Charting a course for the future of coastal communities: Considering perceptions and values in climate vulnerability assessments

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Abstract

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The effects of climate change on fisheries are already apparent, impacting the livelihoods, wellbeing, and food security of communities dependent on marine ecosystems. The resulting vulnerability is distributed unequally among those communities and is a function of the exposure, sensitivity, and adaptive capacity to the impacts of climate change. Vulnerability assessments, an increasingly important approach for understanding variability in susceptibility to climate change, often fail to include or recognize the perceptions of individuals in the focal system. Perceptions of vulnerability may differ from vulnerability measured by subject experts, and failure to acknowledge perceptions as well as the value in local knowledge systems can lead to ineffective climate adaptation plans and lack of support for climate policies. In this dissertation I explore several concepts related to perceptions of climate change vulnerability in fishing communities along the West Coast of the United States. First, working with individuals involved in fisheries management, I used Q methodology to elicit commonly held views regarding priorities for wellbeing in coastal communities. Next, I investigated the beliefs of individuals in those communities by conducting an online and phone survey of commercial fishers from Washington, Oregon, and California to assess variability in perceptions of climate change vulnerability. Since perceived barriers to adaptation may limit action even when one has the resources to do so, I also used survey data to examine views regarding adaptive capacity. The final component draws upon transdisciplinary methods, including co-production with Indigenous communities and nutritional science, to consider how the impacts of climate change on fisheries may affect the food security of the Makah Tribe. Collectively, this work shines a light on the importance of perceptions and values in planning for climate change and highlights the importance of engaging communities to chart a course towards more equitable and effective adaptation.

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DEDICATION

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INTRODUCTION

Climate change is likely to have profound effects on marine ecosystems (Doney et al., 2012; Olsen et al., 2020; Perry et al., 2005), and impacts on fisheries are already apparent in the California Current (Hodgson et al., 2018; Harvey et al., 2021). The livelihoods and food security of those in coastal communities are vulnerable to the impacts of climate change (Selig et al., 2018), as is their sense of place and wellbeing (Poe et al., 2014). Vulnerability, defined here as the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006), depends on the exposure, sensitivity, and adaptive capacity of an individual or community. This dissertation examines climate vulnerability utilizing a coupled social-ecological vulnerability framework (Thiault et al., 2021) considering exposure to be the impacts of climate change on fisheries, sensitivity to be the degree to which the health and wellbeing of individuals is likely to be affected, and adaptive capacity to be the ability to respond or cope with change. The combination of exposure and sensitivity equates to risk, the potential impacts an individual may experience. Vulnerability is determined as the outcome of the potential impacts moderated by adaptive capacity. In ecological contexts, the term risk has been used somewhat inconsistently and occasionally interchangeably with vulnerability (Hodgson et al., 2019), but in this framework risk and vulnerability are related but distinct.

Vulnerability assessments are valuable tools for management, allowing us to identify particularly at-risk communities (Davies et al., 2018), and informing climate adaptation plans (e.g., Metcalf et al., 2015), but they are value laden processes and social and cultural outcomes are frequently ignored (Renn, 2008). While there is a growing movement to include social and cultural data in vulnerability assessments, many approaches center their use of social data on economic and demographic quantitative metrics, missing potentially important contributors to vulnerability and resilience (Hicks et al., 2016). The overarching objective of this dissertation is to address that gap and build upon work that has been done to evaluate climate risk perceptions (Cullen & Anderson, 2017; Howe et al., 2019), and culturally specific contributors to vulnerability (Donatuto et al., 2011). To that end, this research focuses on perceptions, social, and cultural components of coastal community vulnerability from the effects of climate change on fisheries.

The focal system is the California Current Social-Ecological System (SES), a highly productive eastern boundary current that encompasses the ocean and coastal environments from southern British Columbia, Canada to Baja California, Mexico which is home to over 100 communities significantly involved in commercial, recreational, and subsistence fisheries (Norman et al., 2007). The way these communities experience the effects of climate change will be heterogenous and affected by numerous social factors (Otto et al., 2017; Thomas et al., 2019). Previous work in coastal communities has shown how the degree of natural resource dependence, the contribution of the environment to wellbeing and health, and exposure to the bio-physical effects of climate change all interact to affect vulnerability (Cinner et al., 2012; Donatuto et al., 2011; Himes-Cornell & Kasperski, 2015; Sowman & Raemaekers, 2018). Here, I explore coastal community vulnerability at two geographical scales with related, but slightly different objectives. The first part of my dissertation takes a system-level approach and investigates perceptions of vulnerability and wellbeing among commercial fishers, managers, and other stakeholders in Washington, Oregon, and California, while the second part considers climate risks the food security of the Makah Tribe, taking a more nuanced approach to examining contributors to vulnerability and adaptive capacity.

First, I conducted a study using Q methodology to explore the views of individuals engaged in fisheries management regarding priorities for supporting coastal community wellbeing. Though managers strive to make decisions informed by the best available science they are still human, and their values and experiences may influence priority setting and decision making, especially when it comes to evaluating tradeoffs and social impacts. Q methodology is structured approach for studying human subjectivity which uses both quantitative and qualitative techniques to identify common perspectives using a rank ordering exercise and factor analysis (Stephenson, 1953). Study participants, members of advisory bodies of the Pacific Fisheries Management Council, ranked 36 statements that described conditions affecting wellbeing in coastal communities. The statements were derived from a series of semi-structured interviews, and some were explicitly focused on climate change, while others described conditions like improved access to healthcare. The results of the analysis revealed three commonly held perspectives among the participants that respectively centered collaboration, the future of fishers, and the impacts of climate change as priorities for the wellbeing of coastal communities. Daylighting these discourses can help clarify foundational areas of disagreement, sharpen focus on common goals, and prompt consideration of how managers evaluate tradeoffs when setting priorities to mitigate climate impacts on fisheries.

Next, I investigated perceptions of climate change and vulnerability held by commercial fishers from Washington, Oregon, and California. Vulnerable populations often perceive and experience their vulnerability in different ways (Kasperson et al., 2005). A range of variables have been shown to influence perceptions of climate change vulnerability including environmental worldview, personal experience, and political ideology (Sullivan & White, 2019; Weber, 2010). To assess perceptions of climate change vulnerability I employed a mixed-mode survey (Dillman, Smyth, and Christian, 2014) with the following objectives: 1. Explore the views of fishers with regards to their exposure, sensitivity, and adaptive capacity, 2. Investigate how those views vary by fishery, geography, and other demographic factors, and 3. Evaluate how concerns about climate compare with other challenges faced by fishers like markets, infrastructure, and regulations. A series of Likert-scale questions were scored to determine the exposure, sensitivity, and adaptive capacity of each respondent, and vulnerability was determined following methods described in Samhouri & Levin, (2012). The results of a series of analysis of variance (ANOVA) tests showed that views regarding climate change were generally more connected with perceptions of vulnerability than demographic factors.

Perceptions of vulnerability can drive adaptive behaviors, potentially leading to inaction and increased vulnerability if an individual does not view themselves to be at risk (Grothmann & Patt, 2005). As adaptive capacity requires not only the resources or conditions to adapt, but also the ability to activate those resources and a mindset or worldview that supports a decision to change (Mortreux & Barnett, 2017; Nelson et al., 2007), I used the survey data to conduct a more in-depth examination of how perceptions of adaptive capacity vary among West Coast fishers. I organized and scored survey questions according to six domains of adaptive capacity: assets, flexibility, organization, learning, socio-cognitive, and agency (Cinner & Barnes, 2019). This framework includes both objective (i.e., physical resources) and subjective (i.e., risk perception) factors that may enhance to suppress adaptive actions. Then I investigated if perceptions of adaptive capacity vary by location and across factors that have been shown to support adaptive capacity in fisheries including mobility (Fisher et al., 2021; Jardine et al., 2020) and diversification of target species (Cline et al., 2017; Kasperski & Holland, 2013). Fishers clustered into three groups based on views of their adaptive capacity across the six domains. Perceptions of adaptive capacity varied among regions and some indicators of mobility, but no differences were detected between individuals with differing levels of livelihood diversity.

Lastly, to take a deeper look at how social and cultural relationships with the environment interact with concepts of vulnerability and resilience, I worked with the Makah Tribe to investigate climate impacts on marine species important for subsistence harvest and food security. The relationship with food is a prominent cultural dimension of the environment and is tied to physical, emotional, psychological, and spiritual health in Indigenous communities (Lynn et al., 2013). The food security of coastal Indigenous peoples like the Makah Tribe is particularly vulnerable to climate-driven declines in seafood as their fish consumption greatly exceeds national averages (Cisneros-Montemayor et al., 2016), and because many groups already have diminished access to traditional resources (Coté, 2016).

Despite the interruption of traditional diet patterns due to colonization, subsistence practices and use of traditional foods is still a way of life in Neah Bay (Sepez, 2008). For Makah tribal members, these foods provide nutrition, help maintain connections to place and traditions, and contribute to tribal identity. The objectives of this work were to examine how those benefits, among others, are potentially at risk from climate change. To assess these risks, myself and a Makah tribal member conducted surveys that combined a modified food frequency questionnaire (FFQ), and structured, open-ended questions on perceptions of environmental change, the health benefits of seafood, and community food security. Based on survey responses, I developed a framework for Makah Food Security which was then used to evaluate potential climate risks including impacts on species and the nutritional benefits they convey. Survey design was guided by previous work done on tribal seafood consumption with the Makah Tribe and other Indigenous peoples in the region (Donatuto et al., 2011; Donatuto & Harper, 2008; Schuster et al., 2011; Sepez, 2001) and developed with assistance from the Makah Cultural Research Center (MCRC). Comments from the community members that participated in this research stressed what was already known – that access to traditional seafoods is foundational to Makah identity. Every household that participated had eaten subsistence seafood during the previous year, and most said they would eat more if it was available. The impacts of climate change threaten that availability, and along with it the food security of Makah.

The effects of climate change on fisheries are already apparent. Yet as social and cultural divides seem to widen, finding common ground from which to address the impacts is increasingly challenging. This work shines a light on the importance of perceptions and values in planning for climate change and emphasizes the importance of engaging communities to chart a course towards a safe, just, and equitable future.

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Chapter 1. PERSPECTIVES ON MANAGING FISHERIES FOR COMMUNITY WELLBEING IN THE FACE OF CLIMATE CHANGE

1.1 Abstract

Coastal communities are being impacted by climate change, affecting the livelihoods, food security, and wellbeing of residents. Human wellbeing is influenced by the heath of the environment through numerous pathways and is increasingly being included as a desired outcome in environmental management. However, the contributors to wellbeing can be subjective and the values and perspectives of decision-makers can affect the aspects of wellbeing that are included in planning. We used Q methodology to examine how a group of individuals in fisheries management prioritize components of wellbeing that may be important to coastal communities in the California Current social-ecological system (SES). The California Current SES is an integrated system of ecological and human communities with complex linkages and connections where commercial fishing is part of the culture and an important livelihood. We asked individuals that sit on advisory bodies to the Pacific Fisheries Management Council to rank 36 statements about coastal community wellbeing, ultimately revealing three discourses about how we can best support or improve wellbeing in those communities. We examine how the priorities differ between the discourses, identify areas of consensus, and discuss how these perspectives may influence decision-making when it comes to tradeoffs inherent in climate adaptation in fisheries. Lastly, we consider if and how thoughts about priorities have been affected by the COVID-19 pandemic.

1.2 INTRODUCTION

Coastal communities are at risk from many impacts of climate change (IPCC, 2019). Coastal regions are twice as densely populated as inland areas (Sale et al., 2014), and in the United States nearly 40% of the population lives in coastal counties even though they constitute less than 10% of the land in the contiguous U.S (Feist and Levin, 2016). This area would rank third in global gross domestic product (GDP) if it was its own country, behind only China and the United States as a whole (NOAA, 2014). In addition to threats from sea level rise and increasingly intense and frequent storms, climate change will have profound effects on the structure and function of marine ecosystems (Perry et al., 2005; Doney et al., 2012; Olsen et al., 2020) and thus the communities that depend on the abundance and availability of marine resources (Ainsworth et al., 2011). The livelihoods and food security of many are threatened by these changes (Badjeck et al., 2010; Selig et al., 2018). Moreover, cultural values tied to the ocean and a sense of place are also in jeopardy for coastal communities, particularly those that are engaged in fisheries (Poe et al., 2014).

The health of ecosystems influences human wellbeing (Diaz et al., 2015). Following Breslow and colleagues (2016), we define wellbeing as "the state of being with others and the environment which arises when human and ecosystem needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and communities enjoy a satisfactory quality of life." This definition originated in work done by Coulthard et al., (2011) and McGregor (2008), and has been adapted to include the environment by others (Armitage et al., 2012) While there is increasing recognition of the importance of including social data, including measures of wellbeing, in socioecological system management and conservation (Kittinger et al., 2014; Hicks et al., 2016; Bennett et al., 2017), assessments of wellbeing and social vulnerability, particularly those that occur alongside biophysical assessments of environmental conditions, often rely predominantly on quantitative economic or demographic data (Colburn et al., 2016; Harvey et al., 2020). While this practice has benefits, including scalability and the use of secondary data, it often leads to the omission of qualitative evaluation of social and cultural aspects of wellbeing such as the ability to harvest and consume traditional foods (Donatuto et al., 2011), a sense of place (Poe et al., 2016), and opportunities for livelihoods and recreation (Breslow et al., 2017). It can also fail to account for community values; for example, in the fisheries sector, job satisfaction and lifestyle may be valued more highly than economic benefits (Pollnac and Poggie, 2008).

The institutions and governance systems that manage natural resources within social-ecological systems (SESs) also affect wellbeing (Ostrom, 2009). Individuals within those governance systems hold differing values (Rockeach, 2008), which has the potential to affect decision-making processes that impact wellbeing. For example, risk assessments are shaped by the values and knowledge of those conducting the assessments since they determine what endpoints are measured and what outcomes are considered desirable (Renn, 2008). Values also affect the evaluation of trade-offs (Hicks et al., 2009; Levin et al, 2021), a key component of ecosystem-based management (EBM) (Link 2010). These evaluations have social and economic consequences for the wellbeing of individuals in an SES whose values may or may not align with those conducting the work. Therefore, it is essential to explore the values and perspectives of managers within systems to investigate how they may be shaping current management priorities and objectives.

In this paper we build on the growing body of literature examining the role of values and perspectives in environmental management (Satterfield et al., 2013; Chan et al., 2016; Donatuto et al., 2020; Levin et al., 2021). This is important because communities have value-driven definitions of environmental health (Donatuto et al., 2011), and the omission of cultural dimensions of social-ecological systems such as values, identity, and knowledge (Poe et al., 2014), can lead to management decisions that are based on incomplete understanding of the system (Berkes, 2012). Our general objective was to investigate perspectives held by actors engaged in fisheries management about how a variety of environmental and social issues may affect coastal community wellbeing. Specifically, we used Q methodology to investigate differences in prioritization of a variety of issues faced by fishing communities on the west coast of the U.S. and considered how the emergent perspectives may affect decisions in fisheries management. We also explored whether the challenges faced by the industry during the COVID-19 pandemic affected how issues were prioritized.

1.3 Methods

1.3.1 *Study System: The California Current SES*

The focal system in this study was the California Current Large Marine Ecosystem (CCLME) – a highly productive eastern boundary current system that encompasses the ocean and coastal environments from southern British Columbia, Canada to Baja California, Mexico. The coupled SES of the California Current supports the social systems, sense of place, and wellbeing of coastal communities (Breslow et al., 2016). Home to at least 125 fishing communities (Norman et al., 2007), the fishing industry supports 160,000 jobs in Washington, Oregon, and California (NMFS, 2017). The total 2016 commercial landing revenue across all three states was $688.9 million with an estimated $2.3 billion in expenditures related to recreational fishing (NMFS, 2018). The consequences of exposure to climate impacts are already apparent in the CCLME, threatening the benefits communities receive from the system.

Consequences of climate change including ocean warming, ocean acidification (OA), and harmful algal blooms have had, and are projected to continue to have, major impacts on salmon (Crozier et al., 2019), Dungeness crab (Moore et al., 2020; Fisher et al., 2021), and other fisheries (Hodgson et al., 2018). Notable events like the "warm blob" heatwave of 2014 (Bond et al., 2015, Wells et al., 2015), and mass larval mortality events at shellfish hatcheries due to OA (Barton et al., 2015) have shown the harmful effects of these changes. The management of federal fisheries in the CCLME is the responsibility of the Pacific Fisheries Management Council (PFMC), one of eight regional councils in the U.S. This work is particularly relevant for the PFMC at this time as the Council has initiated work to assess effects of climate change on fishing communities as part of their Climate and Communities Initiative[1] and is considering how to incorporate community impacts into its decision making.

1.3.2 *Q methodology*

Q methodology is a structured approach for studying human subjectivity which uses both quantitative and qualitative techniques to identify common perspectives using a rank ordering exercise and factor analysis (Stephenson, 1953; Brown, 1980). The intent is to explore discourses and uncover consensus and divergent views that exist within a group (Brown, 1999). A discourse describes an individual's worldview, their "way of seeing and talking about something" (Barry and Proops, 1999). The Q method has recently seen increasing use in conservation and natural resource management (Gruber, 2011; Ray, 2011; Cairns, 2012; Armatas et al., 2016), including in fisheries and other marine resource management sectors (Carr and Heyman, 2012; MacDonald et al., 2015; Pike et al., 2015; Loring and Hinzman, 2018).

[1] https://www.pcouncil.org/actions/climate-and-communities-initiative/

We employed Q methodology to explore perspectives of individuals involved in fisheries management concerning fishing community wellbeing. The structure of a typical Q study involves the creation of the Q set (the items to be sorted), sorting or ranking those items, followed by factor analysis and interpretation. During the sort, participants place the Q set into a pre-determined, semi-normal distribution along a spectrum such as most important to least important or most agree to least agree (Brown, 1980; Webler et al 2009; Watts and Stenner, 2012). Factor analysis is used on the completed Q sorts to reduce the dimensionality of the data and generate idealized Q sorts which can be interpreted as common perspectives held by members of the group. See Figure 1-1 for a summary of the overall workflow of this study and information on the participants.

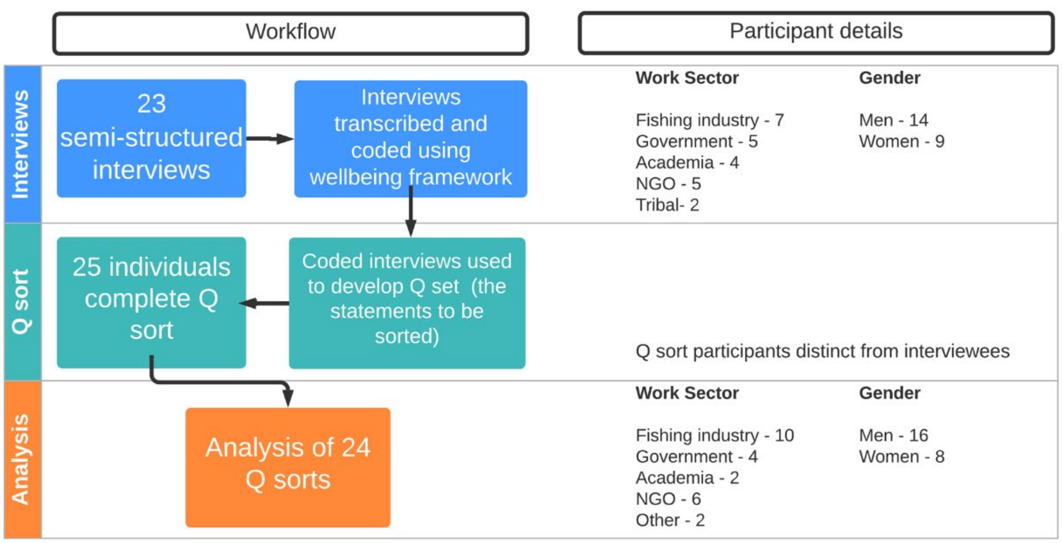

Figure 1-1. Description of project workflow and information about participants in each component of the study.

1.3.3 *Q set*

The first step in Q methodology is to develop the collection of statements or items that will be sorted by participants. The Q set can be sourced from interviews, literature review, or focus groups, and should cover a broad range of perspectives (Stephenson, 1953). We developed the Q set for this study using 23 semi-structured interviews that were conducted with individuals affiliated with or closely connected to PFMC, all of whom possess a depth of knowledge regarding fisheries on the West Coast. The interviewees came from a variety of backgrounds and work in the fishing industry, state or tribal agencies, NGOs, and academia. We asked interviewees a series of questions about recent trends and developments in West Coast fisheries, what they saw to be strong trends and drivers of change, and how West Coast fishing communities and fish stocks may be affected by climate change (See Appendix A for a sample interview script). Interviews were transcribed and deductively coded in ATLAS.ti using the typology of human wellbeing framework developed by Breslow and colleagues (2016).

The wellbeing framework is structured around four constituents of wellbeing: 1) Connections – being with others and the environment; 2) Conditions – when human needs are met; 3) Capabilities – individuals and communities are enabled to pursue their goals; and 4) Cross-cutting – a satisfactory quality of life is sustained. The constituents are broken down into increasingly more specific components which focus on aspects of wellbeing that managers and decision-makers may have influence over (Sojka, 2014; see Breslow et al., 2016 and 2017 for additional framework details). Utilizing this framework, we derived 158 statements about community or individual wellbeing from the interviews. We used a structured approach to generate the Q set (Watts and Stenner, 2012), using the wellbeing framework to identify the range of themes we sought to cover with the final set of statements. The statements were categorized by the attribute of wellbeing with which they most closely aligned and evaluated for clarity and fidelity to the aspect of wellbeing they were slated to represent. Initially, 42 statements were selected for the Q set that represented a variety of environmental, social, and regulatory conditions. Efforts were made to retain the language used by the interviewee, though some statements were reworded for clarity or generalized if the direct quote referred to a specific fishery. After pilot testing, several statements were cut because testers felt they were unclear or redundant, and the final Q set consisted of 36 statements that represented most attributes in the connections, conditions, and capabilities constituents of wellbeing (Table 1-1).

Table 1-1. Q set statements and associated constituent of wellbeing.

	Statement	Constituent of wellbeing
1	There is a demand from consumers for local and sustainable seafood.	Conditions
2	Coastal communities have plans in place in to deal with coastal hazards like tsunamis.	Conditions
3	Fishers have or can access the resources to weather temporary financial stresses due to a downturn in a fishery.	Conditions
4	Extreme and unpredictable ocean conditions threaten fisher safety.	Conditions
5	Direct to consumer selling opportunities exist for local fisheries.	Conditions
6	Seasonal aquaculture jobs are available for fishers to supplement fishing income.	Conditions
7	Small, independently owned fisheries can coexist with larger, vertically integrated companies.	Conditions
8	Fishers can afford to live in the coastal communities they have traditionally resided in.	Connections
9	The fishing industry reduces its fuel consumption and emissions.	Conditions
10	Fishing communities have access to quality healthcare.	Conditions
11	Water quality issues caused by climate change prevent species from being harvested.	Conditions
12	Working waterfronts are going away.	Connections
13	Expanding offshore development has conflicts with fishing.	Connections
14	Commercial and recreational fishers work together rather than argue over how to divide quotas.	Connections
15	Society views the harvest of sustainable seafood as an integral component of a healthy ocean.	Connections
16	Children of fishers want to go into the fishing industry.	Connections
17	Conservation groups work more collaboratively with the fishing industry.	Connections
18	There are more people of color and women in fisheries management.	Connections
19	Subsistence and cultural fishing practices are threatened due to shifting availability of resources.	Capabilities

20	Tourism options are developed to support the local economies in fishing communities.	Capabilities
21	Retraining and other job opportunities are available if people decide to move out of fishing.	Capabilities
22	There is more stakeholder engagement in fisheries management.	Capabilities
23	When responding to uncertainty, novel management approaches are created rather than building on old models.	Capabilities
24	Development of new sources of renewable energy eases the need for dams and hydropower.	Capabilities
25	Fishery management policies are based on social equity as well as economic efficiency.	Capabilities
26	The multi-generational, successful seasonal fishery-based lifestyle is viable.	Connections
27	Fishers are not stuck in individual fisheries but have the flexibility to migrate between them when conditions warrant.	Capabilities
28	The understanding of how socioeconomic and ecosystem indicators fit together is improved.	Capabilities
29	Fishers and managers can prepare and respond to changes in the availability of fish.	Conditions
30	Fishing infrastructure improvements needed to deal with sea level rise are supported by the community.	Conditions
31	Cost effective technology improves accountability without fishers having to absorb the costs.	Capabilities
32	Technology is developed to help fishers determine where not to fish to avoid protected species.	Capabilities
33	The pool of qualified crew is reduced due a decrease in training opportunities.	Capabilities
34	Ocean literacy is woven into curriculum for students starting in elementary school.	Connections
35	Impacts of climate change threaten the availability of target species.	Connections
36	Active recruitment of young fishers lessens the impacts of the aging of the fleet.	Connections

1.3.4 *P set*

Following the guidance of Webler and colleagues (2009), we ensured that the participants of the Q study (the P set) represented a variety of opinions and perspectives. We recruited participants from the advisory bodies to PFMC, groups that advise the Council on fishery management plans and annual measures. Twenty-five individuals from each state part of PFMC (Washington, Oregon, California, and Idaho) participated in the study. They represent the fishing industry, academia, state and tribal governments, conservation, and sport or charter interests, reflective of the overall makeup of the advisory subpanels. Because the aim of the Q method is to understand the internal frame of reference of individuals (Cairns 2012), meaningful results can be achieved with small samples (12-40 participants, e.g., Cairns 2012 Sandbrook et al., 2013). Thus, our sample size of 25 was within typical range, and adequately captured a diversity of experiences (Watts and Stenner, 2012).

1.3.5 *Q sort*

Because of the ongoing COVID-19 pandemic at the time of our study, we used an online platform call Q Method Software to conduct Q sorts[2]. Each participant was guided through the Q sort using the Zoom video conferencing platform. After obtaining consent from the participants, the sessions were recorded to capture the explanations of participants during their sorts. Prior to completing the sort, each participant answered some background demographic and environmental worldview questions (Appendix A) (McNeeley and Lazrus, 2014; Cullen et al., 2018). Next, participants were given the prompt, "Consider the condition described by the statement - is addressing it a higher, moderate, or lower priority when it comes to supporting or improving fishing community wellbeing?" Individuals then conducted a preliminary sort where each statement was ranked as either a higher, moderate, or lower priority. This was followed by the detailed sort where participants placed the statements on the Q board where column 5 represented their highest priority and -5 was the lowest (Figure 1-2). Participants were instructed to consider this a relative ranking; accordingly, some statements with lower rankings may still be things they think are important for coastal communities. Participants were asked to explain the rationale for their sorting choices as they completed the sort. Following the completion of the Q sort, participants were asked the following two questions regarding the degree to which the

[2] https://qmethodsoftware.com/

COVID-19 pandemic may have anchored their responses or contributed to their thoughts about community needs:

1. Knowing what you know now about how the industry has been affected by the COVID-19 crisis, are there statements from the Q Sort that you would re-prioritize? Are there statements that you ranked higher today than you might have a few months ago?
2. Are there any issues that were not part of the sorting activity that you would add based upon lessons learned from COVID-19?

During this time participants were also encouraged to continue any explanation for their sorting choices and express any final thoughts.

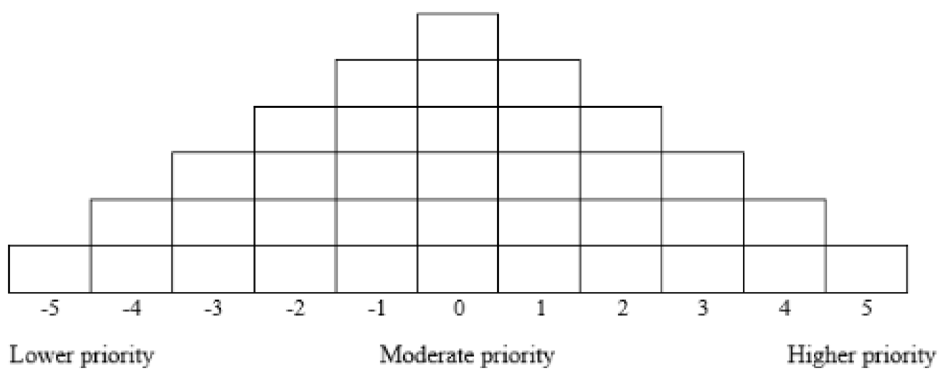

Figure 1-2. Q board distribution.

1.3.6 *Statistical Analyses*

Once all participants completed the exercise, 24 of the 25 Q sorts were analyzed using qmethodsofware.com (Lutfallah and Buchanan, 2019) and the qmethod R package (Zabala, 2014). One individual felt that they had not been able to complete the activity in a way that accurately represented their views and asked that their Q sort be withdrawn from the study. We used principal component analysis to reduce the data into factors which were rotated using varimax rotation to maximize the variance explained and to attempt to associate individuals with just one factor. In Q method, there is not one objectively correct solution regarding the number of factors to extract (Watts and Stenner, 2005), it is instead a process guided by the amount of variability explained, eigenvalue test, screeplot inspection, and the interpretability and theoretical significance of the factors (Brown, 1980, Watts and Stenner, 2012). Based upon evaluation of these criteria, three factors were best supported (see Appendix A for details.)

The resulting factors are idealized Q sorts representing the discourses of the group. As part of the analysis, each statement receives an integer score representing its placement in the idealized Q sort. Each statement also has a z-score, the weighted average of the statement scores from the Q sorts that load on that factor (Zabala et al., 2018). The analysis identifies distinguishing and consensus statements, those where the z-scores are statistically different ($p < 0.05$) or similar to other perspectives, respectively. The discourses (i.e., ways of thinking or worldviews) are interpreted by comparing the ranking of statements as well as considering which had distinguishing or consensus status.

1.4 RESULTS

Twenty-one of the sorts loaded significantly onto the three factors; two sorts were confounded (associated with two factors), while one sort did not align with any of the emergent perspectives. The three factors represent the common perspectives or discourses held by the participants which we refer to as: 1. Collaboration is Key, 2. Fishers Forward, and 3. Climate and Society. The discourses are described below and the distribution of statements in each of the idealized sorts is shown in Figure 1-3. A complete list of statements with associated factor scores and distinguishing or consensus status can be found in Appendix A.

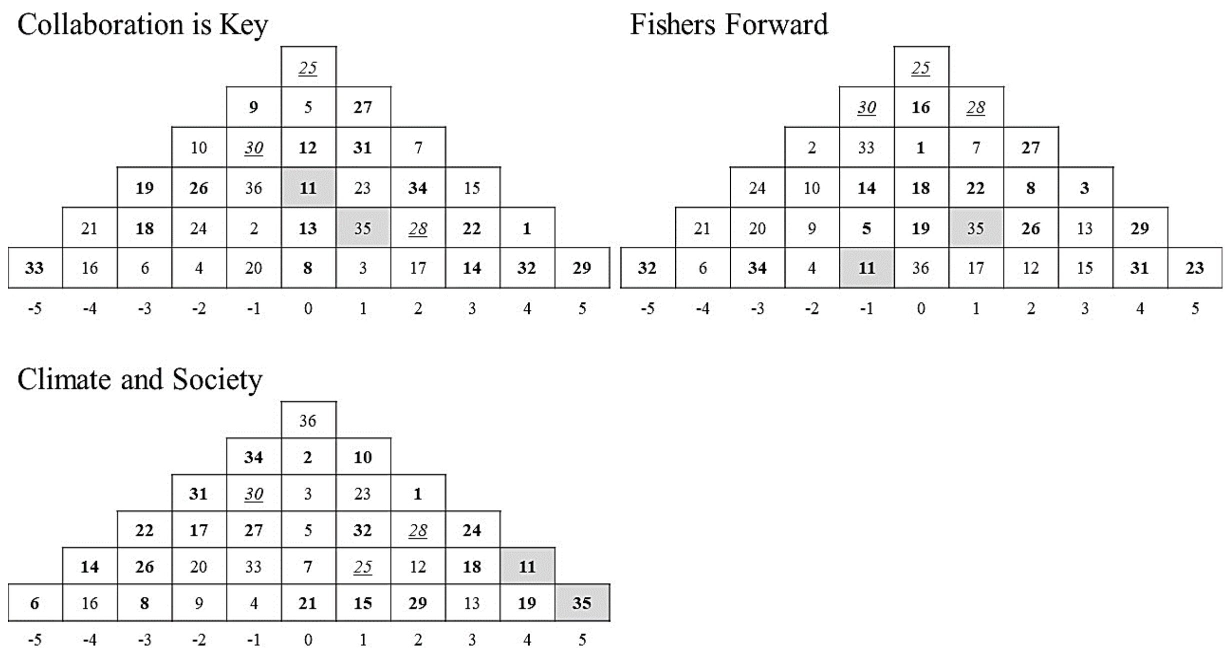

Figure 1-3. Distribution of statements in each discourse. Numbers in bold are distinguishing statements, those italicized and underlined are consensus statements. Grey boxes note the statements that explicitly mentioned climate change. Column 5 is the highest priority while -5 represents the lowest.

