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Main Activities

- Weekly meetings by web conference with project collaborators to define and revise habitat models, plan stakeholder engagement workshops, and review and analyze subsequent modeling results
- Qualitative network modeling applied to seafloor and kelp forest habitat systems
- Stakeholder workshop (October 2020) to review and revise model formulations and perturbation scenarios
- Presentation of modeling results to WCMAC (March 2021)

Executive Summary

The Washington Marine Spatial Plan and supporting documents define the interactions of physical, ecological, and socioeconomic components of important marine habitats. This project extended efforts to describe the structure and function of these habitats to coordinate potential influences of new marine industry uses along the outer coast in state and surrounding federal waters.

We applied Qualitative Network Modeling to the seafloor and kelp forest habitat systems and evaluate potential direct and indirect effects of three prospective new uses: offshore wind farms, offshore finfish aquaculture, and seabed mining. We assessed these effects in the context of changing ocean conditions resulting from global climate change. Qualitative Network Models rely on the direct, linear interactions between variables in a system structured as a network, following conceptual models developed by subject experts. Results were interpreted as directional changes in each variable with one or more pressures applied to the system.

Models were developed through an iterative process with project collaborators, and through a stakeholder workshop held in October 2020. Experts in coastal Washington marine systems from state, tribal, and federal agencies, as well as academic institutions, were invited to participate in the workshop. A pre-meeting survey was used to prioritize variables affecting each habitat system and final model structures were revised given workshop participant input and resources provided to study authors following the workshop.

Modeling results indicated uncertain outcomes for many model elements of management interest, including habitats and managed rockfish groups. Seabed mining resulted in clear negative impacts to the kelp forest system. Benefits were estimated for managed fish groups in both habitats under wind farm and aquaculture scenarios (sablefish, crab and shrimp in seafloor habitat, and salmon, black rockfish, and lingcod in kelp forest). Climate change increased uncertainty of outcomes in all new use scenarios.

Final model results were presented via web conference to the March 2021 meeting of WCMAC.

The analyses conducted in this project provide a rapid method to determine initial risk to habitats and ecological components from new uses in Washington’s outer coastal waters and quantify uncertainty. This assessment revealed ecological components for which new indicators could be developed to better assess the state and functioning of these habitats.

Project deliverables

- Summary document from the Initial Meeting (Appendix 3)

- Qualitative Network Models for the two selected habitat types (potentially three depending on time and complexity of the first two models) (Figure 2)
- R code for the analysis (available at https://github.com/rwildermuth/WA_QNM_MSP)
- Final report for the Washington state agency audience (this document)
    - This will include a data repository (DataDictionary.xlsx in the WA_QNM_MSP repository), documentation of reasoning and decision-making (Appendix 2), and modeling instructions (AssessSeafloorandKelpHabitats.R in the WA_QNM_MSP repository).
- Draft manuscript for peer-reviewed journal article describing modeling work and outcomes of QNM analysis (Not completed. Will be prepared based on this document)
- Presentation to the Washington Coastal Marine Advisory Council (WCMAC) /MSP staff and other interested parties (Appendix 4)
- Video recording of a presentation and presentation materials summarizing the findings of the project (Not completed. RW will record a version of the presentation and add the link to the github code repository)

Background and Scope of Work

The Washington Marine Spatial Plan (MSP) coordinates development of marine industry along the outer coast in state and surrounding federal waters. To inform planning and development of these new marine use sectors (termed "new uses" here), the Washington Department of Ecology initiated a study to evaluate risks of potential new uses in Washington's outer coast in the context of climate change. Based upon conceptual models developed as part of Washington's Marine Spatial Planning (MSP) initiative (Fig 1.), we developed qualitative network models with the goal of evaluating aspects of climate change and other anthropogenic impacts on marine resources. The intended end users of these conceptual models are Washington state agencies looking to better inform coastal and ocean management decisions.

We used existing conceptual models for a.) kelp forests and b.) seafloor habitats to develop qualitative network models (QNMs). QNM is a conceptually-based tool used to determine the relative influence of different factors on a set of known relationships. While QNMs do not provide mechanistic understanding or quantitative outputs, they do allow researchers to evaluate hypotheses of how perturbations to one or more ecosystem components influence other components in the system. Since numerous conceptual models have been developed and vetted as part of the MSP effort, leveraging these for rapid development of QNMs would be ideal in the immediate phase.

The focus of the modeling work was to evaluate climate impacts to the selected habitats. The specific question addressed was: "*What impacts might we expect on various habitats from individual and cumulative impacts of climate change?*" We adapted the existing conceptual models to include specific drivers of climate change (e.g. sea surface temperature, dissolved oxygen, pCO_2, primary production, as per IPCC, e.g. Henson et al. 2017) and perturbed them according to predicted trends (e.g., ↑, ↓, ↑, ↓ for the previous example) to determine what ecosystem components (represented by boxes in the conceptual models) are most affected by these perturbations. Each scenario was run a thousand times to quantify the effects of relative strengths of interactions within the networks. Model outputs included the proportion of simulations for which a given outcome was observed. System perturbations were invoked individually and cumulatively to understand ecosystem response to individual perturbations and ecosystem responses given multiple stressors, which is a more likely scenario. A subset of ecosystem components were chosen to focus on as response variables (Kelp Forest: Hypoxia, Ocean Acidification, Kelp, Zooplankton, Forage Fishes, Black Rockfish & Lingcod, and Recreational Fishing; Seafloor: Hypoxia, Ocean Acidification, Zooplankton, Small Prey, Crabs & Shrimps, Sablefish, Benthic Predators, Slope Rockfishes, Flatfishes, Fishing).

We compared outcomes from the QNMs of the two habitat types where similar response variables allowed for comparison. We identified the nodes and connections that had the greatest influence or leverage on model outputs, and determined if those nodes and connections are monitored effectively or have robust indicators. Tying the modeling effort with existing ecosystem indicators work (e.g. the development of the conceptual models for the MSP in Andrews et al., 2015) would build continuity and further refine indicators and ecosystem components where monitoring is necessary. We thus evaluated the potential direct and indirect effects of three new uses through Qualitative Network Modeling (QNM). As an example, we demonstrated our methods on the seafloor and kelp forest habitat systems described in the MSP and the Ecosystem Indicators report (Andrews et al. 2015, Fig. 1). The purpose of this modeling exercise was to identify data components that the state should prioritize, track, and report on over time, and to indirectly inform resource management decisions for the state, particularly decisions about changing ocean conditions and new ocean uses.

Approach

Conceptual Models

We initiated our modeling effort by translating the conceptual models of each habitat outlined in the Ecosystem Indicators report (Andrews et al. 2015, Fig. 1) into directed networks describing the interactions of physical, ecological, and socioeconomic components.

We chose the seafloor and kelp forest habitats as defined by the Ecological Indicators for Washington State's Outer Coastal Waters report (Andrews et al. 2015, from here "The Indicators Report") to apply the QNM approach to assess the potential effects of new uses in these systems. We used the Indicators Report to develop a glossary of common terminology (Appendix 1) and preliminary network structures based on conceptual models and indicators outlined in the report. As in the Indicator report, the scope of the seafloor model was defined to be all bottom habitats below 30m depth within WA Marine Spatial Planning (WAMSP) waters. This definition restricts the network to represent the benthic and demersal components near the seafloor; pelagic and surface waters and their associated components were considered part of a different habitat. The kelp forest model scope was defined as rocky reefs and areas of floating kelp canopy composed of bull kelp (*Nereocystis leutkeana*) or giant kelp (*Macrocystis pyrifera*) in depths less than 30m within WAMSP waters.

Our application involved a process of unpacking the components and attributes outlined in the indicator report to the level of model elements, which were defined as measurable states of system variables that interact with or depend on states of other variables in the system. This unpacking directly tied an element used in the modeling exercises to an indicator, or a quantitative biological, chemical, physical, social, or economic measurement that serves as a proxy for the conditions (i.e., state) of a system attribute. To further improve communication among authors and stakeholders, these terms and network structures were recorded in a data dictionary that documented definitions, references, and justification for each model element and network link (Appendix 2).

Expert Elicitation and Stakeholder Workshop

To further ensure reliability and common understanding of the models, we engaged in a collaborative expert elicitation process during which we asked local experts in the fields of oceanography, ecology, and resource management to review model definitions and structure and provide additional resources to improve the representation of these two habitats. Our expert elicitation process involved 1) a pre-meeting survey, 2) a two-day virtual workshop, and 3) a post-meeting exit survey. The authors identified and invited experts from tribal, state, federal, and academic institutions with expertise centered in WAMSP waters fields related to resource management, marine policy, kelp forests, seafloor habitats, ocean climates, and marine ecosystems generally. We aimed to have replicated representation from each of these groups to ensure a representative range of perspectives was reflected in our collected responses.

We convened the Qualitative Network Modeling of Washington Ocean Habitats Workshop to review and further develop the seafloor and kelp forest habitat networks over teleconference October 1st and 5th, 2020. The objectives of the workshop were to:

1. Define the model structure of Seafloor and Kelp Forest Habitat QNMs for use in risk assessment of new ocean uses within the boundaries defined under the WA Marine Spatial Plan,
2. Include feedback from stakeholders and experts on relevant model elements, and
3. Increase understanding of model use and output among stakeholders and management bodies.

Experts in coastal Washington marine systems from state, tribal, and federal agencies, as well as academic institutions, were invited to participate in the workshop. A pre-meeting survey was used to prioritize variables affecting each habitat system and final model structures were revised given workshop participant input and resources provided to study authors following the workshop.

Because our workshop was held virtually and we wanted to accommodate the schedules of our participants, we provided introductory materials and a pre-meeting survey to identified experts two weeks before our virtual workshop. This included recorded video presentations of our purpose and goals for this project, proposed habitat model documentation, as well as a worked example to introduce the QNM approach. The pre-meeting survey prompted participants to score model elements based on their importance for system structure, function, and management interest for each habitat. Participants were also provided space to include additional resources, suggest additional elements or potential new uses of interest in each system, and asked to characterize their expertise in the system(s) along with basic demographic information. The survey was deployed using Google Forms and no personal identifying information was collected about survey respondents. We also encouraged participants to fill out the survey even if they could not attend the virtual workshop.

The workshop was held virtually over WebEx on October 1st and 5th, 2020, for a maximum of three hours each day. On Day 1 of the workshop, 29 participants were introduced to the QNM methods and divided into four break-out groups based on habitat expertise to discuss the survey results and edit preliminary model structures developed ahead of the meeting. On Day 2, Robert Wildermuth briefly demonstrated output from habitat models edited with respect to feedback from Day 1, and 31 participants provided further refinements to the model structures in order to bring dynamics exhibited by the models in line with expert understanding of these systems. The resulting habitat network structures served as the basis for the network modeling. Participant feedback from the expert survey, meeting notes, and an exit survey, including additional data and resources, were summarized in the workshop report (Appendix 3).

Qualitative network modeling

For each habitat network, we evaluated modeled responses under multiple climate change and new use scenarios using QNM. Qualitative network models use a network to describe positive or negative relationships between model elements, or system variables. The relationships in the network can be represented as a community matrix where non-zero entries represent links between elements in columns and rows. Positive links are indicated with a 1, negative links with a -1. We simulated the response of every element in the network if one or more elements were consistently increased or decreased through press perturbation (Dambacher et al. 2002, Justus 2006). These models are qualitative because they only describe the nature of a link between elements (positive, negative, or no link), and the output gives a qualitative response of the system's elements (increase, decrease, no change) to each scenario.

Final model structures were confirmed among study authors after integrating input from the workshop notes and surveys. Decisions about which links were strong enough to include and model element definitions were made on the basis of the California Current Ecopath-with-Ecosim model (Koehn et al. 2016). Links were deemed important to include in the network structure if the Koehn et al. model estimated a cumulative 10% contribution of a prey group to the diet of a predator group, or if a link was specified by expert group members. The reasoning and edits to model structures were recorded in a data dictionary (Appendix 3).

