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Heterogeneous Perceptions of Social-Ecological Change Among Small-Scale Fishermen in the Central Gulf of California: Implications for Adaptive Response

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As changes in climate, governance, and organization reshape the dynamics of small-scale fisheries around the globe, the persistence of many local livelihoods appears contingent upon the ability of resource users to respond and adapt. Though significant scholarship has considered the limiting roles of resources and infrastructure, recent research has highlighted the importance of local learning and knowledge. Rather than being driven by forces exogenous to local communities, it is increasingly recognized that adaptation may be limited by perceptions and processes within them. Here, we explore knowledge production and adaptive response within a small-scale fishery in the central Gulf of California following system perturbation. Using mixed methods from the natural and social sciences, we (1) identify local drivers of social-ecological change, (2) document knowledge concerning their causes and consequences across a diverse group of small-scale fishermen, and (3) identify patterns of intracultural agreement and disagreement associated with divergent adaptive response. Results indicate that perceptions of social-ecological change were heterogeneous and that gear ownership and target species diversification were critical factors in determining the cultural models through which fishermen understood and responded to changes in the resource system. Unlike other user groups, owner-operator fishermen pursuing generalist livelihood strategies held consensus beliefs regarding changes to system structure and function and demonstrated increased ability to modify fishing tactics with the best practices for sustainable use. Our findings highlight how local knowledge can be used to assess the proximate impacts of external drivers of change and provide insight into the cultural models influencing *in situ* decision-making and adaptive response within modern fishery systems.

Keywords: small-scale fisheries, adaptation, Gulf of California, local knowledge, cultural models, social-ecological systems

INTRODUCTION

Small-scale fisheries (SSF) employ over 90% of the world's capture fishers (Berkes et al., 2001) and provide food and labor opportunities for 100s of millions of people around the globe (Food and Agriculture Organization [FAO], 2018). Rather than existing as isolated subsystems, SSFs are increasingly threatened by external pressures that jeopardize livelihoods and food security (Kittinger et al., 2013). Already impacted by overfishing, pollution, and habitat loss, the shocks and stressors associated with global environmental and socioeconomic change present a significant challenge for small-scale fishing communities and the marine resources upon which they depend (Allison et al., 2009; Finkbeiner et al., 2017). Marine ecosystems are undergoing rapid shifts (Cavole et al., 2016) as unfamiliar oceanographic conditions (Bond et al., 2015) and increasing climate variability (Sydeman et al., 2013) alter patterns of marine animal abundance and distribution (Perry et al., 2005; Pinsky et al., 2013). Concurrently, marine resource licensing regimes have restricted fishing portfolios (Stoll et al., 2016) as the growth of the international seafood trade has exposed fishers to the demands of distant markets and political systems (Crona et al., 2016). As interactions operating across sectors, scales and geographies link distant populations (Liu et al., 2013), and processes of social and ecological change are rapid, intensive, and intertwined.

In many respects, tropical and semi-tropical SSFs are considered among the systems most vulnerable, threatened and exposed (Lauer et al., 2013; Cinner et al., 2018). Fisheries productivity is expected to decrease across such latitudes (Sumaila et al., 2011) as critical infrastructure and marine habitat are threatened by predicted ocean warming, sea level rise, and increases in the frequency and severity of extreme weather events (Pratchett et al., 2011; Woodruff et al., 2013). In addition, these SSF systems are increasingly embedded in global trade networks and international institutions (Crona et al., 2016), and their high resource dependence, restricted market access, and limited governance capacity make them acutely susceptible to political and economic instability (Lauer et al., 2013; Frawley et al., 2019). Across the Gulf of California, global change is transforming SSFs and the social-ecological systems in which they are embedded (Frawley et al., 2019). Though the sector has long been a major source of regional economic development (Sala et al., 2004), the ecology and biodiversity of the region have suffered considerable degradation (Carvajal et al., 2004; Saenz-Arroyo et al., 2005). Following recent anomalous oceanographic conditions (Robinson et al., 2016; Myers et al., 2018) and decades of intensive and unsustainable marine resource exploitation (Cisneros-Mata, 2010), today many marine resource-dependent livelihoods are being pushed beyond the point of viability (Vásquez-León, 2012; Giron-Nava et al., 2018).

Confronted by the urgent need to manage for change, SSF scholars and practitioners have increasingly concerned themselves with the study of adaptation, i.e., the ability of systems to adjust to disturbance, mitigate potential damages, take advantage of opportunities, and/or cope with the consequences (Gallopín, 2006). Climate and development literature has traditionally emphasized infrastructure and resource restrictions as being the most important determinants of adaptation (Tol et al., 1998; Smit et al., 1999). But, as geographers and sociologists have long-observed, individuals do not make decisions independent of the political and economic conditions in which they exist and the cultural and historical experiences that constrain their options (Hays, 1994; Turner et al., 2003). Rather than being driven by forces exogenous to local communities, it is increasingly recognized that adaptation may be limited by the perceptions and processes within them (Adger et al., 2009; Brown and Westaway, 2011). Understanding what an individual, group, or culture could do (i.e., their objective ability) is not sufficient to determine if an adaptive response is undertaken. Subjective capacities, as determined by beliefs and expectations, may be a limiting factor in determining the amount of time and energy actors are willing to invest in adaptation (Grothmann and Patt, 2005). Though the relationship between perception and behavior is of particular interest to natural resource management scholars (Grothmann and Patt, 2005; Jones et al., 2011), empirical examples of *in situ* decision-making and adaptive response remain scarce.

Increasingly, local ecological knowledge (LEK) is recognized as a valuable tool for understanding social-ecological change and the adaptation strategies designed and implemented by local populations (Adger et al., 2005; Carothers et al., 2014). LEK is defined as a collective body of knowledge, practices, and beliefs concerning "the relationship of living beings (including humans) with one another and with their environment" (Berkes et al., 2000). LEK is based on personal and/or shared experience (Martin et al., 2007) and is typically connected with a particular social group or place (Crona, 2006; Figus et al., 2017). With a holistic emphasis on relationships, processes, and feedbacks (Walsh et al., 2013), LEK can reveal important information about changes to the structure and function of marine social-ecological systems and plays a critical role in defining how such changes are interpreted and understood as risk (Adger et al., 2009; Aswani et al., 2015). While western (i.e., scientific) knowledge is invaluable in quantifying trends and assessing taxonomic relationships (Moller et al., 2004), LEK can ground such findings in the context of specific places, actors, and harvesting dynamics (Farr et al., 2018), and can be used to describe emergent phenomena in real time (Johannes et al., 2000).

With rapid social-ecological change impacting coastal communities worldwide, it is important not just to consider the content of LEK, but also to improve our understanding of the processes through which it is produced, shared and used (Hopping et al., 2016). Drawing inferences from small-scale fishers LEK requires an understanding of how individuals' experiences within marine resource systems may affect their perception of it (Figus et al., 2017). As knowledge is differentiated by the specific environments, skilled practices, and social relationships through which it is generated, local and regional change processes may be perceived differently within and among coastal communities (Bennett et al., 2015; Ensor et al., 2018). When these perceptions are internalized, culturally distinct knowledge structures and belief systems may arise (Holland and Quinn, 1987). Explicit consideration of the factors driving the heterogeneous distribution of knowledge in SSFs may be useful in bridging LEK and other forms of science (Farr et al., 2018) and improve our understanding of the subjective factors and decision-making processes influencing adaptive response.

According to existing theory, the fishing strategies developed and implemented by small-scale fishers are a product of the constraints and objectives associated with unique social, cultural, and economic contexts (Béné, 1996; Hart and Pitcher, 1998). Fishers' interactions with the marine environment are influenced by a myriad of factors including age and experience (Pauly, 1995), access rights (Stoll et al., 2016), gear usage (Ames, 2003), and capital investment (Crona, 2006). Actors that are involved in more than one fishery interact with different parts of the marine environment and have multiple perspectives that may facilitate broader knowledge about the system (Stoll, 2017). While specialization can help fishers maximize revenue during periods of resource abundance, diversification (of gear types and target species) is thought to help fishers mitigate risk and income fluctuations associated with environmental variability (Kasperski and Holland, 2013; Finkbeiner, 2015).

Although LEK studies are abundant within the SSF literature, few studies have attempted to systematically compare the knowledge of user groups following system perturbation (Lauer and Aswani, 2010; Figus et al., 2017) and link them with specific perceptions, behaviors and responses. In this paper, we provide insight into contextual factors influencing knowledge production, decision-making, and adaptive response in a semi-tropical, small-scale fishery system following a period of pronounced social and environmental change. More specifically, our objectives were to: (1) holistically characterize recent social-ecological trends impacting a small-scale fishery system in the central Gulf of California; (2) document knowledge of system change across a heterogeneous group of local small-scale fishermen; and (3) identify the patterns of intracultural agreement and disagreement associated with divergent adaptive response. To accomplish these aims we consulted published literature and used western, scientific data sources to detect changes impacting regional SSF systems over the past decade. Then, we grounded this information within the social-ecological context of our specific study system, using semi-structured interviews and a structured survey instrument to document fishers' knowledge and assess potential drivers of heterogeneity. Finally, we relied on ethnographic research methods (i.e., qualitative data obtained over the duration of ∼10 months in the field) to characterize cultural models of social-ecological change and link them with behavior and adaptive response.

