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RESEARCH ARTICLE

Understanding perceptions of climate vulnerability to inform more effective adaptation in coastal communities

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Abstract

Coastal social-ecological systems are vulnerable to climate change with impacts distributed unequally amongst human communities. 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 climate vulnerability are influenced by experiences, social networks, and cognitive biases, and often differ from vulnerability as measured by subject experts. Because perceptions influence human behavior, including if and how people take adaptive action, a failure to recognize perceptions can lead to ineffective adaptation plans and an incomplete understanding of system vulnerability. Here, as part of a novel, multi-method effort to evaluate vulnerability to climate change in the California Current social-ecological system, we survey fishers from Washington, Oregon, and California to understand their perceived vulnerability and investigate what factors drive variability in their views. We find that while there is a connection between some factors known to influence vulnerability of fishers, including vessel size and the diversity of fishing portfolios, the most significant predictor of higher perceived vulnerability was environmental worldview, specifically a belief that climate change is occurring. Motivation to adapt is also influenced by the sentiment that the impacts of climate change are more urgent and consequential than other problems; thus, we also evaluate how concern levels for environmental issues compare to other challenges that may affect fishing success and wellbeing. While just under half think that they will be personally harmed by climate change, generally the fishers were more concerned about issues like costs and regulations than they were about environmental impacts. This assessment of perceptions highlights the importance of communication and addressing cognitive barriers to adaptation in the effort to develop climate resilient fisheries and fishing communities in the United States.

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Introduction

Climate change is having profound impacts on coastal and marine ecosystems [1–4], and though effects will vary by species, there will be substantial consequences for fisheries worldwide [5, 6]. 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 [7–9], and commercial and recreational fishing has generated nearly $35 billion annually in recent years [10]. Those practices are at risk as climate-driven changes in temperature, pH, and oxygen are leading to shifts in community structure and phenology [11, 12], and range shifts of marine populations [13, 14]. Climate impacts and the resulting effects on fisheries are already apparent in the California Current [15–18], a highly productive eastern boundary current that is defined by seasonal upwelling that spans nearly 3,000 km from southern British Columbia, Canada to Baja California, Mexico. Upwelling systems like the California Current are particularly vulnerable to ocean acidification [19], which has significant negative impacts on calcifying organisms [20], and is also associated with altered ecological communities, food webs, and decreased fishery catches [21–24]. Ocean warming is leading to the deoxygenation of ocean waters [25] and the resulting hypoxia often co-occurs with acidification [26]. Low-oxygen waters have spread onto the shelf in some sections of the California Current, including in areas of valuable commercial fisheries [27].

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 [24]. Additionally, ocean acidification has caused high mortality in shellfish hatcheries [26]. Previous work has predicted groundfish fisheries may remain strong regardless of climate impacts [28] 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 [29]. However, ocean acidification may be a source of vulnerability for demersal fish, even relatively mobile ones, through erosion of their prey base [24] and evidence suggests they are increasingly being impacted by deoxygenation in near-bottom waters [27]. 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 [30]. Overall impacts on Pacific salmon are geographically variable [e.g., 31], and vary by species, but climate change is generally a key driver of population dynamics [32].

The human communities of the California Current, of which at least 125 have been identified as significantly involved in commercial, recreational, and subsistence fisheries [33], 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 [12, 13], with variable effects on fishing fleets depending on their location and target species. 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 [34], and effects may be dampened or exacerbated depending on behavioral patterns of fishing communities [35]. In the Dungeness crab fishery, impacts of harmful algal blooms and the ability of fishers to adapt are distributed unequally across the fleet [36], and communities that are highly reliant on crab have also experienced greater exposure during recent climate shocks [37]. 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 [38, 39]. Large declines in salmon abundance have coastwide impacts, although they are felt more acutely in some areas [40], notably within Indigenous communities of the Pacific

Coast whose health, traditions, and food security are affected by the declines in salmon, shellfish, and other species [41–43].

In these coastal socio-ecological fisheries systems [44], the wellbeing and economies of human communities are closely tied to the health of fish and shellfish populations [41, 45–48] rendering benefits from, and relationships with, nature vulnerable as the abundance and availability of marine species are affected by climate change [49–51]. Vulnerability is a complex concept and is defined and measured using a myriad of methods and frameworks. In AR5, the IPCC shifted from a vulnerability to a risk framework [52]; however, because of its predominant usage, we have chosen to use the vulnerability framework from AR4 [53]. (See [54, 55] for further discussion of the similarities and differences between those frameworks, and [56] to see how they compare when applied). Here, we define vulnerability as 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 [57, 58]. Although the term risk is sometimes used interchangeably with vulnerability [59], here we adopt the convention that vulnerability explicitly accounts for adaptive capacity, while risk does not, reflecting just the potential impacts to the system.

