Title: Facing Change: Individual and Institutional Adaptation Pathways in West Coast Fishing Communities

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1. Introduction

As the impacts of ocean and climate change become more pronounced, fishing communities are experiencing unprecedented disruptions to social and economic life.[1] In the United States (US), environmental changes have resulted in fishery disaster declarations for Dungeness crab and salmon, two economically and personally (e.g., significant for culture and identity) important species for fishers on the West Coast.[2] At the same time, climate impacts are among a constellation of pressures that fishers face (Moerlein and Carothers 2012). Social and economic changes can also have far reaching impacts on fishing livelihoods (Daw et al. 2009). For example, import tariffs (Campling 2015), gentrification (Thompson et al. 2016), and the COVID 19 pandemic (Sorenson et al. 2020) have all impacted business costs, and fishers' access to affordable housing, markets, and revenues. The cumulative effects of environmental and socioeconomic stressors have the potential to cause psychological distress (King et al. 2021), adversely impact the well-being of fishing communities (Breslow et al. 2017), and ultimately create uncertainties for sustaining fisheries-based livelihoods into the future (Daw et al. 2009).

Fisheries research suggests that fishers use a three-prong approach to climate change adaptation: adapting fishing strategies (i.e., where and when they fish) to shifting species distribution patterns, supplementing with non-fishing work, or exiting the fishery, and diversifying their fishing portfolios (Daw et al. 2009, Fuller et al. 2017). However, this understanding of adaptive response is grounded in a narrow interpretation of adaptation that focuses on how fishers are responding to specific environmental shifts linked with climate-driven ocean change. We argue that a broader interpretation of adaptation is required for a comprehensive understanding of fishers' adaptive responses. Instead of examining adaptation in relation to climate driven ocean changes alone, we argue that adaptive responses are shaped by and contingent on compounding social, economic, and environmental stressors.

Fisheries managers have sought out strategies to make management actions more flexible and responsive and to support community and fishery resiliency. For example, in 2017 the Pacific Fisheries Management Council (PFMC), a regional fisheries management body on the US West Coast, launched the Climate and Communities Initiative. The aim was to educate regulators and the public about the effects of short and long-term climate change impacts on fisheries and fishing communities and identify ways to incorporate knowledge about broader ecosystem-wide impacts into policy.[3] While we echo calls for better coordination amongst management entities and for more flexible institutional arrangements, our research indicates that

[1] A fishing community is defined by the Magnuson-Stevens Fishery Conservation and Management Act (the primary piece of U.S. marine fisheries legislation) as those communities which are "substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs." Critics note that this definition is vague and have attempted to develop frameworks for understanding and defining community beyond simple economic dependence to include social, cultural, and place-based factors (see Clay and Olson 2007; Clay and Olson 2008).

[2] A fishery disaster is a term used to describe a natural or manmade event in a commercial fishery in which the fishery incurs significant harm or a serious disruption affecting future productivity. For more information see the National Marine Fisheries Service website https://www.fisheries.noaa.gov/national/resources-fishing/frequent-questions-fishery-disaster-assistance.

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

existing frameworks for adaptive management may not be enough.[4] Industry and managers must think more broadly about how fishing communities can stay resilient and how they might adapt when challenges are multiple, frequent, complex and operating across social, economic, institutional and environmental spheres. Furthermore, although research has produced management frameworks to support adaptation, few concrete examples of management actions exist, particularly actions aimed at compounding social and economic stressors (Chavez et al. 2017). Thus, in this study we focus our analysis on understanding compounding stressors and their impact on adaptation strategies, asking: What actions could management agencies and other institutional actors take to help communities adapt to changing environments?

We share the results from a multi-sited case study in which we conducted a rapid ethnographic assessment of fishing communities on the US West Coast. By examining ocean change in the context of compounding stressors, our study brings two important points to light. First, fishers are employing a wider range of adaptation strategies than previously thought. Second, there are several unrealized institutional pathways that could support and remove barriers to adaption. In the next section, we overview the literature on how fishing communities and management bodies adapt to climate change. Section three provides context on the importance of fishing on the US West Coast with attention to two fisheries: Dungeness crab and Pacific salmon. Drawing on interview data, in section four we argue that understanding adaptation requires examining the social, economic, environmental, and regulatory context which produce compounding stressors that impact vulnerability. Through our analysis we examine existing adaptation strategies, highlighting the spectrum of novel individual actions being taken as well as unrealized institutional actions. In section five, we explore how ocean change compounds existing stressors through two examples, labor shortages and finding new markets. We close by reflecting on how agencies might support climate change adaptation through outside the box solutions that address the cumulative stressors facing fishing communities.

2. Analytical Framing: climate change adaptation in fisheries

Adaptation has always been a key characteristic of fishing-based livelihoods. Yet, the intensity, frequency, variability, and uncertainty of climate changes are argued to make fishers more vulnerable and require an unprecedented scale and scope of adaptive responses (Lindegren and Brander 2018). The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which systems are susceptible to, and unable to cope with, adverse impacts" (IPCC 2007:48). The IPCC defines adaptation as how social and ecological systems react to both real and anticipated climate stimuli to avoid or lessen negative consequences of climate change and/or capitalize on new opportunities and benefits resulting from climate change (IPCC 2007).

Research indicates that fishers' adaptive responses follow a three-prong approach that includes a variety of short and long-term coping and adaptation strategies (Galappaththi et al. 2021). Some fishers adapt their fishing practices, for example, by increasing fishing effort or 'following the fish' by migrating outside of their usual fishing grounds (Papaioannou et al. 2021). As stock distributions fluctuate with changing oceanographic conditions, fishers may follow the fish to a different coastal area to access available species more easily and may do so

[4] According to a report published by the Food and Agricultural Organization of the United Nations, adaptative management is "a systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices." (Bahri et al. 2021).

within or across fishing seasons. In some cases, fishers might even relocate to new ports either temporarily (e.g., in a season) or indefinitely (Chavez and Costello 2017). A second strategy is portfolio diversification in which fishers substitute new or different species in lieu of their preferred fisheries. In effect, this strategy is thought to reduce risks by creating alternative fisheries that buffer the impacts of changes hitting some species harder than others (McCay 1978). A third strategy is to engage in supplemental non-fishing employment or income-generating activities, what is known as occupational pluralism (McCay 1978). In some instances, fishers might exit fishing altogether (e.g., Colburn et al. 2016). However, studies have found that fishers are often unwilling to leave the industry, even in the face of adverse economic conditions (Sievanen et al. 2005, Pollnac et al. 2001, Pollnac and Poggie 2008, Coulthard 2009). While individual fishers are less likely to exit, the labor force is shrinking through a phenomenon often referred to as 'graying of the fleet', whereby fishers are older on average, suggesting more the next generation of fishers are exiting, or never entering, fishing (Haugen et al. 2021).