Background and Study Site

The Gulf of California represents Mexico's primary source of marine resources for foreign and domestic markets and provides food and labor opportunities to approximately 50,000 people (Carvajal et al., 2004; Cisneros-Mata, 2010). But inefficiency within the fisheries sector and the government at large have led to a significant decline in many fisheries' resources over the past several decades (Espinoza-Tenorio et al., 2011). Policy designed to promote the growth and development of export-oriented fisheries has incentivized unsustainable behaviors and accelerated overexploitation (Young, 2001; Defeo and Castilla, 2005). Currently, "85% of the Gulf's fisheries are either at their maximum sustainable yield or over-exploited" (Cisneros-Mata, 2010).

Local Institutions and Rules-in-Use

Mexico traditionally adopted interventionist and protectionist policies to promote the formation of fishing cooperatives (McGoodwin, 1987). However, in 1992 the constitution was amended to attract foreign investment and allow private enterprise to obtain fishing permits and to qualify for government loans and subsidies. As harvesting rights become competitive, conditional, and time-limited (McCay et al., 2014), boats, canneries, processing plants and other essential fishing infrastructure were privatized (DeWalt, 1998). Many traditional fishing cooperatives went bankrupt and were subsequently dismantled. In recent years, SSF in the Gulf of California have been managed through a limited entry permit system. Officially, any commercial fisher must possess a fishing permit, authorization, or concession obtained from the government before entering a marine area and engaging in harvest (Bourillón-Moreno, 2002). In practice, most private permit holders, or *permisionarios,* are buyers that aggregate equipment and access rights while contracting independent fishers, or *pescadores libres*, as a labor force to carry out the harvest (Cinti et al., 2010). These patrons usually supply fishing equipment (boats, motors, nets, etc.) and provide, in advance, the funds needed to cover trip costs. In exchange, fishers are required to sell their catch to the permit holder (Cinti et al., 2010; Basurto et al., 2013). While evidence of ownership of fishing equipment is necessary to become a private permit holder, active participation as a crewmember is not (Cinti et al., 2010). Though the limited entry system relies heavily on enforcement (Bourillón-Moreno, 2002), corruption, increasing coastal immigration, and the significant cost for fishers to organize and participate in collective-action processes (Basurto and Ostrom, 2009; Cudney-Bueno and Basurto, 2009) have promoted *de facto* open access (Cinti et al., 2010).

Recent Oceanographic and Ecological Trends

Though the Gulf of California represents one of the most diverse and productive marine ecosystems in the world (Lluch-Cota et al., 2007), its physical features and their associated biological processes are acutely sensitive to interannual variation in large-scale circulation patterns (Bray and Robles, 1991). A number of important fisheries declined during ocean warming associated with the strong El Niño events of 1982–1983 and 1997–1998, but recovery was observed in both cases during subsequent La Niña conditions as cool, productive water returned to the region (Bakun et al., 2010; Lluch-Cota et al., 2010). However, alongside the return of El Niño conditions in 2009–2010 and 2015–2016, persistent ocean warming (Hoving et al., 2013; Frawley, 2019) has been observed across the central Gulf of California alongside decreasing upwelling and primary productivity (as inferred by chlorophyll a) along the eastern coast (Robinson et al., 2016; García-Morales et al., 2017). Though research results remain disaggregated, observations concerning changes in the distribution and abundance of marine mammals (Elorriaga-Verplancken et al., 2016), seabirds

(Velarde et al., 2015), sea turtles (Zavala-Norzagaray et al., 2017), and other marine taxa (Hoving et al., 2013; Fernández-Rivera Melo et al., 2018) suggest that the impacts on marine animals have been significant. Major fisheries targeting the jumbo squid and the California sardine have collapsed completely (Velarde and Ezcurra, 2015; Robinson et al., 2016) and competition has increased for increasingly scarce marine resources across the SSF sector (Vásquez-León, 2012).

MATERIALS AND METHODS

Field work was conducted in Santa Rosalía (central Gulf of California), a historic hub of the regional jumbo squid fishery, between 2014 and 2016. All research involving human subjects was conducted in accordance with the Human Subjects Research recommendations and guidelines of Stanford University's Institutional Review Board. The research protocol was approved by the panel for non-medical human subjects. All participating informants gave complete and informed oral consent.

Social-Ecological Signals (Oceanographic Anomalies and Fisheries Landings Trends)

We accessed remote sensing data and environmental indices online through NOAA's Earth System Research Laboratory (Optimum Interpolation Sea Surface Temperature, September 1981–2017, 0.25°) and CoastWatch (Aqua MODIS Net Primary Productivity, January 2003–2017, 0.0125°) servers and the Copernicus Marine Service (Global Ocean Physics Reanalysis Sea Surface Height, January 1993–2017, 0.083°) and used R programming language (R Core Team, 2016) to process data and conduct time series analysis. The R package strucchange (Kleiber et al., 2002) was used to detect structural breaks in seasonally adjusted oceanographic time series (Perry and Masson, 2013; Goela et al., 2016) by testing for structural changes in linear regression models and estimating the number of segments and the breakpoints, minimizing the Bayesian information criterion (BIC) and the residual sum of squares (RSS). We obtained monthly fisheries landings data for the Santa Rosalía reporting office (2006–2016) from the DataMares project[1] and inferred relative rates of increase (or decrease) by species by summing landings for each species by year, log transforming the totals, and fitting simple linear models (using year as the independent variable) within R programming language.

Knowledge Content and Structure

Due to limitations of the human mind, individuals selectively filter and interpret overwhelming amounts of incoming information (Sabatier and Jenkins-Smith, 1999). Mental models refer to the internal representations of external reality that form the basis for reasoning, decision-making, and behavior (Jones et al., 2011). Mental models are shaped by social and environmental factors as well as experiences, including failures and successes (Gentner and Stevens, 1983). Over time, as a given group of people internalize their shared experience, cultural meaning is created, which individuals use to perceive and relate to the world around them (Quinn, 2005). Within the current study, cultural knowledge is conceived of as the pool of LEK that is held within the minds of a particular group of individuals while cultural models are conceived of as the knowledge structures used by these groups to organize, interpret, and respond to new information (Holland and Quinn, 1987).

Cultural Consensus Analysis (Semi-Structured Interviews and Surveys)

To assess resource users' cultural knowledge concerning the causes and consequences of social-ecological change, we combined semi-structured interviews (Bernard, 2017) with a cultural consensus analysis (CCA) survey instrument (Romney et al., 1986). The research design was informed by two previous studies (Carothers et al., 2014; Hopping et al., 2016) using CCA to assess LEK and measure intracultural differences among participating informants. "CCA starts with the premise that if informants are part of the same culture, meaning that they share beliefs and mental constructs about the world, then there will be an underlying set of responses about a given topic that are true, or correct, for this group despite some level of heterogeneity in their beliefs," (Romney et al., 1986; Hopping et al., 2016). The advantage of the CCA approach is that it applies rigorous statistical analysis to interview and survey data (typically collected in multiple stages) to assess the extent of knowledge (Caulkins and Hyatt, 1999) or the degree of shared knowledge (Curry et al., 2002) within and among groups (Weller and Baer, 2002). Unlike most conventional survey methods, consensus analysis can produce a high level of statistical confidence with relatively small sample sizes (Romney et al., 1986).

When little information is available about a domain of knowledge, or when this domain is particularly complex, two phases of data collection and analysis are undertaken (Stone-Jovicich et al., 2011). During the first phase (summer 2014 and summer 2015), our objective was to obtain more information about (1) the fishery system under inquiry and (2) locally relevant drivers of social-ecological change. Open-ended conservations, held during the summer of 2014, directed us toward key observations and ideas (Quinn, 2005) that we explored in greater detail using semi-structured interviews (Bernard, 2017) in the summer of 2015. Longhurst (2003) defines a semi-structured interview as "a verbal interchange where one person, the interviewer, attempts to elicit information from another person by asking questions. Although the interviewer prepares a list of predetermined questions, semi-structured interviews unfold in a conversational manner, offering participants the chance to explore issues they feel are important." We used key informants and snowball sampling (Goodman, 1961) to engage a diverse set of current and former fishery participants (n = 35) including processing plant workers, crew members, boat captains, fish buyers, and industry representatives. Interviews, lasting between 45 min and 3 h, were conducted in Spanish and, with permission, digitally recorded and transcribed.