1.5 Discourse Analysis

1.5.1 *Factor A – Collaboration is Key*

Table 1-2. Factor A characteristics.

Name	**Loading Q sorts**	**% variance explained**	**eigenvalues**	**Average age (sd)**	**Genders**	**Work sectors**
Collaboration is Key	8	15	3.6	68 (11.3)	7M, 1F	Industry, government, academia, other
Top 3 priorities						**z-scores**
Fishers and managers can prepare and respond to changes in the availability of fish.						2.097
There is a demand from consumers for local and sustainable seafood.						1.982
Technology is developed to help fishers determine where not to fish to avoid protected species.						1.808

The first discourse, Collaboration is Key, is defined by belief that collaboration in the fisheries world is crucial for the wellbeing of communities. The eight participants in this group were the oldest on average and this was the most male-dominant of the three discourses (Table 1-2). Statements explicitly calling out collaboration were ranked highly, as were those that implied a partnership. This group values positive working relationships between groups typically engaged in fisheries management including conservation organizations, recreational and commercial fishers, and prioritizes stakeholder engagement. Conservation provoked polarizing reactions; participants described constructive and contentious relationships with conservation groups which seemed to vary by fishery and region. In addition to valuing collaboration between the industry and outside groups, they also sought a balance within the industry itself of larger and smaller enterprises.

This group's prioritization of engagement extends to society-at-large as they hope people consider sustainable seafood an integral part of a healthy ocean. Getting consumers to demand local and sustainable seafood is also very important to this discourse, beliefs underscored by the value placed upon starting the cultivation of ocean literate citizens at a young age. One group member stressed the importance of consumers:

> *My primary interest is that there's a well-developed market for the product and then all these other things fall in place because it provides economic benefits to the community, it helps build infrastructure, it makes people want to be in the fishery, all of those things.*

Despite the prioritization of a variety of sectors working together, the focus was on groups already commonly engaged in fisheries management. Increasing diversity and threats to subsistence and cultural fishing were lower priorities for this group than the other discourses. Though they were still of moderate concern, in the Collaboration is Key discourse addressing aspects of the built environment, including offshore development and the status of working waterfronts, were also a lower priority compared to either of the other groups. Less important issues involved the fisheries labor force itself, specifically retraining or aquaculture options and the pipelines that recruit or train people to fish. This is perhaps reflective of the perception that other issues need to change to make the fishing industry a more attractive work sector. For instance, one participant noted,

> *When there's no place for people to go work…I don't think those [training programs] are particularly ethical or doing a very good job. I've heard examples of ones that do a good job, but I struggle with training people who potentially won't have a job.*

1.5.2 *Factor B – Fishers Forward*

Table 1-3. Factor B characteristics.

Name	**Loading Q sorts**	**% variance explained**	**eigenvalues**	**Average age (sd)**	**Genders**	**Work sectors**
Fishers Forward	6	14	3.4	55 (15.0)	3M, 3F	Industry, government, NGO
Top 3 priorities						**z-score**
When responding to uncertainty, novel management approaches are created rather than building on old models.						1.925
Fishers and managers can prepare and respond to changes in the availability of fish.						1.496
Cost effective technology improves accountability without fishers having to absorb the costs.						1.153

The second discourse, Fishers Forward, was populated by three women and three men, and explained 14% of the overall variance (Table 1-3). This discourse is characterized by the prioritization of conditions that support the adaptive capacity of individual fishers and the resilience of the fishing industry. Those holding this perspective connect community wellbeing to the sustainability of a traditional fishing lifestyle and are focused on a mix of actionable items which would directly benefit fishers. These include improving financial support and the development of technology to assist with requirements for independent observers on fishing vessels. Participants in this discourse embrace traditional regulatory tools, but they want these tools to evolve to meet the current challenges. These individuals also highlighted the need for flexibility where it has previously been limited by regulations. This discourse prioritizes areas where managers can have agency, ranking addressing environmental changes and their impacts on fish as only moderate priorities, while considering their ability to prepare for those changes as one of the top issues. One participant summed up that line of thinking by noting:

> *It's virtually impossible to determine what the future is going to bring from the standpoint of climate. So, if we're responding to it and have the ability to change rapidly and the flexibility to change on an annual basis that really should be sufficient to keep us caught up with the environment and we can spend our time, from an administrative, management, and policy standpoint, working on things such as figuring out how we can get more fish to the fleet and to communities.*

The Fishers Forward discourse places a much higher priority on the preservation of a multi-generational fishing lifestyle relative to Collaboration is Key or Climate and Society. They prioritized the affordability of coastal communities, and the entry of children of fishers into the industry much more highly than the other perspectives. Consistent with the focus on putting resources towards a viable and resilient industry is a deemphasis on economic diversity, including retraining people moving out of fishing, a position shared with Collaboration is Key.

The Fishers Forward discourse includes a strong desire that society has a positive image of sustainable fishing. Even so, this discourse places other society/industry interactions and engagement opportunities, like consumer demand, direct to consumer markets, and ocean education, as lower priorities than both other discourses. While Fishers Forward values the development of technology that may benefit fishers’ incomes, technology connected to legally protected species was their lowest priority.

1.5.3 *Factor C – Climate and Society*

Table 1-4. Factor C characteristics.

Name	**Loading Q sorts**	**% variance explained**	**eigenvalues**	**Average age (sd)**	**Genders**	**Work sectors**
Climate and Society	7 (1 negative loading)	13	3.2	59 (11.5)	5M, 2F	Industry, NGO, government
Top 3 priorities						**z-score**
Impacts of climate change threaten the availability of target species.						2.075
Subsistence and cultural fishing practices are threatened due to shifting availability of resources.						1.41
Water quality issues caused by climate change prevent species from being harvested.						1.372

Climate change and its impacts on communities are the highest priorities for the Climate and Society discourse. Seven participants loaded onto this discourse, though one loaded negatively indicating the inverse perspective is held by that individual (Table 1-4). In contrast to Fishers Forward and their prioritization of adaptive capacity actions, Climate and Society emphasizes the need to take a system-level approach by addressing the drivers of vulnerability and promoting resilience. The biggest concerns for those holding this perspective are how climate change will affect the availability and harvestability of fish, and the communities that will suffer food security and cultural impacts due to those changes. They ranked the development of new renewables to ease the need for hydropower much higher than either of the other discourses, perhaps reflective of their acknowledgement of the importance of renewable energy, and the negative impacts that hydropower can have on fish populations.

They think that tackling these challenging problems is going to require the inclusion of a more diverse set of managers and that ensuring wellbeing means taking a community-oriented approach rather than focusing on sources of resilience just for fishers and the industry. This includes ensuring fishing communities have access to quality healthcare, that they are prepared for coastal hazards, and that there are accessible economic opportunities outside of fishing. Though the Climate and Society discourse contrasts strongly with Fishers Forward on the prioritization of statements describing components of the traditional fishing lifestyle, they were in exact agreement on the importance of working waterfronts and addressing conflict between fishers and other users in an increasingly busy offshore environment. They value supporting fishing and its infrastructure needs, while acknowledging that the adherence to traditional models may not encourage the flexibility needed to weather a changing climate. Reflecting on the concept of tradition in fishing, one individual said,

> *We need the ability to not just keep doing what we've been doing, whether that's fishing the same things that have been done for previous years or over multiple generations. This can lead to a lot of stubbornness and not being flexible to take advantage of new opportunities as well as shifting climates…this leads to some challenges on the management front cause there is this idea that because something has been done one way for generations that it shouldn't have to change even though the ocean and communities are changing.*

Though Climate and Society is concerned with offshore conflict, they are less concerned with conflict in the management space. In stark contrast to Collaboration is Key, they give low priority to collaboration with conservation, stakeholder engagement, and harmony between recreational and commercial fishers. This likely partially reflects a belief expressed by many, that at least with regards to conservation and stakeholders, a lot of progress has been made in these areas and that while they are very important, they do not need to receive special attention anymore.

1.5.4 *Consensus Views*

In addition to revealing differences among discourses, we used Q analysis to identify areas of agreement. Of the 36 statements, three were identified as statistical points of consensus across all discourses because there were no significant differences between the z-scores for those statements (p<0.5) (Table 1-7, Appendix A). Evaluating the content of the consensus statements, as well as the gradient of statements from the most agreement to most disagreement, adds additional understanding to the differences and similarities in priorities held among the discourses (Figure 1-4). The consensus statements, 25, 28, and 30, were in the moderate priority range. Two of the three (25 and 28) concerned social issues relevant for fisheries management, specifically a better understanding of the interaction between socioeconomic and ecosystem conditions and the inclusion of some measure of social equity in fisheries management. The other point of consensus was around the need for community support as fishing infrastructure is

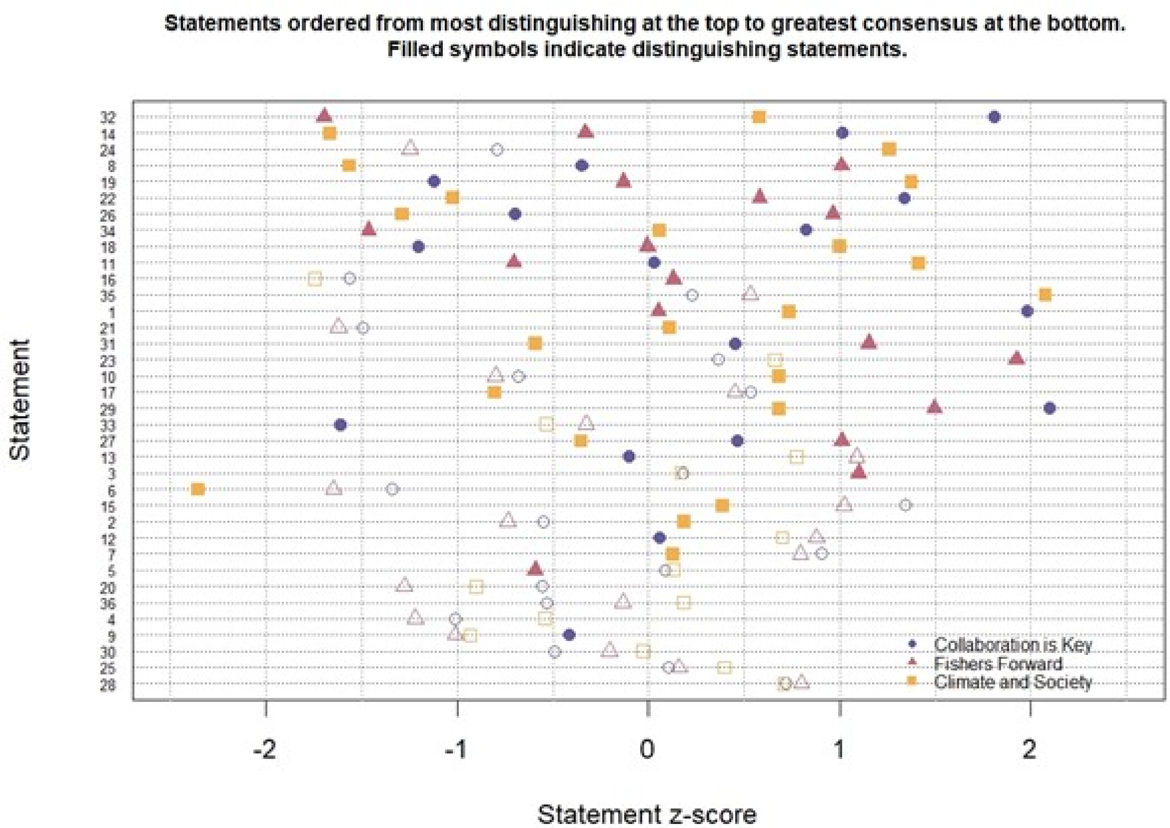

Figure 1-4. Z-scores for each statement in each perspective. A higher z-score indicates a higher priority statement. Statements with tightly clustered z-scores indicate agreement between perspectives about the relative priority of that issue, while greater distance between points indicates greater disagreement. Distinguishing or consensus status is determined by comparing the absolute difference in statement z-scores with significance thresholds.

updated in response to sea level rise. Overall, there was little enthusiasm for the idea of aquaculture jobs as seasonal, supplemental income for fishers and it was the lowest overall priority (overall z-score -5.35). Participants were most supportive of the concept that fishers and mangers can prepare and respond to changes in the availability of fish (overall z-score 4.27).

1.5.5 *COVID-19*

We created the Q set used in this study before the onset of the COVID-19 pandemic, but certain conditions described in the Q set are related to issues that were exacerbated by the pandemic. We included questions about COVID-19 in our post-sort interview to investigate if anchoring on recent events had affected responses. Fifty percent of the participants reported that COVID-19 had affected the way they prioritized statements. The discourse that people were associated with does not appear to be a factor in who responded that way; individuals from each discourse and those not associated with any replied yes to the question. Those that felt like COVID-19 had affected their rankings stressed the importance of local markets, direct to seller opportunities, and demand for local and sustainable seafood. They also noted how the pandemic had highlighted a vulnerability of the industry in its reliance on global supply chains and restaurants. The coping strategies that kept small businesses afloat were acknowledged by some as an opportunity to rethink how fish are sold and marketed in the U.S., and that we may want to act to solidify the direct-to-consumer channels that were developed out of necessity after broad restaurant closures. One response described that thought process,

> *Direct-to-consumer selling has made a difference in people making it right now and has people thinking about supply chains and what is the "right way" for fishermen to sell their fish. Fishers can take initiative and be more flexible in who they sell to, the current structure may not be best long term for fishers.*

Participants also reflected upon how the need for immediate action affected their responses and how the importance of ongoing needs like economic resilience and community health was underscored by the impacts of the pandemic. One individual commented,

> *The statements I prioritized were those that I thought could have the most direct or immediate impacts, rather than affecting systematic change. Climate change is not necessarily having immediate effects that are easy to attribute, and I likely would have considered those a higher priority prior to the pandemic. The effects of the food system and seeing the importance of local networks has also been underscored by the effects of COVID-19.*

Other common responses included how COVID has highlighted the need for agile management and the ability to respond to uncertainty. One response noted the importance of electronic monitoring in a world where it is challenging to safely have an observer onboard fishing vessels. Supply chains, marketing, and financial literacy were noted as issues people became more concerned about during COVID-19 that were not reflected in the Q set. Issues of access and equity were also mentioned, as the barriers to getting out on the water during the pandemic were not distributed equally across fisheries and sectors as was noted by this participant,

> *Recreational community was specifically impacted, and it impacted people differently depending how reliant you were on public infrastructure, i.e., those that have their boats at a slip vs those who needed to use public boat ramps.*

1.6 Discussion

Human wellbeing is connected to the health of the environment (e.g., Frumkin et al. 2017, Bratman et al. 2019), and the wellbeing of those residing in coastal communities is facing pressure from changes to both ecological and social systems (Perry et al., 2010; Willis et at., 2018; Cohen et al., 2019). In Washington, Oregon, and California, communities that are reliant on fishing are particularly vulnerable to environmental change in the California Current (e.g., Fisher et al. 2021). Fishing remains an important livelihood in these communities, providing a source of income and highly valued for contributions to wellbeing like job satisfaction and identity (Holland et al., 2019). How actors in SESs respond to changes is influenced by their perceptions of the best ways to support wellbeing and reduce vulnerability (Eiser et al. 2012). The nature of these challenges, and the complex linkages and feedbacks between people and nature, makes it a difficult task to decide what issues to prioritize in order to best enhance adaptation or build resilience. We used Q methodology to investigate how a group of actors engaged in fisheries management approach that challenge and to explore their perspectives on how to prioritize actions to support or improve the wellbeing of coastal residents, ultimately revealing three emergent discourses focused on the need for collaboration, the future of fishers, and the impacts of climate change on fisheries and communities.

Differences in the nature of issues confronting fishing communities and the scales at which they occur makes prioritization of these issues a challenge (Okamoto et al., 2020), even when it is only a theoretical exercise. Some concepts that we asked participants to consider, like identity and wellbeing, can be particularly hard to evaluate (Satterfield et al., 2013). Many participants expressed having difficulty with the forced distribution in the sort and only being allowed to choose a few top priorities when they thought most of the conditions described in the statements were important. Ultimately, 13 of the 36 different statements received the top ranking during the sorts and 14 received the bottom ranking, reflecting the diversity of opinions still contained within the shared perspectives. The limit on choosing just a few top priorities required that the participants evaluate potential tradeoffs in a manner like those inherent in fisheries management (*c.f.*, Levin et al., 2009). Perceptions and values can shape how people view tradeoffs; what seems to be a tradeoff to some can appear to be mutually beneficial to others

(Campbell et al., 2010). In this study, there were a few areas where participants seemed to be making tradeoffs about the scale, either spatial or temporal, at which action should be prioritized.

The three discourses we described differed in the scale of the issues that they prioritized, from individual to community to entire SES level. Nelson et al. (2007) describe similar scalar differences in adaptation versus resilience research, defining adaptation as an actor-orientated approach that focuses on process, governance, and the individual, and resilience studies as a systems-oriented approach that focuses on ecosystem-level connections. The Fishers Forward discourse aligns with the actor-level approach, focusing on individual adaptive actions, while Climate and Society displays the systems-level thinking of resilience, focusing on large ecosystem and societal processes. Collaboration is Key is in the middle of this range, incorporating the governance and process aspects associated with adaptation and centering action at the community level. Adaptive capacity of individuals contributes to the resilience of the system (Folke et al., 2010), and resilient systems better retain key functions, benefiting the actors. However, greater system-level resilience does not necessarily result in even distribution of improved wellbeing to individuals in that system (Coulthard, 2012). The concern about the consequences for wellbeing in pursuit of resilience is perhaps best represented here by the way the different perspectives perceive aspects of the traditional fishing lifestyle. Climate and Society are open to change in tradition if the flexibility gained allows for the continued functioning of the system overall, while Fishers Forward associate better wellbeing outcomes with the preservation of current practices, which may limit adaptability. While the quest for wellbeing can support adaptation, in some cases it can also restrict it (Coulthard, 2012) and strong, place-based identities can hinder a willingness to adapt (Marshall et al., 2012). System resilience may be a positive objective, but the consequences for individual wellbeing should not be ignored, particularly for often overlooked intangibles like cultural values (Satterfield et al., 2013), though improved environmental quality that comes with some social and economic costs can be acceptable to people (Levin et al., 2015).

The second area where we saw divergence in prioritization was along temporal scales; some preferring to focus on reducing current risk and addressing short-term shocks, while others concentrated on measures that may provide long-term resiliency but not necessarily any near-term relief. This is sometimes described as coping versus adapting (Lebel et al., 2006. See also, Thiault et al. 2020). Research on risk perception has shown that individual perceptions are influenced by events that are situated closely in time or space, and also by the level of agency or control that an individual feels to address the risk (Renn, 2008; Cullen and Anderson, 2017). Cognitive bias to focus on the present as opposed to the future can undermine motivation to respond to long-term, gradual threats like climate change (Clayton et al., 2015). Earlier work finds impacts of both short-term climate anomalies, and long-term climate trends, on individual perceptions of livelihood risk and household vulnerability (Cullen and Anderson, 2017).

COVID-19 has resulted in a number of coping behaviors by the fishing industry, governments, and coastal communities including adjusting practices to protect worker health and shifting emphasis from restaurants to online markets; actions that could potentially become adaptations if continued after COVID-19 decreases in severity (Bennett et al., 2020; Love et al., 2020; Stoll et al., 2021). During other shocks experienced by the fishing industry, including the 2015 HAB event on the West Coast, individuals have exhibited both coping and adaptive actions (Moore et al., 2020). The tradeoff between these approaches is that while coping may provide immediate benefits and a reduction in current risks to an acceptable level, it may result in a loss of the flexibility needed to respond to future change (Nelson et al., 2007). Individuals in the study were dealing with a heightened sense of maintaining this balance as they dealt with the acute market shocks from COVID-19 while also dealing with chronic pressures like climate change. As noted above, 50% said that COVID-19 had changed the way they ranked statements. Even outside of COVID-19, some participants still had a more near-term strategy for coping with change, preferring to work on issues with less perceived uncertainty than climate change.

The Collaboration is Key discourse was once again in the middle, valuing processes that can begin immediately but where it may take time before benefits are conferred. With their focus on climate, Climate and Society maintained a systemic view, prioritizing things that would make long-term, lasting change. A participant described their thought process about this issue in the following way:

> *I'm just thinking about, you know, what are the long-term changes we need to see in the management system as a whole. And if we were talking maybe five years, some of these technology ones might raise to the top, like avoiding bycatch because that's more of like okay, how do fishermen get by next year and get more money. They do that by avoiding bycatch and it's good for the environment. We all win. That's great, but that actually is just kind of on the same management treadmill that we're on, just doing it a little bit better.*

Shocks like a global pandemic notwithstanding, consideration of tradeoffs in adaptive capacity suggests that short-term adaptations like investment in financial or technical assets do not provide the same capacity as long-term social change and risk management (Cinner et al., 2018).

A likely source of influence for participants as they considered these tradeoffs is their sense of agency. A sense of agency may influence if and how individuals respond to stressors, including the environmental changes associated with climate change (Brown and Westaway, 2011). Agency also influences risk perception and risk-taking behaviors (Damen, 2019). Agency, or the ability to take action, mobilize resources, and make progress towards objectives aligned with one's values (Sen, 1985), has been identified as a valuable social science indicator (Hicks et al., 2016) and is applied as such in the self-determination attribute in the framework used in this study (Breslow et al., 2016). The amount of agency a person feels is related to their ability to improve the wellbeing of themselves and others and make choices that either enables them to act upon their values or compromise because they feel they do not have the power to pursue their ideals (Ibrahim and Alkire, 2007). This can affect objectives in conservation; monetary or cultural costs, and political feasibility may limit what people think can be set as targets (Levin et al., 2015), and perceived power, an indicator of agency, has been shown to play a critical role in adaptive behavior and outcomes (Barnes et al., 2020). Despite instructions to not worry about perceived achievability of the conditions, some, like this participant, expressed that feasibility and the power to address certain issues affected their sorting:

> *Because everything is important. but I think that for me, the one thing that made it less challenging was because when I did it [the sort], I really tried to focus on thinking about things that we can make some kind of effort to address versus things that are inherent that we don't really have the ability to deal with.*

A sense of agency, as with the impacts to wellbeing resulting from tradeoffs in management, can be unevenly distributed amongst individuals in a community (Cinner and Barnes, 2019). One of the points of consensus among discourses was the importance of including a measure of equity in fisheries management moving forward, perhaps an acknowledgement that attention must be paid towards potential unintended consequences of policies that widen the gulf between winners and losers (e.g., Carothers et al., 2010). There are places within each perspective to consider the implications of equity. Who is included in partnerships and collaborative processes? What is the distribution of vulnerability if we choose to pursue short-term versus long-term actions? Are the values of the community represented in management's vision of the future? This potentially unifying concept may be a useful touchstone when there are disagreements about the best ways to improve wellbeing. This is also an area where more than economic contribution to wellbeing must be considered. Without inclusion of more dimensions of wellbeing, tradeoffs may exacerbate marginalization and represent the values of the decision makers instead of stakeholders, triggering conflict or opposition to policies (Daw et al., 2015).

Since Q methodology can highlight minority perspectives within a group (Watts and Stenner, 2012), this method may be well suited to bring forward the voices of individuals less well represented in fisheries management and in the literature on coastal communities. The perspectives of those in management are important for a host of reasons we have described, and the people chosen to participate in this study have a wealth of knowledge and experience as fishers and in fishery management. Because of the nature of a Q study, including small sample size and non-random participant selection, the results are not intended to be more broadly applied to the population (Brown et al., 1999). As such, the perspectives highlighted here do not encompass all the views held by those in fisheries management on the West Coast; however, they do highlight some important pathways for improving wellbeing in coastal communities. While we focused on those engaged in the management process in this study, next steps could include broadening the inquiry to residents of coastal communities. Such work could inform the development of reference points for ecosystem-based fisheries management, ensure the saliency of management for all participants, and may hold potential for the further incorporation of perspectives and social data into fisheries management (Levin et al. 2018; Dawson and Levin, 2019).

Inclusion of a holistic view of human wellbeing in fisheries management is clearly a work in progress (Breslow et al 2017), and the wellbeing of many fishing communities has certainly been challenged recently (Knight et al., 2020; Link et al., 2020; White et al., 2021). The ultimate impact of the many obstacles facing fishing communities depends in part on the diverse perspectives of actors in the fisheries sector, be it managers, advisors, or stakeholders. Daylighting discourses can help clarify foundational areas of disagreement and sharpen focus on common goals. Indeed, despite different perspectives on the priorities needed to support the wellbeing of fishing communities, the ultimate goal is shared: thriving and sustainable fisheries and fishing communities that support livelihoods, culture, and a continued connection to the environment for current generations and those to come.

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1.8 Appendix A

1.8.1 *Interviews*

We developed the Q set for this study using 23 semi-structured interviews that were conducted with individuals connected to fisheries on the West Coast, including people that work in the fishing industry, state or tribal agencies, NGOs, and academia. Below is an example script used in the interviews.

Example Interview Script - Climate and Communities- Scenario Planning Project

How will West Coast fishing communities be affected by climate related shifting stock availability and other developments between now and 2040?

Thank you for the opportunity to chat today. I am working with a team from the University of Washington to understand how people engaged in fishing, the seafood industry, or fisheries management perceive changes in fisheries over the last few years, what changes they see coming, and thoughts about dealing with these changes. Before we get started, will it be ok if I record our conversation? I will create a transcript of the interview and only our research team will have access to it. Any summary interview content, or direct quotations from the interview that are made available through academic publication will be made anonymous so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify you will not be revealed. I have 5-6 questions. They are fairly open ended, and they're going to be geared towards getting you to just express your thoughts, questions, opinions, about how you see West Coast fishing communities evolving over the next 10 or 20 years. But first, I'd love for you to give me maybe one or two minutes on your background, and how you connect to West Coast fisheries.

1. Looking back - Over the past decade, what have been the most notable developments in West Coast fishing communities? What about in stock availability? Which trends surprised you most? What are the biggest story lines?
2. If I could answer any questions for you that would help you better understand the future of West Coast fishing communities (in 2040), what would you want to know? What do you not know today that you'd like to know to help have a successful fishing industry on the West Coast? You can ask about the world, the industry, the environment…
3. Thinking about the next 10 or 20 years, what do you think seems like an inevitable trend that will affect stock availability? What are the most important unstoppable or inevitable trends that you think will affect West Coast fishing communities?
4. Wildcard - What low probability events could happen to completely reshape the landscape for West Coast fishing communities?
5. Describe how a bad scenario might evolve for West Coast fishing communities in the next 20 years? Can you describe a good scenario - what might that involve?
6. Is there anything else you would like to add on these topics?

1.8.2 *Environmental Worldview*

A range of variables have been shown to influence people's perception of climate change risk including their environmental worldview, level of perceived personal responsibility for conservation, and political ideology (Weber, 2010; Sullivan and White, 2019). The Cultural

Theory of Risk (CTR) originally developed by Mary Douglas and colleagues (Douglas 1966; Gross and Rayner 1985; Rayner 1992; Douglas and Wildavsky 1982) posits a framework of how culture and social organization inform worldviews and risk perception. In CTR there are 4 worldviews: fatalist, egalitarian, hierarchist, and individualist. Following other work that has considered climate risk perception in the context of CTR (McNeeley and Lazrus, 2014; Cullen et al., 2018), before we had participants complete the Q sort, we asked them about their agreement or disagreement with four statements designed to align with each worldview:

Please indicate the degree to which you agree or disagree with the following statement:

1. There is no need to plan for climate change since we do not know exactly what is going to happen.
2. Regulations are the best way to keep us from pushing the environment past manageable limits.
3. Self-sufficiency is key to weathering natural climate variability.
4. Equity and cooperation are essential in resource management and to maintain the balance between humans and nature

We were curious is there would be any correlation between the discourses and worldviews, and while there was small variation between discourse (Figure 1-5), we did not find any significant patterns.

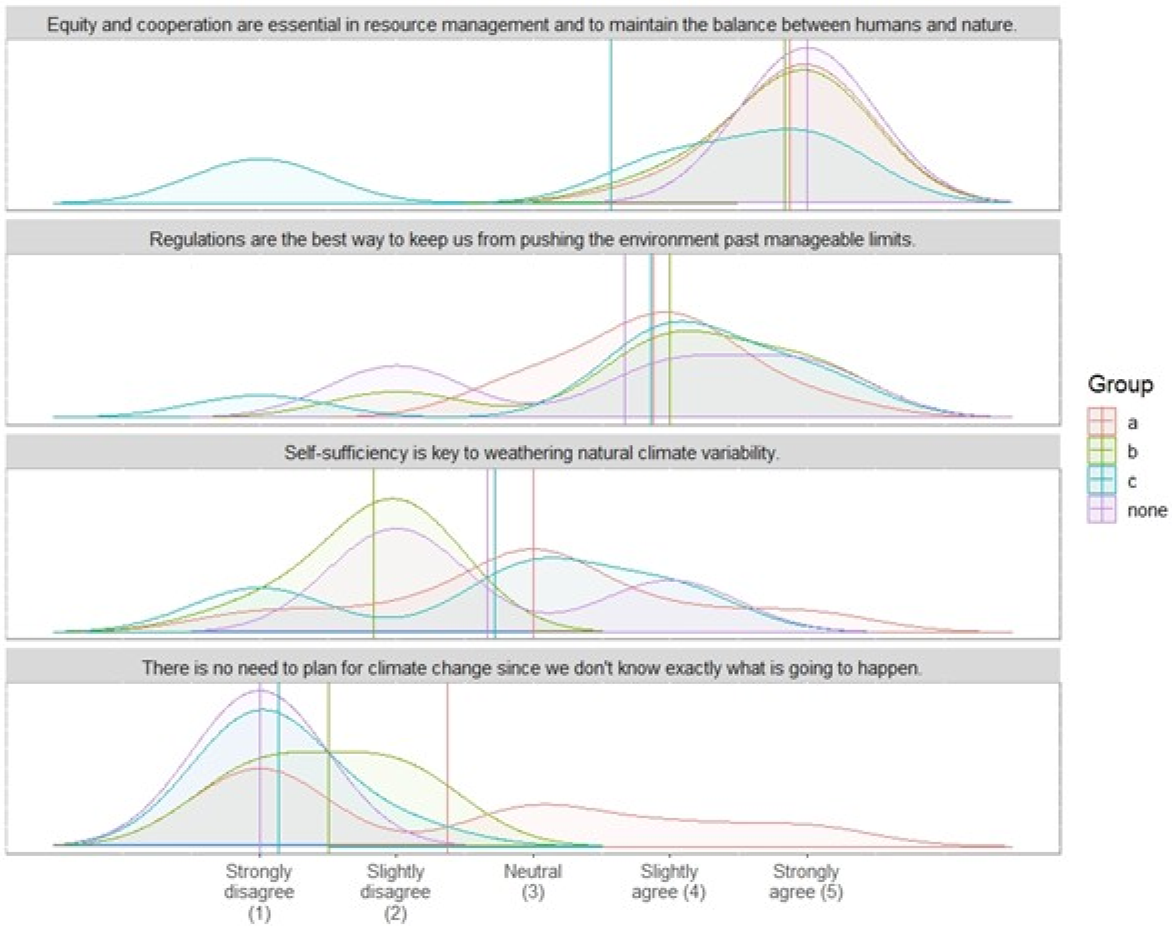


Figure 1-5. Density plot of responses to worldview questions by each discourse: a. Collaboration is Key, b. Fishers Forward, and c. Climate and Society.

1.8.3 *Detailed Q Sort Results*

The following tables and figures expand upon data provided in the body of the manuscript and show general factor characteristics (Table 1-5), support for the three-factor solution (Table 1-6, Figure 1-6), and the factor scores and status of each statement (Table 1-7).

