frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 04 August 2022
DOI 10.3389/fmars.2022.888288

Check for updates

OPEN ACCESS

EDITED BY
Cornelia E. Nauen,
Mundus Maris, Belgium

REVIEWED BY
Robin Kundis Craig,
University of Southern California,
Los Angeles, United States
Lida Teneva,
Independent Researcher, Sacramento,
CA, United States

*CORRESPONDENCE
Diego Salgueiro-Otero
dsalgueiro@uvigo.es

SPECIALTY SECTION
This article was submitted to
Marine Fisheries, Aquaculture and
Living Resources,
a section of the journal
Frontiers in Marine Science

RECEIVED 02 March 2022
ACCEPTED 04 July 2022
PUBLISHED 04 August 2022

CITATION
Salgueiro-Otero D, Barnes ML and
Ojea E (2022) Transformation in times
of climate change: what makes a
fisher diversify livelihoods?
Front. Mar. Sci. 9:888288.
doi: 10.3389/fmars.2022.888288

COPYRIGHT
© 2022 Salgueiro-Otero, Barnes and
Ojea. This is an open-access article
distributed under the terms of the
Creative Commons Attribution License
(CC BY). The use, distribution or
reproduction in other forums is
permitted, provided the original
author(s) and the copyright owner(s)
are credited and that the original
publication in this journal is cited, in
accordance with accepted academic
practice. No use, distribution or
reproduction is permitted which does
not comply with these terms.

Transformation in times of climate change: what makes a fisher diversify livelihoods?

Diego Salgueiro-Otero[1]*, Michele L. Barnes[2] and Elena Ojea[1]

[1]Centro de Investigación Mariña, Universidade de Vigo, Future Oceans Lab, Lagoas-Marcosende, Vigo, Spain, [2]Australian Research Council (ARC) Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia

Despite the importance of livelihood diversification as a transformation strategy in small-scale fisheries facing climate change, empirical evidence on this complex phenomenon is scarce. This work aims to shed light on factors that help to explain the transformative behavior of small-scale fishers when faced with climate change impacts. Using primary survey data from 404 small-scale fishers across 9 communities in Galicia, NW Spain, we examined how different aspects of fishers' adaptive capacities relate to their stated decisions to engage in livelihood diversification when faced with hypothetical climate change scenarios. The results of our multinomial multilevel mixed-effect logit model show that flexibility (current income diversification level and diversity of target fishery resources) has a strong, positive relationship with livelihood diversification responses. In contrast, learning, social organization, and competing concerns played a complex role. Specifically, we found that social-ecological system knowledge, communication with different fishing groups (bridging communication), trust in institutional actors, and gender (female) were positively related to livelihood diversification when faced with climate impacts. Fishing experience, communication within fishing groups (bonding communication), and trust in other fishing groups (bridging trust) were negatively related to diversification. Our results provide new empirical evidence on the factors associated with fisher's decisions to engage in livelihood diversification when faced with climate impacts on fishery resources, lending critical insight for climate adaptation programs and policies.

KEYWORDS

small-scale fisheries, climate change, livelihood diversification, transformation, adaptive capacity, resilience

Introduction

Small-Scale Fisheries (SSF) play a key role in contributing to food security (Maire et al., 2021), sustaining livelihoods (Isaacs, 2012), supporting global economies (Teh and Sumaila, 2011), providing multiple types of knowledge (Norström et al., 2020; Schwermer et al., 2021), and maintaining existing cultural visions and traditions (Kittinger et al., 2015). SSF are set to experience significant impacts as climate change accelerates (Bindoff et al., 2019; Rogers et al., 2019; Ojea et al., 2020), with important implications for the livelihoods they sustain (Salgueiro-Otero and Ojea, 2020). Indeed, countries where SSF are critical, e.g. tropical and low-income countries with a high dependency on marine resources, often have the highest level of socio-economic vulnerability under current climate change projections (Cheung et al., 2009; Cheung et al., 2010; Lam et al., 2014; Lam et al., 2016).

SSF communities facing increasing climate impacts can take a range of adaptive actions that allow them to continue fishing and enable the continuation of their SSF social-ecological system (SES) (Savo et al., 2016). However, existing evidence suggests that for the most adverse impacts, coping and adaptation strategies may not be sufficient, and transformational change will be needed (Fedele et al., 2019). From this perspective, transformation is often argued to capture the capacity to create a fundamentally new system when the existing system becomes untenable (Walker and Holling, 2004). Though research on transformations in SESs is rapidly increasing, understanding transformative processes and the factors that facilitate them remains a challenge (Fedele et al., 2019; Ojea et al., 2020).