While valuable in capturing common fisheries climate change adaptation strategies, this three-prong approach reduces the available responses to ocean change. Fishers' adaptation strategies are thus framed as reactive rather than proactive (Lindegren and Brander 2018). Furthermore, a narrow environmental change framing does not address dependencies between coping strategies and the social, regulatory, and economic contexts and structures in which they are enacted. For example, the severity of impacts of climate change and ability to adapt can vary among fishers and fishing communities depending on a range of factors such as the size and scale of a fishing operation (Frawley et al. 2020, Jardine et al. 2020) poverty and economic conditions, fishers' education and training, among many others. In spatially managed fisheries, fixed areas of resource allocation constrain the ability of fishers to adapt when resource availability shifts geographically. Not only does loyalty to traditional fishing grounds reduce fishers' likelihood to follow fish (Papaioannou et al. 2021), but managers also show relative inflexibility to adjust the boundaries of area-based management (Hilborn et al. 2021) and regulatory environments sometimes limit fishers access to fishing grounds (Pomeroy et al. 2010). Likewise, an individual or communities' access to alternative livelihoods or capital will have profound effects on how they can respond when their primary fisheries experience changes in availability or abundance (Lindegren and Brander 2018, Grafton 2010). While the focus of this paper is on non-tribal commercial fisheries, it is important to note that for tribal fishers, these adaptation constraints can be magnified.

Importantly, although fishers and fishing communities employ a variety of adaptation strategies, institutional and other rule-making bodies have lagged in their ability or willingness to adapt and respond. In recent years, there has been an effort to develop institutional tools and management levers for anticipating and planning for increased uncertainty and adaptation. Through this kind of planned adaptation, managers and scientific bodies raise awareness about how fishers and fishing industries are and will be impacted by climate change. These strategies often begin with a vulnerability assessment in which fisheries and fishing communities are evaluated to understand their exposure to risk from climate change impacts. By assessing vulnerability, scientists and managers hope to better understand a community's sensitivity to climate change impacts and its ability to adapt and respond. Managers may then integrate the results to build flexible management tools to reduce such vulnerability and improve adaptive capacity (Grafton 2010). For example, research has recommended that managers can help fishers adapt to climate change by evaluating permitting structures and adopting flexible permitting, control rules and spatial boundaries. Flexible regulatory approaches are critically needed for

changing fisheries, to facilitate access to emerging and underdeveloped fisheries which supports fisher livelihood diversification, and for improved transboundary management coordination (Pinksy and Mantua 2014).[5] Other approaches advocate for collaborative management strategies that involve cross-organizational cooperation and co-management between government and fishing stakeholders (Pinksy and Mantua 2014; McCay et al 2011; Chavez and Costello 2017). Yet, despite these diverse recommendations for adaptive management, research suggests that on-the-ground implementation is significantly lagging (Whitney and Ban 2019; Whitney et al. 2017).

As climate change continues to worsen, research can no longer focus on adaptation in relation to environmental changes alone but must instead call attention the impacts of broader social, economic, and regulatory contexts (Poulain et al. 2018; Cochrane et al 2020; Cinner et al. 2018). We argue that an approach that examines compounding stressors is needed to fully understand the pressures fishers face, and how they respond. A great deal of knowledge exists about climate change, and with it many recommendations for adaptive management tools. However, there are relatively few examples of those tools in practice: how they have been or should be implemented and to what effect. Thus, there is still much work to be done to identify *concrete actions* that fisheries managers and other institutional bodies can take to support adaptation (Lindegren and Brander 2018). It is here that our research intervenes by identifying opportunities for institutional actions that support adaptation by also addressing the compounding stressors that emerge out of social, economic, and regulatory contexts.

3. Case Study Design

3.1. West Coast Fishing Communities and Ocean Change

Commercial fishing is an important economic sector for many communities along the US West Coast. In 2016 (the year before data collection), commercial landings from California, Washington and Oregon totaled 937,749,000 pounds and $688,922,000, accounting for 12% of all US commercial landings by volume and ex-vessel value (NMFS 2018). Part of the California Current, a naturally variable coastal ecosystem that stretches from British Columbia to Baja Mexico in the eastern North Pacific Ocean, West Coast fisheries have historically been subject to consistent variation linked with warm and cool phases in the ecosystem. Yet in recent years, climate change has brought about more extreme and unpredictable variability, with profound social, ecological, and economic consequences for fisheries (Chavez et al. 2017). Pacific salmon and Dungeness crab are two focal fisheries that offer stark examples of the impacts of climate change on fishing-dependent communities. Each holds great significance for West Coast fishers both in terms of economic value and personal importance (e.g., significant for culture and identity) (Figure 1).

[5] See also emerging research on flexible permits at Lenfest Ocean Program. https://www.lenfestocean.org/en/news-and-publications/fact-sheet/new-research-on-whether-flexible-fishing-permits-can-lessen-climate-stress-on-california-fisheries