[1] http://datamares.ucsd.edu/

During the second phase of research, we used the observations and ideas advanced by informants participating in the first phase of research to create a set of 28 propositions concerning the causes and consequences of social-ecological change observed over the past decade. Following a brief series of questions designed to collect relevant demographic information, participating informants were asked to agree or disagree with each of the 28 propositions. We identified potential respondents (n = 50) on the basis of (1) their willingness to participate and (2) the fact that they made their living as small-scale fishermen at the time of the study or had done so at some point in their lives. Respondents had no access to propositions beforehand and were interviewed individually to minimize opportunities for collusion. We explained to respondents that there were no right or wrong answers to social-ecological propositions. Respondents were encouraged but not required to discuss why they held certain beliefs and survey sessions were digitally recorded and transcribed. If a respondent was unable or unwilling to respond to a certain proposition, we treated their answers as missing data. To meet the assumptions of CCA, the analysis excluded six individuals that had missing responses to more than 10% of the questions (Miller et al., 2004), resulting in a final sample of 44.

Survey responses were transformed into a matrix with respondent rows and proposition columns. Missing data (∼2.5% of total responses) in the matrix was filled in with randomly generated 1 and 0 s (Weller, 2007). In order to assess culturally correct survey answers and the degree of agreement among survey respondents, a formal CCA was conducted on 25 of the 28 propositions using the covariance method (Romney et al., 1986) in the Ucinet software package (Borgatti et al., 2002). This package determines consensus analysis through a factor analysis of the informant-by-informant agreement matrix. The ratio of eigenvalues between the first and second factors (vectors representing the percentage of variance in responses that each factor accounted for) is used to determine consensus. If the ratio between the first and second eigenvalue factors is >3:1 then respondents share a single cultural model, if the ratio between the first and second factors is 2.9 to 2.0 then there is no consensus but weak agreement, and if the ratio between the first and second factors is <2.0 then there is no consensus and no agreement (Caulkins, 2004; Weller, 2007). Cultural knowledge (i.e., competence) scores (a measure of how well each individual represents the entire sample) and disagreement scores (a measure indicating the degree to which cultural knowledge scores account for variance in responses) ranging from 0 to 1 were determined by the loadings on the first and second factors, respectively. Culturally correct answers were inferred by weighting the responses of individuals by their individual competence scores. In order to explore variation in beliefs across respondents and identify statistically significant subcultural groups (Weller, 2007), demographic information was correlated with competence scores using one-way ANOVAs (categorical variables) and Pearson's correlation coefficients (continuous and ordinal variables).

Cultural Models and Adaptive Response (Participant Observation and Ethnography)

While CCA can be used to determine patterns of intracultural agreement or disagreement in particular domains of knowledge (Miller et al., 2004; Johnson and Griffith, 2010), this approach does not provide insights concerning the knowledge structures (i.e., cultural models) that underlie that variation (Garro, 2000). Indeed, researchers who fail to situate CCA within the context of a broader ethnographic approach run the risk of decontextualizing the information they collect (Carothers et al., 2014). To aid in the design of our CCA instrument, the interpretation of its results, and to link our findings with observed behavior and adaptive response, we relied upon qualitative data obtained over the duration of our study. Over the course of three field seasons (summer 2014, summer 2015, and spring 2016) the primary researcher spent ∼300 days in the field. During this time the port of departure was visited regularly to build trust, establish relationships, and observe landings while 45 days were spent at sea as a participant observer onboard small-scale fishing vessels targeting diverse marine resources. Field notes and verbatim interview transcripts (see above) were imported into *NVivo* qualitative data analysis software and inductively coded. Inductive coding involves applying categories to text in order to identify emergent themes and concepts through an iterative processes of analysis (Bernard, 2017). We followed a grounded theory approach (Glaser and Strauss, 1967) where data were used to generate theory by "identifying emergent themes, assembling themes into working hypotheses, testing these hypotheses against the data and reformulating the theory until it was consistent with the evidence" (Fernandez-Gimenez et al., 2006).

RESULTS

Oceanographic and Ecological Trends

Structural breaks analysis of remotely sensed sea surface temperature (SST), sea surface height (SSH), and primary productivity (PP) across coastal fishing grounds (first available data through 2017) determined that each seasonally adjusted time series was optimally partitioned into three segments with two breakpoints. Though differences in time series length complicate efforts to assess and compare initial breakpoints, structural breaks were detected in all three time series between 2012 and 2013 (SST = August, 2012; SSH = September, 2013; PP = December, 2012) (**Figure 1**), suggesting a shift in the oceanographic trajectory of the system. Nearshore SST increased between the El Nino events of 2009–2010 and 2015–2016 alongside a positive shift in the Pacific Decadal Oscillation (**Figure 1**). Although episodic El Niño events are a historic component of the region's intrinsically variable oceanographic climate, such events are typically followed by periods of pronounced cooling (i.e., a La Niña phase) that enable system recovery (Girón-Nava and Johnson, 2016), as was the case following the 1982–1983 and 1997–1998 El Niño events. However, as temperate conditions (as inferred by PDO index values) dominated the North Pacific between 2011–2013, the Central Gulf of California oscillated

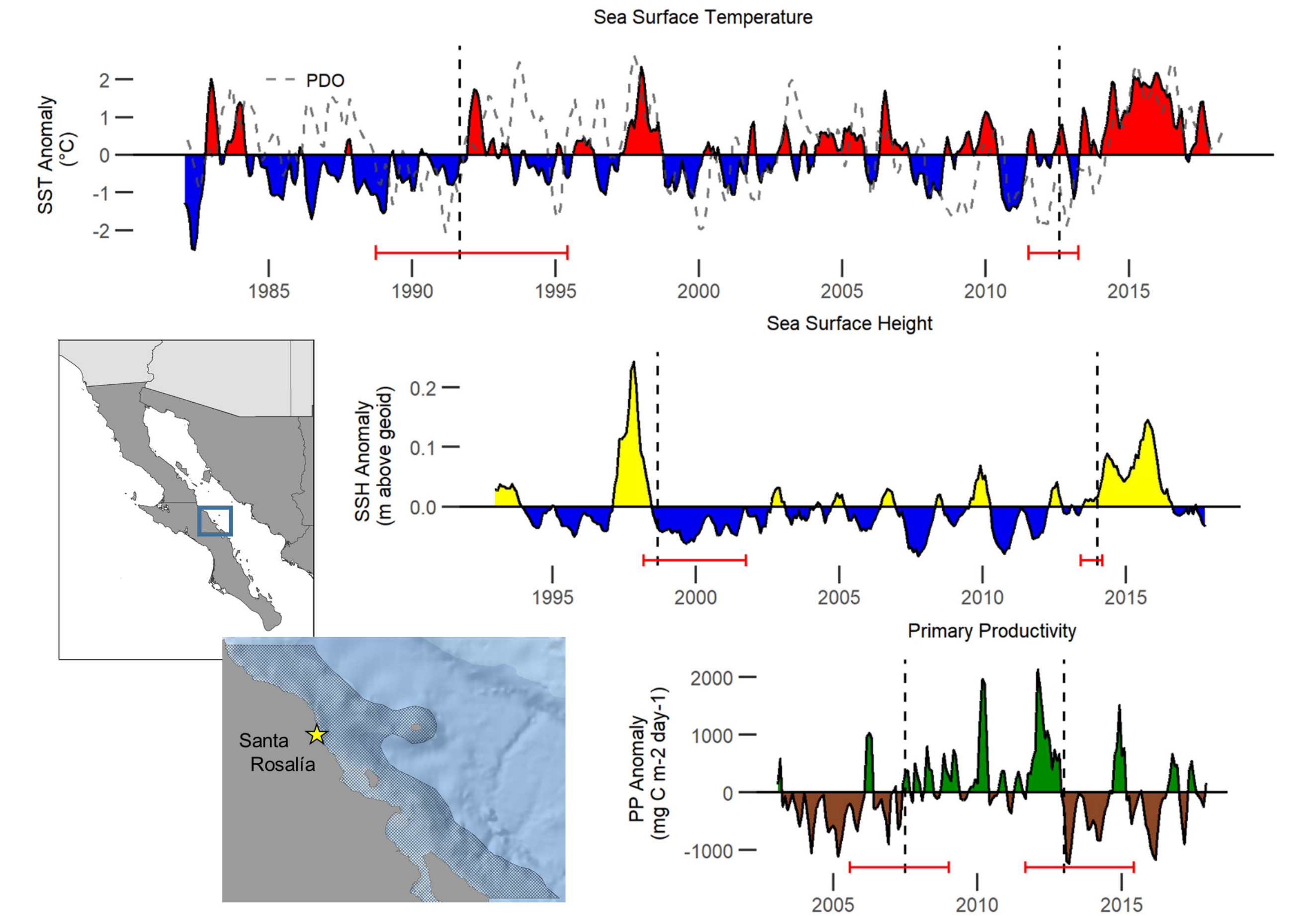

FIGURE 1 | Remotely sensed oceanographic anomalies observed offshore Santa Rosalía and detected breakpoints (+/– confidence intervals, α = 0.05). Values above zero in each panel represent positive anomalies (i.e., above the long-term average) while values below represent negative anomalies (i.e., below the long-term average). Vertical, dashed lines represent estimated structural breaks within each environmental time series. North-south fishing ranges (Frawley, unpublished data) and the 1000 m depth contour were used to determine the bounds of the sampling polygon.

between moderately warm and cool oceanographic conditions. Pronounced increases in SSH (**Figure 1**) across the nearshore environment, beginning in 2012, heralded the return of tropical ocean currents and warm water conditions that dominated through 2017. Though PP levels spiked off the coast of Santa Rosalía in 2015 (**Figure 1**), in aggregate observed values declined following the breakpoint in 2012, consistent with trends reported elsewhere in the Central Gulf (Robinson et al., 2016).