Livelihood diversification, also known as occupational mobility, pluri-activity, occupational multiplicity or occupational pluralism (Brugère et al., 2008; Coulthard, 2012; Daw et al., 2012; Barnes et al., 2020), can be an early sign of a transformation process in SESs such as SSFs (Walker and Holling, 2004; Barnes et al., 2020; Ojea et al., 2020). Livelihood diversification sustains many fishers and communities around the globe, helping them to cope with poverty and vulnerability (Allison and Ellis, 2001; Coulthard, 2009; Isaacs, 2012; Oshbar et al. 2010). Diversification in this sense creates and maintains cultural senses of life, values and identities which are crucial links between the spiritual world and the ecosystems being used and managed (Fabricius et al., 2007; Coulthard, 2008; Pita et al., 2010; Marshall et al., 2012; Cinner, 2014; Diedrich et al., 2019; Fabinyi, 2020). Existing research has demonstrated that livelihood diversification can decrease environmental overexploitation in SSFs while at the same time providing fishers with additional options to fulfill their basic social, financial and cultural needs (Allison and Ellis, 2001; Sievanen et al., 2005; Coulthard, 2009; Muallil et al., 2013; Blythe et al., 2014; Cinner, 2014). In addition, livelihood diversification helps to overcome environmental and climatic instability, which is expected to increase under climate change (Fabricius et al., 2007; Coulthard, 2008; Finkbeiner, 2015).

To date, most of the research on livelihood diversification has been focused on the role of households (Daw et al., 2012; Finkbeiner, 2015; D'agata et al., 2020), with little attention paid to understanding the individual features that allow fishers to engage in these transformative strategies (Olale and Henson, 2012). Yet in overlooking the individual scale when assessing livelihood diversification, we gloss over the heterogeneity of fishers' capacities, characteristics and values as well as the social dynamics and inequities often hidden within households (Magnan et al., 2016). As a result, calls for a shift towards individual-based approaches (sometimes known as bottom-up approach) to better guide robust decision making to understand adaptive choices, such as livelihood diversification, under climate change are growing (Adger et al., 2003; Daw et al., 2012; Finkbeiner, 2015; Salgueiro-Otero and Ojea, 2020).

In this study, we empirically explore individual-level decisions to diversify livelihoods in SSF in order to better understand adaptation choices when faced with climate change impacts, with the aim of informing decision-making processes intending to spur transformative change. For this, we conceive individual livelihood diversification as a transformative strategy that consists of combining SSF extractive livelihoods with non-SSF livelihoods (Cinner and Bodin, 2010) as a way to respond to the impacts from climate change (Finkbeiner, 2015). Despite the importance of livelihood diversification for human transformation under climate change, little is known about the diversification process.

In order to contribute to this gap in the scientific literature, this paper aims to answer three questions: 1) under which impact scenarios does individual livelihood diversification take place? 2) what aspects of adaptive capacity contribute and/or constrain livelihood diversification? and 3) what roles do social-ecological structures play on individual livelihood diversification? The objectives of this research are thus threefold. Firstly, observed data and model projections show a combination of positive and negative effects of climate change on fisheries around the globe (Cheung, 2018; Rogers et al., 2019; Free et al., 2020). In some areas, the abundance of target marine resources increases (Kooij et al., 2016), while in other areas, similar marine resources may decrease or be impacted in different directions (Pinsky et al., 2013; Poloczanska et al., 2013; Poloczanska et al., 2016). Despite this evidence, the SSF literature has mainly focused on livelihood diversification strategies of fishers when faced with negative climate change impacts (i.e. abundance decrease) (Kates et al., 2012), leaving a gap in our understanding of diversification strategies to other types of impacts, such as increases in abundance or higher economic profits. At the same time, studies that look at negative impacts have been focused mostly on scenarios that range from a 10% to 50% decline in resources, disregarding higher impacts scenarios (Cinner et al., 2008; Cinner et al., 2011; Slater et al., 2013). Consequently, the first objective of this work is to look at a broader range of climate change impact scenarios to understand when diversification might take place.

Secondly, in order to facilitate transformative strategies among fishers it is necessary to identify enabling and constraining conditions of adaptation processes (Galappaththi et al., 2019), which in this case refer to the determinants of livelihood diversification under climate-induced impacts. In this realm, the adaptive capacity (AC) framework introduces a set of latent human domains which potentially influence adaptive and transformative behavior: (1) the *assets* that people can draw upon, (2) the *flexibility* to change strategies, (3) the ability to *organize* and act collectively, (4) *learning* to recognize and respond to change, (5) the *socio-cognitive constructs* that enable or constrain human behavior, (6) the *agency* to determine whether to change or not, and (7) the *competing concerns*, or conflicting priorities, that can pose a barrier to adaptation (Mortreux and Barnett, 2017; Cinner et al., 2018; Cinner and Barnes, 2019). Although this framework offers a fruitful synthesis of human capacities that may enable responses to climate change impacts, empirical research has yet to test which of these domains may be more or less attributed to individual transformative behavior under future climate change impact scenarios. Thus, our second objective is to analyze the effects of adaptive capacity determinants on fisher's transformative behavior under climate-impact scenarios.