Given the interconnectedness of people and nature in fisheries systems [60], vulnerability assessments are often employed to examine the impact of specific environmental stressors, including climate change, and the ability of individuals and communities to cope with those stressors [58]. Vulnerability assessments can help to determine priorities and management strategies [61, 62] and identify particularly vulnerable communities [63]. 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 [64], the variability with which societies and people experience those impacts [65, 66], and capacities and constraints in adapting to changing conditions [67–69]. 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 [41, 61, 70–72]. Additionally, previous work has shown that some fishing specific characteristics like fishery participation [73], and vessel length [36, 37] influence adaptive capacity and vulnerability, and how fishery diversification can decrease risk by buffering interannual variability [74, 75].

Often, a goal of a climate vulnerability assessment is to inform plans for climate adaptation [e.g., 76]; 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 by actions which enhance their adaptive capacity [77]. 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 [59, 78]. This omission often leads to a failure to address social and psychological determinants of risk or vulnerability [79] and the exclusion of impacts to important social and cultural practices [80]. Recent work has improved the inclusion of social indicators in understanding vulnerability in fisheries systems [81, 82], however examination of perceptions of risk and vulnerability in those systems remains 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 [83, 84]. Risk perception is affected by demographic traits (e.g., age and gender, [79]), attitudes [85], and the social system within which an individual resides [86]. Additionally, feelings of dread and lack of control, varying levels of familiarity, voluntariness of exposure, and observability all affect risk perception [84]. 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 [83]. 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 [87, 88]. 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 [89, 90]. 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 [91, 92]. 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 [88, 93–95]. This variability is relevant as the perception of risk by general public frequently shapes environmental policy and management [96], and is particularly relevant in climate change policies [97, 98].

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 perceived 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.

Methods

To assess perceptions of climate vulnerability in California Current fishers, we developed a survey consisting of three sections: 1) demographic and fishery participation information, 2) observations of ocean change, and 3) 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 [99]. Following pilot testing, we deployed the survey using a mixed-mode method [100]. 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 [82, 101]. Responses to 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 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. [102] and Schumann [103]. The full survey is available in the (S1 Appendix).

Ethics statement

The survey and research methods were reviewed and approved by the University of Washington Institutional Review Board. Participants were informed about the intent of the study at the start of the survey and provided written consent by answering a question acknowledging their willingness to participate.

Analysis

In the vulnerability framework we use, exposure and sensitivity are combined to estimate risk, which when modified by adaptive capacity yields an estimate of vulnerability (Fig 1). Following Samhouri and Levin [104], we estimated risk as the Euclidean distance from the origin in a space defined by exposure and sensitivity (Eq 1). Vulnerability is calculated similarly by factoring in adaptive capacity and estimating the 3-dimensional Euclidean distance (Eq 2). We also explored an alternate method of estimating vulnerability by summing exposure and sensitivity and then subtracting adaptive capacity [61]. Results of the two methods of calculating risk and vulnerability were highly correlated (S2 Appendix, S1 Fig); thus, we present only the results