Table 1-5. General factor characteristics.

	average reliability coefficient	*loading Q sorts*	*eigenvalues*	*explained variance (%)*	*composite reliability*	*se factor scores*
A. *Collaboration is key*	0.8	8	3.6	15	0.97	0.17
B. *Fishers Forward*	0.8	6	3.4	14	0.96	0.2
C. *Climate and Society*	0.8	7	3.2	13	0.97	0.19

Table 1-6. Correlation between factor z-scores.

	A	*B*	*C*
A	1	0.36	0.2
B	0.36	1	0.11
C	0.2	0.11	1

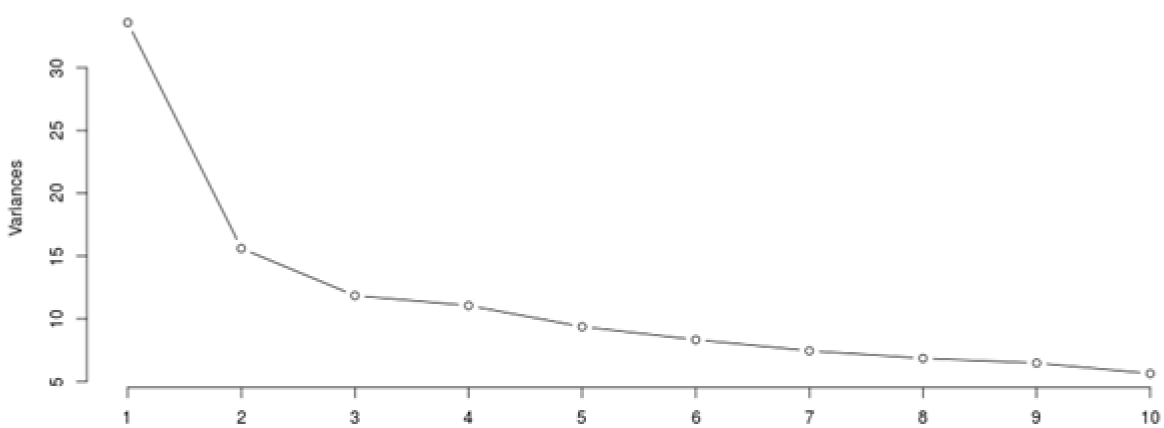


Figure 1-6. Screeplot of unrotated factors.

Table 1-7. Statements and associated factor scores, distinguishing or consensus status, and supporting statistics. A_B represents the absolute difference between the z scores for factors A and B for that statement. That is compared to significance thresholds to determine statistical significance with results in adjacent columns.

	Statement	A	B	C	Distinguishing or Consensus	A_B	Sig A_B	A_C	Sig A_C	B_C	Sig B_C
1	There is a demand from consumers for local and sustainable seafood.	4	0	2	Distinguishes all	1.931	****	1.247	****	-0.683	*
2	Coastal communities have plans in place in to deal with coastal hazards like tsunamis.	-1	-2	0	Distinguishes f3 only	0.188		-0.732	**	-0.92	***
3	Fishers have or can access the resources to weather temporary financial stresses due to a downturn in a fishery.	1	3	0	Distinguishes f2 only	-0.92	***	0.011		0.93	***
4	Extreme and unpredictable ocean conditions threaten fisher safety.	-2	-2	-1		0.207		-0.471		-0.678	*
5	Direct to consumer selling opportunities exist for local fisheries.	0	-1	0	Distinguishes f2 only	0.679	*	-0.047		-0.726	**
6	Seasonal aquaculture jobs are available for fishers to supplement fishing income.	-3	-4	-5	Distinguishes f3 only	0.308		1.02	***	0.712	**
7	Small, independently owned fisheries can coexist with larger, vertically integrated companies.	2	1	0	Distinguishes f3 only	0.111		0.779	**	0.668	*
8	Fishers can afford to live in the coastal communities they have traditionally resided in.	0	2	-3	Distinguishes all	-1.362	****	1.215	****	2.577	****
9	The fishing industry reduces its fuel consumption and emissions.	-1	-2	-2	Distinguishes f1 only	0.595	*	0.519	*	-0.076	
10	Fishing communities have access to quality healthcare.	-2	-2	1	Distinguishes f3 only	0.119		-1.359	****	-1.478	****
11	Water quality issues caused by climate change prevent species from being harvested.	0	-1	4	Distinguishes all	0.732	**	-1.381	****	-2.113	****
12	Working waterfronts are going away.	0	2	2	Distinguishes f1 only	-0.824	**	-0.646	*	0.179	

13	Expanding offshore development has conflicts with fishing.	0	3	3	Distinguishes f1 only	-1.193	***	-0.876	***	0.316	
14	Commercial and recreational fishers work together rather than argue over how to divide quotas.	3	-1	-4	Distinguishes all	1.341	****	2.677	****	1.336	****
15	Society views the harvest of sustainable seafood as an integral component of a healthy ocean.	3	3	1	Distinguishes f3 only	0.321		0.96	***	0.639	*
16	Children of fishers want to go into the fishing industry.	-4	0	-4	Distinguishes f2 only	-1.697	****	0.179		1.876	****
17	Conservation groups work more collaboratively with the fishing industry.	2	1	-2	Distinguishes f3 only	0.08		1.341	****	1.261	***
18	There are more people of color and women in fisheries management.	-3	0	3	Distinguishes all	-1.198	***	-2.201	****	-1.003	***
19	Subsistence and cultural fishing practices are threatened due to shifting availability of resources.	-3	0	4	Distinguishes all	-0.99	***	-2.494	****	-1.503	****
20	Tourism options are developed to support the local economies in fishing communities.	-1	-3	-2		0.723	**	0.347		-0.375	
21	Retraining and other job opportunities are available if people decide to move out of fishing.	-4	-4	0	Distinguishes f3 only	0.13		-1.601	****	-1.73	****
22	There is more stakeholder engagement in fisheries management.	3	1	-3	Distinguishes all	0.753	**	2.361	****	1.608	****
23	When responding to uncertainty, novel management approaches are created rather than building on old models.	1	5	1	Distinguishes f2 only	-1.56	****	-0.297		1.263	***
24	Development of new sources of renewable energy eases the need for dams and hydropower.	-2	-3	3	Distinguishes f3 only	0.456		-2.05	****	-2.506	****
25	Fishery management policies are based on social equity as well as economic efficiency.	0	0	1	Consensus	-0.053		-0.291		-0.239	
26	The multi-generational, successful seasonal fishery-based lifestyle is viable.	-2	2	-3	Distinguishes all	-1.665	****	0.592	*	2.257	****

27	Fishers are not stuck in individual fisheries but have the flexibility to migrate between them when conditions warrant.	1	2	-1	Distinguishes all	-0.544	*	0.823	**	1.367	****
28	The understanding of how socioeconomic and ecosystem indicators fit together is improved.	2	1	2	Consensus	-0.082		0.012		0.094	
29	Fishers and managers can prepare and respond to changes in the availability of fish.	5	4	2	Distinguishes all	0.601	*	1.416	****	0.815	**
30	Fishing infrastructure improvements needed to deal with sea level rise are supported by the community.	-1	-1	-1	Consensus	-0.289		-0.463		-0.174	
31	Cost effective technology improves accountability without fishers having to absorb the costs.	1	4	-2	Distinguishes all	-0.7	**	1.048	***	1.748	****
32	Technology is developed to help fishers determine where not to fish to avoid protected species.	4	-5	1	Distinguishes all	3.505	****	1.23	****	-2.276	****
33	The pool of qualified crew is reduced due a decrease in training opportunities.	-5	-1	-1	Distinguishes f1 only	-1.287	****	-1.077	***	0.211	
34	Ocean literacy is woven into curriculum for students starting in elementary school.	2	-3	-1	Distinguishes all	2.289	****	0.771	**	-1.518	****
35	Impacts of climate change threaten the availability of target species.	1	1	5	Distinguishes f3 only	-0.303		-1.846	****	-1.543	****
36	Active recruitment of young fishers lessens the impacts of the aging of the fleet.	-1	0	0		-0.4		-0.718	**	-0.318	

Chapter 2. PERCEPTIONS OF CLIMATE CHANGE VULNERABILITY AMONG WEST COAST FISHERS

2.1 Abstract

Climate change is impacting marine ecosystems and the livelihoods, wellbeing, and food security of communities dependent upon those systems. The resulting vulnerability is distributed unequally amongst those communities and is a function of their exposure, sensitivity, and adaptive capacity to the impacts of climate change. Vulnerability assessments, an increasingly popular methodology for understanding variability in vulnerability and its components, often fail to include or recognize the perceptions of individuals in the focal system. Perceptions of vulnerability often differ from vulnerability as measured by subject experts, and failure to recognize perceptions can lead to ineffective adaptation plans and lack of support for climate policies. Here, we survey fishers from Washington, Oregon, and California to understand their perceptions regarding their vulnerability to climate change and examine how those perceptions vary by worldview and demographic factors. We also evaluate how concern levels for climate and environmental issues compare to regulatory or operational challenges that may also affect fishing success and wellbeing. Though we found there to be some connection between certain assets, such as vessel size, and adaptive capacity, overall, the most significant predictor of a higher perception of vulnerability was belief that climate change is occurring.

2.2 INTRODUCTION

Climate change is likely to have profound impacts on marine ecosystems (Bakun et al., 2015; Doney et al., 2012; Olsen et al., 2020; Perry et al., 2005), and though effects will vary by species, there will be substantial consequences for fisheries worldwide (Free et al., 2019; Sumaila et al., 2011). Fishing has long been a central part of the culture and economy of the U.S. Pacific Coast. Indigenous peoples have fished and gathered shellfish since time immemorial (Mckechnie et al., 2014; Sepez, 2008; Toniello et al., 2019), and commercial and recreational fishing has generated nearly $35 billion annually in recent years (NMFS, 2018). Those practices are at risk as climate-driven changes in temperature, pH, and oxygen, and the resulting effects on fisheries, are already apparent in the California Current (Hodgson et al., 2018; Harvey et al., 2020). Ocean warming is leading to shifts in community structure and phenology (Thorson et al., 2016), and range shifts of marine populations (Morley et al., 2018). Upwelling systems like the California Current are particularly vulnerable to ocean acidification (Doney, 2010), which has significant negative impacts on calcifying organisms (Busch & McElhany, 2016), and is also associated with altered ecological communities, food webs, and decreased fishery catches (Bednaršek et al., 2016; Kaplan et al., 2010; Klinger et al., 2017; Marshall et al., 2017). Ocean warming is leading to the deoxygenation of ocean waters (Keeling et al., 2010) and the resulting hypoxia often co-occurs with acidification (Chan et al., 2016). Low-oxygen waters have spread onto the shelf in some sections of the California Current, including in areas of valuable commercial fisheries (Keller et al., 2015).

The effects of climate change on the ecological components and fisheries of the California Current are heterogenous. For example, ocean acidification has a greater impact on epibenthic invertebrates like crabs, shrimp and bivalves than on pelagic fish, marine mammals, and seabirds (Marshall et al., 2017). Additionally, ocean acidification causes high mortality in shellfish hatcheries (Chan et al., 2016). Previous work has predicted groundfish fisheries may remain strong regardless of climate impacts (Ainsworth et al., 2011) as many demersal fish like Dover sole, sablefish, and rockfish may be able to take refuge in cooler waters by moving north or into deeper water (King et al., 2011). However, ocean acidification may create large vulnerability for demersal fish, even relatively mobile ones, through erosion of their prey base (Marshall et al., 2017) and evidence suggests they are increasingly being impacted by deoxygenation in near-bottom waters (Keller et al., 2015). Pacific salmon survival is also negatively affected by climate-driven food web impacts as temperature increases cause changes in the zooplankton community and a reduction in abundance of nutritionally important lipid-rich copepods (Peterson et al., 2013). Overall impacts on Pacific salmon are geographically variable (e.g., Tolimieri & Levin, 2004), but climate change is generally a key driver of population dynamics (Crozier et al., 2019).

The human communities of the California Current, of which at least 125 have been identified as significantly involved in commercial, recreational, and subsistence fisheries (Norman et al., 2007), also experience heterogenous effects of climate change due to the distribution of the ecological impacts, resource dependency, and underlying social vulnerabilities. Current projections indicate there will be a shift north in the range of many species of the California Current (Cheung et al., 2015; Morley et al., 2018), with certain fishing fleets particularly vulnerable to the changes. In the sardine and groundfish fisheries, the ability to adapt or benefit from range shifts is affected by port location relative to northward movement of species (Smith et al., 2021), and effects may be dampened or exacerbated depending on fishing community behavioral patterns (Selden et al., 2020). In the Dungeness crab fishery, impacts of harmful algal blooms and the ability of fishers to adapt are distributed unequally across the fleet (Jardine et al., 2020), and communities that are highly reliant on crab have also experienced greater exposure during recent climate shocks (Fisher et al., 2021). Climate-driven events like harmful algal blooms and marine heat waves have caused significant economic and cultural impacts as losses in commercial fishing revenue are compounded by downturns in tourism and other sectors (Moore et al., 2020; Ritzman et al., 2018). Large declines in salmon abundance have coastwide impacts, though they are felt more acutely in some areas (Richerson et al., 2018), including Indigenous cultures of the Pacific Coast whose health, traditions, and food security are affected by the declines in salmon, shellfish, and other species. (Crosman et al., 2019; Donatuto et al., 2011; Lynn et al., 2013).

In these coastal socio-ecological fisheries systems (SEFs) (Marshall et al., 2018), the wellbeing and economies of human communities are closely tied to the health of fish and shellfish populations (Allison et al., 2009; Breslow et al., 2016; Donatuto et al., 2011; Donkersloot et al., 2020; Holland & Leonard, 2020) rendering benefits from and relationships with nature vulnerable as the abundance and availability of marine species are affected by climate change (Badjeck et al., 2010; Perry et al., 2010; Selig et al., 2018). Here, following the IPCC approach (2007), we define vulnerability as the extent to which communities or individuals are susceptible to, or unable to cope with, adverse effects of climate change. Vulnerability is a function of the exposure of an individual or community to climate impacts, sensitivity to that exposure, and capacity to adapt to the effects of climate change (Adger, 2000; Adger, 2006). Though the term risk is sometimes used interchangeably with vulnerability (Hodgson et al., 2019), here it is distinctly different and is defined as the potential impact that results from exposure and sensitivity to climate change, and does not account for adaptive capacity. However, it is used in the discussion of risk perception to indicate concern for a general threat or issue.

Given the interconnectedness of people and nature in SEFS (Ostrom, 2009), vulnerability assessments are often employed in these systems to examine the impact of specific environmental stressors, including climate change, and the ability of individuals and communities to cope with those stressors (Adger, 2006). Vulnerability assessments can help to determine priorities and management strategies (Cinner et al., 2012; Thiault et al., 2018) and identify particularly at-risk communities (Davies et al., 2018). This method, grounded in the risk and hazards fields as well as resilience science, has become a popular approach to understand how the type and severity of climate change effects varies geographically (Bindoff et al., 2019), the variability with which societies and people experience those impacts (Otto et al., 2017; Thomas et al., 2019), and capacities and constraints in adapting to changing conditions (Cinner & Barnes, 2019; Ikeme, 2003; Wilson et al., 2010). Assessments previously conducted in coastal communities have shown how factors like the degree of natural resource dependence, contribution of resources to wellbeing and health, and exposure to the bio-physical effects of climate interact and contribute to overall vulnerability (Cinner et al., 2012; Donatuto et al., 2011; Himes-Cornell & Kasperski, 2015; Morzaria-luna et al., 2014; Sowman & Raemaekers, 2018). Additionally, previous work has shown that some fishing specific characteristics like fishery participation (Rogers et al., 2019), and vessel length (Fisher et al., 2021; Jardine et al., 2020) influence adaptive capacity and vulnerability, and how fishery diversification can decrease risk by buffering interannual variability (Anderson et al., 2017; Kasperski & Holland, 2013).

Often, a goal of a climate vulnerability assessment is to inform adaptation plans (e.g., Metcalf et al., 2015); consequently, understanding what drives vulnerability and the variability among communities and individuals is key to supporting a beneficial and equitable planning process. For example, some individuals may benefit most from environmentally-centered reduction of exposure, while others are best served with actions that would enhance their adaptive capacity (Thiault et al., 2020). However, while risk and vulnerability assessments are valuable tools for risk management and climate adaptation, they are value-laden, and frequently ignore social and cultural outcomes (Hodgson et al., 2019; O Renn, 2008). This omission often leads to a failure to address social and psychological determinants of risk (Flynn et al., 1994) and the exclusion of impacts to important social and cultural practices (Poe et al., 2014). While work has been done to improve the inclusion of social indicators in understanding vulnerability in SEFS (Colburn et al., 2016; Colburn & Jepson, 2012) examination of perceptions of risk and vulnerability are less common.

Perceptions of risk and vulnerability are shaped by personal experience, cognitive biases, and interpretations of information, which can cause risks to be both over and underestimated compared to quantitative measures (Renn, 2003; Slovic, 1987). Risk perception is affected by demographic traits (e.g., age and gender, (Flynn et al., 1994)), attitudes (Peters & Slovic, 1996), and the social system within which an individual resides (Jaeger et al., 1993). Additionally, feelings of dread and lack of control, varying levels of familiarity, voluntariness of exposure, and observability all affect risk perception (Slovic, 1987). Importantly, these disparities can lead to gaps in risk perception between the general public and those with authoritative knowledge in an area (i.e., subject matter experts), and the general population tends to feel higher levels of concern for low probability, high consequence risks than experts (Renn, 2003). These discrepancies are particularly apparent in the United States when it comes to climate change, and there is a well-documented gap between public and expert perceptions of risk with regards to climate change (Ballew et al., 2019; Howe et al., 2019). A range of variables have been shown to influence the public's perception of climate change risk including their environmental worldview, level of perceived personal responsibility for conservation, and political ideology (Sullivan & White, 2019; Weber, 2010). Additionally, many of the factors previously described as affecting general risk perception influence how people view climate change and its impacts including direct experience with extreme events (e.g., severe storms, wildfires, and heat waves) that are likely to increase under climate change (Spence et al., 2011; Weber & Stern, 2011). Perceptions of climate risk also vary geographically, likely in part due to cultural and ideological factors and as a function of personal experience with local weather and anchoring on recent anomalous extremes (Cullen & Anderson, 2017; Howe et al., 2015, 2019; Zaval et al., 2014). This variability is relevant as the perception of risk by general public frequently shapes environmental policy and management (Slovic, 2000), and is particularly relevant in climate change policies (Mayer et al., 2017; Smith & Mayer, 2018).

In this paper we report on the perceptions of climate vulnerability of fishers from the California Current to add to the conversation about climate adaptation on the West Coast and consider how the typical drivers of risk perception may be manifested in this context. Here, we employ a vulnerability assessment framework but use the perceptions of individuals to inform the dimensions of exposure, sensitivity, and adaptive capacity. We investigated how perceptions of vulnerability vary among fisheries, geographic locations, demographic factors, and amongst those holding different worldviews. Finally, we evaluate how fisher concerns about climate compare with other challenges faced such as markets, infrastructure, and regulations, and how levels of concern are connected to perceptions of vulnerability.

2.3 METHODS

To assess perceptions of climate vulnerability in California Current fishers, we developed a survey consisting of three sections: demographic and fishery participation information, observations of ocean change, and perceptions of wellbeing and vulnerability. The survey consisted predominately of Likert-scale questions, but also included open-ended opportunities for survey participants to elaborate on their observations of environmental change and challenges they faced in adaptation (Appendix E: Perceptions of Vulnerability Survey). Following pilot testing, we deployed the survey using a mixed-mode method (Dillman, Smyth, and Christian, 2014). Fisher contact information is managed at the state level and California, Oregon and Washington differ in how they manage and share data; consequently, we targeted fishers from Oregon and Washington primarily by mail and those in California via the internet. 1,000 fishers from Washington and Oregon were randomly selected from lists of licensed commercial fishers and asked to participate in the survey. They were initially contacted with a letter explaining the project and invited to complete the survey using the phone or over the internet. They were subsequently sent two postcards as reminders. To reach fishers living in California we contacted fishing associations and other organizations that work closely with fishers including non-profits and port groups and asked that they share the information and a link to the survey to their memberships or networks. After our initial outreach, we also opportunistically took advantage of meetings or other relevant events to bolster responses which we believed were being somewhat hindered by the COVID-19 pandemic.

A measure of exposure was derived from responses to a series of questions regarding views on the effect that ocean warming is having on fish species. Specifically, the exposure score for each fisher was an average of their responses for the fisheries that they reported participating in. Perceptions regarding sensitivity and adaptive capacity were enumerated using specific questions based on established indicators of wellbeing and adaptive capacity (Breslow et al., 2017; Colburn et al., 2016). Responses to question 39, a series of statements about how changes in the environment and fisheries have affected health and wellbeing, were used to determine sensitivity, and responses to question 43, statements regarding the ability to adapt and perceptions about the future, were used to calculate adaptive capacity. Additional questions in the survey concerning perceptions of risk and resilience were adapted from Cullen et al., (2018) and Schumann (2018).

2.3.1 *Analysis*

There are numerous methods for calculating climate vulnerability. In the vulnerability framework we chose to use, exposure and sensitivity are combined to estimate risk, which when modified by adaptive capacity yields an estimate of vulnerability (Figure 2-1). Following Samhouri & Levin, (2012), we estimated risk as the Euclidean distance from the origin in a space defined by exposures and sensitivity (Eq. 2.1). Vulnerability is calculated similarly by factoring in adaptive capacity and considering the 3-dimensional distance (Eq. 2.2). We considered how this choice of method may affect results and explored an alternate method of estimating vulnerability by summing exposure and sensitivity and then subtracting adaptive capacity (Cinner et al., 2012). We assessed Pearson's correlation on the resulting risk and vulnerability scores to compare outcomes of the two methods. The results of the two methods of calculating risk and vulnerability were highly correlated (Figure 2-11, Appendix B); thus, we present only the results from the Euclidean distance method here. The questions that were part of the exposure, sensitivity, and adaptive capacity indices, all five-level Likert scales, were scored on a scale from 0 to 1. For example, in the adaptive capacity index, answering strongly agree to the

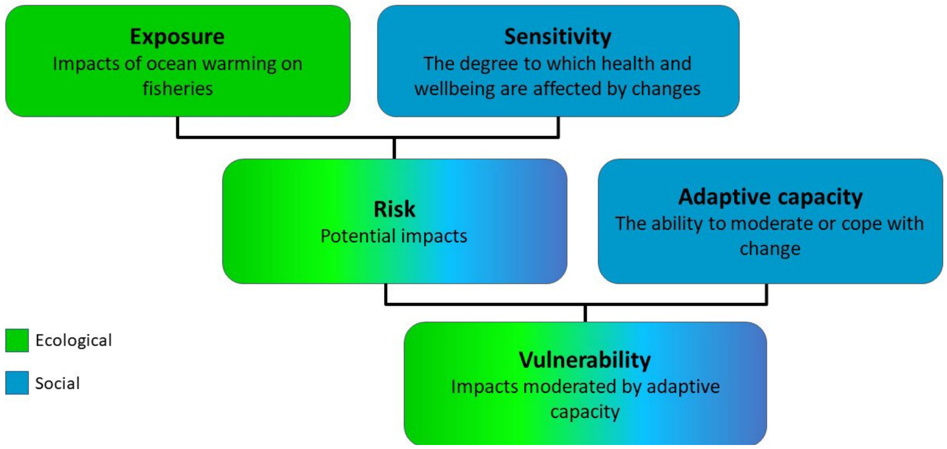


Figure 2-1. Framework for assessing perceptions of vulnerability to climate change in West Coast fishing communities. Modified from Marshall et al. (2013) and Thiault et al. (2021).

statement, "I could easily move into a new fishery" was scored as a 1 indicating high adaptive capacity, while strongly disagree was scored as 0. The questions informing each dimension of vulnerability were averaged to get individual scores of exposure, sensitivity, and adaptive capacity. Since a higher score equates to higher adaptive capacity, 1 – adaptive capacity was used when calculating vulnerability by Euclidean distance. We assumed that each component contributes equally, and each dimension was given equal weight when calculating vulnerability.

$$r = \sqrt{e^2 + s^2} \tag{2.1}$$

$$v = \sqrt{e^2 + s^2 + (1 - ac)^2} \tag{2.2}$$

After calculating vulnerability, we explored its variability and drivers using several methods to assess the potential relationship between risk or vulnerability and a number of factors that have been shown to affect it. Specifically, we used analysis of variance (ANOVA) to test the hypothesis that perceptions of personal vulnerability differ among fishers according to the (1) length vessel they fish on, (2) the number of fisheries they participate in, (3) the percentage of income they get outside fishing, (4) years they've spent fishing, (5) age, and (6) beliefs held about climate change. Because the belief in climate data violated the normality and homogeneity of variance assumptions of ANOVA, for that comparison we used Kruskal-Wallis rank sum test, a non-parametric alternative (Kruskal and Wallis, 1952).

In addition to questions regarding climate vulnerability, the survey included questions about environmental, fishing, and social issues that may affect fishing success and wellbeing. We used these responses, as well as responses to questions about belief in climate change, the future of fishing, and conflict associated with fishing to assess if and how people cluster around types of concerns (Table 2-1). Participants were asked to respond if they were very, somewhat, or not at all concerned about an issue, and whether they thought about those same issues never, occasionally, or often. Level of concern was scored from 1 (not at all) to 3 (very) and weighted by frequency of thought, also scored on a 1 (never) to 3 (frequently) scale. The questions informing outlook and conflict were based on a five-level Likert scale and scored from 1 (strongly disagree) to 5 (strongly agree). The indices were rescaled between 0 and 1 and clustered using hierarchical clustering and the Ward method; indices and individual questions were checked for correlation before clustering. The R package NbClust, which proposes the best clustering scheme after comparing the results from 27 indices (Charrad et al., 2014), was used to determine the appropriate number of clusters. Following clustering, we used Welch's ANOVA and pairwise t-tests with the Bonferroni correction to test whether the mean concern scores were different among the clusters.

To visualize how the concern clusters may relate to perceptions of vulnerability, we modified the vulnerability profile approach described by Thiault et al. (2020) and created quadrants defined by median values in a space defined by risk (exposure plus sensitivity), and adaptive capacity. We included cluster membership when visualizing the distribution of individuals in that space, and profile groups were determined by the quadrant that individuals were located in due to their combination of risk and adaptive capacity.

Table 2-1. Themes and the questions that informed them for the cluster analysis.

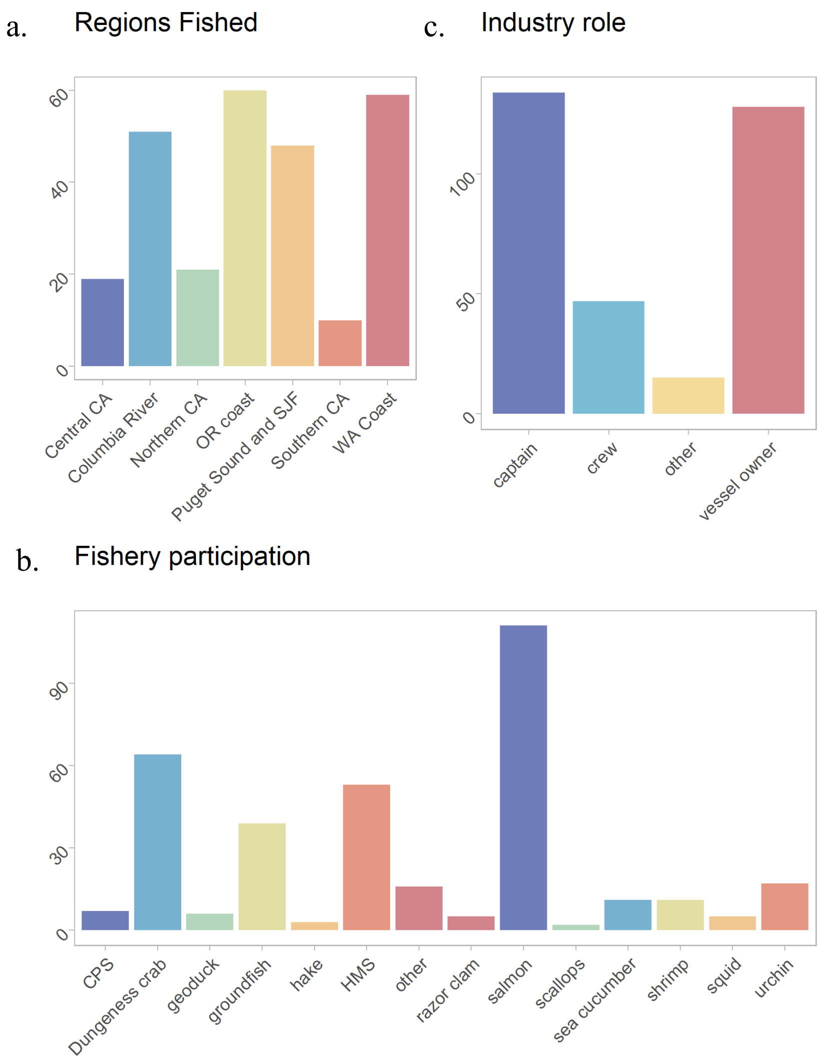
Concerns	**Contributing issues**
Marine environment	Warming waters, OA, changing weather and storms, water quality, HABs, sea level rise, habitat
Fishing	Fish populations, bycatch, landed value, operational costs, stock assessment, regulation, increased travel time
Community and infrastructure	Labor force, community cohesion in fishing and residential communities, coastal and port infrastructure
Personal	Physical and mental health, safety at sea, family
Outlook	Belief in and harm from climate change, leaving or changing fisheries, future of fishing
Conflict	Conflict with recreational fisheries, other commercial fisheries, aquaculture, tourism, coastal and offshore development

Lastly, the results of the open-ended questions in the survey were inductively coded using ATLAS.ti.

2.4 RESULTS

We received 162 responses to our survey from fishers residing in Washington, Oregon, California, and Alaska, giving us a 13% response rate for the fishers that were invited by mail to participate. One individual that lives in Alaska responded, they fish in Washington and were included in the Washington group during analysis to preserve anonymity. Survey participants reported fishing all along the Pacific coast from the Mexico border to Cape Flattery, WA, and participating a variety of fisheries (Figures 2-2a-b). One-third of the fishers who responded fish in other locations in addition to the West Coast, predominantly in Alaska. Because licensed fishers were targeted by our recruitment process, we received more responses from captains and vessel owners than crew (Figures 2-2c). The majority of respondents have been fishing for over

25 years, generate at least 75% of their income through fishing, and are longtime residents of their communities (Table 2-2). Over 90% of the respondents identify as male.



Figures 2-2a-c. Number of responses received for regions fished, industry role, and fisheries. Individuals could respond multiple times for each question. Coastal areas were defined as: WA Coast – Cape Flattery, WA to Cape Disappointment, WA; OR Coast – South of the Columbia River to Mendocino, CA; Northern CA – Mendocino, CA to Point Reyes, CA; Central CA – Point Reyes, CA to Point Conception, CA; Southern CA – south of Point Conception, CA.

Table 2-2. Summary statistics of survey respondents.

State	% (n)	Age group	% (n)	Years fishing	% (n)	Years in community	% (n)	Income from outside fishing	% (n)
WA	58.6 (95)	<30	4.9 (8)	0-5	6.2 (10)	0-5	6.8 (11)	0%	35.8 (58)
OR	19.1 (31)	30-40	11.7 (19)	5-15	16.0 (26)	5-15	8.0 (13)	<10%	21.0 (34)
CA	22.2 (36)	40-50	13.0 (21)	15-25	11.1 (18)	15-25	21.0 (34)	10-25%	6.1 (10)
		50-60	20.4 (33)	25+	66.7 (108)	25+	64.2 (104)	25-50%	8.6 (14)
		60-70	27.2 (44)					>50%	28.4 (46)
		70+	22.8 (37)						

2.4.1 *Climate change and fishing*

Most respondents reported observing some changes in their fisheries and the environment. Just under two-thirds (60%) said they have seen an increase in ocean temperatures in the waters off the West Coast in the last five years and 71% said they felt there has been a decrease in the availability of their target species. When asked to compare the last five years with 30 years ago, 75% said they have seen a range shift in their target species. Half (49%) of respondents reported a shift in the time of year when they fish, and just under that (43%) thought their ability to catch fish has been negatively impacted by climate change. These changes have had consequences for the health and wellbeing of fishers; 70% agree that changes in fisheries have raised their stress levels, and 64% agree that it has negatively affected their overall wellbeing (Figure 2-9, Appendix B).