Finally, recent conceptual advances to the adaptive capacity framework explicitly recognize the importance of social and social-ecological network dynamics within the organizational and learning domains (Cinner et al., 2018; Cinner and Barnes, 2019; Barnes et al., 2020). This recognition is supported by a number of empirical studies applied to fisheries households which have demonstrated the crucial role of network structures in livelihood diversification (Fabricius et al., 2007; Crona and Bodin, 2010; Cinner and Bodin, 2010; Oshbar 2010; Shaffril et al., 2019). For instance, the (network) position of Papua New Guinean households in a complex social-ecological network were recently shown to be significantly related to certain adaptive and transformative responses to climate change (Barnes et al., 2020). This evidence builds on a theoretical foundation developed in Barnes et al., 2017b that conceptualized a continuum of specific bonding and bridging (social-ecological) network structures argued to represent the necessary -but not sufficient- conditions for adaptation-transformation strategies. Here, we aim to build on this foundation by testing the effect of specific social-ecological network structures on individual fisher's transformative responses to climate change as our third objective.

To address our research objectives, we collected information on individual fisher's responses to hypothetical climate change impact scenarios, adaptive capacity components, and network structures. With this novel empirical database, we first identified under which climate change impact scenarios fishers stated they would diversify their livelihoods. Second, we empirically demonstrate the relationships between adaptive capacity components and individual livelihood diversification choices. Third, we provide novel empirical evidence of the role of network structures on individual livelihood diversification responses. This work contributes to advancing our understanding of transformation processes in SSF. The advances presented here provide information that can help to better acknowledge the heterogeneity of SSF and guide equitable climate change policies that can help to facilitate transformative change in SSF when or if they may be required.

Methods

Case study description

Our study is focused on Galicia (NW Spain), where SSF have a key social, historical and economic role in the region (García-Lorenzo et al., 2019). The system is organized into 63 fisher guilds (*Confrarías*), and is highly diverse in terms of targeted main resources (73 taxa), fishing gears (43 different exploitation techniques and 3,900 vessels), and regulations (García-Lorenzo et al., 2019). Each community in the SSF system is strongly attached to a fisher guild, based on a general top-down governance system. In the fisher guilds, fishers carry out their activity under several management regimes (TURFs, TACs, ITQs and effort-based, gear-based and area-based limitations) (Macho et al., 2013; García-Lorenzo et al., 2019; Pita et al., 2019; Villasante et al., 2019). Tight-knit groups of fishers are created around the SSF activity based on common regulations, fishing gears (métiers; Tzanatos et al., 2006), fishing practices, and the cultural context (Alexander et al., 2018). These groups are associated with the distinctive social identity of fishers and are well known for structuring social interactions (Alexander et al., 2018).

For this work we identified 10 different SSF groups: shellfish gatherers on foot, shellfish gatherers on boat, demersal/specific resources on foot, demersal/specific resources on boat, divers, trap fishers, gillnet fishers, bait fishers, small-scale purse seine fishers and artisanal trawling fishers. Institutional actors, who often play a crucial role in SSF dynamics (Bodin and Crona, 2009), are also integrated in these SSF communities. The number of institutional actors and the roles they take on vary across communities and sometimes overlap within the same person. Here, we identified six main institutional profiles for the Galician SSF communities based on the main functional roles of institutional actors which were corroborated by focus groups (these are: community representative, government representative, secretary, surveillance guard, barefoot advisors, and auction manager) (Macho et al., 2013). The tight cultural attachment of Galician SSF to the marine environment, the complex social context of fisher guilds as the core of SSF communities (García-Lorenzo et al., 2019), and the fact that impacts from climate change are already being recognized (Bode et al., 2008) make the Galician SSF an ideal case study for climate change adaptation research.

Sampling design and data collection

We designed a structured survey to be implemented face-to-face where fishers were asked to respond to a set of climate change impact scenarios that affected their income from fishing. Socioeconomic information and indicators of different aspects of adaptive capacity were also gathered, combining Likert scales and multiple-choice questions (Tables S1.2-4). The survey was pre-tested in focus groups in two fishing communities (which were not included in our final sample), with 13 and 12 participants each. The final refined survey was implemented in nine representative fishing communities selected along the Galician coastline (Figure 1). Fishing communities were selected in a stratified manner in order to represent differences in fisher guild size, main target resources and associated fisher groups, geographical location (i.e., covering the south, middle, and northern range of the coastline; and accounting for both the shelter side and open side of the coastline), and presence/lack of protected areas in their seascapes with some restriction for fisheries. A formal agreement with the Galician fisher guild association allowed us to reach the communities and comply with the ethics requirements and guidelines set by H2020 (e.g., the survey protocol included the acceptance of individual fisher guilds to be part of the research project). Five trained interviewers performed the questionnaires face-to-face in the Galician and/or Spanish language during the months of July and August 2018 (in the town, fishing areas, port, guild, and fish market). The average length of the surveys was 45 minutes. All responses were voluntary and anonymous. The final sample of 404 fishers across the 9 communities (Table S1.1) is highly representative of the Galician SSFs system (confidence level higher than 95%), which is roughly composed by 13,500 fishers organized into 63 fisher guilds (*Confrarías*) (García-Lorenzo et al., 2019).

