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Current and Future Adaptation to a Changing Climate in the California Market Squid and California Spiny Lobster Fisheries

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by

Farrah Elise Powell

Committee in charge:

Professor Arielle Levine, Chair

Professor David Lopez-Carr

Professor Atsushi Nara

Professor Hunter Lenihan

June 2024

The dissertation of Farrah Powell is approved.

Hunter Lenihan

Atsushi Nara

David Lopez-Carr

Arielle Levine, Committee Chair

May 2024

Current and Future Adaptation to a Changing Climate in the California Market Squid and

California Spiny Lobster Fisheries

VITA OF FARRAH ELISE POWELL
May 2024

EDUCATION

Doctor of Philosophy in *Geography*, San Diego State University and the University of California, Santa Barbara, Jun 2024

Master of Arts in *Geography*, University of Hawaii at Manoa, Aug 2016

Bachelor of Arts in *Geography & Environmental Studies*, University of California, Los Angeles, June 2013 (College honors, *cum laude*)

PROFESSIONAL APPOINTMENTS

2022-present: **Sr. Program Manager**, Arbor Energy, *El Segundo, California*

2017-2022: **Graduate Student Researcher**, Department of Geography, San Diego State University, *California*

2020-2021: **Teaching Associate**, Department of Geography, San Diego State University, *California*

2014-2017: **Graduate Student Researcher**, Department of Geography, University of Hawaii, *Manoa*

PUBLICATIONS

Powell, F., Levine, A. & Ordonez-Gauger, L. (2024). Fishermen's perceptions of management in the California spiny lobster and California market squid fisheries. *Marine Policy*, 161, 106015. doi.org/10.1016/j.marpol.2024.106015

Powell, F., Levine, A. & Ordonez-Gauger, L. (2022). Fishermen's perceptions of constraints on adaptive capacity in the California market squid and California spiny lobster fisheries. *Frontiers in Marine Science*, **9**. doi.org/10.3389/fmars.2022.1028280

Powell, F., Levine, A. & Ordonez-Gauger, L. (2022). Climate adaptation in the market squid fishery: fishermen responses to past variability associated with El Niño Southern Oscillation cycles inform our understanding of adaptive capacity in the face of future climate change. *Climatic Change,* **173**, 1. doi.org/10.1007/s10584-022-03394-z

Lawrence, A., Heenan, A., Levine, A. Haddaway, N., **Powell, F.** *et al.* (2021). Spatial and temporal scales of coral reef fish ecological research and management: a systematic map protocol. *Environ Evid,* **10**, 3. doi.org/10.1186/s13750-021-00217-z

Mora C, Dousset B, Caldwell IR, **Powell F,** Geronimo RC, et al. (2017). Global risk of deadly heat. *Nature Climate Change*, **7**, 501-506. https://doi.org/10.1038/nclimate3322

FIELDS OF STUDY

Major Field: Geography

Studies in Conservation Science with Arielle Levine and Hunter Lenihan
Studies in Human-Environment Interactions with Arielle Levine and David Lopez-Carr
Studies in Geographic Information Systems with Atsushi Nara

ABSTRACT

Current and Future Adaptation to a Changing Climate in the California Market Squid and California Spiny Lobster Fisheries

by

Farrah Elise Powell

Anthropogenic greenhouse gas emissions have resulted in profound changes in the physical and chemical properties of the ocean that have serious implications for all levels of ecological organization. Concomitant risk to fisheries, economies, and coastal livelihoods that depend on marine species, coupled with projections of intensifying environmental changes, challenge society's capacity to adapt and manage effectively. The variety of complex impact mechanisms and uncertainties associated with interactions between biological and socio-economic components of fisheries necessitate integrated assessments of vulnerability and adaptive capacity at scales necessary for local-scale adaptation planning.

This dissertation integrates fishery-dependent commercial landings data, regional oceanographic anomaly data, semi-structured interviews with fishermen, and fishermen feedback sessions to understand the how the commercial sectors of two of California's most economically valuable fisheries (California spiny lobster and California market squid) will respond to future change, informed by their past responses to short-term historical climate variability, fishermen's perceptions of constraints to adaptive capacity, and their perceptions of the efficacy of fisheries management. Given that risk and/or adaptive capacity have not

been evaluated for either fishery, and considering the notable differences in these fisheries, they were ideal study species for a comparative research assessment.

Chapter 1 shows that market squid fishermen have been able to adapt to dramatic shifts in the geographic range of the fishery given their high mobility. However, fishermen's responses to change are highly contingent on how a given change manifests in the fishery, as well as characteristics of individual fishermen. Chapter 2 revealed important similarities and differences with regard to the likelihood that spiny lobster and market squid fishermen would perceive a given factor as a constraint, as well as the extent to which different domains of adaptive capacity influence their perceptions of constraints. Constraints relating to fishery governance were the most commonly perceived constraints in both fisheries; however, there were clear differences in perceptions of individual-level constraints (i.e., mobility and knowledge). Chapter 3 shows that market squid and spiny lobster fishermen are generally supportive of fishery management, as well as specific management or conservation tools, with lack of support often indicative of a desire for stronger, scientifically-backed management measures and inclusive decision-making processes.

This dissertation highlights the multiple dimensions of adaptive capacity in two highly valuable fisheries, and the critical importance of designing management and decision-making processes that contribute to resilience. Key differences between these fisheries brings explicit attention to the multitude of factors that influence fishermen's responses and perceptions, and the critical need for multi-species approaches to studying fisheries. This research also highlights the need for contextual, place-based management policies and adaptation strategies that integrate the knowledge, lived experiences, and perceptions of resource users to proactively address climate change impacts on fishermen's livelihoods.

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I. Introduction

Fisheries are fundamentally social-ecological systems (SESs), and stresses associated with changes in management, infrastructure, markets and economics, and social institutions have profoundly influenced the status of fisheries and the benefits humans derive from them (McCay et al. 2011). Existing models of climate effects on fisheries indicate foreboding ecological effects of global temperature rise (Cheung et al. 2016; Fiorella 2021). However, how fishermen respond to a range of changing environmental, economic, institutional, and social conditions cannot be discerned solely on the basis of inferences from biological and ecological models (Mills et al. 2013). Rather than viewing humans, including fishermen, as external actors with limited influence, scientists and managers now acknowledge the integral role fishermen play in actively sustaining key ecosystem processes (Prince 2003, Cinner & David 2011; Shen & Song 2023). This has led to a shift in focus from understanding ecological processes and biological resources to also understanding resource users (i.e., fishermen) and their actions for effective planning and management.

Substantial research indicates that climate-induced shifts in species abundance and distributions are already widespread (Pinsky et al. 2013; Poloczanska et al. 2013; Townhill et al. 2023), and output from climate models suggests that such shifts will likely continue to occur in the future (Cheung et al. 2010; García Molinos et al. 2016). In addition to long-term warming trends, when focusing specifically in California, short-term regional climate variability associated with the El Nino Southern Oscillation (ENSO) phenomenon drastically alters fish stocks through direct effects on survival, growth rate, reproduction, and migratory patterns, and indirect effects including phenological changes and changes in abundance and distribution (Roessig et al. 2004; Lehodey et al. 2006; Asch 2015; Kuczynski et al. 2017).

Indirect effects impact local communities who are exploiting the fish stocks via changes in access to or availability of fisheries resources (e.g., fishing operations, allocation of catch shares, and efficacy of fisheries management measures) (OECD 2011; Cheung et al. 2012; Pinsky & Fogarty 2012; Mills et al. 2013). These changes will, in turn, affect the complex infrastructures, economies, and social systems that have been built around exploiting economically important species.

The degree of changes in species distributions, abundance, or phenology drive changes in fisheries is contingent on a range of economic, social, and regulatory factors that mediate the capacity of fisheries to respond (Pinsky & Fogarty 2012). Fishermen's high level of exposure to diverse stressors necessitates behavioral modifications that have the potential to dramatically influence future fisheries' catches and profitability (Cheung et al. 2010; Grafton 2010; Perry et al. 2011). Disregarding fishermen's behavior and the drivers of their responses, especially in the context of designing appropriate management measures, has led to management failures across the globe (Hilborn 2007; Salas & Gaertner 2004). Key drivers such as perceptions of climate change, fishery viability and resources, and efficacy of management strongly influence their behavior and capacity to adapt (Cinner & David 2011; Bennett & Dearden 2014; Leenhardt et al. 2015). Place-based approaches that incorporate local understandings of risk and vulnerability, as well as relevant drivers of perceptions are necessary to increase the likelihood of management success (Prince 2003; Kittinger et al. 2014; Ensor et al. 2018). Despite the importance of understanding adaptation to change, there are few examples of concrete adaptation actions in marine and fishery systems (Lindegren and Brander 2018; Miller et al. 2018). This limits our ability to predict the capacity of fishermen and other marine resource users to respond to future change as well as our understanding of the potential for adaptation that can be incentivized through policy (Coulthard & Britton 2015).

California fisheries have a long history of coping with oceanographic regime cycles that impact the availability of commercially fished species. Planning for resiliency in the face of unprecedented environmental change requires understanding how fishermen have successfully responded to change in the past, as well as how fishery-specific, socio-economic, or perceptions-based factors constrain their capacity to adapt to future change. This dissertation aims to understand the how the commercial sectors of two of California's most economically valuable fisheries (California spiny lobster and California market squid) will respond to future change, informed by their past responses to short-term historical climate variability, fishermen's perceptions of constraints to adaptive capacity, and their perceptions of the efficacy of fisheries management. The chapters integrate spatially explicit, fishery-dependent landings data, regional oceanographic anomaly data, semi-structured interviews with fishermen, managers, and key informants, and fishermen feedback sessions to examine drivers of changes in fishing activity and behavior, flexibility in fishing strategies and livelihoods, and perceptions of agency and risk related to perceived climate impacts and different management alternatives.

Chapter 1 evaluates the strategies California market squid fishermen have used to respond to high seasonal and interannual climate variability associated with ENSO phenomenon as well as how they would theoretically respond to hypothetical future scenarios of low abundance and range shift. I evaluate how characteristics of individual fishermen (e.g., age, boat size, dependence on squid, and access to additional permits) influence decision-making and adaptive responses, and conclude with a discussion of the implications of our findings for the adaptive capacity of the market squid fishery, as well as management considerations that will be critical in ensuring fishery sustainability and adaptation in a changing climate.

Chapter 2 explores fishermen's perceptions of constraints on their ability to adapt to change in the California spiny lobster and California market squid fisheries, as well as how characteristics of individual fisheries and fishermen influence the likelihood of perceiving a given factor as a constraint. Although previous studies show that there are numerous factors that can facilitate or constrain fishermen's adaptive capacity, fishermen act based on their own perceptions of their ability to respond and adapt to change within their broader social, environmental, and governance context, highlighting the importance of perception-based assessments. I situate these findings within the broader fishery and regulatory context in which fishermen operate and conclude with a discussion of how interactions between different domains of adaptive capacity can enhance or negate broader adaptive capacity within fisheries.

Chapter 3 evaluates California market squid and California spiny lobster fishermen's perceptions of and overall support for fishery-specific management measures. I analyze the nuanced and diverse perspectives that fishermen have regarding fishery management, situating findings within broader discussions of governance, including legitimacy, equity, transparency, participation, and trust, and conclude with a discussion of paths forward to communicate these perceptions and incorporate them into policy-making and adaptive management. Understanding fishermen's perceptions of management as well as the factors that influence support for management can inform courses of action to make policy more acceptable to fishermen and can provide important insights into the ecological outcomes of management measures, the perceived legitimacy of governance processes, and the social outcomes of regulatory policies.

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II. Chapter 1: Climate adaptation in the market squid fishery: Fishermen responses to past variability associated with El Niño Southern Oscillation cycles informs our understanding of adaptive capacity in the face of future climate change

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2.1 Introduction

Temporal variability is inherent in natural resource-based sectors, including commercial fisheries (Stoll et al. 2017), and is driven by human-induced global environmental change (Halpern et al. 2015), naturally-occurring climate phenomena (e.g., El Niño Southern Oscillation [ENSO] and Pacific Decadal Oscillation [PDO]) (Hollowed et al. 2001; Perretti & Sedarat 2016), and socioeconomic pressures (e.g., migration to coastal communities and/or changes in market dynamics) (Bennett et al. 2016; Reddy et al. 2013). Thus, it has become increasingly important to understand whether and how communities and/or individuals dependent on natural resources can adapt to change (Bennett et al. 2016; Cinner et al. 2012; Whitney et al. 2017). Despite the importance of understanding adaptation to change, there are few examples of concrete adaptation actions in marine and fishery systems (Lindegren and Brander 2018; Miller et al. 2018). This limits our ability to predict the capacity of fishermen and other marine resource users to respond to future change (Coulthard and Britton 2015) as well as our understanding of the potential for adaptation that can be incentivized through policy (van Putten et al. 2017).

The ways in which fishermen respond to climate change impacts in fisheries can be understood within the broader perspective of resilience thinking, where responses fall along an adaptation continuum - remaining/coping (e.g., no behavioral change), adapting (e.g., changing fishing strategies or location), and transforming (e.g., switching fisheries or exiting a fishery) (Coulthard 2009; Ojea et al. 2020; Rubio et al. 2021). One of the most common adaptive strategies fishermen employ is diversification (Anderson et al. 2017), buffering income variability by targeting multiple species or fisheries and allowing fishermen to shift between fisheries based on what is most convenient, abundant, or valuable at a particular moment in time (Anderson et al. 2017; Kasperski and Holland 2013; Robinson et al. 2020). Another common strategy involves changes in fishing activities, including how, where, and when to fish (Wilson 2017). Fishermen may change method of harvest (Cinner et al. 2015), engage in seasonal fishing effort (Sievanen 2014), change the intensity of fishing effort/activity (Stoll et al. 2017), and/or diversify fishing grounds (Young et al. 2019). Furthermore, to offset potential losses associated with local declines in abundance and/or range shifts, fishermen can migrate to operate out of new ports (Savo et al. 2017; Sievanen 2014; Young et al. 2019). Lastly, and generally the least desirable option, fishermen may choose to exit the fishery and leave fishing altogether and pursue alternative employment (Coulthard 2009; Johnson et al. 2014). Focusing on these responses at the level of the individual fishermen is particularly important (but uncommon) because ultimately, adaptive responses occur at this scale (Stoll et al. 2017).

From an ecological standpoint, ongoing climate change is causing unprecedented changes in ocean and coastal conditions. In the California Current System (CCS), there is considerable evidence of significant ocean warming (Schwing et al. 2010) and associated changes in ocean stratification over the past century (Palacios et al. 2004). A recent study found a robust increase in future Eastern Pacific ENSO sea surface temperature (SST) variability due to greenhouse warming-induced intensification of upper-ocean stratification, as well as an increase in the number of strong Eastern Pacific El Niño events (Cai et al. 2018). Projections show a robust and unambiguous signal of future surface warming in the CCS, with predicted increases in SST between 2.5˚ and 5˚C by 2090 (Pozo Buil et al. 2021), along with changes in the timing and intensity of upwelling, which affects nutrient and oxygen concentrations (Checkley and Barth 2009; Pozo Buil et al. 2021; Xiu et al. 2018). These changes impact many commercial fisheries in the region such as market squid (*Doryteuthis opalescens*), which has routinely ranked as the state of California's top commercial fishery in terms of volume (tons) and value (US dollars) (NMFS 2018).

Market squid abundance exhibits substantial interannual variability due to variable recruitment, growth, and survival of populations in response to fluctuating oceanographic conditions associated with ENSO (Jackson and Domeier 2003; Perretti and Sedarat 2016; Zeidberg et al. 2006). Market squid populations decline drastically in unfavorable environments associated with El Niño events, characterized by warm SST and low productivity, and rebound rapidly during favorable conditions associated with La Niña events, characterized by cool SST and high productivity (Reiss et al. 2004; van Noord and Dorval 2017). Such large-scale population variability and periodic collapses of the fishery not only have a large economic toll on fishing communities, but they also greatly disturb ecosystem food web dynamics given that market squid are one of the state's most important forage species (Alder and Pauly 2006; Morejohn et al. 1978).

In addition to volatility in landings and abundance, the fishery is subject to spatial and phenological changes. Landings in the northern range of the fishery (north of Point Conception, primarily out of Monterey Bay) traditionally take place from April through November, while landings in the southern range of the fishery (south of Point Conception, predominantly around the Channel Islands) traditionally take place from October through March, due to regional and temporal differences in peak spawning (Porzio and Brady 2008). Typically, only about 20% of the annual statewide squid catch comes from the northern fishery, with the remainder caught in the southern fishery (Cavole et al. 2016). However, the availability of market squid to the fleet can vary tremendously from year to year due to regional oceanographic processes (Ralston et al. 2018). Numerous reports of market squid in Oregon, Washington, and Alaska in 2015 and 2016 (Chambers 2016; Columbia Basin Bulletin 2018, Miller 2015) support the prediction that the market squid population along the U.S. west coast shifted north in response to warm water events such as the "Blob" (Cavole et al. 2016), and models based on fishery independent data show that squid has become increasingly abundant in northern latitudes in the California Current over the past two decades (Chasco et. al. 2022). In terms of changes in phenology, warmer ocean temperatures cause squid to mature faster (Forsythe 2004) and recruit to spawning grounds earlier (i.e., before the seasonal peak in prey availability) (Sims et al. 2001). Accelerated maturation could thus cause a "match-mismatch" scenario that alters critical trophic interactions (van Noord and Dorval 2017). Concomitant shifts in species distributions, changes in phenology, and reductions in abundance will redistribute resources available to local fishing communities, possibly leading to revenue losses, disruptions in the processing and supply chain, and less effective fishery management measures (e.g., Mills et al. 2013; Pinsky and Fogarty 2012).

Globalization of the seafood industry has also influenced fishery dynamics over time through shifts in market dynamics and demand. In particular, the rapid expansion of seafood markets to China (Crona et al. 2020; FAO 2020; Porzio and Brady 2008) caused the market squid fishery to expand tremendously in scale. The majority of the commercial catch (~80%) is exported to Asian and European markets, with China being the largest market (Porzio and Brady 2008). Given the market squid fishery's global market, it is also highly susceptible to economic and market volatility associated with changes in international demand and/or tariffs (Ess 2020; FAO 2020). For example, COVID-19-related market volatility was associated with an 80% decline in total landings from ~66,678 metric tons in 2017-2018 to ~13,607 metric tons in both the 2019-2020 and 2020-2021 seasons. Furthermore, in the 2018-19 season (pre-COVID-19), squid exported to China carried a 27% tariff, whereas in 2019-20 season, the United States imposed an additional 25% for a total of 52% (value-added charges and duty combined) (Ess 2020), resulting in very low prices offered to squid fishermen.

The growing international demand coupled with subsequent increases in effort and landings facilitated by newer, larger, and more efficient vessels and greater processing capacity (PFMC 2008) prompted the California Department of Fish and Wildlife (CDFW) to develop the Market Squid Fishery Management Plan (MSFMP) in 2005. The MSFMP established several static management measures including: a fixed seasonal catch limit of 118,000 tons, 2-day weekend closures, light and gear restrictions, a restricted access program, and monitoring programs (port sampling and logbooks) (CDFW 2005). While current management measures prevent excessive fishing effort and allow for critical periods of uninterrupted spawning (CDFW 2005), the static, equilibrium-based fishery control rules do not account for or address climate-driven interannual variability in stock dynamics and productivity. Furthermore, despite the mobility afforded by the large vessels in the squid fleet, the implications of a more permanent northerly range shift could have cascading ecological and economic impacts and may require a shift from a state-based to a regional fishery management approach.

The magnitude of ongoing change (both climatic and socioeconomic) raises important questions and concerns regarding market squid fishermen's capacity to adapt to predicted future climate change, (Chavez et al. 2017; Stoll et al. 2017) and the implications of their adaptive capacity for the future of the fishery. Whether due to cyclical climate variability or market and regulatory influences on fishing dynamics, market squid fishermen have a long history of adapting to challenging conditions. Here, we assess market squid fishermen's responses to past short-term climatic events associated with the ENSO cycle, particularly the regional warming conditions associated with El Niño events, as a proxy to reflect likely response to future, more permanent warming trends. Using landings data and fishermen interviews, we present trends based on fishermen's responses to previous ENSO events as well as their stated responses to potential future scenarios including reductions in species' abundance and range shifts. We also evaluate how characteristics of individual fishermen (e.g., age, boat size, dependence on squid, and access to additional permits) influence decision-making and adaptive responses. We conclude with a discussion of the implications of our findings for the adaptive capacity of the market squid fishery, as well as management considerations that will be critical in ensuring fishery sustainability and adaptation in a changing climate.

2.2 Methods

To understand how fishermen respond to changing conditions in the market squid fishery, we used a convergent mixed methods framework and methodological triangulation (Olsen 2004). We conducted parallel analyses of quantitative fishery-dependent and climate data and qualitative survey data to identify drivers of change relevant to the fishery, examine how fishermen adapt in response to the aforementioned changes, and explore whether fishermen's responses differed based on relevant demographic and socio-economic characteristics. By comparing information obtained from diverse sources, triangulation approaches ensure greater validity and reliability (e.g., Islam et al. 2014; Whitney et al. 2017), and can generate a deeper, contextual, and more comprehensive understanding of complex social-ecological systems (Bennett et al. 2016; Frawley et al. 2021).

2.2.1 Fishery landings data and Oceanic Niño Index

Fishery-dependent landings data were analyzed to explore patterns relating to fishermen's responses to change. Forty seasons (1980–2019) of market squid landings data were obtained through a confidential, non-disclosure agreement with CDFW. This type of data, known as fishery-dependent data, is derived from the fishing process itself and is collected through self-reporting by fishermen. Landing receipts provide detailed daily information on both quantity (lbs) and location (CDFW fishing block) of catch. These blocks (10 x 10 nautical miles) correspond to a three-digit database code that CDFW uses to record and aggregate all "fish ticket" and landings data. Each entry corresponds to a unique fishing trip (N = 102,001 total trips/unique observations). We primarily focused on information pertaining to quantity and location of catch. Given that data is self-reported by fishermen, it is prone to human error and requires data cleaning. This entailed excluding catch data that was not in a recognized CDFW fishing block and eliminating duplicate entries (in which every column was identical).

In order to understand how ENSO-related variability alters fishing patterns, catch data were aggregated spatially (by fishing block) and temporally (by ENSO phenomenon). To explore spatial changes in fishery landings during different ENSO phases, the percentage of total catch obtained from each fishing block was calculated for each season. Each fishing season was assigned to a group corresponding to the strength (weak, moderate, or strong) and type (El Niño, La Niña, or neutral) of event that occurred during that season based on the Oceanic Niño Index (ONI) (see Electronic Supplemental Material [ESM], Table S1). The National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center defines ONI as the 3-month running mean of SST anomalies in the Niño-3.4 region (i.e., 5°N – 5°S, 120° – 170°W), based on centered 30-year base periods updated every five years (NOAA 2019). Events are defined as five consecutive overlapping 3-month periods at or above the +0.5˚C anomaly for warm (El Niño) events and at or below the -0.5˚C anomaly for cold (La Niña) events. The threshold is further broken down into Weak (0.5 to 0.9˚ SST anomaly), Moderate (1.0 to 1.4˚), and Strong (≥ 1.5˚) events. Neutral events indicate seasons with no statistically significant SST anomaly (i.e., those that did not exceed the +/-0.5˚C anomaly).