Survey participants exhibited a range of perspectives about how marine species are being impacted by climate change and expressed a lot of uncertainty as well. People were asked whether they thought ocean warming was having a strong negative, slight negative, neutral, slight positive, or strong positive effect on a list of commercially fished species and management groups, and then asked about their confidence level in that response. They also had the option of responding I don't know. Salmon and Dungeness crab had the lowest percentages of I don't know responses, and 67% and 34% of all participants agreed that ocean warming was having a slight or strong negative effect on those species respectively. Just over 20% of survey participants thought that ocean warming is having a slight or strong positive effect on highly migratory species (such as Pacific tunas, swordfish, sharks, and billfish) (Figure 2-10a, Appendix B). Confidence levels were similar across species with 51%-70% reporting high confidence in their responses (Figure 2-10b, Appendix B). Exposure was calculated based upon this question, but only responses for the fisheries that people participate in were used; these results reflect the responses of all participants.

Fishers that responded to the survey held a diversity of views regarding the occurrence and outcomes of climate change. Two-thirds (66%) of respondents strongly or slightly agree with the statement "I believe climate change is occurring," while about half (48%) think they will personally be harmed by climate change. More (62%) are worried about effects on future generations and just over half (51%) agree that, despite uncertainty, we should be preparing for climate change (Figure 2-3). Though almost 40% think the 20-year outlook for their fishery is poor, most still want to remain in the fishing industry.

The polarization that surrounds climate change in national conversations in the United States was apparent in survey responses to the open-ended questions with some, like this individual, exhibiting concern for the wide-ranging consequences,

> *"Salmon and crab [will be particularly negatively affected], but it is likely that no species will escape effects of climate change. In particular, ocean pH changes have the potential to affect all harvest species."*

While others held forces besides climate change responsible for the changes in fish populations,

> "*Don't believe climate has anything to do with it [changes in fish species]. 99% too much fishing pressure."*

"They [fish populations] seem to be more affected by political regulations than climate change."

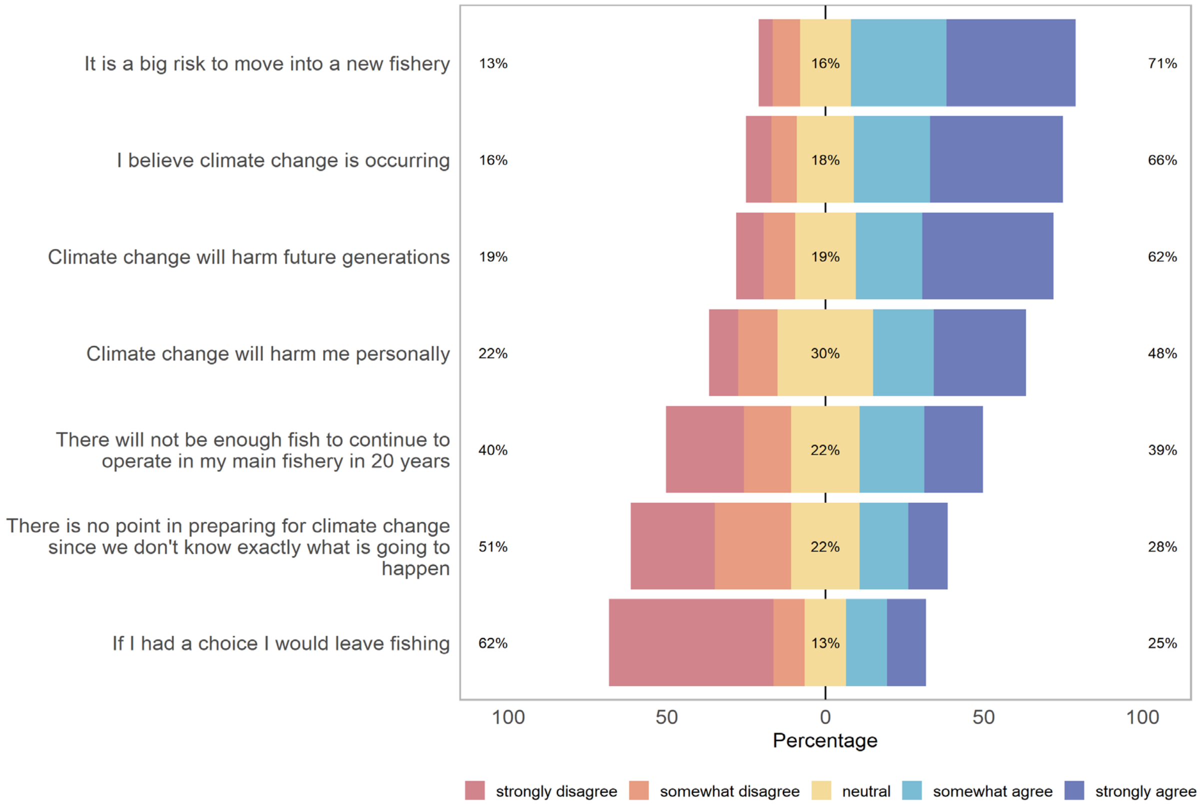


Figure 2-3. Level of agreement of respondents with the statements on the left of the figure. Numbers on the far right and far left are the sum of the strongly and somewhat agree or disagree responses and those in the middle are the percentage of people who answered neutral for that statement. n = 162.

Respondents attributed changes in fisheries to a variety of causes, both environmental and regulatory. Many people noted that they think warmer water is contributing to the reduction in fish abundance, particularly for salmon, and that it is a driving force behind species' range shifts. With their observations of changes in the weather, salmon, and other species, many fishers echoed the sentiments of this individual, describing his observations,

> *"The albacore act weird. They are not where they historically hang out. The fish are skinnier than normal. Water temperatures are sometimes so high our freezers have a difficult time maintaining temperature. The prevailing wind is historically from the NW. For the last 4-5 years it has been directly out of the north which affects upwelling negatively*."

In addition to range shifts, other challenges described by fishers include reduced and unpredictable fish populations, increases in bad weather that interfered with fishing, issues with paralytic shellfish poisoning and domoic acid, and interactions with other species that negatively affected fish populations or fishing ability (Table 2-3). This fisher describes encountering many of those issues in the 2019 season,

> *"In 2019 I fished another delayed California Dungy season, then to Oregon to seine squid that never showed up, to SE salmon season which was strongly affected by the 2019 Pacific Blob of water, finally to longline some black cod in WG [Western Gulf of Alaska] only to have to struggle to catch with whales around. All these fisheries are part of the bigger picture of the Pacific."*

Management actions have also caused challenges for fishers. A decline in salmon populations, specifically in Washington, was attributed by some to a decrease in hatchery production, and some management decisions (e.g., shorter season, later openings) were identified as drivers of temporal shifts in fishing. Because environmental change and regulatory difficulties do not happen independent of each other, often fishing troubles were identified as a combination of both. Here, a fisher describes an issue that has arisen because current regulations have not kept pace with environmental change:

> *"Species shift northward has decreased herring biomass, increased squid stocks that local fishermen cannot access at any level due to restricted limited entry. California has closed the two-ton open access provision that had previously allowed artisanal small-scale fishing for squid. As fishing stocks move north local fishermen are denied access at any scale."*

Table 2-3. Common themes and observations from open-ended questions about range and timing shifts, and effects of climate change on fishing.

Topic	Effects and observations
Fish populations	Generally lower abundance Changing patterns in migration behavior and timing Smaller fish
Warmer waters	Negative effects on salmon survival Warm blob Tuna moving north
Weather	More storms Decreases in upwelling
Habitat and ocean conditions	Unstable and variable ocean conditions Ocean acidification and HABs Loss of kelp beds PSP and domoic acid issues
Species interactions	Pyrosomes interfering with fishing Purple urchins Marine mammal issues
Management	Reduced hatchery production Delayed openings of fisheries

2.4.2 *Perceptions of Climate Vulnerability*

Perceptions of personal climate vulnerability varied among fishers who targeted different taxa. Our cluster analysis revealed two major groupings — fishers targeting echinoderms (urchins and sea cucumbers), geoduck, and salmon clustered together and generally expressed more vulnerability to climate change than fishers targeting other species (Figure 2-4, Table 2-6 in Appendix B). This cluster perceived themselves as being more exposed and having lower adaptive capacity than the other cluster. Conversely, the second cluster – fishers targeting highly migratory species, groundfish, shrimp, CPS, squid, and razor clams – comparatively expressed that they both had less exposure and greater adaptive capacity. While in that cluster, the perceptions of razor clam fishers followed a slightly different pattern; they see themselves as more highly sensitive to climate change, but their overall vulnerability is in the middle of the group due to a lower sense of exposure.

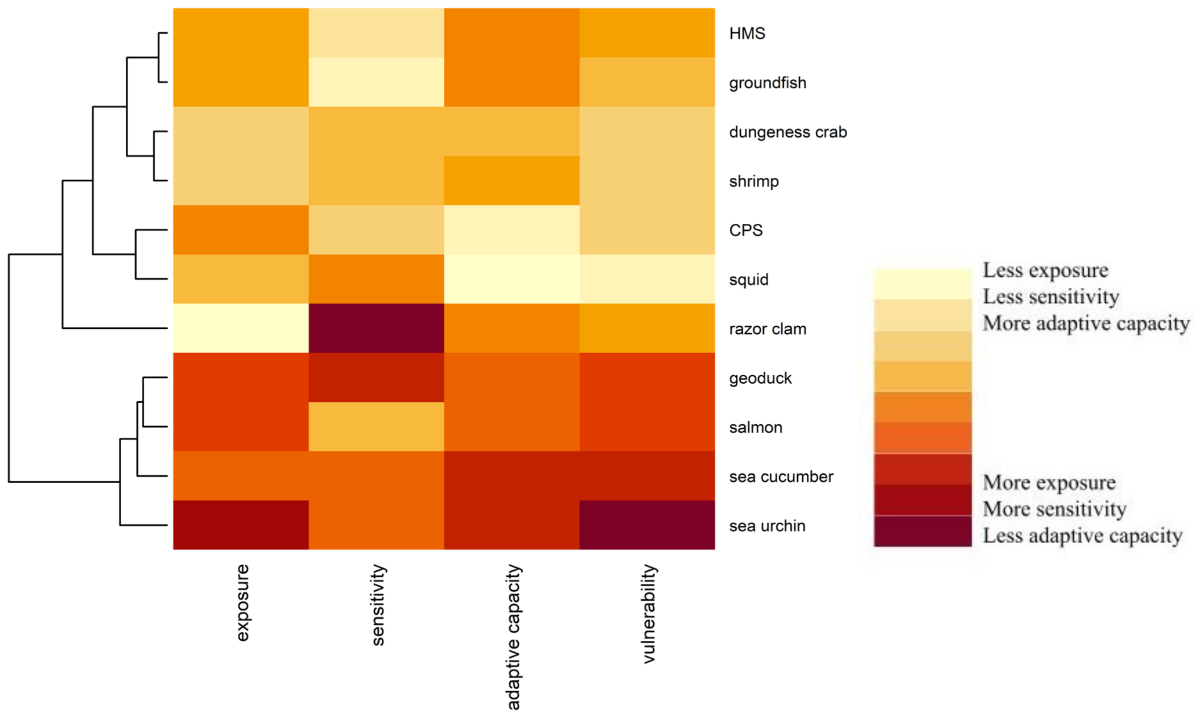


Figure 2-4. Heatmap showing relative scores for the dimensions of vulnerability, organized by fishery participation, where darker red indicates a higher contribution to vulnerability. Each column is scaled independent of the others, therefore the score associated with the darkest red in exposure is not equivalent to that same color in the vulnerability column.

Perceptions of vulnerability generally had more correlation with views regarding climate change than demographics, with some limited exceptions. We did not detect differences in perceptions of exposure, sensitivity, adaptive capacity, or vulnerability among survey respondents of varying age, percentage of income from outside fishing, or years of fishing experience (Table 2-7, Appendix B). Fishers working on larger vessels (>55 m) generally felt that they had greater adaptive capacity than those working on smaller vessels (≤ 55 m) ($F = 5.58$, $df = 5$, $P < 0.001$). We did not detect a difference in perceptions of exposure ($F = 1.23$, $df = 5$, $P = 0.347$) or sensitivity ($F = 1.639$, $df = 5$, $P = 0.153$) between those working on large vs. small vessels. However, the perception of high adaptive capacity of large-vessel fishers was strong enough to lead to a significantly lower assessment of overall vulnerability for them (F = 3.335, df = 5, P = 0.007).

Survey respondents also believe that diversification across target species reduces exposure to climate impacts and those who participated in more fisheries perceived lower climate exposure (Kruskal-Wallis chi-squared = 10.174, df = 3, P = 0.017). Still, diversification was not associated with differences in climate sensitivity (F = 2.23, df = 3, P = 0.087) and adaptive capacity (F = 0.80, df = 3, P = 0.493), and the difference in perceived exposure was not sufficiently large to be expressed as a difference in vulnerability (F = 2.09, df = 3, P = 0.105).

Beliefs regarding whether climate change is occurring was related to fisher perceptions of climate exposure, sensitivity, and vulnerability. Those who responded strongly or somewhat agree to the statement “I believe climate change is occurring” felt on average that they were more exposed than those who responded neutral or somewhat or strongly disagree (Tables 2-4a-b). The agree and neutral groups both had higher perceived mean sensitivity and vulnerability than the disagree group. However, belief in climate change was not related to how people felt about their adaptive capacity (Figure 2-5).

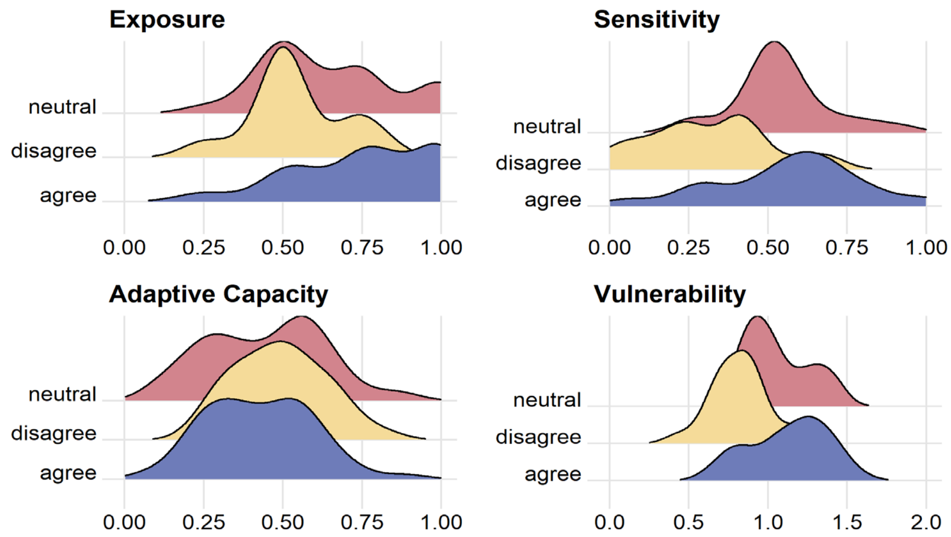


Figure 2-5. Density curves of components of vulnerability with respondents grouped by their responses to the prompt "I believe climate change is occurring."

Tables 2-4a-b. a. Mean values of components of vulnerability when people are clustered by their belief that climate change is occurring, and results of the Kruskal-Wallis statistical test for each component. b. Significance (p-value) for each component of vulnerability from pairwise Wilcoxon rank sum test with Bonferroni correction.

		Exposure	**Sensitivity**	**Adaptive Capacity**	**Vulnerability**	**count**
Neutral		0.64 (.21)	0.53 (.14)	0.44 (0.19)	1.04 (.20)	29
Disagree		0.54 (0.15)	0.31 (0.19)	0.49 (0.14)	0.82 (0.18)	26
Agree		0.75 (0.22)	0.55 (0.22)	0.43 (0.17)	1.12 (0.25)	107
Kruskal-Wallis	Chi-squared	22.56	25.03	3.29	25.81	
	p-value	<0.0001	<0.0001	0.193	<0.0001	

	Exposure		**Sensitivity**		**Adaptive Capacity**		**Vulnerability**	
	Agree	Disagree	Agree	Disagree	Agree	Disagree	Agree	Disagree
Disagree	<0.001		<0.001		0.20		<0.001	
Neutral	0.034	0.335	0.78	<0.001	0.59	0.54	0.297	0.001

2.4.3 *Vulnerability profiles and non-climatic concerns*

When we investigated how concerns about the impacts of climate change compare to other environmental and non-environmental issues potentially confronting fishers, day-to-day operational issues proved to be of higher concern than environmental factors (Figure 2-6). The status of fish populations was the biggest concern with 72% responding that they were very worried about that issue, followed by regulations (68.5%), operational costs (65.4%), and bycatch (61.1%). Around half of respondents expressed that they were very worried about some of the environmental issues with 54.9% saying they were very worried about habitat loss, 50.6% very worried about harmful algal blooms, and 48.1% very worried about water quality. Mental health (8.6% very worried), sea level rise (17.9%) and changing weather patterns (17.9%) were among the issues of least concern.

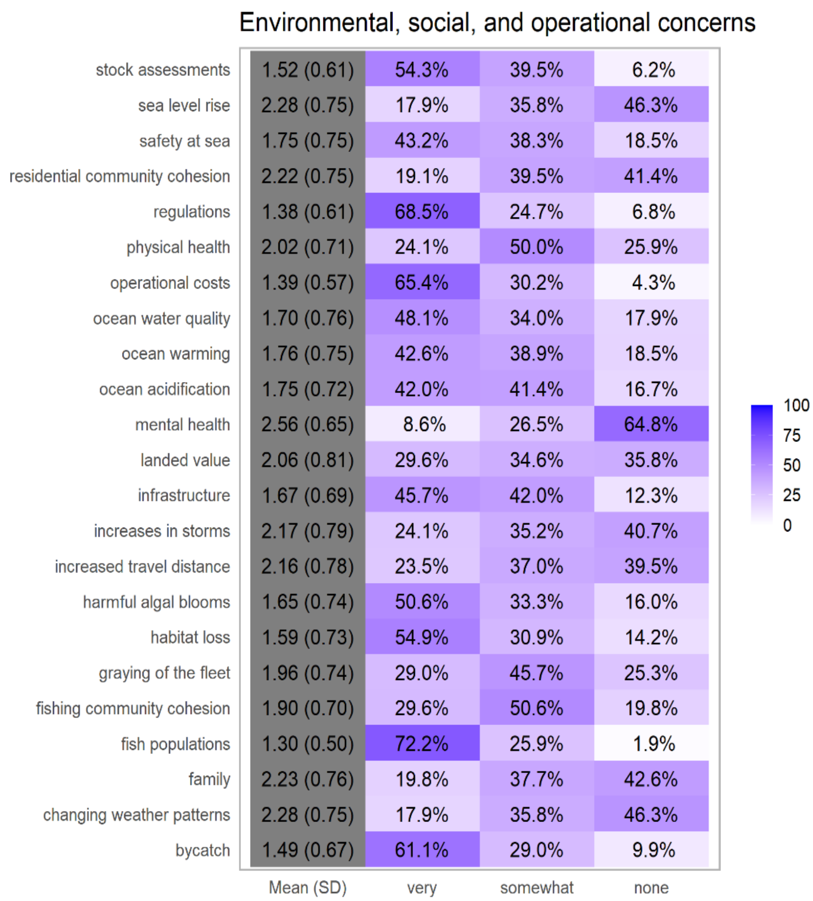


Figure 2-6. Results of Likert-scale question, “Please indicate whether you are very, somewhat, or not at all concerned for the following issues.” Mean column indicates mean level of concern where very = 1, somewhat = 2, and none = 3. n = 162 for each row.

The Likert-responses for the level of concern were converted to a numerical scale and then grouped into the six themes previously described: marine environment, fishing operations, community and infrastructure, personal, outlook, and conflict (Table 2-1), and then hierarchical clustering was performed on the average scores of each theme. A three-cluster solution was the recommended outcome; 14 of the 27 indexes tested recommended three clusters. The resulting three clusters of individuals were relatively distinct in their concern pattern. Cluster 3 exhibited the highest level of concern across the board, standing out in particular for their higher level of concern for the marine environment and community and infrastructure issues (Figure 2-7; Table 2-5).

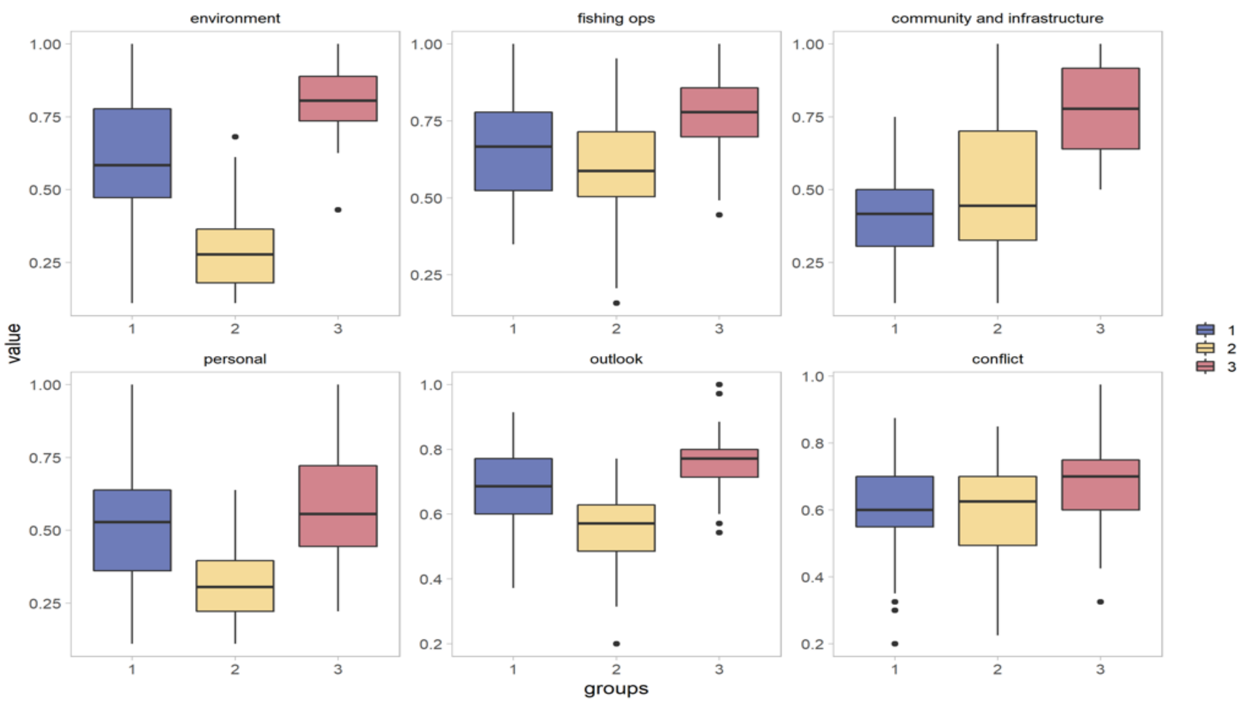


Figure 2-7. Boxplot of average scores for concern clusters 1, 2, and 3 across the six themes. The line in the middle of the box is the median score, the upper and lower end of the box indicate the 75% and 25% percentiles respectively, and dots represent potential outliers. Because of the way the outlook statements were phrased, a higher score indicates a more negative outlook for future fishing prospects. There are 65 people in cluster 1, 60 in cluster 2, and 37 in cluster 3.

Table 2-5. P-values from the results of Welch's ANOVA and pairwise t-tests for differences between mean concern score for cluster groups. The Bonferroni correction was applied to the pairwise t-tests.

	Marine environment		**Fishing operations**		**Community and infrastructure**		**Personal**		**Outlook**		**Conflict**	
Welch's ANOVA	$p < 0.0001$		$p < 0.0001$		$p < 0.0001$		$p < 0.0001$		$p < 0.0001$		$p = 0.009$	
Pairwise t-tests												
	1	2	1	2	1	2	1	2	1	2	1	2
2	< 0.001	-	0.250		0.03	-	< 0.001	-	< 0.001	-	0.521	-
3	< 0.001	< 0.001	0.006	< 0.001	< 0.001	< 0.001	0.140	< 0.001	0.008	< 0.001	0.092	0.007

There was a distinct pattern in how the concern clusters appeared in the vulnerability space defined by average risk and average adaptive capacity (Figure 3-8). This space is split into four quadrants, or vulnerability profiles (Thiault et a., 2020) by the median adaptive capacity and risk scores: 1. Potential adapters, 2. Higher concern, 3. High latent risk, and 4. Lower concern. Individuals in cluster 3, the cluster that expressed greater worry across the themes, predominantly occupy quadrants 1 and 2. These individuals generally perceive themselves to be at higher risk but vary with regards to their level of adaptive capacity. Cluster 2 tended to perceive themselves as having lower risk than cluster 3, but also exhibited an internal range of perceived adaptive capacity resulting in them primarily occupying quadrants 3 and 4. In contrast, individuals in cluster 1 were more spread out but most tended to perceive themselves as either highly vulnerable (high risk and low adaptive capacity) or as having low vulnerability (low risk and high adaptive capacity). Overall, individuals in each cluster tend to be more similar in their perceived level of risk than adaptive capacity.

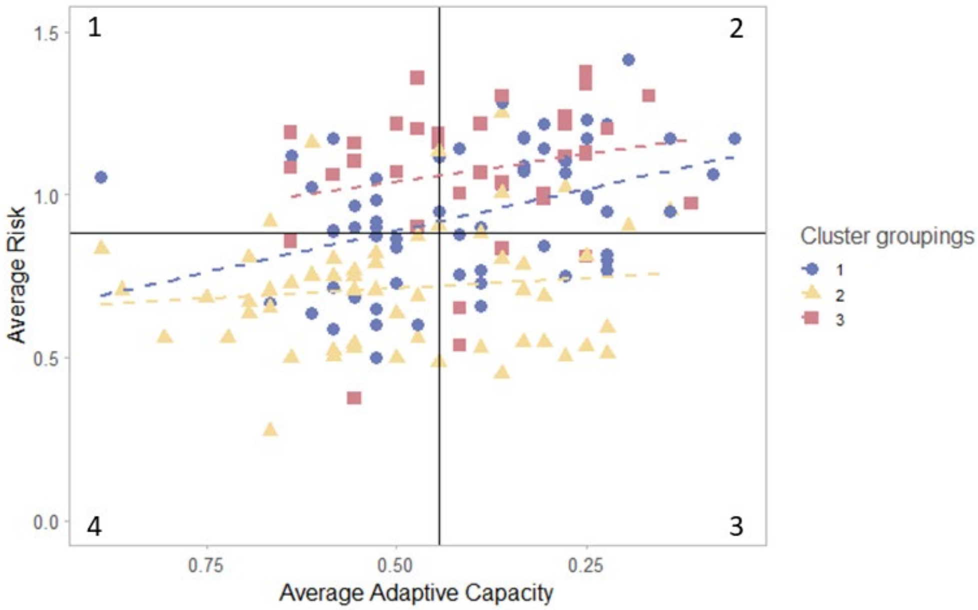


Figure 2-8. Perceived vulnerability of individuals. Colors correspond to the clustered concern groups and black lines correspond to median risk and adaptive capacity. Quadrant vulnerability profiles are 1. Potential adapters, 2. Higher concern, 3. High latent risk, and 4. Lower concern (Thiault et al., 2020). X axis is oriented from 1 to 0 because higher adaptive capacity reduces vulnerability.

2.5 Discussion

Vulnerable populations often experience or perceive their vulnerability in different ways, even people who are susceptible in the same context (Kasperson et al., 2005). We found that fishers from the West Coast exhibited a range of perceptions regarding climate change and their vulnerability to the impacts. There were some areas of relative agreement, like the fact that changes in fisheries are raising the stress levels, and others where people were spread more evenly across the spectrum, like concern about being personally harmed by climate change. These perceptions of climate vulnerability are complex and informed by social, cognitive, and experiential factors. Perceptions inform the ways in which people act and plan for the impacts of climate change, or why they choose to maintain the status quo, making it important to consider perceptions in climate vulnerability assessment and adaptation planning processes. The inclusion of perceptions of climate vulnerability may also help reflect real concerns of people that may be otherwise missed (Aven & Renn, 2018), and better understanding of community concerns and risk perceptions can highlight issues that, if not addressed, may impact the equity and effectiveness of adaptation (Ensor et al., 2018).

Perceptions of risk and vulnerability influence how people engage with the idea of adaptation, shaping their feelings about the need to act and type of adaptive action to take (Clayton et al., 2015; Mortreux & Barnett, 2017). When faced with the same wildfire risk, some communities in Colorado perceived it to be a mitigation issue, others as an emergency response concern, and their actions followed accordingly (Brenkert-Smith et al., 2006). In that case, social context affected how risk perceptions were appraised and converted to action; relative risk perception also drives motivation to adapt. In the risk appraisal process, individuals weigh the severity and urgency of the potential impacts from climate change against other challenges or issues they face (Grothmann & Patt, 2005). Here, many fishers were more concerned about issues like operational costs and regulations than they were about climate change, and such competing concerns can be a barrier to climate adaptation (Mortreux & Barnett, 2017). The fact that people tend to discount future benefits more than future costs may additionally undermine the motivation to take action and incur costs related to adaptation for those who are focused more on immediate and concrete challenges like day-to-day operational issues (Weber, 2010).

The generation of vulnerability profiles (Thiault et al., 2020) is another way to consider how perceptions of risk and adaptive capacity may influence the way in which individuals respond, some of which may warrant particular attention in adaptation planning. Regardless of their other concerns, if people perceive themselves to be at low risk to climate impacts the way they act to reduce their vulnerability, if they choose to act at all, will likely look different than those who feel more at risk. Many individuals in the lobster fishery in Maine had no plans for adaptation because they did not think they would be personally harmed, despite a general consensus among the fishers that ocean waters are warming, while many of those more concerned about climate change were already taking action (McClenachan et al., 2020). A similar reaction may be expected here from individuals in either the high latent risk or lower concern quadrants. While these individuals may legitimately have low risk to the impacts of climate change, denial, fatalistic, or overly optimistic worldviews can influence risk perceptions and lead to avoidant behaviors or maladaptation (Mortreux & Barnett, 2017). Conversely, individuals in the higher concern and high latent risk groups may be limited in adaptation because they perceive themselves to have low adaptive capacity. While that perception may reflect an actual physical inability to adapt, as with risk perception there may be differences between perceptions of adaptive capacity and the objective ability to adapt (Grothmann & Patt, 2005).

While climate policy cannot be scaled to the individual, in the interest of effective adaptation it is important to recognize that not everyone will benefit equally from a single strategy and that risk perceptions will likely inform if and how individuals avail themselves of resources that support adaptation. Additionally, when it comes to adaptive capacity policy makers should be aware that the strategy needed to improve resilience may be one that addresses perceptions of adaptive capacity, not necessarily just providing physical assets that have traditionally been assumed to facilitate adaptation. Since support of climate policies is also influenced by perceptions of risk (Leiserowitz, 2005), and understanding perceptions can help in climate change communication (Leiserowitz et al., 2021), elicitation of perceptions of climate vulnerability may also help to identify management, communication, and adaptation strategies more likely to gain acceptance in fishing communities. Belief in climate change, significantly connected with perceptions of vulnerability in this study, is influenced by political ideology in the United States (Weber, 2010), as is overall trust in science (Lee, 2021). Yet amidst the growing divide between political cultures and the associated worldviews, finding common ground on which to communicate and agree upon the need for climate mitigation and adaptation policies is increasingly challenging. Perceptions about adaptive capacity – here unrelated to belief in climate change – may be a less polarizing way to discuss efforts to address climate change. Future investigations will take a deeper look into what is associated with variations in perceptions of adaptive capacity, and how adaptive capacity may differ if we broaden our definition of what is contributing to it.