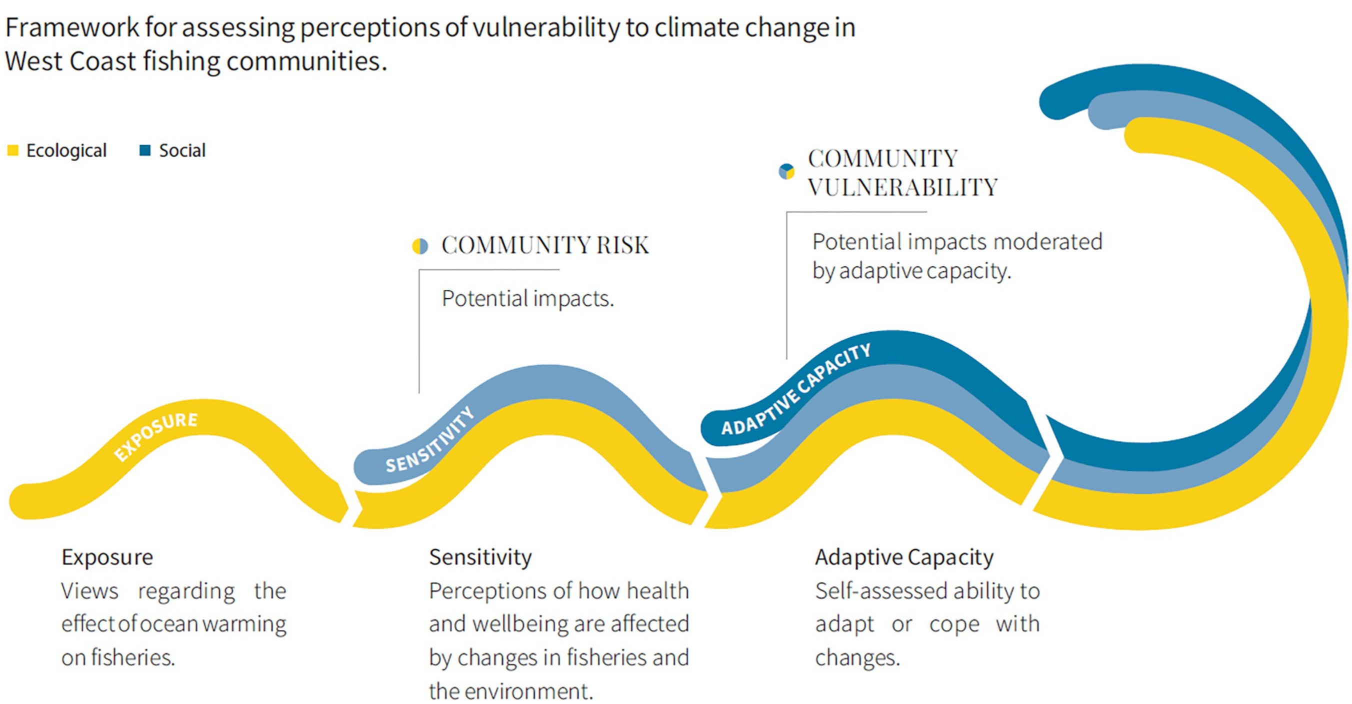

Fig 1. Perceptions of vulnerability framework. Perceived vulnerability of fishers was assessed by combining perceived exposure, sensitivity, and adaptive capacity. Design by SJ Bowden.

https://doi.org/10.1371/journal.pclm.0000103.g001 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 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.

$$r = \sqrt{e^2 + s^2} \qquad \text{(Eq1)}$$

$$v = \sqrt{e^2 + s^2 + (1 - ac)^2} \qquad \text{(Eq2)}$$

We next explored variability in and potential drivers of vulnerability. We used analysis of variance (ANOVA) to test the null hypothesis that perceptions of personal vulnerability do not differ among fishers varying in 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 have 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 [105]. The survey questions regarding age, vessel length, and percentage of income from outside of fishing, and years spent fishing were all categorical, facilitating our use of ANOVA to analyze the responses.

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 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

Table 1. Fishing concerns. Concern themes and the questions that contributed towards 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

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were checked for correlation before clustering. The R package NbClust, which proposes the best clustering scheme after comparing the results from 27 indices [106], 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. [77] and created quadrants characterized 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. The statistical analysis was performed using R [107] while the results of the open-ended questions in the survey were inductively coded and analyzed using ATLAS.ti [108].

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. The survey was ongoing at the time of the onset of the COVID-19 pandemic, and we believe this detracted from our ability to attract participants. Survey participants reported fishing all along the Pacific coast from the Mexico border to Cape Flattery, WA, and participating a variety of fisheries (Fig 2A and 2C). 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 (Fig 2B). 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). Over 90% of the respondents identify as male.

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 (S2 Fig).

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 (S3A Fig). 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). Confidence

