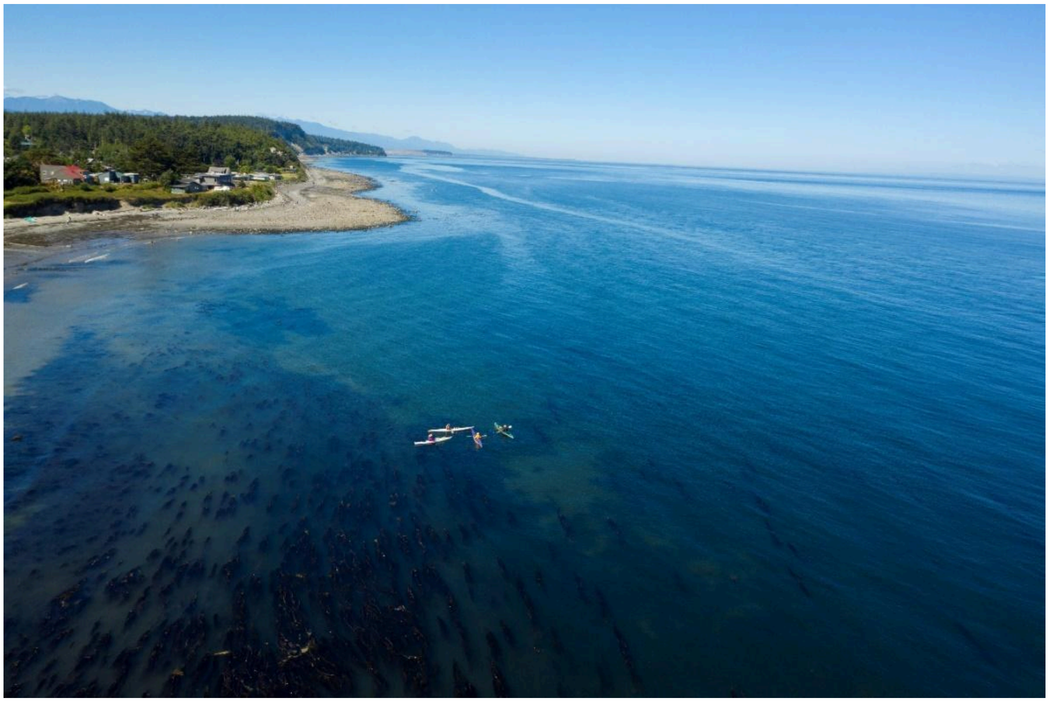
Kelp stressor rating in Washington State

April 29th 2024



PREPARED BY:
Kelp stressor rating workgroup

Washington Department of Fish & Wildlife	Wendel Raymond	Puget Sound Restoration Fund	Hilary Hayford
Puget Sound Institute	Caitlin Magel	The University of Chicago	Cathy Pfister
Washington State Dept of Natural Resources	Danielle Claar	Marine Agronomics	Tom Mumford
University of Washington	David Duggins	USGS	Steve Rubin

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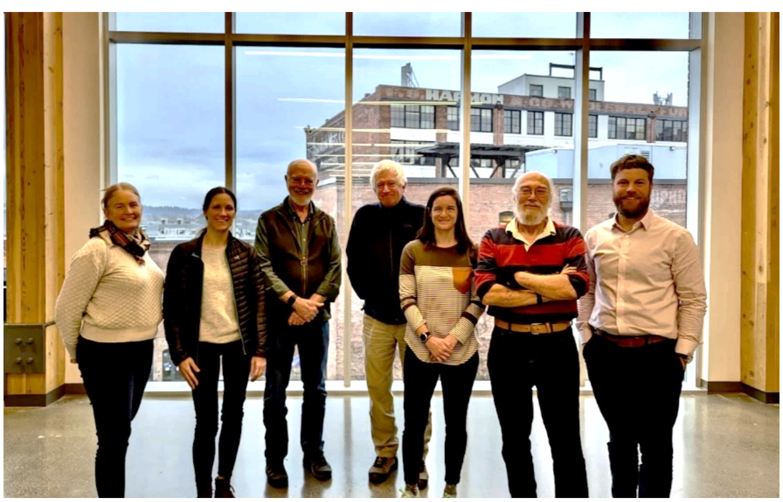
Executive summary

Kelps are a quintessential feature of Washington State nearshore ecosystems and provide habitat for numerous species including commercially harvested fish and invertebrates. Recent data suggest that kelp habitats, especially canopy kelps *Macrocystis* and *Nereocystis* are in decline in the region and globally, potentially threatening the wide range of ecosystem services these habitats provide. Kelps are susceptible to multiple environmental and biological stressors that can contribute to population decline. However, the intensity of these stressors and their ability to cause kelp population decline is not well understood. Here, we built off a previous effort to identify kelp stressors and rated the intensity of kelp stressors in Washington State. We convened a workgroup of six regional kelp experts to rank stressors relying on their own experience, understanding of peer-reviewed literature, and general knowledge of kelp biology and ecology. Experts also rated the degree of certainty of stressor ratings in an attempt to reflect our current understanding of these stressors. This exercise was conducted for three taxa (*Macrocystis, Nereocystis,* and understory kelps) in two life stages – sporophyte and gametophyte. We recognize that there are multiple understory kelp species in Washington State, but given the paucity of direct research on individual understory species we considered understory species together. Compiled workgroup rating results identified temperature and substrate change to be the greatest stressors across all taxa and life stages with a relatively high degree of certainty. High nutrients received the lowest stress score but was accompanied with relatively low certainty. In general, certainty was highest for stressors on *Macrocystis* and *Nereocystis*, taxa with a larger body of scientific research. However, low certainty scores highlight the need for more research on understory kelps and on gametophyte life stages of both understory and floating kelp taxa. Additionally, there was low certainty on the effects of contaminants, high nutrients, and epiphytes on all kelp taxa and life stages. Results from this project will be used to inform a spatial threat assessment of kelps in Puget Sound, which will combine stress scores with spatial data of the distribution of kelps and their stressors using the InVEST Habitat Risk Assessment model.



Kelp stressor rating workgroup. From left, Hilary Hayford, Danielle Claar, Tom Mumford, Steve Rubin, Caitlin Magel, David Duggins, Wendel Raymond, Cathy Pfister (not pictured)

Introduction

The primary goal of this project was to rate known stressors to kelps in Washington State, including Puget Sound, the Strait of Juan de Fuca, and outer Pacific coast. This process is a part of a Puget Sound Partnership (PSP) funded project titled *Distribution of current and future risk of anthropogenic and climate change threats to marine vegetation in Puget Sound* led by the Puget Sound Institute at the University of Washington Tacoma. These expert ratings will be used in conjunction with spatial data of kelps and stressors themselves (or proxies) to build spatially explicit threat assessment models for kelps using publicly available datasets and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Habitat Risk Assessment model. InVEST is a free and open-source modeling tool and the Habitat Risk Assessment model calculates risk based on three aspects: exposure, magnitude, and consequence. Exposure will be based on the spatial co-location of habitats (kelp) and relevant threat layers for a given spatial area. Using the InVEST Habitat Risk Assessment tool, kelp distribution maps will be overlaid with each threat layer. The magnitude of each threat will be based on the intensity category of the threat in that cell: no exposure, low, moderate, and high threat. Consequence is defined as the vulnerability of kelp to that threat, which will be based on the expert scores established in this report.

Rating of kelp stressors was accomplished by an expert working group (hereafter referred to as the "workgroup") comprised of six regional experts in kelp ecology, physiology, and management and led by project personnel Wendel Raymond (WDFW) and Caitlin Magel (UW-Tacoma). The overall goal of the workgroup was to rate kelp stressors based on literature and expert knowledge while capturing differences and nuance of expert opinion in the process. The workgroup proceeded through four phases of work (below) from November 2023 to April 2024.

The project was implemented in four phases (Figure 1; Table 1). Phase 1 (early Nov. 2023 through Dec. 2032) focused on reviewing key literature (Thom et al. 2011, Hollarsmith et al. 2022, McMahon et al. 2022), soliciting the workgroup, and gathering other information. Phase 2 (Jan. 2024) focused on development and deployment of the kelp stressor rating worksheet and supporting materials. The final worksheet was sent to the workgroup for individual ranking in mid-January. Phase 3 (Jan. 2024 – Feb. 2024) focused on building consensus on the final stressor ranting through an in-person workshop on February 21st, 2024. Phase 4 (Feb. 2024 – Apr. 2024) finalized ratings that were reviewed by the workgroup and compiled into this report to be delivered to members of the broader project.

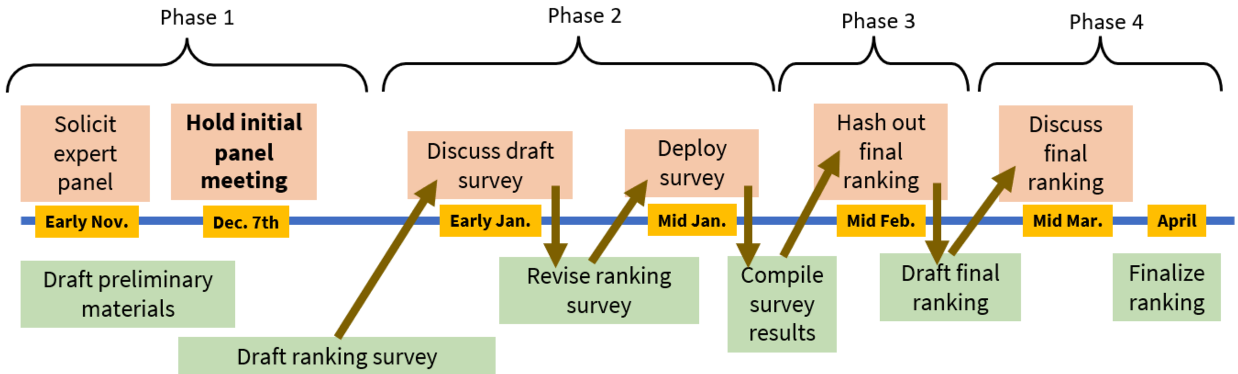


Figure 1: Conceptual timeline of project phases, meetings, and deliverables. Items in orange will involve the whole workgroup, and items in green are the primary responsibility of workgroup leads Wendel Raymond and Caitlin Magel.

Table 1: Workgroup meeting dates and respective goals and outcomes.

Meeting	Date	Goal	Outcomes
Meeting 1 – virtual	7 Dec 2023	Initial meeting to introduce project and workgroup goals and timeline	Review key documents
Meeting 2 – virtual	12 Jan 2024	Discuss draft kelp stressor rating/scoring approach and survey	Finalize and deploy rating survey to workgroup. Summarize results and distribute to workgroup
Meeting 3 – in person	21 Feb 2024	Discuss and finalize kelp stressor ratings/scores based on individual ranks	Draft final report
Meeting 4 – virtual	15 Mar 2024	Discuss draft final kelp stressor rating report	Submit final report to other project objectives. Explore stand-alone publication of this work (optional)

Scope

There are many possible permutations of kelp species, geographic locations, life stages, and morphologies that may affect how biological and environmental stressors influence kelp performance. The goals of the PSP funded grant and subsequent InVEST modeling is focused on adult sporophyte *Nereocystis luetkeana* (bull kelp) in the Washington State portion of the Salish Sea, defined as the inside waters from Cape Flattery east, Puget Sound, and the Washington portion of the southern Strait of Georgia. However, we identified a unique opportunity with the workgroup to expand the scope of stressor rating to include the canopy kelp *Macrocystis pyrifera*, and understory kelps, and the gametophyte life stage of all three taxa. We also expanded the spatial scope to include the outer coast of Washington State as this region supports large populations of kelp. We elected to group all understory kelps as a single guild due to high species diversity and relatively little species-specific knowledge related to stressors. While these divisions may appear coarse, our hope is that they will serve as a starting point for future research and risk assessment and will highlight knowledge gaps.

Project connections

In 2020, the Northwest Straits Commission along with a consortium of state, federal, and regional partners developed the Puget Sound Kelp Conservation and Recovery Plan ("Kelp Plan") which aimed to provide a framework for coordinated research and management actions to protect these foundational and iconic kelp species from a suite of global and local stressors (Calloway et al. 2020). Following the release of the Kelp Plan, the status and trends of kelps in Washington State and the Salish Sea have received a great deal of attention from the resource management, research, and public sectors. The goals of the stressor rating workgroup and the broader spatial modeling project address multiple actions identified in the Kelp Plan including: increasing understanding of kelp stressors to inform management and synthesizing kelp and kelp stressor data to understand distribution and trends, designate protected areas, and promote public awareness.

By the nature of this workgroup and broader project's connection to the Kelp Plan, it is also connected to other Washington State and regional kelp research, monitoring and management efforts. These include, but are not limited to, the Washington State Kelp Research and Monitoring Workgroup, the Kelp Forest Monitoring Alliance of Washington State, the Washington State Floating Kelp Indicator, and British Columbia – Washington State Kelp Node. Furthermore, this project will support multiple Puget Sound Partnership Priority Science Work Actions outlined in the 2020-2024 Science Work Plan, which describes strategies to improve our collective understand of Puget Sound. In particular, Science Work Actions #12 (Risk assessment tools and scenario development) and #13 (Include risk analyses into planning and decision making) will be advanced by providing a risk assessment tool that takes into account the multiple, synergistic threats to kelp and includes the ability to explore how future terrestrial and climate changes could shift the risk landscape for these critical species.

It is the intention of this workgroup and the broader project to integrate and communicate with these and other kelp research, monitoring, and outreach efforts as much as possible.

Kelp stressors

Kelps are subject to a variety of physical and biological stressors that vary in magnitude and spatial and temporal scale (Dayton 1985, Steneck et al. 2002, Filbee-Dexter & Wernberg 2018, Pfister et al. 2019). For this rating exercise we used a list of kelp stressors identified by an expert panel and summarized in Hollarsmith et al. (2022) referred to as "pressures" by those authors. The authors conducted a literature review of peer-reviewed studies from the Salish Sea and temperate nearshore ecosystems worldwide to evaluate the level of support for the drivers and pressures to kelps and the relationships between them (Figure 2).

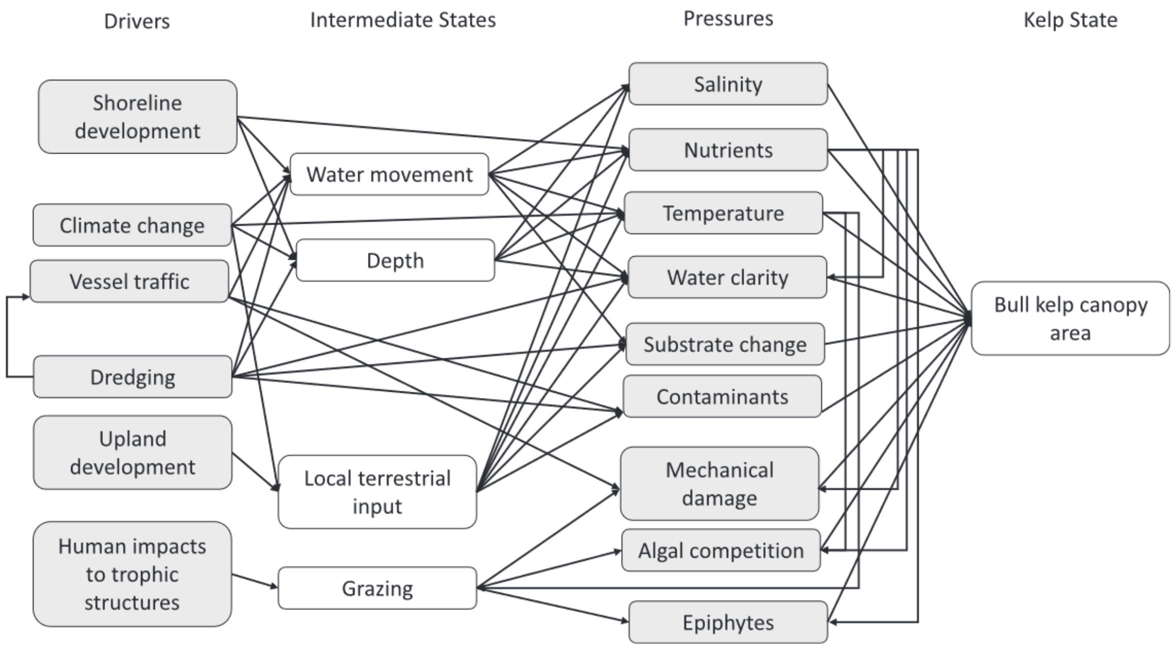


Figure 2: Conceptual diagram of drivers and pressures impacting kelp identified by expert as displayed in Hollarsmith et al. 2022.

We used the nine “pressures” in Hollarsmith et al. (2022) as kelp “stressors” for our rating process (Figure 2). Table 2 defines these stressors in detail, their underlying drivers, interconnections and summarizes their known effects on kelp. While these stressors were identified and defined with regard to *Nereocystis luetkeana* sporophytes, the close ecological relationships among kelps prompted us to apply our framework to the entire Order. However, we feel that they are transferable to *Macrocystis pyrifera*, understory kelps, and the gametophyte life stage. After workgroup discussion, we elected to divide nutrients into two separate stressors, nutrients – high and nutrients – low, leading to 10 total stressors (Table 2; Appendix C).

Stressor rating

Our goal was to incorporate a variety of information from expert judgment and published literature on the nature of kelp stressors in Washington state by deploying a rating survey to the Workgroup. The results of the survey capture the opinions of these experts based on information currently available to them but should be updated over time as new information becomes available. Stressors were rated following a similar process conducted for eelgrass in Puget Sound (Thom et al. 2011). Notably, these eelgrass ratings will be used for an eelgrass risk assessment that is a part of the same larger project as the kelp work described here. The rating approach separates stressors into six stressor characteristics to be scored using a simple low/medium/high or increasing/stable/decreasing scale depending on the stressor. By using qualitative categories, we acknowledge the uncertainty in these ratings. The stressor characteristics scored by Thom et al. (2011) were magnitude, spatial extent, timing, reversibility, and trend over time. Following discussion within the workgroup, we added a seventh stressor characteristic: depth extent. In addition, we modified the low/medium/high scale used by Thom et al. (2011) to include as fourth option: “unknown”. The “unknown” stressor characteristics and associated rating scales are defined in greater detail in the next section.