Analysis of monthly fisheries landings, aggregated by the Santa Rosalía reporting office (**Figure 2**), indicates significant declines in a number of traditionally important marine resources including cabrilla (*Mycteroperca rosacea*), snapper (*Lutjanus* spp.), sierra (*Scomberomorus sierra*), and most importantly, squid (*Dosidicus gigas*). During the most recent peak of the squid fishery in 2008, landings totaled more than 36,000 metric tons and represented 89.9% of the weight and 51.2% of the value of total fisheries landings. Following the El Niño event of 2009–2010, squid landings plummeted to less than 6,150 tons in 2012 (54.6% of total fisheries weight and 31.7% of value) before disappearing completely in 2015 during sustained ocean warming prior to the onset of the El Niño event of 2015–2016. Although statistically significant increases in landings of species like octopus (*Octopus* spp.), halibut (*Paralichthys californicus*), and shark (*Carcharhinus* spp.) were reported, we are unable to determine if such trends reflect increases in local abundance or a redistribution of fishing effort.

Local Knowledge of Social-Ecological Change

During the initial phase of research, small-scale fishermen described a number of changes to system structure and function that had impacted their livelihoods over the past decade. As fieldwork progressed, it became evident that the fishery system we observed and attempted to document had changed dramatically in the years preceding our arrival. While we witnessed a decline in the number of active small-scale fishing vessels from 250 during our initial field season in 2014 (during an ephemeral revival of the squid fishery) to ~30 in 2016, previous accounts (Moncaleano Rubio, 2015) place the number of active vessels during squid fishing activity

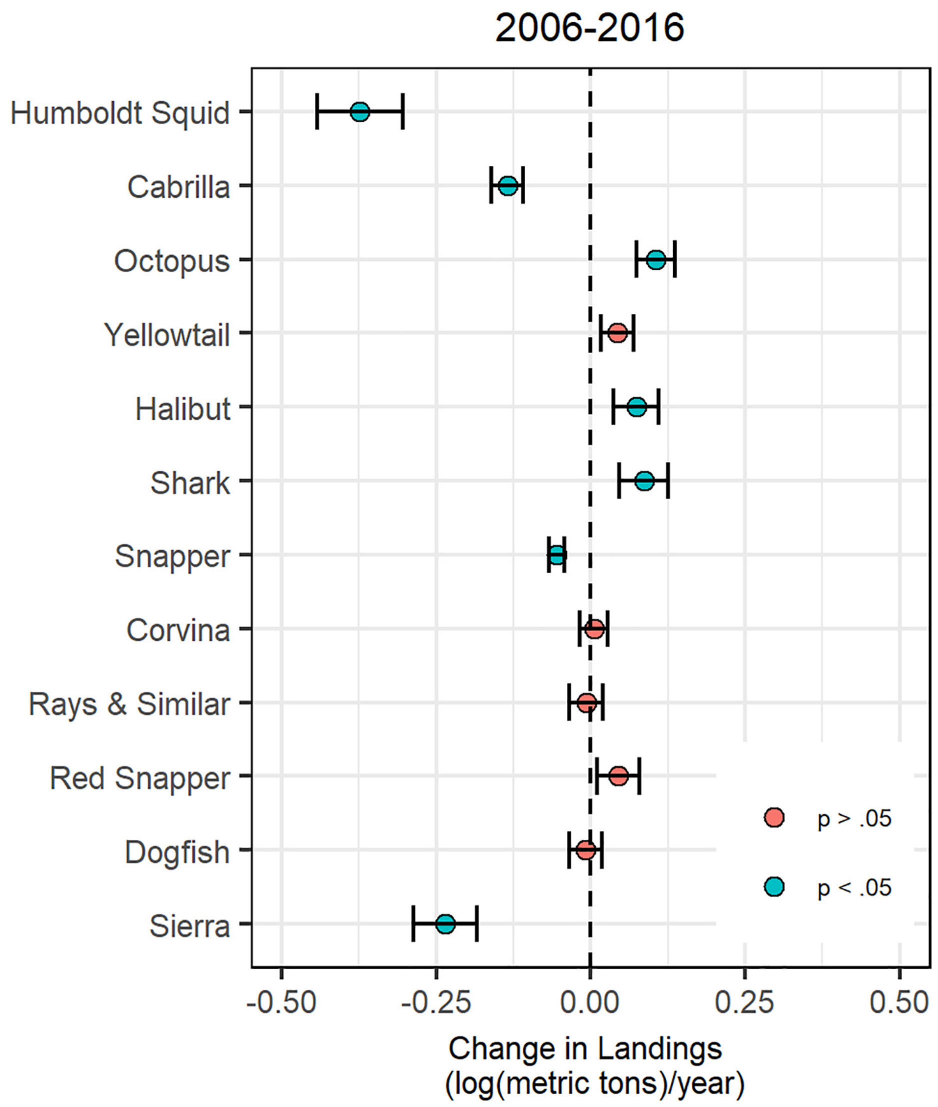

FIGURE 2 | Fisheries landings trends characterizing small-scale fishing activity between 2006 and 2016 in coastal waters offshore Santa Rosalía and adjacent communities, as inferred by monthly landings data. Species/family groupings are displayed in order of their relative contribution to total fisheries value over the same time period.

in 2008 at more than 1,000. Following inductive review of semi-structured interview transcripts, we identified four themes (changing weather patterns; variation in animal size, behavior and abundance; physical changes to the marine environment; socioeconomic and cultural change) derived from number of repeated observations (**Table 1**).

While respondents were largely in agreement that many of these changes could be considered long-term phenomena, the 2009–2010 fishing season appeared to mark a critical turning point in their collective consciousness. Following the landfall of hurricane Jimena, large amounts of fishing equipment and infrastructure were destroyed and the previously abundant jumbo squid resource became scarce. Though fisheries landings were considered cyclical (with good seasons and bad seasons), following 2009–2010 small-scale fishermen reported recurrent difficulty locating and landing squid and other traditionally important species. Some individuals advanced point-source pollution, increased incursions by outside fishermen, and unregulated and/or unsustainable fishing practices as dominant drivers. Others referenced changes in previously persistent weather patterns (i.e., winds) and ocean conditions (i.e., temperatures and currents). Regardless of the causal drivers, when confronted with changes in resource abundance many small-scale fishermen were pressured to the point where traditional fishing practices and livelihood strategies were no longer viable. A large number of individuals left the sector, many seeking employment within a resurgent local mining industry. Those who remained increasingly relied upon novel fishing grounds, technologies, and species assemblages.

TABLE 1 | Common observations of social-ecological change over the past decade as described by small-scale fisher informants (n = 35) of Santa Rosalía (Central Gulf of California) during the summer of 2015.

Salient themes	Common observations
Changing winds and weather patterns	Weaker winds from the North during winter months
	Stronger and more frequent winds during the spring
	More frequent hurricanes
	Warmer air temperatures year-round
Variation in animal size, behavior, and abundance	Smaller size of traditionally important species
	Schools of baitfish are smaller and less abundant
	Less predictable timing and duration of seasonal migrations
	Fish found deeper and further offshore
Physical changes to the marine environment	Warmer water temperatures
	Currents stronger and more irregular
	Decreased water clarity and quality
	Decreased size and density of seaweed patches
	Increased tidal range
Socioeconomic and cultural change	Must travel further to find productive fishing grounds
	Increased incursions by fishermen from mainland Mexico
	Diversification of target species
	Deterioration of traditional ecological knowledge
	Importance of technological adaptation

Cultural Context

Social-ecological systems research typically considers small-scale fishermen as (1) a single resource user unit or (2) identifies sub-groupings based on dominant gear type. However, over the course of our initial field seasons, it became evident that such distinctions were not consistent with how small-scale fishermen self-identified and did not accurately reflect the diversity of user groups present within the fishery system. Respondents directed us toward gear ownership and target species diversification as critical factors informing the continuum along which local fisheries livelihoods were organized and understood (**Figure 3**). At one end of the spectrum are generalist fishermen practicing traditional livelihood strategies (*los pescadores*). These are individuals who fish year-round, changing fishing grounds, gear types, and target species in response to variable patterns of marine resource abundance and distribution. During resource booms, the number of small-scale fishermen working out of the port of Santa Rosalía grows substantially. Generalist fishermen are joined by miners, teachers, taxi drivers and other local professionals looking to supplement their income in addition to large numbers of migrants from Sonora, Sinaloa, and other parts of Baja California. New entrants and recent migrants have historically been drawn to squid and other specialist fishing opportunities because they require fewer technical abilities and may involve lower entry costs. While generalist fishermen are the owners of the fishing gear (i.e., boats, motors, nets, etc.) and, in some cases, permits required of their livelihoods, squid fishing specialists (*calamareros*) rely upon local fisheries patrons to access the resource, forfeiting a percentage of their catch for the right to use permits and equipment owned by others. A third, intermediate livelihood category, is represented by the *piloteros* (seasonal fishermen), who are not owners of their equipment but are contracted by fisheries patrons to target ephemeral aggregations of species like octopus, shark and yellowtail (*Seriola lalandi*) in addition to squid.