We explored both spatial and temporal variability in landings data in relation to past ENSO events. To maintain consistency with fishermen interviews and because extreme events tend to show the clearest signal of change, we focused our analysis on strong El Niño and La Niña events, as well as neutral events. For the spatial component of our analysis, we averaged the percent catch from each block across all seasons that fell into the same event strength grouping. For seasons between 1980-1999, the given block may indicate landing location versus fishing location due to discrepancies in data reporting between earlier and later seasons, but still corresponds with the general latitude of fishing activity. All spatial processing was conducted using the sf package (Pebesma 2018) in R. Mapped data products were projected using the California Teale Albers (NAD83) (Patterson 2018). In order to investigate temporal changes in landings as a function of ENSO, we calculated the percentage of total season catch per month for each season, and then averaged monthly percentages across seasons that fell into the same event strength grouping.

2.2.2 Fishermen surveys

Surveys were conducted with active squid fishermen between January 2017 and January 2018 with the goal of surveying an owner or boat operator representing as many active squid vessel permits as possible. Permits were considered 'active' if the vessel participated in the fishery (landed and reported catch) in at least one of the previous three fishing seasons (i.e., 2014–15, 2015–16, 2016–17) based on a list of permits and landings data obtained from the CDFW. Surveys were conducted at Ventura Harbor, the primary landing port for squid, as well as non-port locations or by phone (if preferred or if fishermen were based outside of southern California). A total of 54 squid fishermen were interviewed, representing 48% of total active vessels (both squid and squid lightboat) during the survey period. The survey consisted of a series of multiple choice, Likert scale, and open-ended questions related to changes in the fishery (i.e., timing, location, abundance, and other) due to ENSO or other regional climate patterns in the last 5-10 years, responses to past warm-water events, and responses to hypothetical lower abundance and species' range shift scenarios. The survey also included a series of multiple-choice and open-ended questions relating to demographic and socio-economic characteristics that might influence fishermen's responses to change.

After familiarizing ourselves with the interview data, open-ended responses were coded using an iterative, inductive approach (e.g., Maguire and Delahunt 2017) to identify themes relating to observed changes, adaptive strategies, and responses to hypothetical scenarios. We reviewed and coded the data until no new themes emerged. Following identification of themes, fishermen's adaptive strategies and responses were analyzed using descriptive (i.e., frequency, mean, and standard deviation) statistics. In order to determine whether responses to hypothetical scenarios were associated with fishermen's demographic or socio-economic characteristics, we used inferential statistics (unpaired two sample *t*-tests, non-parametric two-sample Wilcoxon Rank test, and two proportion *z*-tests) within the R environment (R Core Team 2020).

Fishermen's responses were coded into three distinct groups: continuing to participate in squid (including fishermen who did not change fishing strategies or behavior and those who did), switching to another fishery, and exiting fishing (e.g., selling their permit or taking up non-fishing employment). T-tests were selected under the assumption that both samples are random, independent, and come from normally distributed populations (confirmed using the Shapiro-Wilk test) with unknown but equal variance. If samples were not normally distributed, we used the Wilcoxon Rank Test. When dealing with categorical data (e.g., resource dependence and type of additional fishery permit(s)), we used the two proportion *z*-test to determine if the proportions of categories in two group variables significantly differed from each other. We considered fishermen to be primarily dependent on squid if > 60% of their total annual income was from squid. As we were interested in understanding whether certain types of permits facilitate flexibility in response to change, we grouped fishermen into two groups based on feasibility/ease of switching - those holding only squid or coastal pelagic finfish permits (i.e., mackerel, anchovy, sardine, bonito) in addition to squid, and those holding other types of permits (e.g., salmon, lobster, longline, crab, etc.) in addition to squid.

In order to visualize and explore spatial responses to change as reported by market squid fishermen, participants were asked to identify and delineate fishing grounds during an ENSO neutral season and during an El Niño phase of ENSO. Fishermen either stated specific CDFW fishing blocks or provided ranges (minimum/maximum latitude or northern/southern location) of fishing areas, which we then converted to fishing blocks. All coastal fishing blocks within a stated range were included. We then generated choropleth maps using the sf package (Pebesma 2018) in R to display the percentage of respondents who reported fishing in a given block during El Niño and neutral phases of ENSO. Lastly, in order to determine whether distance traveled to fishing grounds varies between El Niño and neutral phases of ENSO, we calculated the distance traveled (after accounting for land and the curvature of California's coastline) from a fishermen's home port to the centroid of each specified fishing block for each ENSO phase independently. Distance data for each individual fisherman were averaged and then compared for differences between each ENSO neutral and El Niño event years.

2.2.3 Fishermen feedback session

Following completion of data analysis, we held a feedback session with squid fishermen to present preliminary findings in order to get their feedback on data analysis and interpretation and answer outstanding questions that arose from preliminary data analysis.

The session was held in November 2019 with 11 fishermen in Ventura, CA, the primary port for squid and where most fishermen are based during that time in the fishing season. Participants were recruited based on an opt-in question at the end of the survey (asking fishermen if they wanted to participate).

2.3 Results

Results from both the fishermen surveys and landings data are presented thematically in order to corroborate and compare findings.

2.3.1 Observed changes in fishery

There was substantial consensus among fishermen regarding observations of changes in the fishery in relation to regional climate variability (particularly ENSO cycles) in the past 5-10 years. Eighty-seven percent of fishermen acknowledged that they had noticed changes, while only 2% had not. The remaining fishermen were not sure or had been in the fishery for less than five years. Of the fishermen who had noticed changes, 79% noted changes in abundance, 72% noted changes in location/range of squid, and 28% noted changes in the seasonal availability of squid or timing of spawning events.

For each category of change, fishermen were asked to elaborate on the changes they observed. Of the fishermen who observed changes in location/range of squid, 82% stated that squid spawned farther north during El Niño events, resulting in a more productive fishery in the northern range (i.e., north of Point Conception, primarily Monterey), and 41% of respondents believed that squid spawned at deeper depths during El Niño. Several fishermen noted that the most recent El Niño event (2015-16, the "Blob") resulted in the most drastic range shifts, with large quantities of squid found in Humboldt, Oregon, Washington, and Alaska. Fishermen's observations of a fairly recent northward range shift are consistent with trends in fishery landings data. While the proportion of catch in the southern fishery historically has been much greater than that of the northern fishery (except during strong El Niño events and sometimes during the year immediately after the event), since 2014-15, the proportion of catch in the northern fishery has increased (**Supp. Fig. S1**). Percentage catch in the northern fishery increased from an average of 20.2% between 1990-91 and 2013-14 seasons to an average of 49.2% between 2014-15 and 2018-19 seasons.

Of the fishermen who noted changes in abundance, all agreed that there were fewer squid during El Niño events; however, fishermen attributed this decrease in abundance to different factors. Seventy-six percent noted a decrease in abundance of squid as warm temperatures and reduced prey availability (from decreases in upwelling) result in higher mortality rates at each life-history stage of squid. Several of these fishermen specifically noted that El Niño-induced declines in abundance continue to affect the fishery for one to two years after the event. Twenty-seven percent of fishermen who noticed changes in abundance reported that squid were unharvestable, believing they were likely spawning in atypical locations where they could not be easily accessed (i.e., further north or in deeper offshore waters than what is commercially fished).

Finally, of the fishermen who observed changes in the timing and seasonality of fishery events in recent years and during past El Niño events, 82% said that peak fishery landings occurred months earlier, while 18% mentioned that the catch was less seasonal (i.e., occurring year-round versus peaking late in the season). Landings data also showed that during ENSO neutral and strong La Niña seasons, the majority of catch takes place in the southern fishery, whereas during strong El Niño events, catch is concentrated in the northern fishery. The proportion of catch in the northern fishery during El Niño seasons (0.71 ± 0.18)

was, on average, significantly greater than both ENSO neutral seasons (0.21 ± 0.09) (t(7) = 5.56, $p = 8.5 \times 10^{-4}$) and strong La Niña seasons (0.05 ± 0.09) (t(6) = 6.55, $p = 6.1 \times 10^{-4}$) (**Fig. 1**). These spatial shifts in the fishery also affect the timing of peak catch. During ENSO neutral and La Niña seasons, the majority of catch occurs between October and March, which coincides with the timing of peak spawning in the southern portion of their range. During strong El Niño seasons, however, peak landings occur much earlier in the season, between April and September (**Fig. 2**).

Figure 1. Percent of total market squid catch per California Department of Fish & Wildlife (CDFW) fishing block (10 x 10 nautical miles) averaged across each event type (based on the Oceanic Niño Index characterization). The red dashed line indicates the delineation between the northern and southern components of the fishery, which occurs at Point Conception (34.5˚ N). The value above and below the dashed line corresponds to the proportion of catch caught in the northern and southern fishery averaged over seasons of similar event type. For strong El Niño events, individual seasons included: 1982-1983, 1991-1992, 1997-1998, and 2015-2016. For strong La Niña events, individual seasons included: 1998-1999, 1999-2000, 2007-2008, and 2010-2011. For neutral events, individual seasons included: 1996-1997, 2001-2002, 2003-2004, 2012-2013, and 2013-2014. Although there were neutral event seasons prior to 1995, we chose to analyze seasons after this date due to greater reliability of data. Note that the legend increases incrementally until 40.0 - 44.0%.

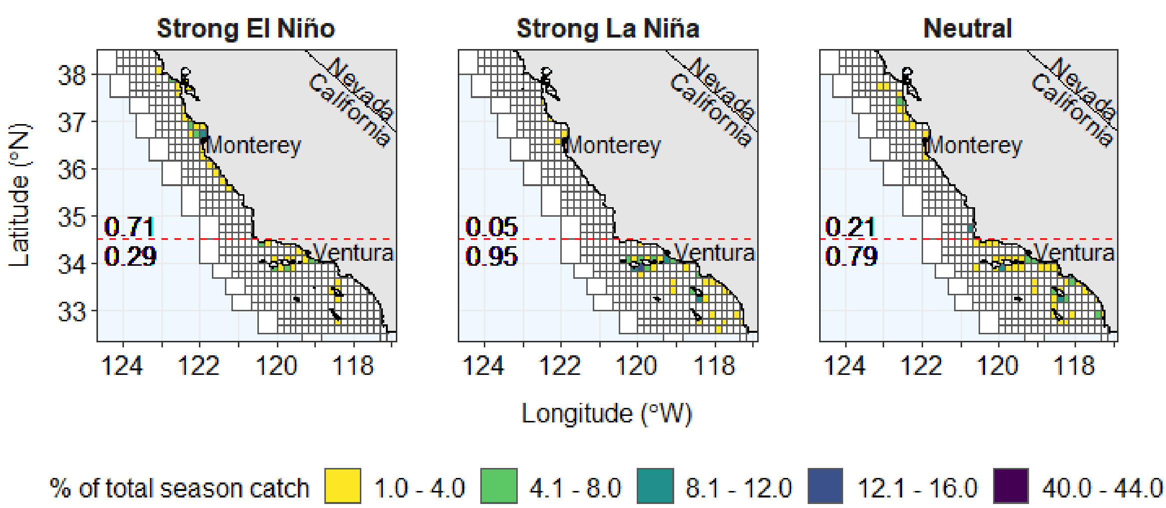
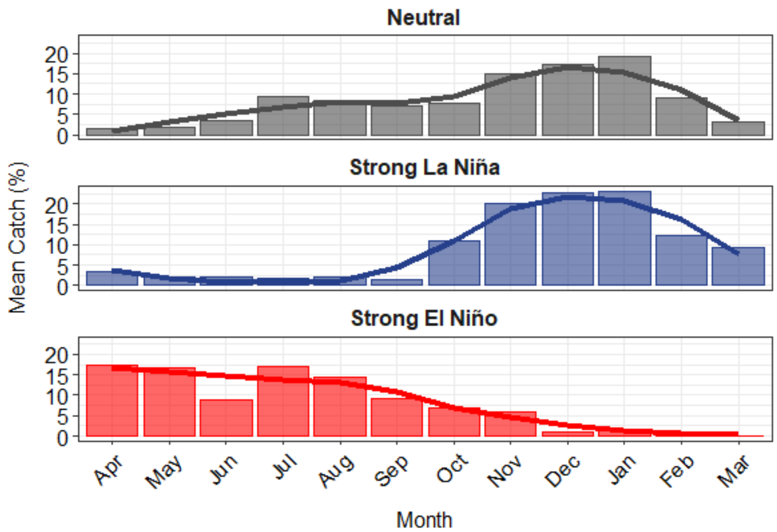


Figure 2. Percentage of total market squid catch per month averaged across seasons (1980-2018) that fell into the same strength/event grouping (based on the Ocean Niño Index characterization). Lines represent smoothed estimates obtained from a loess smoother. Note that fishing season runs from 1 April to 31 March of the subsequent year.

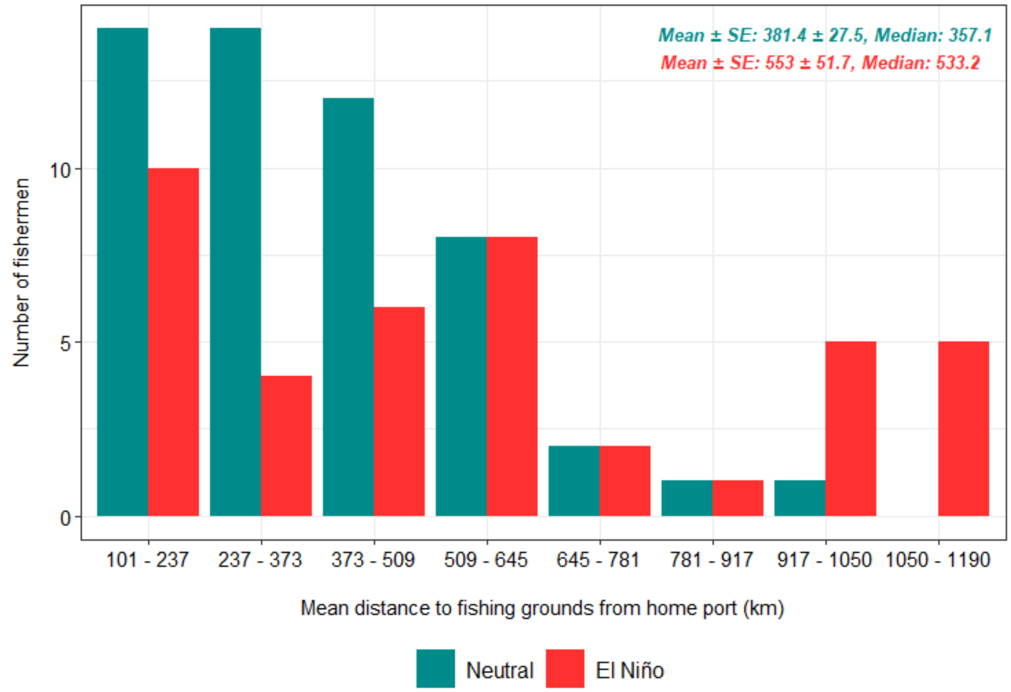


2.3.2 Fishermen's responses to change

2.3.2.1 Previous El Niño events

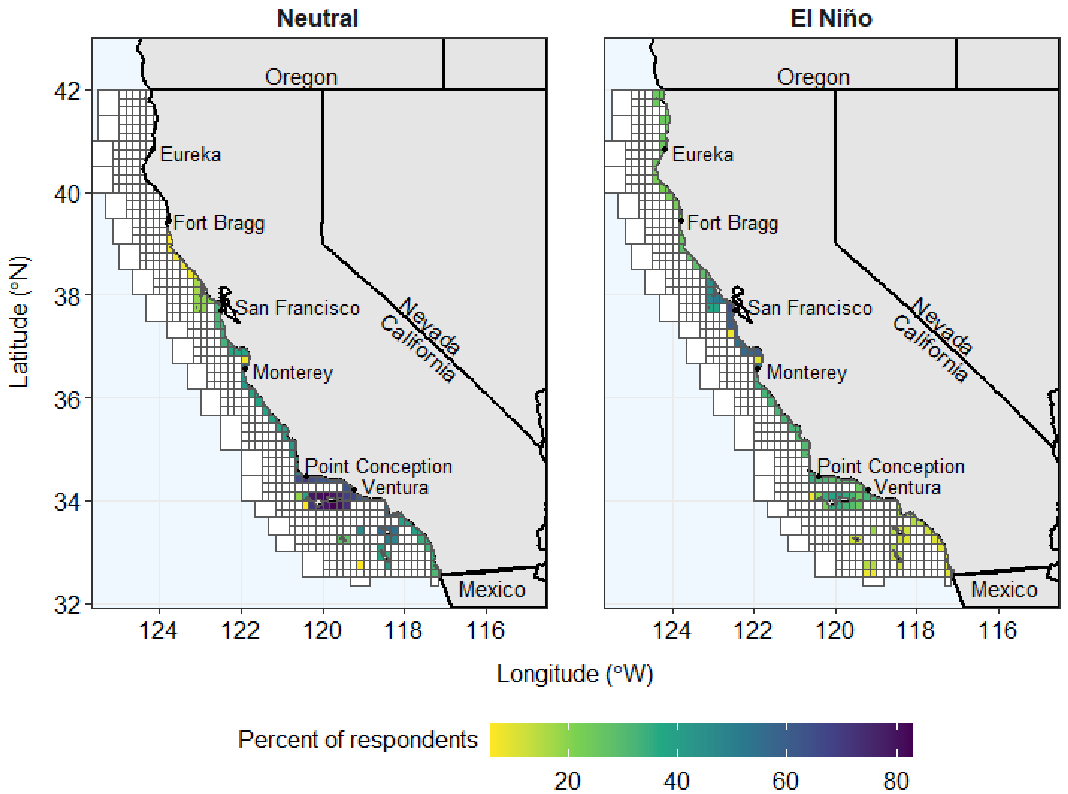
Seventy-six percent of fishermen said that they had changed their fishing strategies in response to previous El Niño events. Of the respondents who altered their fishing strategies, 59% shifted their effort north and fished primarily in the northern range of the fishery, 24% fished deeper, 17% fished further offshore, and 15% temporarily exited the fishery (either tying up their boat for the season or switching to another fishery) (**Supp. Fig. S2**). In addition to changes in the location of fishing activity, fishermen also reported traveling significantly farther from their home ports during El Niño events versus ENSO neutral fishing seasons (**Fig. 3**). During El Niño events, fishermen traveled, on average, 171.6 kilometers (106.6 miles) further to fish than during ENSO neutral seasons ($t(61.9) = 2.9$, $p = 0.005$).

Figure 3. Mean distance to reported market squid fishing locations during neutral (*n* = 52 fishermen) and El Niño (*n* = 41 fishermen) phases of the El Niño Southern Oscillation (ENSO). The distance from a fisherman's home port to the centroid of each reported California Department of Fish and Wildlife (CDFW) fishing block was calculated for each ENSO phase. Individual distance data were averaged and sorted into non-overlapping bins of equal length.



When self-reported changes in fishing location are viewed spatially (by CDFW fishing block), the latitudinal patterns in fishing activity during El Niño and neutral phases of ENSO show clear differences (Fig. 4). In an ENSO neutral fishing season, the fishery is distributed in coastal waters from San Francisco to the California-Mexico border, with the majority of participants fishing south of Point Conception and throughout the Channel Islands. During strong El Niño events, the total fishing area expands and effort is concentrated in central/northern California. Eight fishermen noted that they had traveled well beyond the border and into southern/central Oregon during historically strong El Niño events. Fishermen's reported changes in fishing location/effort (i.e., northward) during El Niño events are consistent with spatial trends in fishery landings data (**Fig. 1**).

Figure 4. Market squid fishing grounds during neutral ($n = 52$ fishermen) and El Niño ($n = 40$ fishermen) phases of the El Niño Southern Oscillation (ENSO). Values indicate the percentage of fishermen who reported fishing in a given California Department of Fish and Wildlife fishing block (10 × 10 nautical miles) for each ENSO phase. Note that blocks with less than 2 entries were excluded.



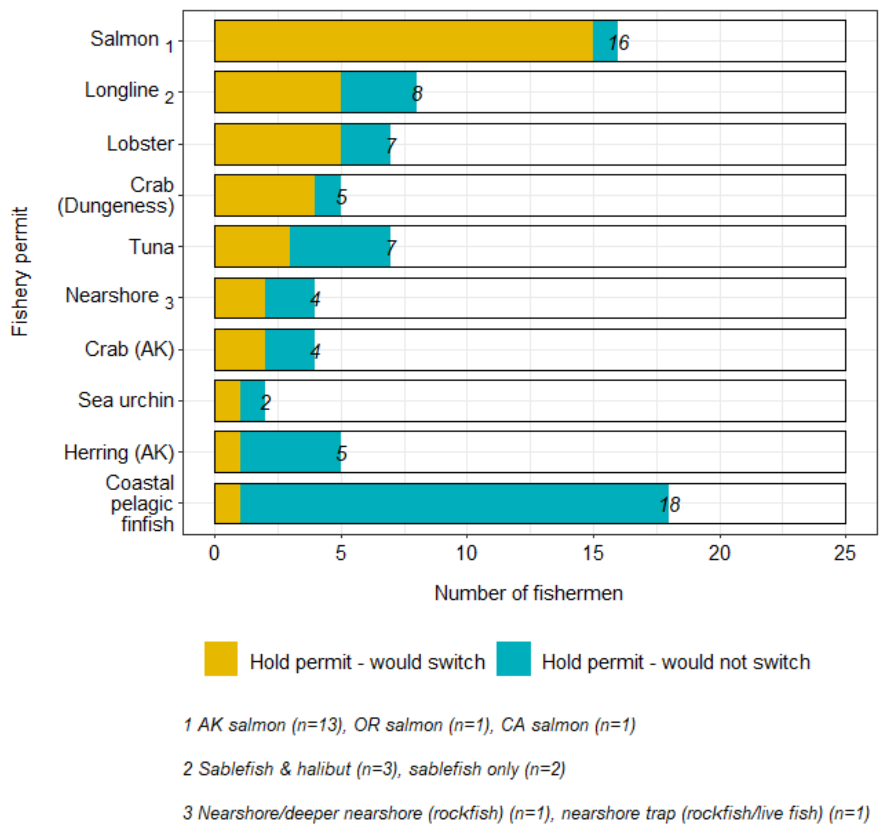
2.3.2.2 Range shift

In addition to understanding how fishermen have responded to past climate variability, we also sought to understand how participants would respond to a hypothetical scenario in which the fishery range shifted north beyond the historical species distribution. Responses to this scenario were highly consistent, with 94% of fishermen saying that they would travel to catch squid in other locations (**Supp. Fig. S3**). Of these fishermen, 87% stated that they would travel an unlimited distance, mentioning Oregon, Washington, and/or Alaska as potential fishing locations due to the mobility afforded by their large vessels. However, 18% provided other contingencies that might affect their willingness to pursue squid, including economic feasibility and consistency of fishing, market price/value, and availability or proximity of offloading facilities. The remaining 14% of fishermen who were willing to travel said they would travel with limitations on distance, generally setting Monterey and/or San Francisco as their northern limit. The fishermen who stated that they would travel with limitations or not travel at all in response to a hypothetical range shift had significantly smaller vessels on average than the fishermen who stated that they were willing to travel an unlimited distance (mean difference: 23.7 feet [7.22 meters]), ($t(42) = 6.5$, $p = 7.7 \times 10^{-8}$).