Analysis of the resulting models was conducted in R (R Core Team 2021), and all model input and results files were uploaded to a GitHub repository (https://github.com/rwildermuth/WA_QNM_MSP). The networks for each model system were represented visually in the Dia software (Breit et al. 2009, v0.97.2), with positive and negative influences on model elements recorded using directed graph notation (Fig. 2a and b). These files were loaded into R and used as input for qualitative network analysis using the *QPress* package (Melbourne-Thomas et al. 2012, available at: https://github.com/SWotherspoon/QPress). Qualitative network models make the assumption that the relationships in the network are linear and that, although the relative amount of each model element may increase or decrease, no element is removed from the system and none are added (Dambacher et al 2002). The relationships in the network are contained in a community matrix where non-zero entries represent links between elements in columns and rows. Positive links are indicated with a 1, negative links with a -1. Using matrix algebra, the response of every element in the network to one or more press perturbations, or a consistent increase of a model element until a new system equilibrium is achieved, can be simulated by calculating the adjoint of the negative of the community matrix (Dambacher et al. 2002, Justus 2006). We enforced self-limitation on all model elements (i.e., assigned a -1 value to all diagonal elements in the community matrix). Using *QPress*, relationship magnitudes were drawn randomly from a uniform distribution between 0 and 1 and were multiplied by the elements in the community matrix to simulate a potential set of system relationships. We repeated this random assignment process and thinned the set of simulated community matrices until we had a set of 10,000 stable matrices for each case study system.

Model Scenarios

We evaluated potential outcomes under three new use scenarios: offshore finfish aquaculture, offshore wind farms, and seabed mining. These scenarios were evaluated under both normal and climate change contexts (Table 1).

To understand the potential effects of changing ocean conditions in the seafloor and kelp forest habitats, we first summarized the effects of climate change via a scenario with pressures from increased ocean temperatures and ocean acidification.

In the kelp forest network, most physical environment and abiotic habitat elements were unaffected, though there were uncertain outcomes for hypoxia, with nearly 70% of simulations resulting in higher hypoxia levels under climate change (Table 1, Fig 3a). Fished and other managed groups (e.g., Black Rockfish & Lingcod, Salmon, Sea Otters, and Young-of-Year Rockfishes) in the kelp forest system, as well as lower trophic groups, were estimated to have negative outcomes in a majority of climate change simulations (Fig 3a). In contrast to kelp forests, seafloor habitat was estimated to have reduced hypoxia under climate change (Table 1, Fig 3b). Most other abiotic environmental elements were also unaffected in the seafloor network, but Rock Habitat tended toward positive outcomes under climate change. Outcomes for seafloor fish groups were highly uncertain, with negative outcomes occurring more often for Small Prey, Slope Rockfishes, and Fishing (Fig. 3b).

We evaluated the new uses in each habitat network alone and combined with the climate change scenario described above. Finfish aquaculture in or near kelp forest habitats was expected to result in higher levels of Nutrients and Sedimentation in the absence of climate change, with possible increases in Forage Fishes, Black Rockfish & Lingcod, Mid-Trophic Fishes, Young-of-Year Rockfishes, and Salmon, among others (Table 1, Fig. 4a). Rocky Reef was expected to decline in kelp forest habitat, with uncertain outcomes for Kelp, Sea Urchins, Sea Stars, Sea Otters, and levels of Hypoxia (Fig 4a). Aquaculture under climate change increased uncertainty in the above outcomes, with more simulations balanced between positive and negative outcomes, except for Kelp coverage which was expected to decline in this scenario. Offshore aquaculture in seafloor habitat resulted in higher levels of Hypoxia, Pollution, and positive outcomes for Corals & Sponges, Sablefish, and Small Prey (Table 1, Fig. 4b). Soft Habitat and Flatfishes were negatively impacted under the aquaculture scenario, with uncertain outcomes for Benthic Predators, Crabs & Shrimps, Shelf and Slope Rockfish groups, and commercial fishing (Fig 4b). Offshore aquaculture under climate change resulted in higher uncertainty in outcomes for managed groups in seafloor habitat, though Hypoxia was expected to be reduced under climate change due to declines in Zooplankton and Detritus & Bacteria. Also, declines in Fishing in this scenario resulted in positive outcomes for Rock Habitat.

Wind farms in or near kelp forest habitat generally had beneficial outcomes for managed fish groups and recreational fishing (Table 1, Fig. 5a). Negative outcomes were expected for Sea

Stars and Rocky Reef, while outcomes were uncertain for Kelp, Hypoxia, and Sea Otters (Fig. 5a). Wind farms in a climate change context increased the uncertainty for the same kelp forest model elements, with negative outcomes occurring in more simulations (Table 1). This climate change scenario increased the negative outcomes for Black Rockfish & Lingcod, Kelp, Sea Otters, and Young-of-Year Rockfishes, and resulted in higher levels of Hypoxia. Wind farms in the seafloor habitat predicted increases in Crabs & Shrimps and Sablefish due to aggregating effects attracting Small Prey to wind turbines despite expected negative outcomes for Soft and Rock Habitats (Table 1, Fig. 5b). Outcomes were more uncertain for other managed fish groups, Corals & Sponges, and Fishing in this scenario. Again, climate change combined with wind farms in seafloor habitat increased the number of negative outcomes for most model elements, increasing uncertainty (Fig. 5b). In this scenario, Fishing, Slope Rockfishes, and Hypoxia were expected to decline.

In contrast to the other new use scenarios for kelp forest, seabed mining was expected to negatively impact a majority of kelp forest network elements (Table 1, Fig 6a). Hypoxia was expected to increase in this scenario, while outcomes for Sea Urchins, Sea Stars, and other Benthic Invertebrates were uncertain. Mining under climate change in the kelp forest system increased the number of simulations with negative outcomes for nearly all model elements (Fig. 6a). Seabed mining in the seafloor habitat model resulted in negative outcomes for Fishing, Flatfishes, Benthic Predators, and Soft Habitat (Table 1, Fig 6b). Hypoxia, Sablefish, and Corals & Sponges increased in this scenario, while outcomes were more uncertain for Crabs & Shrimps, Rock Habitat, and Slope and Shelf Rockfish groups (Fig 6b). Mining in the seafloor habitat under climate change increased uncertainty in outcomes for all managed fish groups. Negative impacts on Fishing and Soft Habitat remained fairly certain in this scenario.

Discussion and Recommendations

The outcomes presented here are dependent on the modeling assumptions made while developing the habitat network structures and implementing the scenarios. For example, the seafloor habitat outcomes in scenarios incorporating climate change were affected by reductions in Zooplankton and resulting Detritus & Bacteria levels due to the combined negative impacts from Ocean Acidification and increased Seafloor Temperature. The kelp forest scenarios were similarly affected by the bottom-up effects of lower trophic groups connecting physical and fish group elements. Thus we recommend that Washington's Department of Ecology develop monitoring for zooplankton and forage fish in both habitats evaluated here to improve quantitative understanding of these dynamics and their effects on species of management, social, and economic interest. We also recommend monitoring highly connected elements with many network links, particularly Benthic Invertebrates (13 links), Kelp (16), and Zooplankton (12) in the kelp forest habitat, and Crabs & Shrimps (13), Small Prey (15), and Fishing (16) in the seafloor habitat. The results provided in this study can help guide ecosystem-based management of Washington's coastal resources and the methods can be applied to other Washington MSP habitat systems.

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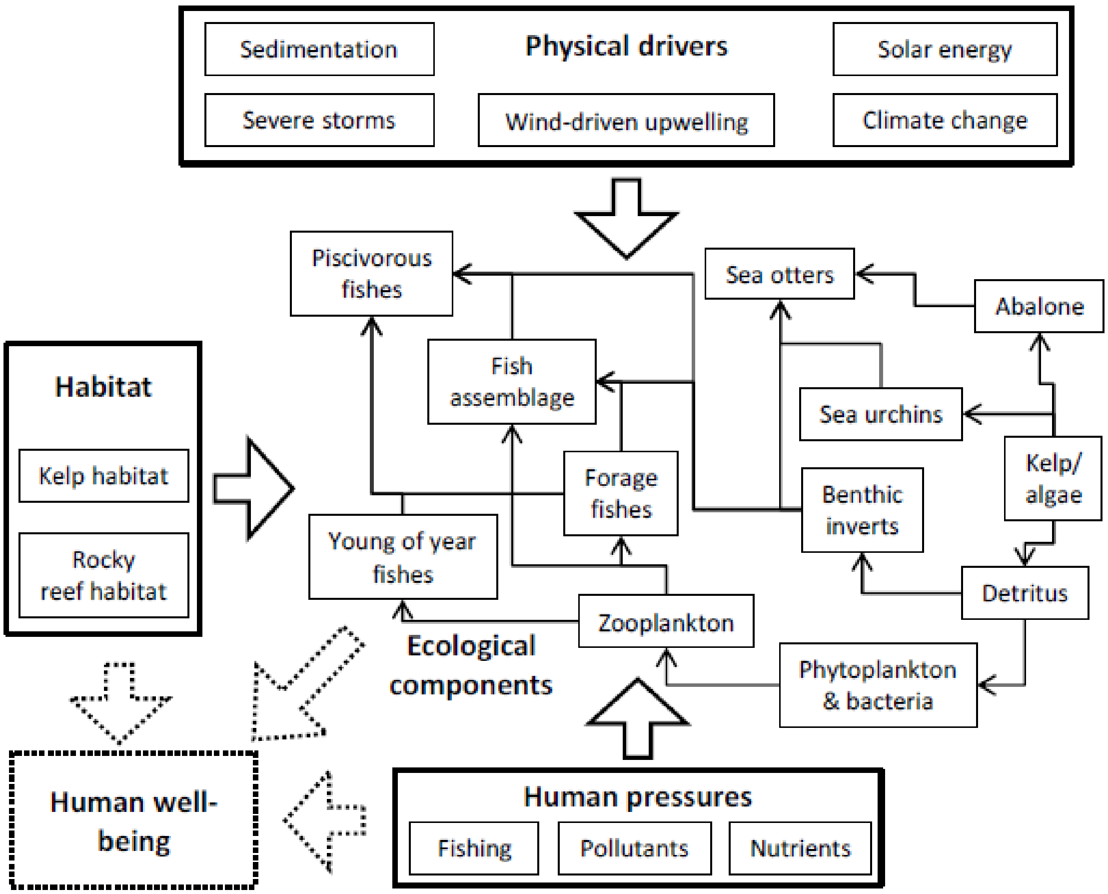
Table 1: Summary of Scenario Evaluations

Scenario	Kelp Forest	Seafloor
Climate Change	↑ Ocean Acidification, Surface Temperature	↑ Ocean Acidification, Seafloor Temperature
+ Finfish Aquaculture	↑ Detritus & Bacteria, Nutrients, Sedimentation, and Forage Fishes ↓ Recreational Fishing and Salmon	↑ Detritus & Bacteria, Pollution, Small Prey, and Corals & Sponges ↓ Fishing and Soft Habitat
+ Offshore Wind Development	↑ Detritus & Bacteria, Recreational Fishing, Forage Fishes, Currents, Eddies & Plumes ↓ Rocky Reef	↑ Small Prey and Corals & Sponges ↓ Fishing, Rock Habitat, and Soft Habitat
+ Seabed Mining of Sand	↑ Sedimentation and Hypoxia ↓ Recreational Fishing, Benthic Invertebrates, and Rocky Reef	↑ Hypoxia ↓ Fishing, Rock Habitat, Soft Habitat, and Small Prey

Figure 1. Ecosystem Indicators Conceptual Models (from Andrews 2015)