Table 2: List of kelp stressors, their underlying drivers and a descriptive summary of the pathways and potential interactions among stressors. List was generated from “pressures” in Hollarsmith et al. (2022), however *note the division of nutrients into two categories, high and low, which differs from Hollarsmith et al. (2022).*

Stressor	**Underlying drivers**	**Summary**
Algal competition [Nut, Temp]	Human impacts to trophic structures	Kelp dominated ecosystems are subject to disturbance and therefore community succession. Competition from other algae species is negatively associated with kelp performance. While this may be a natural part of these systems, competition from invasive species such as *Sargassum* spp. is of concern. Opportunistic algae like *Ulva* spp. may outcompete kelps for light and nutrients.
Contaminants	Upland development, vessel traffic, dredging, climate change	Contaminants (pollutants), including heavy metals, sewage, and petrochemicals, reduce kelp performance. These do not include macronutrients.
Epiphytes [Nut, Temp]	Human impacts to trophic structures	Epiphytes are generally considered to have little effect on kelp performance where they have co-evolved with kelps. However, invasive species such as the bryozoan M*embranipora membranacea* can lead to reduced kelp performance.
Mechanical damage [Nut, Temp]	Vessel traffic, human impacts to trophic structures	Tissue damage from biological (e.g., grazing) and physical forces (e.g., waves, currents). Grazing and the presence of grazer is often associated with loss of kelp. In general kelps are resilient to moderate levels of waves and currents, and high current areas way even serve as a refuge. However, areas susceptible to extreme wave events may have a negative effect on kelp performance.
Nutrients - high	Shoreline development, upland development, climate change	In this stressor category, we are primarily interested in the direct effect of high (above basic physiological requirements) water column macronutrient concentrations which can occur from anthropogenic over enrichment.
Nutrients - low	Shoreline development, upland development, climate change	In this stressor category, we are primarily interested in the direct effect of low (below basic physiological requirements) water column macronutrient concentrations which can occur from strong downwelling and/or rapid uptake of nutrients by other primary producers.
Salinity	Shoreline development, upland development, climate change	Lower salinity is often associated with reduced growth.
Substrate change/benthic sedimentation	Shoreline development, upland development, dredging, climate change	Kelps require hard substrates such as bedrock, boulders, and large cobble. Removal and/or covering up of these substrates can lead to complete loss of kelp.
Temperature	Shoreline development, upland development, climate change	Higher than normal temperatures can lead to damage of kelp tissues and may also enhance algal competition and epiphytic growth.
Water clarity [Nut]	Shoreline development, upland development, climate change	Low water clarity is negatively related to kelp performance. Effects can be nonlinear.

[Nut] Stressor effect may be modulated by nutrients.
[Temp] Stressor effect may be modulated by temperature.

Stressor characteristic scoring

The six stressor characteristics defined by Thom et al. (2011) were the basis for our scoring, with some modifications for kelp as motivated by workgroup discussions. We note that some characteristics may not be used in the final InVEST modeling. However, we elected to rate and score stressors in similar categories as Thom et al. (2011) for consistency and to maximize utility of the scoring exercise to other research and management entities. Each characteristic is scored in two ways: (1) rank (low, medium, high, or unknown) - described for each characteristic below and (2) certainty (very low, low, medium, high, or unknown) – described in "Certainty scoring" section.

Magnitude

The effect of the stressor on a small area of kelp. High: the stressor generally results in mortality. Medium: the stressor has strong but sublethal effects, such that additional stresses will likely lead to mortality and/or reduced reproductive output/success. Low: mild sublethal effects that may limit growth, resilience, and/or reproductive output/success of kelp but not lead to mortality without significant other stressors being present. Unknown: lack of scientific and/or practitioner knowledge precludes scoring.

Spatial extent

The relative amount of kelp habitat that is affected by the stressor in the study area. High: the stressor affects all or most of kelp habitats in Washington State. Medium: the stressor affects large parts of kelp habitats in Washington State. Low: effects are either very small in size or in a limited number of areas. Unknown: lack of scientific and/or practitioner knowledge precludes scoring.

Timing

The duration and/or biological or seasonal timing that kelp habitat is affected by the stressor. High: the stressor is nearly always present (>9 months per year) or always occurs during a critical aspect of life history. Medium: the stressor is often present (4 – 9 months per year) or often occurs during a critical aspect of life history. Low: the stressor is occasionally present (1 – 3 months per year) or is occasionally present during a critical aspect of life history. Unknown: lack of scientific and/or practitioner knowledge precludes scoring.

Reversibility

The degree to which the stressor can be removed, agnostic to cost or political likelihood or feasibility. This characteristic is rated in reverse order to other characteristics. High: the stressor can easily be stopped or removed using existing technology at relatively low effort, and habitat will again be suitable for kelp. Medium: the stressor is difficult – but possible - to remove using existing technology and/or some habitat remediation/restoration is required. Low: it is not practically possible to remove or reverse the stressor, or changes to habitat are extensive and require extensive remediation/restoration. For instance, the technology to mediate the stressor does not exist. Unknown: lack of scientific and/or practitioner knowledge precludes scoring.

Trend over time
The pattern observed in the stressor from historical times to the present, and expected into the future. A stressor can increase, decrease, or remain the same. Unknown: lack of scientific and/or practitioner knowledge precludes scoring.

Depth extent
Indicator of where the stressor is present and/or where the stressor is likely to impact kelp. A stressor can be located near surface, near bottom, both, or unknown.

Compiling final stressor ratings

The categorical scores described above were converted to numerical values as follows; High = 3, Medium = 2, Low = 1, Unknown = 0 with the exception of reversibility, for which points were assigned in reverse order; High = 1 and Low = 3 to indicate that high reversibility reduces the threat presented by a stressor. In addition to evaluating each stressor characteristic separately, values of magnitude, spatial extent, timing, and reversibility were averaged for each combination of stressor, kelp taxa and life stage to produce a “total stress” score. Depth extent and trend over time characteristics were excluded from total stress score as they were provide additional context on when and where the stressor occurs. Categorical ratings of trend over time were converted to numerical values as follows; increasing = 1, stable = 0, decreasing = -1.

Certainty rating

Compiling literature
We used the peer-reviewed literature compiled in Hollarsmith et al. (2022) and their literature search criteria (Appendix A) as our basis of peer-reviewed knowledge of kelp stressors. First, we reviewed and curated the list compiled in Hollarsmith et al. (2022) to meet our project goals. We updated the literature list using the same search criteria as Hollarsmith et al. (2022) but limiting the search to 2021 – 2023, and appending in Appendix B. For all literature we created an Excel file of literature metadata in which we attempted to define the stressor, taxa, and life stage of the literature examined. In many cases, a single citation may have studied multiple stressors, taxa, and/or life stages, leading us to duplicate the entry. Conversely, some citations did not have a clear stressor, taxa, and/or life stage of investigation but still provide useful information about stressor mechanics, patterns, or descriptions of kelp life histories. In these cases, we left the taxa and/or life stage metadata blank. The Excel file of literature metadata was provided to workgroup members as a supporting document for ranking exercise and is available as a supplement to this document. Appendix A and resulting citations were generated using Web of Science (Hollarsmith et al. 2022) and Appendix B and resulting citations were generated using Academic Search Premier.

Workgroup instructions for use of literature metadata
The literature metadata file is laid out in a similar fashion to the raking worksheet with stressor, taxa, and life stage listed in the first three columns. Filtering and/or sorting by these columns will allow users to quickly call up citations that are relevant to a particular stressor and/or taxa and/or life stage. Note that all citations include stressor metadata, but some do not list taxa and/or life stage. Blanks or alternative values such as "multiple" were used when a citation did not nicely fit into the framework of this workgroup. However, this does not mean that the literature is not potentially useful.

Certainty scoring
For all characteristics listed above, experts scored the certainty of the stressor characteristic for each stressor, taxa, and life state following a similar low/medium/high scheme with two additional levels, very low, and unknown, described below. This score was based on their research experience, published literature, and reasonable intuition of kelps and nearshore habitats and spices. While the literature search results and metadata were made available to them, workgroup members were not required to review the compiled literature metadata or literature itself. Categorical scoring is as follows. High: this stressor - characteristic is well known and described through research. There is strong evidence and a high level of consensus. Medium: there is some information about this stressor, but specifics may be unknown and/or there is moderate consensus. Low: information about this characteristic is limited and may rely on general biological principles and/or there is little consensus. Very low: information about this characteristic is very limited and heavily relies on general biological principles and/or there is very little consensus. Unknown: lack of scientific knowledge precludes scoring. The categorical certainty scores were converted to numerical values as follows High = 3, Medium = 2, Low = 1, Very low = 0.5 and Unknown = 0.

Compiling final certainty rating
Total stress certainty was defined as the mean of the certainty values for Magnitude, Spatial extent, Timing, and Reversibility.

Workgroup instructions for completing rating exercise
To capture expert opinion on the kelp stressors we endeavor to assess stressors and their certainty for 10 stressors, 3 taxa, and 2 life stages for a total of 60 unique instances. Each instance was then assessed across the 6 characteristics for stressor rank and certainty, for a total of 720 discrete scoring instances. To aid this process we developed an Excel template which lays out stressors, taxa, life stages, and stressor characteristics in a logical grid. To assist experts in ranking we prioritized the stressor, taxa, life stage combinations based on their applicability to the larger project (Table 3).

Table 3: Prioritized list of taxa and life stage combinations for the stressor ranking exercise and group results.

Priority	Taxa – life stage included	Justification
1	Macrocystis sporophytes Nereocystis sporophytes	Strongest connection to spatial data coverage for final threat modeling. Relatively high amount of available research.
2	Understory sporophytes	Broad spatial coverage in Puget Sound and Salish Sea. Relatively high amount of available research compared to gametophytes.
3	Macrocystis gametophytes Nereocystis gametophytes	Strongest connection to spatial data coverage for final threat modeling.
4	Understory gametophytes	Least understood

Summarized individual stressor scores

Scores from individual workgroup members were summarized and distributed to the workgroup for review. An initial review was conducted at an in-person meeting on February 21st 2024. This meeting highlighted desired changes to details of ranking process and analysis. The meeting also captured an in-depth discussion of kelp stressors and interpretation summarized below. Full meeting notes are available in Appendix C and a recording of the meeting is available here.

Summary of rating workgroup in-person discussion

The Workgroup had a wide-ranging discussion covering aspects of the rating and scoring results that needed clarity and/or had a high degree of disagreement among the Workgroup. For example, the Workgroup discussed at length about the meaning of “reversibility” in this context, how to interpret the “trend over time” stressor characteristic, how we define contaminants and differentiating them from nutrients, and how we define epiphytes. The Workgroup discussed nutrients both how they were initially defined (macronutrients) and how to think of them as a stressor. This led to splitting nutrients in to two stressors, high nutrients and low nutrients, even though there is limited information on the effects of very high nutrients as a direct kelp stressor. The nutrient discussion, and others, highlighted the challenge of considering these stressors as only direct effects (i.e., in isolation). This was clearly, and understandably, a challenge for the Workgroup and the rating project in general. There was general agreement that this should be a critical part of the discussion of this process, especially as interactive and indirect effects are strongly associated with nutrients, temperature, and water clarity. We resolved to remove scores of zero from calculations of total stress but to retain certainty values of zero in total stress certainty calculations. and reviewed some updated plots in the meeting. Following the in-person workshop, Workgroup members Pfister, Duggins, Claar, Rubin, Hayford, and Mumford were tasked with adding scores for the refined nutrient stressor categories and reviewing their individual scores in general. Raymond compiled these updated scores and produce summary tables and figures for review at the March 15th meeting.

Final stressor rating

There are four primary products from the workgroup rating and scoring process that were characterized for both rating and certainty: (1) total stress, (2) individual stressor characteristic scores, (3) depth extent, and (4) trend over time. Each of these products can be separated by taxa, life stage, and stressor. These four products can be visualized in a variety of ways, separated by taxa, life stage, or workgroup priority.

Analysis

Raw rank and certainty values from each workgroup member were compiled into a single long-format data file for analysis in R (R Core Team 2023). We computed the mean and standard deviation of rating and certainty for each stressor characteristic and each unique combination of stressor, taxa, and life stage. Total stress rating is defined as the mean of the workgroup mean stressor and certainty scores of the stressor characteristics magnitude, reversibility, timing, and spatial extent. If a rating value of zero was reported, it was omitted from mean calculations but tabulated separately. We also computed the correlation (Pearson) between stressor and certainty rating to explore the relationship between rating and certainty.

Table 4: Key to abbreviations used in plots

Name	Abbreviation
Macrocystis	Macro
Nereocystis	Nereo
Understory	Under
Gametophyte	Gamet
Sporophyte	Sporo
Magnitude	Mag
Spatial extent	Sp ext
Reversibility	Rev
Timing	Time
Depth extent	Dp ext
Trend over time	Trend

Results

All workgroup members provided stressor and certainty ratings and scores for nearly all stressor – taxa – life stage combinations and all stressor characteristics. Results are organized by project priority, and then by taxa – life stage. A key to abbreviations used in some plot titles is in Table 4.

Overall, mean stress and certainty ratings varied by taxa and life stage. However, we observed some general patterns. First, stress and certainty ratings were somewhat positively correlated across magnitude, spatial extent, reversibility, and timing characteristics (Figure 2; Table 5). We observed the highest correlation between rating and certainty with *Macrocystis* and *Nereocystis* sporophytes at 0.32 and 0.37 respectively. A notable exception is mechanical damage on *Nereocystis* and understory gametophytes. Across all taxa and life stages, temperature, low nutrients, algal competition, and substrate change/benthic sedimentation received the highest total stress ratings. These high ratings were concentrated in the magnitude, reversibility, and spatial extent characteristics. Conversely, contaminants, and high nutrients received the lowest total stress ratings across all taxa and life stages.

Table 5: Pearson correlation coefficients of mean stressor rating and certainty across magnitude, spatial extent, reversibility, and timing characteristics.

Taxa	Life stage	Correlation
Macrocystis	Gametophyte	0.16
Macrocystis	Sporophyte	0.32
Nereocystis	Gametophyte	0.24
Nereocystis	Sporophyte	0.37
Understory	Gametophyte	0.14
Understory	Sporophyte	0.29

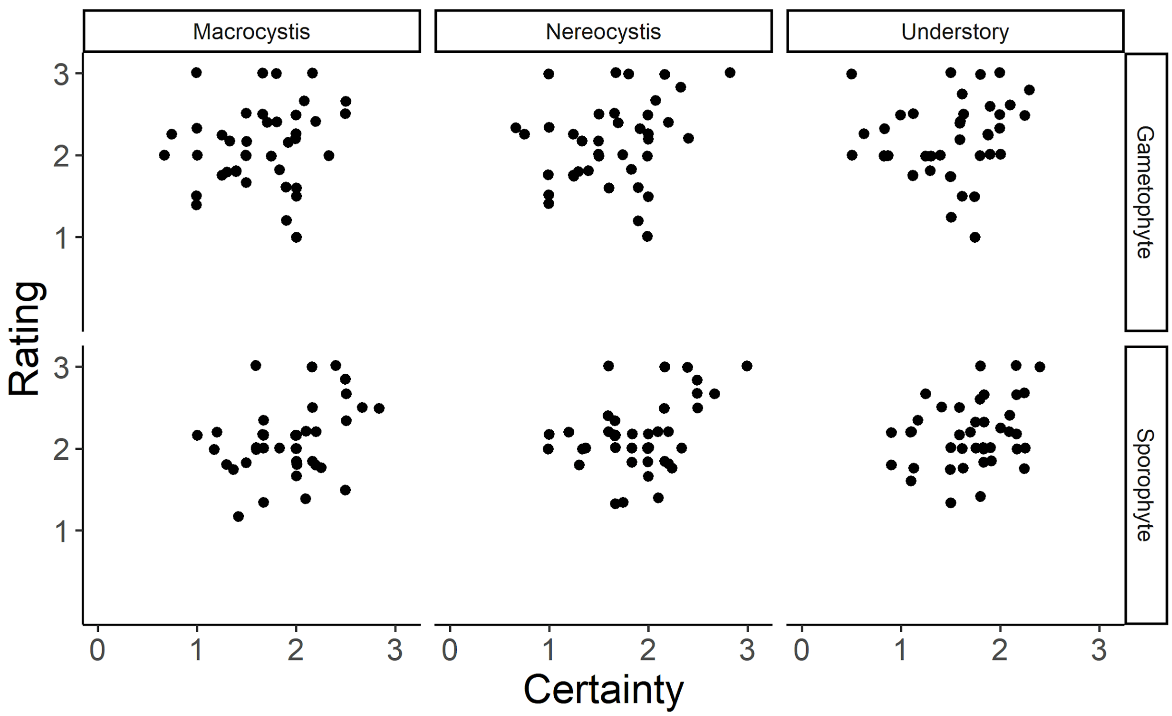


Figure 2: Stressor rating and certainty correlations for magnitude, spatial extent, reversibility, and timing stressor characteristics. Points are mean values from all workgroup members and are jittered for clarity.

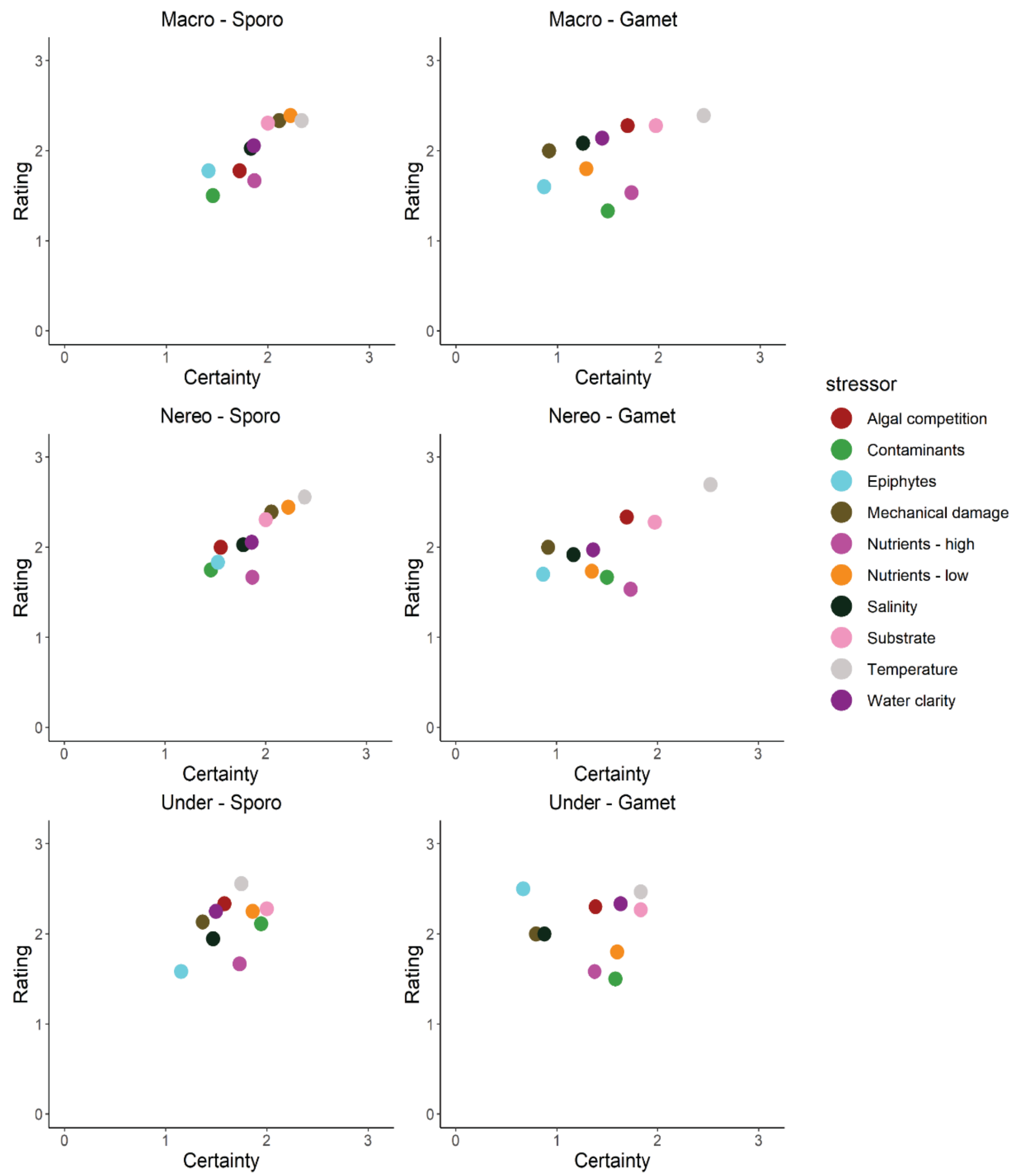


Figure 3: Workgroup mean for total stress rating and certainty for each species – lifestage combination. Colors indicate different stressors.