The key findings from the most recent IPCC report (IPCC, 2021), underscore the need for urgent action for all coastal communities as the options for protection and adaptation in ocean and coastal ecosystems are becoming fewer and less effective with the continued rise in atmospheric CO_2 levels (Gattuso et al., 2015). Efforts are underway throughout the region to develop strategies to support the resilience of fisheries and fishing communities, including the Climate and Communities Initiative of the Pacific Fisheries Management Council (PFMC)[3]. As we work to support the climate-readiness of fisheries, for all the reasons described above regarding the influence of perceptions on behavior and policy support, it is valuable in such efforts to account for the perceptions of fishers on the West Coast regarding their vulnerability to climate change. Here, we have applied a widely used framework to assess vulnerability, but have informed the dimensions using self-assessed survey data to understand how those potentially at

[3] https://www.pcouncil.org/actions/climate-and-communities-initiative/

risk understand and interpret their situation. While perceptions are known to diverge from empirically measured or actuarial risk (in cases where measurement is even possible) (Renn, 2008; Slovic, 1987), here we focus not on assessing those differences but on understanding what factors contribute to an individual perceiving themselves to be vulnerable to climate change, and how perceptions of vulnerability are distributed among fishers on the West Coast of the United States. The results of this in-depth survey of fishers from Washington, Oregon, and California provides additional evidence that when it comes to perceptions of climate vulnerability, the worldviews of individuals hold great influence.

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2.7 Appendix B

2.7.1 *Additional survey results*

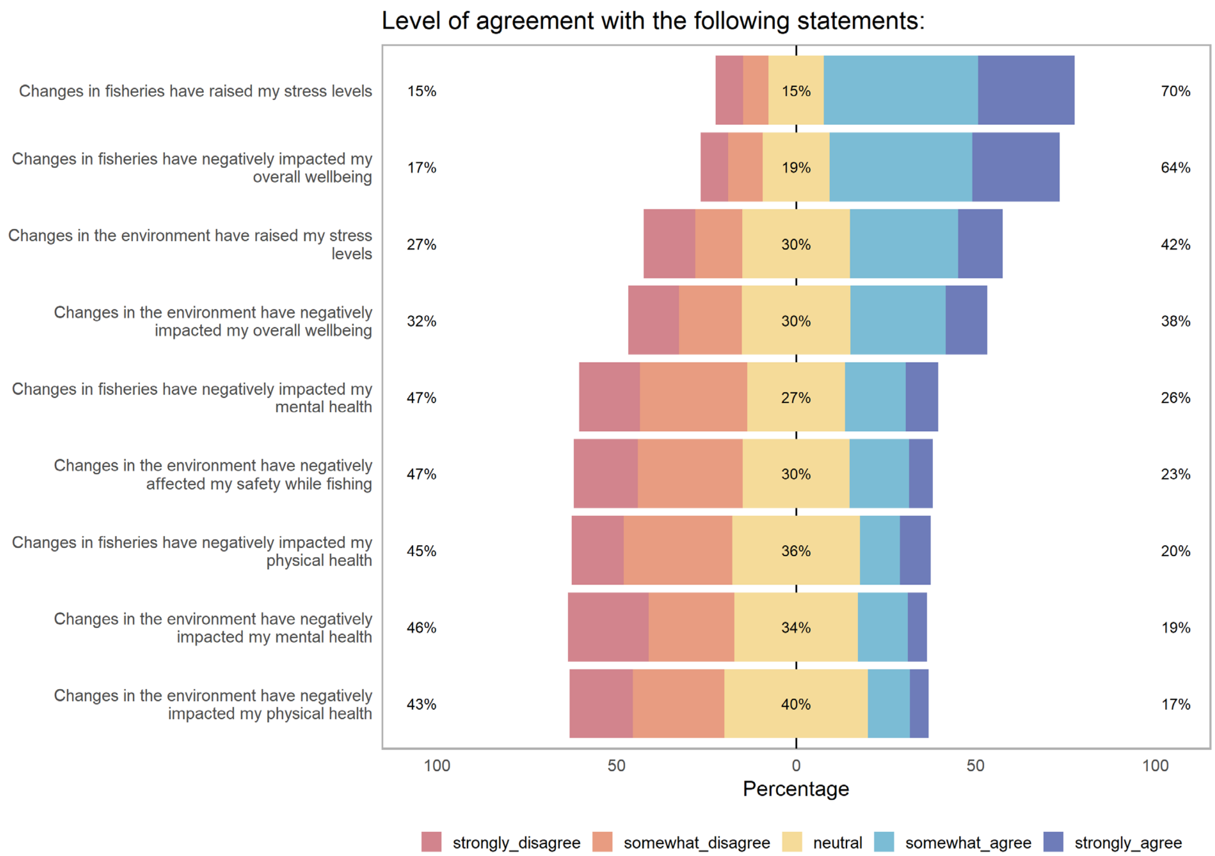
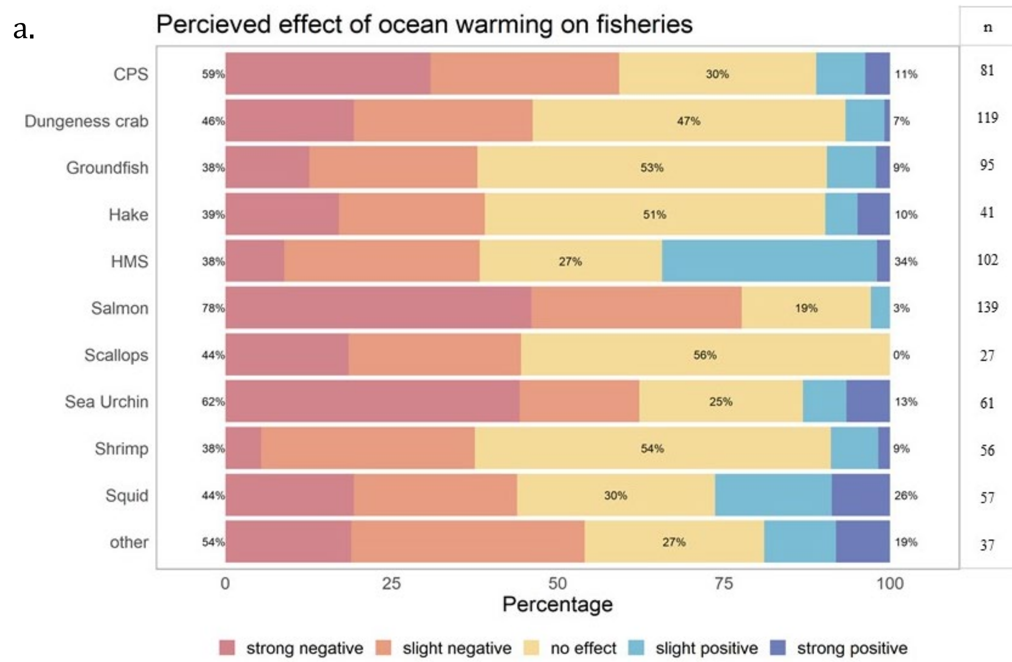
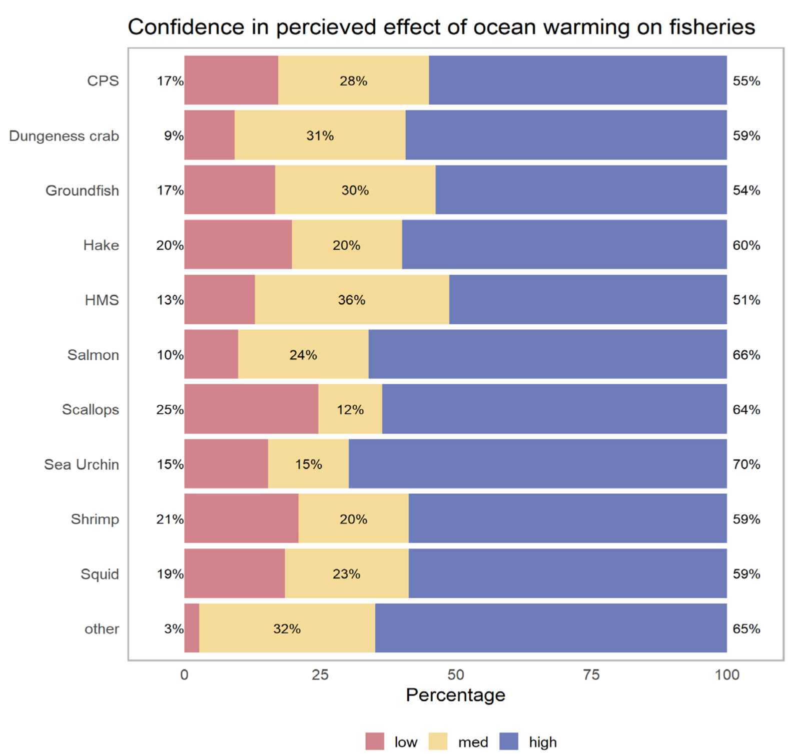


Figure 2-9. Results of responses about level of agreement or disagreement with statements regarding how health and wellbeing is being affected by changes in fisheries and the environment. Responses from this question were used to derive individual sensitivity. Numbers on the far right and far left are the sum of the strongly and somewhat agree or disagree responses and those in the middle are the percentage of people who answered neutral for that statement. n = 162.

a.



b.



Figures 2-10a-b. a. Results of the question, "What, if any, effect do you believe ocean warming is having on these fisheries?" Response options were strong negative effect, slight negative effect, no effect, slight positive effect, strong positive effect, or I don't know. N in column on right is the number of people that gave responses besides "I don't know" and percentages in the figure are of that value. b. Results of the follow-up question, please indicate your level of confidence in your response to the previous question. Response options were low, medium, or high confidence. n = 162.

Table 2-6. Average exposure, sensitivity, adaptive capacity, and vulnerability scores averaged by participants in each fishery. Many people participated in more than one fishery so the total from individual fishers is greater than 162.

Fishery	Exposure (sd)	Sensitivity (sd)	Adaptive Capacity (sd)	Vulnerability (sd)	count
CPS	0.67 (0.24)	0.52 (0.17)	0.52 (0.13)	0.99 (0.24)	7
Dungeness crab	0.62 (0.23)	0.54 (0.21)	0.47 (0.17)	1.01 (0.23)	64
geoduck	0.73 (0.18)	0.55 (0.12)	0.42 (0.19)	1.10 (0.24)	6
groundfish	0.66 (0.20)	0.50 (0.25)	0.44 (0.16)	1.03 (0.26)	39
hake	0.51 (0.43)	0.41 (0.14)	0.53 (0.15)	0.87 (0.27)	3
HMS	0.67 (0.18)	0.51 (0.22)	0.44 (0.16)	1.03 (0.25)	53
razor clam	0.53 (0.29)	0.60 (0.16)	0.43 (0.27)	1.03 (0.23)	5
salmon	0.73 (0.21)	0.53 (0.22)	0.42 (0.16)	1.10 (0.23)	111
sea cucumber	0.71 (0.18)	0.54 (0.19)	0.37 (0.14)	1.12 (0.22)	11
sea urchin	0.77 (0.18)	0.55 (0.24)	0.38 (0.16)	1.16 (0.25)	17
shrimp	0.61 (0.22)	0.52 (0.12)	0.45 (0.14)	1.00 (0.16)	11
squid	0.64 (0.25)	0.54 (0.07)	0.55 (0.2)	0.96 (0.20)	5
All responses	0.70 (0.22)	0.52 (0.21)	0.44 (0.17)	1.07 (0.25)	162

Table 2-7. ANOVA results for selected demographic categories and vulnerability.

	Exposure	Sensitivity	Adaptive capacity	vulnerability
Vessel length	F value 1.129 Pr(>F) 0.347	F value 1.639 Pr(>F)0.153	F value 5.58 Pr(>F) < 0.001 ***	F value 3.335 Pr(>F) 0.007 **
Number of fisheries (1 – 4+)	Krukal-wallis chi-squared = 10.174, p = 0.01714 (fails normality assumption)	F value 2.228 Pr(>F) 0.0871	F value 0.804 Pr(>F) 0.493	F value 2.085 Pr(>F) 0.105
age	F value 1.294 Pr(>F) 0.269	F value 0.447 Pr(>F) 0.815	F value 1.436 Pr(>F) 0.214	F value 0.418 Pr(>F) 0.835
Income	F value 0.734 Pr(>F) 0.57	F value 0.1.187 Pr(>F) 0.319	F value 0.931 Pr(>F) 0.448	F value 0.977 Pr(>F) 0.442
Years fishing	F value 0.817 Pr(>F) 0.486	F value 0.342 Pr(>F) 0.795	F value 1.74 Pr(>F) 0.161	F value 0.634 Pr(>F) 0.594

2.7.2 *Alternate method of calculating vulnerability*

Because there are many methods of calculating vulnerability and the choice of method may influence results, in addition to calculating risk and vulnerability using Euclidean distance (Samhouri and Levin, 2012), we also calculated vulnerability by summing exposure and sensitivity and subtracting adaptive capacity (Cinner et al., 2012) (Eq. 3.3).

$$v = (e + s) - ac \tag{3.3}$$

The results of the two methods of calculating risk and vulnerability were highly correlated (Figure 2-11), thus we felt that presenting the results from one method was sufficient for this study.

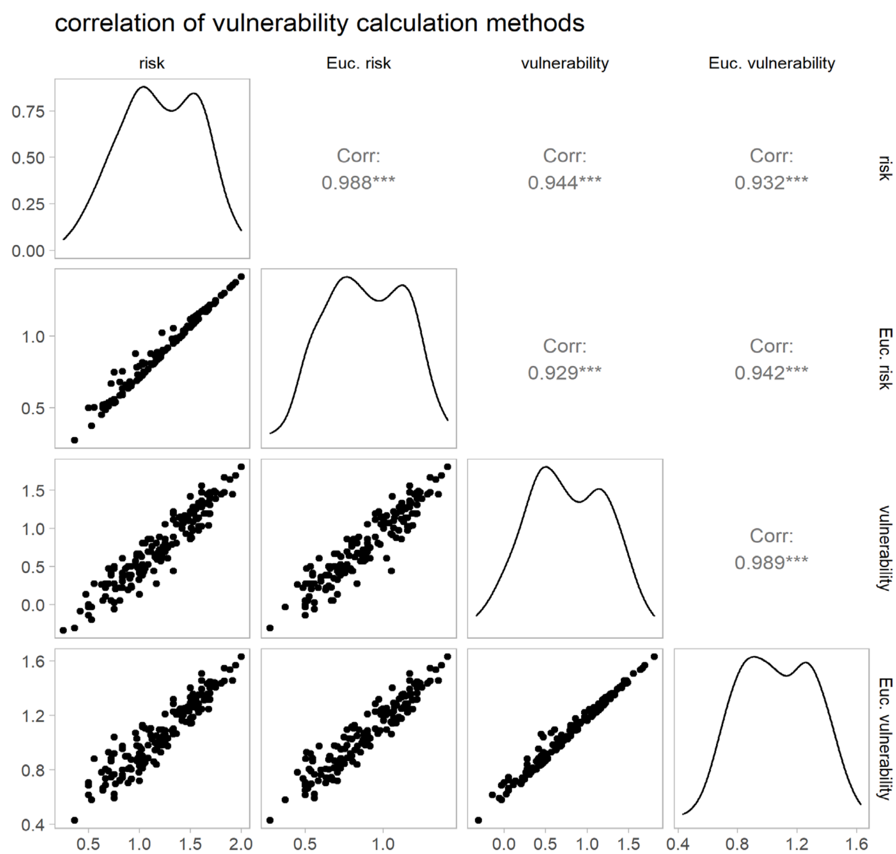


Figure 2-11. Correlation between risk and vulnerability calculations when done using addition (Cinner et al., 2012) versus Euclidean distance (Samhouri and Levin, 2012) and density curves for scores from each method.

Chapter 3. DO CAPABILITIES AND PERCEPTIONS OF ADAPTIVE CAPACITY ALIGN?: VIEWS OF FISHERS ON THEIR ABILITY TO ADAPT

3.1 ABSTRACT

Climate change is having profound impacts on coastal socioecological systems, necessitating individuals and communities to take adaptive actions. Adaptive capacity, or the ability to respond, moderate, or cope with change, is determined by a host of factors including physical resources, as well as social and cognitive drivers of behavior. Thus, how an individual perceives their adaptive capacity, while typically grounded in reality, can differ from their actual ability to adapt. Using data from a survey of commercial fishers from the West Coast of the United States, we built an index to compare perceptions of fishers across six categories that contribute to adaptive capacity. We examined how perceptions of adaptive capacity vary across factors that are known to affect it in fisheries including diversification of target species, diversity of livelihoods, and level of mobility. We also considered if perceptions vary depending on the homeport region of the fisher. Overall, people had medium to low confidence in their ability to take some basic adaptive actions and did differ regionally in how the viewed their adaptive capacity. The variation in how people perceived their assets and the socio-cognitive domains in this study highlights the importance of considering both as potential resources and constraints when working to support effective climate adaptation in fishing communities.

3.2 INTRODUCTION

Coastal communities are dependent on the ocean for a range of benefits including food security, livelihoods, and coastal protection (Selig et al., 2018). Those benefits are being impacted by the effects of climate change on the global ocean (Allison et al., 2009; Sumaila et al., 2011). One of the primary pathways for environmental impacts to be felt in coastal communities is through the effects on fisheries, including changes to the distribution and abundance of fish (Cheung, 2018; Free et al., 2019; Morley et al., 2018). Marine species are shifting evenly more quickly than terrestrial ones (Poloczanska et al., 2013), and climate impacts often magnify existing stressors (Pinsky & Mantua, 2014). The physical impacts of climate change are distributed heterogeneously along the coasts (Cheung et al., 2013; IPCC, 2019), and much work is now devoted to developing methods for assessing vulnerability in coastal social ecological systems (SES) (Allison et al., 2009; Cinner et al., 2012; Dudley et al., 2021; Perry et al., 2010; Thiault et al., 2020). For fishing communities, this includes trying to refine our understanding of how various species will be affected (Crozier et al., 2019; Hare et al., 2016), how characteristics of communities shape how they experience the species level effects (Rogers et al., 2019; Selden et al., 2020), and then coupling that exposure with socioeconomic factors to understand socioecological vulnerability (Colburn et al., 2016; Marshall et al., 2013; Payne et al., 2021).

Often the intent of climate vulnerability assessments is to identify and prioritize options for the reduction of susceptibility to the impacts of climate change (Füssel & Klein, 2006). Decreasing climate change vulnerability is accomplished by either reducing the exposure to the threat of climate change, decreasing the sensitivity to climate-driven changes, or enhancing the capacity to adapt, moderate, and respond to change. Here, we focus on adaptive capacity, defined by the IPCC as “the ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, or to respond to the consequences” (IPCC, 2014). Adaptive action and behaviors can take several different forms which will likely take the individual or system on different trajectories (Ojea et al., 2020). This includes adaptive versus transformative behaviors where adaptation is responding to change, typically in an incremental way, that maintains general system structure, while transformative action entails more fundamental reorganization (Park et al., 2012). People may also respond to changes with avoidant behaviors or in ways that actually increase their vulnerability, actions considered maladaptation (Barnett & O'Neill, 2010), or by coping, reactive and typically short-term behaviors that are usually insufficient for long-term reduction of vulnerability (Fedele et al., 2019). In an effort to avoid unintended consequences or maladaptation, understanding what drives people to act and then shapes the resulting behavior is important information for climate adaptation planning. As adaptive capacity requires not only the resources or conditions to adapt, but also the ability to activate those resources and a mindset or worldview that supports a decision to change (Mortreux & Barnett, 2017; Nelson et al., 2007), here we assess perceptions of adaptive capacity of fishers on the West Coast of the United States.

In fisheries around the United States, geography and diversification are often among the factors that influence outcomes or the need to take adaptive action (Cline et al., 2017; Moore et al., 2020; Young et al., 2019). Mobility, possessing the ability to fish over large areas or to shift fishing grounds, is also an indicator of adaptive capacity (Fisher et al., 2021; Jardine et al., 2020; Selden et al., 2020). The vulnerability of the local ecological system, often considered the exposure of a human community when assessing socioecological vulnerability (Marshall et al., 2013; Thiault et al., 2021), varies along the coast because of heterogeneity in the exposure of fisheries to the impacts of climate change, including ocean warming (Saba et al., 2016), marine heat waves (Cheung & Frölicher, 2020), and ocean acidification (Doney et al., 2020; Marshall et al., 2017). Marine species exhibit different levels of vulnerability to those changes (Crozier et al., 2019; Hare et al., 2016), which translates to variable community impacts depending on which species they are reliant on (Payne et al., 2021; Kohen et al., in review). The severity and nature of changes in their focal fisheries influences the need of fishers to respond and the type of action they take. A greater diversity of target species may dampen the need to act as it has been recognized as a strategy to buffer income fluctuations related to variability in fishing success (Cline et al., 2017; Holland et al., 2017; Kasperski & Holland, 2013). While a diversified fishing portfolio is considered a strong indicator of adaptive capacity, because fishers now tend to be less diversified than they historically have been (Stoll et al., 2016), and the cost of entering or switching fisheries can be prohibitive (Anderson et al., 2017), it may be a strategy that is difficult to enact for those currently in fewer fisheries.

How an individual estimates their adaptive capacity, while usually grounded in reality, can differ in important ways from their actual ability to adapt (Grothmann & Patt, 2005). Using the results of a survey focused broadly on perceptions of climate change vulnerability, we examine how views of adaptive capacity vary among groups that, given evidence from quantitative analyses, would either seem to have the capacity to adapt, or may be driven to take adaptive action. Specifically, we investigate if there are differences in perceived adaptive capacity among fishers with differing levels of mobility, with homeports in different regions along the coast, and with varying diversification of target species. We hypothesize that those with greater mobility and diversification will perceive themselves to have higher adaptive capacity. Given the differences in socioeconomic situations along the coast, we also hypothesize that there will be differences in perceived adaptive capacity among regions.

There are numerous approaches to defining and assessing adaptive capacity in SESs (Whitney et al., 2017); however common across these approaches is the recognition that a wide array of factors encourage or hinder adaptive action. While wealth and physical resources have historically been considered the primary components of adaptive capacity (Smit & Wandel, 2006), recently more focus has been placed on understanding how social and cognitive factors like risk perception and social networks may play a role in shaping adaptive behavior (Adger, 2003; Barnes et al., 2020; Clayton et al., 2015). Risk perception is a significant driver of motivation to undertake adaptive actions; specifically that people perceive the impacts of climate change to be more dangerous and urgent than other issues they may be facing (Grothmann & Patt, 2005). These perceptions also influence the views of individuals on their ability to adapt, and underestimation of that ability can prevent the taking of adaptive action (Grothmann & Patt, 2005).

3.3 Methods

To measure perceptions of adaptive capacity, we developed and deployed a survey comprised of a mix of Likert-scale, categorical, and open-ended questions. We invited a random sample of licensed commercial fishers from Washington, Oregon, and California to take the survey either via internet or over the phone. Fisher contact information is managed at the state level and California, Oregon and Washington differ in how they manage and share data; consequently, we targeted fishers from Oregon and Washington primarily by mail and those in California via outreach efforts with fishing organizations. The survey assessed general perceptions of climate vulnerability, observations of change, and a variety of issues that may affect wellbeing and fishing success. See Chapter 2 for details on survey design, content, and methodology. We used a series of Likert-scale questions, along with some demographic and fishing information, to populate the adaptive capacity framework proposed by Cinner and Barnes (2019). This framework has six domains - assets, flexibility, organization, learning, socio-cognitive, and agency - and includes both objective (i.e., physical resources) and subjective (i.e., risk perception) factors that may enhance to suppress adaptive actions. Survey responses were scored from 0 to 1 using the scales noted below, and their inclusion is supported by the documented contribution to adaptive capacity in other social ecological systems (Table 3-1). The scores were averaged within each domain and then summed across domains to get a value of adaptive capacity. We performed a Pearson correlation on the domain averages and final adaptive capacity scores, as well as a cluster analysis and principal component analysis (PCA) to investigate relationships among the domains and to explore patterns in how individuals perceived their relative strengths and weaknesses with respect to different contributors to adaptive capacity. Individuals were clustered using hierarchical clustering and the Ward method and the appropriate number of clusters was determined using the R package NbClust (Charrad et al., 2014). The PCA was also conducted using RStudio (RStudio Team, 2020). Following clustering, we did several chi-squared tests to see if characteristics related to fishery participation or location affected cluster membership.

Next, we examined how perceptions of adaptive capacity differed among regions and among metrics of mobility and diversity of target species. To evaluate whether adaptive capacity varied by geographic location, we divided the survey participants into five groups depending on the location of their homeport: 1. South of Point Reyes, California, 2. Point Reyes to Newport, Oregon, 3. Newport to Astoria, Oregon, 4. the outer coast of Washington and the Strait of Juan de Fuca to Port Angeles, and 4. East of Port Angeles into Puget Sound. These groupings map roughly onto major biogeographic regions of the California Current (Horn et al., 2006), while maintaining sufficient participants for statistical analyses in each group. We then conducted an Analysis of Variance (ANOVA) to test the null hypothesis that perceptions of adaptive capacity did not vary among geographic locations. Since some of the domain data failed to meet the normality assumption of ANOVA, a Kruskal-Wallis rank sum test, a non-parametric alternative that can be used when the assumptions of ANOVA are not met (Kruskal and Wallis, 1952), was used to examine differences among the average scores for each domain to explore if differences in specific domains drove variations in overall adaptive capacity among the regions. We used two metrics as a proxy for the mobility of a fisher: vessel size and the number of areas along the coast where individuals reported that they regularly fish (Jardine et al., 2020; Stoll et al., 2017). Welch's t-test was used to compare average perceived adaptive capacity between fishers working on vessels over and under 66 feet (Young et al., 2019), and ANOVA was performed to test variance in average adaptive capacity depending on the number of areas fished. We also considered variation in adaptive capacity by two additional measures related to livelihood diversity, fishery diversity and reliance on fisheries, both shown to be linked to the ability of a community to adapt (Finkbeiner 2015; Belhabib et al. 2016). For fishery diversity we counted the number of fisheries people reported participating in, and for reliance data we used NOAA's categorical ranking of community commercial fishing reliance from 2018, the most recent year for which data is available (NOAA, 2019). NOAA defines commercial fishing reliance as "the presence of commercial fishing in relation to the population size of a community through fishing activity."

Table 3-1. Survey questions and scoring methods (different scales but all 0 to 1) used to evaluate relative perceptions of adaptive capacity, organized by domain. The six domains of adaptive capacity are defined by Cinner & Barnes, 2019 in the following ways: "The assets that people can draw upon, the flexibility to change strategies, the ability to organize and act collectively, learning to recognize and respond to change, the socio-cognitive constructs that enable or constrain human behavior, and the agency to determine whether to change or not."

Domain	**Description**	**Survey question**	**scoring**	**References**
Assets	Wealth including income and other property assets	I make enough money to support my family.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	(Brooks et al., 2005; Joshua E. Cinner et al., 2015; Gupta et al., 2010; R. Nelson et al., 2010; Payne et al., 2021; Smit & Wandel, 2006; Whitney et al., 2017)
		Industry role	Vessel owner = 1, if not = 0	
	Access to credit and/or additional financial resources	I could easily get a loan or some other form of financial support.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
Flexibility	Diversity of livelihood(s)	Do you participate in fisheries in other parts of the country?	Yes = 1 No = 0	(Badjeck et al., 2010; Belhabib et al., 2016; Brooks et al., 2005; Joshua E. Cinner et al., 2009; Cline et al., 2017; Finkbeiner, 2015; Holland et al., 2017; Kasperski & Holland, 2013; McClenachan et al., 2020; Murciano et al., 2021; Payne et al., 2021; Quentin Grafton, 2010; Russell et al., 2018; Sumaila et al., 2011; Whitney et al., 2017)
		I could easily move into a new fishery.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	

		What percentage of your annual income comes from outside of fishing?	<50% = 1, 10 - 25 = .5, none = 0	
		I could easily get income not related to natural resource harvest, fishing or otherwise.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
		Number of different gear types used	1 = .25, 2 = .50, 3 = .75, 4 = 1	
Organization	Trust in institutions and management	I think the fisheries I participate in are managed effectively.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	(Adger, 2003; Gupta et al., 2010; Murciano et al., 2021; Runnebaum et al., 2019; Stern & Coleman, 2015)
		I think the fisheries I participate in are managed in an equitable way.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
		I think fisheries management can adapt and respond quickly to changing environmental conditions.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	

	Social networks	I feel a connection to my community.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
		I believe my community has a strong and viable future ahead.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
Learning	Access to information	I have access to the data and information I need for successful fishing.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	(Whitney et al., 2017; Williams et al., 2015)
	Knowledge sharing	I am passing down knowledge to the next generation.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	
Socio-cognitive constructs	Risk perception regarding climate impacts and personal harm	Average of responses to 1. I believe climate change is occurring, 2. Climate change will harm me personally, and 3. Climate change will harm future generations	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	(Clayton et al., 2015; Grothmann & Patt, 2005; Mortreux & Barnett, 2017)

	Climate change is an urgent concern	Where concerns about climate impacts on the marine environment rank compared to concerns about infrastructure, personal or fishing operational issues.	Environment is top concern = 1, environment is 2nd, or 3rd concern = .5, environment is lowest concern = 0	
Agency	Feelings of power and/or ability to influence outcomes	I feel constrained in my ability to adapt to changes because of regulations	Strongly disagree = 1, slightly disagree = .75, Neutral = .5, Slightly agree = .25, Strongly agree = 0	(Barnes et al., 2020; Joshua E. Cinner et al., 2015; Finkbeiner, 2015; McClenachan et al., 2020)
	Worldview	There is no point in preparing for climate change since we don't know exactly what will happen.	Strongly disagree = 1, slightly disagree = .75, Neutral = .5, Slightly agree = .25, Strongly agree = 0	
	Active in decision making	I have a voice in fisheries management.	Strongly agree = 1, slightly agree = .75, neutral = .5, slightly disagree = .25, strongly disagree = 0	

3.4 RESULTS

We received 162 responses to our survey from people who commercially fish in the waters off of Washington, Oregon, California, giving us a 13% response rate for fishers that were invited by mail to participate. The fishers that participated in the survey held a variety of views regarding basic aspects of adaptive capacity. People were not especially optimistic about their ability to enact some potential adaptive strategies as only a quarter (24%) thought they could easily move into a new fishery; the percentage of people who thought they could easily find another job in the natural resource sector was even lower (20%). However, they were slightly more confident (37%) that they could get income outside of natural resources harvest. When we examined the responses to the same questions according to the homeport region of each fisher, the group of fishers with ports south of Point Reyes, CA had the lowest rates of agreement of believing they can enter new fisheries or stay in natural resources, but had the highest rates of agreeing with being able to get other jobs (Figure 3-1). Fishers from the Washington coast had the next lowest rates of thinking they could easily move fisheries (15%) and also had the lowest rates overall of thinking they could get income outside of natural resources (26%).

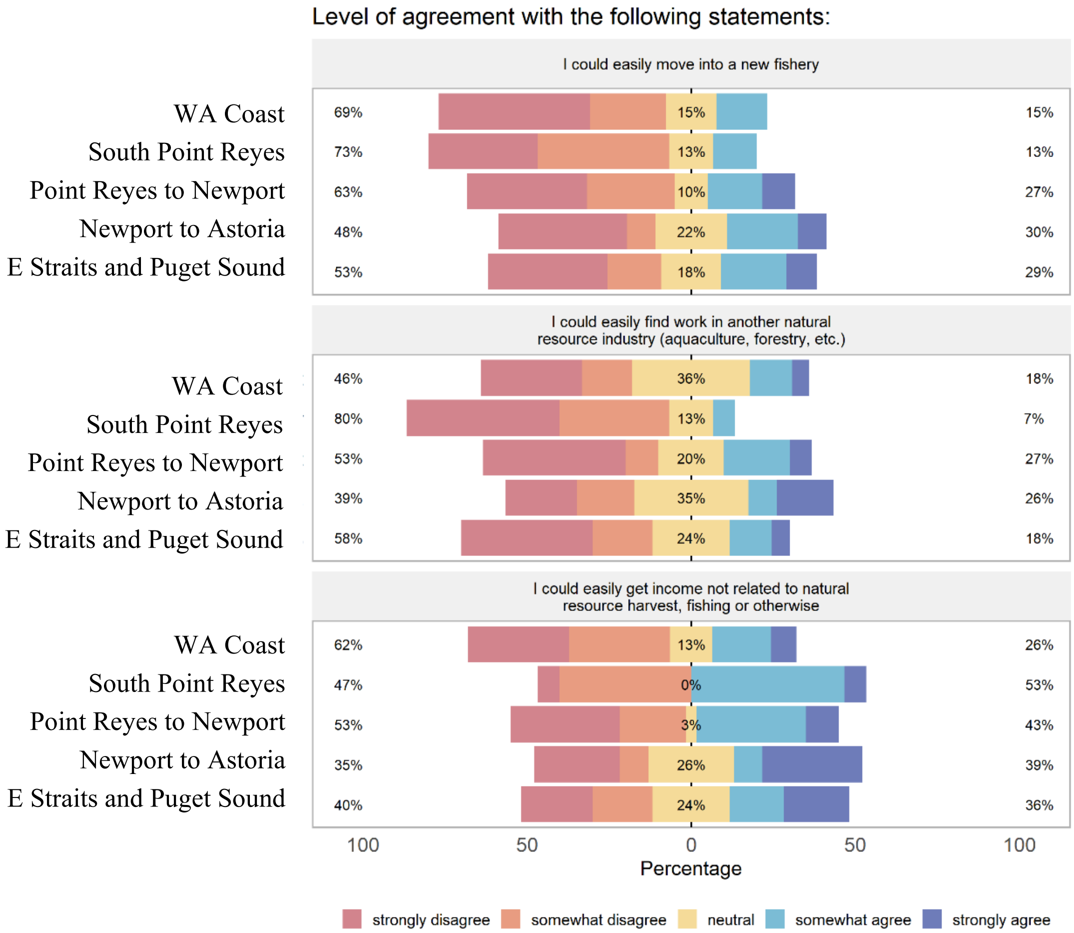


Figure 3-1. Responses to questions regarding specific adaptive and transformative actions organized by homeport region. See Table 3.2 for numbers of fishers in each region.