Community members hold generalist fishermen pursuing traditional livelihood strategies in high esteem. They represent a link to a common cultural heritage and are the physical embodiment of knowledge and techniques that have been passed down from generation to generation. In contrast, specialist fishermen are viewed primarily as economic opportunists that lack the knowledge and skills required to sustain fisheries livelihoods over the long-term. Within the fishing community,

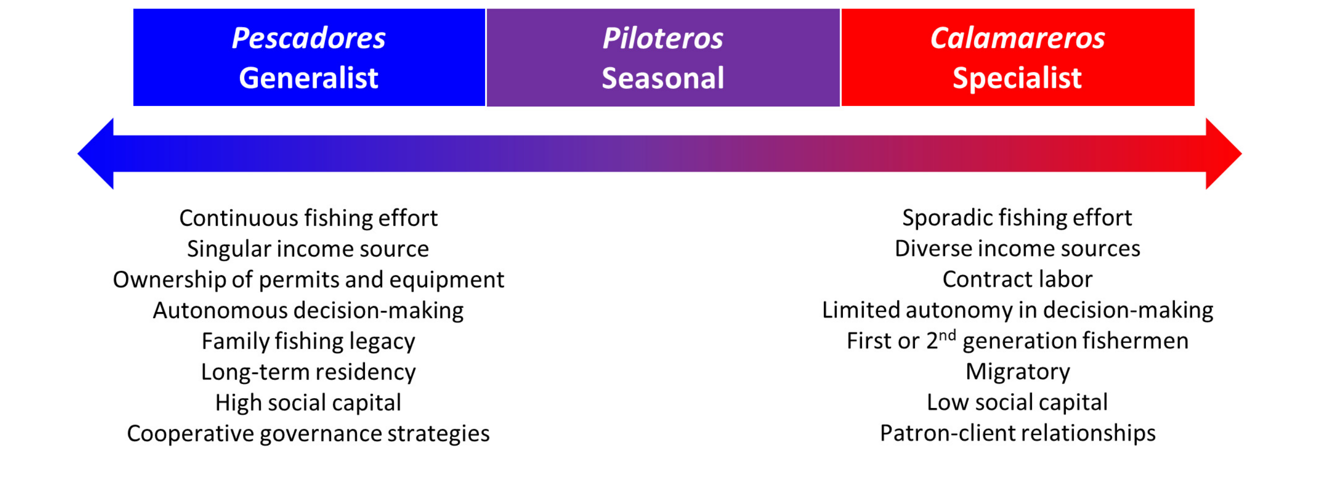

FIGURE 3 | Small-scale fisheries (SSF) livelihood continuum across coastal fishing communities in the Central Gulf of California.

seasonal and specialist fishermen are generally considered second and third-tier professionals. While generalist fishermen are admired for their knowledge and technical skills, fishing specialists are often derided for their coarse and unrefined approach to the occupation and their transgressions against traditional codes of conduct and rules-in-use. As one long-time fisherman asserts "the *calamarero* has no technique; the *pescador* for example, one that lives by fishing, is a hard worker that must wake early and catch bait because when the sun rises you ought to already be where you plan to fish. *Pescadores* are technicians that know how to catch different species... for the *calamareros* it is more a question of physical force," (Generalist Fisherman, Age: 68).

Faced with declines in resource abundance and shrinking profit margins following the El Niño event of 2009–2010, the fisheries patrons who owned the vast majority of fisheries capital pulled their boats from the water and placed motors into storage. Many of the specialist fishermen previously employed in the jumbo squid fishery migrated and/or found alternative employment. In Santa Rosalía and the surrounding municipalities, it was common to drive past processing plants and scrap yards where equipment lay idle and overturned fiberglass fishing boats covered the grounds. Among those individuals that continued to pursue livelihoods contingent upon the extraction of marine resources, ∼80% were generalist fishermen.

Consensus Analysis of Social-Ecological Propositions

The responses of 44 individuals were assessed in the CCA. Assigning livelihood subgroupings based upon gear ownership and target species diversification, the sample consisted of 15 generalist fishermen, 15 seasonal fishermen, and 14 specialist fishermen. All generalist fishermen, with the exception of one recently retired individual, were active participants in fisheries operations when the survey instrument was executed. The seasonal fishermen subgroup was composed of a mixture of active and inactive respondents. All specialist fishermen were inactive. Relevant demographic information is presented in **Supplementary Table 1**. In summary, participating informants had an average age of 45.8 years (± *S.D.* 13.1) and the majority were long-term residents of the study region (mean residency = 35.3 years ± *S.D.* 15.4). More than 93% of generalists described themselves as free fishermen or members of cooperatives, while only 6.6% reported working for fisheries patrons. In contrast, 85.7% of specialist fishermen described themselves as working for fisheries patrons. Seasonal fishermen reported mixed associations, with 20.0% describing themselves as cooperative members, 13.3% as free fishermen, and 66.7% as working for fisheries patrons. Generalist fishermen had the most fishing experience (27.2 years ± *S.D.* 11.7) while specialist fishermen had the least (14.5 years ± *S.D.* 3.73).

A first round of consensus analysis considered all respondents together to assess the existence of a single pattern of responses across all social-ecological propositions. A low first to second eigenvalue ratio (2.830) and a relatively high proportion of low (<0.5) and negative cultural knowledge scores (loadings on the first factor) indicated a lack of agreement among all respondents (**Table 2**). When analyzing the relationships between demographic variables and knowledge scores, only livelihood subgroupings were significantly correlated ($p = 0.0058$). A second round of consensus analysis that considered livelihood subgroupings separately determined that the highest level of within-group agreement occurred amongst generalist fishermen, as indicated by the highest average first-to-second eigenvalue ratio (3.390) and the absence of negative cultural knowledge scores, signifying consensus. Lower within-group agreement occurred amongst seasonal (1.897) and specialist fishermen (2.033), three of whom had negative cultural knowledge scores. Comparing cultural knowledge scores across livelihood subgroupings, generalists had the highest knowledge score (0.554 ± *S.D.* 0.156) while specialists had the lowest (0.314 ± *S.D.* 0.328). Percent agreement and disagreement for each social-ecological proposition are presented for the aggregate sample and by livelihood subgrouping in **Table 3**. Multiple correspondence analysis was used to graphically compare the difference between cultural knowledge and disagreement scores (first and second factor loadings) for each survey respondent and to assess similarity in responses among livelihood subgroupings (**Figure 4**). While less variation existed among responses of generalist fishermen as compared to seasonal fishermen, the substantial overlap of categorical ellipses (drawn at 95% confidence interval) suggests that the cultural knowledge of the two groups is similar. In contrast, significantly more variation exists across the responses of specialist fishermen, which appears to be distributed along an independent axis, suggesting a different underlying cultural model.

Cultural Models of Environmental Change

Generalist fishermen were more likely to advance progressive, long-term environmental change as a causal driver of fisheries decline as compared to seasonal and specialist fishermen. However, gradual increases in sea surface temperature and height and changes in primary production were more difficult to observe and had less direct significance than did changes in phenology. Many informants practicing generalist livelihood strategies reported that over the past decade the strength and duration of winter blows had diminished and that the strongest winds now arrived during the spring. Though the "calms of May" once represented the region's most diverse and productive fishing period, fishermen reported that increased variation in winds and surface currents had disrupted many of the long-standing natural patterns and processes upon which harvesting operations were dependent. In addition to reporting decreases in animal size and abundance, informants referenced changes in behavior (e.g., increased variation in the timing and duration of seasonal migrations) and distribution (e.g., organisms found deeper and further offshore). As one long-time fishermen explained, "Before, depending if you were in the cold season or the warm season, you would go out and you knew what you were going to catch and the runs would last a long time. It is not like that now"

TABLE 2 | Results of the consensus analysis of the dichotomous social-ecological questionnaire (25 items) presented by livelihood subgrouping.

Group	Factor and eigenvalue	Ratio between factors	Average competence score	Negative scorers?	Conclusion
All groups (N = 44)	1 = 10.871 2 = 3.841	2.830	0.441 *(± 0.227)*	Yes (3)	No consensus (Weak agreement)
Generalist (N = 15)	1 = 4.974 2 = 1.467	3.390	0.554 *(± 0.156)*	No	Consensus
Seasonal (N = 15)	1 = 3.884 2 = 2.047	1.897	0.481 *(± 0.165)*	No	No consensus
Specialist (N = 14)	1 = 2.895 2 = 1.424	2.033	0.314 *(± 0.328)*	Yes (3)	No consensus (Weak agreement)

TABLE 3 | Percentage of respondents in each group answering "agree" to individual propositions.