Priority 1: Macrocystis *and* Nereocystis *sporophytes*

Mean total stress was greatest for temperature, low nutrients, mechanical damage, and substrate change / benthic sedimentation for *Macrocystis* and *Nereocystis* sporophytes (Table 6; Figure 4). High total stress values were driven by high ratings in magnitude, reversibility and spatial extent characteristics (Table 6; Figure 16 - 17). High ratings were accompanied by relatively high certainty ratings. Mean trend over time ratings suggest that all stressors have been and likely will continue to increase with temperature receiving unanimous increasing designations from the workgroup (Figure 5). Certainty ratings of high was also unanimous for temperature. However, the remaining certainty ratings for trend over time were relatively low, ranging from 0.92 to 2.0. Substrate change / benthic sedimentation, water clarity, and algal competition were indicated as stressors which occur near the bottom while the remaining stressors were indicated to occur in the water column or near the surface (Figure 6). Certainty ratings were relatively high for both depth extents was considered for stressors including temperature, low nutrients, mechanical damage, water clarity, salinity, and algal competition. Contaminants received the lowest certainty rank at 1.2 for both taxa.

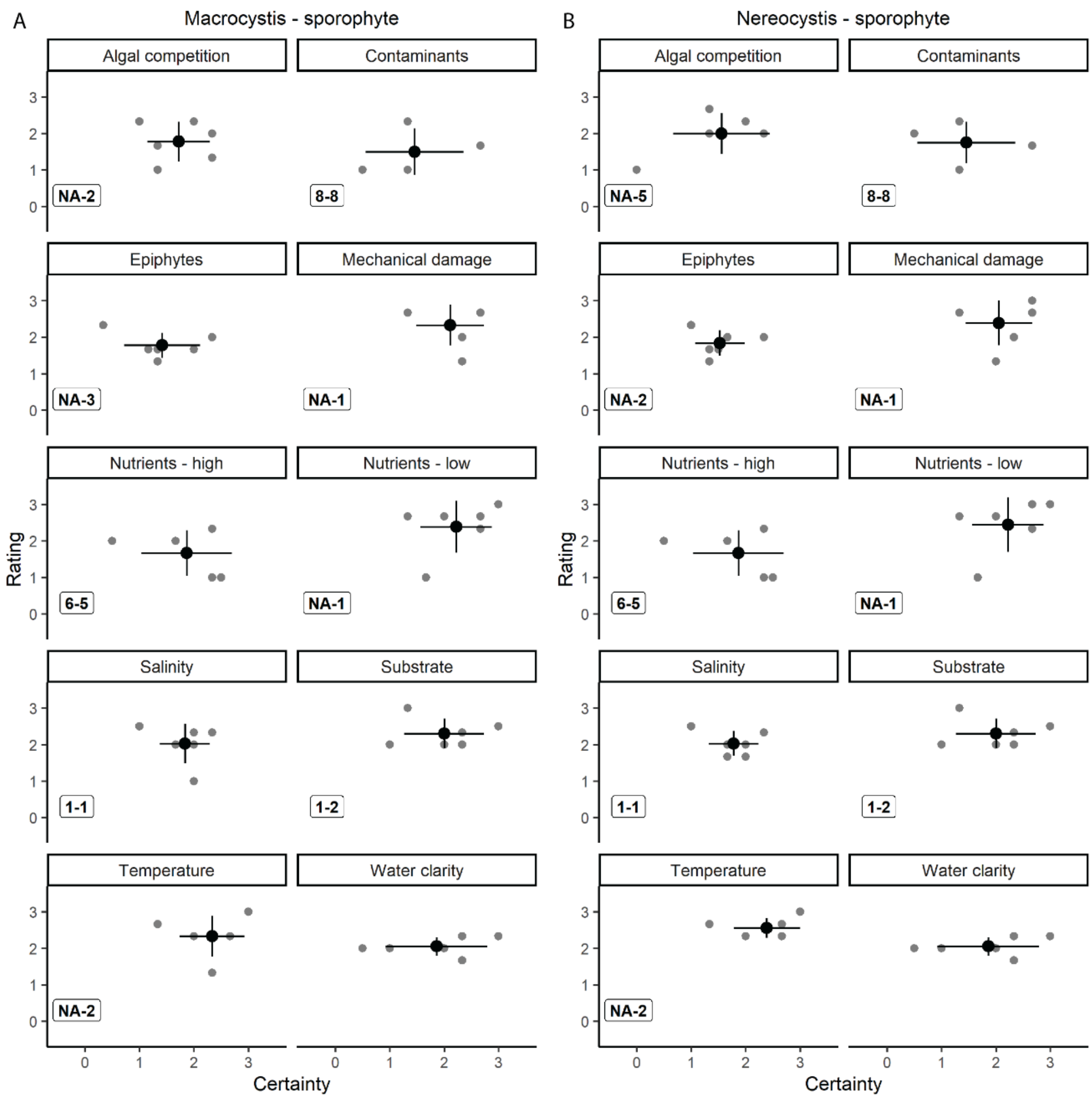


Figure 4: Total stress ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rating calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

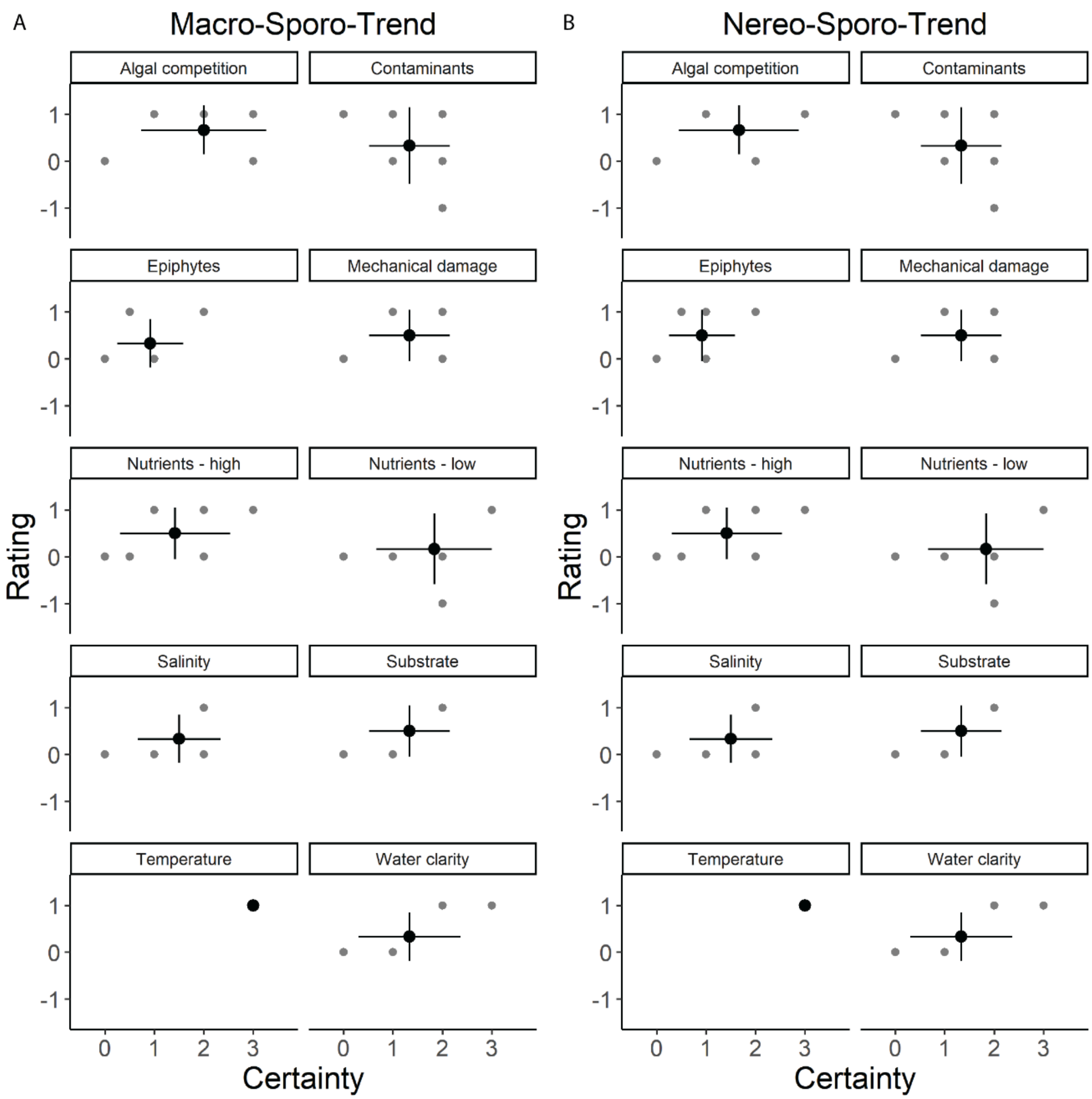


Figure 5: Trend over time ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.*

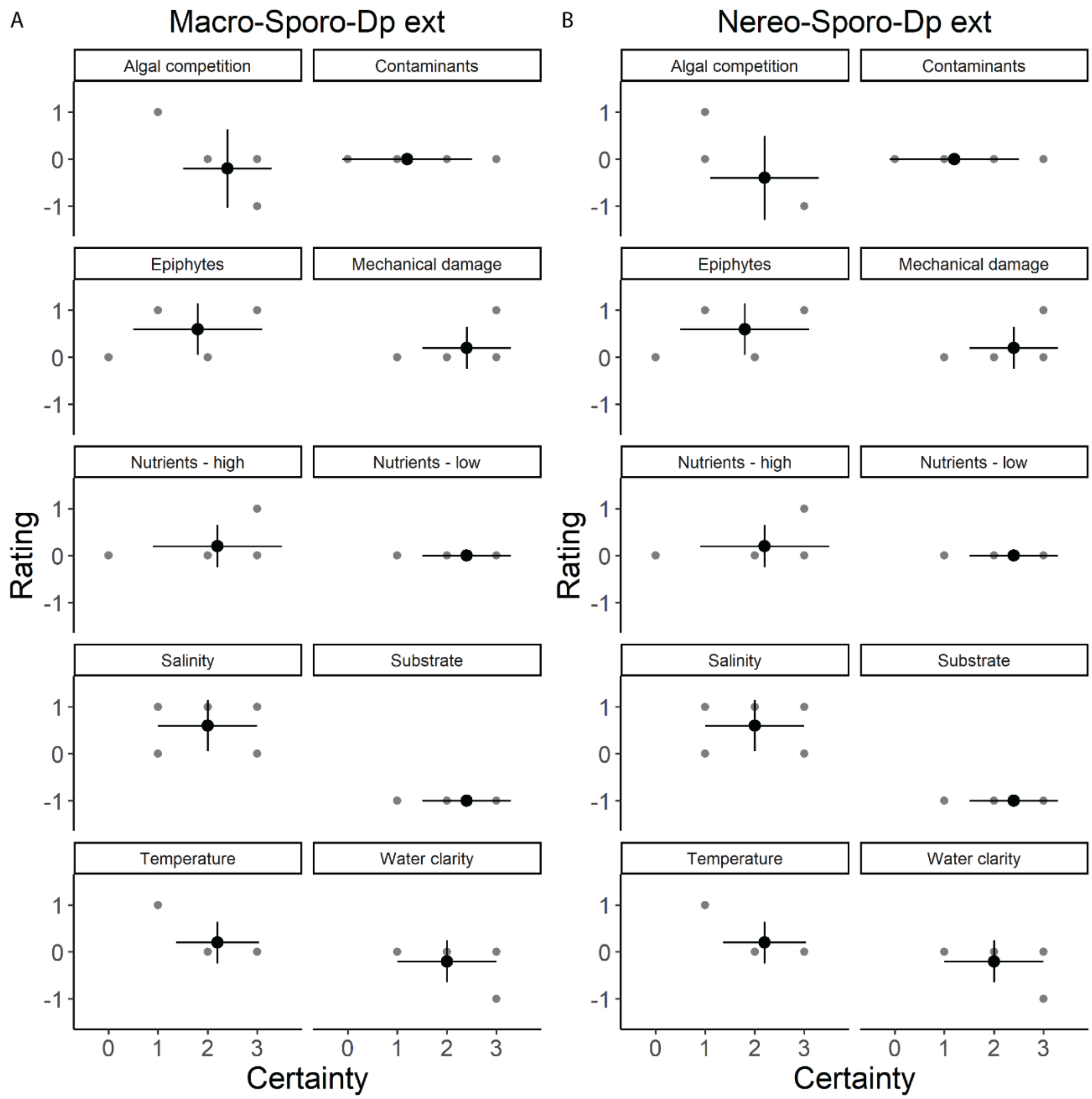


Figure 6: Depth extent ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.*

Table 6: Mean stressor ratings and certainty ratings for all taxa and life stages.

				Stressor characteristics													
				Magnitude		Reversibility		Spatial Extent		Timing		Total Stress		Trend over time		Depth extent	
Priority	Stressor	Taxa	Life stage	Rating	Certainty	Rating	Certainty	Rating	Certainty	Rating	Certainty	Rating	Certainty	Rating	Certainty	Level	Certainty
1	Algal competition	Macrocystis	Sporophyte	1.5	2.5	2	1.6	2	1.17	1.83	1.5	1.78	1.72	0.67	2	-0.2	2.4
1	Algal competition	Nereocystis	Sporophyte	2	2.33	2.4	1.6	2	1	2	1.33	2	1.56	0.67	1.67	-0.4	2.2
1	Contaminants	Macrocystis	Sporophyte	1.33	1.67	1.8	1.3	1.75	1.38	1.67	2	1.5	1.46	0.33	1.33	0	1.2
1	Contaminants	Nereocystis	Sporophyte	1.33	1.67	1.8	1.3	2	1.38	1.67	2	1.75	1.46	0.33	1.33	0	1.2
1	Epiphytes	Macrocystis	Sporophyte	1.17	1.42	3	1.6	2.17	1	2	1.83	1.78	1.42	0.33	0.92	0.6	1.8
1	Epiphytes	Nereocystis	Sporophyte	1.33	1.75	3	1.6	2.17	1	2	1.83	1.83	1.53	0.5	0.92	0.6	1.8
1	Mechanical damage	Macrocystis	Sporophyte	2.5	2.67	1.8	2	2.17	2	2.33	1.67	2.33	2.11	0.5	1.33	0.2	2.4
1	Mechanical damage	Nereocystis	Sporophyte	2.67	2.67	2	2	2.17	1.83	2.33	1.67	2.39	2.06	0.5	1.33	0.2	2.4
1	Nutrients - high	Macrocystis	Sporophyte	1.75	2.25	2.2	2.1	1.4	2.1	2	1.67	1.67	1.87	0.5	1.42	0.2	2.2
1	Nutrients - high	Nereocystis	Sporophyte	1.75	2.25	2.2	2.1	1.4	2.1	2	1.67	1.67	1.87	0.5	1.42	0.2	2.2
1	Nutrients - low	Macrocystis	Sporophyte	2.67	2.5	1.83	2.17	2	2	2.5	2.17	2.39	2.22	0.17	1.83	0	2.4
1	Nutrients - low	Nereocystis	Sporophyte	2.67	2.5	1.83	2.17	2.17	2	2.5	2.17	2.44	2.22	0.17	1.83	0	2.4
1	Salinity	Macrocystis	Sporophyte	2.17	2	3	2.4	1.83	2	2	1.6	2.03	1.83	0.33	1.5	0.6	2
1	Salinity	Nereocystis	Sporophyte	1.83	1.83	3	2.4	2	2	2.2	1.6	2.03	1.78	0.33	1.5	0.6	2
1	Substrate change	Macrocystis	Sporophyte	2.83	2.5	2.17	1.67	1.83	2	2.2	1.2	2.31	2	0.5	1.33	-1	2.4
1	Substrate change	Nereocystis	Sporophyte	2.83	2.5	2.17	1.67	1.83	2	2.2	1.2	2.31	2	0.5	1.33	-1	2.4
1	Temperature	Macrocystis	Sporophyte	2.5	2.83	3	2.17	2.33	2.5	2.17	1.67	2.33	2.33	1	3	0.2	2.2
1	Temperature	Nereocystis	Sporophyte	3	3	3	2.17	2.5	2.5	2.17	1.67	2.56	2.39	1	3	0.2	2.2
1	Water clarity	Macrocystis	Sporophyte	2.17	1.67	2	2	2.2	2.2	1.8	2.2	2.06	1.86	0.33	1.33	-0.2	2