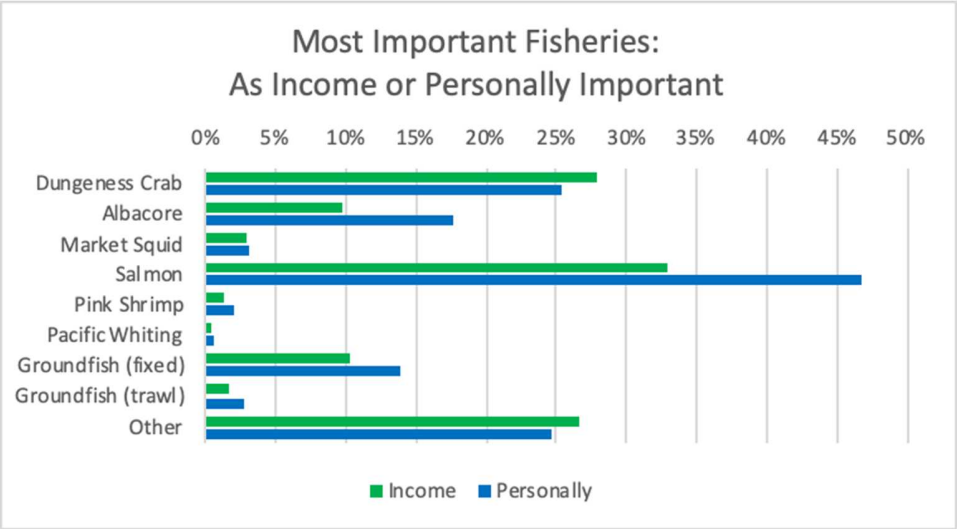

Figure 1: Most Important Fisheries: As Income or Personally Important. Data compiled from responses to the West Coast Fisheries Participation Survey in 2017, see https://www.fisheries.noaa.gov/national/west-coast-fisheries-participation-survey-results. The table compares responses to two survey questions: Which fishery is most important to you personally, not necessarily financially, but in terms of your identity or enjoyment? Which fishery is your most important source of fishing income?

Climate change impacts have resulted in frequent and lengthy closures or delays in the Dungeness crab fishery over the last decade (Magel et al. 2020). Sustained warmer ocean temperatures create ideal conditions for harmful algal blooms (HABs). HABs are linked with the accumulation of domoic acid (DA), a potent neurotoxin with public health risks, in shellfish. From 2013-2015 the Pacific Ocean experienced unprecedented concentrations of warm water. The 'Blob" resulted in the West Coast's longest, most widespread, and economically disruptive HAB event and Dungeness crab fishery closure (Jardine et al. 2020). Communities in Northern California were amongst the worst impacted, prompting a federal fisheries disaster declaration (Moore et al. 2019, Ritzman et al. 2018). Less severe delays have occurred since that time. Extreme marine heatwave events, such as the blob, are also thought to contribute to habitat compression and species shifts, resulting in increased encounters between whales and crabbing gear (Santora et al. 2020). Following the 2015-2016 Dungeness crab delay, crabbers saw a notable increase in the number of humpback whale entanglements, which resulted in additional layers of preventative regulatory measures. In addition, changing ocean conditions are likely to impact the distribution of Dungeness crab, resulting in declining catch particularly for communities in Washington state (Magel et al. 2020).

Salmon are likewise vulnerable to climate and ocean changes. Higher temperatures impact salmon returns and juvenile survival rates. Furthermore, a loss of genetic diversity in Pacific Northwest salmon means they are less able to develop local adaptations in heat tolerance. Changes in streamflow, due to anthropogenic and climate changes (e.g., dams and droughts), are also known to impact some salmon populations (Crozier 2015). As a result, the US West Coast ocean salmon fishery has undergone sweeping declines in catch, frequent closures, and constraining catch limits, impacting fishers in unequal ways (Richerson et al. 2018; Richerson and Holland 2017).

3.2. Management Context: Dungeness crab and Ocean salmon

The commercial Dungeness crab fishery is managed by state level departments of fish and wildlife in both state and federal waters, in consultation with the Tri-State Dungeness Crab Committee. Across all states, Dungeness crab is a restricted access fishery, meaning there are a limited number of permits that have been allocated across the fishery, though the permits are transferable. Management measures include specifications regarding size, sex, season, and gear (e.g., trap limits). All three states have tiered trap limit programs, but there are no caps on total allowable catch. Trap tiers are assigned to the fishing vessel are based on vessel size. The fishery is considered a derby fishery such that most of the catch occurs within the first six weeks after the season opens. In other words, there is pressure to fish early and often or risk losing out on the season. In each state, the fishery is divided into sub-regions which have staggered openings.[6] In Washington, sub-regions in Puget Sound are co-managed with tribal nations, who are also entitled to half of the state's harvest allocation. In California, the California Dungeness Crab Task Force, which is made up representatives from across industry, management and the conservation sectors, advises on management decisions (CDFW 2020, ODFW 2022, WDFW 2022).

The ocean salmon fishery is managed by the Pacific Fisheries Management Council, a federal fisheries management authority. Salmon caught within three miles of shore or in freshwater fall within state jurisdiction, however the states' regulations for ocean salmon match the federal regulations. Management measures include quotas and specifications regarding size, season, gear, and area restrictions. Seasons are dependent on region, and season length and quotas are dependent on annual salmon returns. In most regions, the start of salmon season closely aligns with the end of Dungeness crab season. Salmon is also a limited entry fishery. In Washington and in some regions in California, the commercial salmon fishery shares allocations with tribal fisheries and in Washington the fishery is co-managed by the state, the federal authority, and tribal nations.[7]

3.3. Research Methods

For this study, we employed a multi-sited Rapid Ethnographic Assessment (REA) (Sangaramoorthy and Kroeger 2020) to assess fishing community adaptation strategies. REA is a methodology developed first in public health and later in other fields such as disaster response, epidemiology, or more general social and environmental assessments that must serve immediate data needs (Trotter et al. 2001). Data collection techniques include participant observation and interviews, both used to develop a deep understanding of the phenomena of interest during a relatively short period 'on-site', compared to traditional long-term ethnographic encounters which often last several years. Furthermore, unlike the 'one ethnographer' model of traditional ethnography, REA projects involve an ebb and flow of multiple researchers and often include members of the community at different stages in the process (Pink and Morgon 2013, Taplin et al. 2002). We developed our study design using grounded theory (Glaser and Strauss 1967): interview questions emerged out of preliminary conversations with West Coast fishers, which were then piloted with a small subset to hone our interview guide. The research design followed

[6] In California the fishery is into the Northern and Southern regions, and the Northern region is subject to preseason quality tests to ensure no domoic acid is present. In Washington the fishery is managed as two separate fisheries, the coastal fishery, and the Puget Sound fishery. For this study respondents participated in the coastal fishery only.

[7] For more information on Ocean salmon management see https://www.pcouncil.org/managed_fishery/salmon/.

ethical protocols common to ethnography and was reviewed by the University of Washington Institutional Review Board to ensure minimal risks to people (HSD study #51793).