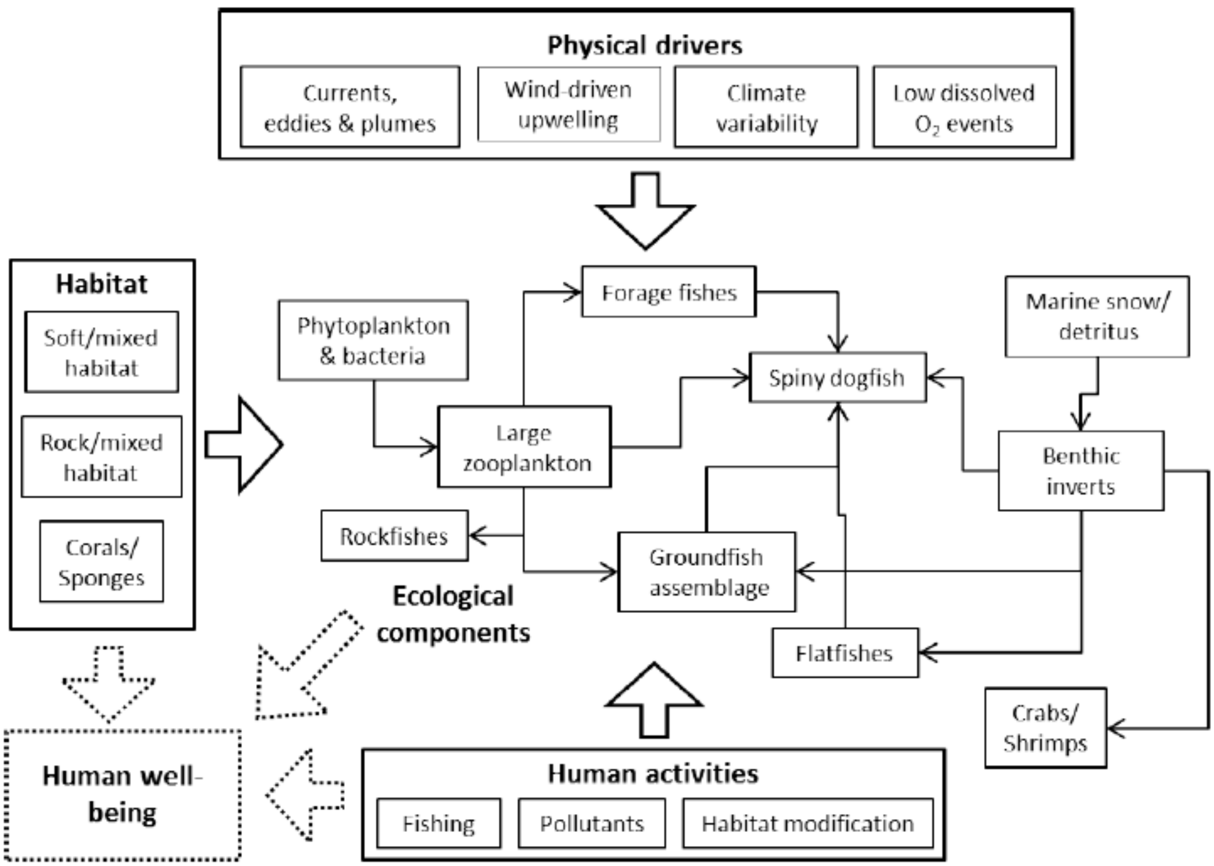
a.) Kelp Forest Conceptual Model

Represents two general types of habitat in our definition of kelp forest habitat for WA MSP waters: (1) habitats that consist of floating kelp canopies of bull kelp *Nereocystis leutkeana* or giant kelp *Macrocystis pyrifera*; and (2) rocky reefs that occur at depths of less than 30m. Rocky reefs are included in this category because many of the species that inhabit kelp forests also inhabit shallow rocky reefs without kelp.



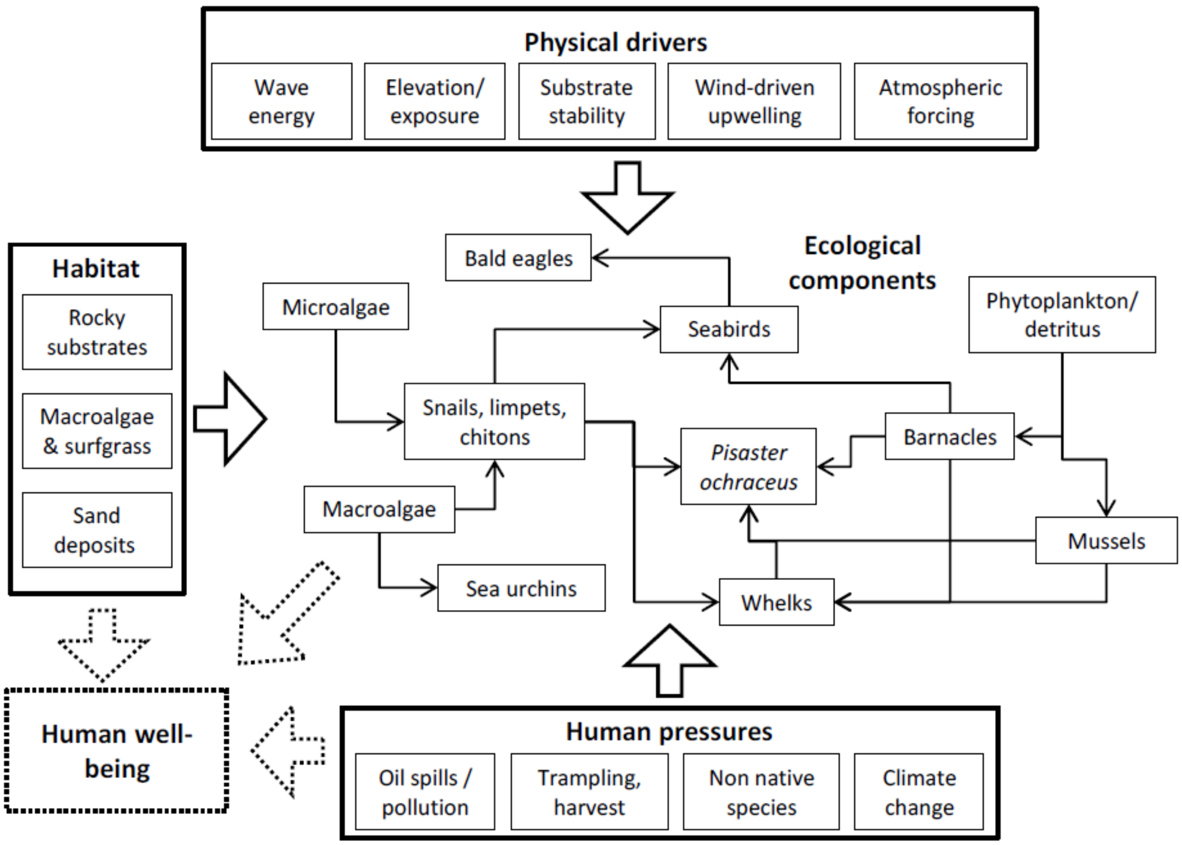
b.) Seafloor Conceptual Model

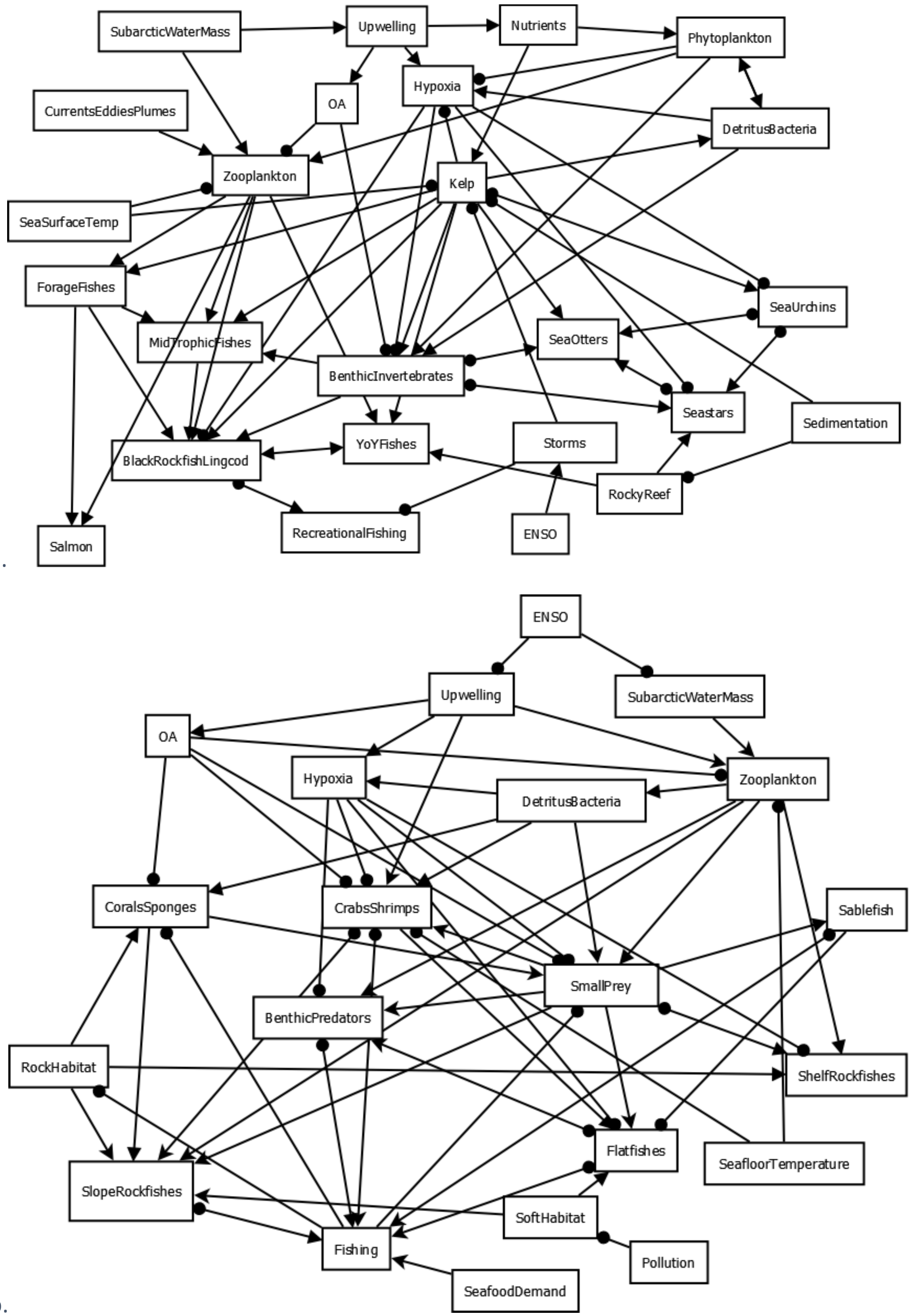
Represents all bottom habitat below 30m depth in WA State waters.



c.) Rocky Shores Conceptual Model

Represents rocky intertidal habitats in WA MSP waters.





a.

b.

Figure 2: Final network structures for the Kelp Forest (a.) and Seafloor (b.) systems following stakeholder workshop and revision