2.3.2.3 Lower abundance

Fishermen were also posed with a hypothetical scenario of lower abundance of squid in the future. In the event of low squid abundance, 46% of the participants said that they would switch to another fishery (**Supp. Fig. S4**). Alaskan salmon was the most commonly mentioned fishery that fishermen would switch to, and it was the second most commonly held permit in addition to squid. While coastal pelagic species permits (i.e., sardine, anchovy, mackerel, bonito) were the most commonly held additional permits, this was the least commonly mentioned alternative fishery choice (**Fig. 5**). Approximately 41% of fishermen stated that they would continue to participate in the squid fishery, with 35% of fishermen reporting they would do so with altered fishing strategies (e.g., increasing distance traveled, increasing effort, or fishing a longer season) and 6% stating they would continue without changes in effort and/or behavior (**Supp. Fig. S4).** Additional responses to a hypothetical reduction in abundance include: permanently exiting the fishing industry and/or seeking non-fishing employment (~7%) and temporarily dropping out of fishing for the remainder of the season (or until conditions improve) (~6%). Seventeen fishermen gave first and second resorts (i.e., for low abundance and very low abundance scenarios); however, overall trends remained the same, but with an increase in the number of fishermen who stated they would quit fishing or sell their permit and/or seek non-fishing employment (as a second resort) (**Supp. Fig. S5**).

Figure 5. Stacked barplot showing the number of market squid fishermen who hold permits for additional fisheries (total number indicated by italicized value) out of those who stated they would switch to an alternative fishery in response to hypothetical lower abundance ($n = 25$). The yellow bar indicates the number of fishermen who stated they would switch to each fishery, and the turquoise bar shows the total number of fishermen who hold a given fishery permit but would not choose to switch to it as an alternative to squid.



We found that fishermen's age, the number of years they had participated in the fishery, the percent of total income derived from squid, and the type of additional fisheries permits held all influenced fishermen's stated responses to hypothetical low squid abundance. On average, fishermen who stated they would exit the fishing industry were significantly older than those who stated that they would switch to another fishery (mean difference: 17.6 years), ($t(27) = 3.08$, $p = 0.005$). Similarly, fishermen who stated that they would switch to another fishery had participated in commercial squid fishing for fewer years than those who stated that they would quit/exit fishing (W = 90, $p = 0.008$). Resource dependence, or percent of total income from commercial squid fishing, also differed between response groups. Fishermen who are primarily dependent on squid (i.e., > 60% of total annual income) were significantly more likely to state that they would continue to participate in the squid fishery (0.95) given a hypothetical decline in abundance than switch to another fishery (0.3) ($z = 3.92$, $p = 8.9 \times 10^{-5}$). The proportion of fishermen primarily dependent on squid were also significantly more likely to state that they would exit the fishing industry (1) than switch to another fishery (0.3) ($z = 2.04$, $p = 0.02$). The type of additional fishery permits that fisherman held also significantly influenced fishermen's stated response to hypothetical lower abundance. The proportion of fishermen who only held squid and coastal pelagic finfish permits (versus those holding other additional permits) were significantly more likely to state that they would either continue to fish for squid or exit the fishing industry (0.92) than switch to another fishery (0.27) ($z = 4.44$, $p = 9.2 \times 10^{-6}$).

2.4 Discussion

Our mixed-methods approach employed complementary data sources to investigate fishermen's responses to climate variability in the market squid fishery. Findings were consistent between quantitative and qualitative data sources, strengthening the validity of our results. This mixed-methods approach also provided a more in-depth, contextual, and comprehensive understanding of fishermen's adaptive capacity in regards to how they have responded to past change as well as considerations for how they might respond to future change.

Short-term variability in ocean and climate conditions associated with ENSO has resulted in notable changes in the market squid fishery over the past several decades. During past El Niño events, fishermen have observed marked reductions in squid abundance and/or availability, northward and possibly depth-related changes in spawning location, and changes in timing of peak fishery landings. Given projections of an increase in the frequency and intensity of strong eastern Pacific El Niño events (Cai et al. 2018) coupled with the species' high sensitivity to fluctuating environmental conditions (van Noord and Dorval 2017), the market squid fishery will likely be subject to significant changing conditions in the future. As climate change continues to shift the distribution of squid northward and potentially deeper, fishermen will experience economic and logistical challenges associated with shifting fishery operations, including learning about and fishing in geographically new areas and traveling further to reach more favorable grounds, likely raising safety concerns and increasing fuel, bait, and crew costs (e.g., Chavez et al. 2017; Pinsky and Fogarty 2012). Additionally, due to the very high perishability of the product as well as the limited infrastructure for offloading, processing, and cold freezer storage in northern ports, potential expansion in areas where the fishery is emerging is currently limited.

2.4.1 Implications for adaptive capacity in the market squid fishery

2.4.1.1 Mobility

Market squid fishermen have exhibited highly adaptive behavior when faced with past ENSO-related changes in the fishery, and they expressed confidence in their ability to continue to adapt to hypothetical future scenarios of species' range shifts and low abundance. The majority of participants were able to cope with changes in the fishery associated with past El Niño events by shifting the location (north) or depth (deeper) of fishing, which was facilitated by large and mobile vessels characteristic of the market squid fleet. This is in line with other studies that found that high mobility can buffer fishing communities from the effects of environmental change (Sievanen 2014; Young et al. 2019). When posed with a hypothetical future scenario in which the fishery range shifted north beyond the historical focus, nearly all fishermen were willing to travel great distances to target market squid in other locations. While attachment to a particular place can limit fishermen's willingness to travel far from their home fishing grounds (Cinner et al. 2018, Seara et al. 2016, Shaffril et al. 2015), highly mobile fleets may be less likely to express strong attachment to fishing in a particular place (NOAA 1993), and squid fishermen already cover large ranges while fishing. During the feedback session, fishermen noted that this willingness to travel has increased dramatically over the last five years due to higher demand for squid. They also noted that many individuals had quickly responded to previous challenges relating to limited offloading infrastructure in northern California by using mobile pumps.

While greater mobility enables fishermen to adapt to fluctuations in stock distribution and abundance, short- or long-term migration could have significant socio-economic consequences for fishing communities. In addition to economic and logistical consequences to the fishermen themselves (discussed above), shoreside services that support market squid fisheries, including traditional ports, processors, dealers, and supply houses could experience reduced revenue and income flow as fishermen migrate from their traditional grounds to land and process their catch in new locations (Chavez et al. 2017).

Given that fishermen with larger vessels are more mobile, fleet composition could shift toward larger vessels if the range of squid continues to expand. Such a shift would have implications for catch efficiency as larger vessels can capture and store greater quantities of squid with less effort than smaller vessels. In addition, larger vessels with greater engine power will likely have higher total catch due to their ability to exploit distant (and potentially less exploited) fishing grounds and deal with adverse weather and ocean conditions, thus potentially increasing fishing days (e.g., Robinson et al. 2020). A shift toward larger vessels could also push smaller vessel owners and operators, typical of those with lightboat and brail/scoop permits, out of the fleet. Fishermen noted during the feedback session that market squid permits are increasingly owned by large corporations rather than by the fishermen operating the boats, as large seafood processing companies have bought out independent fishermen to secure their supply over competing buyers (Rahaim 2016). This recent trend toward consolidation, coupled with a potential shift toward larger vessels as the fishery expands northward, may push the remaining smaller-scale owner-operators out of the fishery. To date, fishermen based in northern California who wanted to participate in the emerging squid fishery have been restricted by the extremely high cost of entry, incompatible vessels (and gear), inflexible permitting which was based on historical participation in the fishery, and a lack of offloading, storage, and processing infrastructure (Chambers 2016; Chavez et al. 2017).

2.4.1.2 Diversification

As ocean systems continue to be affected by climate change, the fishing industry and associated management systems must adapt and develop novel ways to ensure sustainable fisheries into the future. In the U.S., many fisheries are managed by limited entry permit systems that restrict access to help prevent overexploitation. However, the high cost of permits and overall lack of flexibility in permitting and quota allocation also prevents fishermen from diversifying their target stocks as changes in the climate, ecosystem, and fishery occur, ultimately reducing their adaptive capacity (Gourlie 2017; Mills et al. 2013). To viably continue to participate in fishing in light of ongoing climate change, fishermen need the flexibility to adjust where, when, and what they catch, which necessitates flexibility in the management system.

While the majority of market squid fishermen held permits for multiple fisheries, we found that the degree of flexibility afforded by holding additional permits is contingent on the type of additional permit(s) held, as well as the status of the stock and economic value of the fishery. The most frequently held additional permit for market squid fishermen is for coastal pelagic finfish fisheries (i.e., Pacific sardine, Pacific mackerel, and northern anchovy), given their overlapping ranges, gear and vessel requirements (i.e., round haul gear such as purse seines and drum seines), and personnel (i.e., crew, buyers and shoreside receivers and processors) (Pomeroy et al. 2002). This interconnected fishery system has historically enhanced flexibility, as fishermen have shifted effort among these fisheries in response to fluctuations in resource availability or demand associated with climate (given that the species favor different ENSO phases), market, and regulatory changes (Aguilera et al. 2015; Pomeroy et al. 2002). However, the closure of the Pacific sardine fishery in 2015, as well as reductions in demand and thus value of anchovy and mackerel fisheries, now undercut the advantages of having a coastal pelagic finfish permit, meaning the most complementary and commonly held additional permit that market squid fishermen hold no longer increases flexibility. While most market squid fishermen stated that they would move or shift target species in response to climate perturbations, a smaller group, primarily older fishermen who had been in the fishery longer, were highly dependent on squid for income, and who held only squid and/or coastal pelagic finfish permits, stated they would resort to temporarily or permanently exiting fishing in response to climate-induced declines in market squid abundance.

2.4.1.3 Adaptive permit allocation

Adaptive, responsive, and proactive management and decision-making frameworks are essential to mitigate impacts of climate change on fisheries (FAO 2020). Distributive conflicts and policy revisions are already occurring in states where stocks straddle management boundaries but are undergoing a spatial redistribution. For example, warming ocean temperatures along the East Coast of the United States have resulted in large-scale northward shifts in fishery stocks for the summer flounder (*Paralichthys dentatus*) and black sea bass (*Centropristis striata*) fisheries. Fishermen in northern regions of these species' ranges either do not have permits for landing and processing the fish, or quotas, which are based on historical fishery catch, are allocated primarily to southern states (Dubik et al. 2019; MAFMC 2021). The misalignment between fish allocations and their geography, which has generated frustration in the fleets and conflict between management authorities, led to policy revisions seeking to equitably reallocate quota; however, the process has been highly contentious (Suatoni 2020). This will be an emerging issue on the West Coast as species shift beyond the jurisdictions in which they are traditionally managed, which is already occurring with market squid.

To facilitate access to market squid for fishermen based out of northern California ports, new legislation has recently been passed to initiate an Experimental Fishing Permit (EFP) program for small-scale operators from Point Arena to the California/Oregon border (Marine fisheries: experimental fishing permits, 2018). This trial EFP could provide new opportunities for local fishermen in these northern California ports (e.g., Eureka, Fort Bragg, and Crescent City) who are currently dealing with closures and/or declines of previously abundant and commercially important species (e.g., salmon, groundfish, herring, abalone, and sea urchin) (Bates and Hildebrand 2018; Pomeroy et al. 2010). Proponents of this trial EFP state that it would enable collection of real-time fishing reports on northern California market squid stocks and resource availability, which could be utilized to test and develop more dynamic management strategies within a smaller fleet or cooperative. Programs such as this have the potential to facilitate adaptive permit allocation (on a small scale), promote collaborative and cooperative fisheries research, and decrease the likelihood of conflict with fishermen in northern parts of the state as fisheries migrate northward.

2.4.1.4 Trans-jurisdictional fishery management

The northward shift in market squid catch also has implications for trans-jurisdictional fishery management. Historically, the market squid fishery has been managed by the state of California, given that the vast majority of catch occurs within state waters. As such, geographic movement of resources across political boundaries in a state-managed fishery raises important discussions regarding whether and how fishermen follow the fish, the allocation of permits to potential new fishery entrants, the social impacts of shifts in fishery resources, trans-jurisdictional institutional coordination, and sustainable fishery management.

With warming ocean temperatures, market squid have been increasingly found in large aggregations outside of California, such as in Oregon, Washington, and Alaska (Chambers 2016; Columbia Basin Bulletin 2018; Soley 2018). This trend was corroborated during surveys and follow-up sessions, where fishermen mentioned that people had traveled well beyond the border and into southern/central Oregon to land squid during recent strong

El Niño events. In fact, from 2016-2020, nearly 25.4 million pounds of market squid were landed in Oregon ports (ODFW 2021), with a catch value of approximately $6 million in 2020 (Tims 2021). In 2021, in response to these recent increases, the Oregon Department of Fish and Wildlife (ODFW) implemented new regulations specific to market squid fishing in state waters, including a weekend closure (similar to California to allow for uninterrupted spawning), rib line requirements (to reduce bycatch and destruction of benthic habitat), and logbook requirements for lightboats (to track participation and effort). Given the consistency of squid landings in Oregon since 2016, ODFW has plans to establish a control date for a limited entry fishery in the near future, although information regarding qualifying criteria, permit allocation, and quota have yet to be determined (T. Buell, personal communication, September 29, 2021).

A more permanent and northward range shift across fixed jurisdictional or management boundaries (e.g., to Oregon, Washington, Alaska, or Canada) would likely lead to conflicts over property rights and resource access, raising complex discussions regarding coordination and equity (Pinsky and Mantua 2014; Pinsky et al. 2018). Given the high mobility of the current fleet of California permit holders, it is likely that these individuals will advocate for continued fishing rights as stocks shift north. Still, decisions regarding who would have access to emerging fisheries and how quota and permits would be allocated are likely to be contentious given the extremely high value nature of the fishery, as vested stakeholder interests vie with new regional interest groups. However, a shift in species range could also create a unique opportunity to work to develop more flexible and adaptive trans-jurisdictional management systems.

2.5 Conclusion

Given the high interannual variability in market squid stocks (driven by the species' high sensitivity to ENSO), the fleet has a long history of overcoming uncertainty and adapting to change. Market squid fishermen have employed diverse strategies to buffer against environmental and associated income variability, and have expressed confidence in their ability to continue to adapt to future change. However, as climate change intensifies, the capacity of fishermen, and associated fishery management systems, to adapt to novel conditions may be tested.

Our research revealed two key responses to historical shifts in market squid abundance and distribution: shifts in fishing grounds and shifts in target species. Due to the industrial nature of the fishery, characterized by large and highly mobile vessels, the fleet has been able to track northward shifts in stock distribution, frequently traveling several hundred miles from their home ports to harvest market squid during historically strong El Niño events. Despite significantly greater costs associated with travel and increased effort, given the extremely high value of this fishery, many fishermen (particularly those with large vessels) are willing to travel an unlimited distance in the event of future range shift. In recent years, however, market squid have appeared in large quantities in locations well beyond the fishery's historic focus, raising questions about whether current management systems and allocation policies will be sufficient to manage the stock in the future. While market squid fishermen are remarkably flexible when it comes to shifting fishing locations, shifting to alternative species can be more challenging. In the past, the interconnectedness of market squid and other coastal pelagic species facilitated shifting target species during unfavorable environmental and/or market conditions. However, regulations and markets now constrain market squid fishermen's ability to take advantage of coastal pelagic species, and access to other permit types is limited. Understanding how fishermen's connections to other fisheries, as well as the status and economic value of these fisheries, influence their response to change is critical to assessing a fishery's adaptive capacity.

Given observed and predicted changes in the market squid fishery, it is important to plan for fishery management under future climate conditions. Monitoring stocks and tracking potential distribution shifts in areas beyond traditional market squid fishery boundaries can help inform future management considerations and challenges, anticipate potential conflicts over resource allocation, and evaluate the need to develop novel management approaches. Engaging in preliminary discussions with fishermen and managers and planning ahead for cooperative management in regions where the fishery is emerging could also help to prevent conflicts associated with trans-jurisdictional species range shifts. Continued and planned engagement with fishermen to understand what facilitates or inhibits adaptation can increase both the effectiveness of policies and the resilience of fishing communities to climate change.

Fishermen's responses to past change serve as a valuable tool for anticipating their capacity to adapt to future change. While there is extensive literature on adaptive capacity and vulnerability frameworks in fishery systems, this study provides concrete examples of observed and implemented adaptation actions evidenced from historic catch records and fishermen's own stated adaptive responses. The challenges and potential opportunities associated with species' range shifts that are highlighted in this study serve as a preview of the types of changes and associated responses that are likely to occur or are already occurring in other fisheries. Identifying cases and examples of successful adaptation is critical for developing adaptation strategies and policies that will enhance existing capacities to sustain fisheries under ongoing climate change.

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III. Chapter 2: Fishermen's perceptions of constraints on adaptive capacity in the California market squid and California spiny lobster fisheries

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3.1 Introduction

Rapid and unprecedented environmental change is reshaping ocean ecosystems, dramatically affecting those dependent on natural resources, and raising concerns regarding how communities will respond and adapt (Marshall and Marshall, 2007; McClanahan and Cinner, 2011). The degree to which changes in climate affect human populations varies considerably across both places and individuals, depending on the local manifestations of a given stressor (i.e., exposure), the degree to which people depend on affected resources (i.e., sensitivity), and on their capacity to adapt to or take advantage of the changes they experience (i.e., adaptive capacity) (Adger, 2006; Gallopín, 2006; Cinner et al., 2018). Affected communities and individuals must respond to both climatic and non-climatic stressors, and understanding how they respond and their ability and willingness to adapt is essential for climate adaptation planning.

Scholarship on adaptive capacity seeks to better understand the conditions that enable individuals or communities to anticipate and respond to changes, to minimize and recover from the consequences of change, or take advantage of new opportunities (Grothmann and Patt, 2005; Gallopín, 2006). Some scholars identify key underlying determinants of adaptive capacity as the availability of and access to different forms of capital, such as natural, human, social, financial, and physical capital (Adger, 2003; Smit and Wandel, 2006; Hinkel, 2011). However, adaptive capacity is not solely determined by underlying access to capital (Mortreux and Barnett, 2017; Cinner et al., 2018; Green et al., 2021). It is also contingent on people's willingness and capability to convert resources into effective action, and thus adaptation efforts can be hindered in a multitude of ways (Coulthard, 2012; Islam et al., 2014). Other less tangible domains of adaptive capacity, including governance and institutions, learning and knowledge, diversity and flexibility, and agency also play key roles in facilitating or hindering a social system's ability to adapt to climate change (Brown and Westaway, 2011; Bennett et al., 2014; Whitney et al., 2017; Cinner et al., 2018; Green et al., 2021). As such, conceptualizing adaptive capacity as constrained primarily by resources and capital can obscure value-laden personal and societal limits to adaptation and the ways in which different strategies are negotiated. In the face of stressors, people typically act upon their subjective internal perceptions rather than objective external measures (Grothmann and Patt, 2005; Smith and Clay, 2010). Thus, subjective assessments of adaptive capacity deal with perceptions of the adequacy of available resources and the factors that empower or constrain social systems or actors to adapt (Adger et al., 2009; Seara et al., 2016).

In the context of fisheries, fishermen have historically employed multiple strategies to cope with or adapt to variable conditions including: diversifying fishing portfolios and targeting multiple species (Anderson et al., 2017; Cline et al., 2017; Robinson et al., 2020), diversifying fishing grounds (Young et al., 2019), altering harvesting techniques (Sievanen, 2014; Cinner et al., 2015), or exiting a fishery and pursuing alternative employment (Coulthard, 2009). These strategies fall under the flexibility domain of adaptive capacity and reflect options for altering one's livelihood within fishing or outside the fishing sector entirely in response to stressors (Cinner et al., 2018; Oestreich et al., 2019). While the literature concerning adaptation in commercial fisheries has shown that these strategies can buffer against environmental uncertainty and income variability (Kasperski and Holland, 2013), their feasibility requires a holistic consideration of the costs and constraints to pursuing them, which will differ amongst individuals and communities (Islam et al., 2014; Anderson et al., 2017; Ward et al., 2018; Beaudreau et al., 2019).

Limits and barriers to adaptation emerge as a result of specific characteristics of the individuals involved, the nature and scale of the fishery systems involved, and/or the larger regulatory context within which the systems operate (Moser and Ekstrom, 2010; Islam et al., 2014). Prior to changing harvest locations, times, or targeting species, new information and knowledge may be needed. Fishermen are typically limited in where they can fish based on local ecological knowledge, vessel size or gear type, geographic distance, and costs (Rogers et al., 2019; Young et al., 2019; Papaioannou et al., 2021). The high financial capital necessary to augment physical capital (e.g., larger vessels or new gear), to purchase additional fishing permits (assuming they are available), or to travel to more distant fishing grounds may limit the viability of pursuing a given strategy (Stoll et al., 2017). In addition, fishermen's ability to diversify is constrained by their regulatory context, including restrictions on access to licenses and fishing rights, spatial management measures, jurisdictional boundaries, and at times, customary territoriality (Murray et al., 2010; Sievanen, 2014).

While effective adaptation to climate change requires that individuals have assets, flexibility, and knowledge, they must also have the ability to mobilize these elements of adaptive capacity, which relates to the agency domain of adaptive capacity (Cinner et al., 2018). Distorted beliefs regarding an individual's own ability to respond to and manage climate impacts, whether it relates to personal traits or to larger regulatory factors, can pose barriers to adaptation. Despite the importance agency plays in activating other domains of adaptive capacity (Cinner et al., 2018; Green et al., 2021), this domain is underutilized (Hicks et al., 2016). An improved understanding of fishermen's own perceptions of constraints on their capacity to adapt can assist in the development of policies that remove barriers to key adaptation options, promote resilience, and maintain livelihoods while simultaneously ensuring the sustainability of resources (Seara et al., 2016).

In this study, we directly engaged with fishermen to better understand their perceptions of constraints on their capacity to adapt to change in two diverse fisheries in the California Current System (CCS): California spiny lobster (*Panulirus interruptus*) and California market squid (*Doryteuthis opalescens*). The CCS is a highly productive upwelling system, producing and supporting numerous fisheries (Harvey et al., 2021). It is characterized by seasonal wind-driven upwelling and high biological productivity (García-Reyes and Largier, 2012). Climate change projections indicate a robust and unambiguous signal of future surface warming in the CCS (Pozo Buil et al., 2021), along with changes in the timing and intensity of upwelling, which critically affects the productivity and distribution of marine species from primary producers to top predators (Checkley and Barth, 2009; Iles et al., 2012; Xiu et al., 2018; Pozo Buil et al., 2021). Furthermore, although market squid and spiny lobster rank among the highest value commercial fisheries in the CCS (NMFS, 2018), studies addressing the adaptive capacity of these fisheries are limited. There are also notable differences in these fisheries in terms of scale of operations, seasonality, gear and vessels, regulations, and species' responses to climate variability, which can generate dramatically different adaptation responses and outcomes. We examine how perceptions of constraints on adaptive capacity vary across these two fisheries, as well as how characteristics of individual fishermen, particularly as they relate to assets, flexibility, and agency, influence the likelihood that they will perceive different factors to be constraints within each fishery. We situate our findings within the broader fishery and regulatory context in which fishermen operate and conclude with a discussion of how interactions between different domains of adaptive capacity can enhance or negate broader adaptive capacity within fisheries.