Proposition	*All*	*Spec.*	*Seas.*	*Gen.*
1. It's more difficult to make a living on the sea these days than it was before	95.5%	92.8%	100%	**100% (Agree)**
2. If fishermen are patient, fishery production will return to its previous levels	81.8%	71.4%	80.0%	**93.3% (Agree)**
3. The technology that fishermen use today is more destructive than what was used in the past	45.5%	21.4%	53.3%	**60.0% (Agree)**
4. The waters around Santa Rosalía are contaminated to the degree that they are not suitable for many animals	77.3%	64.3%	86.7%	**80.0% (Agree)**
5. In recent years, changes in wind and weather patterns have affected the number and type of animals you can find in the sea	81.8%	64.3%	80.0%	**93.3% (Agree)**
6. "Night Divers" have had no impact on the amount of high quality fish available to catch by hook and line	34.1%	71.4%	20.0%	**13.3% (Disagree)**
7. There were years in the past where environmental conditions were similar to how they are today	22.7%	42.9%	26.7%	**0.0% (Disagree)**
8. Today, the majority of marine resources in the Gulf are overexploited	72.7%	71.4%	73.3%	**73.3% (Agree)**
9. Climate change has not had a large influence on fisheries' productivity in the Gulf	34.1%	42.9%	33.3%	**26.6% (Disagree)**
10. If fishermen want to survive in the future they need to develop new techniques and focus on different species	68.2%	50.0%	66.7%	**86.7% (Agree)**
11. On their own, the activities of the small-scale fleet are not large enough to affect levels of marine resources	56.8%	57.1%	60.0%	**53.3% (Disagree)**
12. If prices were higher, fishermen would not fish as hard as they do now	54.5%	28.6%	53.3%	**80.0% (Agree)**
13. If the fishing community was better organized, it would be easier to maintain sustainable resources and high incomes	97.7%	92.8%	100%	**100% (Agree)**
14. I have confidence in the ability of the government and SAGARPA to manage resources in a just and sustainable manner	18.2%	14.2%	26.7%	**13.3% (Disagree)**
15. If it was easier to access legitimate permits, there would be less illegal fishing in this zone	65.5%	57.1%	73.3%	**66.7% (Agree)**
16. Now, on account of the industrial fleet's activities, there is not sufficient bait fish in this area to support populations of squid, shark, and yellowtail	81.8%	78.6%	86.7%	**80.0% (Agree)**
17. The fishing of industrial boats hasn't had any effect on the resources available to the small scale fleet	13.6%	21.4%	0.0%	**20.0% (Disagree)**
18. Without the industrial contamination that occurred after the hurricanes in 2009 and 2014, there would still be a squid fishery today in Santa Rosalía	45.5%	50.0%	46.6%	**40.0% (Disagree)**
19. We already have sufficient rules and regulations to maintain sustainable resources in this zone	34.1%	50.0%	13.3%	**40.0% (Disagree)**
20. In terms of fishery production, the effects of natural phenomenon are small as compared to factors directed by man	56.8%	71.4%	53.3%	**46.7% (Disagree)**
21. Today anyone can make a living on the sea if they are willing to work hard	65.9%	40.0%	80.0%	**73.3% (Agree)**
22. Fishermen these days don't have the same knowledge of the sea that previous generations had	59.1%	57.1%	60.0%	**60.0% (Agree)**
23. The fishing industry will be an important part of the future of this town	52.3%	50.0%	53.3%	**53.3% (Disagree)**
24. I have confidence in fishing community's ability to overcome obstacles and come together during difficult times	56.8%	64.3%	46.7%	**60.0% (Agree)**
25. Many marine animals have changed their migration routes and now no longer pass by Santa Rosalía	86.4%	85.7%	80.0%	**93.3% (Agree)**

Bolded items represent a set of culturally correct answers estimated by consensus analysis where the assumptions of the model are met (i.e., an eigenvalue ratio > 3).

(Generalist Fisherman, Age: 52). While 93.3% of generalist and 80% of seasonal fishermen agreed that changes in wind and weather patterns had affected the number and type of animals that one could obtain from the sea, only 64.3% of specialists believed the same.

Though specialist fishermen also reported changes in the distribution and abundance of target species, they more commonly associated such observations with discrete events rather than progressive environmental trends. The most popular explanations for fisheries collapse revolved around declines in water quality following hurricane Jimena, which made landfall on the Baja California Peninsula in September of 2009. In the weeks and months following the storm, local resource abundance was reported to have declined rapidly as coastal waters adjacent

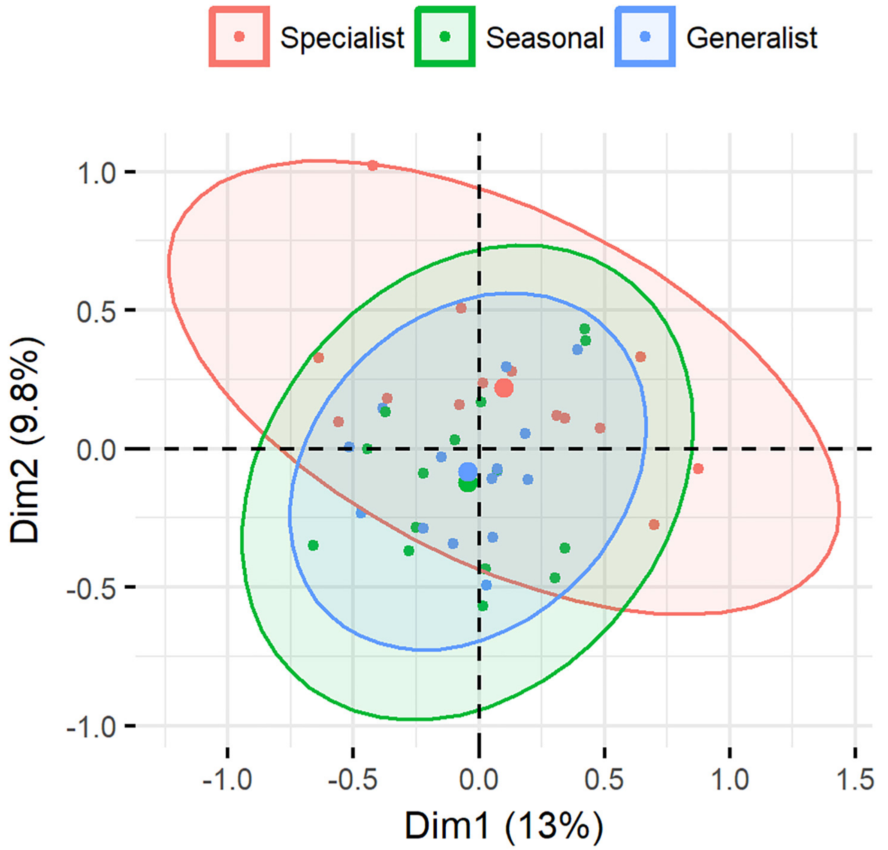

FIGURE 4 | Results of multiple correspondence analysis depicting the degree of similarity across responses to social-ecological propositions by livelihood subgrouping.

to Santa Rosalía, laden with storm runoff and physical debris, were persistently turbulent. Several informants claimed that the squid population and (more specifically) their eggs were washed away during the storm as nearshore habitat became unsuitable. While a majority of fishermen agreed that historical, regional mining activity had made the nearshore habitat unsuitable for many species, specialist and seasonal fishermen placed greater emphasis on specific actions and events (i.e., industrial spills) as compared to generalist fishermen.

Cultural Models of Socioeconomic Change

Informants' perceptions of the impacts of their own (small-scale) fishing activities were mixed across livelihood categories. Though most fishers acknowledged that the majority of the Gulf's marine resources were overexploited and many identified sustainability concerns surrounding the use of popular fishing gears (i.e., gillnets and traps), 60% of generalist and 53.3% of seasonal fishermen believed that the use of destructive and/or illegal fishing gears was intensifying as compared to only 21.4% of specialists. Informants reported that as fisheries production had faltered across the Eastern Gulf, fishermen from Sonora and Sinaloa had begun targeting the fishing grounds near Santa Rosalía more frequently and intensively. Night Divers (i.e., fishermen reliant on hookahs, flashlights and spear guns to target high-value species at night) were repeatedly referenced as the most flagrant offenders, indiscriminately harvesting fisheries products regardless of size, reproductive condition, or protected status. While most (71.4%) specialist fishermen doubted that such behaviors negatively impacted the catches of fishers using traditional hook and line methods, few generalist (13.3%) and seasonal (20%) fishermen agreed. Though fishermen held diverse and often competing beliefs concerning the relative importance of many social-ecological drivers, the deleterious impact of the industrial fishing fleet represented a point of common understanding. Only a small percentage of informants believed that the fishing of industrial boats did not have any impact upon the resources available to the small-scale fleet. Fishermen across livelihood subgroupings repeatedly referenced the importance of small-pelagic species (and sardines in particular) in supporting the regional food webs upon which their livelihoods were dependent alongside the belief that such dynamics were being undermined by the industrial sector. Though the incursions of industrial fishing boats and outside fishermen were considered unlawful and unethical, informants emphasized that such activities were likely to continue as long as local fisheries patrons and administrative officials were willing to tolerate and/or facilitate them. When asked whether they had confidence in the ability of local authorities to manage fisheries in a just and sustainable manner, 81.8% of informants said that they did not.