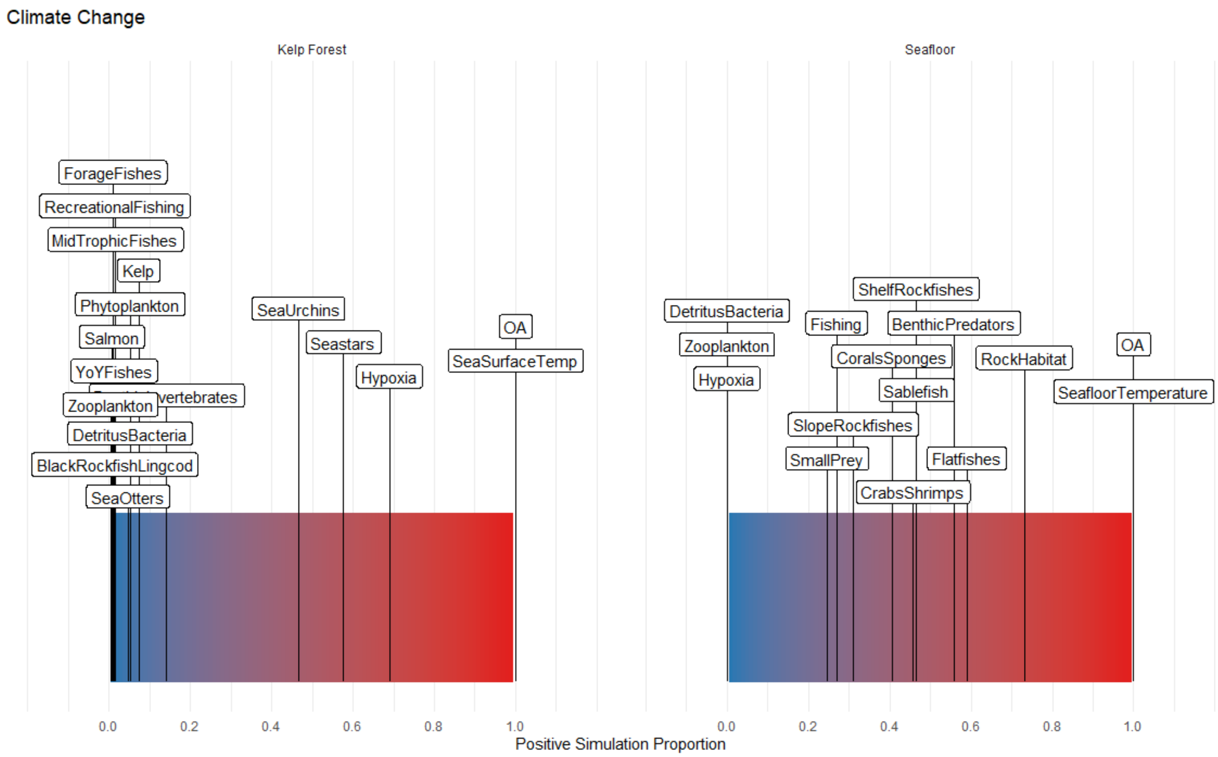


Figure 3: Climate change scenario for both kelp forest and seafloor habitats

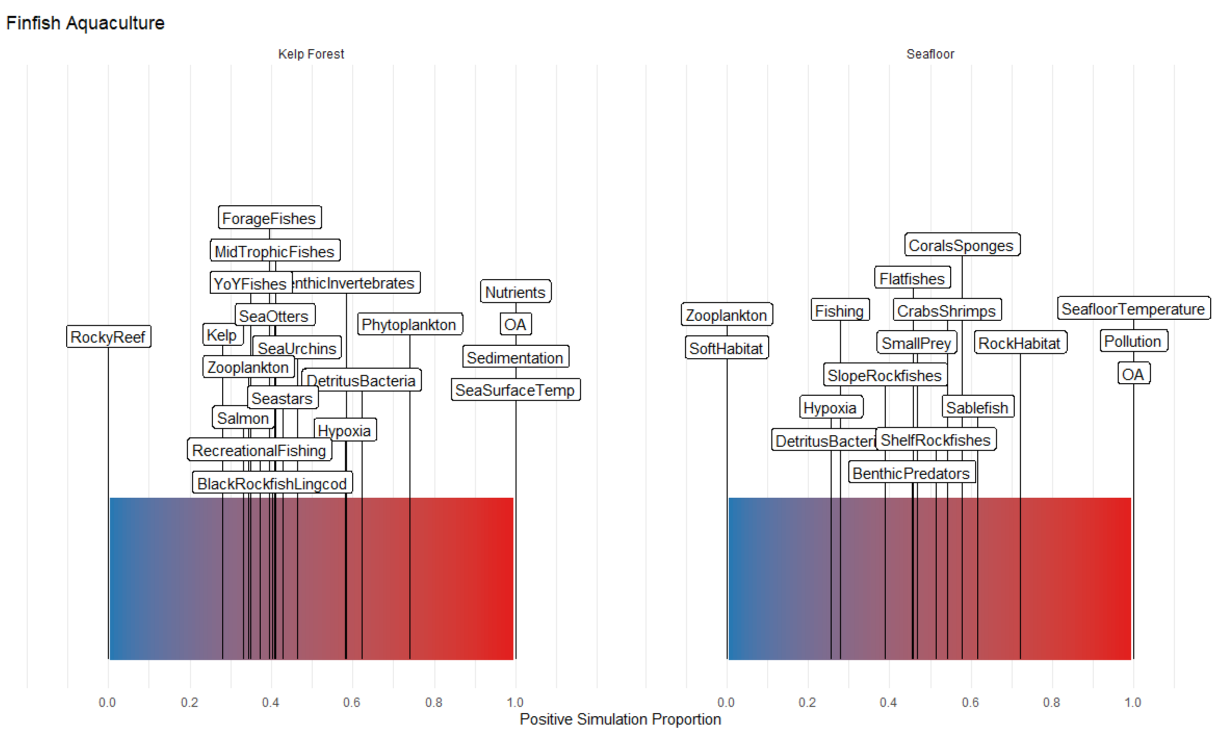


Figure 4: Finfish Aquaculture scenario for both kelp forest and seafloor habitats

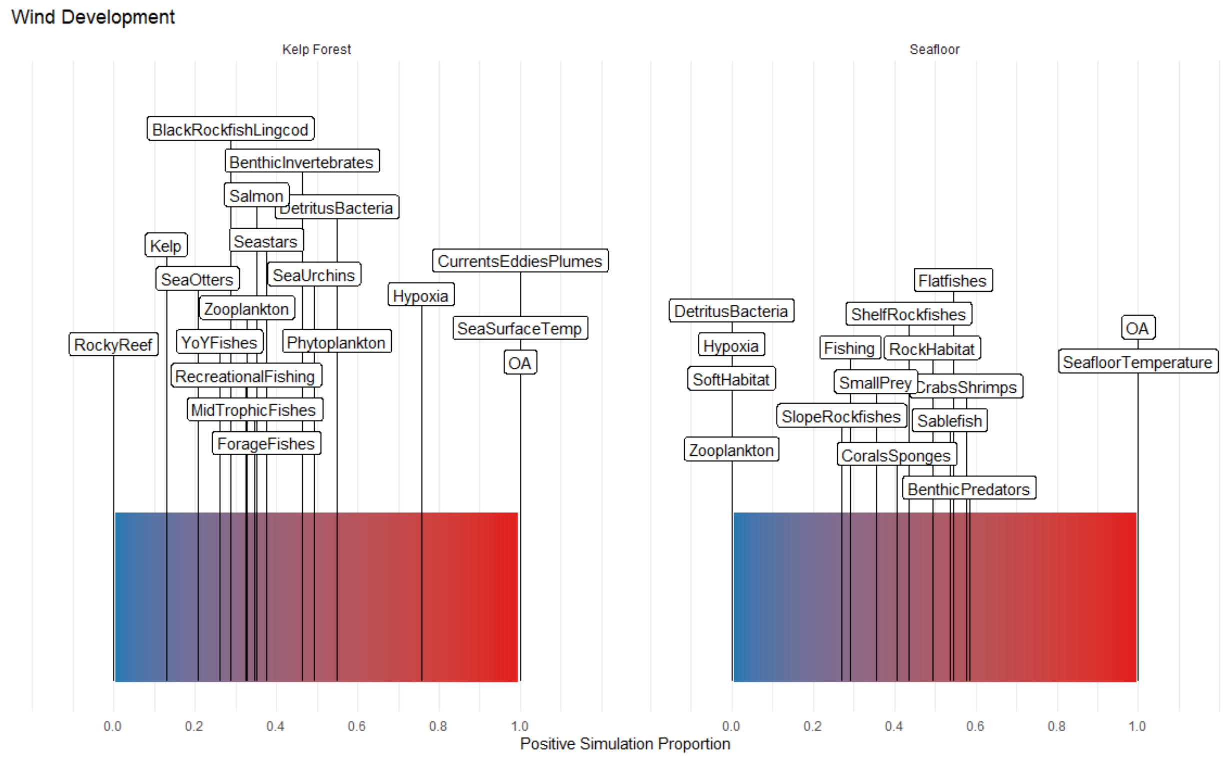


Figure 5: Wind development scenario for kelp forest and seafloor habitats

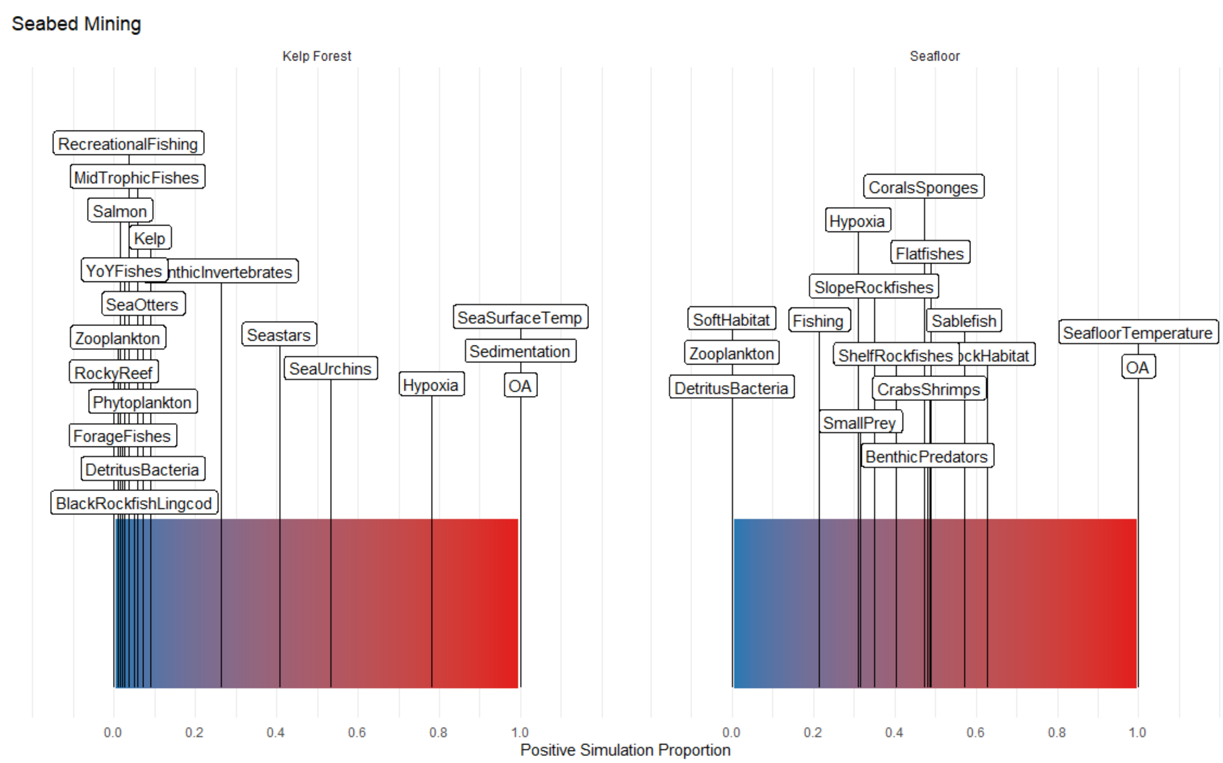


Figure 6: Seabed mining scenario for kelp forest and seafloor habitats

Appendix 1: Glossary

Term	Definition	Reference
Seafloor Habitat	All bottom habitats below ~30 m depth in WAMSP waters	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Kelp Forrest Habitat	Habitats that consist of floating kelp canopies of bull kelp *Nereocystis leutkeana* or giant kelp *Macrocystis pyrifera or* rocky reefs that occur at depths <30 m within WAMSP waters	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Model Element	Measurable states of system parts or variables that interact or depend on states of other variables in the system	Justus 2006, Dambacher et al. 2002
Link	A directional interaction between one model element or variable and another represented as a functional relationship with positive (increasing) or negative (decreasing) direct response on the dependent variable	Justus 2006
Component	A discrete segment of the ecosystem (biological, physical, or human-dimension related) that reflects societal goals or values and should be relevant to the policy goals of Washington State	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Attribute	A characteristic of a component that defines the structure, composition, and function of the ecosystem that is of scientific or management importance but insufficiently specific or logistically challenging to measure directly.	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Indicator	A quantitative biological, chemical, physical, social, or economic measurement that serves as a proxy for the conditions of an attribute(s) of natural and socioeconomic systems	Landres et al. 1988, Kurtz et al. 2001, EPA 2008, Fleishman and Murphy 2009

Appendix 2: Data Dictionary

The data dictionary is a large spreadsheet, available at:

https://drive.google.com/file/d/1hTWylw9zletFz7f9QNCoc7QgL94nv7G5/view?usp=sharing

Appendix 3: **Summary of the Qualitative Network Modeling for Washington Ocean Habitats Workshop**

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Draft document prepared: November 18, 2020

Workshop Summary

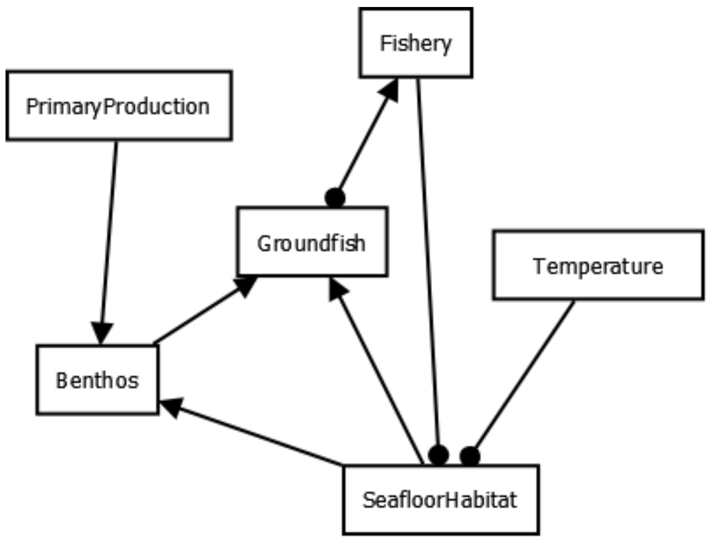
The Washington Department of Ecology contracted Robert Wildermuth of the University of Massachusetts Dartmouth to develop qualitative network models (QNMs) to help guide management decisions regarding new ocean uses and changing ocean conditions in the waters along the outer coast of Washington State. This project builds on the seafloor and kelp forest habitats conceptual models developed during the marine spatial planning process (Andrews et al., 2015). These models will be used to identify data components that the state should prioritize, track, and report on over time, and to indirectly inform resource management decisions for the state, particularly decisions about changing ocean conditions and new ocean uses. As a first step, the Washington Department of Ecology virtually hosted the Qualitative Network Modeling for Washington Ocean Habitats Workshop over Webex on the morning of Oct 1st and 5th, 2020. The objectives of the workshop were to:

4. Define the model structure of Seafloor and Kelp Forest Habitat QNMs for use in risk assessment of new ocean uses within the boundaries defined under the WA Marine Spatial Plan,
5. Include feedback from stakeholders and experts on relevant model elements, and
6. Increase understanding of model use and output among stakeholders and management bodies.

