLW to -1.5 m (-5 ft) MLLW but generally not below MLLW.

Subtidal kelps: -3 to -6 m (-10 to -20 ft), potentially to -15 m (-50 ft) MLLW In the Strait & SJI.

Gray McKenna: Between MLLW and -10 m (-30 ft) MLLW, with forests seemingly shallower CPS, and SPS than forests farther north/in the Strait, SJI, and SoG.

3. Do you expect species specific responses to SOWS associated stressors (shading, alterations to water flow, substrate impacts, sediment disturbance from construction)?

Tom Mumford: Yes.

Megan Dethier: Do not know. Probably likely.

Hilary Hayford: No. I expect most kelp within a habitat, and depth to have about the same response. Between-species differences are likely of the same magnitude as within-species differences, depending on conditions.

4. Have you directly observed negative impacts to kelp populations due to construction of OWS generally and small overwater structures (SOWS: residential docks, piers, floats) specifically?

Tom Mumford: Yes. Informal drop camera surveys found no kelp under docks near Friday Harbor Labs.

Megan Dethier: No. In fact, I think it's going to be the opposite in a lot of places, because they are the only hard substrate, and they provide substrates for kelp that aren't otherwise present.

Hilary Hayford: No.

Gray McKenna: No, I haven't observed any negative impacts myself. In fact, I've often seen kelp recruit to small overwater structures that did not seem abundant or maybe were not even present at a site before the SOW was present.

5. Do you feel that SOWS negatively impact Puget Sound kelp populations? If so, through what mechanisms?

Tom Mumford: In certain areas, yes potentially due to light attenuation, sedimentation, changes to water flow, prop wash, and/or pollutants. HPA construction activities likely do not have a huge impact on kelp populations. Follow up monitoring means no information on direct or cumulative impacts. Potential shift in species composition to Agarum species as they are deepest distributed species in WA.

Megan Dethier: Very large docks that are place over rocky areas would inevitably have negative impacts. But a dock in a soft sediment/ gravelly area where kelp is not present already, it's likely that it will be good for kelp.

Dayv Lowry: The footprint of SOWS are generally small enough that localized effects to vegetation almost certainly occur during construction, and to a lesser degree as a continuing effect of shading, but most species are resilient and grow back in a season or two. The cumulative effects of many SOWS in a small area, however, can affect nearshore (especially along-shore) flow patterns and mess with propagule movement and nutrient/sediment delivery. I feel any HPA rules should account for the density of SOWS in an area to avoid broad-scale impacts to habitat dynamics that influence broad-scale persistence of kelps. The specifics of such an approach still need to be worked out, and until they are the "death by a thousand cuts" scenario will remain a very real concern.

Todd Sandell: Potentially in certain areas. Only existing examples of shade impacts come from large overwater structures like ferry terminals.

Hilary Hayford: Light is the obvious impact, but it's also one the easiest to regulate. Suspect (do not know) understory kelp is robust. Could see a potential shift if there are any uncommon or rare species. *Saccharina* complex species are likely not light limited due to SOWS .Very competitive environment for space and light and yet it persists. Impacts from alterations to water flow may be most prevalent in high laminar flow areas; turbulent flow (from introduction of artificial structures) may increase siltation/sedimentation, but also may increase nutrient delivery to algae.

5a. Are there specific times when adult sporophytes would be more susceptible to negative impacts of HPA related construction activities?

Tom Mumford: This is species dependent.

Megan Dethier: Sporophytes are likely resilient.

Hilary Hayford: For *Nereocystis* Juvenile sporophytes in spring are most susceptible; unsure if this pattern applies to understory species.

5b. Are there specific times when adult microscopic forms would be more susceptible to negative impacts of HPA related construction activities?

Tom Mumford: Gametophyte dormancy is really a black box, likely species dependent but we just don't have the data.

Hilary Hayford: well, we need to figure out where those microscopic forms even are!

Megan Dethier: Gametophytes of annual species like *Nereocystis* or *Costaria* are likely impacted. But we really don't know much about perennial gametophytes.

6. Do you feel like the minimum 3 µmol/m²/day threshold established for eelgrass is appropriate for use as a minimum threshold for kelp species generally?

Tom Mumford: Probably not but here is no available evidence. Thresholds (light) for persistence are different than effects to productivity, less light results in reduced productivity, what if productivity drops to 50% or 75%? Thinking of only standing crop during summer may miss reductions in fish habitat quality from decreased overall kelp productivity.

Megan Dethier: No information is available to answer this question. Very easy low hanging fruit for future research.

Hilary Hayford: Potentially. Kelp may do better with lower light than eelgrass, at least over the short-term, but this is a data gap.

7. Is there any evidence that SOWS are potentially less harmful to kelp than eelgrass because they provide additional hard substrates on which to recruit?

Tom Mumford: In areas with kelp and kelp habitat, the additional hard structure may have a negative or positive effect to overall kelp habitat. Also not understood how floating kelp on docks differs from natural kelp forests in terms of fish habitat or ecosystem services.