3.2 Methods

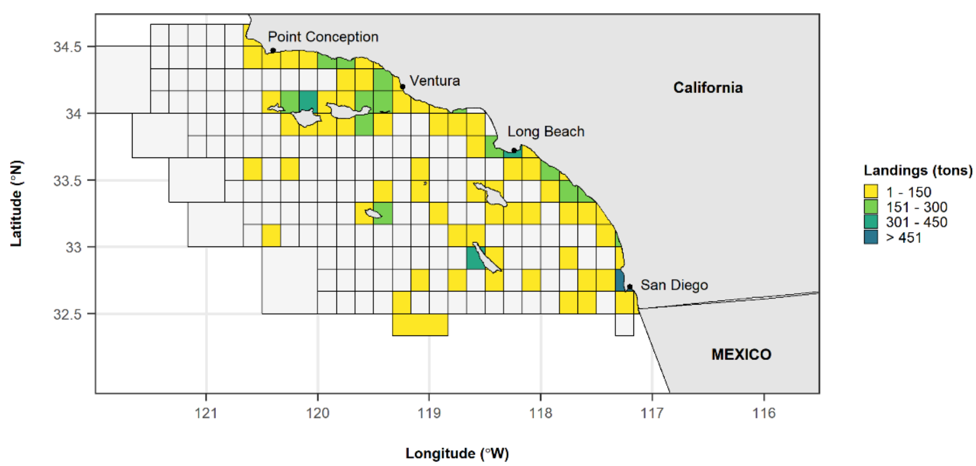
We employed a comparative research approach to understand constraints on adaptive capacity in California spiny lobster and California market squid fisheries. Previous fisheries research has demonstrated the usefulness of the comparative approach for identifying similarities and differences between fishery systems (Gaichas et al., 2012; Dey et al., 2016; Murciano et al., 2021).

3.2.1 Study fisheries

The California spiny lobster fishery is a relatively small-scale fishery, with the majority of fishing activity occurring in the Southern California Bight, from Point Conception to the California-Mexico border, including some areas surrounding the offshore Channel Islands (CDFW, 2019) (**Fig. 1**). The fishing season runs from early October to mid-March each year, although 80% of a season's catch is landed between October and mid-January (CDFW, 2016). There is considerable evidence that the spiny lobster fishery is enhanced during warm sea surface temperature (SST) conditions associated with El Niño events and the warm phase of the Pacific Decadal Oscillation (Koslow et al., 2012).

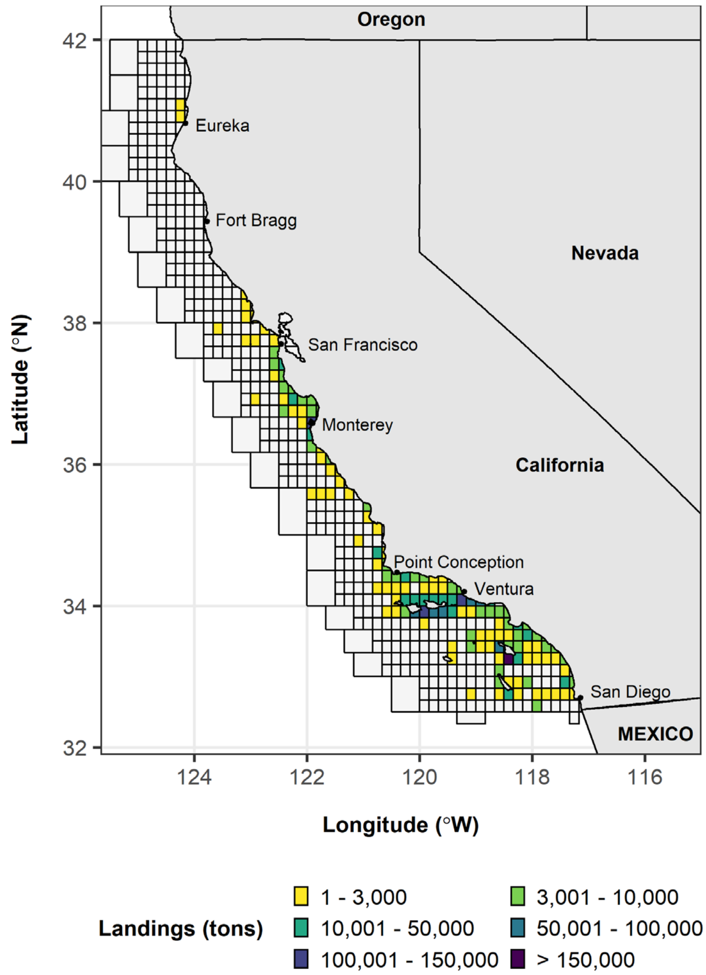
Fishermen operate relatively small boats (mean size 30.5 feet) to deploy baited rectangular traps made of wire or plastic mesh and set on the bottom (CDFW, 2019). The spiny lobster stock has been managed using a number of regulations designed to protect the spawning potential of spiny lobster including restrictions on: size, season, access (number of permits), gear type, and total harvest (CDFW, 2016). Marine protected areas (MPAs) implemented under the Marine Life Protection Act in 2012, also prohibit take of lobster in certain locations to increase egg and larval production (Lenihan et al., 2021). The CDFW adopted the California Spiny Lobster Fishery Management Plan (FMP) in 2016, which put into place a cohesive management strategy to guide the future sustainable management of the recreational and commercial lobster fisheries, as required by the Marine Life Management Act (CDFW, 2016). The purpose of the FMP was to formalize a management strategy for spiny lobster that is responsive to environmental and socio-economic changes and establish a framework for informed decision-making to achieve a sustainable fishery integrating the entire ecosystem.

Figure 1. Map of total California commercial spiny lobster fishery landings (tons) by fishing block from 2000 to 2019 fishing seasons (CDFW Marine Landings Database System, MLDS). Fishing blocks with less than 15 entries were excluded.



The California market squid fishery is a large-scale industrial fishery operating over a significantly larger geographic range. The fishery in California is comprised of northern (centered in Monterey Bay) and southern components (predominantly in the Channel Islands vicinity and coastal areas within the Southern California Bight), with the majority of landings historically occurring in the southern fishery (**Fig. 2**). The northern fishery typically operates from April through November, while the southern fishery operates from October through March (CDFW, 2005). Recently, fishing activity has extended into northern California, Oregon, Washington, and Alaska as a result of warming ocean temperatures (Chambers, 2016; Columbia Basin Bulletin, 2018). Market squid fishermen operate large, high-capacity vessels (mean size 55 feet, mean capacity 64 tons) alongside lightboats that are used to attract the squid. Market squid is harvested primarily using roundhaul gear (e.g., purse seine, drum seine, and lampara nets) with a minor proportion of seasonal catch coming from brail/dip net gear (CDFW, 2005). In order to prevent excessive fishing effort (facilitated by newer, larger, and more efficient vessels) and allow for critical periods of uninterrupted spawning, the CDFW developed the Market Squid FMP in 2005, which consists of several static management measures including: a fixed seasonal catch limit of 118,000 tons, 2-day weekend closures, light and gear restrictions, a restricted access program, and monitoring programs (port sampling and logbooks) (CDFW, 2005). Market squid populations, and associated catch, fluctuate dramatically in response to variations in ocean conditions, declining drastically in unfavorable environments associated with El Niño events, characterized by warm SST and low productivity, and rebound rapidly during favorable conditions associated with La Niña events, characterized by cool SST and high productivity (Reiss et al., 2004; van Noord and Dorval, 2017; Powell et al., 2022).

Figure 2. Map of total California commercial market squid fishery landings (tons) by fishing block from 1996 to 2018 fishing seasons (CDFW MLDS). Fishing blocks with less than 15 entries were excluded.



3.2.2 Data collection

Semi-structured interviews were conducted with owners and operators of vessels participating in the commercial California market squid and California spiny lobster fisheries during the 2017-2019 fishing seasons (see Supplementary Material for relevant interview questions). Interview subjects were primarily identified at fishing docks and by snowball sampling, later supplemented with a contact list from the CDFW. Interviews for both fisheries consisted of closed-ended, open-ended, and multiple-choice questions. We used a series of yes/no questions to examine whether fishermen experienced a pre-defined list of constraints to adaptive capacity, including permit access, regulations, mobility, knowledge of other locations, and knowledge of other fisheries. They were also provided the opportunity to add additional constraints to this pre-defined list, and to elaborate and explain their responses for each identified constraint. The interviews also included a series of multiple-choice and open-ended questions concerning fishermen’s access to assets or capital, as well as diversity and flexibility that might influence the likelihood of experiencing a given constraint. The interviews lasted approximately 60 minutes, and any personally identifiable information was removed from interviews prior to analysis.

Interviews with spiny lobster fishermen were conducted with the goal of surveying as many active fishermen as possible. Permit-holding fishermen were considered ‘active’ if the fisherman participated in the fishery (landed and reported catch) in at least one of the previous three fishing seasons (i.e., 2014–15, 2015–16, 2016–17) based on a list of permits and landings data obtained from CDFW. Interviews were conducted at major southern California fishing ports in San Diego, Orange County, Los Angeles, and Santa Barbara or by phone (based on fishermen's preference). A total of 88 lobster fishermen were interviewed, representing 59% of total active fishermen during the interview period.

Interviews were conducted with active market squid fishermen with the goal of surveying an owner or boat operator representing as many active squid vessel permits as possible. Vessel permits were considered ‘active’ if the vessel participated in the fishery (landed and reported catch) in at least one of the previous three fishing seasons (i.e., 2014–15, 2015–16, 2016–17) based on a list of permits and landings data obtained from CDFW. Interviews were conducted at Ventura Harbor, the primary landing port for squid, as well as non-port locations or by phone (if preferred or if fishermen were based outside of southern

California). A total of 54 squid fishermen were interviewed, representing 48% of total active vessels (both squid and squid lightboat) during the interview period.

3.2.3 Data analysis

After reviewing and familiarizing ourselves with the interview data, open-ended responses were coded using an iterative, inductive approach (Maguire and Delahunt, 2017). We identified an initial list of themes pertaining to the nature and context of each constraint for each fishery individually. Initial codes were reviewed and refined for internal consistency and to reduce overlap across themes. After identification of themes, fishermen's responses to perceived constraints were analyzed using descriptive statistics (frequency, mean, and standard deviation). In order to determine whether the likelihood of experiencing a given constraint was associated with fishery-specific, demographic, or socio-economic characteristics, we used inferential statistics within the R environment (R Core Team, 2020). T-tests were selected under the assumption that both samples are random, independent, and come from normally distributed populations (confirmed using the Shapiro-Wilk test) with unknown but equal variance. If samples were not normally distributed, we used the Wilcoxon Rank Test. When dealing with categorical data, we used the two-proportion z-test to determine if the proportions of categories in two group variables significantly differed from each other.

3.2.4 Fishermen feedback sessions

As a supplement to the interviews, we engaged groups of knowledgeable fishery participants in a series of feedback sessions. Those who had participated in the survey were recruited based on an opt-in question at the end of the survey (asking fishermen if they wanted to participate), and some fishermen were recruited by word-of-mouth at the harbor for the market squid feedback session. Preliminary findings were presented during the feedback sessions to invite discussion, validate results, and address additional questions that emerged from our preliminary data analysis.

The market squid feedback session was held in November 2019 with 11 fishermen in Ventura, CA, the primary port for squid and where most fishermen are based during that time in the fishing season. Detailed notes were taken throughout the session. Due to the pandemic, spiny lobster fishermen feedback sessions were conducted via Zoom, and thus in much smaller groups. For these meetings, we attained verbal consent for audio recording of the meeting into written transcriptions. A total of eight spiny lobster fishermen participated in three different sessions held in April and May 2021. Participants included fishermen from San Diego, Newport, and Santa Barbara.

3.3 Results and Discussion

Planning for resiliency in light of ongoing climate change requires understanding and addressing the factors that constrain fishermen's capacity to adapt. Our study focused on subjective assessments, or fishermen's own perceptions of constraints to their adaptive capacity. This focus has been noted for its importance, given that people act based on their own perceived capacity, regardless of what might be considered more objective measures of their adaptive capacity (Seara et al., 2016).

Given the geographic proximity of market squid and spiny lobster fisheries, both are exposed to similar climatic, regulatory, and socio-economic stressors. However, inherent differences between the fisheries, including the scale of operation, management policies, vessels, and gear, influence fishermen's perceptions of constraints to adaptation and thus adaptation outcomes. We found that fishermen participating in both the squid and lobster fisheries perceived regulatory and governance related constraints as influencing their capacity to adapt to future change, in particular: 1) limited access to additional fishery permits, 2) restrictive fishery regulations, and 3) broader concerns with fishery management processes (**Fig. 3**). Factors related to individual fishermen's knowledge or ability to act, including 1) limited mobility or 2) knowledge of other locations and fisheries, were also seen as constraining adaptation in both fisheries, although to a lesser extent (**Fig. 3**). Each of these factors was expressed in different ways across the two fisheries, as well as amongst individuals within each fishery, highlighting the importance of comparative assessments of adaptive capacity both within and between fisheries.

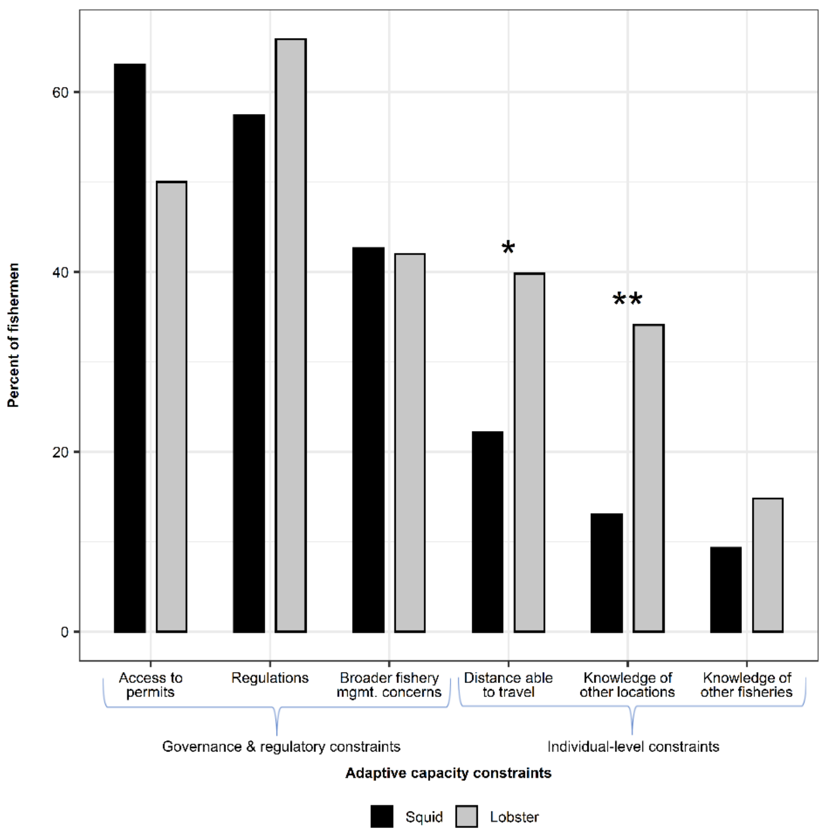


Figure 3. Percent of market squid fishermen (n = 54) and spiny lobster fishermen (n = 88) who stated that each factor constrained their capacity to adapt to future change. * Statistically significant difference between the proportion of fishermen in each fishery (z = 2.16, p = 0.015). ** Statistically significant difference between the proportion of fishermen in each fishery (z = 2.78, p = 0.003).

While there were significant differences between the two fisheries in the proportion of fishermen who perceived mobility or knowledge of other locations to be constraints, the proportion of fishermen who cited regulatory and governance-related constraints was similar in each fishery. Furthermore, fishermen's access to individual assets (financial and physical capital), and their flexibility within and across fisheries, influenced their perceptions of constraints. In both fisheries, fishermen who had less financial capital and less diversity and flexibility in livelihood options were more likely to perceive certain factors as constraints (**Table 1**). For lobster fishermen, physical capital (smaller boat size) also increased the likelihood of fishermen perceiving a constraint (travel and distance), and for squid fishermen, learning/ knowledge (in the form of years of fishing experience) was associated with greater likelihood of perceiving regulations as a constraint.

Although all of these factors have been cited as important for adaptive capacity in fisheries (Whitney et al., 2017; Cinner et al., 2018), our results demonstrate that the extent to which each of these influences fishermen's perceptions of constraints is fishery-dependent. Furthermore, our results suggest that the broader governance context may limit fishermen's agency and their ability to take advantage of assets such as large vessels, mobile gear, and knowledge of additional species and fishing grounds. If fishermen view regulatory and management structures and policies as inflexible and feel that they are unable to influence fishery governance processes, they may perceive themselves as limited in their ability to adapt, in spite of high 'objective' levels of adaptive capacity associated with individual access to capital, learning/knowledge, and flexibility.

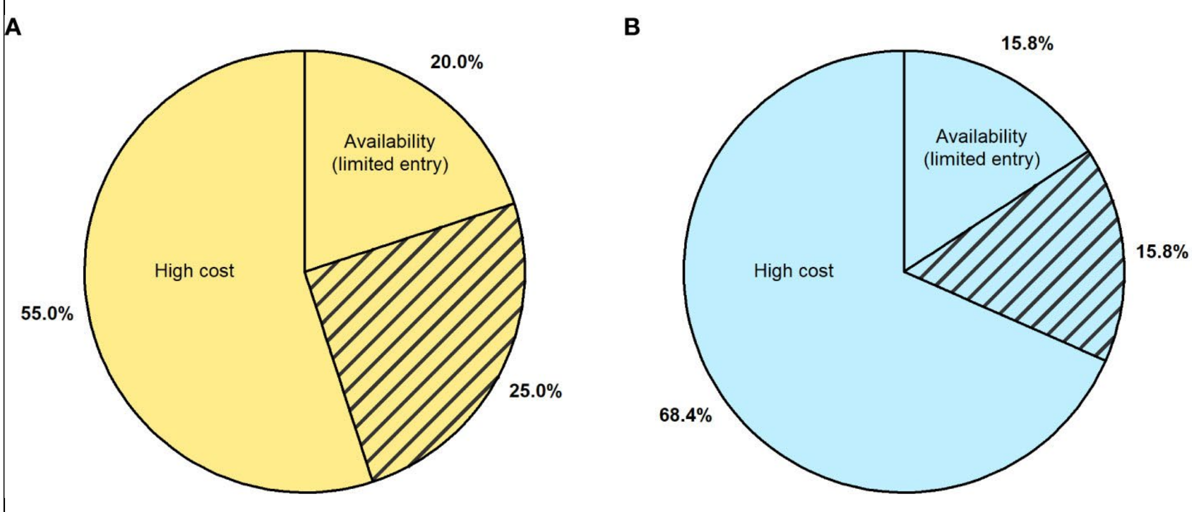
Table 1. Results from significance tests (two-prop. z-test, Wilcoxon rank test) showing factors associated with perceived constraints in each fishery. Significance tests were only conducted if at least 30% of fishermen in each fishery cited a given constraint. * *p* value < 0.05, ** *p* value < 0.01, *** *p* value < 0.001.						
Constraint	Variable	Adaptive capacity domain	Fishery	Test statistic	p-value	Value associated w/ constraint
Inability to obtain or access permits	Access to/reliance on alternative income (non-fishing) (Y or N)	Diversity/ flexibility	Market squid	z = 2.17	0.015 *	No
			Spiny lobster	z = 2.57	0.005 **	Yes
	Household income category (≤ $150,000 or > $150,000)	Financial capital	Market squid	z = 0.53	0.297	
			Spiny lobster	z = 1.99	0.023 *	≤ $150,000
	Additional fishing permits held (Y or N)	Diversity/ flexibility	Market squid	z = 2.05	0.02 *	No
			Spiny lobster	z = 2.01	0.022 *	No
Strict regulations	Years fishing (in respective fishery)	Learning/ knowledge	Market squid	W = 186	0.001 ***	Longer duration
			Spiny lobster	W = 970	0.189	
	Household income category (≤ $150,000 or > $150,000)	Financial capital	Market squid	z = 1.38	0.084	
			Spiny lobster	z = 2.42	0.008 **	≤ $150,000
	Type of permit held (light boat/brail or vessel/seine)	Financial capital	Market squid	z = 2.01	0.022 *	Light boat/brail
Distance able to travel	Household income category (≤ $150,000 or > $150,000)	Financial capital	Spiny lobster	z = 2.08	0.019 *	≤ $150,000
	Vessel size (≤ 30 ft or > 30 ft)	Physical capital	Spiny lobster	z = 2.99	0.001 ***	≤ 30 ft
Knowledge of other locations	Household income category (≤ $150,000 or > $150,000)	Financial capital	Spiny lobster	z = 2.63	0.004 **	≤ $150,000
	Resource dependence (≤ 60% or > 60% of total annual income)	Diversity/ flexibility	Spiny lobster	z = 3.54	0.0002 ***	> 60% of total annual income
	Vessel size (≤ 30 ft or > 30 ft)	Financial & physical capital	Spiny lobster	z = 2.81	0.002 **	≤ 30 ft

3.3.1 Institutional influences on adaptive capacity (governance and regulations)

3.3.1.1 Ability to access or obtain permits

In order to sustainably manage fisheries and halt or prevent stock declines, fisheries in the U.S. and internationally have been subject to increasingly restrictive regulatory measures including: limited access or catch share programs, fishery closures, quota reductions, and MPAs (Murawski et al., 2000; Roberts et al., 2005; Costello et al., 2008; Mora et al., 2009; O'Keefe et al., 2014). While this regulatory context has been critical to preventing overfishing and rebuilding U.S. fish stocks (NOAA Fisheries, 2021), it also constrains fishermen's actions and access to fisheries in which they participate, as well as complimentary fisheries in which they may wish to participate. We found that 63% of squid fishermen and 50% of lobster fishermen cited the ability to obtain permits for other fisheries as a factor that limited their ability to adapt to future change (**Fig. 3**). There was consensus among fishermen in both fisheries that the high cost and limited availability of permits reduce the number of different fisheries that they can potentially access (**Fig. 4**). Indeed, given the large number of limited entry fisheries and high cost of entry for most fisheries on the U.S. West Coast, permit-related constraints have been documented to affect nearly all fishermen and fisheries operating within this region (Holland and Kasperski, 2016; Richerson and Holland, 2017; Frawley et al., 2021).

Figure 4. Themes from open-ended responses from fishermen who chose to elaborate on the ability to access or obtain permits as a constraint to adaptive capacity. **(A)** indicates the percent of responses from market squid fishermen who chose to elaborate (n=20) and **(B)** indicates the percent of responses from spiny lobster fishermen who chose to elaborate (n=19). Each theme is labeled in the pie chart and hashing indicates overlap between two adjacent themes.