Experts in coastal Washington marine systems from state, tribal, and federal agencies, as well as academic institutions, were invited to participate in the workshop. Ahead of the meeting, participants were surveyed about their expertise and were asked to rank the importance of conceptual model components to system function and human wellbeing. On Day 1 of the workshop, 29 participants were introduced to the QNM methods and divided into four break-out groups based on habitat expertise to discuss the survey results and edit preliminary model structures developed ahead of the meeting. On Day 2, Robert Wildermuth briefly demonstrated output from habitat models altered with respect to feedback from Day 1, and 31 participants provided feedback to further refine the model structures in order to bring dynamics exhibited by the models in line with expert understanding of these systems. Participant feedback from the expert survey, meeting notes, and an exit survey, including additional data and resources, are summarized in the following report.

Description of the Modeling Approach

The Washington Department of Ecology will use outputs from qualitative network models for the Seafloor and Kelp Forest habitats described in the WA Marine Spatial Plan (Andrews et al. 2015) to identify data components that the state should prioritize, track, and report on over time, and to indirectly inform resource management decisions about changing ocean conditions and new ocean uses. Qualitative network models use a network to describe positive or negative relationships between model elements (e.g., Fig. 1). In the WA MSP Habitat models, the model elements include physical forces or states, ecological groups, or human activities, and the links represent interactions or drivers of change in one element due to changes in another. As a simplified example, in Figure 1, Temperature has a negative link (filled dot) to Seafloor Habitat because as Temperature increases, the quality of Seafloor Habitat for Groundfish and Benthos



declines. On the other hand, Groundfish benefit from good quality Seafloor Habitat and eat invertebrates in the Benthos, so those elements have a positive link (arrows) to Groundfish.

The relationships in the network can be represented as a community matrix where non-zero entries represent links between elements in columns and rows. Positive links are indicated with a 1, negative links with a -1. We can use matrix algebra to simulate the response of every element in the network if one or more elements is consistently increased or decreased with a press perturbation (Dambacher et al. 2002, Justus 2006). In our simple example, we can simulate a climate change scenario by applying a press perturbation to increase Temperature and recording the resulting responses on the other elements. In this scenario, Seafloor Habitat, Benthos, Groundfish, and the Fishery are negatively impacted, but Primary Production is unaffected because no links are directed at Primary Production in the network (Fig. 1).

Scenarios using press perturbation of the qualitative network depend on three main assumptions:

1. **The system is stable**, meaning if one element is pressed, the levels of all elements will balance out at some new level, but no element goes to zero (i.e., no group goes extinct).
2. The relationships between elements are linear with some undefined, constant slope. This means all increases or decreases from the press perturbation scenarios are relative. **The model doesn't specify the magnitude of change from a scenario.**
3. Press perturbations represent a consistent change in one or more model elements until the system balances again. **The model doesn't describe how a model element gets to its new stable level.**

These models are qualitative because they only describe the quality of a link between elements (positive, negative, or no link), and the output gives a qualitative response of the system's elements (increase, decrease, no change) to each scenario.

Summary of Expert Survey Responses

Experts invited to the workshop were asked to provide information about themselves and their expertise in seafloor and kelp forest habitats through a survey before the first day of the workshop. A total of 17 experts filled out the survey, with a majority (10) having 15 or more years of experience working, living, and/or invested in Washington's outer coast. This resulted in a cumulative minimum of 183 years of experience in Washington marine systems and coastal communities among our respondents. Except for one respondent who preferred not to provide information on their gender, the gender ratio of respondents to the survey was relatively balanced, with a female to male ratio of 9:7. All respondents choosing to report their race and ethnicity were White or European without Hispanic, Latinx, Chicanx, or Spanish origin. The majority of respondents were marine resource managers or policy practitioners (6), employed by the federal government (7), and/or general experts on Washington's coastal ecology (7) (Table 1). We note that the survey allowed respondents to choose multiple roles to better reflect the range of their expertise and therefore the total responses in Table 1 is larger than the number of respondents.

Table 1: Roles self-identified by survey respondents. Note: respondents were allowed to select more than one role and therefore the respondents self-identifying column sums to more than the total number of respondents (n = 17).

Role	**Respondents self-identifying**
Federal government	7
General expert in the ecology of coastal Washington	7
Marine resource manager or policy practitioner	6
Expert in climate change	4
State government	4
Expert in WA seafloor habitats	3
Expert in the oceanography or physical drivers of WA's marine systems	3
Non-tribal coastal community stakeholder	3
Marine recreation stakeholder	2
Expert in WA kelp forest habitats	2
Expert in ocean acidification	1
Tribal government or stakeholder	1
Aquaculture stakeholder or expert	1
Academia/Research	1

For each habitat (seafloor or kelp forest), experts were asked to identify the importance of each component or attribute identified in the respective conceptual model (Andrews et al. 2015). Components and attributes (hereafter model elements) were divided into physical drivers, ecological and fisheries elements, and human activities, and then scored from most to least important based on survey responses: Very Important (rank score of 3), Fairly Important (2), Somewhat Important (1), No Opinion (0), and Not Important (-1). We then calculated the cumulative rank for each model element as the sum of importance scores for that element. We also summarized the minimum and maximum rank given to each model element (Tables 2 and 3).

In the seafloor model, the Dissolved Oxygen physical driver had the highest cumulative rank of any model element (45), followed by Fishing (43) and Crabs (40) in the human dimensions and ecological and fisheries element types, respectively (Table 2). The lowest ranked model elements were Currents and Mid-Water Rockfishes, with a cumulative rank of 24 for each (Table 2). All model elements were scored as Very Important by at least one survey respondent, but the highest ranked elements also had the highest minimum importance score (Fairly Important, 2). Model elements with lower minimum importance scores (No Opinion, 0, or Not Important, -1) also tended to have lower cumulative ranks. We view this as evidence that the experts responding to the survey had a general consensus about which components and attributes of the seafloor habitat are most and least important. One exception to this conclusion may be the Forage Fishes element, which had a moderate importance rank (35), but also received at least one score of Not Important (-1) in the survey responses.

In the kelp forest model, Kelp Habitat received the highest importance score (45), followed by Nutrients and Rocky Reef Habitat, each with a score of 41 (Table 3). The lowest ranked model element was Marine Snow with a cumulative rank of 10, followed by Local Weather with a rank of 25 (Table 3). As with the seafloor model, every kelp forest model element was scored a maximum importance of Very Important (3) at least once, however the minimum scores were less consistent. Again, the highest ranked model elements all had minimum importance scores of Fairly Important (2), but minimum scores of Somewhat Important (1), Not Important (-1), and No Opinion (0) were more evenly distributed among the remaining elements. Although the consistency in highly ranked model elements likely still serves as evidence of consensus among expert respondents on which elements are most important in kelp forest habitats, the wide range of importance scores for other elements may indicate more uncertainty in which elements play an important role in this habitat.

These survey results were reported to participants on Day 1 of the workshop and used to help frame discussion about changes to preliminary versions of the QNM model structures. We summarize these discussions and model edits in the next section.

Table 2: Total rank, minimum and maximum score for seafloor habitat model elements (n = 17).

Element Type	Model Element	Total Rank	Minimum Score	Maximum Score
Physical Drivers	Dissolved Oxygen	45	2	3
	Upwelling	39	1	3
	Ocean Acidity	36	1	3
	Seafloor Temperature	36	1	3
	Rock Habitat	35	0	3

	Soft Habitat	31	0	3
	Source Waters	27	0	3
	El Nino Southern Oscillation	27	-1	3
	Currents	24	0	3
Ecological and Fisheries	Crabs	40	1	3
	Benthic Invertebrates	39	0	3
	Phytoplankton	38	1	3
	Zooplankton	37	1	3
	Forage Fishes	35	-1	3
	Corals	34	0	3
	Deep Targeted Rockfishes	34	0	3
	Benthic Predators	33	0	3
	Flatfishes	32	0	3
	Groundfish Assemblage	32	0	3
	Shelf Rockfish	32	0	3
	Trophic Structure	31	1	3
	Marine Snow	27	-1	3
	Mid-Water Rockfishes	24	-1	3
Human Activities	Fishing	43	2	3
	Seafood Demand	33	1	3
	Pollution	28	0	3

Table 3: Total rank, minimum and maximum score for kelp forest habitat model elements (n = 17).

Element Type	Model Element	Total Rank	Minimum Score	Maximum Score
Physical Drivers	Nutrients	41	2	3
	Rocky Reef Habitat	41	2	3
	Sea Surface Temperature	39	2	3
	Upwelling	32	0	3

	Dissolved Oxygen	30	1	3
	Sedimentation	30	1	3
	El Nino Southern Oscillation	29	-1	3
	Ocean Acidity	28	1	3
	Currents	27	-1	3
	Source Waters	27	0	3
	Local Weather	25	0	3
Ecological and Fisheries	Kelp Habitat	45	2	3
	Sea Urchins	39	0	3
	Forage Fishes	37	-1	3
	Sea Otters	34	-1	3
	Trophic Structure	34	1	3
	Young of year Fishes	34	0	3
	Zooplankton	33	1	3
	Benthic Invertebrates	31	0	3
	Black Rockfish	31	0	3
	Phytoplankton	30	-1	3
	Mid-Trophic Fishes	28	0	3
	Marine Snow	10	-1	3
Human Activities	Pollution	33	1	3
	Recreational Fishing	29	1	3

Summary of Workshop Discussions and Model Structure Edits

On Day 1 of the workshop, after reviewing the QNM modeling approach and responses to the expert survey, workshop participants were divided into four breakout groups according to their expertise in a particular habitat or system (two groups per habitat). These breakout groups were facilitated by the workshop hosts and notes were recorded with the help of rapporteurs from the Coastal States Organization, the University of Washington, and University of Massachusetts Dartmouth. Group facilitators were directed to guide discussion of their respective habitat models around elements of the models that are important for management directives, ecosystem services, or wellbeing. We also asked participants to suggest new model elements or relationships between elements based on their experiences and available data sources. Group facilitators guided discussion around which relationships between elements were strong enough or relevant for representing system dynamics, and thus important to include as positive or negative links in the network. Discussion on Day 2 of the workshop was used to review changes made to model structures based on breakout group edits, suggest further changes, and identify remaining gaps in understanding and additional resources that may fill those gaps. Finally, respondents were asked to provide feedback about the workshop through an exit survey, where they were provided another opportunity to suggest edits to the model anonymously. Below we summarize the suggestions for changes to model definitions and structures based on responses in both surveys, notes from the breakout groups, and discussion from Day 2 of the workshop.