Our research sites included Westport, Washington, Coos Bay/Charleston, Oregon, Crescent City, California, and Bodega Bay, California. We used two metrics (Table 1) to select communities: the NOAA Community Social Vulnerability Index (CSVI) and an index assessing West Coast fishing community dependence on Dungeness crab specifically (Norman personal communication, see also Magel et al. 2020, Moore et al. 2019 for an explanation of the Dungeness crab dependence ranking).[8] We selected communities that ranked as 'high' commercial fishing dependence and 'high' Dungeness crab dependence.

Table 1: Summative details for community selection criteria.

	Number of Interview Participants	Total Population 2018	Median Age 2018	% Below Poverty Level*	CSVI Social Vulnerability Ranking*	CSVI Fishing Dependence*	Crab Dependence*
Westport, WA	15	2,091	41	24%	High	High	High
Charleston/Coos Bay, OR	11	16,176	41	19%	High	High	High
Crescent City, CA	9	6,681	34	31%	High	High	High
Bodega Bay, CA	12	733	65	5%	Low	High	High

*Rankings at the time of study in 2017.

Interviews and field visits took place from April-August 2018. Interviews were conducted with commercial fishers and other members of the fishing community. Participants were recruited through non-probability sampling techniques (purposive and snowball) as well as through a random dock-side intercept. We selected interview participants from those who indicated in a previous coastwide survey that they'd be interested in a follow-up interview that constituted the first round of recruitment contacts.[9] We identified additional participants based on interviewees' recommendations and through internet searches for individuals who were involved in the fishing industry either as commercial fisheries or in some other capacity (e.g., community group). During site visits, we conducted dockside study recruitment.

We collected data using semi-structured interviews primarily in-person at the respondents' place of work (e.g., fishing vessel). Interviews were conducted by researchers based

[8] The CSVI utilizes 14 indicators that describe and evaluate a coastal community's adaptive capacity. The indices measure facets of commercial and recreational fishing dependence, among other attributes that impact vulnerability. The CSVI classifies communities as 'low', 'moderate', and 'high' commercial fishing dependence. The CSVI map tool can be found at https://www.st.nmfs.noaa.gov/data-and-tools/social-indicators/.

[9] See Holland et al. 2020 for partial results from that survey and discussion of methods. Additional data can be viewed and accessed online at https://www.fisheries.noaa.gov/national/west-coast-fisheries-participation-survey-results

at the University of Washington and the National Marine Fisheries Service Northwest Fisheries Science Center who had no specific ties to the study sites. During semi-structured interviews, fishers were asked about their fishing history and business, observations of novel changes in the ocean environment and how these changes affect well-being, and to identify the actions they have taken to cope with the challenges of environmental change. They were given a series of prompts describing potential actions derived from the literature on fishing community adaptation and resilience to climate change. They were also asked to identify future actions or strategies that either they, or external organizations and institutions, could use to help them adapt. A list of interview questions is included in the supplemental materials.

4. A compounding stressors approach to vulnerability and adaptation

Climate change and related changes in the ocean are already impacting fishers and fishing communities (including participants in the Pacific salmon and Dungeness crab fisheries described above), and these impacts are likely to increase over time. But ocean change is just one of a constellation of pressures that fishers must cope with in the day-to-day operations of a fishing business. During interviews, fishers highlighted the daily pressures they face, which are not always directly linked with climate change, as well as the structural and institutional barriers that produce new, or complicate existing, pressures. We grouped fishers' responses based on their primary fishery (i.e., Dungeness crab or Pacific salmon) and categorized stressors according to five thematic areas that emerged through their responses: environmental, regulatory, economic, operational, and social (Table 2). Our findings indicate that fishers and fishing communities are suffering from chronic social and economic hardships and regulatory barriers that limit their adaptive capacity, making them more vulnerable to the negative impacts of acute and emerging environmental change. In short, ocean changes make a hard-living harder.

Table 2: Climate change impacts by fishery and compounding stressors

SALMON		CRAB	
Climate Change Impact	**Compounding Stressors**	**Climate Change Impact**	**Compounding Stressors**
Drought, warming waters -closures -low harvest -fishery/econmic disaster and impact	ENVIRONMENTAL: habitat loss/dams water quality pyrosomes predation (birds, sea lions) reduced baitfish bad weather days REGULATORY: hatchery loss water allocations (e.g., seasonal timing and agricultural diversions) sectoral conflicts (i.e., tribal, recreational & charter fisheries) sea lion management politics of management conservation restrictions on other fisheries rising permit costs repacking liferaft yearly ECONOMIC: rising business costs repacking liferaft yearly disaster releif slow or never realized rising permit costs OPERATIONAL: access to skilled crew boats not suited to other fisheries loss of infrastructure rising permit costs SOCIAL: graying of the fleet caring for self/family ports promote recreational fishing lack of local seafood	**Harmful Algal Blooms (HABs) Domoic acid** -delayed and unpredictable openings -fishery/economic disaster and impact	ENVIRONMENTAL: Safety risk in foul weather Whale entanglement REGULATORY: spatial area limits fishing pressure derby style conflict with tribal fisheries rising permit costs direct-to-consumer sales restrictions ECONOMIC: buyer consolidation increased permit costs rising business costs price flooding rising permit costs OPERATIONAL: access to skilled crew permit consolidation rising permit costs large/small boat competition safety at sea SOCIAL: graying of the fleet caring for self/family health insurance (i.e., coverage costs & requirements) lack of local seafood

Some stressors crosscut categories, illustrating an additional aspect of their compounding effects. For example, fishers named rising permit costs as a regulatory barrier, however the increased cost of permits creates operational and economic challenges. As will be discussed in section 4.1, permit costs pose obstacles for fishermen to diversify their portfolio limiting adaptative responses when a fishery is impacted my climate change. Likewise, permit costs can create barriers for fishing crew who aspire to build fishing businesses of their own. This is not to downplay the importance of permit fees for management purposes or to replace fishers' income in the case of permit lease or transfer. However, it is critical to acknowledge the potential impact that permit costs may have on the social sustainability of the fishery. As will be discussed in section 4.2, this has a cascading effect of leaving crew in precarious working conditions, more vulnerable, and with fewer adaptive responses available when climate change impacts fisheries. In concert, these and other stressors compound the impacts of ocean and climate change, further hampering fishers' adaptive capacities.