Decision-Making and Adaptive Response

While all generalist fishermen agreed that the changes characterizing recent years were without precedent, some seasonal (26.7%) and specialist (42.9%) fishermen were unwilling or unable to distinguish the current era from other cyclical periods of resource scarcity. *Calamareros*, whose knowledge of the marine environment was limited to interactions with the jumbo squid, recalled similar periods in the late 80s and early 90s, when squid were not found in significant quantities. While the vast majority of generalist fishermen recognized the need to develop new techniques and focus on different/alternative species, many seasonal and specialist fishermen seemed content to wait for conditions to improve. In addition to differences in the structure and function of LEK across livelihood subgroupings, such responses are also likely related to variation in occupational multiplicity. While many seasonal and specialist fishermen reported supplementing or replacing fisheries income with earnings from land-based occupations (i.e., construction), generalist fishermen continued working on the water even as revenues declined. Several informants confided that without financial support from spouses or other household members they would be unable to cover the cost of gasoline and equipment maintenance. Respondents across subgroupings reported mixed confidence in the community's ability to overcome obstacles (56.8%) and whether the fishing industry would be an important part of the region's future (52.2%). While 73.3% of generalist fishermen believed that opportunity still existed for those willing to work hard, only 40% of specialists believed the same.

Generalist fishermen practicing traditional livelihood strategies confronted periods of ecological and/or economic uncertainty with patience, persistence, and innovation. Without the contractual obligation to generate income for fisheries patrons or repay accumulated debt, many simply scaled back operations by reducing the number and length of fishing trips. Rather than continuing to supply external markets, some individuals began selling their catch directly to local businesses and throughout their extended kin networks. Others relied upon their direct observations of the marine environment and extensive knowledge of species behavior to develop new fishing methods. Upon observing that yellowtail were running deeper and further offshore, a number of individuals abandoned traditional surface gillnets and began experimenting with deep-set buoy gear. Though LEK was invaluable in developing and implementing such techniques, several informants emphasized its limitations. As natural patterns and processes have grown increasingly irregular, fishermen increasingly supplemented observations of winds, tides, and currents with information from novel sources. Several referenced the critical role of technology (weather reports obtained from the internet, *in situ* data provided by depth sounders, waypoints marked with GPS units, etc.) in augmenting their ability to respond and adapt to unfamiliar environmental conditions.

Reliant upon fisheries patrons to access and market ephemeral fisheries resources, many specialist and seasonal fishermen did not possess the ability to modify fishing tactics and/or switch target species in response to declines in resource abundance. In contrast with generalist fishermen, who remained autonomous and flexible even as catches declined, hired fishing hands lacked agency. Their interactions within the marine environment were ultimately dictated by the priorities of the fisheries patrons for whom they worked. As one squid fishing specialist remarked, "We need some sort of plan to identify where the squid are but we do not know how. We are lost. We don't know where to capture them. The bosses don't want to invest. If the bosses don't want to invest, how can the fishermen push them? What can we do?" (Specialist Fisherman, Age: 39). While the vast majority of specialist and seasonal fishing informants had abandoned or been excluded from the small-scale fishing sector, to an individual each reported a preference for fishing as compared to their current occupation (or lack thereof). Those that continued to work for fisheries patrons were often compelled to fish increasingly distant waters, incurring significant gasoline expenditures, in order to access unexploited aggregations of high-value species. While this high-risk, high-reward strategy was occasionally profitable, when fishing trips were unsuccessful many fishers found themselves spiraling further and further into debt. Though informants were hesitant to confirm their participation in specific activities, many expressed willingness to supplement legal catch with poached products that could be marketed and sold in the underground economy.

DISCUSSION

In the Gulf of California, external drivers of change are transforming the structure and function of modern SSF systems. Traditional livelihood strategies are increasingly impacted not only by extreme weather events and increasing climate variability, but also by systems of governance that have separated many resource users from the marine environment. Throughout history, small-scale fishers have relied upon LEK to develop strategies to identify and accommodate system disturbance (Berkes, 2008). Yet, knowledge systems are subject to degradation when exposed to rapid, and often compounding, processes of social and environmental change (Fernández-Llamazares et al., 2015). Signals of change may not be detected if actors' cultural models filter them out, if individuals are too busy or distracted to detect them, or if actors are too far removed from the system to take note (Moser and Ekstrom, 2010). If LEK is to be used to facilitate adaptive response at the local level (Berkes et al., 2000), scholars and practitioners must appraise the developmental and contextual processes through which small-scale fishers construct knowledge, evaluate risks and negotiate adversity (Coulthard, 2012). Resource users' perceptions of and interactions within marine social-ecological systems are impacted not only by external shocks and stressors, but also dynamic knowledge structures specific to the cultures of which they are a part (**Figure 5**). Though cultural models are likely influenced by diverse factors whose relative importance may vary across study systems, our findings support the assertion that that livelihood practices (i.e., diversification) and assets (i.e., gear and permit ownership) are critical factors within SSF (Crona, 2006; Farr et al., 2018).

Knowledge Production and Differentiation

Social-ecological systems science increasingly calls for the integration of LEK and traditional scientific methods to help improve understanding of the impacts of global change and to develop initiatives aimed at fostering adaptive response (Berkes et al., 2000; Carothers et al., 2014). However, LEK is not without its limitations. Good governance depends on trustworthy information (Dietz et al., 2003), and access to information is likely to be asymmetrical among coastal resource users (Aswani et al., 2015). Inattention to the diverse connections that fishers have with the systems in which they operate obscures meaningful differences in the knowledge they possess, the interactions they pursue, and the behaviors they initiate (Stoll, 2017).

Across the Gulf of California, sustaining a traditional fisheries livelihood approach requires a sophisticated understanding of the ecosystem, the biology and behavior of diverse species, as well as access to a variety of fishing gear and the ability to use it appropriately (Vásquez-León, 2012). Fishers monitor those environmental features that are linked with fishing success and the physical characteristics of marine habitat that affect the distribution of animals and the effectiveness of gear (Mackinson, 2001). Highly diversified, multiple species, and multiple gear fishers continuously sample the marine environment throughout the year and possess extensive knowledge of the local species and habitats. For them, fishing is more than an occupation through which income is generated, it is a way of life indelibly tied to the rhythms of the natural world; the phases of the moon, the rise and fall of the tide, the passage of the seasons, and the annual runs of migrating animals. Such informants repeatedly described and demonstrated the ability to modify fishing tactics in response to seasonal and interannual environmental change. As a generalist fisherman explained, "I come and I fish. I