				Stressor characteristics													
				Magnitude		Reversibility		Spatial Extent		Timing		Total Stress		Trend over time		Depth extent	
Priority	Stressor	Taxa	Life stage	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Level*	*Certainty*
1	Water clarity	Nereocystis	Sporophyte	2.17	1.67	2	2	2.2	2.2	1.8	2.2	2.06	1.86	0.33	1.33	-0.2	2
2	Algal competition	Understory	Sporophyte	1.83	1.92	2.6	1.8	2.67	1.25	2.5	1.58	2.33	1.58	0.33	1.5	-0.6	2.4
2	Contaminants	Understory	Sporophyte	2	1.83	1.75	1.5	2	2.17	2.33	1.83	2.11	1.94	0.33	1.5	-0.2	2
2	Epiphytes	Understory	Sporophyte	1.33	1.5	3	1.8	1.8	0.9	1.6	1.1	1.58	1.15	0.33	0.67	-0.2	1.6
2	Mechanical damage	Understory	Sporophyte	2	1.9	1.75	2.25	2.2	1.1	2.2	1.1	2.13	1.37	0.5	1.42	-0.6	2
2	Nutrients - high	Understory	Sporophyte	2	1.83	2.2	2.1	1.4	1.8	2	1.5	1.67	1.73	0.5	1.42	0.2	2.2
2	Nutrients - low	Understory	Sporophyte	2.4	2.1	2.17	2.17	2	1.75	2.33	1.75	2.25	1.86	0.17	1.75	0	2.4
2	Salinity	Understory	Sporophyte	1.75	1.62	3	2.4	2.17	1.58	1.75	1.12	1.94	1.47	0.33	1.67	-0.2	1.8
2	Substrate change	Understory	Sporophyte	2.67	2.17	2.33	1.17	1.83	1.83	2.25	2	2.28	2	0.5	1.58	-0.8	2.4
2	Temperature	Understory	Sporophyte	2.67	2.25	3	2.17	2.67	1.83	2.2	0.9	2.56	1.75	1	3	-0.2	2.6
2	Water clarity	Understory	Sporophyte	2.5	1.42	2	2.25	2.2	1.7	2	1.62	2.25	1.5	0.33	1.25	0	2.2
3	Algal competition	Macrocystis	Gametophyte	2.17	1.92	2.4	2.2	2.5	1.67	2.17	1.5	2.28	1.69	0.5	1.42	-0.8	2.6
3	Algal competition	Nereocystis	Gametophyte	2.33	1.92	2.4	2.2	2.5	1.67	2.17	1.5	2.33	1.69	0.5	1.42	-0.8	2.6
3	Contaminants	Macrocystis	Gametophyte	1.5	2	1.8	1.3	1.67	1.5	1	2	1.33	1.5	0.17	1.25	-0.6	1.8
3	Contaminants	Nereocystis	Gametophyte	1.5	2	1.8	1.3	2	1.5	1	2	1.67	1.5	0.17	1.25	-0.4	1.8
3	Epiphytes	Macrocystis	Gametophyte	1.4	1	3	1.67	3	1	2	0.67	1.6	0.87	0.17	0.58	-0.4	1.6
3	Epiphytes	Nereocystis	Gametophyte	1.4	1	3	1.67	3	1	2.33	0.67	1.7	0.87	0.17	0.58	-0.4	1.6
3	Mechanical damage	Macrocystis	Gametophyte	1.75	1.25	2.5	1.5	2.25	0.75	2.33	1	2	0.92	0.33	1.08	-1	2.2
3	Mechanical damage	Nereocystis	Gametophyte	1.75	1.25	2.5	1.5	2.25	0.75	2.33	1	2	0.92	0.33	1.08	-1	2.2
3	Nutrients - high	Macrocystis	Gametophyte	1.6	1.9	2.4	1.7	1.2	1.9	1.8	1.4	1.53	1.73	0.33	1.33	-0.5	1.6
3	Nutrients - high	Nereocystis	Gametophyte	1.6	1.9	2.4	1.7	1.2	1.9	1.8	1.4	1.53	1.73	0.33	1.33	-0.75	1.8
3	Nutrients - low	Macrocystis	Gametophyte	1.8	1.4	1.6	2	2	1.5	1.5	1	1.8	1.28	0.17	1.75	-0.75	1.8
3	Nutrients - low	Nereocystis	Gametophyte	1.6	1.6	2	2	2	1.5	1.5	1	1.73	1.35	0.17	1.75	-0.75	1.8
3	Salinity	Macrocystis	Gametophyte	2	1.5	3	1.8	2.25	1.25	2	1	2.08	1.25	-0.17	0.92	-1	2.4
3	Salinity	Nereocystis	Gametophyte	1.75	1.25	3	1.8	2.25	1.25	1.75	1	1.92	1.17	-0.17	0.92	-1	2.4
3	Substrate change	Macrocystis	Gametophyte	2.67	2.08	2.2	2	1.83	1.83	2.25	2	2.28	1.97	0.5	1.42	-1	2.4

				Stressor characteristics													
				Magnitude		**Reversibility**		**Spatial Extent**		**Timing**		**Total Stress**		**Trend over time**		**Depth extent**	
Priority	**Stressor**	**Taxa**	**Life stage**	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Rating*	*Certainty*	*Level*	*Certainty*
3	Substrate change	Nereocystis	Gametophyte	2.67	2.08	2.2	2	1.83	1.83	2.25	2	2.28	1.97	0.5	1.42	-1	2.4
3	Temperature	Macrocystis	Gametophyte	2.5	2.5	3	2.17	2.67	2.5	2	2.33	2.39	2.44	1	3	-0.8	2.6
3	Temperature	Nereocystis	Gametophyte	3	2.83	3	2.17	2.83	2.33	2.2	2.4	2.69	2.53	1	3	-0.8	2.6
3	Water clarity	Macrocystis	Gametophyte	2.17	1.33	2.5	2	2.4	1.8	2	1.75	2.14	1.44	0.33	1.25	-0.4	2.2
3	Water clarity	Nereocystis	Gametophyte	2.17	1.33	2.5	2	2.25	2	2	1.75	1.97	1.36	0.33	1.25	-0.2	2.2
4	Algal competition	Understory	Gametophyte	2.4	1.6	2.5	2.25	2.5	1.12	2	1.4	2.3	1.38	0.33	1	-0.75	1.8
4	Contaminants	Understory	Gametophyte	1.5	1.75	1.75	1.5	2	1.25	1	1.75	1.5	1.58	0.17	1.58	-0.5	1.2
4	Epiphytes	Understory	Gametophyte	2	0.5	3	1.5	3	0.5	2.5	1	2.5	0.67	0.17	0.58	-1	1.8
4	Mechanical damage	Understory	Gametophyte	1.75	1.12	2.33	2	2.25	0.62	2.33	0.83	2	0.79	0.5	1.08	-1	1.6
4	Nutrients - high	Understory	Gametophyte	1.75	1.5	2.5	1.62	1.25	1.5	1.75	1.12	1.58	1.38	0.33	1.33	-0.75	1.8
4	Nutrients - low	Understory	Gametophyte	2	1.9	2	2	1.5	1.62	1.8	1.3	1.8	1.6	0.17	1.75	-0.75	1.8
4	Salinity	Understory	Gametophyte	2	0.83	3	1.8	2	0.88	2	0.83	2	0.88	-0.17	0.92	-1	1.8
4	Substrate change	Understory	Gametophyte	2.6	2.1	2.4	1.6	2	1.8	2.2	1.6	2.27	1.83	0.5	1.42	-1	1.8
4	Temperature	Understory	Gametophyte	2.8	2.3	3	2	2.6	1.9	2	1.3	2.47	1.83	0.83	2.58	-1	2
4	Water clarity	Understory	Gametophyte	2.75	1.62	2.5	2	2.25	1.88	2.25	1.88	2.33	1.63	0.33	1.25	-0.5	1.6

Priority 2: Understory sporophytes

Total stress ratings for understory sporophytes were rated highest for temperature, algal competition, substrate change / benthic sedimentation, low nutrients and water clarity (Table 6; Figure 7). Ratings for high total stress was driven by high reversibility, spatial extent, and magnitude characteristics values. Certainty ratings for total stress were generally low, especially compared to priority one taxa and ranged from 1.15 to 2.0, with a mean across all stressors of 1.64. Magnitude and reversibility had the relative highest certainty of all total stress characteristics. All stressors were scored to be increasing but with low certainty with the expectation of temperature (Figure 8). Workgroup ratings were unanimous that temperature is increasing with a high certainty. The depth extent of stressors was considered near bottom for most stressors with reasonably high certainty (Figure 9). Figure 18 details ranks and certainty of individual stressor characteristics.

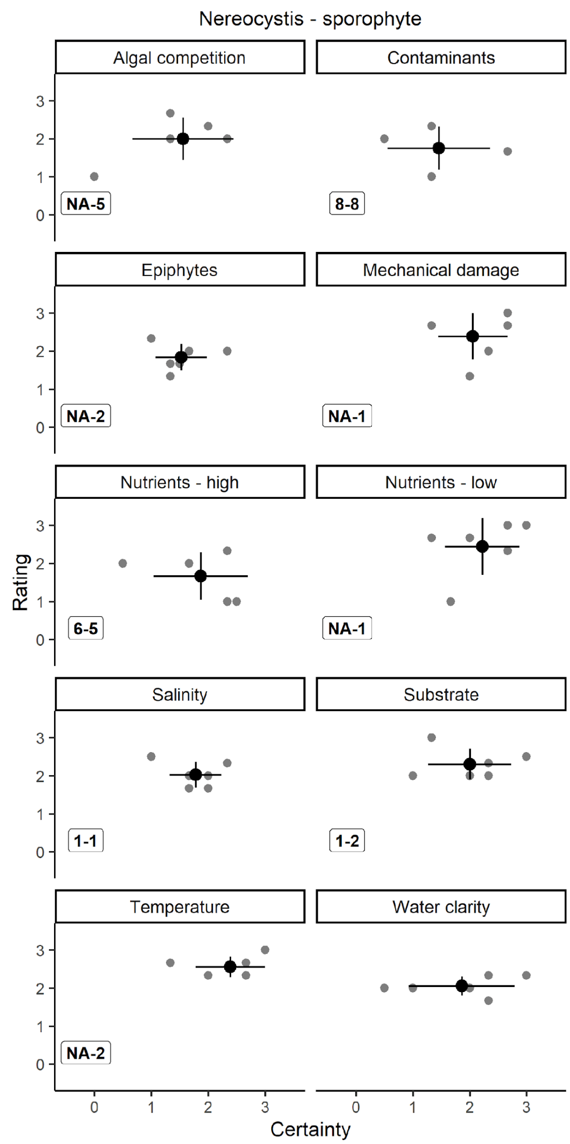


Figure 7: Total stress ratings and certainty for each kelp stressor of understory sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note, zeros are omitted from mean rating calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.

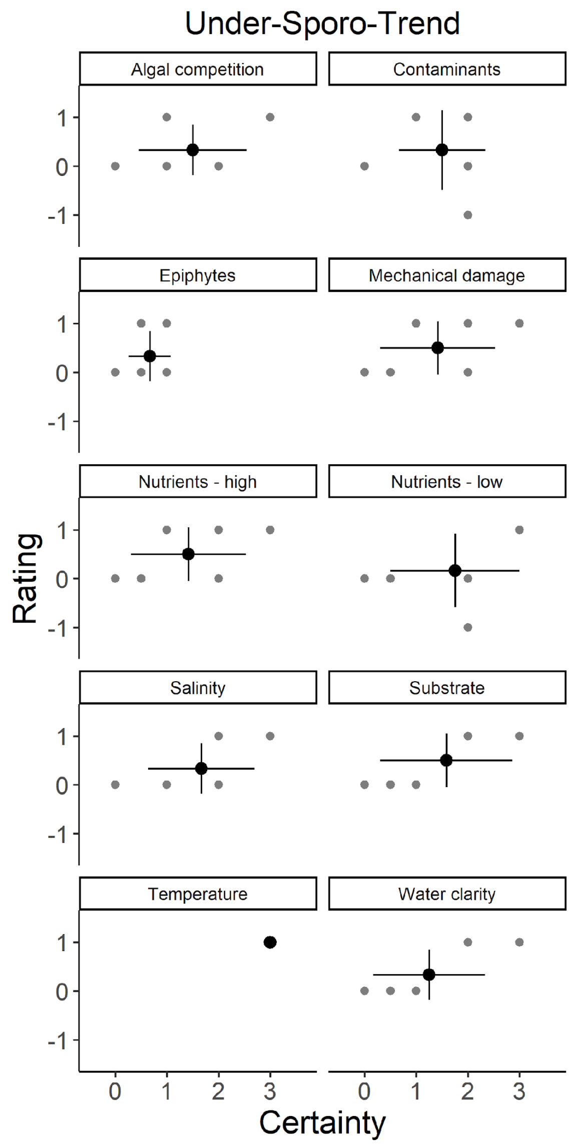


Figure 8: Trend over time ratings and certainty for each kelp stressor understory sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.

Priority 3: Macrocystis *and* Nereocystis *gametophytes*

The total stress for *Macrocystis* and *Nereocystis* gametophytes was rated highest for temperature, algal competition, and substrate change / benthic sedimentation (Table 6; Figure 10). High total stress was driven by reversibility and spatial extent characteristic values. Contaminants for *Macrocystis* gametophytes, received the lowest total stress accompanied by a relatively low certainty of 1.5. Certainty was low ranging from 0.87 to 1.97 for all stressors, except temperature which scored 2.44 and 2.53 for *Nereocystis* and *Macrocystis* respectively. The workgroup indicated that all stressors are increasing, with the exception of salinity which received a slight decreasing score of -0.17 for both taxa (Figure 11). Paired certainty ratings were generally low, ranging between 0.58 and 1.75, with the exception of temperature which received a unanimous ranking of 3. All stressors received near bottom depth extent ratings ranging from -1 to -0.2 (Figure 12). Most stressors received relatively high certainty ratings, except for low and high nutrients, epiphytes, and contaminants. Figure 19 - 20 details ranks and certainty of individual stressor characteristics.

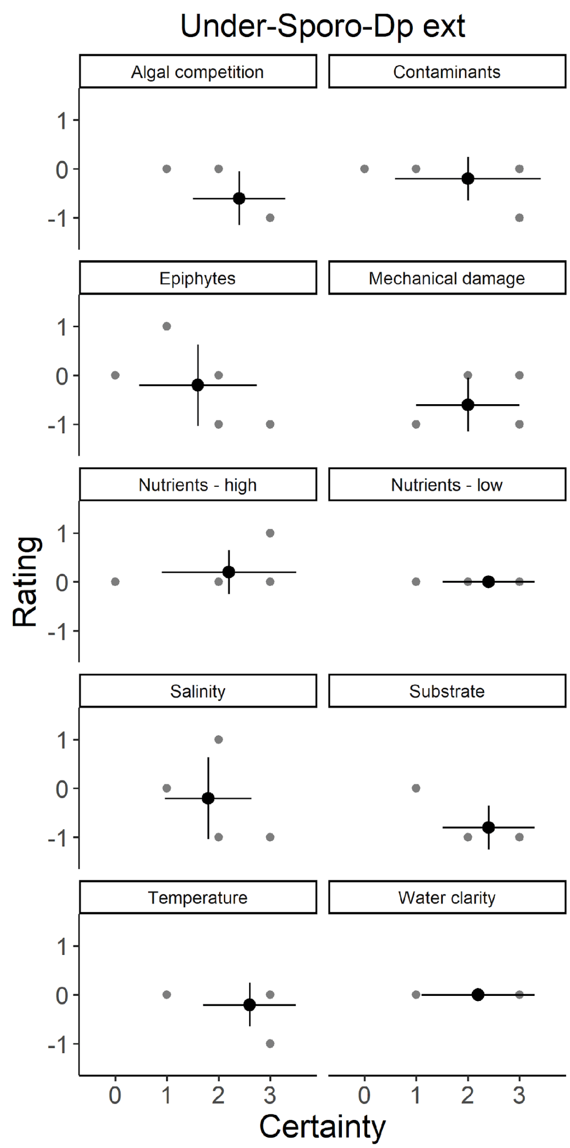


Figure 9: Depth extent ratings and certainty for each kelp stressor of understory sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.

Priority 4: Understory gametophytes.

Total stress for understory gametophytes was rated highest for epiphytes, temperature, water clarity, algal competition, and substrate change / benthic sedimentation (Table 6; Figure 13). High total stress values were driven by magnitude, reversibility, and spatial extent. High nutrients and contaminants received relatively low total stress values. Certainty values for total stress, and all stressor characteristics, were universally low compared to other taxa – life stages. Total stress certainty ranged from 0.67 to 1.83. All stressors received slightly increasing trend over times scores with the exception of salinity which was slightly negative at -0.17. However, certainty was relatively low for all stressors ranging from 0.58 to 1.75, except for temperature which was scored at 2.58 (Figure 14). All stressors received near bottom depth extent scores ranging from -1 to -0.5. These were accompanied by moderate certainty scores ranging from 1.2 to 2.0 (Figure 15). Figure 21 details ranks and certainty of individual stressor characteristics.