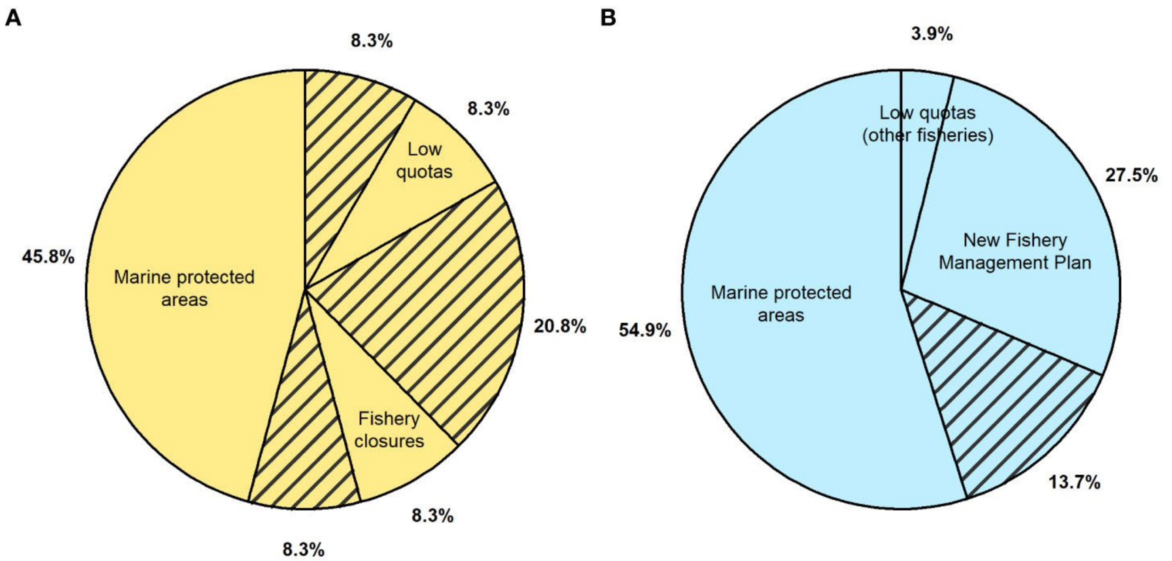


Diversity and flexibility in livelihood options and access to financial capital influenced whether fishermen perceived their ability to obtain or access additional permits as a constraint (**Table 1**). The high cost of entry disproportionately impacts fishermen in lower income brackets given that obtaining access to fishing rights and associated permits requires high financial capital. This corresponds with our finding that lobster fishermen in lower income brackets (annual household income below $150,000) were significantly more likely to perceive access to additional permits as a constraint than those in higher income brackets (annual household income $150,000 or more) (**Table 1**). Moreover, we found that both squid and lobster fishermen were more likely to perceive access to permits as a constraint if they did not already hold additional permits due to their limited availability, regardless of whether they could afford the expense (**Table 1**). Access to permits in limited entry or quota-regulated fisheries is also likely to limit newer entrants to fishing as an occupation, given that permits and quota are typically initially allocated based on historical participation and catch (Bertheussen et al., 2021). Although access to non-fishing sources of income was correlated with whether or not fishermen perceived access to additional permits as a constraint, the direction of the relationship differed between fisheries. While squid fishermen who relied on alternative sources of income (as opposed to those solely dependent on fishing for income) were significantly less likely to perceive their ability to obtain or access additional permits as constraining their adaptive capacity, the opposite was the case for lobster fishermen (**Table 1**). This suggests greater complexity in these relationships possibly related to the level of dependence on alternative income sources or potentially other factors we did not test for.

3.3.1.2 Regulatory constraints

Fishermen from both the squid (57%) and lobster (66%) fisheries cited fishery regulations as constraining their capacity to adapt to future change (Fig. 3). However, the specific regulations that were cited as constraining adaptive capacity varied by fishery (**Fig. 5**). For squid fishermen, closures and quota reductions in other fisheries were a frequently cited regulatory constraint (Fig. 5a). While access to multiple permits is often cited as increasing fishermen's flexibility, and thus overall ability to adapt to environmental change (Aguilera et al., 2015; Cinner et al., 2018; Young et al., 2019), closures or quota reductions in alternative fisheries may negate the benefit of holding additional permits. Squid fishermen historically have shifted effort among coastal pelagic finfish species (i.e., Pacific sardine, Pacific and jack mackerel, and northern anchovy) in response to fluctuations in resource availability or demand associated with climate, market, and regulatory changes (Pomeroy et al., 2002; Aguilera et al., 2015). Coastal pelagic finfish permits are the most frequently held additional permit for market squid fishermen (Powell et al., 2022) due to their overlapping ranges, and overlapping requirements for gear, vessels, and personnel (Pomeroy et al., 2002). Despite the interconnectedness of these fisheries and the flexibility it historically afforded fishermen, recent closures of the sardine fishery, an overall decrease in market value, and quota reductions now undercut the advantages of having this permit, meaning the most complementary and commonly held additional permit no longer increases flexibility (Powell et al., 2022).

Figure 5. Themes from open-ended responses from fishermen who chose to elaborate on regulatory-based constraints to adaptive capacity. **(A)** indicates the percent of responses from market squid fishermen who chose to elaborate (n=24) and **(B)** indicates the percent of responses from spiny lobster fishermen who chose to elaborate (n=51). Each theme is labeled in the pie chart and hashing indicates overlap between two adjacent themes.



One fisherman who commented on the implications of recent fishery closures stated, "It's dangerous to have all your eggs in one basket. We've always had another fishery to move to, and sardine helped us stay afloat. Now there's nothing else you can do." These closures and quota reductions not only reduce fishermen's flexibility to shift target species, but they have also led to much higher effort and competition within the squid fishery, evidenced by one fisherman who stated, "I was involved in many fisheries, but it's all gone to hell. I can't make any money. Salmon's not very good, sardine's closed… we're getting squeezed and having to spend more time in squid." Although only a few lobster fishermen cited low quotas in other fisheries as a constraint to their adaptive capacity (**Fig. 5b**), one fisherman specifically commented on the loss of opportunity and flexibility in the face of larger regulatory constraints, stating, "It used to be that rock cod was a fill-in fishery for slow lobster seasons, but the quota is now so low you may as well toss the permit. Someone with the knowledge, boat, and gear for another fishery often can't even use it because of issues like this with quota being lowered and lowered.”

Over half of squid fishermen and the majority of lobster fishermen who elaborated on regulatory constraints specifically cited MPAs as constraining their capacity to adapt to future change (**Fig. 5**). Fishermen perceived MPAs to reduce their adaptive capacity by restricting their access to fishing locations, and in many cases displacing them from traditional harvesting grounds (Charles and Wilson, 2009; Moreno-Sánchez and Maldonado, 2013). However, more recent research indicates that MPAs can benefit fisheries (Lenihan et al. 2024). Displacement associated with MPAs has been documented to lead to overcrowding and social tension, increased travel costs to new fishing grounds, and increased time spent ‘learning’ new fishing areas (Murray et al., 2010; Bennett and Dearden, 2014; Guenther et al., 2015). Furthermore, nearly all of the respondents who elaborated on MPAs as a constraint expressed their dissatisfaction with the implementation process as well as the chosen locations for the protected areas. As one lobster fisherman stated, “I am not okay with the way managers did it and the way areas were chosen. They took some of the best fishing away from us, and they didn’t do it fairly. They changed meeting dates and nobody was able to show up. They got people that don’t even fish to represent people from the islands.” Another fisherman said, “MPAs are killing us. The best and most productive areas were taken away. MPAs took all the reefs and left us sand. Everything that closed hurt us or was our habitat.”

Lobster fishermen who elaborated on regulatory constraints as limiting their capacity to adapt to future change also cited the new Fishery Management Plan (FMP) (**Fig. 5b**). Nearly all of these fishermen expressed their dissatisfaction with the new trap limit (300 per season) and the allowance of permit stacking. Whether or not fishermen saw the new trap limit as a constraint varied based on their scale of operation. Larger-scale operators felt disproportionately impacted by the new, lower trap limit, stating that it is too restrictive for larger vessels that have greater trap capacity. Some of these fishermen commented on the loss of opportunity associated with the lower limit, stating, "The new trap limit inhibits ambition and money you can make, [reducing] production potential for good, established fishermen. We should have the right to work harder if we want to, to get more reward." Conversely, smaller-scale operators, who generally fish less than 300 traps per season, felt that the allotment was unnecessarily high and will lead to an unsustainable number of traps in the water. Furthermore, fishermen felt that permit stacking only favors the wealthier individuals and will lead to excessive trap neglect, evidenced by one fisherman's comment: "I am not okay with stacking. It's becoming an arms race. It lets the rich get richer. It's classist and unfair, and it's not even realistic to service that many traps."

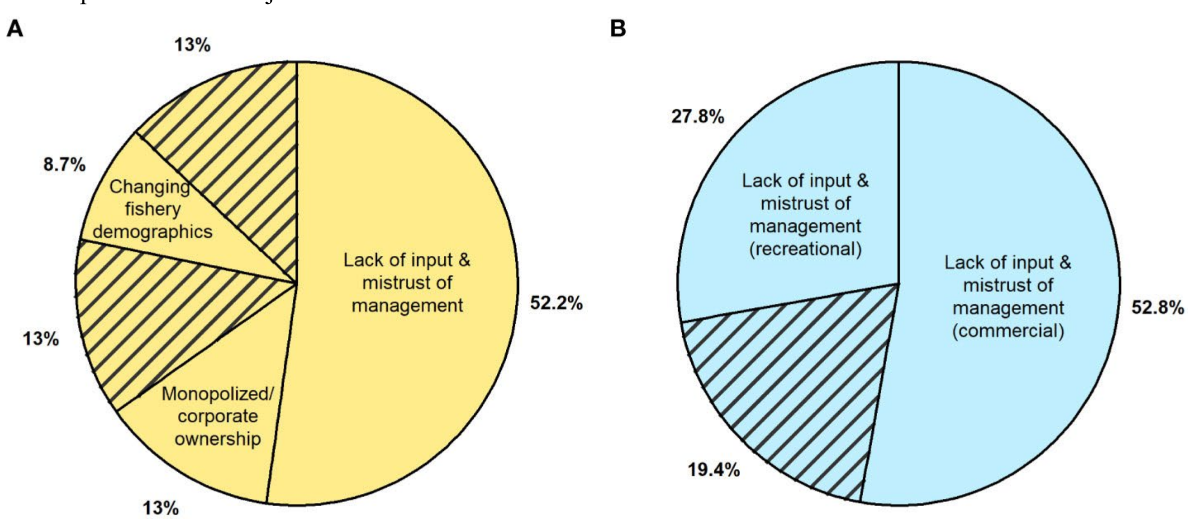
Within each fishery, different types of factors including access to financial capital and fishery-specific knowledge influenced whether fishermen perceived certain management measures as constraining their capacity to adapt to future change (**Table 1**). For squid fishermen, we found that those holding brail permits (as opposed to those holding vessel/seine permits) were more likely to perceive within-fishery regulations such as quota as a constraint (Table 1), likely due to differences in vessel capacity and the timing of harvesting associated with each type of permit (Hennessey, 2013). We also found that those who had more years of participation in the commercial fishery (i.e., greater experience and knowledge) were more likely to feel constrained by fishery regulations (**Table 1**). Given that fisheries in California have undergone substantial and increasingly restrictive regulatory changes over the last several decades, fishermen who have participated in the fishery for longer have experienced dramatic changes in the regulatory context, whereas newer entrants may accept the current regulatory regime as the status quo.

For lobster fishermen, those in lower income brackets (with lower financial capital) were more likely to perceive fishery-specific regulations as a constraint than those in higher income brackets (**Table 1**). Given that MPAs were a frequently cited regulatory constraint, this relationship could be related (in part) to financial costs associated with MPAs such as increased travel expenses or loss of income (typically short-term) from restricted access (Davis et al., 2019), both of which disproportionately impact individuals with lower financial capital. The permit stacking allowance in the new FMP was another frequently cited regulatory constraint that benefits only fishermen who can afford multiple permits. Thus, those in lower income brackets would not have access to the same opportunity and may be more likely to perceive this as a constraint.

3.3.1.3 Broader concerns with fishery governance

Both market squid and spiny lobster fishermen were given the option to list additional constraints that limited their adaptive capacity and were not represented by the pre-defined constraint categories provided during the interviews. Forty-three percent of squid fishermen and 42% of lobster fishermen cited additional constraints, all of which were related to broader concerns with fishery governance (**Fig. 3**). The majority of fishermen in each fishery specifically mentioned mistrust in management entities and limited fishermen representation and input in decision-making as constraints (**Fig. 6**). Mistrust in authorities also stemmed from fishermen's perceptions of a lack of science-based management as well as a perception of insufficient fishing regulations. One squid fisherman stated, "We want net depth restrictions please. Ban cable purse and require rib line. Managers don't listen to us. We need changes to save the resource or we're going to lose it." Another squid fisherman who commented on his general mistrust in management and lack of input in decision-making said, "I inherently don't trust CDFW. They get way too carried away with everything. MPAs, all these regulations, they're just shoved down our throats. If we manage to get a say, it's once they've already made the big decisions so our opinion doesn't really matter." For lobster fishermen, concerns with fishery management included both the commercial and recreational sectors of the fishery (**Fig. 6b**). Lobster fishermen expressed similar sentiments regarding mistrust and exclusion from decision-making, with one stating, "I really get the feeling that our input as fishermen isn't valued by managers or scientists. At the hearings, your voice isn't heard. I would like to see a higher value placed on fishermen's intrinsic knowledge. Management needs to talk to fishermen one-on-one, work directly with us, not just top-down process of acknowledgement."

Figure 6. Themes from open-ended responses from fishermen who chose to elaborate on broader concerns with fishery governance and its effects on adaptive capacity. **(A)** indicates the percent of responses from market squid fishermen who chose to elaborate (n=23) and **(B)** indicates the percent of responses from spiny lobster fishermen who chose to elaborate (n=37). Each theme is labeled in the pie chart and hashing indicates overlap between two adjacent themes.



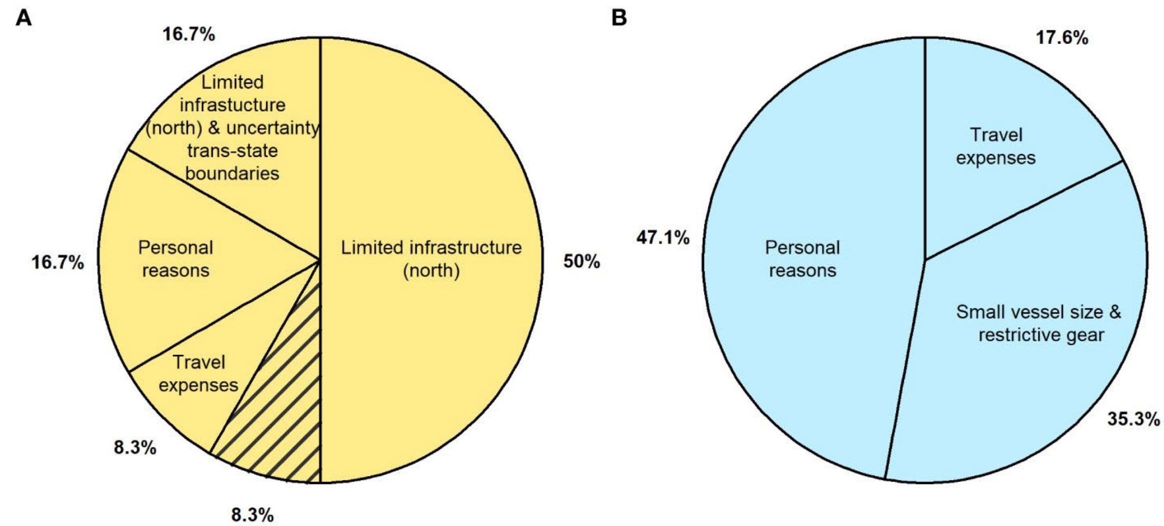
Both squid and lobster fishermen who perceived management of their respective fishery as a constraint to their ability to adapt also mentioned the lack of enforcement of existing fishing regulations, including spatial and temporal management measures, gear restrictions, permitting issues, and size limits (specifically poaching of undersized lobster). Weak or inconsistent enforcement of local rules can exacerbate mistrust, diminish perceived legitimacy in local rules and policy-makers, and perpetuate non-compliance, all of which constrain fishermen's adaptive capacity (Islam et al., 2014; Rohe et al., 2017). For many lobster fishermen, their concerns about poaching and the loss of access to fishing areas were exacerbated by perceptions that rules are unequally enforced between the recreational and commercial fisheries. Nearly all lobster fishermen who discussed their concerns with management of the recreational fishery commented on the perceived widespread poaching due to weak enforcement and regulation, particularly in MPAs and lobster nurseries or in reference to size or bag limits, which directly impacts the commercial fishery via removal of the breeding stock. For example, one fisherman who commented on the management of the recreational fishery said, "It is so poorly managed. They kill more than we do. Hoop netters are going wild, catching 8lb lobsters in the bay and catching tons of undocumented ones… everybody sees and knows. Why is nothing being done? Enforcement is not paying attention." Another lobster fisherman who discussed the perceived lack of enforcement said, "Our biggest problem is Fish & Game's [CDFW's] lack of manpower to enforce their regulations. All of the veteran guys are very frustrated with the lack of enforcement and low fines and penalties for taking of shorts. We need stronger penalties to incentivize compliance."

Many squid fishermen who elaborated on broader concerns with fishery management discussed the influx of out-of-state fishery participants (primarily from Alaska) as well as the increasing corporate ownership of vessels and subsequent monopolization of the industry (**Fig. 6a**). One squid fisherman who commented on the more aggressive fishing style of the recent out-of-state entrants and subsequent increased competition for fishery resources stated, "Our fishery changed last year with all the new Alaska guys entering the fishery. These are heavy weather fishermen, fishing any weather, any time, and it's pushing us to fish in more dangerous conditions. The fishery is so aggressive now. They want every squid." In regards to increasing corporate ownership of the fleet, fishermen were concerned about the impact of this trend on profit to operators, particularly when a single corporation controlled both fishing permits and processors. As one fisherman stated, "Traditional Italian families buy up all the boats and permits. Employees end up with no say on the price and we can't go on strike. No competitive action is available in reaction to price collusion. Having permit holders and processors as one is a monopoly. Processors should never own boats." Several lightboat captains also discussed the implications of corporate ownership of vessels in regards to their inability to unionize and strike.

3.3.2 Individual level-constraints on adaptive capacity: mobility and knowledge

Both squid (22%) and lobster (40%) fishermen cited the distance they are able to travel for fishing as limiting their capacity to adapt, although the proportion of lobster fishermen who listed this as a constraint was significantly greater than that of squid fishermen (**Fig. 3**). Of the market squid fishermen who elaborated on this constraint, the majority cited the limited infrastructure for offloading, processing, and cold freezer storage in northern ports where the fishery has recently expanded as constraining factors (**Fig. 7a**). It is important to note that at the time of the interviews, squid fishermen were limited by the distance they were able to travel due to a lack of offloading infrastructure in the most northern range of the fishery. Due to the high perishability of squid once it is caught, specialized offloading, processing, and cold freezer storage facilities are needed within an 8 to 10 hour travel range from the place it is caught. However, with the more recent increasing use of mobile pumps and proposed investment into new industrial scale infrastructure (Bates & Hildebrand 2018), insufficient infrastructure is now less likely to pose a significant constraint to mobility in the squid fishery. Other squid fishermen who elaborated on this constraint mentioned: personal reasons such as age, family, or place attachment, travel expenses such as fuel and trucking, and uncertainty regarding trans-jurisdictional fishery boundaries as constraints to mobility. Of the spiny lobster fishermen who elaborated on this constraint, about half of respondents cited personal reasons such as age, health, family, place attachment, while others cited small vessel size and restrictive gear and travel expenses as constraints to the distance they are able to travel for fishing (**Fig. 7b**).

Figure 7. Themes from open-ended responses from fishermen who chose to elaborate on travel/mobility-related constraints to adaptive capacity. **(A)** indicates the percent of responses from market squid fishermen who chose to elaborate (n=11) and **(B)** indicates the percent of responses from spiny lobster fishermen who chose to elaborate (n=17). Each theme is labeled in the pie chart and hashing indicates overlap between two adjacent themes. Note that half of fishermen cited limited infrastructure in northern regions alone and an additional 16.7% cited that along with uncertainty in trans-state fishery boundaries (e.g., Oregon, Washington, Alaska).



Both squid (13%) and lobster (34%) fishermen also cited knowledge of other locations as limiting their capacity to adapt, although the proportion of lobster fishermen who listed this as a constraint was significantly greater than that of squid fishermen (**Fig. 3**). Of the fishermen who elaborated on their limited knowledge of other locations as a constraint, all market squid fishermen and the majority of spiny lobster fishermen discussed the importance of local ecological knowledge for fishing and the difficult and time-consuming learning curve associated with obtaining this knowledge (**Fig. 8**). Lobster fishermen who elaborated on this constraint also referenced the territorial nature of the fishery as a related constraint, referring to social etiquette, shaming, and conflict if they moved into the established zones of other fishermen.

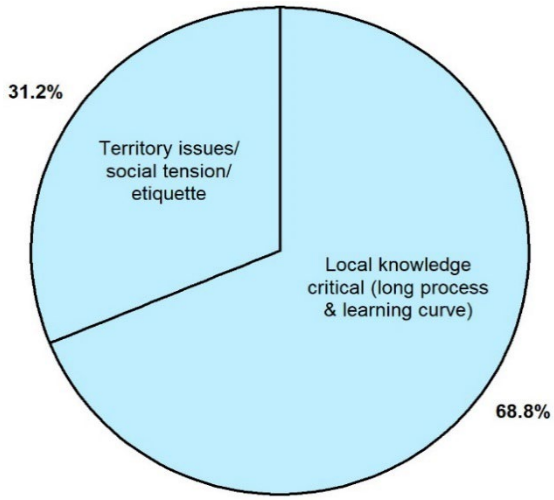


Figure 8. Themes from open-ended responses from spiny lobster fishermen who chose to elaborate on locational knowledge-related constraints to adaptive capacity (n=16). Responses by market squid fishermen (n = 5) are not displayed as a pie chart given that 100% of fishermen who elaborated cited the importance of local ecological knowledge.

Differences in the nature and scale of the two fisheries may explain the notable differences in the proportion of fishermen in each fishery who perceived the distance they are able to travel for fishing and knowledge of other locations as constraints. Squid fishermen operate large industrial-scale vessels capable of extensive travel, whereas lobster fishermen operate much smaller vessels with limited ranges. In addition, the spiny lobster fishery operates with fixed gear, and space is "marked" or occupied, reducing the likelihood that another fisherman will fish that space (Wilson et al., 2013; Guenther et al., 2015). As a result, lobster trap fisheries are notoriously territorial and fishermen typically have limited knowledge of locations outside their specific territories. Furthermore, lobster fishermen do not anticipate net benefits from increasing their range or shifting fishing grounds large distances due to unsuitable habitat and environmental conditions beyond the current range of the fishery in the California Bight. For squid fishermen, however, high mobility is a requirement due to dramatic species range shifts associated with cyclical ENSO-related climate variability (Powell et al., 2022). Recently observed temperature-driven northward shifts in market squid distribution (Chasco et al., 2022) also indicate that fishermen will need to continue to expand their fishing grounds and travel farther up the coast to continue to participate in the squid fishery in the future. Squid fishermen's ability and past experiences travelling substantial distances to harvest squid all contribute to observed differences in individual-level constraints between the two fisheries.