4.1. Individual and Institutional Adaptation Pathways

Through our interview questionnaire, we asked fishers to describe the strategies they use to mitigate the impact of compounding stressors and climate-driven ocean change. Our findings

show that by examining adaptation using a broader definition that considers the impacts of compounded stressors, the adaptive responses we observe among fishers and fishing communities are more diverse than previously thought. We developed an adaption matrix (Table 3) to understand the range of adaptive responses available to fishers. We used the matrix to differentiate between existing strategies fishers employ, and possible future strategies that they could adopt. We classified fisher adaptation strategies as either 'conventional' (i.e., the three-prong approach to adaptation) and 'novel' (e.g., unexpected or creative). We further categorized novel strategies using the same five thematic areas noted previously. Two points become apparent when we assess the matrix. First, fishers are implementing a wide variety of novel strategies that in fact outnumber the conventional strategies previously thought to characterize adaption. For example, with many communities seeing their fleets shrinking, there fewer opportunities for informal socializing and information exchange locally. Many fishers have begun using social media to fill this void. Referencing a fishers' group on Facebook, one fisher explained:

> That's the only reason I have a Facebook account. No joke. That is the only reason I have a Facebook account because the information is on there… Like the domoic acid test. They pop up on there long before Fish and Game releases the results. Prices, and everything shows up on there long before we ever hear about it as a fleet. Now, social media is providing us with 60% of our information." (CR6)

The second point that becomes clear when comparing existing actions to possible/future actions identified by fishers is that many feel they have exhausted their options. For example, some fishers noted that they could potentially explore new markets and fisheries, however as we will discuss in the next section, there are numerous challenges to adopting this strategy.

Table 3: Individual/Community adapation pathways, exisitng and possible future strategies.

Adaptation Pathways: *Individual/Community*		
	Existing Strategies	**Possible/Future Strategies**
Conventional	Fishing Strategy - Fish farther away or more frequently (crab) - Fish in foul weather - Relocate to a new port - Reduce fuel usage (fewer, closer, slower trips) (salmon) Diversify portfolio - Collect permits - Find new buyers/new markets Non-fishing Work - Sitting out season/roll with punches - Exit	Diversify Portfolio - Access new/emerging fisheries - Find new marktets, buyers Non-fishing work - Exit
Novel	*Economic* *- Rely on family or partner income* *- Startup loans, take on debt* *- Use savings, financial management* *- Buy permits for children (future planning)* *Regulatory* *- Dungeness Crab Task Force* *- Participate in management* *Operational* *- Improve boat/new technology* *- Preventative boat upkeep* *- Social media for information/crew* *- Hire crew from other cities* *Environmental* *- Fishing association helped with hatchery* *Social* *- Community efforts (Build shared hoist, outreach)* *- Labor Strike*	*Economic* *- Loans* *Regulatory* *- More involvement in management*

Fishers also discussed existing and possible/future actions that could be taken at the institutional scale, which we characterized in a similar adaption matrix (Table 4). A stark difference is clear when comparing the Individual/Community and Institutional Adaption matrices: they show an inverse relationship between the actions taken by and available to fishers and institutions. This leads us to a second key finding from our research which is that unlike fishers who are currently exploring a wide range of novel adaption strategies, with few options remaining, there are numerous unrealized institutional pathways that could support and/or remove barriers to adaption.[10] Fishers had many ideas for actions that institutional actors, such as resource management and regulatory agencies, could take to support and enhance adaptive responses. Some of these align with conventional wisdom on adaptive management, for example,

[10] It should be noted that some of these suggestions, like all management actions, may come with social, economic, and biological/ecological risks or unintended impacts. Though it is beyond the scope of this paper, each suggestion should be carefully evaluated before implementation to ensure the benefits warrant current or potential future consequences.

creating more flexible regulations and opening new fisheries. Fishers also identified innovative solutions that crossed regulatory, and agency siloes. These imaginative and outside of the box strategies, such as developing boat share programs or offering staggered payment plans for required life raft inspections and repacking, would provide fishers the support they need to overcome compounding stressors that stymie their ability to adapt to environmental changes.

Table 4:Institutional adapation pathways, exisitng and possible future strategies.

Adaptation Pathways: *Institutional*		
	Existing Strategies	**Possible/Future Strategies**
Conventional	Economic - Disaster funds - Loans/advances from buyers Environmental - Hatcheries Regulatory - Improved Management (Dungeness Task Force, pot limits)	Economic - Disaster funds (accessible to crew) - Buy back program for exit (salmon) Environmental - Hatcheries – more, improved Regulatory - Change management tools (e.g. open access, reduce pot limits) - Open new fisheries - Ease conservation area restrictions for other species
Novel	*Economic* *- Loans/advances from buyers*	*Economic* *- Start up capital/financial backing (crab)* *- Diversify processor/buyer sector* *- Support building new markets/cooperatives* *Environmental* *- Salmon Habitat Restoration - remove dams* *- Sea lion management actions* *Regulatory* *- Liferafts - alleviate cost burden (payment plan, reduce frequency)* *- Permit on owner not boat, lottery* *- Account for bad weather days in season length* *- Timing/sequence of openers (e.g. by sector and/or vessel size)* *- Improve/update science, data and testing* *Social* *- Boat share program* *- Fisherman's training and mentorship program* *- Crew insurance (health, liability)* *- Crew labor hub website*

5. Examining pathways and barriers to adaptation under compounding stressors

We now focus our discussion on two specific compounding issues that fishers across all case studies were coping with: labor shortages and limited capacity to develop new markets. These issues offer illustrative examples of how environmental change compounds socioeconomic stressors and how institutional actors constrain, or could potentially enable, fishers' adaptive capacity.

5.1. Portfolio diversification in the context of compounding stressors: Challenges to developing new fisheries and markets

One of the biggest challenges of ocean change is the impact it has on fishing income. Fisheries economists promote portfolio diversification as a means for fishers to mitigate the economic impacts of income variability (Kasperski and Holland 2013). However, our findings indicate that adding new fisheries is not always a pragmatic option for fishers, particularly as a stopgap in the case of unexpected fishery changes or closures. Accessing new or varied fisheries can also mean facing compounding social environmental, economic, and regulatory challenges. Most obviously accessing new fisheries requires other fisheries to be present, but may also mean as needing specialized knowledge, training, new or different gears, capital funds for permits, or overcoming structural and institutional barriers to developing new markets. The quote below demonstrates how cascading effects from environmental change and other factors constrain a fisher's ability to diversify their fishing.