Seafloor Habitat Model Changes

The first set of changes to the seafloor habitat model involved renaming and redefining some physical driver and lower trophic elements. The Source Waters element was re-defined as Subarctic Water Mass to better distinguish the relationship between this water mass and zooplankton communities from faster (i.e., intra-annual scale) physical drivers in the coastal Washington system. We also redefined Dissolved Oxygen as Hypoxia to improve interpretation of risk to the system from low oxygen (increased hypoxic) events. The Hypoxia redefinition also required changing the nature of links originating from this element to reflect the unfavorable nature of effects from increased hypoxia. Lastly, the function of bacteria in the system necessitated that this biomass pool be transferred to the detritus group (changed from Marine Snow), resulting in newly defined elements of Phytoplankton and Detritus & Bacteria.

Multiple links between new and existing elements were edited. Effects of Ocean Acidification were removed from mobile fish groups, assuming that these groups could relocate to better habitat temporarily. Negative Ocean Acidification impacts were included for shelled invertebrate and structural groups, including Crabs & Shrimp, Zooplankton, and Corals & Sponges. The link between Ocean Acidification and Detritus & Bacteria was also removed. The breakout groups also decided to remove links from Hypoxia to Corals & Sponges, from Seafloor Temperature to Rockfish, and from Subarctic Water Mass to Ocean Acidification. Positive links were added from Zooplankton to Benthic Invertebrates and Flatfishes, from Detritus & Bacteria to Benthic Invertebrates and Corals & Sponges, and from Soft Habitat to Flatfishes. A negative link was added from Benthic Predators to Deep Rockfishes. Negative Fishing impacts on Rock Habitat were added, which then had a positive impact on Corals & Sponges. Workshop participants also added the positive pathway from Zooplankton to Detritus & Bacteria to Crabs & Shrimp.

To simplify the model, multiple element removals were discussed. Shelf Rockfish were removed, as was recommended for Mid-Water Rockfish. After discussion, Forage Fish were suggested to be redefined as Small Fish, which reflects mesopelagic fish at depth as opposed to more surface-oriented species and provides a link between invertebrates and higher trophic levels. One breakout group discussed removing Rock Habitat from the model to narrow the scope of the model specification to describe soft bottom habitats where most current human activities overlap.

The workshop organizers decided against this tack because the models were meant to be generalizable for all seafloor habitat effects, particularly in the case of new uses which may impact Rock Habitat more. Rock Habitat was also retained to reflect the designation of these habitats as Essential Fish Habitat for some rockfishes.

Given the redefinition of physical drivers model elements and output from two simple climate change scenarios (Seafloor Temperature warming and increased Ocean Acidification), workshop participants suggested the following refinements of the physical drivers sub-system to possibly better reflect expert understanding of these dynamics and the patterns of hypoxia, warming, and acidification observed in the system. Positive links from Upwelling to Hypoxia and Ocean Acidification were included to reflect the intra-annual linkages between these phenomena. A positive link from El Niño Southern Oscillation to Subarctic Water Mass was added, as well as a link from Detritus & Bacteria to Hypoxia to reflect eutrophication. Currents, Eddies & Plumes were removed from the seafloor habitat model because they were likely not of large influence at these depths.

Further, the seafloor habitat experts chose to simplify representation of the biogeophysical process surrounding lower trophic interactions in waters below 30 m depth. Rather than reflect the process of primary production, which occurs in surface waters, Phytoplankton was removed from the model, with a positive link included directly from Upwelling to Zooplankton to reflect the effect of upwelling-driven blooms on grazing and export of biomass and detritus to depth. Justification for the elements and links, with associated references, are logged in the data dictionary that accompany the final model used for analyses.

Based on discussions during the second day of the workshop and the exit survey, the following topics need further clarification in the seafloor habitat model definition:

1. Workshop participants expected a negative impact of the El Niño Southern Oscillation on Upwelling, resulting in reduced upwelling in high ENSO phases. Further clarification may be found in Jacox et al. (2015).
2. Based on preliminary scenarios, the model does not reflect the expected correlation between Hypoxia and Ocean Acidification. This may be possible to correct with a connection from Detritus & Bacteria to Ocean Acidification. Workshop participants suggested conferring with Simone Alin about the PMEL OA cruise in 2016 to confirm about the relationships between ENSO, warming, OA, and hypoxia, along with Marshall et al. (2017) and Hodgson et al. (2018).
3. Related to (2) above, it may be helpful to include a model element reflecting marine heatwaves in the system.
4. It was recommended in multiple contexts that sablefish should be separated from the Benthic Predators. One breakout group suggested possibly defining a DTS (Dover sole, Thornyhead, and Sablefish) Complex element, which all have similar tolerance to hypoxia, as well as management relevance. This may require re-inclusion of the Shelf Rockfish element.
5. Forage fish, particularly mesopelagics, were identified as important with potential to include them as a Small Fish element. Evidence for links to these fish was provided in Koehn et al. (2016) and supporting material.

6. Respondents to the pre-meeting survey suggested we consider adding other benthic structure-forming organisms as a separate element.

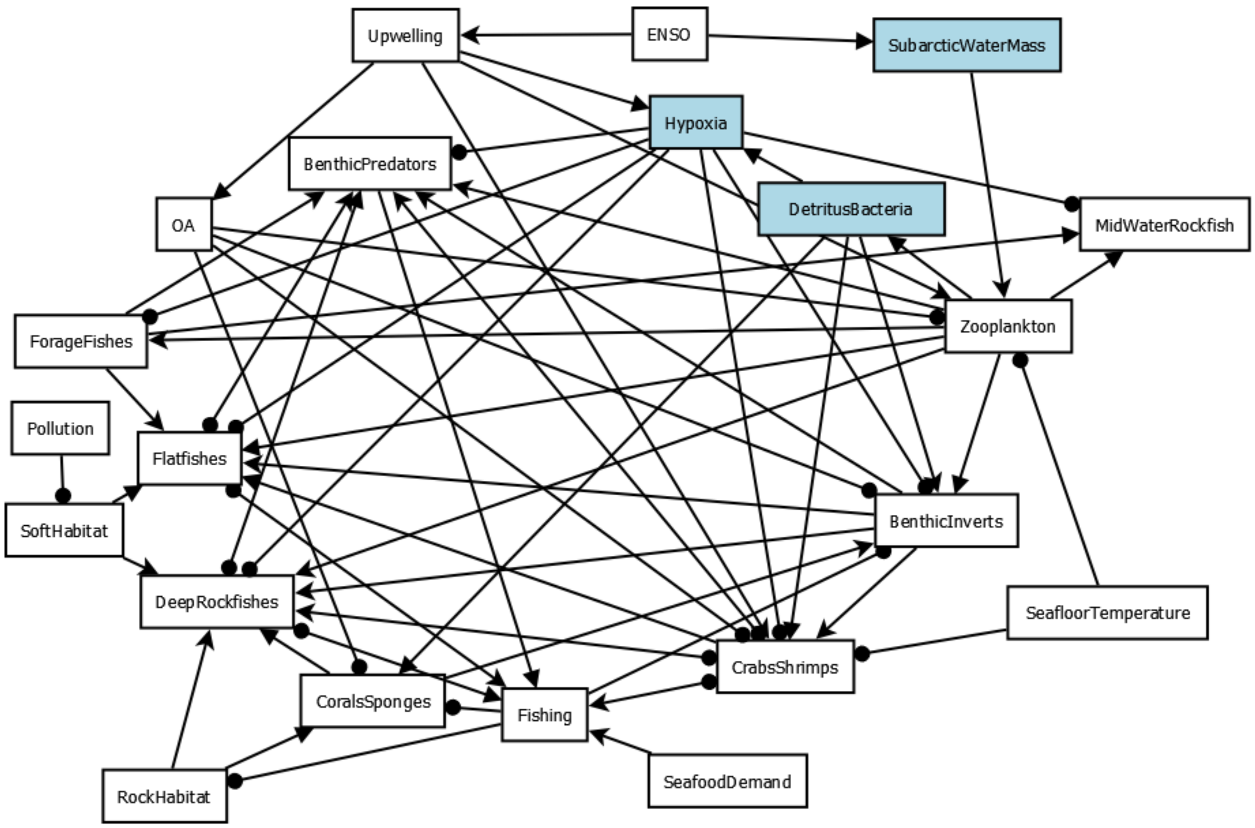


Figure 2: Edited seafloor habitat network presented on Day 2 (Oct. 5th) of the workshop. Blue elements are elements redefined following breakout groups.

Kelp Forest Habitat Model Changes

The redefinitions for Phytoplankton, Detritus & Bacteria, Subarctic Water Mass, and Hypoxia defined for seafloor habitat above were also implemented for the kelp forest model. In addition, the Local Weather model element was redefined as Storms to improve interpretation. A Commercial Fishing model element targeting Lingcod & Black Rockfish was suggested by one breakout group, though there was some uncertainty about including this element. Experts confirmed that Pollution could be removed from the model structure, and suggested potential for removing or redefining the Forage Fishes and Rocky Reef elements. The argument made for hard habitats in the seafloor habitat model was also made for Rocky Reef, which provides habitat to Young-of-Year Fishes, specifically Essential Fish Habitat to rockfish, including yelloweye rockfish.

Multiple new links were suggested during Day 1. The positive link path from Subarctic Water Mass to Upwelling and then to Hypoxia was added, ending with a negative impact from Hypoxia on Benthic Invertebrates. The influence of Upwelling on Phytoplankton was removed to include the more mechanistic pathway of Upwelling having a positive effect on Nutrients, which then positively influenced Phytoplankton. The remaining suggested additional links are summarized below:

- Positive links
  - From Upwelling to Ocean Acidification
  - From Phytoplankton to Benthic Invertebrates
  - From Rocky Reef to Young-of-Year Fishes
  - From Kelp to Forage Fish
  - From Nutrients to Kelp
  - From Detritus & Bacteria to Hypoxia
  - Reciprocal positive links between Phytoplankton and Detritus & Bacteria
- Negative links
  - From Ocean Acidification to Zooplankton
  - From Sedimentation to Rocky Reefs
  - From Commercial Fishing to Rocky Reefs
  - From Storms to Recreational Fishing
  - From Storms to Kelp
  - From Phytoplankton to Hypoxia
  - From Kelp to Hypoxia
  - From Hypoxia to Black Rockfish & Lingcod, Benthic Invertebrates, Sea Stars, and Urchins
  - From Sedimentation to Kelp, but at a lower relative impact than other impacts on Kelp

The resulting changes with preliminary scenario analyses were presented to workshop participants on Day 2 and can be seen in the diagram in Figure 3. The resulting discussion on Day 2 confirmed that Young-of-Year Fish and Forage Fish should not be condensed into a single element, and that there is no commercial fishing by fixed or bottom gears in kelp forest or Rocky Reef on the outer coast of Washington, nor is there fishing for Urchins in this system. Remaining topics discussed for the kelp forest habitat that need further evidence to complete the model are as follows:

1. The definition of the physical drivers for this model is different from the seafloor model, but this structure does reflect the correlation between Ocean Acidification and Hypoxia expected in this coastal system.
2. There was some debate on whether Kelp counteracts Ocean Acidification, particularly at more than a local scale. Work by Pfister et al. (2018, 2019) was suggested to help clarify these points.
3. Most effects of Ocean Acidification on calcareous invertebrates and Phytoplankton seemed reasonable, but confirmation was needed for effects on Urchins
4. An additional requested scenario attempted to model the trophic cascade resulting from addition or removal of Sea Otters and their effect on Urchins and Kelp, but the preliminary structure in Figure 3 did not reflect this. Shelton et al. (2018) was suggested as a resource showing that this classic dynamic is decoupled in recent years in offshore kelp forests.
5. Including salmon, at least in juvenile stages, was suggested in the surveys and discussion, with emphasis on the cultural importance of these habitats for salmon harvest by local tribes and the inclusion of these habitats as Essential Fish Habitat in federal management documents for these

species. Multiple resources were provided, which appear in the Additional Resources section below.