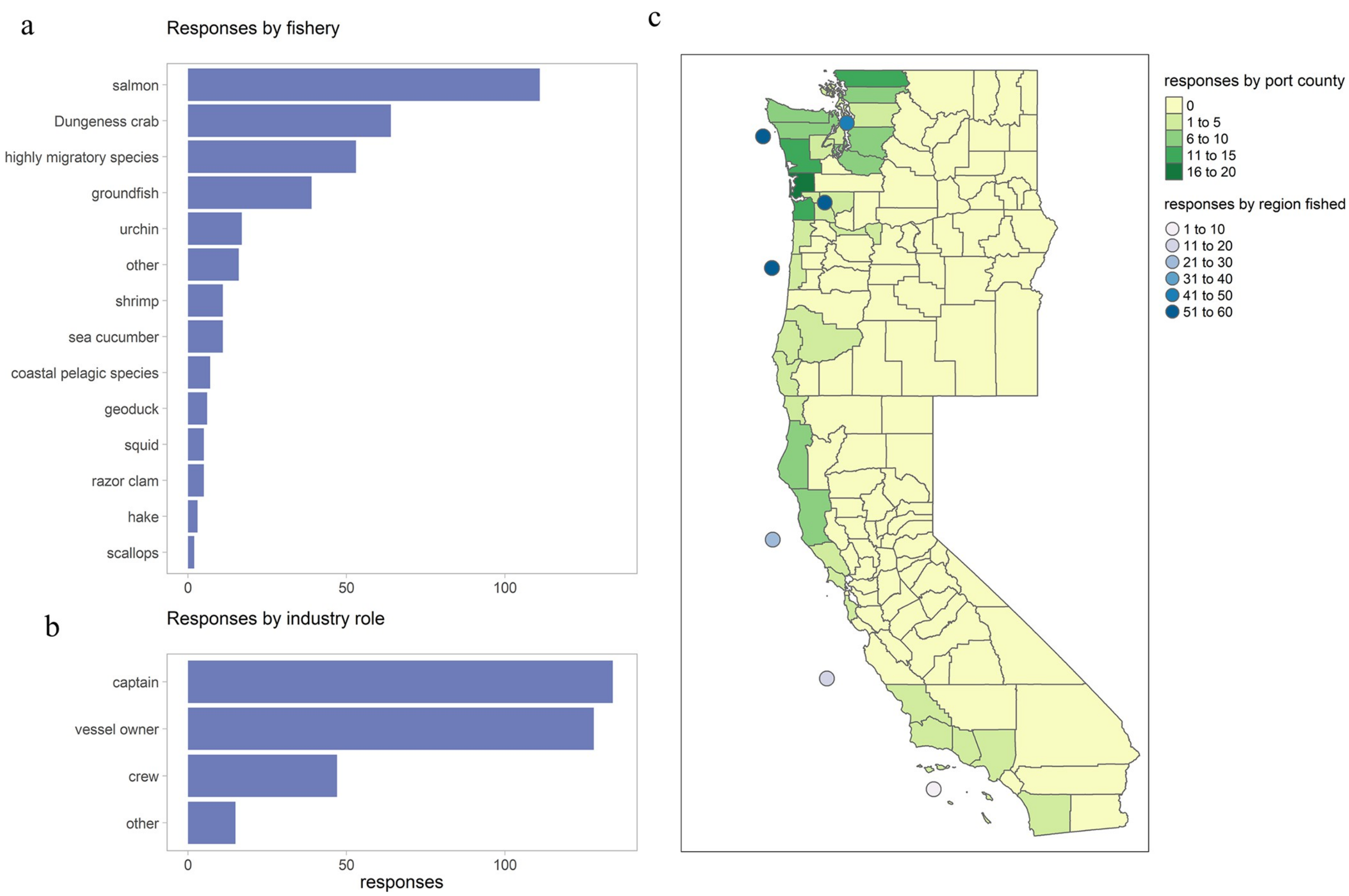

Fig 2. Survey responses. a) Number of responses received by fishery and b) industry role. c) Response numbers by county of homeport and regions regularly fished. Individuals could respond multiple times for each question except for homeport. Fishing regions were defined as: Puget Sound and the Strait of Juan de Fuca; WA Coast–Cape Flattery, WA to Cape Disappointment, WA; the Columbia River; 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. The map was made using the tigris R package which uses TIGER/Line shapefiles from the US Census Bureau. https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html.

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levels were similar across species with 51%-70% reporting high confidence in their responses (S3B Fig). Exposure was calculated based upon this question, but only responses for the fisheries that people participate in were used; versus these results which 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

Table 2. Summary statistics of survey respondents. One individual that lives in Alaska responded, they fish in Washington and were included in the Washington group during analysis to preserve anonymity.

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)						

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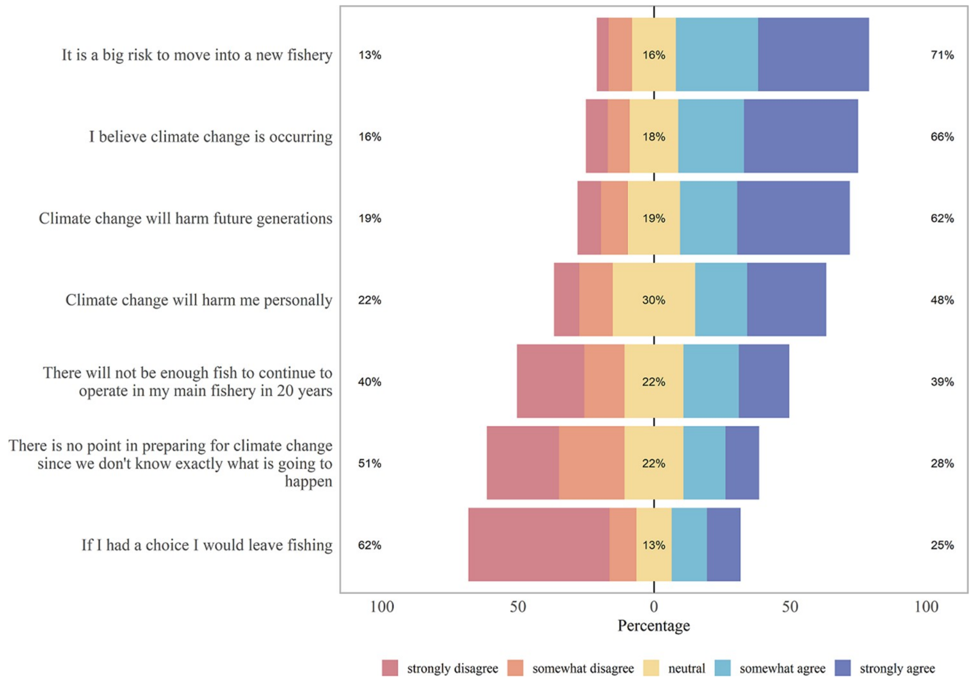

Fig 3. Future of fishing and climate change. The percentage of respondents that agreed or disagreed with the statements on the left of the figure. Numbers on the far right and far left are the sum of the strongly and somewhat agree or disagree responses and those in the middle are the percentage of people who answered neutral for that statement. n = 162.