> What we used to be able to do is we could fish crab, make whatever money we could fishing crab, and then we could swing around saying, "I'll make it through the summer with my salmon fishing." Well, now there's no... there's this big gap, and most of the guys can't afford that. So, they're looking for every opportunity. And unfortunately, due to regulations and everything like that, and the problems we've had with the rockfish, we haven't been able to fish offshore for rockfish for a number of years. That used to be a potential income, not much, but something to keep you going. Well, the guys don't have that anymore. So now the next focus is the black cod. And so, they're trying to make some money fishing black cod. Well, that's all weather dependent and how much gear you can't put in the water and so on and so forth. (B1)

For a new fishery to have a return on the investment, there needs to be a profitable sales outlet. Consolidation in the fishing industry has meant a reduction in the number of buyers and processors, and many fishers have little or no choice about who they will sell their fish to locally. As one fisher put it bluntly, "Basically the fisherman's biggest problem right now that puts him on the brink of survival is marketing." (CR5). Large-scale corporate buyers may not be as willing to process small volumes of niche species. For example, if a fisher wanted to diversify their portfolio by periodically fishing an open access fishery, the catch limits may be too low to meet the processor's requirements, or the processor may be unwilling to or unable to find buyers without product regularity. Likewise, if fishers opt to diversify their portfolio, they may not be able to generate enough income to support their crew, contributing to labor issues which we discuss in the next section. The exchange below illustrates this point.

> Interviewer: Is it viable to have lots of little niche fisheries, like black cod, once or twice a month throughout the year? And a little rock cod here on the side. Is that a way to

diversify the portfolio in a way to make it more sustainable to have a fishing base livelihood?

Fisher: If you could put enough of that together to where it makes it work out, to where you can keep a crew, absolutely. But the way it is now, I mean, the bite catch on the black cod, is something to do. It's not enough to make it through the season, no. No, I mean, your crew is not making enough money to ... They're making the money for a day, but they're not making the money for a month. (BB12)

Some fishers have been able to develop niche markets and value-added products. For example, we spoke to a fishing family who ran a profitable fishing business, canning their product for sale to retail outlets and direct to consumer. Not only did their niche product and market create added value, but as a couple they were able to share in the added workload that comes with marketing. Despite their success, expressed deep concern over the financial stability of their business particularly as they attempted to raise a family. Most fishers, however, expressed that developing new markets was especially challenging without the help of a spouse or business partner, because of the time it took to find buyers, maintain relationships, and market products and deliver products. As one fisher explained when asked if they had considered self-marketing:

I think it would be wise to do, but unfortunately, that takes a whole lot of time, do you know what I mean? There's only so much time. You got to be working out there catching the product. If you're trying to market it yourself, it's a whole other ballgame. (CR4)

In efforts to develop new markets, other fishers have faced institutional barriers. For example, a fisher was unable to obtain clear information on the rules and regulations for transporting catch over state borders, where they could fetch a higher price for their catch. In another instance, fishers in a port had attempted to supplement their primary income from processors by building a public hoist where they could offload to sell their product at local farmer’s markets. However, they faced threat of repercussions from the local processors. As this fisher explained.

We got a person to run the hoist and then she was gonna go around and sell to farmer's markets and just take a little bit of product from each boat. Unfortunately, when the other buyers found out, they were like, "Well, if you take any of your product over there, take it all and don't come back to us." So, and that kind of really hurt because, obviously, that little [community] hoist couldn't take all of the product from all of our boats. So instead of us being able to just give 'em a little bit and let the thing build, we were kind of shut down that way. And it made guys scared because if you gotta have some place to sell your product and it was a risk to take it over there. (BB12)

However, even when fishers can find marketable secondary fisheries, prosecuting those fisheries may not be a profitable solution in instances of rapid environmental change. For example, the 2015-2016 Dungeness crab season opening was delayed for four and a half months due to potentially toxic domoic acid levels. Public health officials and scientists repeated tests weekly and sometimes daily, meaning that at any moment the fishery could reopen without

warning. Fishers reported in our interviews that the option of fishing less profitable secondary fisheries during the closure posed too much financial risk with the opening of Dungeness crab being so unpredictable. This was in large part because Dungeness crab was their most profitable fishery, with the highest value fetched at the beginning of the season. Not only would fishers risk lost time returning to port at a moment's notice, but the process of switching fishing gear between Dungeness crab and other fisheries was also costly, and time and labor-intensive. As one fisher explained:

> In 2015, the boat was ready to go crab fishing for the November opener in San Francisco. By October, we were stripped down, poles were off, we were rigged for crabs, boat was loaded with gear, I had the crew lined up and everything. That closure lasted all the way out until the middle of May of 2016. Well, the salmon season opens on May 1st of 2016. In order to prosecute that crab fishery, I basically had to take a pass on the salmon fishery. Right? Can't do them both. That was it. Basically, it created its own little disaster in the salmon fishery, where a lot of guys were unable to participate in that fishery in order to get our crab season done. (OC2)

As this quote demonstrates, environmental change does not happen in isolation, and often secondary fisheries are also in decline or negatively impacted, as with fishers who fish for salmon and Dungeness crab, a common fisheries portfolio, creating a one-two punch (Fuller et al. 2017).

In summary, while diversifying one's fishing portfolio has the potential to provide more distributed and less variable income, many profitable fisheries require expensive permits or gear improvements to participate. Supplementing with small-scale open-access fisheries is only an effective option if fishers can find outlets to move small volumes of niche products. Time constraints and institutional barriers limit fishers' ability to develop new markets.

In the face of these compounding challenges, fishers identified potential pathways for adaptive response. Specifically, fishers identified possibilities for institutional support to improve marketing opportunities and disrupt buyer consolidation. Innovative solutions included: developing a fisher co-op or an online fish auction platform that connected fishers to buyers in real-time. Institutional support for building market infrastructure emerging from the public sector could therefore prove an important pathway to adaptation and building community resilience.