Hilary Hayford: Certainly possible, lots of kelps on artificial structures (e.g. dock floats). Also consider that artificial structures are often built over soft sediments where kelps would otherwise be rare due to a lack of suitable substrate. Qualitative observations from multiple groups, noted cement is a huge kelp recruitment substrate. Eliot bay saw massive recruitment on new concrete dock in the marina. Chemical signals on substrate may be important for kelp recruitment.

8. Is there evidence to suggest that herring preferentially spawn on any kelp species?

Tom Mumford: A review of WDFW herring spawn data may provide insight to this question.

Megan Dethier: Perhaps but do not know, logical based on size and surface area relative to other SAV.

Dayv Lowry: It is more about the vicinity where spawning occurs, and the presence of vegetation therein, than any specific substrate. Spawning locations are culturally inherited (i.e., learned) by herring and good sites are used repeatedly. Vegetation composition in a region may change over time, but herring will continue to use the site and spawn on substrates in proportion to their relative occurrence in the area. Sargassum is used a lot, but not because it is preferred -- it's just ubiquitous. Kelps have the capacity to hold many, many eggs given their large surface area relative to species like eelgrass, so in some areas kelps may have a high proportion of eggs attached to them.

Todd Sandell: Eelgrass is most common on fine substrate, *Sargassum* and a variety of other reds seaweed species most common on rocky substrates, so they don't really "compete" for habitat.

Eelgrass and red seaweeds are the most common targeted by herring, but given the broadcast nature of spawning everything else in the area will have some spawn on it (usually less dense), including terrestrial debris, crabs, seals, etc.

Hilary Hayford: Herring spawning substrate is more tied to location than dominant vegetation type, with available substrates used indiscriminately at a given site. 40-50% of herring spawn found on *Sargassum*, potentially due to its shallow subtidal distribution.

9. Are there any data gaps or concerns pertaining to OWS and kelp not covered in these questions?

Tom Mumford:

- How do shading related decreases in kelp primary productivity (as a proportion of maximum productivity during saturating irradiances) impact kelp forest foodwebs?
- What are the differences in juvenile and adult finifish use of kelp forests with different dominant morphologies (Ex. Floating surface canopy vs. prostrate canopy)?
- No understanding of SOWS use related and cumulative impacts to kelp species.
- Imperative to conduct follow-up / long-term monitoring and/or observational studies at SOWS in multiple basins.

Megan Dethier:

- Potential for feeder bluffs and shoreline hardening to interact with SOWS related impacts to kelp habitats.
- I have not observed *Sargassum* attached to floating structures or artificial structures. Additional hard structures from SOWS might change competition dynamics between kelps and *Sargassum.*
- Need to get data on light impacts from SOWS.
- Use and cumulative impacts of SOWS are important to understand.
  - More shading than from the footprint of the SOWS alone (Ex. There is no grating on boats).
  - Cumulative use, prop wash,
  - Water quality impacts from spilled fuel and other chemicals, and improper septic / waste disposal.

Potential regional kelp and kelp associated species experts for future expert elicitation

Experts included in this appendix are not listed. This list is not an exhaustive list and further consideration should be given to additional experts for any future efforts.

Name	Organization	Position	Email Address
Brian Allan	PSRF	Habitat Restoration Director	brian@resotrationfund.org

Kelly Andrews	NOAA National Marine Fisheries Service	Research Fisheries Biologist	kelly.andrews@noaa.gov
Ashely Bagley	Long Live the Kings	Project Manager	abagley@lltk.org
Helen Berry	WA-DNR	Nearshore Habitat Program Manger	helen.berry@dnr.wa.gov
Josh Bouma	PSRF	Abalone Program Director	josh@restorationfund.org
Jennifer Blaine	WDFW	Fish & Wildlife Biologist	jennifer.blaine@dfw.was.gov
Henry Carson	WDFW	Research Scientist	henry.carson@dfw.wa.gov
Cinde Donoghue	WA-DNR	Aquatic Assessment and Management Team Lead	cinde.donoghue@dnr.wa.gov
Mark Donnahugh	Salish Seaweeds	Owner	info@salishseaweeds.com
Phillip Dionne	WDFW	Fish and Wildlife Research Scientist	phillip.dionne@dfw.wa.gov
David Duggins	UW FHL	Resident Scientist	dduggins@uw.edu
Robin Fales	UW FHL	Graduate student	rjfales@uw.edu
Eliza Heery	UW FHL	Postdoctoral Fellow	eliza.heery@gmail.com
Paul Herschberger	USGS Marrowstone Marine Field Station	Station Leader and Research Fish Biologist	phershberger@usgs.gov
Wendell Raymond	UW FHL	Nearshore Ecology Research Scientist	wraymond@uw.edu
Beth Tate	Jen Jay, Inc. / San Juan County Marine Resources Committee	Lead Wildlife Biologist	beth@jenjayinc.com
Brooke Weigel	UW FHL	Postdoctoral Fellow	blweigel@uw.edu