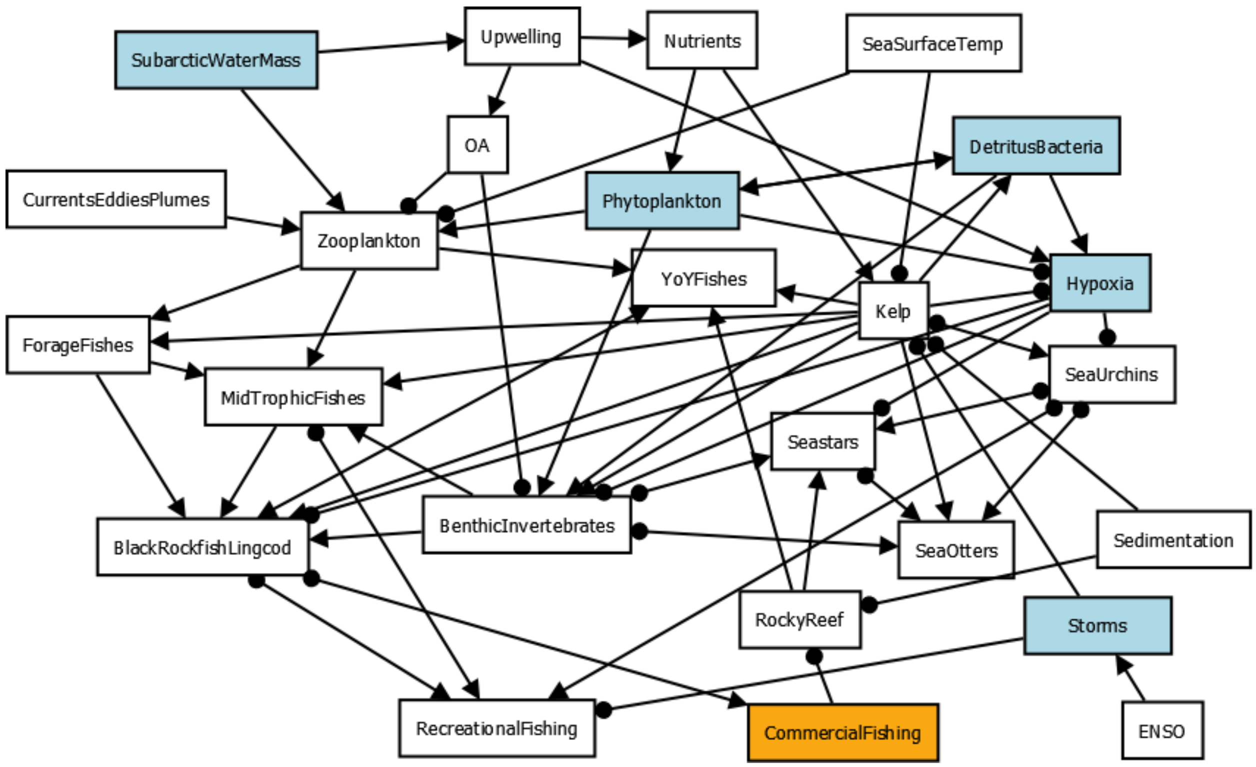


Figure 3: Edited kelp forest habitat network presented on Day 2 (Oct. 5th) of the workshop. Blue elements are elements redefined following breakout groups and yellow elements were added in breakout groups.

Remaining Tasks for Model Development

The models presented on Day 2 of the workshop are not the final versions that will be used for decision-making. Based on participant input outlined in the previous section and additional resources provided, Robert Wildermuth, with the help of collaborators, will finalize the model structures and present the draft models and analyses to the Washington Coastal Marine Advisory Group (WCMAC) and interested workshop participants. The remaining steps for the project are summarized below:

1. Finalize seafloor and kelp forest habitat model structures and element definitions, including full documentation of data sources and rationale based on workshop participant input.
    a. This may include relevant aspects of human dimensions related to human wellbeing (see below).
2. Incorporate effects of likely new uses in these habitats, including offshore wind energy development, offshore aquaculture, and seafloor mining.
3. Evaluate which habitat elements of importance to management and human wellbeing are most sensitive to these new uses and changing climate conditions.

    a. This includes identifying highly influential model elements in each system, highly uncertain yet important estimated pathways in the modeled systems, and whether indicator data exist to closely monitor these elements and relationships.
4. Report draft results to WCMAC and workshop participants.
5. If needed, revise models based on WCMAC and participant comments.
6. Hand-off final models and analyses in the form of a project report to Washington's Department of Ecology.
    a. Time was provided to discuss ownership of the final model and possible future collaboration on Day 2 of the workshop, but this was not of interest to workshop participants. Model ownership must still be resolved.
7. Publish findings in a peer-reviewed scientific journal.

Potential New Ocean Uses for Consideration

As part of the workshop, we recorded potential new ocean uses mentioned by workshop participants in discussions and pre-meeting and exit surveys that may need to be considered in these models under the Washington Marine Spatial Plan. In addition to the uses identified by Washington's Department of Ecology (i.e., offshore renewable energy development, offshore aquaculture, and seafloor mining) workshop participants also identified vessel traffic as a use in kelp forest habitats. Although not a new ocean use in terms of resource extraction by a particular industry sector, one respondent to the surveys also posed the effects of habitat restoration as another activity in these habitats that may be evaluated with these models.

Human Dimensions of Note

Similar to potential new ocean uses, we also asked workshop participants about important socioeconomic or other human dimensions contributing to human wellbeing in the seafloor and kelp forest systems. These human dimensions, or potential interactions with the ecological system, mentioned during the workshop and in the surveys are noted below:

- Tribal treaty rights and Usual and Accustomed (U&A) fishing grounds
- Harvest of kelp
- Discards resulting in detritus
- The definition of Pollution in each model was not sufficient for including in these structures, but refining the types of pollution, and particularly allowing descriptions of oil spill impacts, may better reflect impacts on these habitats.
- Disturbance to seafloor structure-forming elements
- Interactions between salmon and Southern Resident orca populations were mentioned in the context of meeting management directives.

Finally, the work of Breslow et al. (2017) and Poe et al. (2014) were offered as resources on aspects of human wellbeing to include in our analyses.

Additional Resources

Meeting documents and model code can be made available upon request.

Websites:

- Northwest Straits Commission: https://nwstraits.org/our-work/kelp/
- NOAA's West Coast Habitat Conservation:
    - https://www.fisheries.noaa.gov/west-coast/habitat-conservation/kelp-forest-habitat-west-coast
    - https://www.fisheries.noaa.gov/west-coast/habitat-conservation/habitat-areas-particular-concern-west-coast
    - https://www.fisheries.noaa.gov/west-coast/habitat-conservation/essential-fish-habitat-west-coast
- The Ocean Carbon and Biogeochemistry Project: https://www.us-ocb.org/dominant-physical-mechanisms-driving-ecosystem-response-to-enso-in-the-california-current-system/

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Miscellaneous:

Kelly Andrews also provided the workshop hosts with figures from the 2020 Olympic Coast National Marine Sanctuary's Condition Report detailing the amount of soft and hard seafloor habitats exposed to bottom trawl gear and a PowerPoint presentation by Sara Hamilton of Oregon State University about kelp population dynamics along the Oregon coast.

Project Glossary

Term	Definition	Reference
Seafloor Habitat	All bottom habitats below ~30 m depth in WAMSP waters	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Kelp Forest Habitat	Habitats that consist of floating kelp canopies of bull kelp *Nereocystis leutkeana* or giant kelp *Macrocystis pyrifera* or rocky reefs that occur at depths <30 m within WAMSP waters	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Model Element	Measurable states of system parts or variables that interact or depend on states of other variables in the system	Justus 2006, Dambacher et al. 2002
Link	A directional interaction between one model element or variable and another represented as a functional relationship with positive (increasing) or negative (decreasing) direct response on the dependent variable	Justus 2006
Component	A discrete segment of the ecosystem (biological, physical, or human-dimension related) that reflects societal goals or values and should be relevant to the policy goals of Washington State	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Attribute	A characteristic of a component that defines the structure, composition, and function of the ecosystem that is of scientific or management importance but insufficiently specific or logistically challenging to measure directly	WA Ecosystem Indicator Report, Andrews, Coyle & Harvey, 2015
Indicator	A quantitative biological, chemical, physical, social, or economic measurement that serves as a proxy for the conditions of an attribute(s) of natural and socioeconomic systems	Landres et al. 1988, Kurtz et al. 2001, EPA 2008, Fleishman and Murphy 2009

Participant List

Participant	Affiliation	Role
Teressa Pucylowski	WA Dept. of Ecology	Host

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P. Sean McDonald	University of Washington	Host, Facilitator
Gavin Fay	University of Massachusetts Dartmouth	Host, Facilitator
Robert Wildermuth	University of Massachusetts Dartmouth	Host
Amanda Hart	University of Massachusetts Dartmouth	Rapporteur
John Ryan-Henry	Coastal States Organization	Rapporteur
Mike Molnar	Coastal States Organization	Rapporteur
Rachel Keylon	Coastal States Organization	Rapporteur
Brittney Parker	Coastal States Organization	Rapporteur
Scott Mazzone	Quinault Indian Nation	Participant
Julie Ann Koehlinger	Hoh Tribe	Participant
Staci McMahon	University of Washington	Participant
Andy Lanier	West Coast Ocean Data Portal	Participant
Katie Wrubel	Olympic Coast National Marine Sanctuary	Participant
Waldo Lakefield	Oregon State University	Participant
Micah Horwith	WA Dept. of Ecology	Participant
Laura Koehn	NOAA West Coast Region Protected Resources	Participant
Kym Jacobsen	Northwest Fisheries Science Center, NOAA	Participant
Kelly Andrews	Northwest Fisheries Science Center, NOAA	Participant
Shallin Busch	Northwest Fisheries Science Center, NOAA	Participant
Corey Niles	WA Dept. of Fish and Wildlife	Participant
John Vavrinec	Pacific Northwest National Laboratory	Participant
Natalie Coleman	WA Dept. of Ecology	Participant
Whitney Roberts	WA Dept. of Fish and Wildlife	Participant
Rich Osborne	University of Washington	Participant
Abigail Harley	NOAA Fisheries	Participant
Tarang Khangaonkar	Pacific Northwest National Laboratory	Participant

Tommy Moore	Northwest Indian Fisheries Commission	Participant
Helen Berry	WA Dept. of Natural Resources	Participant
Marisa Nixon	West Coast Ocean Data Portal	Participant
Roxanne Carini	Northwest Association of Networked Ocean Observing Systems	Participant
Terrie Klinger	University of Washington	Participant
Samantha Siedlecki	University of Connecticut	Participant
Simone Alin	Pacific Marine Environmental Laboratory, NOAA	Participant
Genevra Harker-Klimes	Pacific Northwest National Laboratory	Participant
Elizabeth Clarke	Northwest Fisheries Science Center, NOAA	Participant
Jan Newton	University of Washington, Northwest Association of Networked Ocean Observing Systems	Participant

Appendix 4: Slide deck for March 2021 presentation to WCMAC.

Powerpoint presentation also available at:

https://drive.google.com/file/d/1wL5ewDzSxa8w5d0PBlUkHaz5eajpqzwF/view?usp=sharing

QUALITATIVE NETWORK ANALYSIS OF NEW OCEAN USES IN WASHINGTON STATE WATERS

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WCMAC, March 17, 2021

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Goal

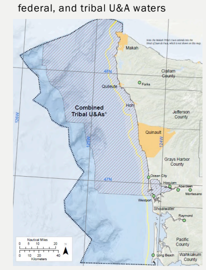
Tasked by WA Dept. of Ecology to provide model-based advice for:

- Development of indicators to track and report on
- Guiding management of new ocean uses
  - *Offshore finfish aquaculture*
  - *Offshore wind development*
  - *Seabed mining*

Supports directives of the Washington Marine Spatial Plan

Builds from the MSP Indicators report (Andrews et al. 2015)

WA MSP Study Area in state, federal, and tribal U&A waters



WA MSP 2017

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Outline

- Modeling Background
- Development of Model Structures
  - Review of Expert Workshop Outcomes
- Scenario Application
- Overview of Outcomes and Results
- Advice and Next Steps

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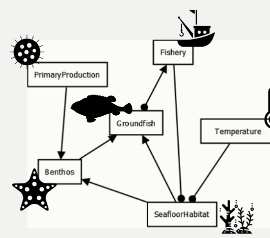
Why Qualitative Network Modeling?