5.2. Compounding social and operational stressors: Coping with labor shortages

Fishers from all ports identified the lack of a skilled fisheries labor force, specifically difficulties finding and retaining skilled crew, as a major inhibitor to running a successful fishing business. As one fisher put it, "Everybody has crew problems. It's not lucrative enough for anybody to make a living." (B6). It may mean they have fewer fishing opportunities when crew are unavailable. Captains need and expect crew to be experienced and knowledgeable for the obvious reasons of safety and increased efficiency, but also to ensure compliance with fishing regulations. The stress of fishing with inexperienced crew that lack adequate knowledge of regulations is compounded by an increasingly complex regulatory environment. As the following quotes illustrates:

> "If a deck hand, say my deck hand messes up and puts an eighth one on there, and I get boarded by Fish and Game, I'm going to get fined, and possibly have my permit pulled, just because a kid that's new made a mistake." (CC6).

Although there are multiple reasons for this perennial labor shortage, they are intrinsically linked to environmental and regulatory changes. For example, salmon boats provide an ideal entry-level position for commercial fishers to 'get their sea legs' because they fish nearer to shore in safer, slower-paced, and less intense environmental conditions than what they might face in fisheries such as Dungeness crab and albacore tuna. Many of the fishers we interviewed got their start in the fishing industry by crewing on, and eventually buying a salmon boat. However, declines in salmon returns and closures make salmon an unreliable fishery for new fishers. As this quote illustrates:

> I have a couple of young crewmen that would like to fish, run their own boats and everything, but it's so expensive to get into, and what's changed there from when I got in ... When I got in, like I said, we had full salmon seasons. You could go buy a little junkie trailer boat to start with, you know, make a few dollars and work your way up. Well, now, because of the uncertainty of the salmon seasons, you know, you won't make any kind of investment that you're unsure of, and then also attached to getting into any fishery now is permits, and the permits are worth more than these boats, and it takes a lot of money to get into it anymore…(B4)

Because of closures many older fishers skip fishing seasons, or exit the fishery altogether, reducing crew employment opportunities. This results in fewer opportunities to train and mentor prospective fishers, particularly those who do not come from a fishing family. Therefore, the decline in the salmon industry contributes to labor shortages through the loss of consistent paid employment and decreased workforce development opportunities.

Even profitable fisheries such as Dungeness crab face issues with crew retention. Domoic acid has caused closures and delays in recent years that can last for months at a time. Captains and vessel owners generally have greater financial security than crew through savings or loans (accessible with the collateral of the boats), and they are eligible for disaster relief funds in extreme cases. This is in stark contrast to crew who lack access to a formal social safety net. Crew cannot access disaster funds or loans and may not be able to withstand the extended loss of pay during a fishery disaster. Thus, the conventional strategies used by institutional actors are of little use in addressing the socioeconomic stressors compounded by climate change.

To address these compounded stressors, fishers turned to novel adaptation pathways. In terms of possible institutional support, they recommended the government develop fisheries disaster funds and resources aimed at crew. However, fishers have already begun implementing novel adaption strategies as a stop gap. In one instance fishers rallied community support for crew during a Dungeness crab delayed opening:

> "What I did for the crew members out here when we had the domoic acid issue was I went to the county and asked for help for the crew. Because I felt that the captains can make it, we can make it through the long four or five months that we're not gonna get any income. But the crew can't. They're relying on us. So, what we were able to do is I

got funding from the community around here. We set up a food bank. We actually got $100 per crew member every week for a while to help them out food-wise." (B1).

Finally, fishers reported that the shortage of skilled labor is due to a more systemic problem in which young fishers face insurmountable financial barriers to entering the fishery as an owner-operator. Though limited entry programs have helped ease fishing pressure and ecological decline, they have also made the cost of permits skyrocket as fishers must buy or lease the permit from another fisher in a limited entry fishery. This in turn has made it impossible for a fisher to enter the fishery without substantial financial backing or a family connection through which they can inherit permits. With little hope for career advancement, few crewmembers are compelled to develop the skills and experience they would need to make careers out of fishing. As one fisher explained:

> Today, what I'm seeing happened and the change from when I came into it with basically nothing but just a desire to fish and a little bit of money is that today, for me to walk into the fishery and the business that I have, I would already have to have a strong backing, financial backing to get involved. You don't see the opportunities today that you did 30, 40 years ago when I was involved. (CB1)

Fishers have developed several adaptive strategies to cope with skilled labor shortages that are compounded by economic, regulatory, and environmental factors. Many fishers are turning to new channels for connecting with crew. As one fisher told us "Lot of these old captains that are in their 60s and 70s have turned to social media to try to find new deck hands." (CC6). Smaller operations that are unable to recruit crew from the limited pool of skilled labor, have coped by sometimes choosing to fish alone, with family or with fewer crew than needed. However, these choices can lead to safety risks when boat captions fish with fewer crewmembers, or inexperienced crew. Fishers also reported hiring or retaining older crew, who may not be as agile or fast as a younger person, in some cases resulting in a less productive trip and greater risk of injury. As one fisher explained:

> "When I first started, 18 to 25 was your good deck hand because they were young, strong, fast. Now they'll just take guys that are reliable. I got one guy on my deck that's almost 50 years old. I take him because he's so reliable, and he knows all his stuff. He knows his knots, his splices, knows how to net pots, knit net. I mean he knows how to work in hydraulics. He knows how to drive the boat if something's wrong, or I need a nap, or I'm sick. He's almost 50 years old. To find a deck hand 18 to 25 that's worth a shit anymore is damned near impossible. It just doesn't happen." (CC6)

For their part, crew may cope by seeking out alternative employment, for example in construction or some other form of skilled labor, limiting their availability or willingness to engage in fishing if they have found more consistent employment through other occupations.

While fishers felt limited in what additional strategies, they could employ to solve labor issues, they had many suggestions for institutional pathways for adaptation. Several fishers suggested that creating financially secure training opportunities for young fishers, such as a vocational training or apprenticeship program would be beneficial. Yet training fishers only solves part of the problem. To maintain crew in the industry, external support is needed to

overcome barriers to entry that prevent young fishers from transitioning from crew positions to viable fishing careers as captains or owner-operators. In this regard, fishers suggested financial support programs that could provide start-up capital for permits, or boat and gear share programs or disaster relief programs aimed at supporting fishing crew.