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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 (Fig 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."*

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 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:

Table 3. Observations of change. 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

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"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."

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 (Fig 4, S1 Table). 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.

Perceived vulnerability generally had higher 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 (S2 Table, $P > 0.05$). Fishers working on larger vessels (>55 ft) generally felt that they had greater adaptive capacity than those working on smaller vessels ($\leq$ 55 ft) ($F = 5.58$, $df = 5$, $P < 0.001$). We did not

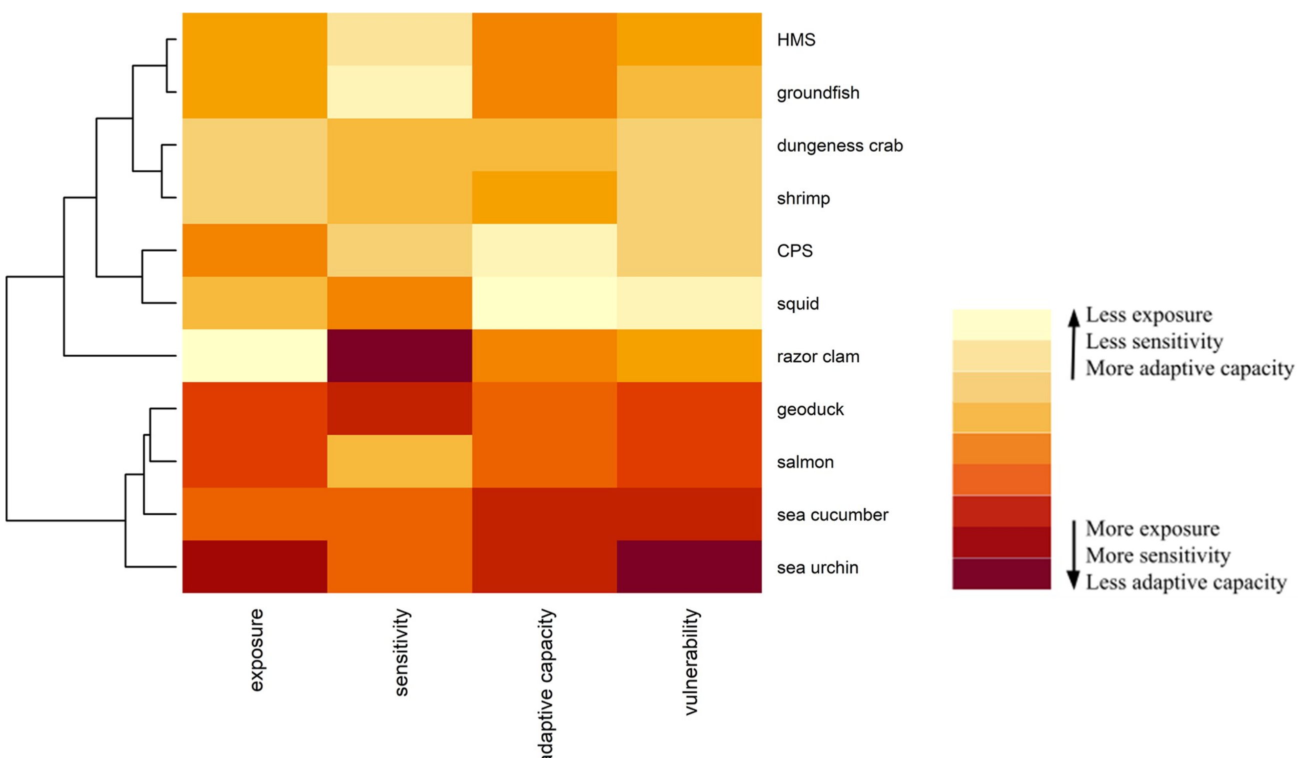

Fig 4. Heatmap of dimensions of vulnerability by fishery. Relative average levels of exposure, sensitivity, adaptive capacity, and vulnerability for select fisheries where darker red indicates a higher contribution to vulnerability. Each column is scaled independent of the others, therefore the score associated with the darkest red in exposure is not equivalent to that same color in the vulnerability column.

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Table 4. Vulnerability scores. Mean scores 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.

		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	

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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 (Table 4, S3). 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 (Fig 5).