- Gives indication of indirect effects of pressures in a system
- Uses expert knowledge and simplifying assumptions
- Describes wide range of variables without need of quantitative data



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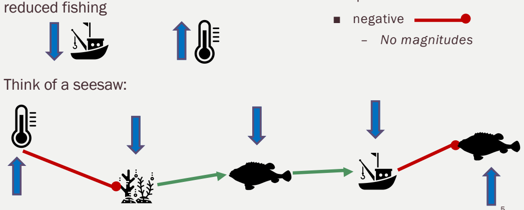
Simulating change

- Evaluate how system responds to a consistent increased temperature and reduced fishing

Interactions are:

- positive
- negative
  - *No magnitudes*

- Think of a seesaw:



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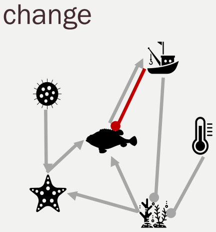
Simulating change



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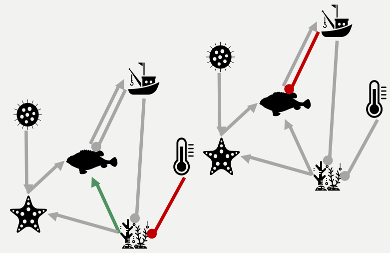
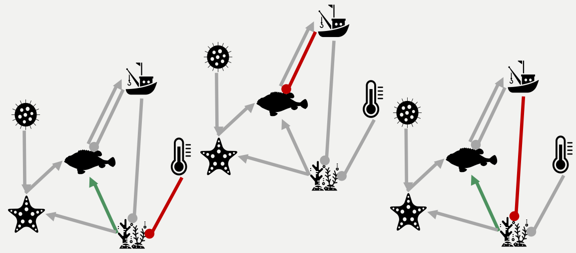
Simulating change



Simulating change



Outline

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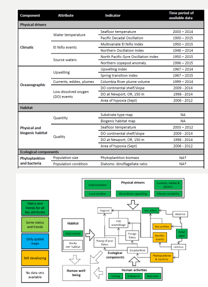
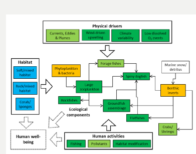
Habitat models for the Washington Marine Spatial Plan

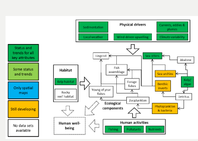
- The Marine Spatial Plan (2017) and Andrews et al. (2015) define habitats in waters of Washington's outer coast
  - *Conceptual models and indicator data*
- **Case Study Systems:**
  - ***Seafloor***
  - ***Kelp Forest***



Expert Workshop Goals

- Translate conceptual models into networks
  - Started with WA Ecosystem Indicator report (Andrews et al. 2015)
  - Ranking of important variables to human wellbeing and system function
- Provide additional resources





Expert Workshop

- 29 participants on Day 1
- 31 on Day 2
- 17 participants filled out pre-workshop survey
  - *183 years of total experience*
  - *Mostly resource managers (6), ecology experts (7), and federal employees (7)*

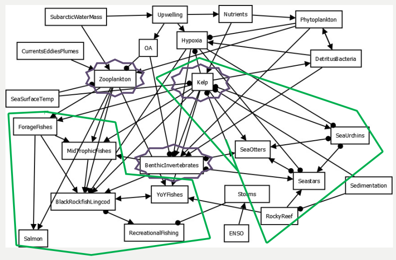
Highly Ranked Model Elements

Kelp Forest	Seafloor
Kelp Habitat	Hypoxia (Dissolved Oxygen)
Nutrients	Fishing
Rocky Reef Habitat	Crabs (& Shrimps)
Sea Surface Temperature	Upwelling
Sea Urchins	Benthic Invertebrates

Kelp forest model

- 26 Model Elements
- Kelp, Zooplankton, and Benthic Invertebrates highly connected
- 2 sub-networks
  - *Sea Otters and Sea Urchins*
  - *Managed fish groups*

Draft QNM



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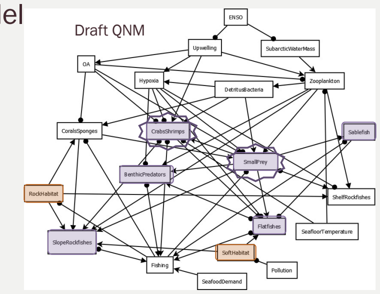
Seafloor model

- 21 Model Elements
- 6 Fished groups
- 2 Habitat elements
- Crabs & Shrimps and Small Prey highly connected

Draft QNM



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Scenario Evaluations

Scenario	Kelp Forest	Seafloor
Climate Change	↑ Ocean Acidification, Surface Temperature	↑ Ocean Acidification, Seafloor Temperature
+ Finfish Aquaculture	↑ Detritus & Bacteria, Nutrients, Sedimentation, and Forage Fishes ↓ Recreational Fishing and Salmon	↑ Detritus & Bacteria, Pollution, Small Prey, and Corals & Sponges ↓ Fishing and Soft Habitat
+ Offshore Wind Development	↑ Detritus & Bacteria, Recreational Fishing, Forage Fishes, Currents, Eddies & Plumes ↓ Rocky Reef	↑ Small Prey and Corals & Sponges ↓ Fishing, Rock Habitat, and Soft Habitat
+ Seabed Mining of Sand	↑ Sedimentation and Hypoxia ↓ Recreational Fishing, Benthic Invertebrates, and Rocky Reef	↑ Hypoxia ↓ Fishing, Rock Habitat, Soft Habitat, and Small Prey

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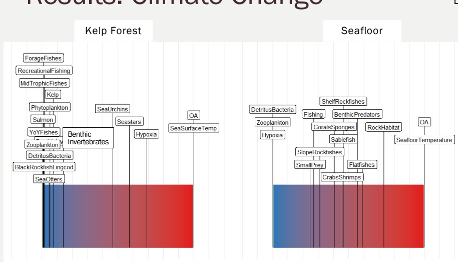
Results: Climate Change

Increased:
Decreased:



Unaffected:
ENSO
Pollution
Seafood Demand
Soft Habitat
Subarctic Water Mass
Upwelling Currents, Eddies & Plumes
Nutrients
Rocky Reef
Sedimentation
Storms

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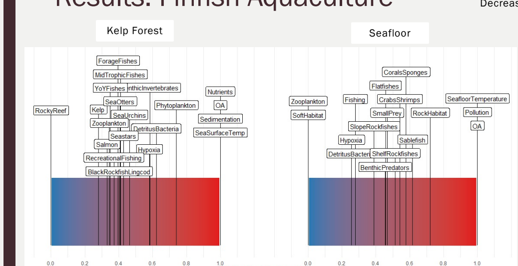
Results: Finfish Aquaculture

Increased:
Decreased:



Unaffected:
ENSO
Seafood Demand
Subarctic Water Mass
Upwelling Currents, Eddies & Plumes
Storms

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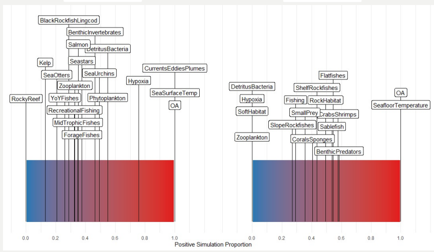
Results: Wind Development

Increased:
Decreased:

Kelp Forest   Seafloor



Unaffected:
ENSO
Pollution
Seafood Demand
Subarctic Water Mass
Upwelling
Nutrients
Storms
Sedimentation

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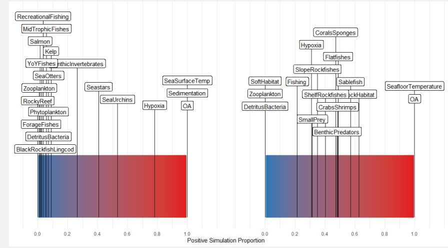
Results: Seabed Mining

Increased:
Decreased:

Kelp Forest   Seafloor



Unaffected:
ENSO
Pollution
Seafood Demand
Subarctic Water Mass
Upwelling
Currents, Eddies & Plumes
Nutrients
Storms

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General Outcomes & Advice

- Climate change increased uncertainty in outcomes across scenarios and model elements
  - *More unfavored outcomes in Kelp Forest system*
- Negative effects on fishing and fished groups in both systems
- Negative impacts on soft substrate and kelp habitats
- Zooplankton and forage fish groups indicate bottom-up effects on fished groups
- Further study of highly connected elements needed to improve understanding of system and new use impacts
  - *Crabs & Shrimp, Kelp Habitat, Fishing, and forage species*

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Next Steps

- Identify additional links to social, economic, and cultural components
  - *Tribal Usual & Accustomed fishing grounds*
  - *Kelp harvest*
  - *Discards*
  - *Clarity in defining Pollution*
  - *Disturbance of structural biotic elements*
  - *Connections to orca populations*
  - *Job quality*
  - *Subsistence and food provision*
  - *Resource access and tenure*
  - *Local and informal economies*
  - *Sense of place*
  - *Cultural values and practices*
  - *Emotional and mental health*
- Code and methodology available to apply toward other MSP habitat systems
  - *https://github.com/rwildermuth/WA_QNM_MSP*

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Contact information

Questions or suggestions

- Robert Wildermuth
- RWildermuth@umassd.edu

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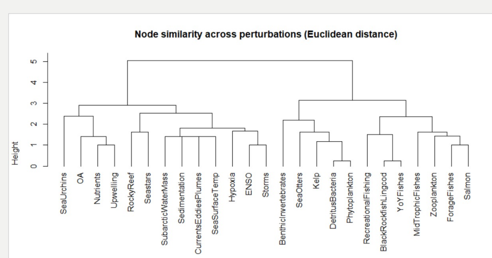
Kelp Forest – indicator correlation



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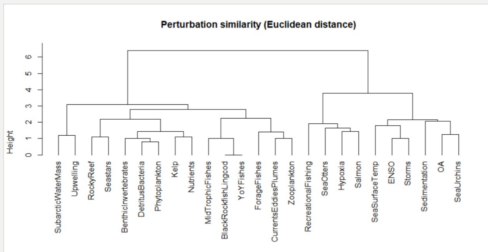
Kelp Forest – correlation in effects



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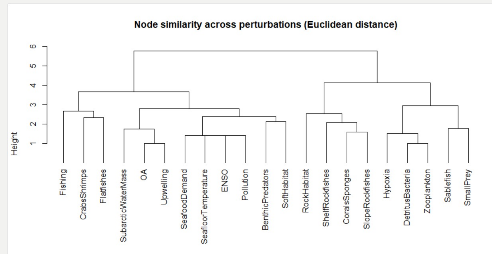
Seafloor – indicator correlation



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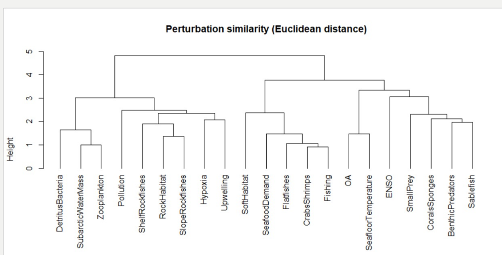
Seafloor – correlation in effects



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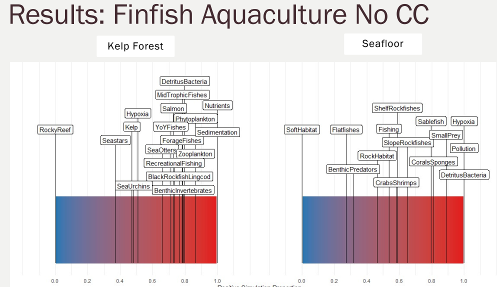
Results: Finfish Aquaculture No CC



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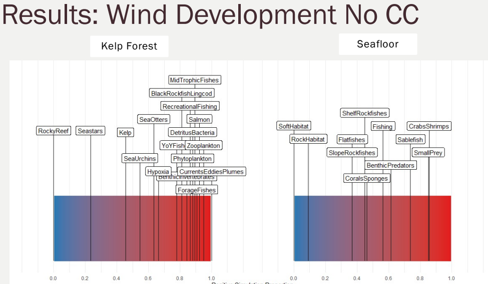
Results: Wind Development No CC



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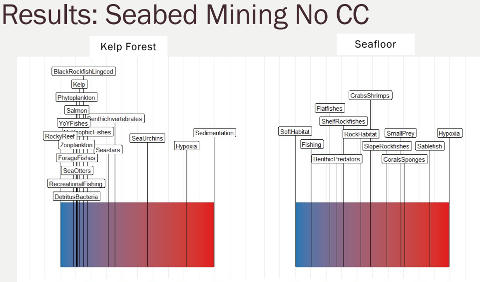
Results: Seabed Mining No CC



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