6. Conclusions

Where climate change intersects with fishing livelihoods, there are a wide range of stressors compounding the impacts to people and communities dependent on the ocean. These stressors include a variety of environmental, regulatory, social, and economic factors. Together, these factors constitute what Moerlein and Carothers (2012) describe as "total environments of change", where the combined effect can be greater than the sum. In this article, we have argued that climate change adaption must studied within the broader context of compounding stressors to understand an individual and community's adaptive capacity. As we have demonstrated, ocean change, in conjunction with compounding stressors, can be a tipping point pushing fishers beyond their capacity to cope or adapt. Biological stressors resulting from ocean change are difficult to predict, making them notoriously hard to incorporate into fisheries management and business decisions. Thus, to be effective, adaptation solutions must address the synergistic effect of cumulative stressors. But to do so, managers must think beyond the immediate impacts of ocean change and consider interdependencies across social, economic, and geographic scales.

Our research indicates fishers are utilizing a variety of strategies to cope with changes, including many novel adaptative strategies that help them manage compounding stressors. They are in effect already using all the tools available to them. In contrast, institutions, such as fisheries management agencies and county economic development districts, are not taking as varied approaches to meet challenges, and conventional government programs (e.g., disaster funds) may only have limited effects. Our research points to two underutilized, and potentially more impactful, adaptation strategies available to supporting institutions: 1) employing solutions to compounding social and economic stressors and 2) reducing and/or mitigating barriers to adaptation. Within these two strategies, there are many possible solutions to pursue.

Most broadly, to move towards more creative and novel climate-resilient fisheries management strategies, we recommend climate adaptation visioning in which managers engage fishers. As frontline workers, fishers possess innovative solutions and expert knowledge about how to meet their individual and community needs. While the research presented here offers a window into the challenges fishers face, and possible solutions, we see great potential for managers to create opportunities for dialogue with fishing communities aimed at understanding their needs. Additionally, addressing these complex and multifaceted problems will likely require new kinds of multi-scalar and multi-sectoral partnerships that work across institutions at multiple levels of government and the private sector (Mills et al. 2022). Finding novel solutions in such unprecedented times further means being open-minded, particularly to outside of the box solutions and interventions that might be challenging to implement within the bounds of existing frameworks.

Most management solutions focus on what fishers can do to be resilient (e.g., diversify their portfolio), yet such an approach ignores the challenges fishers face, many of which are outside of their control such as rising costs of permits and gear, needing specialized knowledge to capitalize on new fisheries, or needing access to new sales outlets and market. Solutions instead may require structural changes associated with regulation and markets, and some may be

indirectly related to fisheries management. Fishers identified possibilities for institutional support to improve marketing opportunities and disrupt buyer consolidation. There is also opportunity for institutional actors to use novel strategies that reimagine marketing infrastructure such as creating a fisher co-op or an online fish auction platform that connected fishers to buyers in real-time. In terms of removing barriers, management bodies should consider the practicality of fishers in each port or subsector (e.g., gear type) adopting a new or supplemental fishery given their respective constraints on gear, location, knowledge, time, permits and processing/buyer capacity. Doing so might help to determine if additional supports are needed to make that strategy effective.

The loss of skilled labor is an ongoing issue in the fishing industry, and one that is exacerbated my ocean change and compounding social, economic, and environmental stressors. Labor shortages have important implications amidst mounting evidence of "graying of the fleet" along the West Coast (Cramer et al. 2018). The average age of fishers is increasing, with many fishers near or entering retirement. Young fishers are needed to carry on the industry, but young, skilled labor is also needed to improve safety conditions for older fishers, particularly as weather patterns become more extreme or as fishers must travel farther from port for longer trips. In this regard, fishers suggested a wide range of institutional actions to improve the drivers of a shrinking fishery sector labor force. The compounded effects of a shrinking fleet and less profitable and consistent fishing seasons have meant fewer employment and training opportunities for crew. Institutional scale actors could support adaption by creating vocational and/or apprenticeship programs to prepare aspiring fishers who might not have other opportunities receive on-the-job training. Financial support programs aimed specifically at fishing crew and the next generation of fishers. Likewise, fishers saw opportunity for institutional scale actions to give crew (and fishers more generally) access to affordable health insurance and/or health care. Though fishing has always been a dangerous profession, safety and self-care are even more important as changing environmental conditions bring severe weather. In terms of addressing barriers, management agencies could develop programs that assist fishers with start-up capital for permits or facilitate boat and gear share programs amongst new or would-be fishers. Another example of an adaption barrier was disaster relief programs which are not currently available to crew. Policymakers could explore opportunities expand the fisheries disaster relief to account for losses incurred by fishing crew.

Although this study was focused on non-tribal fisheries, it is important to note that for tribal fishers, adaptation constraints can be magnified. For example, for tribes with treaty fisheries tied to specific areas, the follow-the-fish strategy to adapt is largely untenable. For them, adaptation may entail adjusting use and other activities in place, relative to a range of local species (Chavez and Costello 2017, Lindegren and Brander 2018). Indigenous peoples' unique social and cultural ties (and values associated with) species and places also limit the potential of other common adaptation strategies (e.g., substituting species when those lost fisheries are fundamentally tied to spiritual and cultural identities). Tribal fisheries climate adaptation planning in some cases takes a different approach similarly looks to address compounding stressors, for example, investing in habitat restoration to recover species and expand possible refugia, increasing equity of resource access among harvesters, better coordination with adjacent communities and resource managers (for resource sharing), as well as building capacity among youth and leaders to respond to dynamically changing conditions (Green et al. 2016, Northwest Treaty Tribes 2016). Thus, tribal adaptation strategies may offer lessons for broader (non-tribal) fisheries management.

To be effective, climate change adaptation research must increase the general awareness of climate change impacts as they intersect with social, economic, and regulatory contexts. Because these contexts are dynamic and constantly changing, it is unlikely that implementing the actions identified here will return the Dungeness crab, salmon, or any other impacted fisheries to a prior state in terms of their social and economic characteristics. Instead, they help to build a solid political, legal, financial, and social infrastructure within which communities can develop the capacities to adapt, imagining and pursuing new possible futures in the face of change.

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