Metadata for Raymond et al. "Washington State Kelp Threat Rating: data and analysis code"
ResearchWorks Repository contains data spreadsheet and analysis code

1.1. Expert panel

Our panel consisted of regional experts in kelp ecology, physiology, and restoration, and was tasked with defining and rating kelp stressors and certainty in Washington State. Authors Raymond and Magel identified and contacted researchers and practitioners who already participated in regional kelp research and/or policy groups including the Kelp Plan, and participants in the kelp stressor identification panel detailed in Hollarsmith et al. (2022). These contacts subsequently identified other potential members for this panel. The final panel consisted of six participants, authors Claar, Duggins, Hayford, Mumford, Pfister, and Rubin, with authors Raymond and Magel serving as facilitators.

Over approximately six months, the panel met multiple times over videoconference and once in-person to discuss the goals, scope, and details of rating the severity of kelp stressors and the level of scientific certainty related to those stressors. During project scoping, the panel expressed strong interest in including both dominant floating kelp species in Washington State, *Nereocystis luetkeana* and *Macrocystis pyrifera*, understory species and the gametophyte (microscopic) and sporophyte (macroscopic) phases in kelp life histories in the rating exercise. The panel acknowledged that understory kelps represent a diverse group of species that likely have species-specific responses to stressors, which are relatively under-studied in Washington State compared to floating kelp species. However, the panel agreed to take advantage of the opportunity to provide expert opinion on the intensity and certainty of stressors to understory species, even if there was limited information available for these species. The panel also agreed to separate the stressor "nutrients" described in Hollarsmith et al. (2022) into "nutrients-high" and "nutrients-low" (defined below) to recognize two stressor states with potentially differing impacts on kelp.

1.2. Stressor rating

1.2.1. Scope

The panel considered 10 stressors, 6 characteristics assigned to each stressor, and rating and certainty scores for those stressors for each unique combination of taxa and life stage (720 unique combinations). The panel provided stressor rating and certainty scores for the stressors identified in Hollarsmith et al. (2022) (defined as "pressures" by those authors) including splitting "nutrients" into "nutrients-high" and "nutrients-low" for a total of 10 stressors. We defined certainty as the panelist's subjective appraisal of the degree of scientific certainty of a given rating. Stressor definitions were taken from Hollarsmith et al. (2022) but modified slightly to account for the inclusion of *Macrocystis* and understory species (Table 1). For each stressor, 6 characteristics were assigned their own rating and certainty score. Stressor characteristics were modeled after a similar stressor rating effort focused on eelgrass (*Zostera marina*) in

Washington State (Thom et al. 2011) to allow for comparisons between efforts but modified slightly for use with kelps. Stressor characteristics included magnitude, spatial extent, timing, reversibility, trend over time, and depth extent (Table 2). Depth extent did not appear in the eelgrass effort but was identified by panelists as important for describing stressors to kelps. The panel considered the entire extent of coastal Washington State including the Pacific coast, Strait of Juan de Fuca, and Puget Sound when rating stressors to *Nereocystis*, *Macrocystis*, and understory kelps in both their gametophyte and sporophyte life stages. We assumed that stressors would have the same effect regardless of geographic location, unless there was strong evidence of local adaptation/susceptibility to a stressor. However, we note that *Macrocystis* is only found on the Pacific coast and portions of the western Strait of Juan de Fuca, and *Nereocystis* and understory species are found throughout the study area. The panel also acknowledged that temperature and nutrients may modulate other stressors (Table 2).

1.2.2. Stressor rating and certainty scoring

Each panelist (n = 6) rated 10 stressors in 6 characteristics (Table 2) for each taxa-life stage combination following a high, medium, low, and unknown hierarchy (Table 3). Panelists also evaluated the degree of certainty of their stressor rating using a high, medium, low, very low, and unknown hierarchy, following the procedure conducted for eelgrass by Thom et al. (2011). Depth extent was rated following a near-surface, near-bottom, or both scheme, and trend over time was rated following an increasing, decreasing, or stable scheme (Table 3). Panelists were directed to assign certainty scores based on their own research experience, peer-reviewed literature and reports, and reasonable intuition of kelps and nearshore habitats and species. Literature search results and metadata, described above, were made available to panel members, but panelists were not required to cite literature in their stressor severity or certainty scoring determination.

References

Hollarsmith, J. A., K. Andrews, N. Naar, S. Starko, M. Calloway, A. Obaza, E. Buckner, D. Tonnes, J. Selleck, and T. W. Therriault. 2022. Toward a conceptual framework for managing and conserving marine habitats: A case study of kelp forests in the Salish Sea. *Ecology and Evolution* 12: e8510. https://doi.org/10.1002/ece3.8510.

Thom, R., K. E. Buenau, C. Judd, and V. I. Cullinan. 2011. *Eelgrass (*Zostera marina *L.) Stressors in Puget Sound*. Prepared for Washington State Department of Natural Resources PNNL-20508. Sequim, WA: Pacific Northwest National Laboratory.