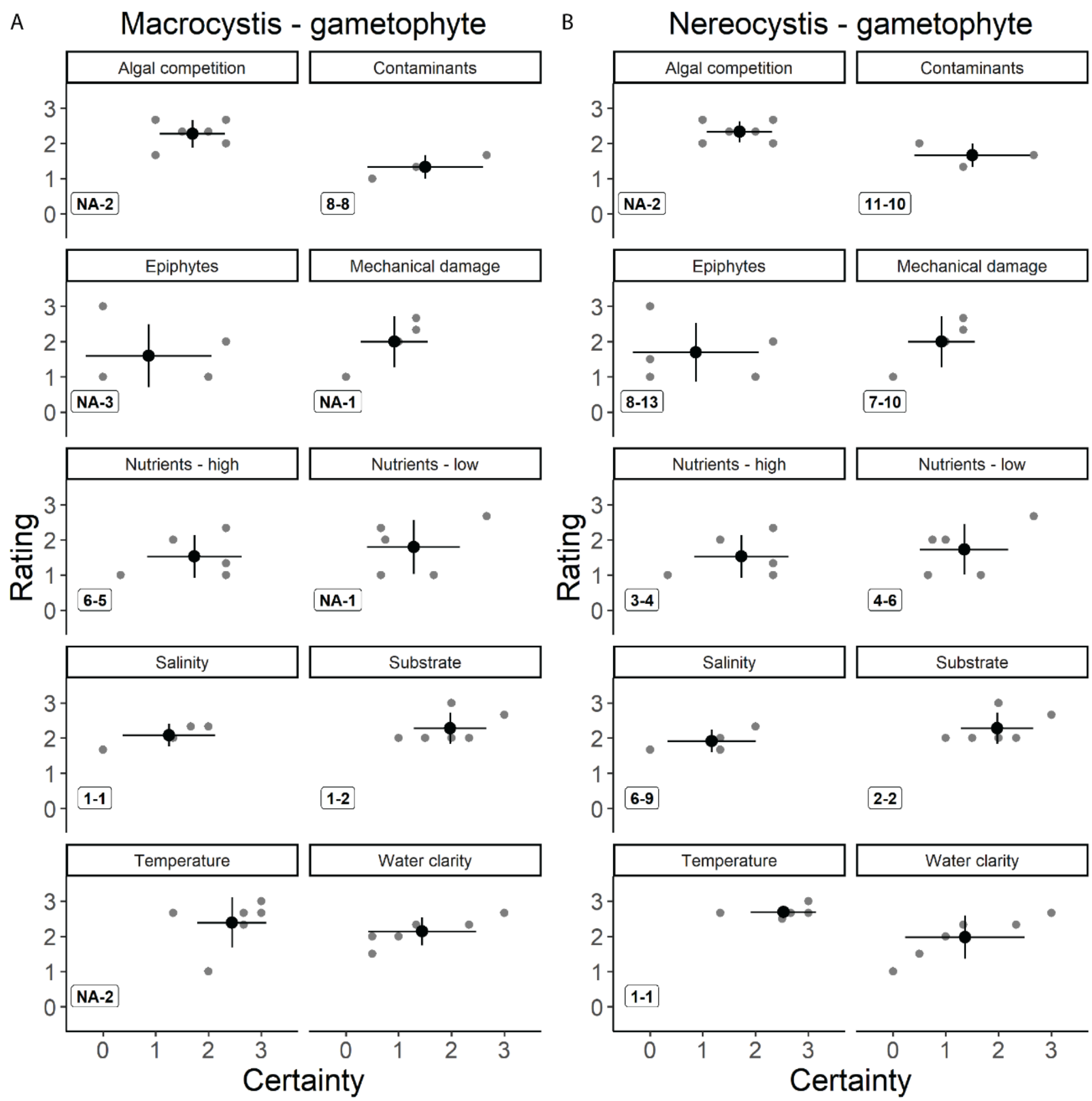


Figure 10: Total stress ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean ratings calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

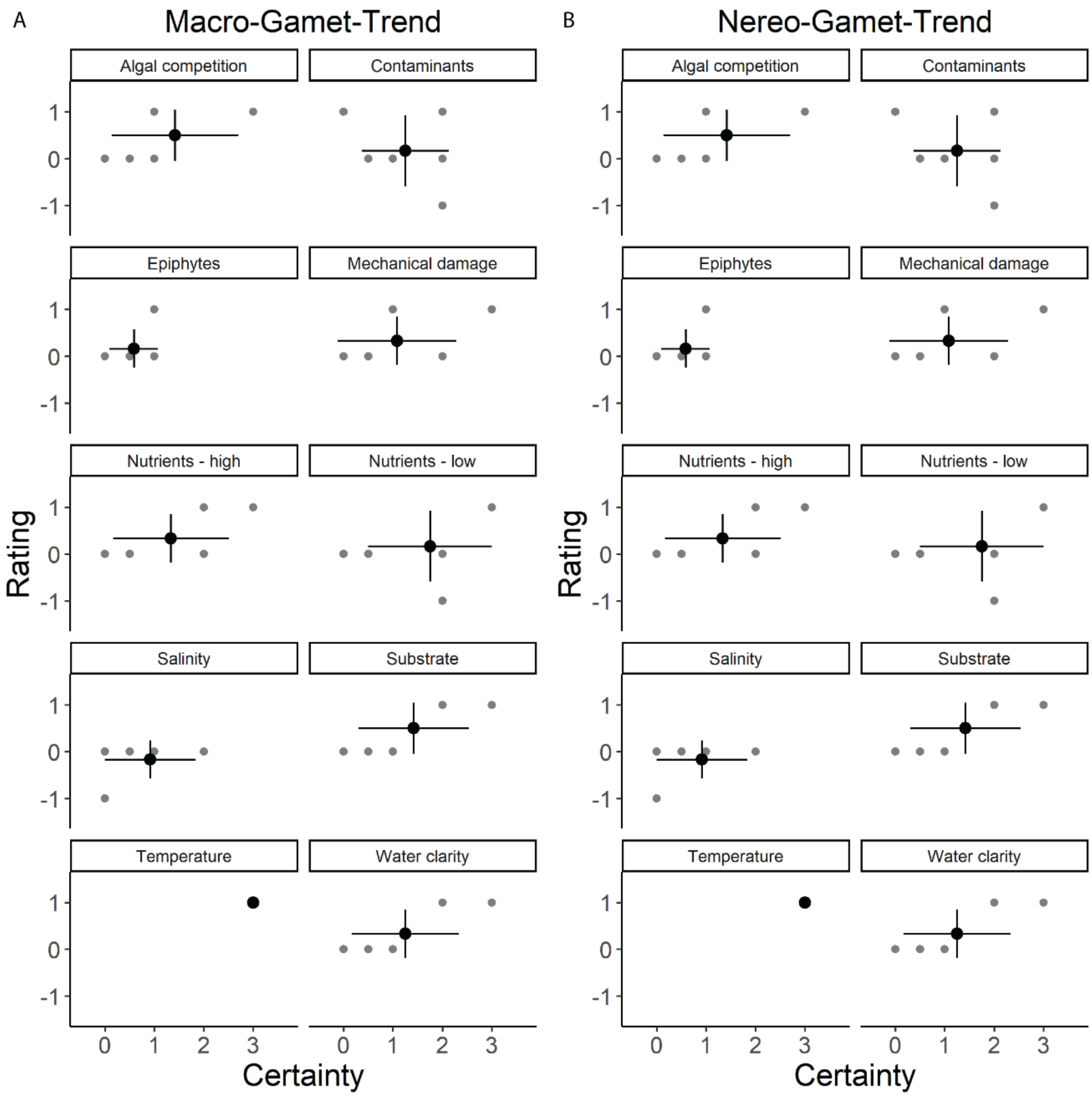


Figure 11: Trend over time ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.*

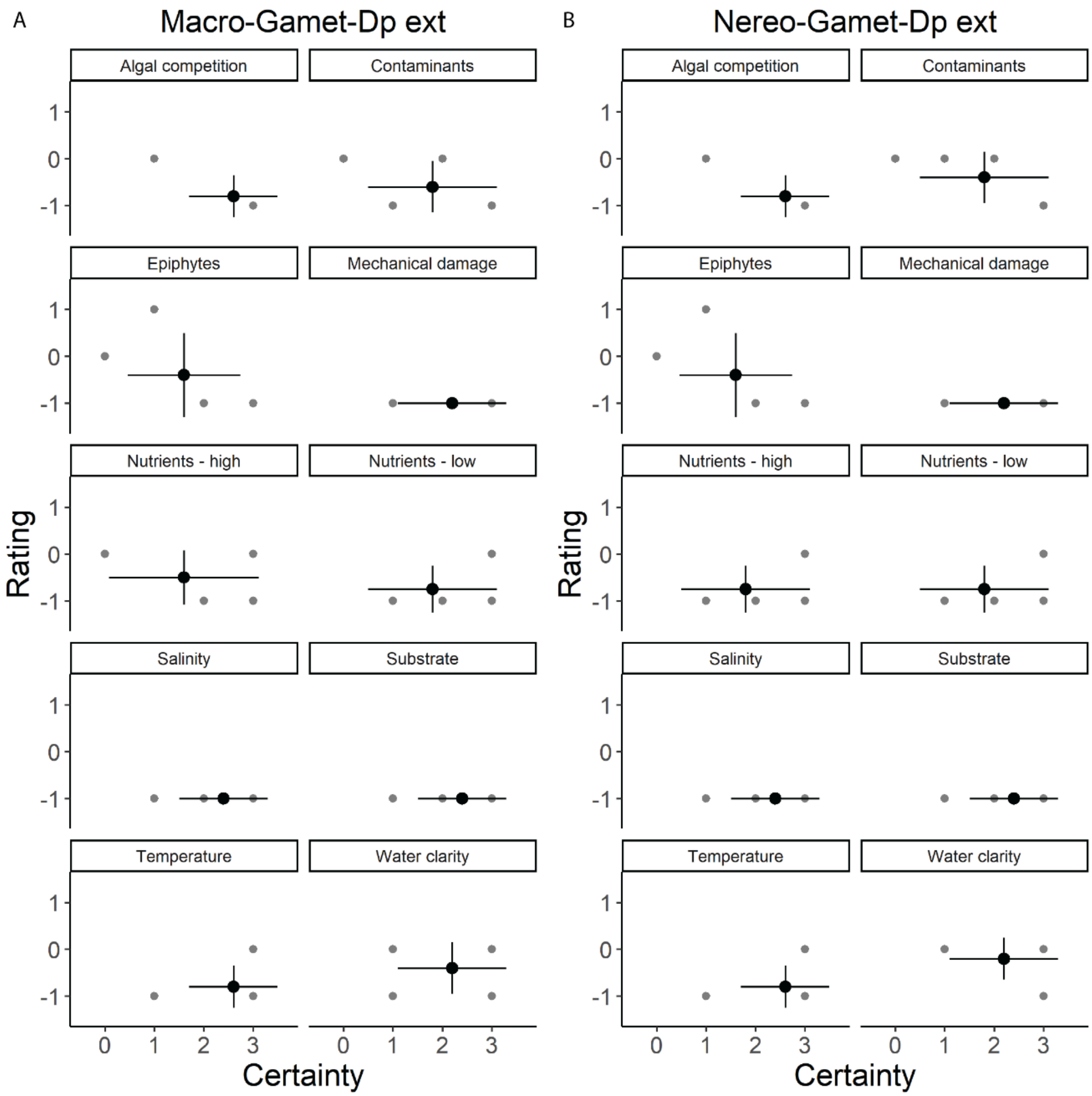


Figure 12: Depth extent ratings and certainty for each kelp stressor of (A) Macrocystis *and (B)* Nereocystis *gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note that instances where less than six grey points are visible reflect overlapping grey points.*

Workgroup variability

Variation of stressor ratings and certainty ranged widely among the workgroup. In general stressor ratings were relatively less variable than certainty ratings. Priority 1 total stress taxa – life stages had the least variability among workgroup members, ranging from 0.25 to 0.75 for ranks, and 0.45 to 0.89 for certainty. Stressor and certainty rating variability generally increased as priority group increased.

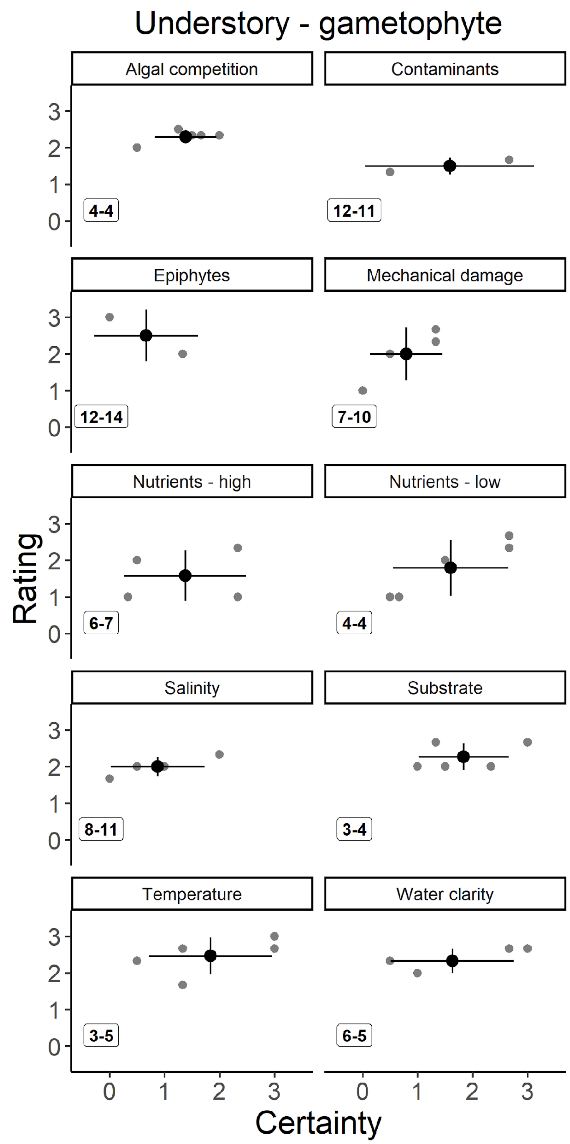


Figure 13: Total stress ratings and certainty for each kelp stressor of understory gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note, zeros are omitted from mean ratings calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.

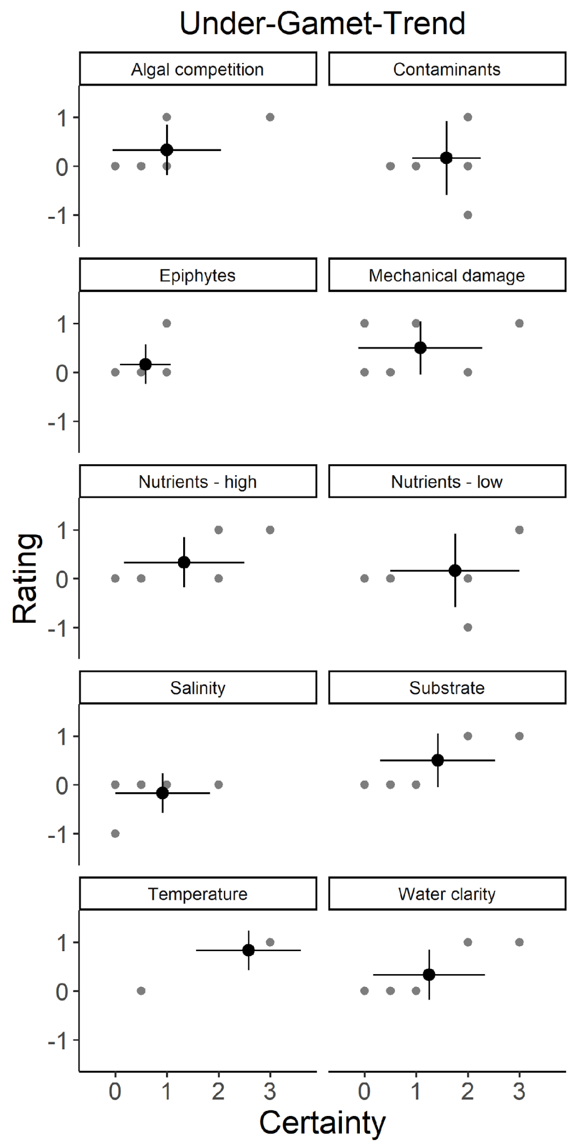


Figure 14: Trend over time ratings and certainty for each kelp stressor of understory gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note, zeros are omitted from mean ratings calculations but not certainty. Note that instances where less than six grey points are visible reflect overlapping grey points.

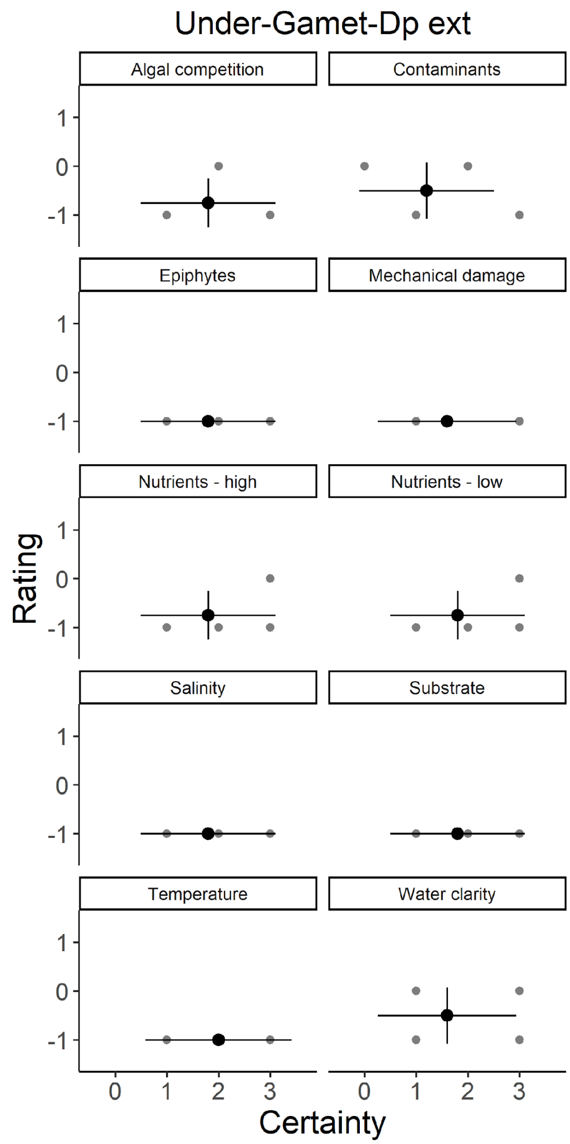


Figure 15: Depth extent ratings and certainty for each kelp stressor of understory gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Note, zeros are omitted from mean ratings calculations but not certainty. Note that instances where less than six grey points are visible reflect overlapping grey points.

Summary

Mean workgroup stressor and certainty ratings provide the most complete assessment kelp stressor intensity in the Washington portion of the Salish Sea to date. Temperature and substrate change consistently received the highest ratings in individual stressor characteristics and total stress. Conversely, high nutrients consistently received low stressor ratings in individual stressor characteristics and total stress. Certainty was highest for *Macrocystis* and *Nereocystis* sporophytes, likely reflecting the relatively large amount of research focused on these taxa. Certainty ratings were generally lower for understory, and for gametophyte life stages, reflecting the relative lack of research on these taxa and life stages. Nearly all stressors were indicated to be increasing, especially temperature. The lone exception was salinity which received a slightly declining trend. Depth extent ratings generally followed life history with *Macrocystis* and *Nereocystis* sporophytes receiving near surface ratings and understory and gametophytes receiving near bottom ratings.

Spatial risk modeling

The stressor and certainty ratings provided here will be used in a subsequent spatially explicit, cumulative risk assessment, as described in the Introduction of this report. Our approach will be similar to McMahon et al. (2022), including the use of InVEST's Habitat Risk Assessment Model, and will be performed for canopy kelp and eelgrass in the Washington State portion of the Salish Sea. While the exact method is still being determined, some combination of the stressor rank and certainty values will be paired with spatial data of the habitats and spatial data describing the stressors or reasonable proxies. A tentative list of spatial data sources to describe each stressor (or serve as a stressor proxy) is provided in Table 7.

Table 7: Tentative list of stressor or stressor proxies spatial data layers and sources for the spatially-explicit, cumulative risk assessment for kelp in Puget Sound.