Responses to change are based not only on the nature of a fishery itself, but also on what individuals and communities participating in the fishery value, their history, and their attachment to particular places (Hidalgo and Hernández, 2001; Devine-Wright, 2013). As evidenced from both interviews and follow-up sessions, harvesting lobster requires specialized local ecological knowledge of bottom benthic habitat as well as trap placement, which increases investment in learning and attachment to fishing in a particular place. Lobster fishermen frequently change where they set traps based on storms and weather, local conditions, and seasonal patterns, and acquisition of this specialized local knowledge in variable environments requires a significant investment of time (Wilson et al., 2013). The long-term investment associated with acquisition of local ecological knowledge, coupled with the territorial nature of the fishery, make it more challenging for fishermen to fish for lobster in new locations.

Financial capital, physical capital, and individual-level constraints on adaptive capacity are inter-related (Young et al., 2019), which was corroborated by the associations we found between smaller vessel size, lower income, and a higher likelihood that lobster fishermen perceived the distance they are able to travel for fishing as well as their knowledge of other locations as constraints to adaptive capacity (**Table 1**). Although high mobility has been shown to buffer fishing communities from the effects of environmental change (Sievanen, 2014; Young et al., 2019; Fisher et al., 2021), in order to expand or move into new fishing grounds, fishermen may need larger, longer-range fishing vessels, which requires access to financial and physical capital. In addition, there are typically higher fuel costs to power larger vessels and to travel farther, compounding the challenges faced by fishermen with limited financial resources. Even if fishermen have sufficient financial capital and/or large fishing vessels, they could still be limited in their ability to diversify fishing grounds and travel beyond their current range if they did not possess the local ecological knowledge necessary to fish successfully in new locations. Furthermore, we found that lobster fishermen with high resource dependence (> 60% of annual income) were more likely to perceive limited knowledge of other locations as a constraint (**Table 1**). Actors who participate in more than one fishery interact with different parts of the marine environment and have multiple perspectives that can enhance broader knowledge about the system and other fishing locations (Stoll, 2017; Frawley et al., 2019). In this case, high dependency on a single fishery resource may lead to increased specialization, limited knowledge of other species and/or locations, and thus, lower capacity to diversify and adapt (Daw et al., 2012; Blythe et al., 2014).

Knowledge of other fisheries was the least commonly cited constraint in both fisheries. Nine percent of squid fishermen and 15% of lobster fishermen stated that they were limited by their knowledge of other fisheries (Fig. 3). Although neither group of fishermen chose to elaborate specifically on this constraint, several fishermen indicated that they would switch fisheries but given their limited knowledge of other fisheries, it is not a viable option. Ultimately, even if fishermen were knowledgeable about other fisheries, limited access to permits and/or fishery closures constrain their ability to switch fisheries.

3.4 Conclusion

Attention to the interactions between factors constraining different elements of adaptive capacity is critical for effective adaptation planning and for ensuring continued resiliency in the face of future change. Our results demonstrate that some characteristics that have been shown to enhance adaptive capacity may be constrained by pressures inhibiting other aspects of adaptive capacity. In the squid and lobster fisheries, we found that governance and regulatory constraints are viewed as the most significant factors constraining fishermen's adaptive capacity. Although individual-level constraints including mobility and knowledge are relevant, they were viewed as less important in the face of a highly constraining regulatory environment. Even if fishermen have assets, flexibility, and knowledge, effective adaptation requires that they have the power and ability to mobilize these domains of adaptive capacity to actively shape their future (Brown and Westaway, 2011; Coulthard, 2012; Cinner et al., 2018).

Certain factors including fishermen's engagement and representation in decision-making, trust in management and institutions, and perceptions of risk all influence fishermen's perceptions of their own agency and thus which adaptation strategies they can or will pursue (Cinner et al., 2015; Frawley et al., 2019b). Studies have shown that fishermen who do not participate in decision-making generally have limited agency to influence resource governance and are least able to respond and adapt to negative changes (Cinner et al., 2015; Mortreux and Barnett, 2017; McClenachan et al., 2019). Furthermore, resource users feel less prepared to handle future challenges when perceived levels of trust are low, and they have little incentive to adapt unless they believe that their input is valued and their adaptive actions can produce desired outcomes (Bandura, 2000; Dressel et al., 2020). Given that low levels of trust in management, as well as limited input in decision-making, were commonly cited constraints amongst fishermen in both fisheries, it is likely that many fishermen have low perceptions of their own agency in the face of governance and regulatory constraints, creating a substantial barrier to adaptation.

Given that governance and institutional dimensions of adaptive capacity, the dimensions over which fishermen have the least control, are perceived as inhibiting their capacity to adapt, this study highlights an opportunity for enhanced resilience through participatory governance processes to strengthen fishermen's individual agency and ability to meaningfully act in the face of change. Although many studies highlight how fishery management is ignoring, or cannot accommodate, climate change (Pershing et al., 2015), it is evident that fishery management decisions are actively structuring where and how communities can adapt (Suatoni, 2020; MAFMC and ASMFC, 2021). As such, attention to adaptive capacity in management decision-making and acknowledgement of the multiple ways regulatory policies can enhance or constrain adaptation is increasingly important with ongoing climate change.

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IV. Chapter 3: Fishermen's perceptions of management in the California spiny lobster and California market squid fisheries

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4.1 Introduction

The California Current System (CCS) is a highly productive upwelling ecosystem, supporting an important ocean economy, including commercial and recreational fisheries that are essential to quality of life, livelihoods, and cultures along the West Coast of the United States. In order to sustainably manage fisheries and halt or prevent stock declines associated with climate change, overfishing, illegal fishing, and other human impacts [1-3], fishery managers use a combination of tools and measures including: harvest control rules, restricted access/limited entry programs, seasonal closures, marine protected areas (MPAs), gear restrictions, and experimental fishing permits [4-6]

Because management decisions affect fishermen and fishing communities, policymakers must also consider the impacts of current or proposed management actions on the communities that depend on the abundance and availability of marine resources [7]. In California, the Marine Life Management Act (MLMA), enacted in 1998, calls for conservation and sustainable management of state fisheries "to assure the long-term economic, recreational, ecological, cultural, and social benefits of these fisheries and the marine habitats on which they depend." Under the MLMA, Fishery Management Plans (FMPs), which represent the primary vehicle for managing fisheries, require strong collaboration with fishery participants and other relevant stakeholder groups in devising management actions [8]. In addition, if an FMP includes new management measures, it must evaluate the expected economic and social effects on fishermen and other shoreside businesses and communities that depend on fishery resources [8].

Despite the requirements to ensure fishermen's participation in fishery management decision-making processes, many studies have shown that fishermen in California and elsewhere do not feel that they are involved in these processes [9-13]. Researchers and communities have recently called for greater bottom-up governance of fisheries through the use of participatory frameworks that fully integrate stakeholder needs and perspectives [14, 15]. While conservation and management measures employed in the US West Coast have helped to prevent substantial depletion of fisheries resources [4], a failure to integrate fishermen's knowledge about ecological processes or to understand the impacts of management processes on fishing communities has the potential to limit the long-term effectiveness of management, particularly in the face of changing environmental conditions [9, 16-18]. Furthermore, social acceptability and support of management measures may vary due to a variety of social, economic, political, cultural, and technological factors [19, 20]. Understanding perceptions of resource users can provide important insights into observations, understandings, and interpretations of the social impacts and the ecological outcomes of management measures, the legitimacy of governance, as well as the social acceptability of regulatory policies [21]. Research on fishermen's perceptions allows policy-makers to evaluate the outcomes and feasibility of management efforts and can inform courses of action to make regulatory systems more acceptable to fishermen, thereby improving conservation and governance [9, 12, 22, 23].

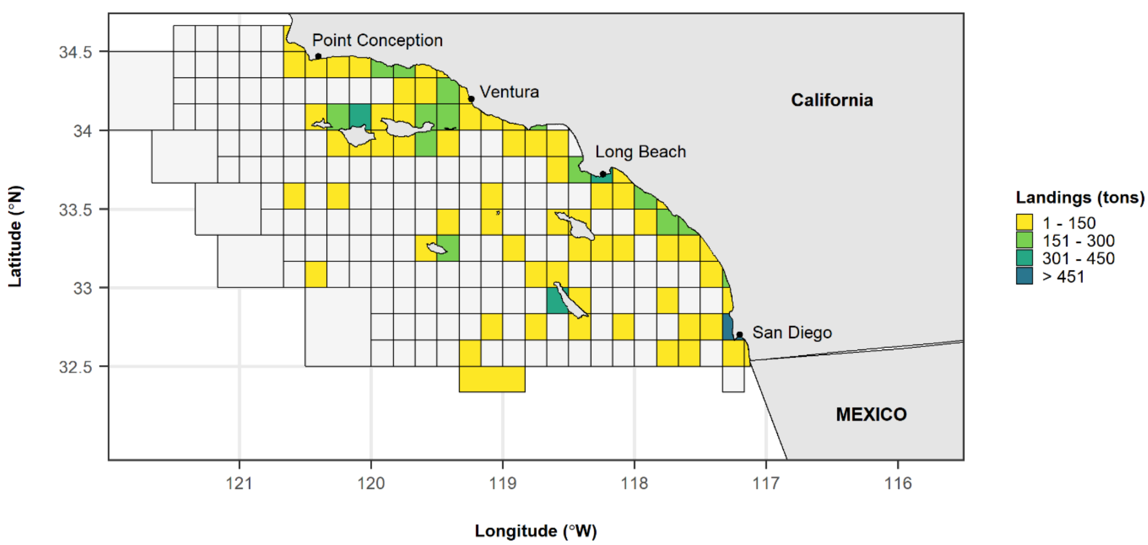
Here, we directly engaged with commercial fishermen participating in California market squid (*Doryteuthis opalescens*) and California spiny lobster (*Panulirus interruptus*) fisheries to better understand their perceptions of management as well as their level of support for specific management measures in each fishery. Market squid and spiny lobster fisheries routinely rank among the highest value commercial fisheries in the CCS [25, 26], but studies addressing fishermen's perceptions of management for these fisheries are limited. These fisheries are both managed by the California Department of Fish and Wildlife (CDFW), but management measures for each fishery vary considerably. In this study, we first describe the regulations specific to each fishery to ensure their sustainability. We then present outcomes from semi-structured interviews and fishermen feedback sessions, which explored fishermen's perceptions of regulations and their rationale for supporting or not supporting regulatory policies. We discuss the nuanced and diverse perspectives that fishermen have regarding fishery management, situating our findings within broader discussions of governance, including legitimacy, equity, transparency, participation, and trust, and conclude with a discussion of paths forward to communicate these perceptions and incorporate them into policy-making and adaptive management.

4.1.1 Case study fisheries

4.1.1.1 Spiny lobster

The California spiny lobster fishery has been managed by the state of California for over 100 years. The species supports an ecologically and economically valuable commercial fishery as well as a significant recreational fishery. Lobsters are thought to be a keystone predator within California's rocky reef kelp forests, limiting the abundance, size, and density of many of their prey items, including top snails, mussels, and urchins in cobble and rocky reef habitats [27, 28]. The majority of lobster catch in California occurs within the Southern California Bight, from Point Conception to the U.S.-Mexico border, including some areas surrounding the offshore Channel Islands [29] (**Fig. 1**). The fishing season runs from early October to mid-March each year, although 80% of a season's catch is landed between October and mid-January [30]. Fishermen operate relatively small boats (mean size 30.5 feet) to deploy baited rectangular traps made of wire or plastic mesh that are set on bottom habitat [29]. Each trap must have a rigid rectangular escape gap for undersized individuals to escape and must include a destruct device. Lobster traps are generally set individually, and are required to have a buoy attached to each of them for identification.

Figure 1. Map of total California commercial spiny lobster fishery landings (tons) by fishing block from 2000 to 2019 fishing seasons (CDFW Marine Landings Database System, MLDS). Fishing blocks with less than 15 entries were excluded (Figure from [11]).



The CDFW manages the lobster fishery through an FMP, adopted in 2016, which is intended to guide the future sustainable management of the recreational and commercial lobster fisheries, as required by the MLMA [30]. The stock is managed using a number of regulations designed to protect the spawning potential of spiny lobster including restrictions on: size (minimum carapace length of 3 ¼ inches), season, access (number of permits), gear type, and traps (300 traps per permit, with the more recent allowance of stacking up to two permits on a vessel under the 2016 FMP) [30]. The purpose of the FMP was to formalize a management strategy for spiny lobster that is responsive to environmental and socio-economic changes and establish a framework for informed decision-making to achieve a sustainable fishery integrating the entire ecosystem. Furthermore, marine protected areas (MPAs) implemented under the Marine Life Protection Act (MLPA) in 2012, also prohibit take of lobster in certain locations to increase egg and larval production [31].

4.1.1.2 Market squid

Since the decline of the anchovy fishery, California market squid has potentially the largest biomass of any single marketable species in the coastal environment of California [32]. Market squid are a crucial forage species, with at least 38 species of fish, birds, and marine mammals depending on squid as a food source [33, 34]. The California market squid fishery supports a large-scale industrial fishery, operating over a significantly larger geographic range than that of California spiny lobster. The fishery in California is comprised of northern and southern components (**Fig. 2**). The northern fishery (centered in Monterey Bay) typically operates from April through November, while the southern fishery (predominantly in the Channel Islands vicinity and coastal areas within the Southern California Bight) operates from October through March [35]. Market squid populations, and associated catch, fluctuate dramatically in response to variations in ocean conditions, declining drastically in unfavorable environments associated with El Niño events, characterized by warm SST and low productivity, and rebound rapidly during favorable conditions associated with La Niña events, characterized by cool SST and high productivity [36]. Recently, fishing activity has extended into northern California, Oregon, Washington, and Alaska as a result of warming ocean temperatures [37, 38]. Market squid fishermen operate large, high-capacity vessels (mean size 55 feet, mean capacity 64 tons) alongside lightboats that are used to attract the squid. The species is harvested primarily using roundhaul gear (e.g., purse seine, drum seine, and lampara nets) with a minor proportion of seasonal catch coming from brail/dip net gear [35].

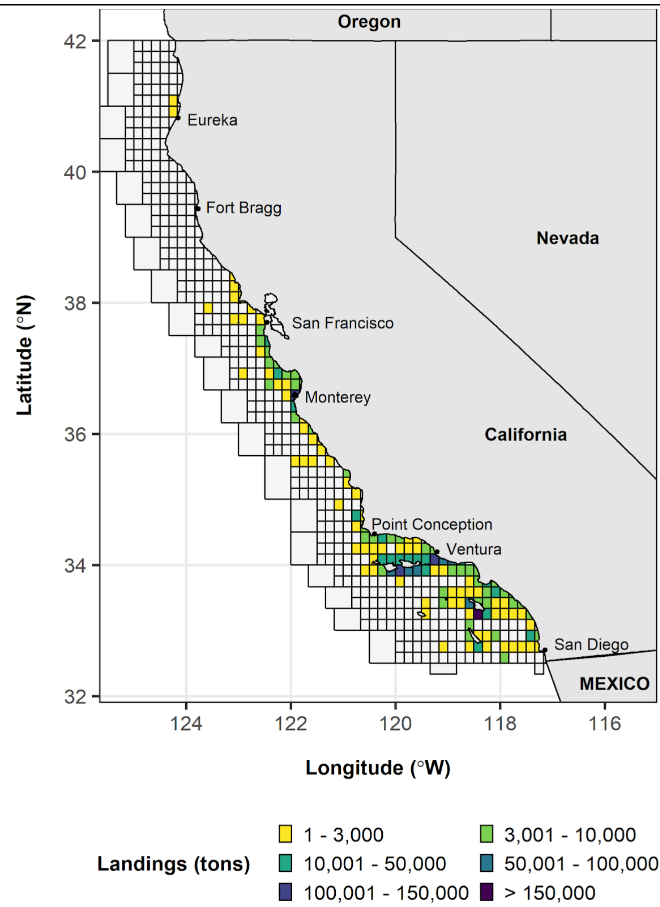


Figure 2. Map of total California commercial market squid fishery landings (tons) by fishing block from 1996 to 2018 fishing seasons (CDFW MLDS). Fishing blocks with less than 15 entries were excluded. (Figure from [11]).

The Market Squid FMP, completed in 2005, has remained the primary management tool for the fishery. The Market Squid FMP established four components of management to regulate the fishery consisting of: 1) fishery control rules enforced through specific regulatory tools including: a fixed seasonal catch limit of 118,000 tons, light and gear restrictions, 2-day weekend closures, and fishery-dependent monitoring programs utilizing logbooks and biological port sampling; 2) a restricted access program consisting of: a fleet capacity goal based on historical participation in the fishery to produce a moderately productive and specialized fleet (55 purse seine vessels, 18 brail vessels and 34 light boats), permit fees, and designation of transferable and non-transferable permits; 3) area closures for squid vessels using attracting lights to protect seabirds at the Farallon Islands; and 4) administrative items that establish an advisory committee which includes scientific, environmental, and industry representatives [35, 39]. Harvesting of market squid is prohibited in state MPAs established under the MLPA in order protect the resource and create harvest replenishment areas [35].

4.2 Methods

4.2.1 Data collection

Semi-structured interviews were conducted with commercial fishermen participating in the California market squid and California spiny lobster fisheries between January 2017 and 2019. Interview subjects were primarily identified at fishing docks and by snowball sampling, later supplemented with a contact list from the CDFW. Interviews for both fisheries consisted of Likert-scale, multiple-choice, and open-ended questions. Likert-scale questions were used to assess fishermen's overall perception of management, to which participants responded from very poorly managed (1) to very well managed (5). We used a series of multiple choice questions to assess fishermen's level of support for individual regulatory measures relevant to each fishery. For lobster, these consisted of: MPAs, a 5-month fishing season, trap limit, gear restrictions, size limit, and limited entry restrictions. For squid, measures consisted of: MPAs, a 12-month fishing season, weekend closure, quota, gear restrictions, and limited entry restrictions. Responses to multiple choice questions included: “Support”, “Somewhat support / Support with caveats”, “Do not support”, “Do not support (as is)”, and “Unsure”. A “Somewhat support / Support with caveats” response was representative of fishermen who supported the management strategy, but desired certain changes that would increase their level of support. Alternatively, a “Do not support (as is)” response consisted of fishermen who currently do not support a specific management measure, but would support it with specific changes. Fishermen had the option to not give an opinion (“Unsure”) as some of the participants were more recent entrants and potentially not as familiar with specific regulations or the effects of a given regulation on their fishing. They were also asked an open-ended question to elaborate on and explain their support (or lack of support) for the aforementioned regulatory measures as well how each measure influences their ability to participate in their respective fisheries. As part of this open-ended question, fishermen were given the opportunity to discuss additional management-related concerns that were not included in the aforementioned list of regulatory measures for each fishery. The interviews lasted approximately 60 minutes, and any personally identifiable information was removed from interviews prior to analysis. The study protocol was approved by San Diego State University Institutional Review Board (# 2459098).

Interviews with spiny lobster fishermen were conducted with the goal of surveying as many active fishermen as possible. Permit-holding fishermen were considered ‘active’ if the fisherman participated in the fishery (landed and reported catch) in at least one of the previous three fishing seasons (i.e., 2014–15, 2015–16, 2016–17) based on a list of permits and landings data obtained from CDFW. Interviews were conducted at major southern California fishing ports in San Diego, Orange County, Los Angeles, and Santa Barbara or by phone (based on the fishermen's preference). A total of 88 lobster fishermen were interviewed, representing 59% of total active fishermen during the interview period.

Interviews were conducted with active market squid fishermen with the goal of surveying an owner or boat operator representing as many active squid vessel permits as possible. Vessel permits were considered ‘active’ if the vessel participated in the fishery (landed and reported catch) in at least one of the previous three fishing seasons (i.e., 2014–15, 2015–16, 2016–17) based on a list of permits and landings data obtained from CDFW. Interviews were conducted at Ventura Harbor, the primary landing port for squid, as well as non-port locations or by phone (if preferred or if fishermen were based outside of southern California). A total of 54 squid fishermen were interviewed, representing 48% of total active vessels (both squid and squid lightboat) during the interview period.

4.2.2 Data analysis

Responses to likert-scale and multiple-choice questions were analyzed using summary statistics. Responses to open-ended questions were categorized according to whether fishermen were explaining their support for a given measure or lack of support. The latter also included responses of fishermen who suggested changes to a given management measure that would increase their level of support. After reviewing and familiarizing ourselves with the open-ended component of interviews, thematic analysis was conducted using an iterative, inductive approach [40]. Initial themes were reviewed and refined for internal consistency and to reduce overlap. Themes that emerged frequently were identified and are described in the results and discussion with illustrative quotes to provide additional contextual information on the reasons behind fishermen’s support, or lack of support, for specific regulatory policies. We also reviewed key scientific literature on fishermen’s perceptions of management in other fisheries and compliance with spatial management policies [9-12, 16-18, 41] in order to identify important social, environmental, and policy factors to complement our thematic analysis.

4.2.3 Fishermen feedback sessions

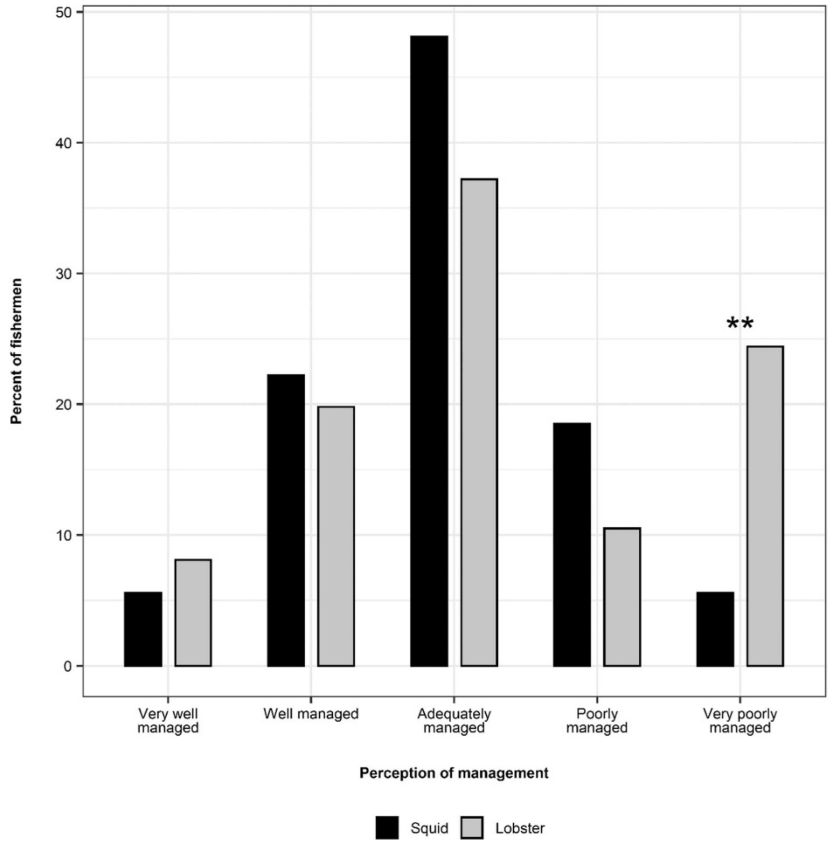
As a supplement to the interviews, we engaged groups of knowledgeable fishery participants in a series of feedback sessions. Those who had participated in the survey were recruited based on an opt-in question at the end of the survey (asking fishermen if they wanted to participate), and some fishermen were recruited by word-of-mouth at the harbor for the market squid feedback session. Preliminary findings were presented during the feedback sessions to invite discussion, validate results, and address additional questions that emerged from our preliminary data analysis.