When we considered adaptive capacity using our index across the six domains of assets, flexibility, organization, learning, socio-cognitive, and agency, we got a more nuanced look at how perceptions of adaptive capacity are influenced by the more subjective components, like organization and agency, that are increasingly recognized as having an influence on adaptive behavior. The organization and agency domains had the strongest correlation with adaptive capacity (Figure 3-5, Appendix C), and each loaded onto the first dimension defined in the principal component analysis. PC1 was largely defined by the more subjective components and distinguished from PC2 by the contribution of perceptions of risk and power, while assets load strongly on PC2 (Table 3-2).

Fishers clustered into three groups, visualized in Figure 3-2 with the variables from the principal component analysis, with 53 people in group 1, 71 in group 2, and 38 in group 3. There was a difference in the adaptive capacity among the groups (F=172.1, df = 2, $p < 0.001$) and group 2 perceived themselves to have highest overall adaptive capacity, scoring high in all domains (Table 3-4, Appendix C). There was a difference between group scores across all domains and groups 1 and 3 had contrasting views; group 3 views themselves as having physical resources but has lower trust in management and belief that they have agency. Group 1 is characterized by fewer assets but a moderate sense of agency and level of risk perception that may motivate adaptation. There was no disproportionate amount of cluster membership related to region (chi.sq = 13.22, df = 8, p = 0.104), the total areas fished (chi.sq = 11.28, df = 10, p-value = 0.3362), or level of community

Table 3-2. Loading of each domain on the first two principal components.

Domain	PC1	PC2
Assets	0.027	0.622
Flexibility	0.031	0.145
Organization	0.444	0.325
Learning	0.400	0.477
Socio-cognitive	0.652	-0.505
Agency	0.464	-0.058

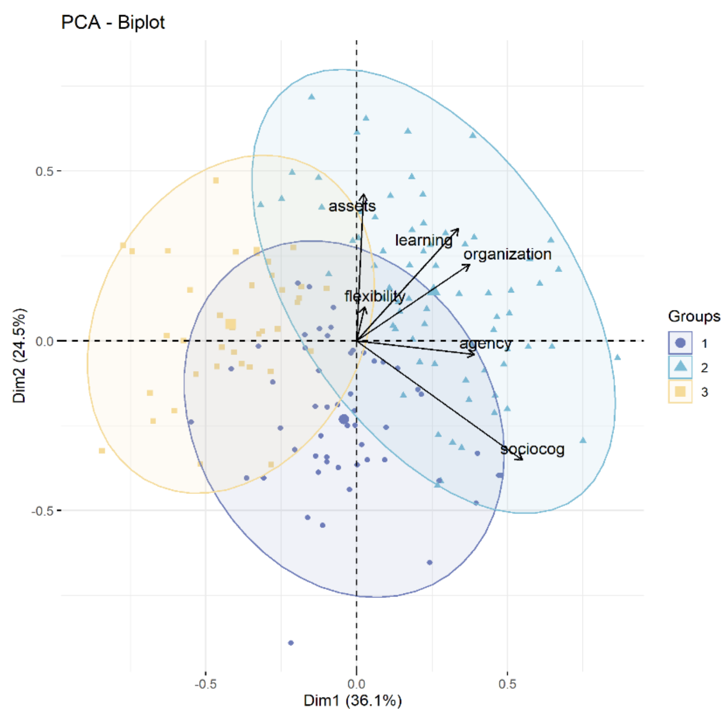


Figure 3-2. Biplot of results of the principal component analysis. The groups are the result of the cluster analysis of how individuals scored across the six domains.

reliance on fishing (chi.sq = 4.9981, df = 8, p-value = 0.7578), however there was a difference regarding the number of fisheries someone participates in and cluster membership (chi.sq = 17.073, df = 6, p-value = 0.009018).

3.4.1 *Geographic and livelihood diversity*

When we examined adaptive capacity across the regions, there was a difference in overall perceived level of adaptive capacity (ANOVA F = 3.002, df = 4, P = 0.02), and it was primarily driven by differences in the socio-cognitive (KW chi-sq = 14.25, df = 4, p = 0.007) and agency domains (KW chi-sq = 11.332, df = 4, p-value = 0.02) (Figure 3-3). Fishers with ports south of Point Reyes had the highest average perceived adaptive capacity, followed by the eastern Strait of Juan de Fuca and Puget Sound. Fishers with ports to the west of Port Angeles and on the outer coast of Washington had the lowest average perceived adaptive capacity (Table 3-3).

We used the number of fisheries that people participate in as an indicator of diversity within the sector, and the community reliance on fishing as an indicator of the potential for economic opportunity in the community outside of fishing. People reported participating in between 1 and 6 fisheries and given the small number of responses from people participating

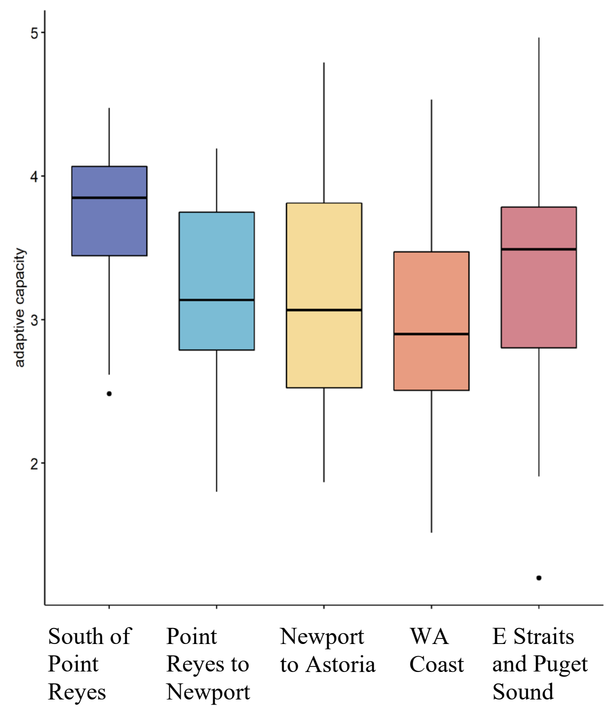


Figure 3-3. Boxplot showing the range of adaptive capacity of fishers with homeports in each region. The box represents the upper and lower quartiles, and the black line is the median value of adaptive capacity. See Table 3.2 for numbers of fishers in each region.

in greater than 4, we grouped everyone that participated in 4 or more together. We did not detect a difference in average perceived adaptive capacity based on the number of fisheries people participated in (F = 0.556, df = 3, p = 0.638). Likewise, we did not detect a difference in average perceived adaptive capacity across the categories of community reliance on commercial fishing (F = 1.231, df = 4, P = 0.30).

Table 3-3. Average scores across each domain of adaptive capacity. The range for each domain was 0 to 1, with a potential max adaptive capacity score of 6.

region	Assets	Flexibility	Organization	Learning	Socio-cog	Agency	AC	Count
E Straits and Puget Sound	0.63	0.43	0.48	0.70	0.63	0.49	3.35	55
Newport to Astoria	0.60	0.45	0.44	0.70	0.49	0.42	3.10	23
Point Reyes to Newport	0.58	0.35	0.49	0.67	0.61	0.48	3.18	30
South of Point Reyes	0.61	0.32	0.59	0.77	0.78	0.62	3.68	15
WA Coast	0.62	0.37	0.41	0.65	0.52	0.40	2.98	39

3.4.2 *Mobility*

Overall, only half of the respondents (49%) agreed that they were confident in their ability to travel further to fish. When we considered the same question on a region by region basis, Point Reyes to Newport and the Eastern Straits and Puget Sound had the highest percentages of agreement with that statement at 60% and 58% respectively (Figure 3-4), greater rates of agreement than expected given the average responses (chi.sq = 32.782, df = 16, p-value = 0.008). There were mixed results in how our metrics of mobility related to perceptions of adaptive capacity. People fishing from larger vessels (>66 ft) had higher perceived adaptive capacity than those fishing from smaller ones (< 66 ft) (p = 0.0176). Respondents said they regularly fished in 1 to 6 areas, out of a possible 7 options listed on the survey. Only two people said they fished in 5 or 6 areas, so for comparing across the number of regions fished we used the categories, 1, 2, 3, and 4+. We did not detect a difference in perceived adaptive capacity among those who fish multiple areas of the coast compared to those with a more limited range (F = 1.301, df = 3, P = 0.276).

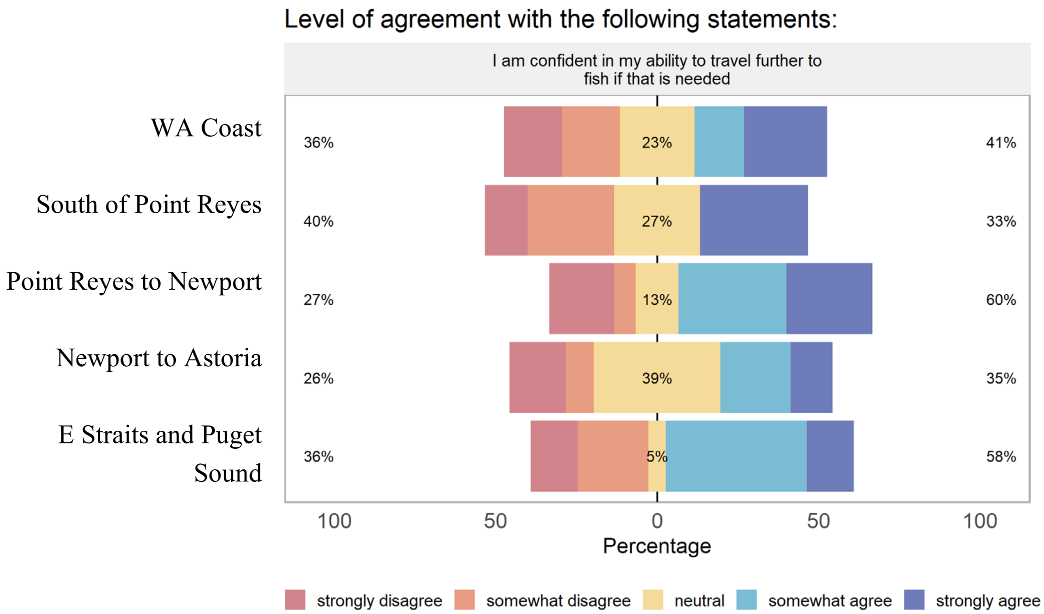


Figure 3-4. Responses to Likert-scale question about adapting through traveling longer distances to fish. See Table 4.2 for numbers of fishers in each region.

3.5 Discussion

Climate impacts on fisheries are already apparent in the California Current and are likely to exacerbate underlying stressors in both the ecological and human communities. Even with a drastic reduction in emissions, the impacts of climate change will continue to be felt in coastal communities for a long time, necessitating adaptation even under ambitious mitigation agreements (Gattuso et al., 2015). These results show that fishers on the West Coast hold a variety of perceptions about their ability to respond to current and future impacts of climate change. Broadly, there were medium to low levels of confidence in their ability to take several actions that have been shown to support adaptive capacity, including flexibility and diversification within and outside of fisheries. The difficulty in gaining entrance to a new fisheries because of regulatory and cost barriers is well documented (Holland et al., 2017; Kasperski & Holland, 2013); and reflected here in the lack of optimism regarding that option. Across the regions, fishers were more confident in diversifying with income from outside of fishing and natural resources all together, an adaptation that could lead to transformative action depending on the degree to which they remain engaged in both sectors. However, livelihood diversification can have negative outcomes for fisher wellbeing (Moore et al., 2020), and community reliance on fishing may dampen the effectiveness of income diversification as the economic impacts of fishery losses are felt strongly throughout communities with economies strongly tied to fisheries (Ritzman et al., 2018). There was greater confidence in adapting through mobility, though that confidence was distributed unequally between regions and those working on vessels that may support larger ranges. In addition to having lesser mobility, in some fisheries smaller vessels face extra burdens to adapting as the costs of things like observers and quota is a higher proportion of their revenue than compared to larger vessels (Russell et al., 2018).

When we examined perceptions of adaptive capacity across the six domains three patterns emerged. Some fishers scored high across all domains, while one group of individuals felt they were lacking in physical assets, and the other possessed a lower a sense of agency, trust in management, and different risk perceptions. The cluster that scored high on resources but low on agency and faith in management may be among those whose adaptation is limited more by perceptions than lack of resources (Grothmann & Patt, 2005). While the sample size in this survey limits our ability to draw too broad of a conclusion, the fact that those clusters exhibited limited patterns of membership regarding characteristics that objectively influence adaptive capacity like reliance and diversification seems to indicate that individual worldview and the more subjective side of adaptive capacity is at least partly responsible for some of the differences between clusters.

The lower level of organizational faith exhibited by cluster 2 highlights the importance of trust in institutions and the ability to engage with them as it relates to a sense of adaptive capacity. Trust in institutions affects adaptive capacity (Gupta et al., 2010; Stern & Coleman, 2015), as does faith in science (Runnebaum et al., 2019), and here agency and organization were the domains that were the most strongly correlated with adaptive capacity. However, only 22% of respondents agreed that fisheries management can adapt and respond quickly to changing conditions and 53% feel constrained in their ability to adapt to changes because of regulations. A major challenge for fisheries management on the West Coast will be to find ways to earn trust and support flexibility while also meeting the sustainability goals of ecosystem-based management.

Supporting climate adaptation will not be a one size fits all endeavor and examining how physical resources and socio-cognitive factors affect adaptive capacity can help provide a better understanding of how management interventions can address adaptation limitations and the needs of individuals and communities. While we cannot link the perceived levels of adaptive capacity in this study to specific adaptive behaviors without additional work, evidence here does support the assertion that the level of perceived adaptive capacity is related to more than just the possession of physical resources and wealth. Recognition that when it comes to adaptive capacity, communities and individuals vary in their physical, social, and cognitive needs is crucial if adaption is to be accomplished in an equitable way.

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3.7 Appendix C

Additional figures.

Table 3-4. Average scores in each domain and for adaptive capacity for the clusters as determined by the cluster analysis.

cluster	assets	flexibility	organization	learning	socio-cog	agency	ac	n
1	0.461	0.397	0.366	0.578	0.697	0.436	2.934	53
2	0.724	0.425	0.638	0.833	0.681	0.599	3.890	71
3	0.616	0.317	0.299	0.572	0.282	0.274	2.360	38
KW	Chi.sq = 35.414 p < 0.001	Chi.sq = 10.174 p = 0.006	Chi.sq = 71.472 p < 0.001	Chi.sq = 48.377 p < 0.001	Chi.sq = 58.896 p < 0.001	Chi.sq = 59.733 p < 0.001	F=172.1, p < 0.001 (ANOVA)	

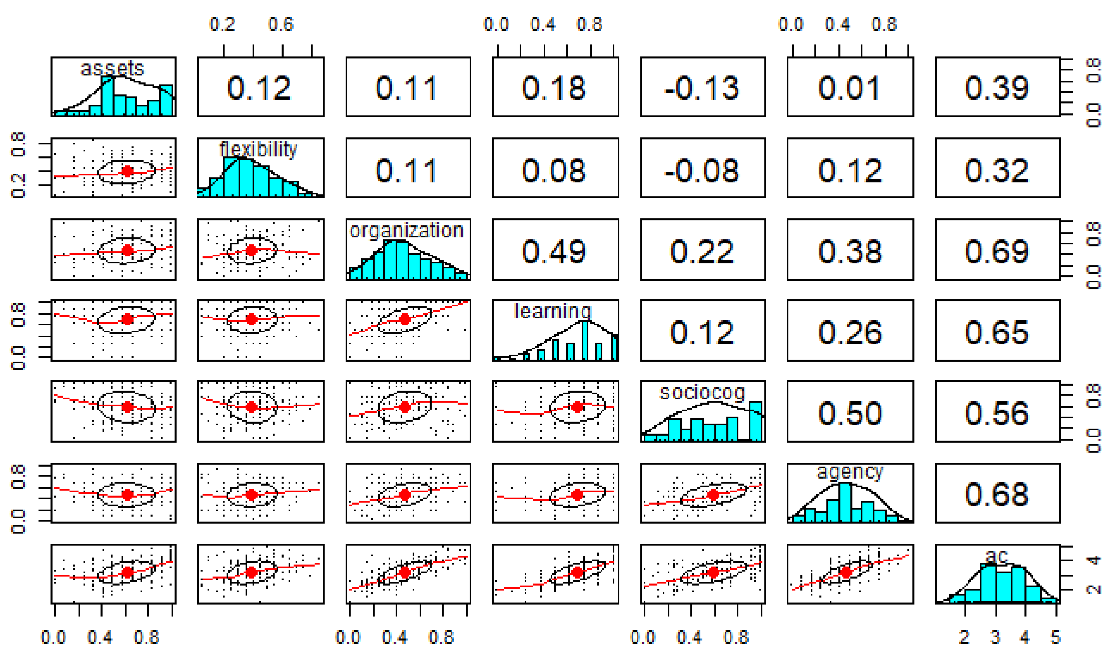

Figure 3-5. Three representations of the distribution and correlation of the domains and adaptive capacity scores. The histograms on the diagonal show the distribution of averages scores in each domain. Below and to the left of the histograms are scatter plots of the scores from each domain with correlation ellipses. Above and to the right of the histograms is the Pearson correlation. This figure was created using the R package psych.

Chapter 4. CLIMATE IMPACTS ON THE TRADITIONAL SEAFOOD SPECIES AND FOOD SECURITY OF THE MAKAH TRIBE

4.1 ABSTRACT

Since time immemorial, the Makah Tribe has lived in the Cape Flattery region of northwest Olympic Peninsula, depending on the ocean for their economy, food, and culture. This relationship with the ocean, foundational to Makah identity, is at risk from the unprecedented threats that climate change poses to ocean and coastal ecosystems. Among the effects of climate change are shifts in the distribution and abundance of marine species, threatening to disrupt the harvest of traditional seafoods and the food security of the Makah. These changes will have consequences for the health and wellbeing of Tribal members. Traditional seafoods are crucial for culture and traditions; they are also valuable sources of protein and micronutrients, providing both spiritual and physical health benefits. In collaboration with the Tribe, we conducted a household survey to investigate these issues with the overarching objectives of understanding current subsistence seafood use of Tribal members, as well as their observations of environmental change, and definitions of food security. From those definitions, we conceptualized a framework for Makah Food Security with four components: health, continuity, accessibility, and self-determination. We considered some of the climate risks to that system, specifically portions of the health and continuity components, assessing how the nutritional benefits of traditional seafoods and the availability of those species may be affected by the impacts of climate change on the ocean.

4.2 INTRODUCTION

Climate change is having profound effects on marine ecosystems, threatening communities that are part of coastal social-ecological systems (SESs) with sea level rise and increasingly frequent and severe storms (IPCC, 2019). Fisheries are being impacted by ocean warming (Cheung & Frölicher, 2020; Free et al., 2019) and acidification (Doney et al., 2020) affecting food security (Golden et al., 2021; Marushka et al., 2019), and livelihoods in coastal communities (Barange et al., 2014; Selig et al., 2018). The cultures and economies of many Indigenous communities are place-based and environmentally connected, making them highly susceptible to the impacts of climate change (Wildcat, 2013). Indeed, Indigenous communities face disproportionate risks to their cultures (Mathews & Turner, 2017; Turner & Clifton, 2009), food security (Ford, 2009; Marushka et al., 2019; Satterfield et al., 2017), and health (Durkalec et al., 2015; Ford, 2012; Gadamus, 2013). Even the land on which communities are currently located is at risk (Fang et al., 2018; Simms et al., 2021), as climate change exacerbates other social vulnerabilities rooted in the legacies and contemporary realities of colonialism and capitalism (Whyte, 2015).

Studies of climate vulnerability are increasingly focusing on understanding the impacts on human communities, including Indigenous peoples, and their potential options for climate adaptation. While there are many examples of Tribally led climate vulnerability assessments (see Figure 15.1 in Jantarasami et al., 2018), climate research (and research more broadly) on Tribal lands and waters is frequently conducted with insufficient community input (Maldonado et al., 2016), leading to work that can be at best, misrepresentative of community priorities and values (Donatuto et al., 2020), and at worst an extension of colonialism that disregards or undervalues traditional knowledge (Veland et al., 2013). Effective vulnerability assessment requires a transdisciplinary approach that also values different ways of knowing (Aswani et al., 2015), and omission of community concerns and risk perceptions can influence the equity and effectiveness of adaption plans (Ensor et al., 2018). Therefore, it is important that communities define what is at risk and that Tribal values are centered while assessing climate impacts on the environment, health and wellbeing, culture, and food security (ICC, 2015; Donatuto et al., 2014, 2016; Martin et al., 2020; STACCWG, 2021; Turner & Clifton, 2009). Here, we discuss the results of a co-produced effort informed by those values to conceptualize the food security of the Makah Tribe of Neah Bay, Washington, and consider how food security may be affected by climate change impacts on traditional seafood species. The original idea for this work was generated in discussions regarding oil spill preparedness and response for the waters around Neah Bay, and a desire to update survey data from 1998. Following those initial discussions, Makah Tribal members and researchers at the University of Washington collaborated to develop this project and broadened the scope to have three objectives: 1. Document what types and amounts of fish and shellfish are currently being consumed by Makah Tribal members and evaluate if there are any major differences from the 1998 survey, 2. Understand how Tribal members define food security, and 3. Consider risks to food security due to climate impacts on traditional seafood species.

4.2.1 *Makah Tribe*

Since time immemorial, the Makah Tribe has lived on the northwest section of the Olympic Peninsula (Figure 4-1). The traditional name of Makah is *Qʷidiččaʔa·tx̌* meaning "people of the cape" and the name Makah came from neighboring S'Klallam peoples and means "people generous with food" in the Salish language (Reid, 2015). Makah are the southernmost Nuu-chah-nulth peoples and the only Wakashan speaking group in the United States. A connection to the ocean is part of the Makah identity. Although the current Usual and Accustomed Area (U&A) is adjudicated to roughly 1,550 nm^2 in the Strait of Juan de Fuca and off the coast of Washington, their traditional ocean use extended north into what is now Canadian waters, south to the Columbia River, and into Puget Sound. Prior to Western contact, Makah had a thriving maritime-based economy (Reid, 2015) which continues to this day through treaty fisheries. When they signed the Treaty of Neah Bay in 1855, the Makah prioritized maintenance of their fishing and whaling rights over land and are notably the only Tribe in the United States to have the right to whale explicitly guaranteed in their treaty.

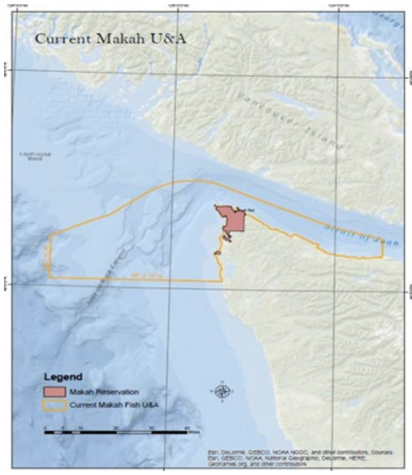

Figure 4-1. Usual and Accustomed Area and current reservation of the Makah Tribe located at Neah Bay, Washington, the northwestern most point of the contiguous United States.

Meat, blubber, and oil from whales, as well as meat from other marine mammals, were historically among the primary traditional food sources for Makah. Other traditional seafoods included halibut, salmon, other fish, and various shellfish including mussels, crabs, clams, cockles, limpets, sea slugs, and snails (Swan, 1870). Elk, deer, and bear were among the terrestrial species hunted for food (Renker, 2012). Traditional Makah diet patterns were interrupted when they were dispossessed of their land, and their primarily fish and marine mammal-based diet was gradually replaced by a western diet centered around beef, cereals, and dairy products (Renker, 2012). Despite the interruption of traditional diet patterns, subsistence practices and consumption of traditional foods is still a common occurrence in Neah Bay. Between 1997 and 1999, 99% of surveyed households participated in subsistence activities over the course of a year with over 80 species identified as being used in the subsistence practices

(Sepez, 2001). There has been strong continuity in the use of traditional species. Over half (56%) of species identified in the archaeological excavations of Ozette middens, dated to roughly 1500 AD, were used by community members in 1998. This includes 87% of fish taxa and 84% of shellfish taxa (Sepez, 2008). Halibut and salmon were the most commonly consumed fish, eaten by 93% and 88% of households respectively, while crabs and clams were also widely consumed and were utilized by 80% and 74% of households (Sepez, 2001). Sepez calculated that the average annual per capita subsistence meat consumption (including fish, shellfish, land mammals, marine mammals, and birds) was about 162 lbs., or 59% of total annual household meat consumption, with some households eating very little, some getting nearly all their meat from subsistence, and most somewhere in the middle. Fish and shellfish constituted 72% of the subsistence meat consumption, a much higher rate of fish consumption than the average American at the time (NMFS, 2001) or today (Love et al., 2020).

4.2.2 *Indigenous food systems*

In Indigenous communities, the relationship with food is a prominent cultural dimension of the environment and is tied to physical, emotional, psychological, and spiritual health (Lynn et al., 2013). Many of the health and inequality issues faced by Indigenous peoples today stem from disruptions to their traditional food systems from colonization (Gracey & King, 2009). This forced dispossession of homelands, cultures, and languages interrupted the transfer of knowledge connected to the harvest, preparation, and consumption of traditional foods (Grey & Patel, 2015). Policies that led to the loss of ancestral land and limited the right to hunt, fish, and gather traditional foods are a significant contributor to historical trauma and contemporary food issues (Kuhnlein & Receveur, 1996; Compher, 2006; Edwards & Patchell, 2009). As a result of those policies, as well as urbanization and environmental contamination, many Indigenous peoples can no longer access their traditional foods (Coté, 2016) and in the U.S., modern politics and the consequences of the reservation system continue to affect access (Sepez, 2001). This historical undermining of food security is exacerbated by the effects of climate change on the plants and animals that are important to Indigenous communities (Lynn et al., 2013).

The Food and Agriculture Organization of the United Nations (FAO) defines food security as “when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for a healthy and active life” (1996). Food sovereignty is related to but distinct from food security and is the right to define, control, and access healthy food that is also socially and culturally appropriate and relevant (Declaration of Nyéléni, 2007). Indigenous food sovereignty includes the right to define, control, and access traditional foods and stresses that food practices are a necessary component of Indigenous identity, that harvesting traditional foods is a cultural practice (Coulthard, 2010), and recognizes the role that colonialism has played in disrupting Indigenous food systems (Grey & Patel, 2015). There is tension about when and how to use the terms food security or sovereignty and ongoing debate about the potentially oppositional nature of the discourses (Clapp, 2014; Jarosz, 2014). The Inuit Circumpolar Council elegantly reframed it for themselves, declaring that food sovereignty is a precondition of food security (ICC Alaska, 2015). For both Indigenous and non-Indigenous groups, food security and sovereignty can be considered central to the resilience of social-ecological systems (Pinstrup-Anderson, 2009).

For health and cultural reasons, as well as desire to decolonize and assert self-determination, many Indigenous communities are working to take more control over their food systems and move towards traditional diets (Mailer & Hale, 2015; Satterfield et al., 2017). The health benefits of traditional diets, including the reduction of diabetes, heart disease, and increase in micronutrient intake, have been shown in multiple studies of Indigenous communities (Kuhnlein & Receveur 1996; Receveur et al., 1997; Mailer & Hale, 2015), and it is increasingly accepted that the traditional diets of Indigenous peoples can protect against chronic disease (Damman, 2008). Traditional foods contribute such large amounts of essential nutrients that individuals have significantly higher micronutrient intakes on days when traditional foods are consumed, even if they are only eaten in small amounts (Kuhnlein & Receveur 1996; Receveur et al., 1997; Kuhnlein & Receveur 2007). Seafood, a substantial component of Makah traditional foods, is rich in protein, contains several essential amino acids and long-chain, poly-unsaturated fatty acids (LC-PUFAs), and is also an important source of micronutrients including vitamins A, B, and minerals including calcium, iron, zinc, and iodine (Béné et al., 2015). Often policy and research on the importance of fish to food security stress its importance as a source of protein, but its value is more significant as a source of micronutrients and lipids (Allison, 2011). In addition to physical health benefits, the intergenerational educational opportunities and ability to act in a self-determined manner associated with traditional harvesting practices contribute to tribal wellbeing (Burnette et al., 2018; Donatuto et al., 2014; Ranco et al., 2011). Many conventional health assessments fail to capture those less visible benefits (Turner et al., 2008), and public health conceptualizations of food security have typically been developed in non-Indigenous contexts that do not consider benefits related to the harvesting, sharing, and consumption of traditional foods (Ericksen, 2008).

The traditional marine resources of the Makah Tribe that contribute to those aspects of physical and cultural wellbeing are at risk from the impacts of climate change. In general, the food security of coastal Indigenous peoples is particularly vulnerable to climate-driven declines in seafood as their fish consumption greatly exceeds national averages (Cisneros-Montemayor et al., 2016), and because many groups already have diminished access to traditional resources (Coté, 2016). With traditional and current homelands at the northwest point of the Olympic Peninsula in Washington State, the traditional seafoods of Makah are already experiencing marine heatwaves (Cheung & Frölicher, 2020), effects of ocean acidification (Marshall et al., 2017), and may have to contend with disruptions to physical processes (Bakun et al., 2015) occurring in the California Current. Here, drawing on community definitions of the benefits of traditional seafoods, we conceptualize and explore how climate change may affect select components of Makah Food Security.

4.3 METHODS

4.3.1 *Household Survey*

We used a mixed methods approach guided by best practices for co-production with Indigenous communities (Chief et al., 2016; Cozetto et al., 2021) to gather thoughts on the importance of traditional seafood, its significance for food security, and to understand current patterns of use. We conducted household surveys that began with a modified food frequency questionnaire (FFQ) (Appendix D). The FFQ portion asked people to estimate how many times a season their household ate 47 species of fish, shellfish, and other invertebrates, and included space to add species that were not otherwise listed. The FFQ asked for estimation of seasonal household fish consumption and harvest over the course of the previous year. Asking people to estimate consumption over that length of time can lead to recall bias, but it does accommodate for the seasonal variation of those activities (EPA, 2016). We also asked people to estimate the average portion size of foods they had eaten over the past year using to-scale pictures showing the size of what several ounces of a few species of fish look like as a reference. Marine mammals, while an important food source, were not included due to ongoing litigation about the exercise of Makah treaty whaling rights at the time of this work. The second part of the survey consisted of a mix of Likert-scale and structured, open-ended questions and was conducted like an interview (Huntington, 1998). The questions in this section asked about perceptions of the health of the environment and foods, changes in the availability of specific species, the health benefits of seafood, and community food security. The survey, including the list of species in the FFQ, was designed in collaboration with the Makah Cultural Research Center (MCRC) as a follow-up to a survey conducted in 1998 (Sepez, 2001), and to provide data in support of ongoing climate adaption and other environmental policy efforts in addition to the results presented here. It was also guided by previous work done on Tribal seafood consumption (CRITFC, 1994; Suquamish Tribe, 2000; Donatuto 2008, 2011) and by an EPA fish consumption survey guidance document (2016).