Kelp Stressor	Time	Proposed Variable or Proxy	Prospective Available Data Source(s)	Links/Contact
Algal competition	Current	Riverine and wastewater treatment plant nutrient loading & variability (causes eutrophication)	WA Dept. of Ecology; Salish Sea Model	https://apps.ecology.wa.gov/eim/search/Default.aspx
Algal competition	Current	modeled temperature	Salish Sea Model or LiveOcean	
Contaminants	Current	% area in catchment with industrial land use	Department of Commerce	https://geo.wa.gov/datasets/a0ddbd4e0e2141b3841a6a42ff5aff46_0/explore
Contaminants	Current	presence of oil/gas production in cell or adjacent cell	Dept. of Ecology Spills Program Facilities & reported spills	https://apps.ecology.wa.gov/coastalatlas/storymaps/spills/spills_sm.html
Contaminants	Current	presence of vessels in cell or adjacent cell	MarineCadastre.gov	https://marinecadastre.gov/ais/
Contaminants	Current	designated dredge disposal sites in cell or adjacent cell	US Army Corps	https://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/
Epiphytes	Current	Riverine and wastewater treatment plant nutrient loading & variability (causes algal overgrowth)	WA Dept. of Ecology; Salish Sea Model	https://apps.ecology.wa.gov/eim/search/Default.aspx
Mechanical damage	Current	presence of vessels in cell or adjacent cell	MarineCadastre.gov	https://marinecadastre.gov/ais/
Mechanical damage	Current	presence of port or record of dredging in cell or adjacent cell	WDNR Port Facility maps	https://data-wadnr.opendata.arcgis.com/
Nutrients (high)	Current	riverine and wastewater treatment plant loading & variability	WA Dept. of Ecology; Salish Sea Model	https://apps.ecology.wa.gov/eim/search/Default.aspx

Kelp Stressor	Time	Proposed Variable or Proxy	Prospective Available Data Source(s)	Links/Contact
Nutrients (high)	Current	shoreline development - presence of shoreline armoring in cell or adjacent drift cell	WDNR; Beach Strategies Tool, and PSNERP	https://data-wadnr.opendata.arcgis.com/ ; https://beach-strategies-wdfw-hub.hub.arcgis.com/
Nutrients (high)	Future	future catchment condition (% area modified vs. unmodified) OR estimated % impervious surface cover	PSI Land Cover Change Model	https://www.pugetsoundinstitute.org/psimf-lccm/
Nutrients (high)	Future	Modeled nutrients under future climate scenario (exceeding a high threshold)	Salish Sea Model (Khangaokar et al. 2021 Ecological Modeling)	https://doi.org/10.1016/j.ecolmodel.2020.109420
Nutrients (low)	Current			
Nutrients (low)	Future	Modeled nutrients under future climate scenario (exceeding a low threshold)	Salish Sea Model (Khangaokar et al. 2021 Ecological Modeling)	https://doi.org/10.1016/j.ecolmodel.2020.109420
Salinity	Current	modeled salinity	Salish Sea Model or LiveOcean	
Salinity	Future	Modeled salinity under future climate scenario	Salish Sea Model (Khangaokar et al. 2021 Ecological Modeling)	https://doi.org/10.1016/j.ecolmodel.2020.109420
Substrate change / benthic sedimentation	Current	designated dredge disposal sites in cell or adjacent cell	US Army Corps	https://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/
Substrate change / benthic sedimentation	Current	% area in catchment with high/medium intensity development OR % impervious surface coverage	Department of Commerce	https://geo.wa.gov/datasets/a0ddbd4e0e2141b3841a6a42ff5aff46_0/explore
Substrate change / benthic sedimentation	Future	future catchment condition (% area modified vs. unmodified) OR estimated % impervious surface cover	PSI Land Cover Change Model	https://www.pugetsoundinstitute.org/psimf-lccm/

Kelp Stressor	Time	Proposed Variable or Proxy	Prospective Available Data Source(s)	Links/Contact
Temperature	Current	modeled temperature	Salish Sea Model or LiveOcean	
Temperature	Future	Modeled temperature under future climate scenario	Salish Sea Model (Khangaokar et al. 2021 Ecological Modeling)	https://doi.org/10.1016/j.ecolmodel.2020.109420
Water clarity	Current	presence of port or record of dredging in cell or adjacent cell	WDNR Port Facility maps	https://data-wadnr.opendata.arcgis.com/
Water clarity	Current	designated dredge disposal sites in cell or adjacent cell - source of sediment load	US Army Corps	
Water clarity	Current	river mouth in cell or adjacent cell - source of sediment load		

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McMahon K, Kilminster K, Canto R, Roelfsema C, Lyons M, Kendrick GA, Waycott M, Udy J (2022) The Risk of Multiple Anthropogenic and Climate Change Threats Must Be Considered for Continental Scale Conservation and Management of Seagrass Habitat. Front Mar Sci 9:837259.

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Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner MJ (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. Envir Conserv 29:436–459.

Thom R, Judd C, Buenau K, Cullinan V (2011) Eelgrass (*Zostera marina* L.) Stressors in Puget Sound. U.S. Department of Energy.

Stressor characteristics figures

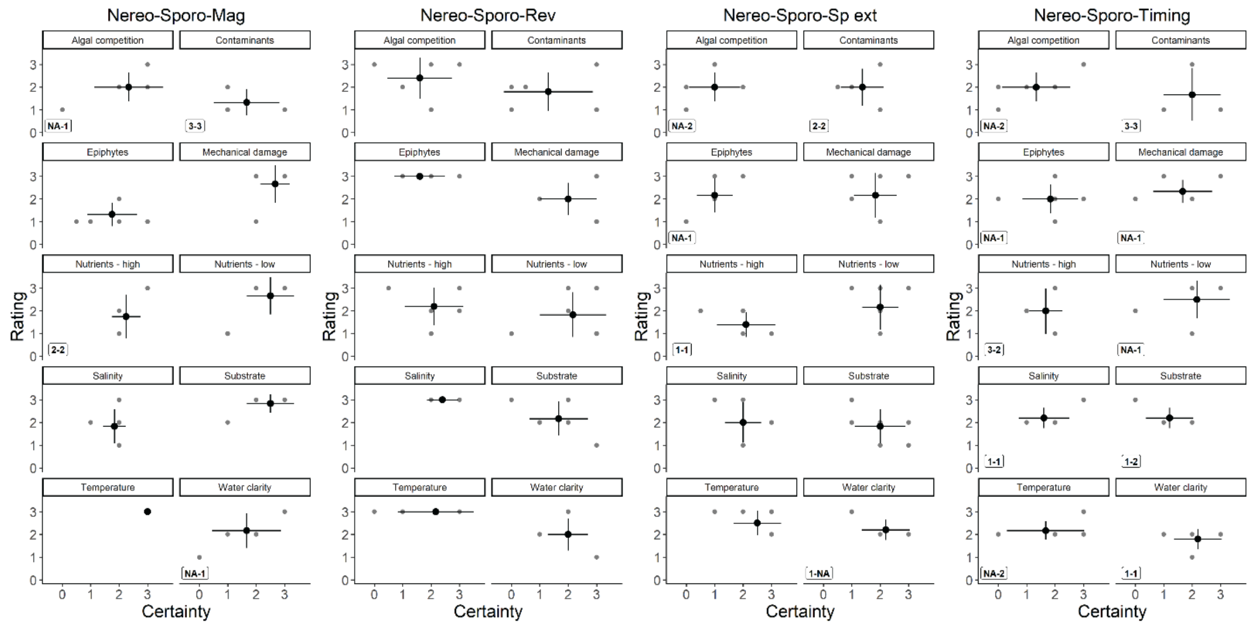


Figure 16: Individual stressor characteristics ratings and certainty for Macrocystis *sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

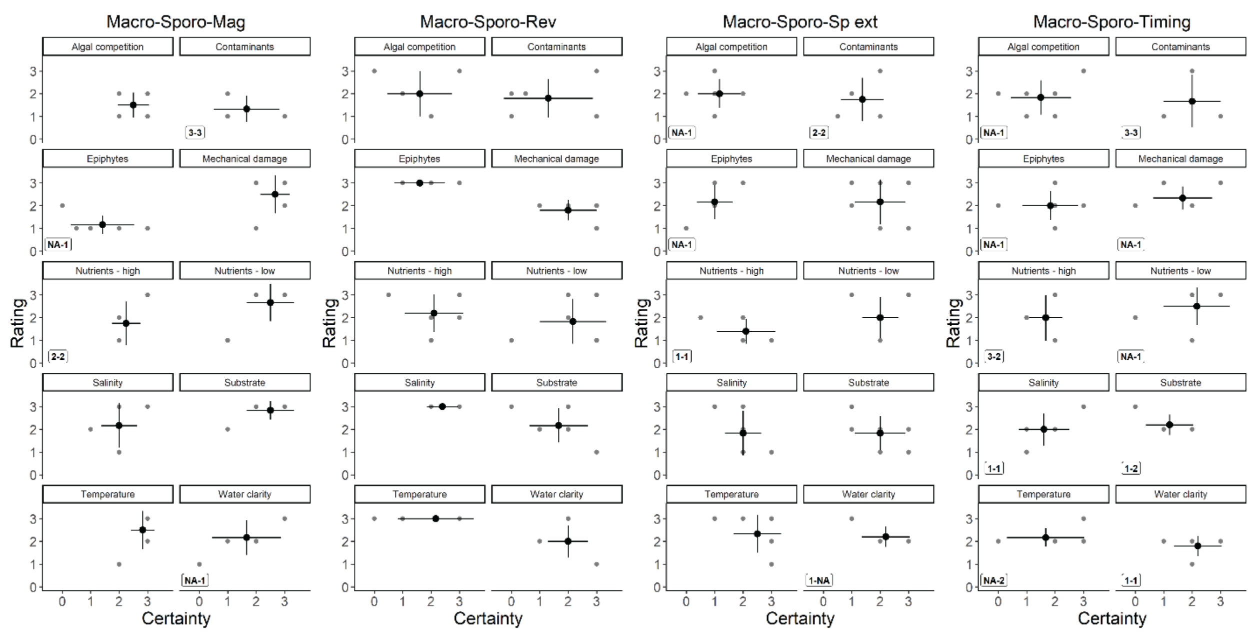


Figure 17: Individual stressor characteristics ratings and certainty for Nereocystis *sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

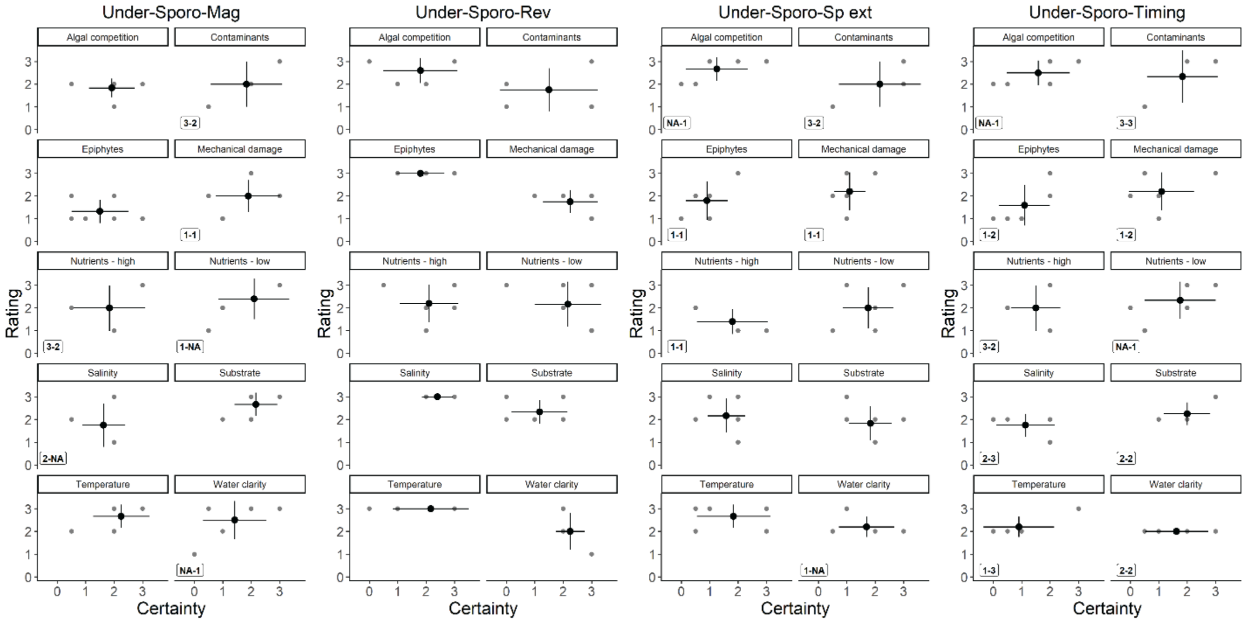


Figure 18: Individual stressor characteristics ratings and certainty for understory sporophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.

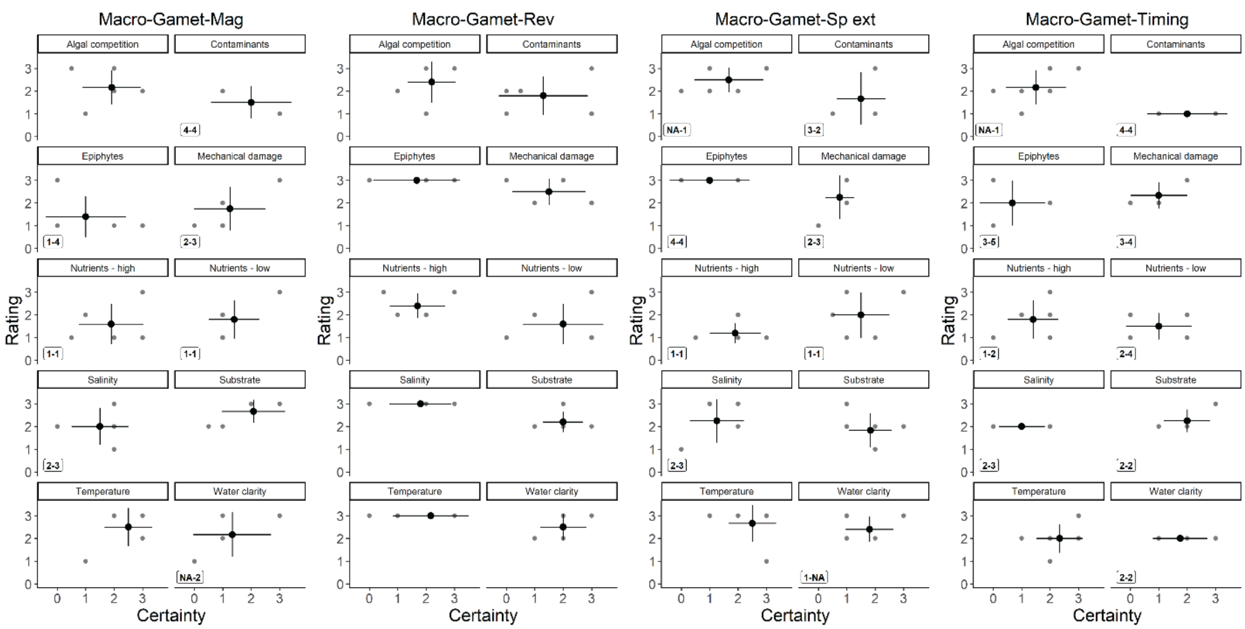


Figure 19: Individual stressor characteristics ratings and certainty for Macrocystis *gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

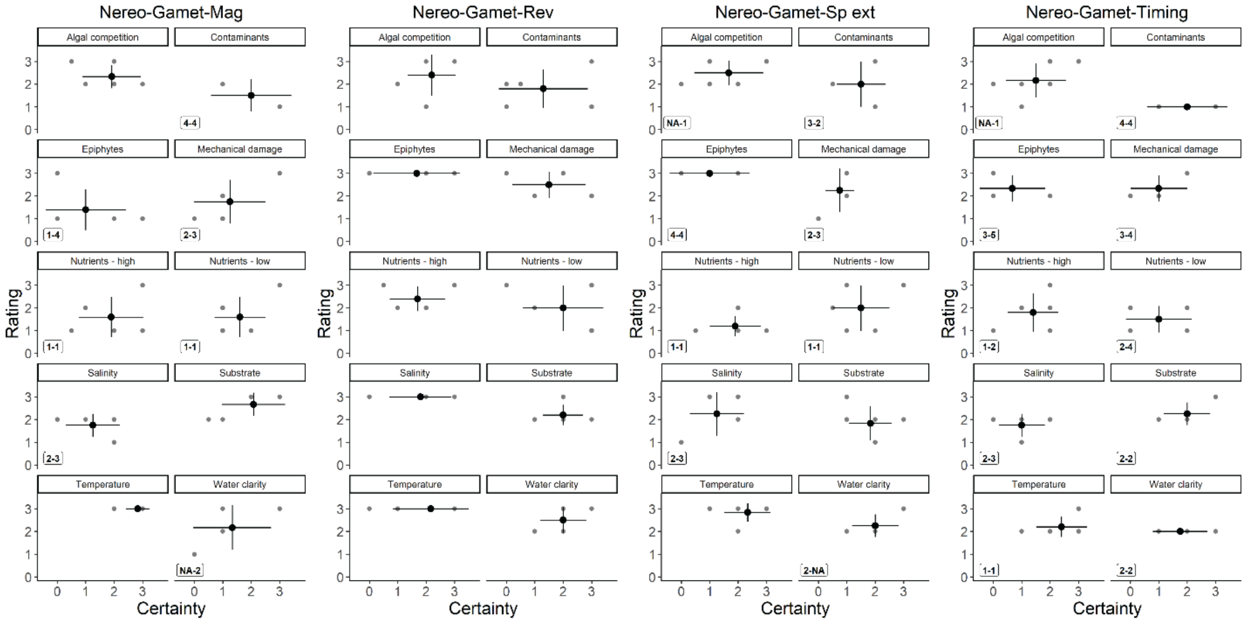


Figure 20: Individual stressor characteristics ratings and certainty for Nereocystis *gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.*

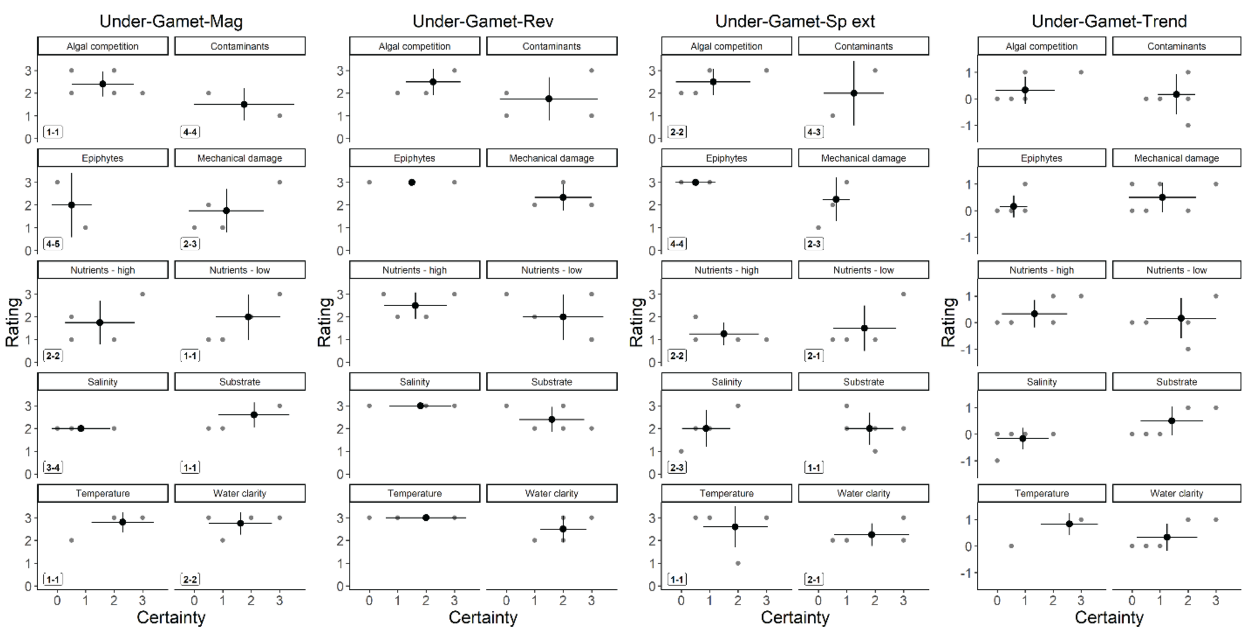


Figure 21: Individual stressor characteristics ratings and certainty for understory gametophytes. Black points are workgroup means with one SD error bars. Gray points are individual workgroup member values. Values in lower left of each plot are the sum of instances were zero – indicating unknown – was selected by a workgroup member. The first value represents ranks of zero and the second represents certainties of zero. Note, zeros are omitted from mean rank calculations but not certainty. Note that instances where less than six grey points are visible and there are no zero tabulation reflect overlapping grey points.