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 (S4 Fig). 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.

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 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 (Fig 6; S4 Table).

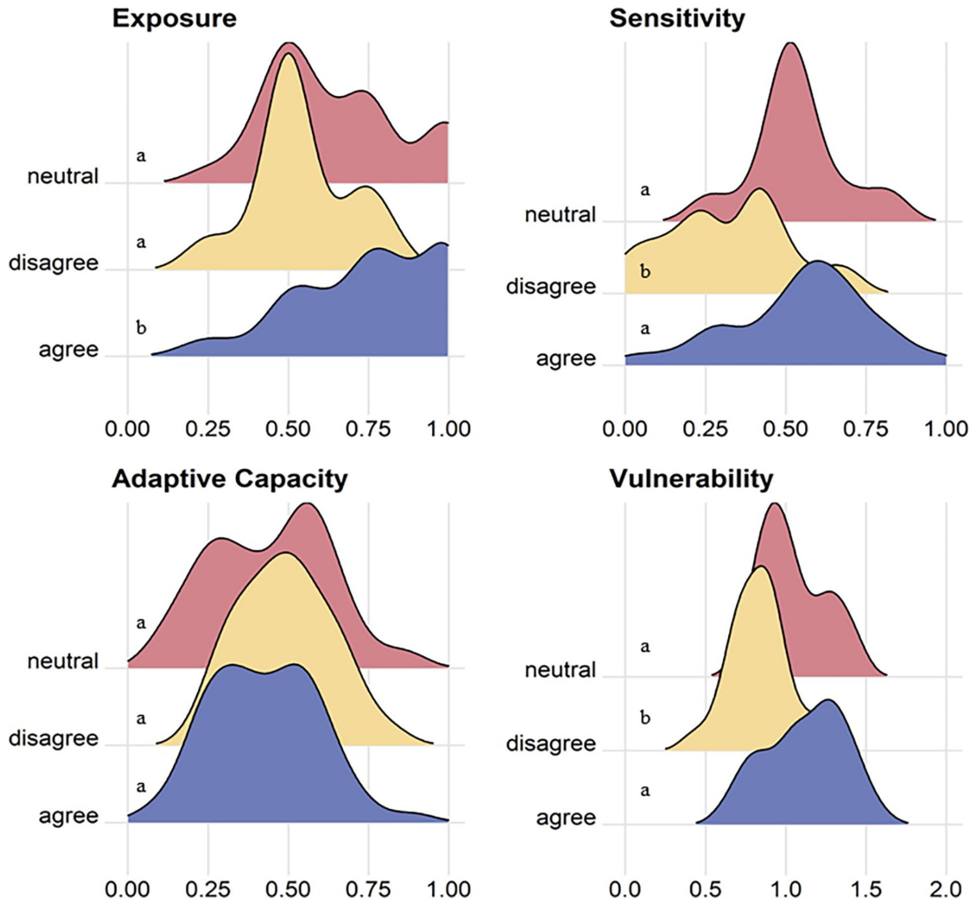

Fig 5. Density curves of components of vulnerability. The distribution of scores within each component of vulnerability is shown with respondents grouped by their responses to the prompt "I believe climate change is occurring." Letters indicate which groups are statistically different ($p < 0.05$) according to the results of pairwise Wilcoxon rank sum tests with Bonferroni correction.

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There was a distinct pattern in how the concern clusters appeared in the vulnerability space defined by average risk and average adaptive capacity (Fig 7). This space is split into four quadrants, or vulnerability profiles [77] 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.

Discussion

Vulnerable populations often experience or perceive their vulnerability in different ways, even people who are susceptible in the same context [109]. We found that fishers from the West