The survey and methods were reviewed by MCRC and the Makah Ocean Policy Workgroup for clarity and cultural appropriateness, and the methods were approved by University of Washington Institutional Review Board. Pilot surveys were conducted prior to the wider administration of the survey to community members. MCRC provided an initial list of key informants and referral sampling was used to identify additional participants, all of whom are tribal members living in Neah Bay. Some opportunistic sampling also occurred. Surveys were conducted by a Makah Tribal member with experience conducting community surveys and by the lead author. Prior to each survey informed consent was received from the participants and we had a discussion regarding the planned outcomes of the work.

4.3.2 *Analysis*

4.3.2.1 Nutrient density and contribution

Analysis of quantitative portions of the survey was conducted in R Studio (RStudio Team, 2020). Following the approach of Schuster et al., (2011), and so that data was comparable to Sepez (2001), we used the FFQ data to calculate the average annual consumption of each species. To get those values we focused only on households that ate the food in question and multiplied the total days of consumption by the average, per person portion size of that household. That data, the annual, per capita consumption of each household, was then averaged. The nutrient content information is for raw fish or shellfish and primarily came from the USDA FoodData Central Database (USDA, 2019), and was supplemented by information from the Canadian Nutrient File as needed to get complete profiles (Health Canada, 2015). We used Dietary Reference Intakes (DRI) (NAS, 2019) to assess the potential of certain foods in the study to meet daily nutritional requirements. Specifically, we compared nutrient composition in seafood species to the Recommended Dietary Allowance (RDA), the average daily level of intake sufficient to meet nutrient requirements of most (97-98%) of healthy people (NIH). There is not currently an established RDA or adequate intake (AI) for eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), long-chain omega-3 polyunsaturated fatty acids found in seafood, but the current guidelines suggest between 250-500 mg of combined EPA and DHA a day supports cardiac health in healthy individuals (USDA, 2010; Lavie et al., 2009). Seafood is a valuable source of the nutrients we chose to include in the analysis: protein, vitamins A, B12, D, zinc, selenium, iron, calcium, EPA, and DHA. This list has significant, though not exact, overlap with several recent studies considering food security issues related to the nutritional content of seafood (Bernhardt & O'Connor, 2021; Hicks et al., 2019; Marushka et al., 2019). We modified the approach of Hallström et al. (2019) to evaluate nutritional density of seafood species:

$$\sum_{i=1}^{x} \frac{nutrient\ i}{RDA\ i} \tag{4.1}$$

Here x is the number of nutrients included and nutrient *i* is the value of the nutrient in question per 100 g of raw seafood and RDA is the recommended dietary allowance of that same nutrient (except for EPA and DHA as noted above). RDA values vary for men and women and by age; we used the recommendations for men and women from 19-50 and then averaged the density results from each gender.

To examine if nutrient contribution from seafood has changed in comparison with 1998, we calculated the average daily per capita consumption of select species and the percent of the RDA met by that level of consumption for the nutritional components mentioned above. We did the same thing with the data from 1998, however since that was reported as an annual average there is one value for each species instead of a range of RDA met.

4.3.2.2 Climate risk

Values of climate exposure, sensitivity, and risk come from a climate vulnerability assessment of West Coast species conducted by Kohen et al. (in review). Exposure is the degree to which a particular species is subject to the impacts of climate change and was assessed across changes in their range to four conditions: temperature, pH, chlorophyll, and oxygen. Sensitivity, or how likely a species is to be affected by those changes, was assessed by considering the breadth of those conditions aquatic species currently experience in their range. Risk is calculated as the Euclidean distance from the origin in a space defined by exposure and sensitivity (Samhouri & Levin, 2012):

$$r = \sqrt{e^2 + s^2} \quad (4.2)$$

See Kohen et al. for a more detailed explanation of these methods.

4.3.2.3 Food security framework

Responses to open-ended questions were transcribed and coded using Atlas T.I. Initially, questions about definitions of food security, health benefits of seafood, and final thoughts were inductively coded and analyzed using a grounded theory approach (Corbin & Strauss, 1990) to develop an initial conceptual framework for Makah Food Security. Following discussions with collaborators and the Makah Food Security working group, the framework was refined, and then all open-ended responses were deductively coded using that framework.

4.3.2.4 Comparison of historical and current data

There are several sources of data about Makah traditional food systems. A survey conducted by Sepez in 1998 provides contemporary data, while relative abundance of historically used resources is available from results of excavations of middens at Ozette, a late-prehistoric Makah village (Huelsbeck, 1994; Wesson 1994). Information is also available from the work of James Swan (1870), a schoolteacher on the reservation. Using a paired sign test, we examined the contemporary datasets for major changes, comparing this work to data from Sepez to examine trends in the percentage of households consuming different species, and the average, annual, per capita consumption of priority species. Because of how data is reported in the Sepez survey, some groups of species (i.e., salmon and clams) are consolidated in this comparison.

Lastly, we considered how all of these factors combined to explore how the continuity and physical health components of Makah Food Security may be at risk from climate change. For foods used by at least 10% of surveyed households, we performed a cluster analysis of the percent rank of the average climate risk, the household utilization, and nutrient density of the species. Unfortunately, there are a few species for which there is incomplete or no nutrient data, including some of importance like chitons and gooseneck barnacles, locally referred to as slippers and boots.

4.3 Results

4.3.3 *Survey results*

We interviewed 43 households between the early spring of 2019 and early winter of 2020; 69% of individuals surveyed were women and 31% were men. The households represented a total of 153 people, or roughly 10% of the population of Neah Bay, and were nearly evenly balanced between men and women (Table 4-1). All surveys were conducted prior to the onset of the COVID-19 pandemic, as safety concerns resulted in the cessation of the survey. Every household represented in the survey consumed subsistence fish and shellfish during the year prior to survey administration, and just over half of households (51%) said there was someone in the household that leads fishing or gathering trips. The other half of households were given fish and/or shellfish from friends or family members or gathered their own with guidance from someone from outside the household. Household consumption ranged between 2 and 34 different types of fish and shellfish with 50% eating between 9 and 21 species.

Table 4-1. Summary of survey participants.

Total households	**43**
Total people represented	153
Average age	28.9
Women	70 (45.8%)
Men	83 (54.2%)
People leading fishing or gathering trips	28 (18.3 %)
People assisting with fishing or gathering	76 (49.7 %)
Households with someone that leads	22 (51.2%)

Halibut was the most widely consumed fish, eaten by every household, followed closely by salmon, crab, and clams (Figure 4-2). The percentage of households getting many the of foods remained relatively consistent since the 1998 survey, and though there were some exceptions with notable increases in a few species including tuna and black cod, overall there was no statistically significant difference (sign test, p = 0.064). However, the volume of seafood that people have been able to get generally declined (sign test p = 0.021). The mean per capita consumption of halibut decreased between 1998 and 2019 from 28.9 lbs. to 9.5 lbs. It is unlikely that this is reflective of a particular poor year of halibut fishing as 28 households said that compared to other years, this was close to average consumption; 6 said they had less than usual in 2018-2019. Even black cod and lingcod, which more households reporting getting, showed decreases in per capita annual average from 5.9 lbs. to 2.6 lbs. and 6.9 to 2.5 lbs. respectively. Crabs are one of the few foods to not exhibit that trend, at 2.2 and 2.8 lbs./person in 2019 and 1998.

This decrease in the amount of seafood people have been able to get was underscored in the responses to questions about general changes in seafood consumption. Just over half (56%) said their seafood consumption has changed over the past twenty years, and 51% said they felt they were able to get less now than they used to. Just under half (46%) said that they felt that in general they did not have as much seafood as they would like, and 81% said they would eat more seafood if they could. Of those that did not respond yes to that statement, roughly half said they were able to get as much as they wanted, and the other half declined to answer the question.

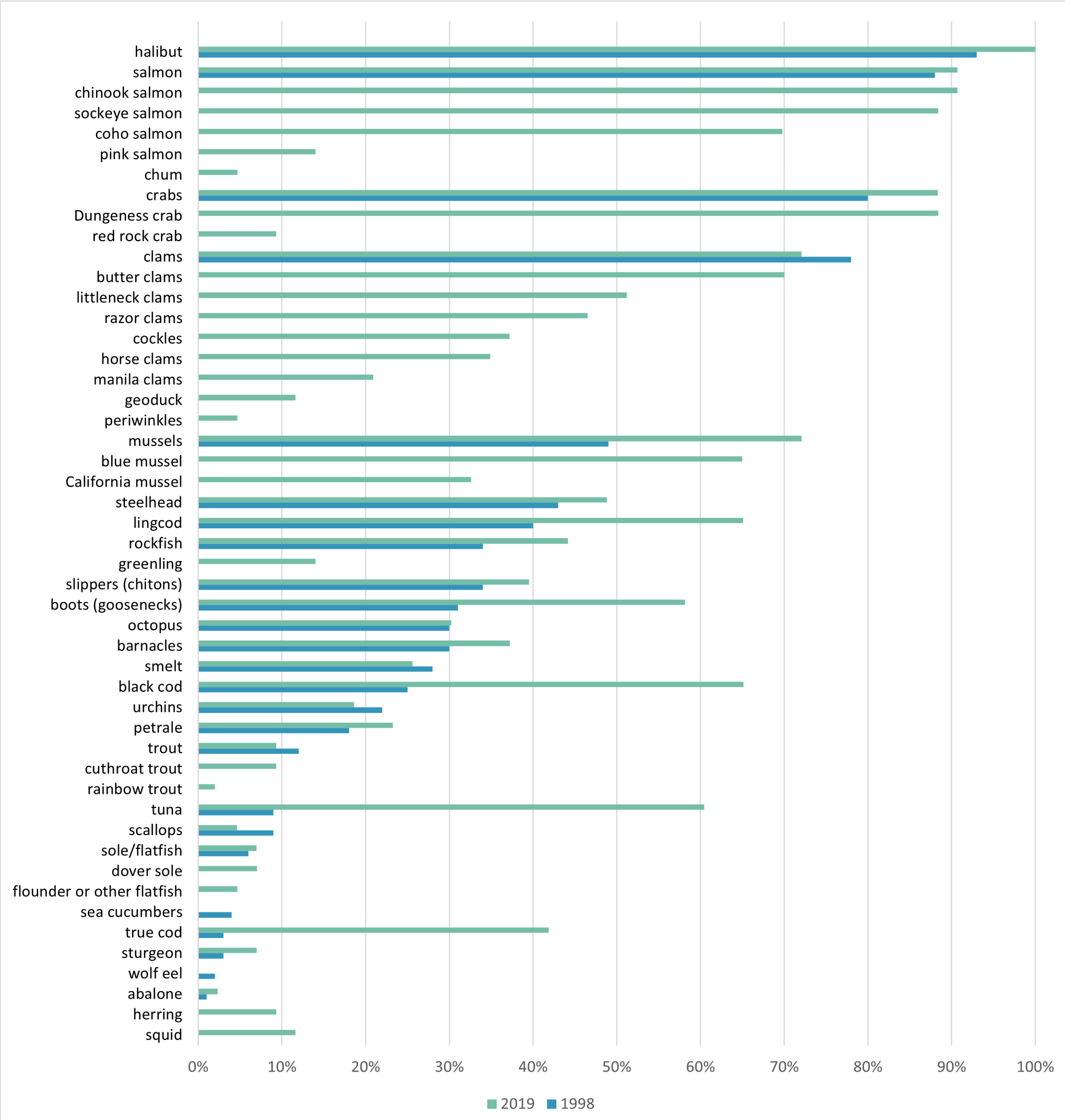

Figure 4-2. Percentage of households that reported eating different types of fish and shellfish in the 2019 and 1998 (Sepez) surveys. In this graph the columns for salmon, crab, and clams represent the total number of households that consumed any of a number of species in those categories while the following columns are the individual species included within that grouping. Though individual species of salmon, clams, mussels, and trout were asked about in the 1998 survey, data on household consumption was only presented for consolidated groups.

Associated with a decline in the availability of fish and shellfish has been a decrease in the potential micronurtient contribution of those foods. A snapshot of the average annual daily nutrient contribution of a few important species shows that while high volume consumers are still getting micronutrient contributions above the average from 1998, in general these species are contributing less to the RDA of several vitamins, micronutrients, fatty acids, and protein (Figure 4-3).

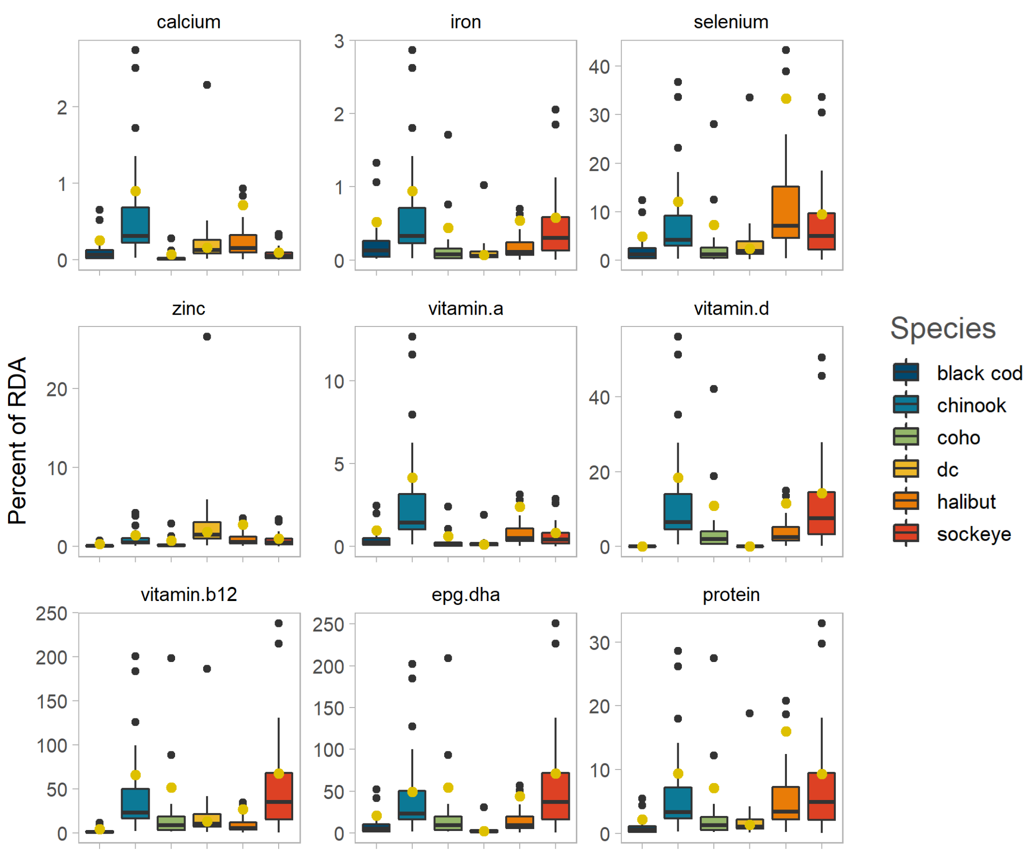

Figure 4-3. The average percent of RDA met by the daily average intake of six important species. The boxplots indicate the upper and lower quartiles and medians of the RDA contributions of each species. The yellow dots are the percent of RDA met by the per capita daily average of those same species from the 1998 survey (Sepez, 2001). DC is Dungeness crab.

4.3.4 *Conceptualization of Makah Food Security*

There were four emergent themes from the responses regarding food security and the health benefits of seafood: health, continuity, accessibility, and self-determination (Table 4-2). Based upon these responses, in order for the Makah Tribe be food secure, all Makah people must be able to access abundant and healthy traditional foods that fulfill their spiritual, cultural, and nutritional needs, and people should be able to exercise their preferences with regards to food. The environment must be able to support healthy populations of uncontaminated seafood for today and for future generations. Food security includes a connection to the generations that have come before, providing for those yet to come through caring for the lands and waters, and the transfer of knowledge related to the harvest, preparation, and sharing of traditional foods. It is, as one community member succinctly summed up, "Life."

Table 4-2. Description of the components of Makah Food Security.

Component	Definition	Supporting quotes
Health	Food provides the physical and spiritual health benefits desired by people. To convey these benefits, the foods themselves must be healthy and available in the amounts needed to meet nutritional and spiritual needs.	"It provides a connection to food, local/traditional sources. It feeds the spirit in a way that food bought from the store does not." "Our bodies are healthier because of this ancestral eating. There are no preservatives, no deep frying, all good, clean, healthy food." "Healthy body, healthy soul." "It's great for our bodies - I believe our bodies are adapted to seafood and see benefits from a seafood diet - less tired, more energy, full longer, all seafood is nutritious!"
Continuity	The connection that traditional foods provide to the past through eating, teaching, and sharing with community and family is supported in the present and the future through stewardship of	"It means preserving the harvestable foods so that they will be available for years to come." "Protect our ocean so she continues to feed us."

	resources, the environment, and traditional knowledge.	"Connects me with my tribal members, past and present." "Being able to have continued access to cultural and natural resources, efforts being put towards sustainability and security of those resources."
Self-determination	People can get the types of food desired and needed in order to fulfill culture practices and exercise treaty rights. The contribution of food to Makah identify is met.	"Food security means cultural identify and security." "As long as I am able to cast a rod or dig a hole my family will never go hungry." "Seafood is who we are"
Accessibility	There are no political, regulatory, or physical barriers to getting traditional foods. Sharing networks connect those unable to harvest themselves with sources of food.	"I am Makah, I can live off our natural resources, but I feel like that is being taken from us!" "I would get more salmon and whale. Treaty rights to whaling are restricted" "Barriers to getting more food include seasonal fishing regulations regarding take-home, time needed to fish."

4.3.5 *Climate risks to food security*

While climate change will affect many aspects of Makah Food Security, here we focus on impacts to components of continuity and health, specifically looking at what species are more at risk from climate change and the potential nutritional consequences. Many community members expressed concern about climate change and environmental health in general affecting the abundance and condition of seafoods. In response to the Likert-scale questions regarding the quality of fish, shellfish, fresh, and ocean water, 35% to 50% thought each was slightly contaminated (Figure 4-4). Shellfish was the resource people were most concerned about with 34.9% saying they avoid or moderate how much their family eats due to contamination concerns.

Many people provided a caveat to that however, saying they were far more concerned about the bay side than the ocean side, and that concern levels and avoidance fluctuated seasonally and with the occurrence of harmful algal blooms. Octopus, sockeye, crab, and a variety of shellfish were among the foods that people said they normally get that they had not had during the past year, or that they had had in significantly reduced amounts. People attributed negative effects on fish and shellfish populations to warming waters, ocean acidification, and red tides (harmful algal blooms).

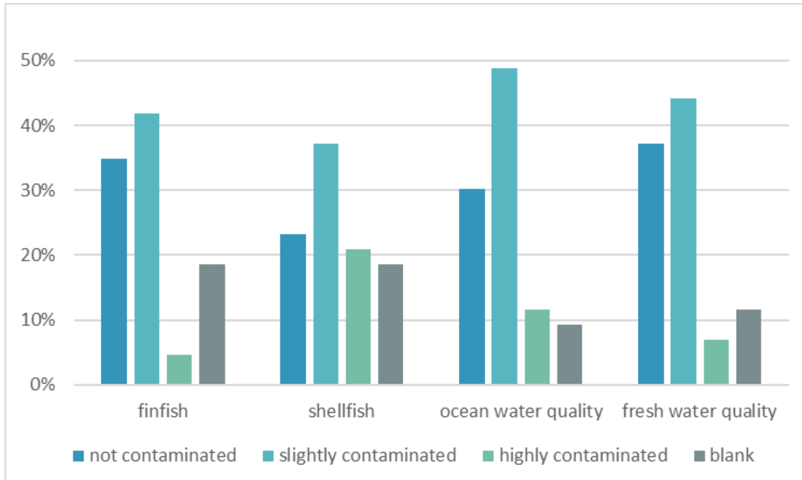

Figure 4-4. Responses to questions regarding perceptions of contamination level of finfish and shellfish and water quality around Neah Bay.

Ten species of fish and shellfish used by at least 3 households in this survey were among the top 25% of most at risk species in the assessment conducted by Koehn et al. (in review). These include black cod (sablefish), chinook, sockeye, and pink salmon, and butter clams. Other species important to Makah with higher relative levels of climate risk include albacore, boots (gooseneck barnacles), littleneck clams, and mussels (Figure 4-5). Species with higher levels of climate risk exhibit one of three patterns. The shellfish species and albacore have their higher levels of risk driven primarily by higher exposure, conversely sablefish are less exposed but are

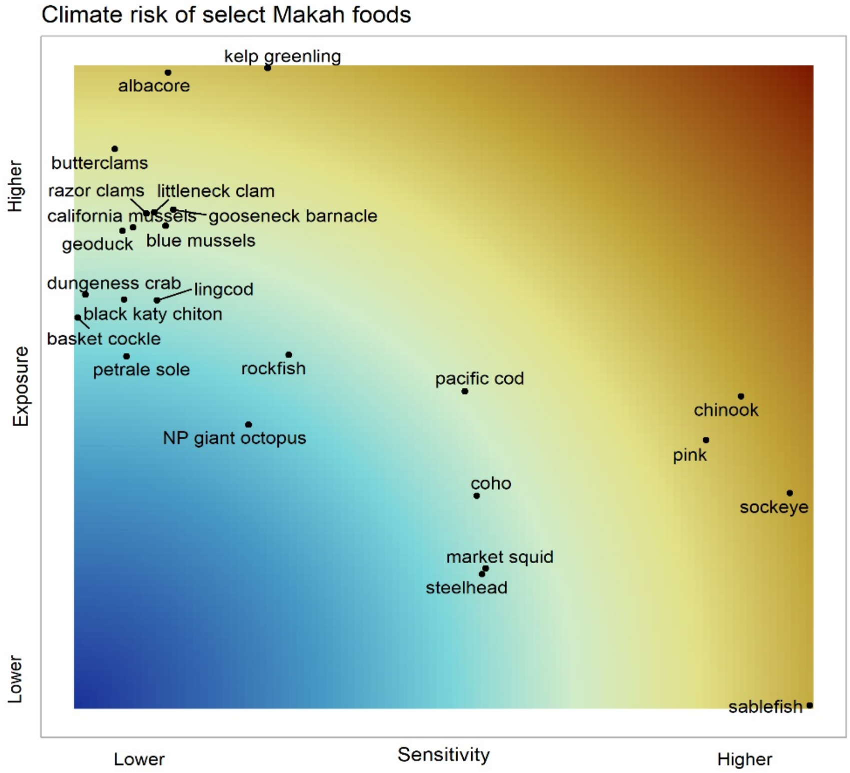

Figure 4-5. Relative climate risk, as defined by exposure and sensitivity, of species consumed by at least 5 households. Color bands reflect equivalent levels of climate risk.

highly sensitive to the impacts of climate change. Salmon meanwhile are both exposed and sensitive to climate impacts. Pacific halibut, a species of both commercial and subsistence importance for Makah, was not included in their analysis due to data constraints, but a qualitative discussion of the climate risk of Pacific halibut based upon other work is included in the discussion.

The foods cluster into six different groups when we consider how they varied in climate risk, household usage, and nutrient density (Figure 4-6). The first cluster, containing a mix of shellfish species, sablefish, and albacore, is characterized by relatively high climate risk and household utilization, and medium nutrient density. The second cluster contains the salmonid species and blue mussels. This cluster is defined by being some of the most nutrient dense and highly consumed species, with chinook and sockeye also among the most at-risk from climate change. The third cluster, a group of bivalves, mollusks, and steelhead, exhibit relatively lower risk from climate change and are lesser consumed species with high nutrient densities. The fourth cluster, also having relatively lower climate risk, exhibits contrasting usage and nutritional patterns from three with medium to high household use and medium to low nutrient density. This cluster is comprised of lingcod, rockfish, and Dungeness crab. Clusters five and six are made up of species that are of medium to low nutrient density and consumption and are delineated from each other by their level of climate risk with cluster 5 being of relatively high risk and cluster 6 having relatively low risk.

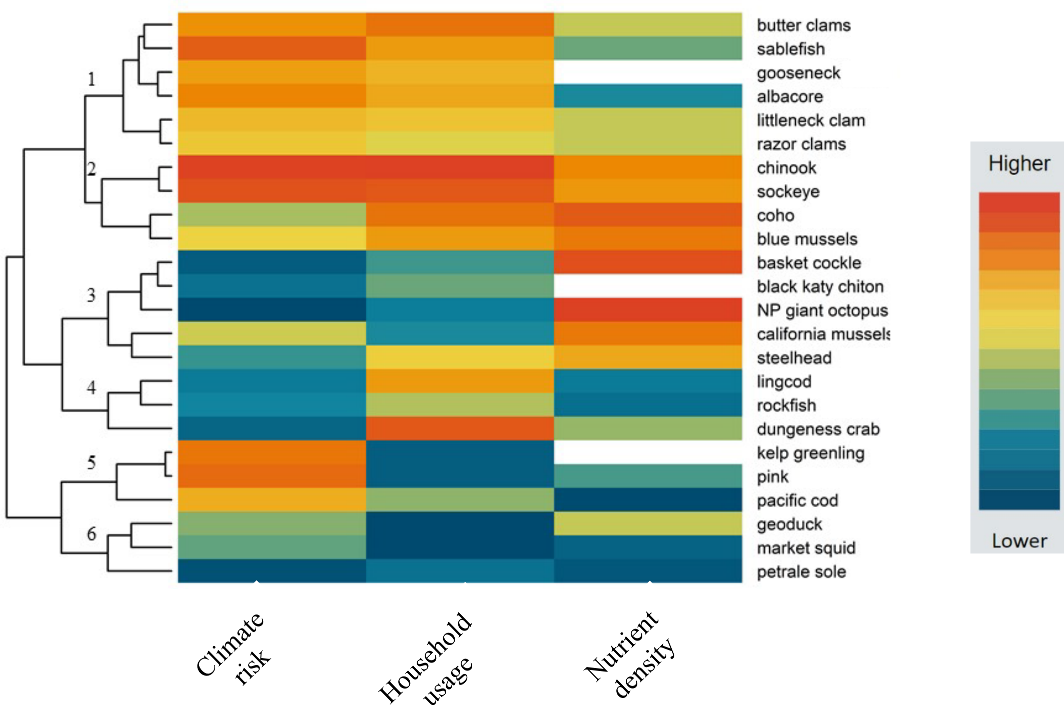

Figure 4-6. Heat map of the percent rank of climate risk, household utilization rates, and nutrient density. Red indicates higher percent rank while blue represents lower rank. White bars in nutrient density are for species for which there is insufficient nutrient information for a density calculation.

4.4 DISCUSSION

Traditional seafoods have been fundamental to the Makah existence since time immemorial, and the ability to continue to access those foods is essential for contemporary and future Makah Food Security. As such, climate-driven changes in the abundance and availability of marine resources will have negative impacts on food security and overall wellbeing for Makah Tribal members. Makah Tribal members continue to use a large variety of seafood species, a subset of which are both highly nutrient dense and at relatively high risk from climate change. While the nutritious nature of seafood is valued by community members, the benefits of eating traditional seafood extend beyond just the nutrient content of a species and include a connection to and continuation of cultural traditions that contribute to spiritual and community health. Based upon these results, we propose a conceptualization of Makah Food Security that is grounded in survey responses about food security and health (Figure 4-7).

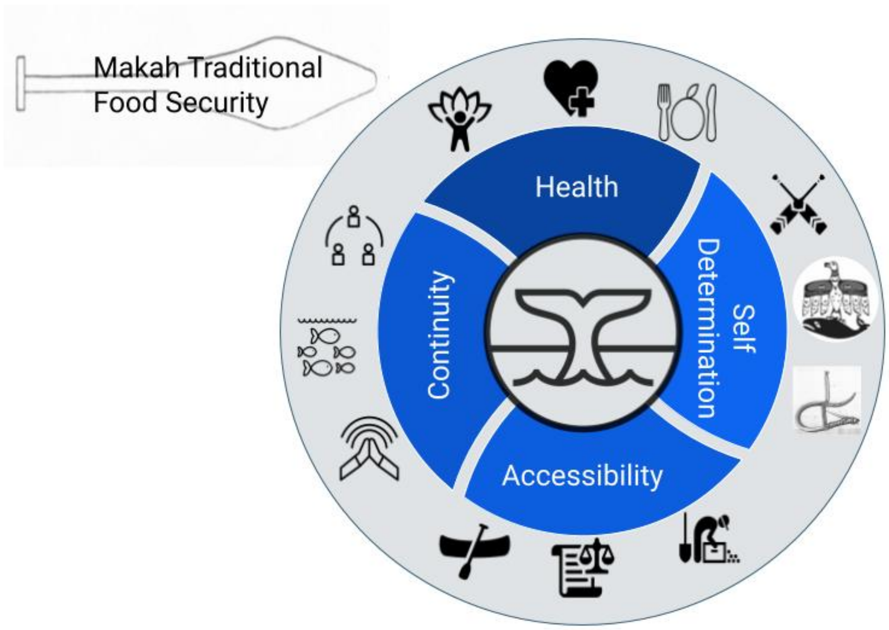

Figure 4-7. Conceptual framework of Makah Food Security. Each component is supported by three subcomponents, for health they are overall wellbeing, nutrition, and spiritual health, for continuity they are environmental health, knowledge, and management, for accessibility they are the physical resources and health and lack of regulatory barriers to harvest, and for self-determination they are identity, culture, and sovereignty.

This framework is similar, but distinct, from general representations of food security. Here, health goes beyond the requirement of the FAO, that nutritional needs are met, to recognize that both physical and spiritual fulfillment are gained from traditional foods. There is an interconnectedness between health and traditional seafood; a connection that exists not only at the individual level but at the community level. Overall wellbeing, nutrition, and spiritual health are subcomponents, each reflected in the responses about the health benefits of seafood. People noted specific physical benefits that they felt they got from seafood including omega-3s and healthy protein, a general sense about feeling healthier when they have more seafood, and preferring it to processed options from the store. Several people also specifically mentioned the health benefits of eating as their ancestors did.

Continuity is about the connection between the past, present, and future provided by the harvesting, sharing, and eating of traditional foods. For this component to be fulfilled, traditional foods must exist in sufficient abundance that people are able to get the foods they desire today, and that allows for sustainable, healthy fish and shellfish populations to exist in perpetuity. Environmental health, knowledge, and management are subcomponents of the Continuity pillar. The component of Continuity most closely aligns with the UN's definition of stability in its sentiment that true food security cannot be a temporary state, however, here we also look to the past for that consistency in addition to the future. Part of the way that connection is maintained is through the passing of knowledge to the next generation regarding harvest, preparation, and sharing; practices that have been interrupted by colonialism for many Tribes (Grey & Patel, 2015). The ability to share knowledge is contingent upon foods being present in a sufficient abundance that allows for harvesting and sharing to occur.

In contrast with the environmental focus of Continuity, Accessibility is concentrated on the regulatory, political, or physical barriers that may prevent people or the community from getting the traditional foods they desire and thus inhibiting their food security. Many people noted the lack of time for fishing or gathering, while a small subset said they lack the physical ability to gather for themselves or have lost someone who used to share food with them. Though Makah have one advantage over Tribes that have endured forced migration in that they are still on a portion of their original homelands and maintain their place-based identity and food sources, they still must contend with a colonial regulatory system that limits access to certain foods. For Makah, the most glaring example of that is the ongoing effort to overcome regulatory barriers to exercise their treaty right to whale. Given the threat of climate change, the inability of national politics to enact any major efforts to address to address climate change could potentially also be considered an accessibility issue.

Self-determination recognizes that traditional seafood and harvesting from the ocean are foundational to Makah identify. For this component of food security to be met, Makah must be able to exercise treaty rights and use foods in the manner desired for culture and identity. The community must be able to assert control and manage its traditional foods, and individuals must be able to exercise choice with respect to the foods they want. The sentiment that traditional seafoods contribute to self-determination is a long-held belief at Makah, reflected in the preservation of access to the ocean in the Treaty of Neah Bay, and people have cited Tribal heritage, homage to environmental abundance and self-reliance, and resistance to colonial domination as motivation for subsistence practices (Sepez, 2001).