Appendix A: Hollarsmith et al. (2022) literature search

From Hollarsmith et al. 2022 but with updated date range

All searches were filtered by dates 2021-01-01 to 2023-12-31.

<u>Drivers</u>

Human impacts to trophic structures and epiphytes:

- ((invasive OR reintroduc* OR fisher* OR fishing) AND epiphyt* AND marine NOT coral NOT tropic*)

Human impacts to trophic structures and algal competition:

- (invasive OR reintroduc* OR fisher* OR fishing) AND algal competition NOT coral NOT tropic*

Nutrients and epiphytes

- "nutrient* AND epiphyte* AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia") NOT terrestrial*
- "nutrient* AND epiphyte* AND marine* NOT tropic* (category = ''marine freshwater biology')

Nutrients and algal competition:

- ("nutrient* AND algal competition AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia"))

- "nutrient* AND epiphyte* AND marine* NOT tropic* (category = ''marine freshwater biology')

Nutrients and water clarity

- "nutrient* AND (turbid* OR "water clarity" OR light availab*) AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Temperature and algal competition

- temperature* AND algal competition AND marine* NOT tropic*

Temperature and epiphytes

- "temperature* AND epiphyte* AND marine* NOT tropic*

Temperature and grazing

- "temperature* AND grazer* AND marine* NOT tropic*

Dredging and contaminants

- (dredg* AND marine AND (pollut* OR contamin* OR "water quality"))

Dredging and benthic sedimentation

- dredg* AND (benth* AND sediment* AND marine)

Dredging and water clarity

- dredg* AND (turbid* OR "water clarity" OR light availab*)

Upland development and contaminants

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND (pollut* OR contamin*) AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Upland development and nutrients

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND marine AND nutrient* NOT tropic*
- (logging OR agricultur* OR urban* OR dam* OR industr*) AND nutrient* AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Upland development and salinity

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND salin* AND nearshore AND marine NOT tropic*

Upland development and benthic sedimentation

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND benthic AND sediment* AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Upland development and temperature

- (logging OR agricultur* OR urbaniz* OR industr*) AND marine AND temperature NOT tropic* NOT *arctic)

Upland development and water clarity

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND (turbid* OR "water clarity" OR light availab*) AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")
- ((logging OR agricultur* OR urban* OR dam* OR industr*) AND (turbid* OR "water clarity" OR "light availability") AND marine NOT tropic*)

Vessel traffic and contaminants

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (pollut* OR contamin* OR "water quality")

Vessel traffic and benthic sedimentation

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (benth* AND sediment*)

Vessel traffic and water clarity

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (turbid* OR "water clarity" OR light availab*)

Climate change and contaminants

- ("climate change" AND runoff AND (contaminant* OR pollut*) AND marine NOT tropic* NOT coral NOT *arctic)

Climate change and nutrients

- "climate change" AND nutrient* AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")
- ("climate change" AND nutrient* AND marine NOT tropical NOT coral) categories: oceanography

Climate change and salinity

- "climate change" AND "salinity" AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")
- ("climate change" AND "salinity" AND marine NOT tropical); categories: environmental sciences, oceanography

Climate change and benthic sedimentation

- "climate change" AND benthic AND sedimentation AND marine NOT tropic* NOT *arctic

Climate change and temperature

- "climate change" AND "temperature" AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Climate change and water clarity

- ("climate change" AND (turbid* OR "water clarity" OR light availab*) AND marine NOT tropic*)

Shoreline development and nutrients

- "shoreline development" AND "nutrients"
- "shoreline development" AND "nitrogen"

Shoreline development and salinity

- "shoreline development" AND "salinity"
- shore* armor* salinity

Shoreline development and benthic sedimentation

- "shoreline development" AND "sediment"
- "shoreline armor*" AND "sediment"

Shoreline development and temperature

- "shoreline armor*" AND "temperature"

<u>Pressures</u>

Benthic sedimentation:

- kelp AND benthic AND sediment* AND marine NOT tropic*

Mechanical damage:

- kelp AND ("mechanical damage" OR damage OR graz* OR herb* OR defoliat*)

Epiphytes:

- kelp AND epiphyt*

Contaminants:

- kelp AND (pollut* OR contamin*) NOT tropic*

Nutrients

- "nutrient* AND (kelp or Laminariales)
- (nutrient* OR temperature) AND (kelp OR Laminariales)

Salinity

- kelp AND salinity

Water clarity

kelp AND (turbid* OR "water clarity" OR light availab*)

Appendix B: Updated literature search

Searches completed for Kelp Stressor Ranking Workgroup and filtered by years 2021 - 2023

Benthic sedimentation:

- kelp AND benthic AND sediment* AND marine NOT tropic*

Mechanical damage:

- kelp AND ("mechanical damage" OR damage OR graz* OR herb* OR defoliat*)

Epiphytes:

- kelp AND epiphyt*

Contaminants:

- kelp AND (pollut* OR contamin*) NOT tropic*

Nutrients

- "nutrient* AND (kelp or Laminariales)
- (nutrient* OR temperature) AND (kelp OR Laminariales)

Salinity

- kelp AND salinity

Water clarity

kelp AND (turbid* OR "water clarity" OR light availab*)

Shoreline development and nutrients

- "shoreline development" AND "nutrients"
- "shoreline development" AND "nitrogen"

Shoreline development and salinity

- "shoreline development" AND "salinity"
- shore* armor* salinity

Shoreline development and benthic sedimentation

- "shoreline development" AND "sediment"
- "shoreline armor*" AND "sediment"

Shoreline development and temperature

- "shoreline armor*" AND "temperature"

Vessel traffic and contaminants

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (pollut* OR contamin* OR "water quality")

Vessel traffic and benthic sedimentation

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (benth* AND sediment*)

Vessel traffic and water clarity

- ("vessel traffic" OR "boat traffic" OR "ship* traffic") AND (turbid* OR "water clarity" OR light availab*)

Upland development and contaminants

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND (pollut* OR contamin*) AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Upland development and nutrients

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND marine AND nutrient* NOT tropic* Returned 1079 citations. Not reviewed
- (logging OR agricultur* OR urban* OR dam* OR industr*) AND nutrient* AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia") Returned 338 citations. Not reviewed
- (logging OR agricultur* OR urban* OR dam* OR industr*) AND salin* AND nearshore AND marine NOT tropic*

Upland development and benthic sedimentation

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND benthic AND sediment* AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

Upland development and temperature

- (logging OR agricultur* OR urbaniz* OR industr*) AND marine AND temperature NOT tropic* NOT *arctic) Returned 2463 citations not reviewed

Upland development and water clarity

- (logging OR agricultur* OR urban* OR dam* OR industr*) AND (turbid* OR "water clarity" OR light availab*) AND marine AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia")

- ((logging OR agricultur* OR urban* OR dam* OR industr*) AND (turbid* OR "water clarity" OR "light availability") AND marine NOT tropic*) Returned 379 citations. Not reviewed

Nutrients and algal competition:

- ("nutrient* AND algal competition AND ("Salish Sea" OR "Puget Sound" OR "Strait of Georgia" OR "San Juan Islands" OR "Gulf Islands" OR "Vancouver Island" OR "Washington" OR "British Columbia"))
- "nutrient* AND epiphyte* AND marine* NOT tropic* (category = ''marine freshwater biology')

Drivers

Human impacts to trophic structures and epiphytes:

- ((invasive OR reintroduc* OR fisher* OR fishing) AND epiphyt* AND marine NOT coral NOT tropic*)

Human impacts to trophic structures and algal competition:

- (invasive OR reintroduc* OR fisher* OR fishing) AND algal competition NOT coral NOT tropic*

Appendix C: Notes from in-person workgroup meeting

Feb 21, 2024 Kelp Threat Ranking In-Person Workshop
Meeting transcript and audio recording: 21 Feb Workshop Recording
Meeting video recording

Summary
We had a wide-ranging discussion that dug into multiple areas that needed clarity and/or had a high degree of disagreement among the workgroup. We talked at length about the meaning of "reversibility" in this context, who to interpret the "trend over time" stressor characteristic, contaminants and who those are different from nutrients. We discussed nutrients both how we are defining them (macronutrients) and how to think of them as a stressor. This led to splitting nutrients in to two stressors, high nutrients and low nutrients, even though there is limited information on the effects of very high nutrients as a direst kelp stressor. The nutrient discussion, and others highlighted the challenge of considering these stressors as only direct effects (in isolation). This was clearly, and understandably, a challenge for the WG and the ranking project in general. There was general agreement that this should be a critical part of the discussion of this process, especially as interactive and indirect effects are strongly associated with nutrients, temperature, and water clarity. We also discussed epiphyte stressors in general. We resolved to remove ranks of zero from calculations of total stress, and reviewed some updated plots in the meeting. WG members were tasked with adding ranks to the new nutrients stressor category and to review their ranks in general following the discussion. Wendel will recompile the ranks and produce summary tables and figures for review at the March 15th meeting. This plan may extend the total timeline of a draft and final report of the kelp stressor ranking by a few weeks.

Original Rough Agenda

- **1000 – 1010:** Introduction
- **1010 – 1050:** Overall gut check
- **1050 – 1100:** Break
- **1100 – 1200:** Review priority 1 and discussion
- **1200 – 1300:** Lunch
- **1300 – 1350:** Priority 1 continued
- **1350 – 1400:** Break
- **1400 – 1450:** Review priority 2 and discussion
- **1450 – 1500:** Break
- **1500 – 1600:** Review priority 3/4, discussion, and any other wrap up.

Things to Keep in Mind

- Reversibility: Does the technology or method exist to reduce or mitigate this stressor (e.g., drop rocks to improve substrate)?
    - Does **not** include political feasibility
    - When talking with managers it's important to differentiate between this can be done vs. we don't think you're going to do it

    - Consider whether it's permanently reversible vs. something that requires ongoing management (e.g., eradication vs. controlling invasive species)
- When considering trend over time
    - It could either be:
        - Certain and stable
        - Uncertain and therefore stable (0) as the null
    - Keep in mind extreme events
- Update nutrients to lack of or overabundance of macronutrients
    - Do **not** include indirect effects
- Differentiate between:
    - We don't know, but we don't care
    - We don't know, but we think it might be important
- When reporting out we will:
    - Ranking: Consider the 0's null when calculating a mean
        - Report how many 0's somewhere
    - Certainty: Include the 0's when calculating a mean

Next steps
- Rename rank as score?
- Wendel send out notes and an updated scoring template with additional rows
- Everyone, revisit scores **by 2/29** with a particular focus on:
    - Lack of or overabundance of macronutrients, not including the indirect impacts
    - Contaminants, particularly for the understory
    - Anything else you'd like to updated based on the discussion (e.g., epiphytes, salinity)
- Wendel based on the updated scoring, share visualizations, including:
    - Magnitude with certainty
    - Total stress with certainty
        - Standard deviation for the means
    - Compare results for understory with surface kelp
- Caitlin/Wendel discuss how consistent the characteristics need to be between the kelp and eelgrass ranking
    - Potentially talk with Ron
- March 15 agenda
    - Review the results to discuss the main messages
        - Touch on interactive effects
    - Caitlin present on how this will be incorporated into the risk assessment modeling, including how you can have a rank of -1
    - Timeline for the full report
    - Potential for publication

Detailed Notes
- Will the certainty values be included in the model?
    - Yes, certainty will be incorporated into the model. Consistency could also be incorporated into the certainty score

- Yes, there will be an opportunity to adjust individual rankings either during/after this meeting
- Total stress: mean of magnitude, spatial extent, timing, and reversibility
- Variability is okay - it reflects the different knowledge in the group
- **Reversibility**
  - Ranked in reverse order - experts selected low, medium, high, or unknown. On the back-end, high = 1 because it's really easy to reverse the stressor
  - Challenging because it asks for this ranking to be agnostic to cost and political likelihood because those feel central to the feasibility
    - Does the technology or method exist already?
    - Goal is to present this to managers/decision makers: differentiate between this can be done vs. we don't think you're going to do it
  - Feasibility, was political/social, but not ignoring cost, so proximate technology
  - For example - algal competition Macrocystis sporophyte - mitigating algal competition would be extremely challenging
    - Cathy - invasions by sargassum - know they're detrimental, with enough effort in the water, they could be reversible (ranked as high reversibility)
    - David - 0 because didn't feel like enough information to make an educated guess. For example, it'd take an army to reverse sargassum
    - Danielle - What could we do at Squaxin? To remove sargassum to provide more space. Small scale, but possible
    - Recurring management action - Can get rid of it, but it'll come back each year
      - "Controlling vs. eradicating"
    - California made some Sargussm efforts 20 years ago and it didn't work well
  - Reversibility is combined with others, but could be broken out
  - + Discussion paragraph - lot of discussion about reversibility and scale that managers should consider
- **Low salinity and other "trend over time" ranks**
  - Is the amount of stress going to increase, stay the same, or decrease?
    - E.g., Salinity in the environment may go down, but doesn't necessarily mean the stressor decreases
    - E.g, Temperature is going to go up, temperature stress will also increase
  - Add another layer of complexity - timing (Tom's idea, Hilary agreed)
    - Less snow, more rain, which will change the freshwater input significantly. The seasonality of Fraser in June vs. December
    - Changes in the hydrograph from the dams and coming from pipes vs. stream mouths
    - Not just the annual average, but changes in extremes (more on this below)

- Unknown wasn't an option, which would have been nice
    - Hilary landed on stable because the salinity would be lower in the fall through spring and possible higher in the summer, but the impact is pretty unknown
    - So many levels of uncertainty: is it going to rain more, is it going to result in lower salinity in the ocean, will that be in the range that affects kelp
        - Generally if people were uncertainty, they ranked as 0 (stable)
            - Potentially highlight paired 0-0 scoring
            - No trend is a null
    - Confidence decreased going left to right in the spreadsheet because adding complexity in terms of how things will change over time or at specific places
    - Could reflect this with stable + high uncertainty ranking
    - Comforting to hear that others felt torn in the ranking process
- Change in extremes
    - California has had a lot of atmospheric rivers recently - did they lose kelp?
    - Extremes do a better job of telling the story than a mean (e.g., salinity for 0 for a week)
- Example of how this rolls up
    - Salinity example: Average rank is 0.4, so slightly increasing, but certainty is rather low 1.6
        - Seeing this Cathy feels less certain because it's based on downscaled climate models and precipitation. How poor the global climate models do when downscaled for specific parameters, including precipitation
        - Highest certainty in timing and type of precipitation, not necessarily amount of precipitation. Same amount of precipitation, but not saved to go into the summer
        - New pattern of extreme rainfall then drought
    - Temperature example: Average rank is 1, increasing, with strong certainty at 3
    - Substrate example: Average rank is 0.4, but certainty is 1.2, so slighlighty less certain
- Not a lot of research on the effect of salinity on different plants and stages

- Rank isn't relative, actually a score
- Interaction terms between stressors makes it complicated
- **Gametophytes**
    - Range makes sense because there's significantly less research
- **Contaminants**
    - Can make an educated guess based on another species, or it's too unknown
    - + List of contaminants/pollution
        - Heavy metals, sewage, and petrochemicals

    - Unknown unknowns
    - Natural, but in excess (e.g., turbidity, copper)
        - Right things at the right place at the right time
    - Very little research, particularly gametophytes
    - Steve found some research that suggests it's worse for animals than kelp (Sheila & Foster?), particularly after oil spills
    - Dick Steele at EPA Newport was using kelp gametophyte germination as a bioindicator/bioassay for contaminants - very gray literature
    - Simplace One by Kathy Van Elstein looking at the elemental composition. Tissues were relatively unenriched
    - Always wondered about the effects of hydrocarbons and the hormones
- + Roadmap for future research needs
    - We don't know, but we don't care
    - We don't know, but we think it might be important
    - I don't know - differentiate between I can't back up my statement with a reference vs. my expert opinion is this is a concern
        - It's okay to rely on expert opinion without a reference
- Are any of this contaminants implicated in the disappearance of kelp vs. quality of food source (micronutrients)
    - Contaminated sediments you see impacts on gametophytes - sitting on the top of the bottom
- Is there data on contaminants?
    - Sediments more than the water column
    - Ecology often geoduck tissue, which doesn't help
    - Look at a highly contaminated decade (e.g., Tacoma - early 1900s)
        - If there are healthy kelp beds where there are high contaminants would suggest contaminants don't matter
        - High levels of copper and arsenic at Vashon didn't eliminate the kelp
- What life history is actually exposed?
- Sub-lethal stressors
    - South Sound petered out over a long period of time
    - Down 80% of floating kelp, could be related to urbanization over time
- Difference in risk between macro and nero was often more about proximity to urban input
- How differentiating between sewage and nutrients
    - Bacteria
    - Contaminants of emerging concern
    - "Replumbing" the freshwater input
- Differentiating between sewage and stormwater runoff?
- DNA found fecal coliform was from cats
- + Good literature research with a particular focus on Asian research
    - May be on different species (e.g., Odarea)