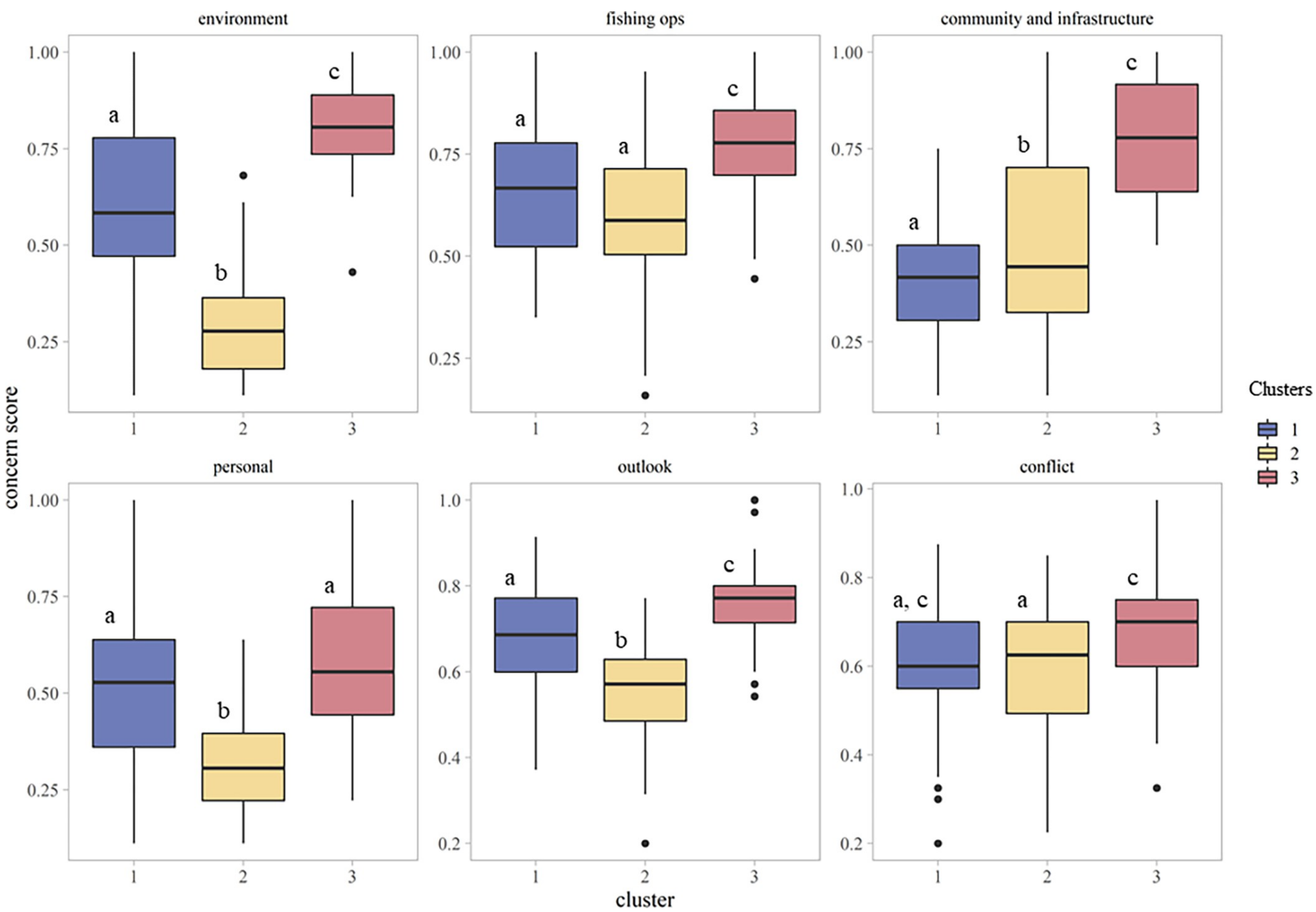

Fig 6. Boxplot of average scores for concern clusters 1, 2, and 3 across the six themes. The line in the middle of the box is the median score, the upper and lower end of the box indicate the 75% and 25% percentiles respectively, and dots represent potential outliers. Because of the way the outlook statements were phrased, a higher score indicates a more negative outlook for future fishing prospects. Letters indicate significantly different groups $p < 0.05$ according to the results of pairwise t-tests. There are 65 people in cluster 1, 60 in cluster 2, and 37 in cluster 3.

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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 [110], and better understanding of community concerns and risk perceptions can highlight issues that, if not addressed, may impact the equity and effectiveness of adaptation [111].

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 [112, 113]. For instance, 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 [114]. In that case, social context affected how risk perceptions were appraised