The market squid feedback session was held in November 2019 with 11 fishermen in Ventura, CA, the primary port for squid and where most fishermen are based during that time in the fishing season. Detailed notes were taken throughout the session. Due to the pandemic, spiny lobster fishermen feedback sessions were conducted via Zoom, and thus in much smaller groups. For these meetings, we attained verbal consent for audio recording of the meeting into written transcriptions. A total of eight spiny lobster fishermen participated in three different sessions held in April and May 2021. Participants included fishermen from San Diego, Newport, and Santa Barbara.

4.3 Results & Discussion

Many studies have demonstrated commercial fishermen's skepticism of regulatory legitimacy, particularly given that regulatory actions can dramatically impact their ability to pursue their livelihoods [13, 16, 42-44]. While our results found that this was true with certain regulatory measures, fishermen participating in both the market squid and spiny lobster fisheries were generally supportive of the way their fisheries were managed. Seventy-six percent of squid fishermen and 65% of lobster fishermen surveyed stated that their fishery was either very well managed, well managed, or adequately managed (**Fig. 3**). However, even fishermen who were generally supportive of fishery management were not necessarily supportive of each regulatory measure in place within the fishery, and a significantly greater proportion of lobster fishermen (24.4%) perceived the fishery to be very poorly managed than did squid fishermen (5.6%) ($Z = 2.83$, $p = 0.002$). In the following section, we describe fishermen's level of support for specific management measures in each fishery as well as their rationale for supporting, conditionally supporting, or not supporting each measure.

Figure 3. Percent of market squid fishermen (n = 54) and spiny lobster fishermen (n = 88) indicating their perception of fishery management in their respective fisheries. ** Statistically significant difference between the proportion of fishermen in each fishery (Z = 2.83, p = 0.002).



4.3.1 Regulations common to both fisheries

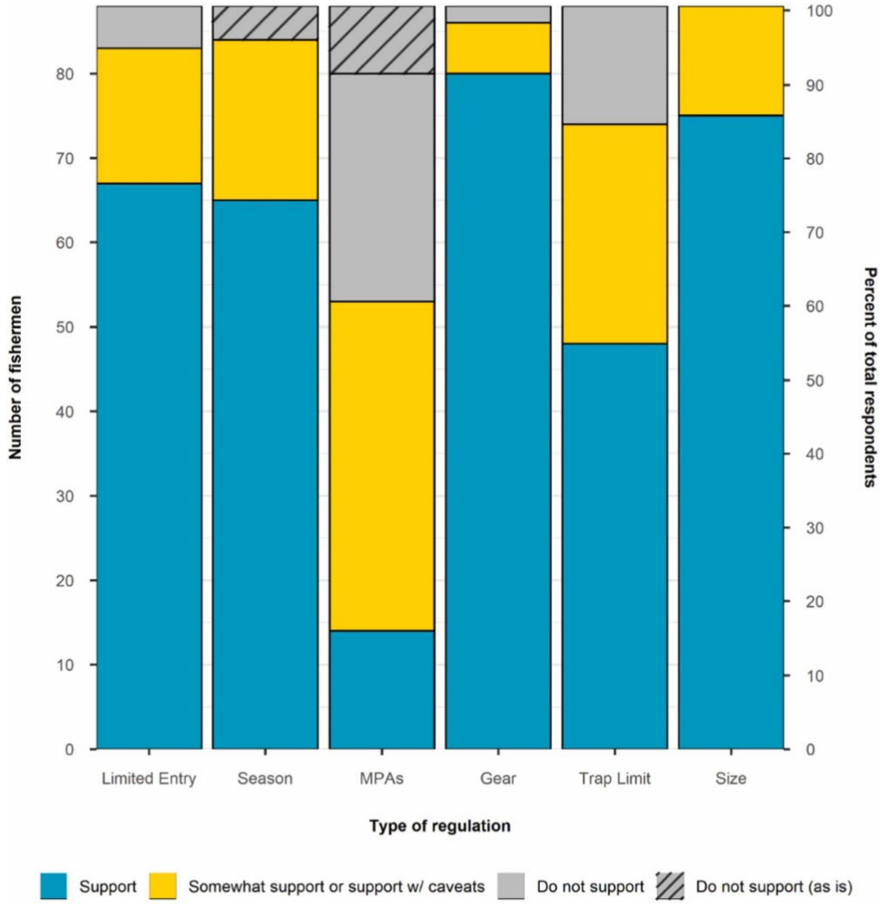
4.3.1.1 Limited entry

Overall, there was broad support for limited entry restrictions in both fisheries. Seventy-two percent of squid fishermen (**Fig. 4**) and 76% of lobster fishermen (**Fig. 5**) expressed support for limited entry regulations. Fishermen in both fisheries commented on the need for limited entry regulations in order to prevent oversaturation, ensure resource sustainability, and reduce competition. In California's limited entry programs, eligibility is based on past participation in the fishery and experience [45], and the fishermen we interviewed had already benefitted as recipients of (now highly valuable) limited entry permits. It is possible that fishermen not currently in possession of limited entry permits may be less supportive of limited entry restrictions given the high cost of entry for these fisheries, and the substantial institutional and financial barriers now in place for new fishery entrants [46]. Previous research has shown that even fishermen who acknowledge the importance of restricted access to reduce pressure on the fishery are concerned that limited entry restrictions will eventually favor wealthier individuals and corporations, thus limiting opportunities for younger, new entrants [47, 48], and that these restrictions reduce fishermen's flexibility in the face of climate change [11, 49, 50].

4.3.1.2 Seasonal restrictions

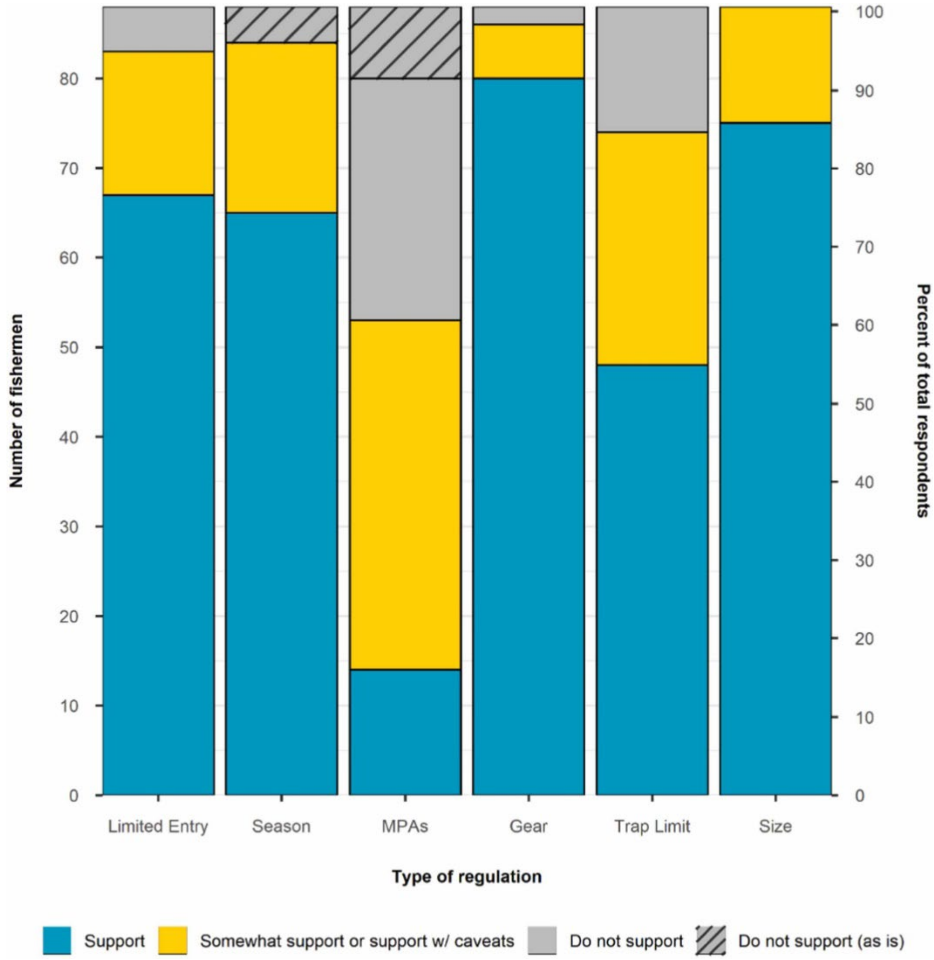
There was also broad support for the seasonal restrictions in both fisheries, although this is more relevant to lobster fishermen given that the squid fishing season lasts the entire year (except in the rare years when quota is reached). Our results are in line with previous research showing that seasonal closures are generally perceived to be an effective management tool given that fishermen readily understand that successful reproduction is essential for stock conservation and livelihood continuity, and closures enhance fishing opportunities both during and outside of spawning periods [51, 52]. We found that sixty-four percent of squid fishermen fully supported the seasonal regulations in the squid fishery (**Fig. 4**). Several of these fishermen advocated for a shorter season with a 2-to-3-month seasonal closure during the less productive months to allow them to focus on other fisheries, reduce burnout, and enhance fishery productivity. One fisherman who commented on this stated, "We should probably have seasonal closures during the slow season. This keeps a fair fishery, lets things breathe and recuperate. Also, there is less fuel burned. Searching all around for the last scraps of quota is wasteful, not productive, and costly."

Figure 4. Market squid fishermen's level of support for specific fishery regulations ($n = 54$). The number of fishermen choosing each response is shown on the left y-axis, while the percentage of fishermen is shown on the right y- axis.



Seventy-four percent of lobster fishermen fully supported the 6-month seasonal closure, mentioning that it was well designed to align with and thus protect lobster spawning and molting (**Fig. 5**). Those who were not fully supportive of the lobster season or suggested changes advocated having an earlier season start date in September to coincide with the start date of the spiny lobster fishery in Mexico, which would help to prevent the market from being flooded with Mexican lobster prior to the opening of the California fishery and ensure more competitive prices. Many lobster fishermen also suggested shortening the season and closing it earlier to align with phenological shifts associated with climate change. These fishermen were concerned about the sustainability of the resource, evidenced as one fisherman stated, “Things have shifted because of climate change. Everything, like molt and breeding, has shifted 2 months early, so I keep catching impregnated females at the end of the season, which hurts the resource.” Fishermen also felt that a shorter season would reduce lobster mortality, with one fisherman stating, “The season is open too long. Lobsters are getting killed by predation, handling, and lost traps.” This sentiment was in line with Agar et al.’s [52] findings that although most fishermen supported seasonal closures to protect resource sustainability, others felt that closure dates should be adjusted to account for mismatches in the timing of the closure with market conditions (e.g., periods of high demand) and with ecological factors specific to the fishery.

Figure 5. Spiny lobster fishermen's level of support for specific fishery regulations (n = 88). The number of fishermen choosing each response is shown on the left y-axis, while the percentage of fishermen is shown on the right y-axis.



4.3.1.3 Marine protected areas

MPAs were by far the most controversial conservation tool among both groups of fishermen, which is unsurprising given a long history of distrust and contention regarding the establishment of the MPA network in California [13, 53]. Socio-economic concerns associated with MPAs including displacement of fishing effort due to loss of important fishing grounds, reductions in landings, increased travel distance to fish, and increased pressure in fishable waters all impact fishermen's well-being and livelihoods [53-55]. As such, fishermen's perceptions of MPAs are an important area of concern for management as compliance of commercial fishermen is essential to ensure the effectiveness of MPAs [43, 56-58].

Only 42% of squid fishermen (**Fig. 4**) fully supported MPAs. Those who did not support MPAs, or supported MPAs with caveats, suggested several changes including: eliminating fines for drifting violations (when fishermen unintentionally drift into MPA boundaries with fishing gear after catching squid outside of the MPA), reducing the total number of closures, and rotating closure locations. One fisherman who commented on the aforementioned reasons for lack of support stated, “MPAs put way too much pressure on the rest of the ocean, and there are way too many. We should move them or re-open them in five years. And we’re not hurting the MPA while we’re pumping or rolling up our nets, but we can still get massively fined if we’re doing either inside an MPA. I understand no fishing inside, but this level of regulation is unnecessary… basically a felony to get a ticket for this.” There was a widespread perception by many of the fishermen who did not support MPAs of unsatisfactory monitoring and limited science behind their implementation, evidenced as one fisherman stated, “There was no data supporting their establishment. There’s no science or research on their effectiveness. I would support MPAs if they were monitored and if I could see the benefits. But still, no evidence that they’re working, it’s just a gut feeling that things are okay.” Squid fishermen also felt that they had been excluded from decision-making and that the government had dismissed their concerns regarding MPAs, leaving them with limited options for action. One squid fisherman commented on the lack of fishermen’s input during the designation process, stating “MPAs were just shoved down our throats. I’m all for marine management, but the way they did it was negative. Once the conservationists and managers get something, they have a stronger voice than people working the ocean, even though we know more than the people making the rules."

MPAs were even more controversial as a consevation tool among lobster fishermen, with only 16% of lobster fishermen fully supporting MPAs (**Fig. 5**). The majority of lobster fishermen who did not fully support or suggested caveats to MPA regulations felt that the designation process was unfair and did not take fishermen input into account. Some fishermen stated that during the MPA designation process, they had been told that MPAs would rotate, allowing fishing to take place after a period of resource replenishment. Fishermen felt that MPA rotation would prevent excessive biomass die-off occurring in reserves (since most fishermen reported that lobsters tend to remain within reserve boundaries). In addition, many fishermen stated that the chosen locations for the MPAs coincided with the most productive fishing grounds and habitat, and felt that rotation would allow intermittent access to these locations. One fisherman who expressed his dissatisfaction with the loss of access to preferred fishing grounds and the overall process for MPA designation stated, "When they originally set up the plan, they asked fishermen which areas they didn't want the MPAs, and that's exactly where they put them. We fought it tooth and nail and we lost. Five or six miles of the most productive coastline, the area we wanted to keep, were taken away... they didn't do it fairly, and we had no say in the matter." Fishermen also raised concerns regarding fairness and equity in the decision-making process relating to the uneven distribution of negative impacts between commercial and recreational fishermen, evidenced as one fisherman stated, "Why are certain areas open for recreational, but not commercial [fishing]? The leeward side of Catalina, inside harbors, San Diego Bay, all these really productive areas where they let hoop netters fish. They're taking them all, they're creaming the broodstock in areas we can't even fish."

Other lobster fishermen felt that MPAs were ineffective and unnecessary given the existence of other regulations in the fishery and because there is minimal bycatch or habitat damage associated with lobster fishing. One fisherman stated, "Lobster fishing is getting worse every year because MPAs are confining people. The only thing they do is limit access for people to get fish. We don't do any damage, we don't hurt the bottom, we have very little bycatch. It makes no sense to think the fish will leave the MPA. They school up, they don't leave. We already have trap and size limits… they work. Why did we need MPAs?" Furthermore, fishermen reported challenges associated with increased fishing pressure and compaction in areas that remain open to fishing. One fisherman who discussed this stated, "You can't deny that fishing the line [along the MPA boundary] is good. But these areas are overly crowded because of the squeeze [people being pushed out of former fishing grounds]. Problems have been created because of these MPAs, we're catching too many lobsters in the open areas. We need rotation."

Many lobster fishermen also expressed dissatisfaction with what they perceived as a lack of science and data supporting the effectiveness of MPAs, as well as inadequate enforcement and monitoring within MPAs. Fishermen discussed poor communication regarding current MPA management and monitoring activities, which further contributed to perceptions that the MPA network is not managed or monitored effectively. One fisherman stated, "We need better data. There was no initial study proving we needed them [MPAs] and they did not consider lobster biology. MPAs are not being monitored like they're supposed to be. Managers are relying on fishermen for that data, because they don't have the money to collect it themselves." Although a recent study has documented that fishing blocks containing MPAs have higher catch rates for spiny lobster [31], potentially increasing fishermen's overall catch through lobster spillover, this benefit might not be immediately apparent to fishermen. During interviews and follow-up sessions, many fishermen acknowledged that although an increase in lobster size and abundance inside reserves was likely, they were skeptical of purported fishery benefits given their perception that most lobster remain within reserve boundaries and if spillover occurs, such large lobsters are undesirable in foreign markets. Although considerable biological research has been conducted in California's MPA network, the outputs are not easily accessible to the fishing community, as scientific information is predominantly disseminated via scientific journals [59], many of which require paid subscriptions to access. The lack of regular communication of scientific outputs has likely contributed to fishermen's sense that there is limited science behind the MPAs.

4.3.1.4 Gear restrictions

Both the squid and lobster fisheries have restrictions on the types and use of gear allowed during fishing, but the specific restrictions are unique to each fishery given the different ways that species are harvested. Gear restrictions had the lowest level of support amongst squid fishermen, with only 36% of fishermen fully supporting current restrictions in the fishery (**Fig. 4**). However, the lack of support was entirely attributed to fishermen's perceptions that current regulations were not strong enough, severely jeopardizing the sustainability of the resource. For squid, gear restrictions consist of wattage/lighting restrictions, which most fishermen expressed indifference about, as well as net type and length. All of the fishermen who did not support gear restrictions were strongly opposed to the continued allowance of steel cable purse lines and advocated for the use of rib lines as well as restrictions on net length to reduce destruction to benthic habitat. Steel cable purse lines are heavier and can be pursed much more rapidly and aggressively than traditional rope lines, thereby increasing the likelihood of impacts to benthic habitats, bycatch, and disturbance of squid egg cases that have already been deposited [60]. Alternatively, rib lines purse the net 18-36 inches above the lead line, which can substantially reduce negative impacts to benthic habitat. One fisherman commenting on the need for stricter gear regulations said, "We need to ban cable purse and require rib line. The recent increase in fishery pressure is hard on the fish - we need some management! Methods like cable pursing means setting nets hundreds of times in the same spot, basically sterilizing the bottom. We need net size limits on length and depth." Another fisherman commenting on the lack of regulations stated, "There are none. Nobody cares about the wattage. I hate to get government involved, but we desperately need to ban cable line. It's unnecessary and rips up the habitat."

Spiny lobster gear restrictions consist of regulations on gear (trap) type, as well as limits on the total number of traps deployed. Gear type restrictions had the highest level of support amongst lobster fishermen, with 91% fully supporting current regulations (**Fig. 5**). There was consensus among fishermen that gear type regulations are very effective in ensuring fishery sustainability via minimizing damage to habitat and ensuring the release of immature lobster (through an escape portal). Overall, fishermen supported the trap limit (300 per permit) (**Fig. 5**), stating that it increases the quality of fishing and reduces trap neglect, which occurs when fishermen do not tend to their gear. Fishermen who conditionally supported or did not support the trap limit often were not opposed to the quantity of traps allowed per permit; rather, they were opposed to the permit stacking allowance associated with this regulation. These fishermen felt that permit stacking was unfair, favoring wealthier fishermen capable of purchasing additional permits (and thus servicing more traps). The few fishermen who did not support the limit itself were predominantly very large-scale operators who wanted to maximize economic opportunity via the ability to fish a greater number of traps.

4.3.2 Fishery-specific regulations

4.3.2.1 Weekend closure (squid)

Sixty-eight percent of squid fishermen fully supported the 2-day weekend closure, stating that this was essential for squid spawning as well as for preventing burnout among fishermen (**Fig. 4**). Nearly all fishermen who did not fully support the weekend closure advocated for a longer (3-day) closure in order to increase fishery productivity, reduce burnout, and allow fishermen to recover and pursue activities outside of fishing. One fisherman who expressed support for a longer closure said, "We need a 3-day closure. That way, when we find them [squid], they will be more abundant, which makes our lives easier. We're going to catch them all regardless. Plus, a 2-day closure means nothing when we're scraping the bottom with cable purse [line gear]."

4.3.2.2 Quota (squid)

Fifty-seven percent of fishermen supported the existing quota on total squid caught during a season, explaining that it prevents market flooding and ensures that prices remain high (**Fig. 4**). Of the fishermen who either somewhat supported or did not support the quota, many stated that they would prefer a flexible, adaptive quota, including in-season and annual adjustments according to climatic conditions and stock levels, as these can fluctuate dramatically from year to year [36]. One of the fishermen who elaborated on his desire for a flexible, adaptive quota said, "There could be a better system with in-season adjustments. Total quota has only been a concern in 10-15% of the seasons. We don't usually reach it (maybe 3 times in the last 30 years). It's crazy to say we should stop fishing on the years there's an amazing abundance of squid. It's better to spread out the catch. If everything's caught before it spawns, it's not good for the resource to take everything at once, which is what the quota does. Fast as you can, however you can. It's good for money, but not good for the longevity of the resource." Another fisherman expressed similar sentiments: "It's bad for the big years when we hit quota because it prevents us from catching when there's such large remaining biomass. And it's bad for the slow years when we're not catching because the season never ends and we can't stop and end up wasting gas and time… It's a poor management technique." Other fishermen who elaborated on their lack of support for the quota felt that the chosen limit was arbitrary and was not supported by scientific data or research.

4.3.2.3 Size limit (lobster)

There was widespread support for the lobster size limit, with 85% of fishermen fully supporting this restriction (**Fig. 5**). Lobster fishermen felt that the minimum size limit, which restricts catch of immature lobster (i.e., those that have not reproduced at least once), is essential for ensuring the long-term sustainability of the fishery. The remaining 15% of fishermen who somewhat supported this measure suggested that in addition to a minimum size limit, there should be a maximum size limit in order to protect the large, healthy breeding stock (i.e., the largest, most prolific breeders).

4.3.3 Additional management related concerns

4.3.3.1 Squid

Of the squid fishermen who discussed additional management-related concerns (n = 26), all but one discussed the need for managers to address the recent increase in fishing pressure. Fishermen attributed this increase in fishing pressure to multiple factors. Many fishermen cited the recent influx of out-of-state fishery participants (primarily from Alaska and Washington) who have a much more aggressive style of fishing. As one fisherman commented: “Our fishery changed last year with all the new Alaska guys entering the fishery. These are heavy weather fishermen, fishing any weather, any time, and it’s pushing us to fish in more dangerous conditions. The fishery is so aggressive now. They want every squid.” Closures and/or low quotas in other fisheries that fishermen historically depended on (e.g., sardine), was also cited as a factor that forced fishermen to continue fishing for squid when they otherwise would have switched to an alternative fishery. For example, one fisherman explained, “I was involved in many fisheries, but it’s all gone to hell. Salmon’s not very good, sardine’s gone, herring’s gone… Now, we’re all spending more time in squid, seeing more effort through summertime because we don’t have any other options.” Some fishermen also cited inconsistencies between vessel hold capacities and permit allowances, which enabled fisherman to fish more than they should under current regulations. One fisherman stated, “One-third of the permits out there are illegal. This was done poorly by management when they did the transfers. Guys are getting 60-ton permits for 150-ton boats - it's not right. It’s created a higher than recommended fleet size and it’s crucial to fix this.” In addition, nearly half of the fishermen who mentioned additional management-related concerns commented on the need for more scientific data and research informing policy. Nearly half also mentioned the need for increased communication between fishermen and managers in decision-making processes, both of which were frequently cited concerns that came up throughout interviews.