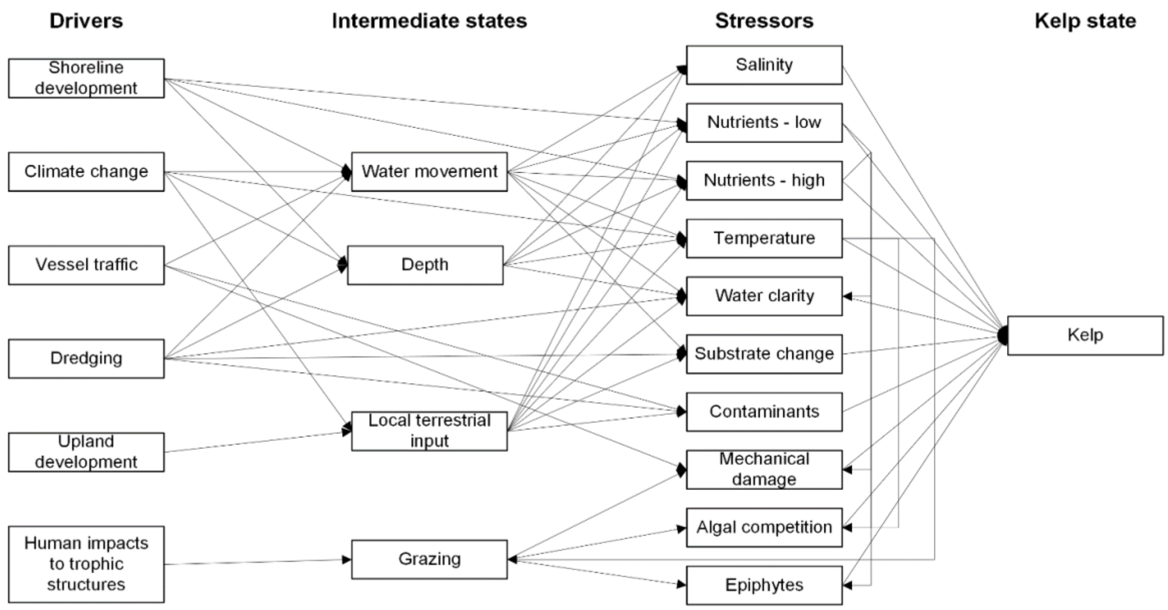

Figure 1: Conceptual diagram of drivers, the intermediate state and the stressors effecting kelp. Modified from Hollarsmith et al. (2022) to include nutrients – high and nutrients – low and generalized to kelp.

Tables

Table 1: List of kelp stressors, their underlying drivers and a descriptive summary of the pathways and potential interactions among stressors. Stressors, their underlying drivers and definitions analogous to "pressures" in Hollarsmith et al. (2022), however we divided nutrients into two categories, high and low. ^{Nut} identifies stressors whose effects may be modulated by nutrients, and ^{Temp} identifies stressors whose effects may be modulated by temperature.

Stressor	Underlying drivers	Definition
Algal competition $^{Nut, Temp}$	Human impacts to trophic structures	Kelp dominated ecosystems are subject to disturbance and therefore community succession. Competition from other algal 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 – exclusive of macronutrients), including heavy metals, sewage, and petrochemicals, reduce kelp performance.
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 grazers 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.

Table 2: List of stressor characteristics scored (rank and certainty) for each stressor (Table 1). Characteristics were modified from Thom et al. (2011) stressor rating for eelgrass and applied to kelps.

Characteristic	**Definition**
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.

Table 3: Definitions and rubric for rating and certainty scores. Reversibility was scored i inversely. i.e., high = 1, low = 3.

Level	**Applied to characteristics**	**Included in Total Stress**	**Definition**	**Numerical value**
High	Magnitude, reversibility, spatial extent, timing	Yes	The stressor-characteristic is well known and described through research. There is strong evidence and a high level of consensus	3
Medium	Magnitude, reversibility, spatial extent, timing	Yes	There is some information about the stressor-characteristic, but specifics may be unknown and/or there is moderate consensus.	2
Low	Magnitude, reversibility, spatial extent, timing	Yes	Information about the stressor-characteristic is limited and may rely on general biological principles and/or there is little consensus.	1
Very low*	Magnitude, reversibility, spatial extent, timing	Yes	Information about the stressor-characteristic is very limited and heavily relies on general biological principles and/or there is very little consensus.	0.5
Unknown	Magnitude, reversibility, spatial extent, timing	Yes – certainty only	Lack of scientific knowledge precludes scoring.	0
Near surface	Depth extent	No	Stressor occurs near or at the surface of the water (top of the water column)	1
Near bottom	Depth extent	No	Stressor occurs near or at the benthos bottom of the water column)	-1
Both	Depth extent	No	Stressor occurs at both the surface and bottom of the water column (throughout the water column)	0
Increasing	Trend over time	No	The stressor has been generally increasing in intensity/prevalence through time	1
Decreasing	Trend over time	No	The stressor has been generally decreasing in intensity/prevalence through time	-1
Stable	Trend over time	No	The stressor has been stable in intensity/prevalence through time	0

*Very low was only used as a level in certainty scoring.