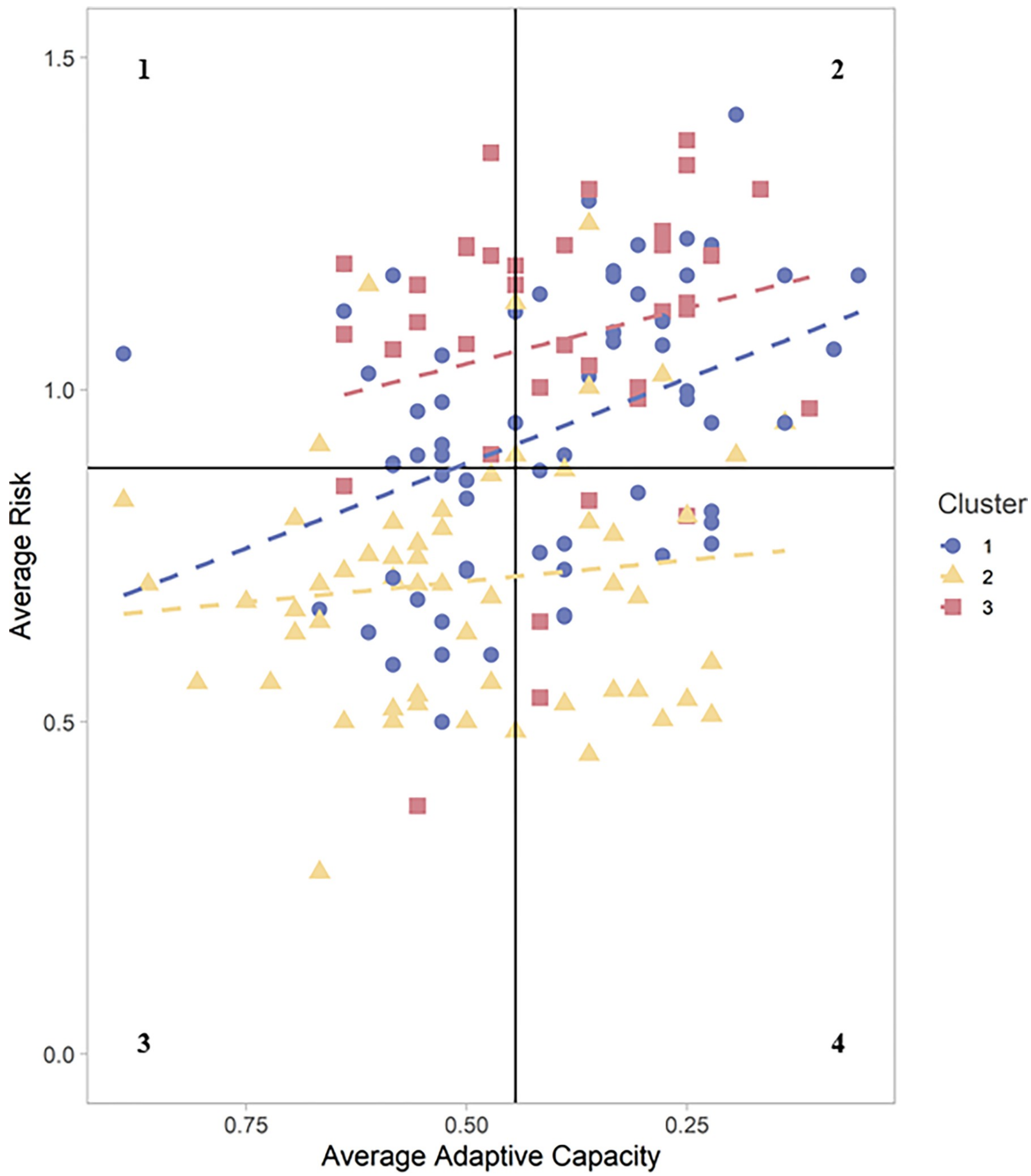

Fig 7. Perceived vulnerability of individuals. Colors correspond to the clustered concern groups and black lines correspond to median risk and adaptive capacity. Quadrant vulnerability profiles are 1. Potential adapters, 2. Higher concern, 3. High latent risk, and 4. Lower concern [77]. X axis is oriented from 1 to 0 because higher adaptive capacity reduces vulnerability.

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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 [115]. 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 [112]. 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 [89].

The generation of vulnerability profiles [77] 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. For example, one group of 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 [116]. 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 [112]. 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 [115].

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 public support of climate policies is also influenced by perceptions of risk [117], and understanding perceptions can help in climate change communication [118], 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 [89], as is overall trust in science [119]. 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 [120], 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 [121]. Efforts are underway throughout the region to develop strategies to support the resilience of fisheries and fishing communities, including initiatives within the Pacific Fisheries Management Council. 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 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) [78, 84], 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.

Supporting information

S1 Fig. Comparison of vulnerability calculation methods. Correlation between risk and vulnerability scores when calculated either by summing exposure and sensitivity and subtracting adaptive capacity (risk and vulnerability) or by using the Euclidean distance method (Euc. risk and Euc. vulnerability). Panels on the left side are scatterplots of each set of variables, the diagonal shows variable distribution, and the results of the Pearson correlation are found on the right.
(TIF)

S2 Fig. Health impacts. 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.
(TIF)

S3 Fig. Views on ocean warming and fisheries. 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.
(TIF)

S4 Fig. Level of concern for select issues that may affect fishing. 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.
(TIF)

S1 Table. Vulnerability scores by fishery. 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.
(DOCX)

S2 Table. Vulnerability comparisons. ANOVA results for selected demographic categories and vulnerability.
(DOCX)

S3 Table. Vulnerability score comparison based on belief in climate change. Comparison between Significance (p-value) for each component of vulnerability from pairwise Wilcoxon rank sum test with Bonferroni correction conducted following Kruskal-Wallis tests.
(DOCX)

S4 Table. Comparison of concern levels between clusters. 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.
(DOCX)

S1 Appendix. Questions included in the online survey instrument.
(PDF)

S2 Appendix. Description and comparison of different methods used to calculate vulnerability.
(DOCX)

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