In this work we have focused primarily on risk to two of those components: health and continuity. Climate change threatens both through impacts on high-risk species like clams that are consumed by a high percentage of households, and salmon that are both highly consumed and highly nutritious. One important species missing from the climate component of this work is Pacific halibut (*Hippoglossus stenolepis*). In addition to being a staple of subsistence in Neah Bay, halibut is also a valuable commercial fishery for Makah. Pacific halibut was not included in the Kohen et al. analysis as only a small proportion of their habitat falls within the specified region and range of the climate projections used in their vulnerability assessment. Therefore, the analysis would not have accurately captured past and future climate experienced by Pacific halibut throughout its range, which would likely bias the calculation of sensitivity and exposure. A species risk assessment conducted for the Bering Sea found Pacific halibut to be moderately sensitive, have low exposure, and overall be at low risk from climate change (Spencer et al., 2019). In Figure 4-6, halibut would likely be in cluster 4, a group containing other groundfish and Dungeness crab that also have lower climate risk, medium to high household use, and medium to low nutrient density.

Identifying risks associated with the nutritional value derived from seafood is intended to assist with setting management priorities and conservation efforts, not to identify nutrient gaps to be filled by supplements or substitute food sources. As acknowledged, the health benefits of traditional seafoods extend far beyond their nutritional contributions, however, the health benefits are also valued by Makah and well recognized in Indigenous communities (Kuhnlein & Receveur, 1996; Mailer & Hale, 2015; Receveur et al., 1997). The most nutrient-rich species at higher risk from climate change are several species of clams and the salmonids. Salmon are particularly good sources of vitamin D, B12, and omega-3 fatty acids (EPA and DHA), while clams contribute to selenium and B12 intake. While it may have medium nutrient density overall, black cod also contains high levels of valuable omega-3's and is at high risk from climate impacts. The benefits of polyunsaturated fatty acids have been noted in other cultures that consume large amounts of fatty fish and marine mammal oil (Carpentier et al., 2006), as has its benefits for diabetes and rheumatoid arthritis (Belch et al., 1988; Keen, et al. 1993). Additional sources of omega-3 fatty acids could be available in the community if they are successful in exercising their treaty right to whale as whale blubber and oil are also good sources and have been shown to provide substantial health benefits for subsistence consumers in the Arctic (Reynolds et al. 2006). We should note that the RDA values used in this work do not reflect the higher nutritional needs of the young and the elderly, or individuals with health challenges that may have different nutritional requirements. Additionally, nutritional content can vary between parts of fish, and future work may consider the nutrient intake in a more nuanced way that accounts more specifically for preparation and consumption patterns.

Lastly, it is important to put these results into context and note what they are and what they are not. While the quantitative measures of seafood consumption in this survey are valuable for understanding risks to current levels of consumption from the effects of climate change, for a variety of social and environmental reasons modern levels of subsistence seafood consumption are typically suppressed below traditional, heritage rates (Donatuto & Harper, 2008). While the percentage of households that are eating specific species has remained relatively consistent, the decrease in the volume of many of those foods is concerning. Even some of the potential bright spots come with a caveat; the Sepez data for black cod, one of the species with a large increase in the percentage of household consumption, was likely affected by a 1998 coast-wide reduction in allowable harvest which was then returned to near-previous levels in following years (Sepez, 2001). Though fish consumption data is often used for setting water quality standards, if that is needed, rather than the quantitative measures here, the data used should be reflective of the habitat quality required to support the desired fish consumption levels of the community, higher than current rates as reflected in survey responses.

While continuity of traditional foods remains of vital importance, it is not as if the marine environment and the foods the Makah Tribe has harvested from it has always been static; the ocean has always been a dynamic environment and the Tribe has adapted as needed. What has changed are the external forces putting constraints on access to food and adaptation options, and the rate of change caused by climate impacts. Limitations placed on the ability to adapt and determine the future of a food system not only constrains adaptive capacity more broadly, but is a form of injustice (Whyte, 2018). The results presented here and the components outlined in

Makah Food Security will hopefully contribute to ongoing efforts as the Makah Tribe works to navigate the increasingly choppy waters of enhancing self-determination while adapting to climate change.

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4.6 Appendix D

4.6.1 *Climate risk details*

Koehn et al. (in review) calculated the climate risk for 69 species of fish and shellfish species in the California Current. In Figure 4.6, the climate risk for relevant species of clams and rockfish are averaged for comparison to nutrient density data. The following species were included for each:

- Rockfish – black, blackgill, blue, brown, chilipepper, longspine thornyhead, shortspine thornyhead, vermillion, and yellowtail rockfish
- Clams – geoduck, pacific littleneck, pacific razor, and Washington butter clams

4.6.2 *Makah household survey*

Subsistence Seafood Consumption Survey

We appreciate your willingness to participate in our fish and shellfish consumption survey, a joint effort between the Makah Tribe and the University of Washington. We're gathering information about the consumption of marine resources and community observations about availability and access of fish and shellfish in order to understand how food resources may be at risk from climate change. This information will also be used to update Tribal data on subsistence resource use to be used to protect resources in case an oil spill or similar disaster. The focus for this survey is seafood that has been caught or harvested by you or another community member, please do not include fish or shellfish bought at the store in your estimates. All of the information you provide to us is confidential and will remain property of the Tribe. During analysis, your responses to the questions will be combined with those of others so that your answers cannot be identified. If you have any questions, you are welcome to email Laura Nelson from the University of Washington at lknelson@uw.edu.

It takes about 30 to 40 minutes to complete this questionnaire. There are four parts:

1. Basic household information;
2. Questions about fish and shellfish eaten in the last 24 hours;
3. Questions about annual consumption of fish and shellfish including what species you ate, how they were harvested, and how much you usually eat in one setting; and
4. General questions about your perceptions of the quality of the resources and how they have changed over time.

I will guide you through the survey, you can ask for a clarification about a question at any time. We will begin by asking about who lives in this home.

Part 1: Household Information

1. Please list the age and gender of the members of the household starting with yourself, and everyone's relationship to you.

Age	Gender	Relationship (daughter, nephew, etc.)	Leads harvesting or fishing trips?	Assists with harvesting or fishing trips?

Part 2: 24-hour recall

It is easier to remember what you ate yesterday than it is to remember what you ate over the course of the last year. We will ask both to get a complete picture of your household's seafood consumption.

Did you eat any fish or shellfish yesterday from the time you woke up until the time you went to sleep last night? Please include all meals and snacks.

☐ Yes

☐ No (go to next section)

Please fill out the table for any fish or shellfish that you ate yesterday.

Species	Portion size	Harvested by you or someone in the household	Given to you	Fresh	Frozen	Eaten at home	Eaten outside of your home
Example: Chinook Salmon	*6 oz*	*X*			*X*	*X*	

Part 3: Annual seafood consumption

For this part of the survey, we will ask about your household's consumption of fish and shellfish over the past 12 months. The first questions are about what species you ate, the amount you ate, and how often you ate each species over the course of last year. We will ask you to estimate how many times you ate each type of food during each season, recognizing that people may eat more or less of certain types of fish and shellfish during different times of the year. We have models and pictures of some species to help with portion size estimate. Please remember to include fish you ate for any meal (breakfast, lunch, dinner, and snacks). If there are species you eat that do not appear on the list, please note them under "other."

Please indicate if you have eaten any of the following species in the past year, your best estimate of how many times a season you ate that food, and the average portion size of that species.

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
Finfish								
Pacific halibut	Yes No							
Sablefish/Black Cod	Yes No							
True cod	Yes No							
Chinook (King or Fat Jack) salmon	Yes No							

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
Sockeye (Blueback) salmon	Yes No							
Coho (Silver) salmon	Yes No							
Chum (Dog) salmon	Yes No							
Pink salmon	Yes No							
Rainbow trout	Yes No							
Cutthroat trout	Yes No							
Smelt (Surf Smelt, Eulachon)	Yes No							
Steelhead	Yes No							
Lingcod	Yes No							
Rockfish (Yelloweye, Pacific rock cod, etc.)	Yes No							
Greenling (kelp greenling, etc.)	Yes No							

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
Dover sole	Yes No							
Petrale sole	Yes No							
Pacific ocean perch	Yes No							
Sturgeon (Green or White)	Yes No							
Flounder or other flatfish	Yes No							
Skates	Yes No							
Pacific hake (whiting)	Yes No							
Tuna	Yes No							
Wolf eel	Yes No							
Herring	Yes No							
Other ________________								
Other ________________								

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
Invertebrates								
Butter clams	Yes No							
Littleneck steamers	Yes No							
Horse clams	Yes No							
Razor clams	Yes No							
Cockles	Yes No							
Periwinkles	Yes No							
Geoduck	Yes No							
Manila clams	Yes No							
California mussel	Yes No							
Blue mussel	Yes No							
Purple-hinged rock scallops	Yes No							

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
Weathervane scallops	Yes No							
Oysters	Yes No							
Octopus	Yes No							
Squid	Yes No							
Dungeness crabs	Yes No							
Red rock crab	Yes No							
Boots (Gooseneck barnacles)	Yes No							
Barnacles (acorn, thatched, or giant barnacles)	Yes No							
Slippers (Black chitons)	Yes No							
Purple sea urchins	Yes No							
Green sea urchins	Yes No							
Black turban snails	Yes No							

Species	Did you eat any of this during the past year?	Approximately how many days in each season did you eat that fish? (leave blank if none was eaten all year)				What was the average portion size? (oz.)	Compared to other years, was the amount your household ate of this fish higher or lower, or about average?	Parts eaten in addition to filets? (skin, organs, eggs, etc.)
		Summer (June – Aug)	Fall (Sept – Nov)	Winter (Dec – Feb)	Spring (Mar – May)			
California sea cucumber	Yes No							
Other ___________________	Yes No							
Other ___________________	Yes No							

For any species that you ate during the previous year, please answer the additional questions in this table regarding where and how the fish was harvested, how this year compared to other years, and if it was shared at all. The reason there is a question about location is that it is helpful to have it documented for the portion of the project collecting data in case of an oil spill.

Species	Fished or collected by someone in your household?	How many trips to get this do you make a year?	How much do you usually get per trip? (pounds, fish, bucket, etc.)	Did you find the availability of this species to be average, more abundant, or scarcer this year compared to a normal year?	Did you catch/collect this food in the U and A? (Yes, No, or prefer not to answer)	Was this ever given to you? About how much did you receive?	Eaten at a community dinner? (yes or no)
Finfish							
Pacific halibut	Yes No						
Sablefish/Black Cod	Yes No						
True cod	Yes No						
Chinook (King or Fat Jack) salmon	Yes No						
Sockeye (Blueback) salmon	Yes No						
Coho (Silver) salmon	Yes No						
Chum (Dog) salmon	Yes No						
Pink salmon	Yes No						

Species	Fished or collected by someone in your household?	How many trips to get this do you make a year?	How much do you usually get per trip? (pounds, fish, bucket, etc.)	Did you find the availability of this species to be average, more abundant, or scarcer this year compared to a normal year?	Did you catch/collect this food in the U and A? (Yes, No, or prefer not to answer)	Was this ever given to you? About how much did you receive?	Eaten at a community dinner? (yes or no)
Rainbow trout	Yes No						
Cutthroat trout	Yes No						
Smelt (Surf Smelt, Eulachon)	Yes No						
Steelhead	Yes No						
Lingcod	Yes No						
Rockfish (Yelloweye, Pacific rock cod, etc.)	Yes No						
Greenling (kelp greenling, etc.)	Yes No						
Dover sole	Yes No						
Petrale sole	Yes No						
Pacific ocean perch	Yes No						
Sturgeon (Green or White)	Yes No						
Flounder or other flatfish	Yes No						

Species	Fished or collected by someone in your household?	How many trips to get this do you make a year?	How much do you usually get per trip? (pounds, fish, bucket, etc.)	Did you find the availability of this species to be average, more abundant, or scarcer this year compared to a normal year?	Did you catch/collect this food in the U and A? (Yes, No, or prefer not to answer)	Was this ever given to you? About how much did you receive?	Eaten at a community dinner? (yes or no)
Skates	Yes No						
Pacific hake (whiting)	Yes No						
Tuna	Yes No						
Wolf eel	Yes No						
Herring	Yes No						
Other ________							
Other ________							
Invertebrates							
Butter clams	Yes No						
Littleneck steamers	Yes No						
Horse clams	Yes No						
Razor clams	Yes No						

Species	Fished or collected by someone in your household?	How many trips to get this do you make a year?	How much do you usually get per trip? (pounds, fish, bucket, clams etc.)	Did you find the availability of this species to be average, more abundant, or scarcer this year compared to a normal year?	Did you catch/collect this food in the U and A? (Yes, No, or prefer not to answer)	Was this ever given to you? About how much did you receive?	Eaten at a community dinner? (yes or no)
Cockles	Yes No						
Periwinkles	Yes No						
Geoduck	Yes No						
Manila clams	Yes No						
California mussel	Yes No						
Blue mussel	Yes No						
Purple-hinged rock scallops	Yes No						
Weathervane scallops	Yes No						
Oysters	Yes No						
Octopus	Yes No						
Squid	Yes No						
Dungeness crabs	Yes No						

Species	Fished or collected by someone in your household?	How many trips to get this do you make a year?	How much do you usually get per trip? (pounds, fish, bucket, etc.)	Did you find the availability of this species to be average, more abundant, or scarcer this year compared to a normal year?	Did you catch/collect this food in the U and A? (Yes, No, or prefer not to answer)	Was this ever given to you? About how much did you receive?	Eaten at a community dinner? (yes or no)
Red rock crab	Yes No						
Boots (Gooseneck barnacles)	Yes No						
Barnacles (acorn barnacle, thatched barnacle, giant barnacles)	Yes No						
Slippers (Black chitons)	Yes No						
Purple sea urchins	Yes No						
Green sea urchins	Yes No						
Black turban snails	Yes No						
California sea cucumber	Yes No						
Other ________________	Yes No						
Other ________________	Yes No						

Part 4: Environmental observations and perceptions about resource quality

We are interested in community perceptions of environmental health and if or how that might affect how you make choices about what type of seafood to eat. This is helpful for developing environmental policy and guiding communication about the environment.

1. What is your perception of water quality and contamination levels in seafood gathered in the U and A? Check one per row.

	Highly contaminated	Slightly contaminated	Not contaminated
Finfish			
Shellfish			
Ocean water			
Fresh water			

2. Does your perception of the health of marine resources change how often you eat them? If you avoid or moderate how much you eat because of health concerns please list which, if any, species you are avoiding for those reasons.

	I avoid or moderate how much my family eats due to contamination concerns.	Specific species of concern	I have contamination concerns, but they don't affect my food choices	Resources are healthy
Finfish				
Shellfish				

3. What do you feel are the benefits of eating seafood? Are there any fish or shellfish you consider to be especially nutritious?

____

____

____

____

4. Are there any local seafood resources that you usually get that you did not eat this year?

____

____

____

5. Do you feel that your household's overall consumption of fish and shellfish (amounts and species) has changed over the last 20 years?
   - ☐Yes
   - ☐No (skip next question)
   - ☐Maybe

6. How has the amount of fish and shellfish that your household has eat over the past 20 years changed? Check all that apply.
   - ☐ Eat more now
   - ☐ Eat less now
   - ☐ Eat different types now
   - ☐ Prefer not to answer
   - ☐ Don't know
   - ☐ Other ____

Explanation
(optional)____

____

7. Do you feel that in general you had adequate access to the fish and shellfish that you want or need?
   ☐ Yes
   ☐ No
   ☐ Yes, but had to supplement with fish bought at the store
   ☐ Other ____

8. Would you eat more fish or shellfish if you could? If so, what prevents you from eating as much as you'd like? What species would you want more of?

____

____

____

9. If there have been changes in the amounts or types of fish or shellfish that you eat, what do you think is responsible for the difference?

____

____

____

10. Is there anything that makes it easier or harder for you to get the food you want? (do not have time to harvest yourself, do not have access to a boat, etc.).

____

____

____

11. What does food security mean to you?

____

____

12. Are you interested in any classes or other forms or information that would give you more guidance on harvesting, processing, or preparing these foods? What topics would be most of interest to you?

____

13. Are there any other thoughts you would like to add about subsistence harvesting, seafood, or environmental change?

4.7 Appendix E: Perceptions of Vulnerability Survey

Stakeholder Survey

Scientists predict that climate-driven changes to the California Current Ecosystem have the potential to disrupt the social and economic fabric of fishing communities. Researchers at the University of Washington are conducting this survey as part of an effort to assess the social and ecological vulnerability of fishing communities along the U.S. West Coast and getting input from fishermen is a vital part of the project. We are interested in your perceptions of the vulnerabilities of coastal fisheries and fishing communities, and the strengths and resilience that help them adapt to change. We are coordinating this effort with the Pacific Fisheries Management Council's Climate and Community Initiative, and our results will be shared with them.

All of the information you provide is confidential; individual surveys will only be seen by the research team. It will take about twenty minutes to complete. Please answer all the questions to the best of your knowledge and feel free to ask to have a question repeated or for clarification at any time. We appreciate your willingness to participate in this survey and thank you for your time.

Background Information

This section will ask a few questions about you, the fisheries you participate in, and the regions where you fish.

1. **What west coast fisheries do you participate in?**
Check all that apply.

- [ ] Coastal Pelagic Species (e.g. Pacific Sardine, Pacific Mackerel, Northern Anchovy, California Market Squid)
- [ ] Dungeness Crab
- [ ] Groundfish (e.g. Rockfish, Flounder, Lingcod, Pacific Cod, Skates)
- [ ] Hake
- [ ] Highly Migratory Species (e.g. Pacific Tunas, Swordfish, Sharks, Billfish)
- [ ] Salmon
- [ ] Scallops
- [ ] Sea Urchin
- [ ] Shrimp
- [ ] Squid
- [ ] Other: ______________________

2. **Which species or fisheries generate at least 25% of your fishing income? Check all that apply. Please think of these fisheries when you are asked other questions about your main or primary fisheries.**

Check all that apply.

- [ ] Coastal Pelagic Species (e.g. Pacific Sardine, Pacific Mackerel, Northern Anchovy, California Market Squid)
- [ ] Dungeness Crab
- [ ] Groundfish (e.g. Rockfish, Flounder, Lingcod, Pacific Cod, Skates)
- [ ] Hake
- [ ] Highly Migratory Species (e.g. Pacific Tunas, Swordfish, Sharks, Billfish)
- [ ] Salmon
- [ ] Scallops
- [ ] Sea Urchin
- [ ] Shrimp
- [ ] Squid
- [ ] Other: ______________________

3. **Below is a list of sections of the west coast and its major inland waterways. Please check the box of any region where you fish regularly.**

Check all that apply.

- [ ] Puget Sound and the Strait of Juan de Fuca
- [ ] Cape Flattery, WA to Cape Disappointment, WA
- [ ] Columbia River
- [ ] South of the Columbia River to Mendocino, CA
- [ ] Mendocino, CA to Point Reyes, CA
- [ ] Point Reyes, CA to Point Conception, CA
- [ ] South of Point Conception, CA

4. **Where is your homeport?**

____

5. **How long have you been fishing?**

Mark only one oval.

- ( ) 0 - 5 years
- ( ) 5 -15 years
- ( ) 15 - 25 years
- ( ) more than 25 years

6. **Where do you live? Please include the name and zip code of your town.**

____

7. **How long have you lived in your current community?**
Mark only one oval.

- 0 - 5 years
- 5 -15 years
- 15 - 25 years
- more than 25 years

8. **What is your role in the fishing industry? (check all that apply)**
Check all that apply.

- [ ] Captain
- [ ] Vessel Owner
- [ ] Crew member
- [ ] Other: ____________________

9. **(If answer to previous question is captain or vessel owner) How many crew do you typically employ during your main fishing season?**
Mark only one oval.

- 1-3
- 4-7
- 7-11
- greater than 11

10. **What length of vessel do you work on or operate?**
Mark only one oval.

- 25 ft. or less
- 26 to 35 ft.
- 36 to 45 ft.
- 46 to 55 ft.
- 56 to 65 ft.
- 66 ft. or greater

11. **What gear types do you use? Please check all that apply.**
Check all that apply.

- [ ] Longlines
- [ ] Midwater trawl
- [ ] Bottom trawl
- [ ] Pots
- [ ] Purse seine
- [ ] Gillnet
- [ ] Troll
- [ ] Other: ____________________

12. **Do you currently participate fisheries in other parts of the country in addition to those off of Washington, Oregon, or California?**
Mark only one oval.

- ( ) Yes
- ( ) No

13. **(If yes to previous question) Where and which fisheries?**

____

14. **What percentage, if any, of your annual income comes from jobs or sources outside of fishing?**
Mark only one oval.

- ( ) none
- ( ) 10% or less
- ( ) 10% to 25%
- ( ) 25% to 50%
- ( ) more than 50%

15. **How old are you?**
Mark only one oval.

- ( ) Under 30
- ( ) 30 - 40
- ( ) 40 - 50
- ( ) 50 to 60
- ( ) 60 to 70
- ( ) over 70 years

16. **What is your gender identity?**
Mark only one oval.

- ( ) Female
- ( ) Male
- ( ) Prefer not to say
- ( ) Other: ______________________________

17. **Are you an enrolled tribal member?**
Mark only one oval.

- ( ) Yes
- ( ) No

18. **Do you regularly smoke cigarettes?**

Mark only one oval.

- Yes
- No

19. **During the last 12 months, on days when you drank alcohol how many drinks did you usually have?**

Mark only one oval.

- 1-2
- 3-4
- 5-6
- 7-8
- greater than 8

Observations of ocean change

This section asks about your observations and understanding of changes in the ocean and how those changes may have impacted fisheries. There is not a right or wrong answer to these questions, we are trying to get a sense of what you have seen or experienced.

20. **Please indicate any changes you have observed in the waters off of Washington, Oregon, and California in the last 5 years.**

Mark only one oval per row.

	Decrease	No change	Increase
Ocean temperature			
Severe weather			
Availability of your main target species			
Other			

21. **Do you think your ability to catch fish has been affected by climate change?**

Mark only one oval.

- Yes, positively affected
- Yes, negatively affected
- No
- I have not observed any changes

22. **Please elaborate if you answered yes to the previous question.**

Impacts on fisheries

For the next question, you will be asked what, if any, effect you believe ocean warming is having on specific fisheries. For each fishery, we would like you to indicate if you think ocean warming is having a strong or slightly negative effect, no effect, or a slightly or strongly positive effect. You many also answer I don't know. Then you will be be asked about your confidence level in that answer before moving on to the next fishery.

23. **What, if any, effect do you believe ocean warming is having on these fisheries?**
Mark only one oval per row.

	Strong negative effect	Slight negative effect	No effect	Slight positive effect	Strong positive effect	I don't know
Coastal Pelagic Species (e.g. Pacific Sardine, Pacific Mackerel, Northern Anchovy, California Market Squid)						
Dungeness Crab						
Groundfish (e.g. Rockfish, Flounder, Lingcod, Pacific Cod, Skates)						
Hake						
Highly Migratory Species (e.g. Pacific Tunas, Swordfish, Sharks, Billfish)						
Salmon						
Scallops						
Sea Urchin						
Shrimp						
Squid						
Other						

24. **Please indicate your level of confidence in your responses to the previous question.**
Mark only one oval per row.

	Low confidence	Medium confidence	High confidence
Coastal Pelagic Species (e.g. Pacific Sardine, Pacific Mackerel, Northern Anchovy, California Market Squid)			
Dungeness Crab			
Groundfish (e.g. Rockfish, Flounder, Lingcod, Pacific Cod, Skates)			
Hake			
Highly Migratory Species (e.g. Pacific Tunas, Swordfish, Sharks, Billfish)			
Salmon			
Scallops			
Sea Urchin			
Shrimp			
Squid			
Other			

25. **Are any of your primary fisheries being affected by changes in other marine species?**
Mark only one oval.

- ( ) Yes
- ( ) No

26. **If yes, how is it being affected?**

The next two questions ask you to how fishing in recent years compares to 30 years ago. If you were not fishing 30 years ago, please answer based on what you have heard from others or your understanding of what it was like during that time.

27. **When you compare the last 5 years to 30 years ago, have you seen changes in the range of your primary target species?**
Mark only one oval.

- ( ) Yes
- ( ) No

28. **If yes, how has it changed?**

29. **When you compare the last 5 years to 30 years ago, has the time of year of when you fish shifted at all?**
Mark only one oval.

- ( ) Yes
- ( ) No

30. **If yes, how has it changed?**

Perceptions of Exposure and Risk

This section asks about environmental, fishing, or community issues; your level of concern about those issues; and how often you think about them.

31. **What west coast species or fisheries do you think are most likely to be negatively affected by climate change?**

32. **Are there any species or fisheries that you think will be positively affected by climate change?**

Below is a list of issues that may affect fishing success, your wellbeing, or the wellbeing of your community. For the following questions, please mark 2 answers in each row - 1 indicating your level of concern and 1 for how often you think about the topic.

33. **Marine Environment**
Check all that apply.

	Not concerned at all	Somewhat concerned	Very concerned	Never	Occasionally	Frequently
Warming waters	☐	☐	☐	☐	☐	☐
Ocean acidification	☐	☐	☐	☐	☐	☐
Increases in severe storms	☐	☐	☐	☐	☐	☐
Sea level rise	☐	☐	☐	☐	☐	☐
Changing weather patterns	☐	☐	☐	☐	☐	☐
Ocean water quality	☐	☐	☐	☐	☐	☐
Harmful algal blooms	☐	☐	☐	☐	☐	☐
Habitat degradation or loss	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

34. **Fishing**
Check all that apply.

	Not concerned at all	Somewhat concerned	Very concerned	Never	Occasionally	Frequently
Size of fish populations	☐	☐	☐	☐	☐	☐
Bycatch	☐	☐	☐	☐	☐	☐
Landed value	☐	☐	☐	☐	☐	☐
Costs associated with fishing (fuel, vessel maintenance, etc.)	☐	☐	☐	☐	☐	☐
The stock assessment process	☐	☐	☐	☐	☐	☐
Travel time to fishing grounds increasing	☐	☐	☐	☐	☐	☐
Regulation	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

35. **Community and infrastructure**
Check all that apply.

	Not concerned at all	Somewhat concerned	Very concerned	Never	Occasionally	Frequently
Aging labor force	☐	☐	☐	☐	☐	☐
Community cohesion in the fishing community	☐	☐	☐	☐	☐	☐
Community cohesion in your residential community	☐	☐	☐	☐	☐	☐
Coastal and port infrastructure	☐	☐	☐	☐	☐	☐

36. **Personal**
Check all that apply.

	Not concerned at all	Somewhat concerned	Very concerned	Never	Occasionally	Frequently
Physical health problems	☐	☐	☐	☐	☐	☐
Mental health problems	☐	☐	☐	☐	☐	☐
Safety at sea	☐	☐	☐	☐	☐	☐
Familial relationships	☐	☐	☐	☐	☐	☐

37. **Please indicate your level of agreement with the following statements.**

Mark only one oval per row.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
I believe climate change is occurring	⬭	⬭	⬭	⬭	⬭
Climate change will harm me personally	⬭	⬭	⬭	⬭	⬭
Climate change will harm future generations	⬭	⬭	⬭	⬭	⬭
If I had a choice I would leave fishing	⬭	⬭	⬭	⬭	⬭
It is a big risk to move into a new fishery	⬭	⬭	⬭	⬭	⬭
There is no point in preparing for climate change since we don't know exactly what will happen	⬭	⬭	⬭	⬭	⬭
There will not be enough fish to continue to operate in my main fishery in 20 years	⬭	⬭	⬭	⬭	⬭

38. **Fisheries occasionally have conflicts with other fisheries or other activities that take place in the ocean or coastal environment. Please indicate your level of agreement with the following statement. My fishing is negatively affected by _________.**

Mark only one oval per row.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
Recreational fisheries	⬭	⬭	⬭	⬭	⬭
Other commercial fisheries	⬭	⬭	⬭	⬭	⬭
There is internal conflict within my commercial fishery	⬭	⬭	⬭	⬭	⬭
Aquaculture	⬭	⬭	⬭	⬭	⬭
Hatcheries	⬭	⬭	⬭	⬭	⬭
Tourism	⬭	⬭	⬭	⬭	⬭
Coastal development	⬭	⬭	⬭	⬭	⬭
Competing ocean uses like shipping or offshore energy development	⬭	⬭	⬭	⬭	⬭

Sensitivity

Below is a list of statements that may indicate the degree to which community and individual wellbeing is sensitive to changes in the health of fisheries and the environment. Please indicate your level of agreement with each statement. Define physical and mental health and wellbeing.

39. **Conditions**

Check all that apply.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	I have not observed any changes
Changes in fisheries have negatively impacted my overall wellbeing	☐	☐	☐	☐	☐	☐
Changes in fisheries have negatively impacted my physical health	☐	☐	☐	☐	☐	☐
Changes in fisheries have negatively impacted my mental health	☐	☐	☐	☐	☐	☐
Changes in fisheries have raised my stress levels	☐	☐	☐	☐	☐	☐
Changes in the environment have negatively impacted my overall wellbeing	☐	☐	☐	☐	☐	☐
Changes in the environment have negatively impacted my physical health	☐	☐	☐	☐	☐	☐
Changes in the environment have negatively impacted my mental health	☐	☐	☐	☐	☐	☐
Changes in the environment have raised my stress levels	☐	☐	☐	☐	☐	☐
Changes in the environment have negatively affected my safety while fishing	☐	☐	☐	☐	☐	☐

40. **Connections**

Mark only one oval per row.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
I would encourage my children to be fishermen	○	○	○	○	○
Fishing is important to my identity	○	○	○	○	○
Fishermen are supported in my community	○	○	○	○	○
I am passing down fishing knowledge to the next generation	○	○	○	○	○
I feel a connection to my environment	○	○	○	○	○
I feel a connection to my community	○	○	○	○	○

41. **Capabilities**

Mark only one oval per row.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
I make enough money to support my family	○	○	○	○	○
I am able to plan two years out in the future	○	○	○	○	○
I am satisfied with my job	○	○	○	○	○
I think the fisheries I participate in are managed effectively	○	○	○	○	○
I have access to the data and information I need for successful fishing	○	○	○	○	○
I can find qualified crew with the skills they need to do a good job	○	○	○	○	○
I have a voice in fisheries management	○	○	○	○	○
Climate change should be considered in fisheries management	○	○	○	○	○

42. **Cross-cutting**

Mark only one oval per row.

	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
The fisheries I participate in are managed in an equitable way	○	○	○	○	○
There are opportunities for people who are not currently fishing to enter into west coast fisheries	○	○	○	○	○
There are opportunities for deckhands and other lower level crew to advance	○	○	○	○	○

Adaptive Capacity

Responding to changes, stemming from climate or other issues, will require adaptations by individuals, communities, and governance structures; this section asks for your perspective on their ability to do so.

43. **With regard to the future security of yourself, your residential community, or your fishery, please indicate the extent to which you agree or disagree with the following statements:**
Mark only one oval per row.

	Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree
I could easily move into a new fishery	◯	◯	◯	◯	◯
I could easily find work in another natural resource industry (aquaculture, forestry, etc.)	◯	◯	◯	◯	◯
I could easily get income not related to natural resource harvest, fishing or otherwise.	◯	◯	◯	◯	◯
I could easily get a loan or some other form of financial support	◯	◯	◯	◯	◯
I am confident in my ability to travel further to fish if that is needed	◯	◯	◯	◯	◯
I believe my community has a strong and viable future ahead	◯	◯	◯	◯	◯
I am concerned that climate change may lead to people moving out of my community.	◯	◯	◯	◯	◯
I think fisheries management can adapt and respond quickly to changing environmental conditions	◯	◯	◯	◯	◯
I feel constrained in my ability to adapt to changes because of regulations.	◯	◯	◯	◯	◯

44. **What sorts of changes could quicken response time and make fisheries management more flexible as it responds to future challenges?**

____
____
____
____
____

45. **Are there other concerns or thoughts you would like to share about the future of fishing or your community?**

____
____
____
____
____

VITA

Laura Nelson's love of water drives most of her professional and recreational pursuits. Originally from Hinsdale, IL, Laura grew up spending time around the lakes of northern Wisconsin and Michigan before pursuing a degree in biology at Dartmouth College. Following her time at Dartmouth, she worked for several years as a scientist for the Sea Education Association, sailing on the Atlantic and Pacific Oceans and teaching undergraduates and high school students about the ocean. Eventually, Laura moved on to the University of Washington where she completed a Master of Marine and Environmental Affairs. Between her masters and PhD, she worked for several years for the Makah Tribe, first as a Hershman Marine Policy Fellow and then as a consultant for the Makah Office of Marine Affairs, work that directly inspired some of the research in this dissertation. Her doctoral work focuses on aspects of climate change vulnerability of fishing communities on the West Coast of the United States.