4.3.3.2 Lobster

Of the lobster fishermen who discussed additional management-related concerns (n = 61), many commented on the need for stronger and more proactive enforcement and regulation, including harsher penalties and fines for poaching, particularly in MPAs. Most of these fishermen were particularly concerned with enforcement in the recreational fishery, but they also expressed concerns with lack of enforcement in the commercial fishery. As one fisherman stated, “We need stronger enforcement. The fines are way too small, so people continue to violate the regulations. Fish and Game does not have the manpower to enforce them and poaching has gotten out of control. Its causing major problems for the longevity of the resource.” Fishermen also discussed the need for stronger enforcement of minimum size limits, with many fishermen commenting on the frequent illegal take of 'shorts' (i.e., lobsters under the minimum size limit) in both the recreational (particularly hoop net) and commercial fisheries, which impacts the population's reproduction rate and can substantially reduce lobster populations [61]. Research has shown that proper enforcement can have both ecological and socio-economic benefits, given that it reduces the incidence of poaching, thereby potentially increasing resource biomass [62].

Furthermore, nearly one-third of lobster fishermen who mentioned additional management-related concerns discussed the need for increased communication between fishermen and managers in decision-making processes, evidenced by one fisherman who said, “I really get the feeling our input [as fishermen] isn't valued [by managers or scientists]. We have a vested interest in this fishery and want to see it thriving. I would gladly sacrifice a percentage of the lobster I can harvest to know that it will be viable and thriving in the future. I could provide the best information, and it still comes down to what they [managers] choose." This aligns with other research that has similarly shown that fishermen's support of management is higher when fishermen are present within management boards [16, 62].

4.4 Conclusion

The future of fisheries is influenced by the responsiveness and flexibility of institutions that regulate the industry, as well as perceptions of the legitimacy of management and governance processes [63-65]. As such, evaluating and understanding fishermen's perceptions of management interventions is essential. Our research shows that although fishermen in the squid and lobster fisheries expressed varying levels of support for specific fishery regulations, both groups of fishermen were generally supportive of management overall. Fishermen's lack of support was in most cases indicative of a desire for stronger management measures, based on sound science, in order to increase the quality of fishing and long-term sustainability of the fishery, as well as to find an appropriate balance for fishermen's economic needs and their overall well-being. Across both fisheries, MPAs were the most controversial conservation tool and fishermen expressed dissatisfaction with the lack of communication between managers and fishermen, as well as with their limited inclusion and participation in decision-making processes.

Although California's MLMA specifically requires that fishery participants are engaged in management decision-making processes and strongly encourages the consideration of local knowledge throughout the process [8], from the perspectives of the fishermen interviewed, these processes are not sufficiently taking place, highlighting a key opportunity for improving management in our study fisheries. Although CDFW forms advisory committees composed of stakeholders including fishery participants, scientists, and environmental interest groups to provide crucial inputs during the drafting process of an FMP, there is little consistent engagement with fishermen outside of these formal fishery management plan processes. Of note, CDFW has recently convened a new Squid Fishery Advisory Committee, with plans to provide recommendations for updates to the market squid FMP by Fall of 2024. As fishery policies continue to evolve in California, particularly in the face of changing climatic and natural resource conditions, it will be increasingly important to engage fishermen early and often in management planning and processes [66], as well as to assess fishermen's perceptions of the effectiveness of ongoing management measures. Likewise, improving governance processes to make them more participatory and transparent, and accounting for social impacts of management measures can improve trust and perceptions of legitimacy [10, 21, 43, 59].

Previous research has shown that perceptions of benefits of conservation measures, such as MPAs, may be a precursor for their support [19, 21]. In fact, recent research indicates that although the effectiveness of MPAs may be context-dependent, the ecological benefits from reserves in terms of increases in catch-per-unit-effort are clear, highlighting the need for collaborative research and education programs [67]. It is important to recognize that while fishermen's perceptions of the status of a fishery are based in practical experience, managers and policy makers rely on data from scientific studies and fishery monitoring programs as their source of knowledge [42]. As such, there can be a mismatch between what fishermen see as reasonable and imperative within the local context in which they operate, and what fishery management agencies regard as rational and efficient from a broader perspective [68]. In most cases, neither of these knowledge sources is comprehensive, and they are sometimes in conflict. Given the extensive, practical, and unique knowledge fishermen have of their resources and environment, it is imperative that this knowledge is integrated into monitoring and decision-making processes, both to increase fishermen's support, as well as the overall effectiveness of, fishery regulations [69]. Likewise, the outcomes of scientific studies and fishery monitoring should be communicated back to fishermen. Beyond filling gaps in scientific knowledge, integrating fishermen's local knowledge can enhance their confidence and engagement with research and planning activities, and thus overall support of and trust in management [41].

The broad support for the majority of fishery regulations in the market squid and spiny lobster fisheries reflects the successful management of these fisheries to date. However, fishery management is a continuously evolving process. Monitoring fishermen's perceptions can help identify actions (e.g., relationship building, communicating science, incorporating local knowledge, and increasing transparency) that can help improve perceptions of management and increase support for management measures. It can also inform potential regulatory changes, particularly in cases where fishermen perceive management measures to be unfair or inadequate. Understanding fishermen's perceptions of management, as well as clear, two-way communication between regulatory agencies and fishermen throughout the management process, can help to reduce potential controversy, address stakeholder's concerns, and increase the likelihood of developing effective and sustainable policies.

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V. Conclusion

The climate change impacts already affecting the world's oceans provide a compelling need to understand whether fishermen and current fisheries management systems are resilient and how they are likely to fare under future conditions. This dissertation highlights the multiple dimensions of adaptive capacity in two highly valuable California fisheries, and the critical importance of designing management strategies and decision-making processes that contribute to resilience. Planning for resiliency in the face of unprecedented environmental change requires understanding how fishermen have successfully responded to change in the past, as well as how fishery-specific, socio-economic, or perceptions-based factors constrain their capacity to adapt to future change.

The diverse, interdisciplinary team assembled for this project is in line with recent calls for researchers and managers to collaborate with local communities and resource users to examine the predicted impacts of climate change on coastal fisheries to ultimately assist in the design of adaptation strategies and management measures for affected groups. This research is also in line with the Pacific Fishery Management Council's and the California Marine Life Management Act's emphasis on the importance of considering societal effects of fisheries management, including participation in and dependence on the fishery, fishery alternatives, and historical practices.

Chapter 1 assessed California market squid fishermen's responses to historical short-term climatic events associated with the ENSO cycle as a proxy to reflect likely response to future, more permanent warming trends. Using historic catch records and fishermen interviews, I presented trends based on fishermen's responses to previous ENSO events as well as their stated responses to potential future scenarios including reductions in species' abundance and range shifts. I found that fishermen have able to adapt to dramatic shifts in the geographic range of the fishery given the mobility of the fleet, particularly those with large seine vessels. Nearly half of fishermen stated that they would switch fisheries if market squid decreased dramatically in abundance; however, several factors including age, resource dependency, and access to other permits reduced the likelihood that they would switch to another fishery. While market squid fishermen have exhibited highly adaptive behavior in the face of past climate variability, recent (and likely future) range shifts across state boundaries, as well as closures of other fisheries, constrain fishermen's choices and emphasize the need for flexibility in management systems. This study highlights the importance of considering connectivity between fisheries and monitoring and anticipating trans-jurisdictional range shifts to facilitate adaptive fishery management.

Chapter 2 examined how perceptions of constraints to adaptive capacity vary across California market squid and California spiny lobster fishermen, as well as how characteristics of individual fishermen (e.g., assets, flexibility, and agency) influence the likelihood that they would perceive various factors as constraints. I found key similarities and differences with regard to the likelihood that fishermen would perceive a given factor as a constraint, as well as the extent to which different domains of adaptive capacity, including diversity and flexibility in livelihood options, knowledge, and access to physical and financial capital, influence fishermen's perceptions of constraints. Constraints relating to fishery governance, including permit access, fishery regulations, and broader concerns with fishery management were the most commonly perceived constraints in both fisheries. Individual-level constraints including mobility and knowledge of other fisheries and fishing locations were less frequently cited and significantly more likely to be perceived as constraints by spiny lobster fishermen than market squid fishermen. The results highlight the importance of considering interactions between factors constraining different elements of adaptive capacity given that the broader governance context of fisheries can inhibit individual-level adaptive strategies. Ultimately, overcoming barriers to adaptation necessitates planned and participatory governance processes that strengthen fishermen's individual agency and ability to take meaningful action in the face of change.

Chapter 3 examined California market squid and California spiny lobster fishermen's perceptions of and level of support for fishery management measures. I found that both groups of fishermen were generally supportive of fishery management as well as specific regulations, and a lack of support was often indicative of a desire for stronger, scientifically backed management measures. MPAs were the most controversial type of regulation in both fisheries, reflecting fishermen's desire for greater participation and inclusion in decision-making processes, as well as a need for better communication of ecological monitoring outcomes. The overwhelming perception of lack of consultation and involvement in the decision-making process is not exclusive to these fisheries (Pita et al. 2010). Decision-making bodies need to work closely with fishermen, in an open and transparent way, for management measures to be viewed as legitimate. Moreover, the stakeholders involved in co-management measures need to feel that the process benefits them and that participation results in meaningful and real decision-making. Understanding fishermen's perceptions of management provides important insights into the ecological outcomes of management measures, the perceived legitimacy of governance processes, and the social outcomes of regulatory policies.

Overall, the effects of climate change will vary among fisheries, fleets, and regions. The variability observed between each fishery and even individual fishermen in terms of adaptation strategies, perceptions of constraints to adaptive capacity, and perceptions of fishery management highlight the need for contextual, place-based management policies and practices that integrate the knowledge of resource users. Attention to adaptive capacity in management decision-making and acknowledgement of the multiple ways regulatory policies can enhance or constrain adaptation is essential as climate change progresses and future conditions are more uncertain. Integrating local knowledge into decision-making processes will help to develop a shared and comprehensive understanding of highly dynamic fishery systems and to proactively address climate change impacts on fishermen's livelihoods.

Appendix

A. Chapter 2 Supplementary Materials

Table S1. All market squid fishing seasons (1980-2018) grouped by strength and type of El Niño Southern Oscillation event that occurred, according to the Oceanic Niño Index characterization. Events are defined as 5 consecutive overlapping 3-month periods at or above the +0.5º C anomaly for warm (El Niño) events and at or below the -0. 5º C anomaly for cold (La Niña) events. The threshold is further broken down into Weak (0.5 to 0.9˚ SST anomaly), Moderate (1.0 to 1.4˚), and Strong (≥ 1.5˚) events. Neutral events indicate seasons with no statistically significant SST anomaly (i.e., those that did not exceed the +/-0.5˚C anomaly).

El Niño			**La Niña**			**Neutral**
Weak (*n*= 3)	**Moderate** (*n*= 6)	**Strong** (*n*= 3)	**Weak** (*n*= 7)	**Moderate** (*n*= 2)	**Strong** (*n*= 5)	**Neutral** (*n*= 12)
2004-2005	**1986-1987**	**1982-1983**	**1983-1984**	**1995-1996**	**1988-1989**	**1980-1981**
2006-2007	**1987-1988**	**1997-1998**	**1984-1985**	**2011-2012**	**1998-1999**	**1981-1982**
2014-2015	**1991-1992**	**2015-2016**	**2000-2001**		**1999-2000**	**1985-1986**
	1994-1995		**2005-2006**		**2007-2008**	**1989-1990**
	2002-2003		**2008-2009**		**2010-2011**	**1990-1991**
	2009-2010		**2016-2017**			**1992-1993**
			2017-2018			**1993-1994**
						1996-1997
						2001-2002
						2003-2004
						2012-2013
						2013-2014

Fig. S1 Proportion of market squid catch coming from the northern (north of Point Conception, California Department of Fish and Wildlife [CDFW] fishing blocks < 651) versus the southern (south of Point Conception, CDFW fishing blocks ≥ 651) components of the fishery. X-axis tick labels are color-coded by the strength (i.e., weak, moderate, and strong) and phase (i.e., El Niño, La Niña, and neutral) of the El Niño Southern Oscillation during that season. Note that although data is available prior to 1990, earlier data is not reflective of the present-day fishery given that the southern fishery did not emerge and expand until the 1980s and 1990s and thus all catch occurred in the northern fishery.

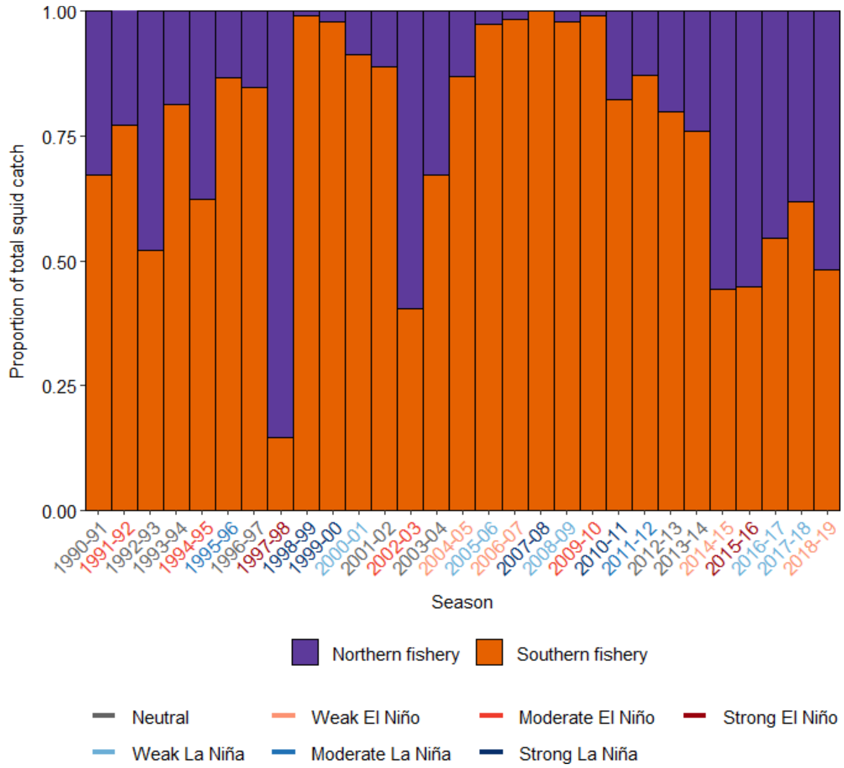


Fig. S2 Responses of market squid fishermen (n = 41) to past El Niño events. The remaining fishermen (n = 13) reported no change in fishing location. The number of fishermen choosing each response is shown on the left y-axis, while the percentage of fishermen is shown on the right y-axis. Note that deeper and further offshore were coded separately as fishing offshore does not necessarily mean fishing deeper (e.g., Channel Islands, Tanner/Cortes Bank).

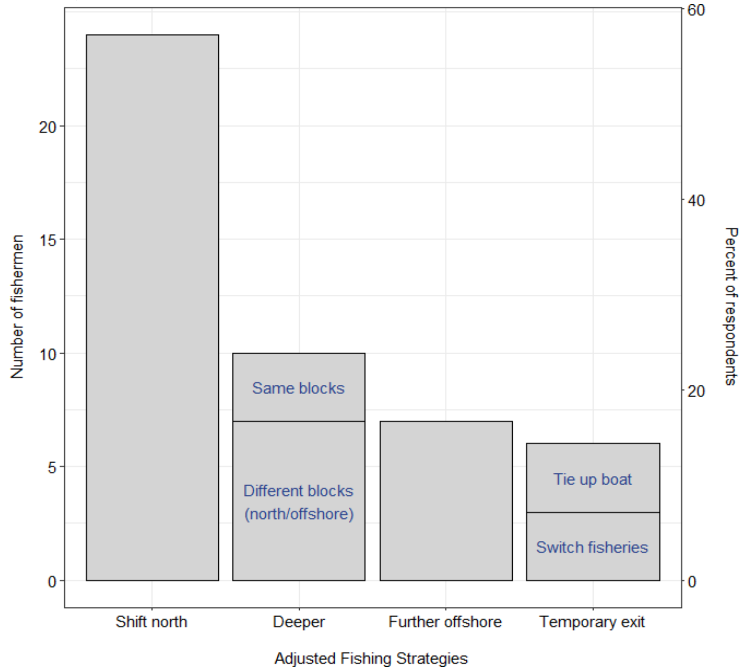
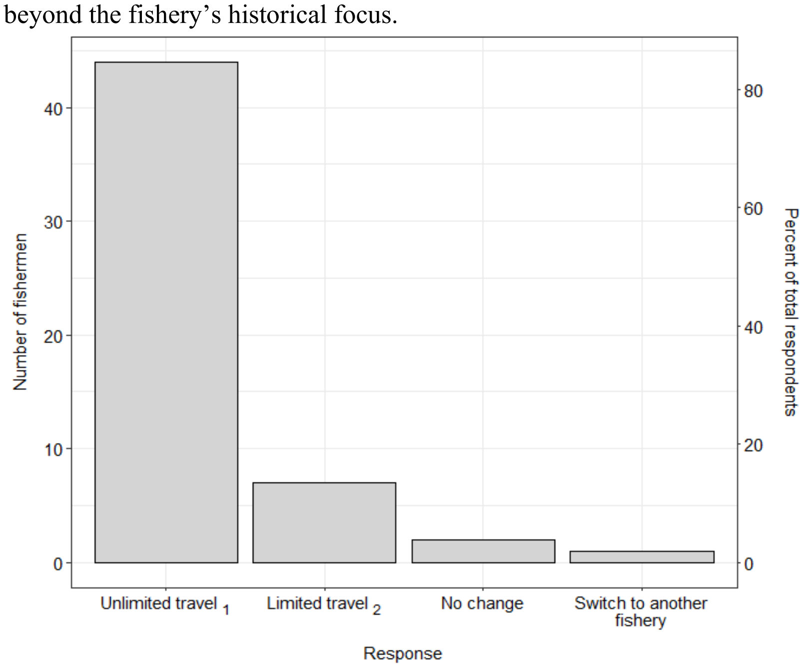


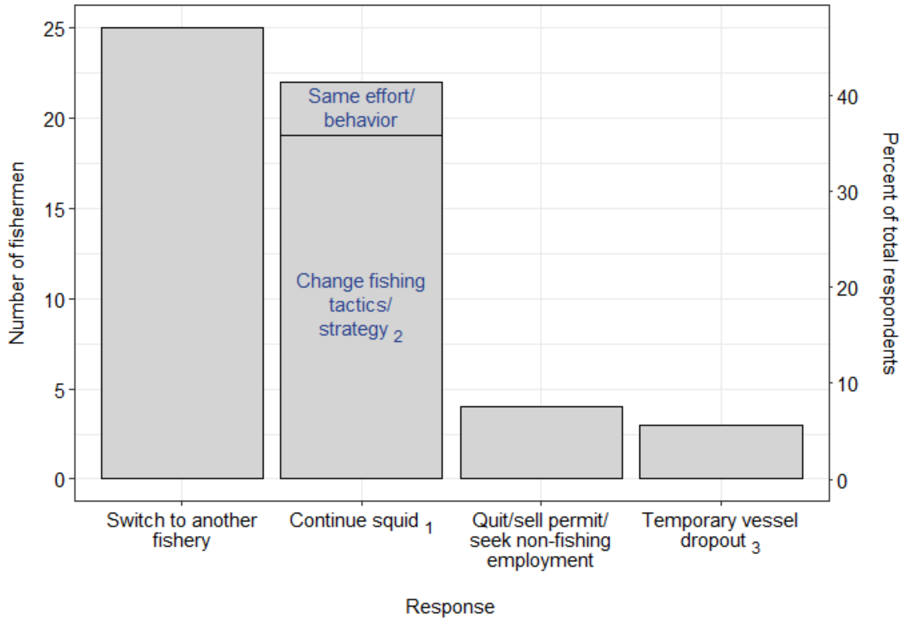
Fig. S3 Responses of market squid fishermen (n = 54) to a hypothetical scenario in which the range of market squid shifted north beyond the fishery's historical focus.



1 Nine fishermen provided contingencies that might affect their willingness to travel: economic feasibility/consistency of fishing (n=7) & accessibility to pump/unloading facilities (n=4)

2 Mexican border to Monterey/SF (n=6), Mexican border to Point Arena (n=1)

Fig. S4 Responses of market squid fishermen (n = 54) to a hypothetical scenario of low squid abundance.

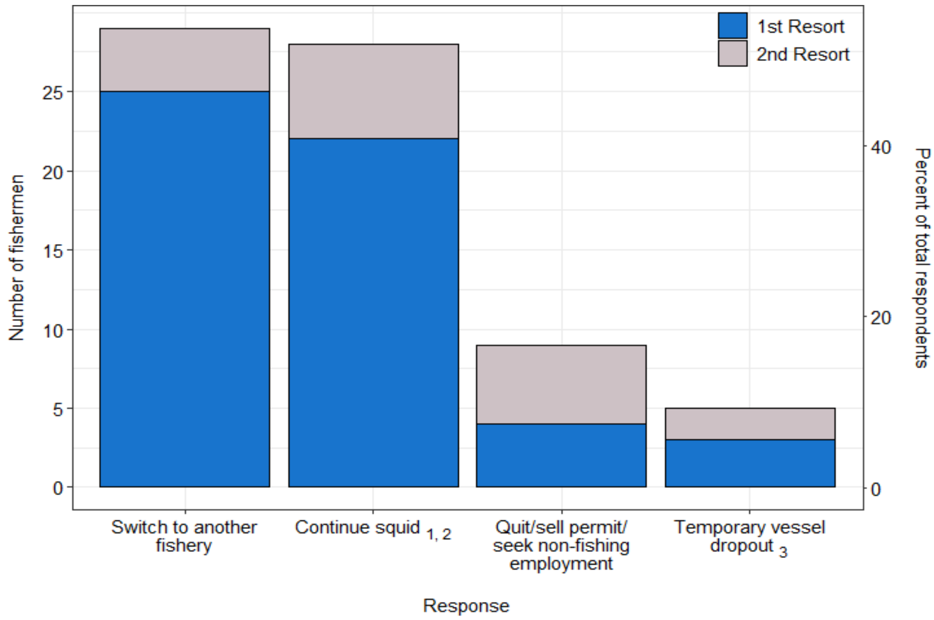


1 Four fishermen noted their decision to continue to participate in squid was due to or contingent on increase in market value/price when supply is low

2 Increase distance (n=7), increase effort (n=3), increase effort & distance (n=3), fish longer season (n=2), team up (n=1), fish deeper/change lights (n=1), drop some crew (n=1), set on smaller quantities of fish (n=1)

3 Refers to fishermen temporarily exiting the fishing industry (e.g., tying up boat for remainder of season)

Fig. S5 Responses of market squid fishermen (n = 54) to a hypothetical scenario of low squid abundance (same as Figure 7); some fishermen (n = 17) also provided a second resort (i.e., in the event of very low squid abundance), indicated in gray.



1 Six fishermen noted that their decision to continue to participate in squid was due to or contingent on increase in market value/price when supply is low

2 Increase distance (n=9), increase effort (n=6), no change in effort/behavior (n=4), increase effort & distance (n=3), fish longer season (n=2), team up (n=1), fish deeper/change lights (n=1), drop crew (n=1), set on smaller quantities of fish (n=1)

3 Refers to fishermen temporarily exiting the fishing industry (e.g., tying up boat for remainder of season)