        - Aquaculture literature
        - But wouldn't prioritize this for primary research
        - King County labs is studying Daphnia and could potentially add kelp
        - In lab exposure, but has to consider different life histories
    - More reversible than climate change
- **Epibionts (to include epiphytes and epizoos)**
    - More confident because of the research out of Bamfield for Membranipora?
        - Found plants with and without the Membranipora and seemed to have an impact on kelp
        - El Ninos where the water was warm it was everywhere
    - Porphyra - how does it get there, what effect does it have?
    - Are the epiphytes chasing the sinesses?
    - Rhizomes is a different story
    - More research in Canada - Maycira doing remote sensing
    - Unhappy bull kelp was full of
    - There are a lot of epiphytes on the outer coast and it doesn't seem to affect the plant, but then see them in Puget Sound and the kelp doesn't look good
        - Effects may be highly variable depending on the context
        - Kelps in protected areas seem to be more susceptible
        - Epiphyte free floating kelps in Puget Sound look terrible already
        - Do healthy kelp have some resistance to epibionts
            - Guess - kelp are constantly sloughing and as soon as it slows down they become more susceptible to overgrowth of epibionts
        - Perpetual that animal or other plant taxa that will use these as hosts - TBD on whether they'll do more so when the host is under stress
    - Changed Cathy's confidence scores which aligned more
    - Gametophytes can live inside the tissues of some red algae and still reproduce
    - (Cathy) Ignored microbes in this category
        - Lots more to be learned still - patterns are not useful in this context yet
- **Rename as Low Macro-Nutrients (Nitrogen & Phosphorous)**
    - + Separate into macronutrients too much/excess/overenrichment and too little
        - For example, less confident in the impact of high nutrients
        - Note that nutrients can be really high. We don't have much to go on though. There is good documentation of the indirect effects of high nutrients to kelp and other things
        - Differentiating would highlight this as a high research need
        - F/2 in lab studies have astronomically high nitrogen levels

    - Macro and Nereo sporophytes - there's both lots of confidence and very different scores
    - Assume the background average is sufficient for growth and persistence, but do the amount of nutrients whether they're high or low what sort of threat does that pose?
        - Louis Druehl - low nitrogen levels in Barkley Sound being responsible for disappearance
        - Danielle - interpreted this to mean that low nutrients wasn't a problem
    - Is there a realistic upper level that could be affecting kelp?
    - DIN is always too low and probably limits kelp growth in Puget Sound
        - Cathy - We know nutrients are important and we know that with certainty
    - Low nutrients is more of a natural stressor than high nutrients. Although seasonally low nutrients could be the result of an algal bloom
    - Very seasonal
        - Stratify in the summer - really high temperatures and very low nutrients
        - High nutrients in Puget Sound is still usually a third of what it is out in the Straits
    - Stratification is an important consideration
        - California getting nutrients locked out of the top layer
        - Depth matters a lot
    - Does **not** include interactions or indirect effects
        - Epiphyte or sporophyte
        - Causing a bloom could be out competing the kelp uptake, especially if you have sporadic influx of sewage plant flooding
        - Hallersmith paper there are many things that circle back to nutrients
    - Does anyone know what the limiting nutrients/ratios are for kelp?
        - We know more about nitrogen
        - Ratio (e.g., coral)
    - Microhabitat issues with epiphytes in a boundary layer - needs and exposure to nutrients might be quite different
    - Differentiate between macronutrients (nitrogen and phosphorous) vs. micronutrients
    - Once you get to the modeling how will you incorporate macronutrients since the stress is different if excess or limited?
        - Unique in terms of being bi-modal
    - How often is there actually an excess of nitrogen in the water given how quickly the algae consume it?
        - In the last 2 years, Westpoint had 11 sewage floods
- **Other/Mechanical Damage**
    - If you lose the brown algae, what happens to the kelp?
    - Importance of looking at microbial community present
- **Recap values**

- Total stress ranking: magnitude, timing, reversibility, and spatial extent
    - Updated the 0’s
        - Ranking: 0 should be a null and removed
        - Certainty: 0 maintained
    - Differences in scores may indicate differences in knowledge
    - Important to capture how many people said they don’t know. Could segment when there are different opinions eg. x people said y with z confidence vs. a people said b with c confidence
    - Moderately low confidence in the effect of the stressor on kelp, how can I comfortably say anything about the temporal and spatial future?
- Wendel follow-up with Danielle - blanks are essentially 0’s
- High priorities - Nereocystis and Macrocystis sporophyte -
    - Ranks are more tightly clustered than our certainty
        - Because everyone has a different tolerance for certainty?
    - Substrate
        - Clear determinate of kelp health. Change from rock to mud would be a stressor. Not going to change in our lifetime, so it should be a low stressor
        - Change entirely to soft substrate, but some changes can be less extreme
        - Much smaller area that’s likely to change with new sedimentation
            - Seasonal in very specific habitats
        - Reversibility - can deliver rock
            - South Puget Sound, major issue is a lot has turned to silt
            - Upland management to reduce sedimentation
            - Not going to reverse, but can mitigate
    - Water clarity
        - Changed David’s confidence in water clarity certainty to a 3
        - Danielle had lower certainty because of timing of water clarity relative to growing season
        - If light gets low enough, Nereocystis don’t make it to the surface
            - Not in the western Alutians because it’s light limited
- Understory sporophyte
    - Flexibility in terms of how far to take this discussion
        - Potential focus for future work
    - Includes numerous species that are significantly different
        - Different anti-herbivore chemicals in understory
        - Depth distribution is different - zonation
    - Are they different from the nero/macro?
        - Longevity of the species (this applies to nero/macro too)
        - Vulnerable annuals -you can’t harvest Postelsia in California
        - E.g., temperature

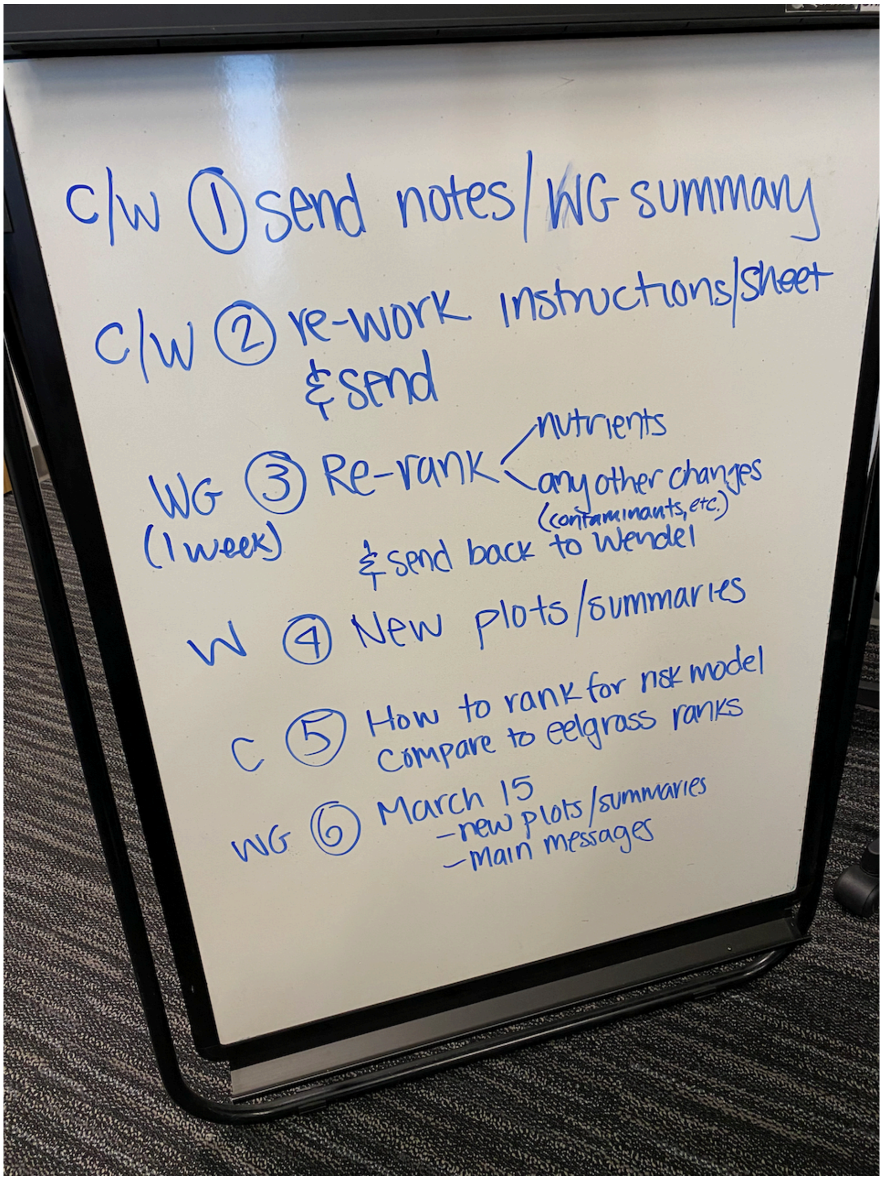
            - The difference in exposure may come out more in the modeling
            - Understory will likely react the same way, just haven't been exposed yet
    - It might be valuable to differentiate between annual and perennial
    - Are we at risk of losing an understory vs. the composition of an understory
        - Hilary just thinking about Laminariales (kelp)
        - Shifting to Desmarestia - not a kelp, but habitat for small fishes may do just as good of a job as some understory kelp species. Similar to sargassum
        - Same function as understory (food web productivity, habitat, etc.)
    - Ecologically, as important, if not more than the floating kelp
    - Not a lot of intertidal kelps, so probably isn't changing net answer

Visualizations

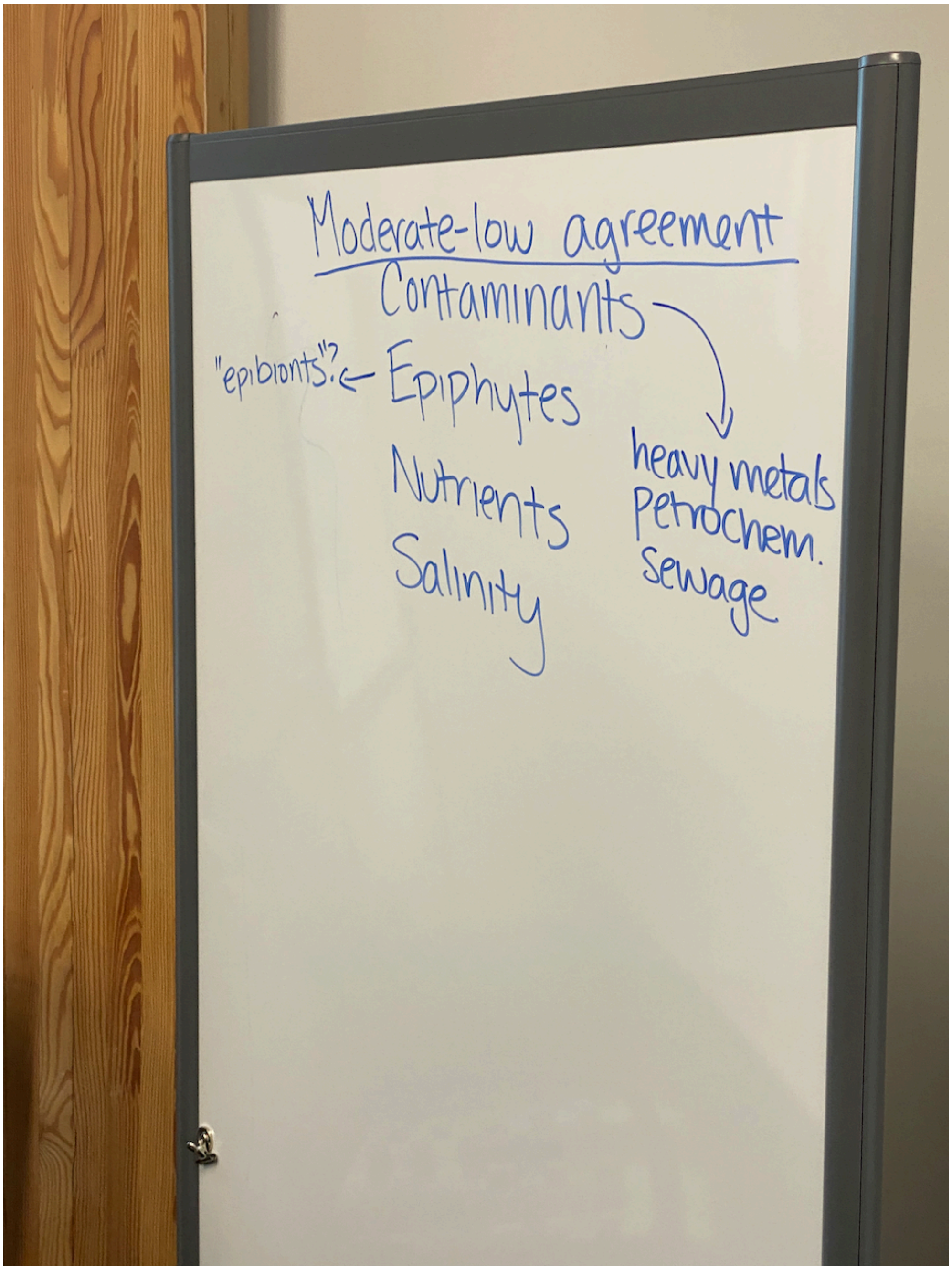
1. First certainty for magnitude - how certain are we that this is bad for help
    - Bivariate with some color coding - ellipses rank and certainty
    - NNBS or PCA plot
    - Most concerned high rank and certainty should be targeted by management actions
2. Then certainty for total stress - how certain are we that this matters in Puget Sound
    - Updated the 0's
        - Ranking: 0 should be a null and removed
        - Certainty: 0 maintained
    - Make the size of the dot the magnitude
    - Consider a weighted average to emphasize the magnitude
    - Consider a weighted average that considers the certainty for each variable
    - Subsequent heatmap
    - Spatial extent and reversibility may be inversely related
        - Spatial model, so may not need to include that in the ranking
            - Definition of spatial extent here and in the model are considered differently
        - Ranking does not include local adaptation. The model will start to layering in exposure
    - Star shape: magnitude, spatial extent, timing, and reversibility
    - Is there statistically significant difference between the total score?
        - Self-reflection: Are my most important things getting the highest score?
            - Revisit the relative ranking after the updated scores

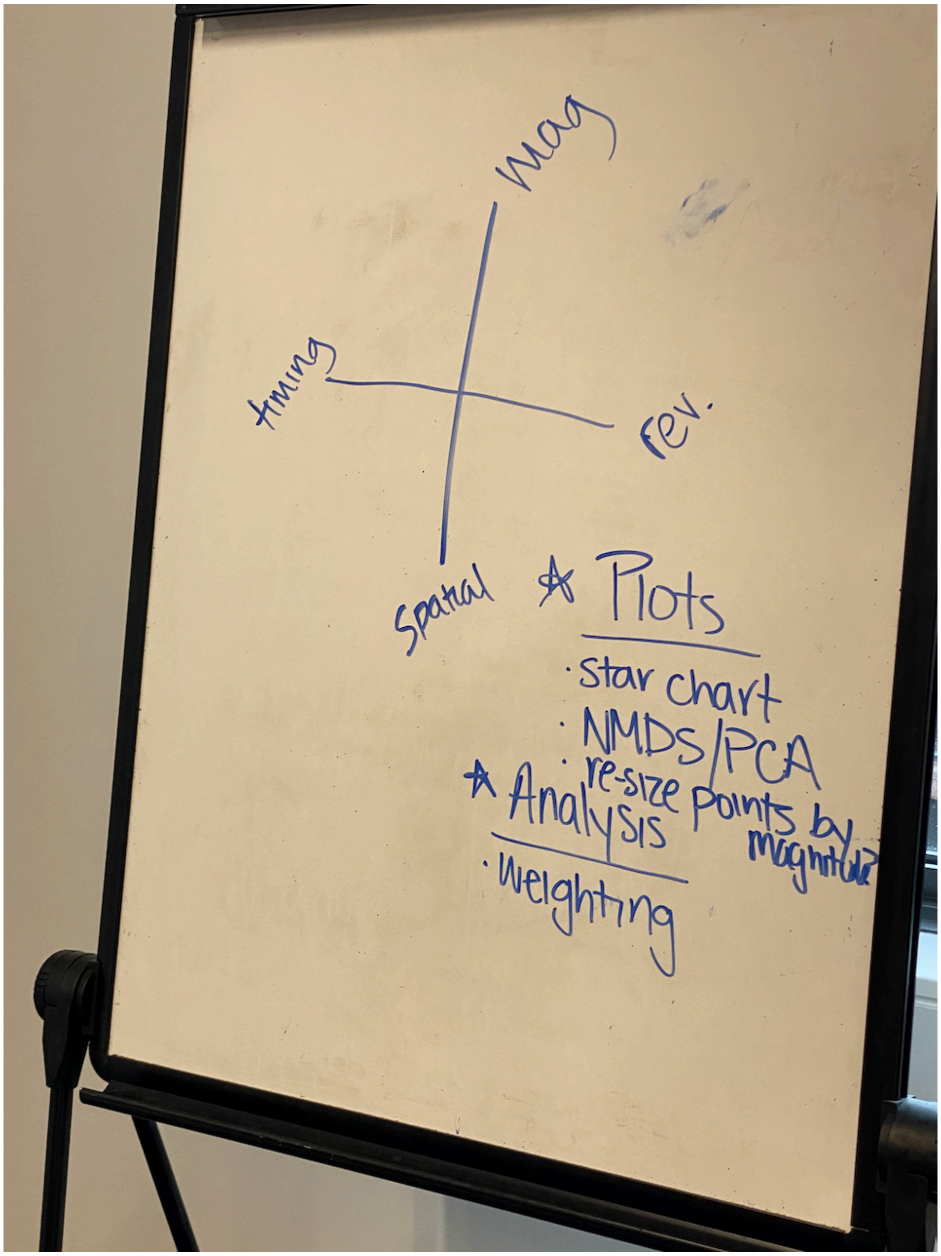
- Manager
    - Will first look at rank, then reversibility

- Important not to give the managers a watered down version - need to have a basic understanding of the complexity and uncertainty
- Education is as an important component of this effort
- If you can't fix x (e.g., temperature) what do you do
- What are the decisions managers are going to make and how?
    - DNR is looking at both kelp and eelgrass health plan. Where we want to protect and how
    - Regulation often lumps kelp and eelgrass together (e.g., Shoreline Management Act)



^C = Caitlin, W = Wendel, WG = Workgroup


Moderate-low agreement
Contaminants
"epibionts"? ← Epiphytes
Nutrients
Salinity
heavy metals
Petrochem.
Sewage


mag
timing
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spatial
Plots
· star chart
· NMDS/PCA
· re-size points by magnitude
Analysis
· weighting