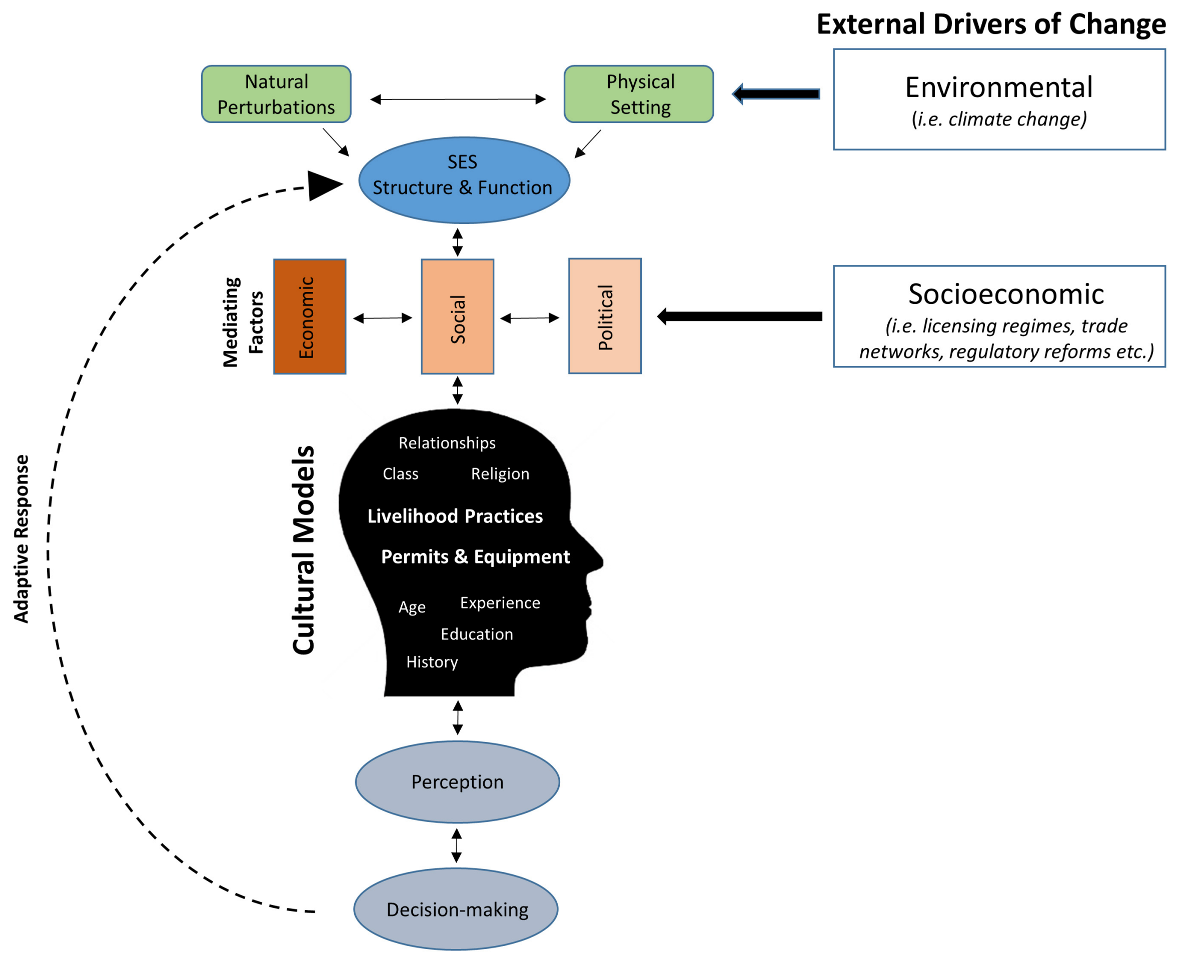

FIGURE 5 | Resource users' knowledge of and interactions within marine social-ecological systems are influenced by the cultural models which mediate their perception of and response to environmental and socioeconomic change. Bolded items (i.e., livelihood practices, permits, and equipment) represent critical factors driving divergent cultural models within SSF systems.

fish with traps during the trap fishing season. During the diving season, I will dive. During yellowtail season, I go to fish yellowtail. You have to learn everything. You need to learn a lot of skills and variations and you need to be able to do each part of your job well. You need to know the different seasons, the different types of fish, the different rocks. When they are going to eat, when they reproduce... everything. It takes time, experience, and equipment" (Generalist Fisherman, Age: 35).

Though diversification is considered an important adaptation strategy, giving fishers the ability to shift species based on what is most convenient, valuable or abundant (Finkbeiner, 2015; Stoll et al., 2016), many fishers are reliant on fewer species now than ever before. As global markets offer economic incentives to focus on particular local stocks (Kittinger et al., 2013; Kininmonth et al., 2017), external regimes of management and regulation have restricted fishing portfolios (Hilborn et al., 2001; Stoll et al., 2016). In the modern era, many fishermen possessing knowledge about marine ecosystems have reduced decision-making power as compared to fisheries patrons, particularly if these patrons provide fishers with access rights, fishing equipment, or credit and loans (Basurto et al., 2013). Amongst hired fishing hands, critical decisions concerning effort allocation and target species selection are made by permit holders and business administrators on the basis of perceived economic returns rather than first-hand observations amassed during harvesting operations. While generalist fishermen are dependent on the sea to earn a living, seasonal and specialist fishermen are dependent, first and foremost, on the graciousness and good humor of their employers. When profits decline, individuals lacking secure access and tenure rights may be abruptly excluded from the marine environment as extractive operations are curtailed and equipment is placed into storage. With their interactions and activities limited by fisheries patrons to distinct periods of elevated resource abundance, seasonal and specialist fishermen had a fundamentally different relationship with and perception of the marine environment.

Faced with the inherent uncertainty of their occupations, seasonal and specialist fishermen operate on fundamentally different time horizons, prioritize different kinds of interactions within the social-ecological system, and value different kinds of knowledge. In contrast to the holistic appreciation of system structure and function advanced by generalist fishermen, the environmental knowledge of fishing specialists was more commonly grounded in observations of a specific species (e.g., squid) and the localized processes (e.g., tides and currents) that impacted their distribution and abundance between distinct fishing periods. Generalist fishermen prided themselves upon their astute observations of complex natural phenomena. In contrast, specialist fishermen would often boast of their ability to "game" the system, subverting the authority and oversight of fisheries patrons while working beyond the bounds of formal regulations and traditional rules-in-use. While the compliance of generalist fishermen may, in part, be motivated by fear of reprisal (e.g., losing one's license, market, or reputation), seasonal and specialist fishermen with short-term economic outlooks may perceive such risks differently, having little to lose.

Divergent Cultural Models of System Structure and Function

Throughout the Gulf of California, relations of production shape patterns of resource use and governance by dictating who controls access rights, capital, and profits (Frawley et al., 2019). As fisheries patrons have consolidated control over regional marine resources, many fishers have lost access to traditional fishing grounds and species assemblages (Sievanen, 2014). Though flexibility and independence in decision-making are considered important components of knowledge production and resilience (Berkes et al., 2000), many fishermen have sacrificed their autonomy in exchange for the ability to access essential fishing rights and equipment. Changes in social and economic life that impact autonomy in decision-making are often accompanied by changes in environmental cognition (Ross, 2002). As fishermen become alienated from the marine environment, the traditional knowledge structures and social relationships supporting adaptive response may be subordinated by concerns surrounding who derives benefits from a fishery, who drives resource degradation, and who should incur the costs of regulation (Fabinyi et al., 2013). When long-time fishermen retire or are otherwise excluded, those replacing them are increasingly fishing specialists who lack the LEK and attachment to place that once served to regulate regional resource use and buffer against environmental uncertainty (Vásquez-León, 1994; Rubio-Cisneros et al., 2017).

The erosion of resource users' LEK, without replacement by the production of new knowledge suited to new circumstances, can reduce local capacity to cope with environmental change and have cascading effects for ecosystem health and the provision of ecosystem services (Hopping et al., 2016). Though specialists expressed an interest in diversifying their livelihoods to adapt to changes in the fishery system, they were constrained by inconsistent access to the required permits and equipment as well as a lack of knowledge concerning how to use them appropriately. Deprived of the knowledge and agency required to develop and diversify their activities, many such individuals are increasingly concerned with survival rather than sustainability (Cruz-Torres, 2001). Specialist and seasonal fishermen with short-term economic outlooks face compelling incentives to engage in destructive and illegal fishing practices (Cruz-Torres, 2001; Cinti et al., 2010). While generalist fishermen would often reference the importance of self-regulating behavior, i.e., leaving some fish for future seasons and/or generations rather than trying to "catch everything in 1 day" (Generalist Fisherman, Age: 55), seasonal and specialist fishermen were motivated to maximize revenues during periods of opportunity, regardless of the ethical and environmental implications.

CONCLUSION

It is increasingly recognized that research on global change and adaptation requires an interdisciplinary approach that combines different types of knowledge and data (Aswani et al., 2015). Creating shared understanding among stakeholders is critical if collective decision-making processes and actions aimed at resolving social-ecological problems are to be reached (Röling, 2002; Adams et al., 2003; Salick and Ross, 2009). A better understanding of cultural models may help better frame perspectives and facilitate negotiation (Stone-Jovicich et al., 2011; Naves et al., 2015). While much of the current scientific emphasis on global change and human response concerns large-scale patterns and processes, LEK can be valuable in providing fine-scale, place-based information (Hopping et al., 2016) and in advancing useful scientific hypotheses (Neis et al., 1999). Though LEK is heterogeneous and contradictions may exist between cultures and knowledge systems, oftentimes these points of divergence are the most productive points of inquiry (Klein et al., 2014).

We argue that within SSF, ecological proximity actively shapes the cultural models that inform how fishermen perceive and respond to changes in the fishery system. Though livelihood diversification can be an effective adaptive response, the ability to diversify is limited to those individuals with the knowledge, means, and desire to do so. Practices and policies that function to limit access to the marine environment or restrict fishing portfolios may ultimately amplify the divisions between human and natural populations and adversely impact system resilience. Rather than pursuing external interventions at odds with local values and needs, scholars and practitioners seeking to promote sustainable and effective adaptation would be well-served to consider how local knowledge could be leveraged to support social learning processes and enhance environmental stewardship. Within and beyond SSF in the Gulf of California, such policy might incorporate efforts designed to identify local experts and knowledge carriers and to elevate their voices within civil, scientific, and political discourse.

As the rate of global change accelerates, the ability of fishermen to detect and respond to changes in the resource systems in which they are embedded is of critical importance (Lauer and Aswani, 2010). By identifying intracultural differences in the knowledge and behavior of small-scale fishermen following a period of pronounced social-ecological change, we hope to provide new insights into the processes of knowledge production, decision-making and adaptive response. Though the majority of adaptation literature relies upon determinants and attributes selected by the researchers *a priori* (Smit and Wandel, 2006), academic theory and accrued experience (Moser and Ekstrom, 2010; Coulthard, 2012) increasingly suggest that feasible strategies to facilitate adaptation and overcome its associated barriers will likely be context-dependent. Here we advance LEK and cultural models as promising components of situated research designed to advance our understanding of the developmental and contextual processes through which resource-dependent communities perceive and respond to change.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

TF, LC, and KB conceived and planned the study. TF conducted field work and performed the analysis. KB and LC verified the analytical methods and contributed to the interpretation of results. All authors contributed to the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2019.00078/full#supplementary-material

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