Climate impact scenarios and identifying 'diversifiers'

Following the recommendations resulting from our focus groups, we presented fishers with climate change impacts in the form of scenarios where fishery resources increased or decreased, ultimately affecting the fisher's income level. Climate impacts on the abundance of primary fishery resources were directly tied to catch levels and associated income from fishing to deter individuals from making predictions about fluctuating prices due to a potential variability in resources resulting from the impacts, which could have biased our results. We presented ten gradual impact scenarios in line with existing research (Daw et al., 2012), with five levels of income increase (15%, 30%, 50%, 70% and 90%) and five levels of income decrease (15%, 30%, 50%, 70% and 90%) associated with climate impacts. Based on information from our focus groups and in line with existing work (Daw et al., 2012; Fedele et al., 2019), we asked fishers to choose between three general adaptation responses for each

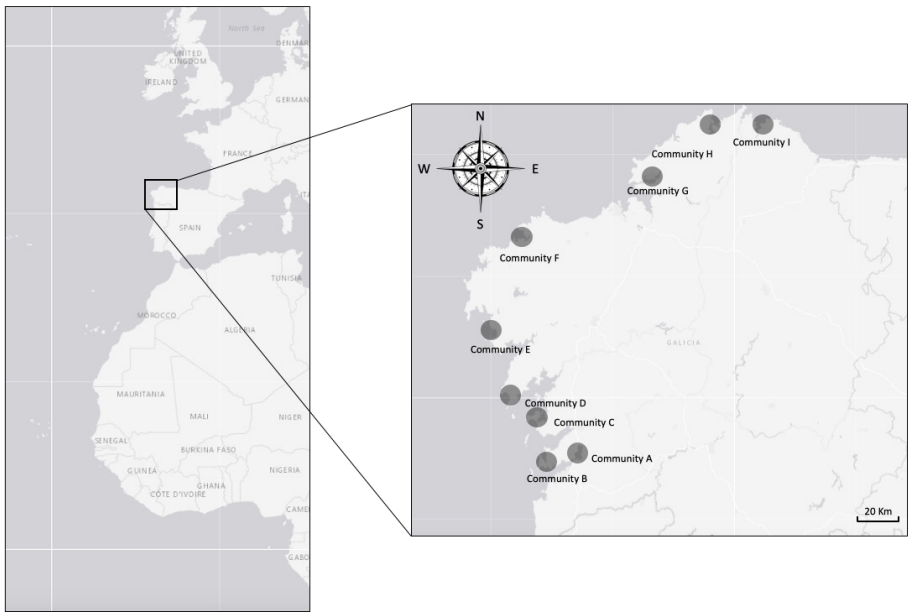

FIGURE 1
Map of the study region in Galician, Spain (left), and the nine small-scale fisheries communities (right).

hypothetical scenario presented in order to classify different types of individual responses to climate change. These were: 1) remain within the SSF as the unique labor activity, 2) diversify their livelihood by engaging in a different activity in addition to fishing, and 3) exit the fishery completely. Respondents were guided to select one single response per climate change scenario (Figure S1.1).

This study is part of a larger project so it has data of a broad range of individual responses but for the purposes of this analysis, which is to uncover the factors that can support the continuation of fishing and fishing culture in the face of climate threats while at the same time alleviating some of the pressure on the fishery theoretically, we focus here on understanding the factors that relate to the livelihood diversification response (#2 described above). In order to identify livelihood diversifiers, we assigned a value of 1 to fishers that, at any given impact level (including increasing or decreasing catch and income), decided to combine their current fishing activity with other external labor outside of the fishery (called 'diversifiers' hereafter in the text). Next, a value of 2 was assigned to all fishers who chose to remain in the SSF system and not engage in livelihood diversification outside of the SSF sector across all impact scenarios (referred to as 'remainers' hereafter in the text). Finally, those fishers who at any stage chose to exit the SSF completely, and never chose to combine their SSF activities with other external labor activities were coded with a 3 (referred to as 'exiters' hereafter in the text). We choose this classification in order to conceptually isolate fishers who chose diversification as a response to climate impacts, as opposed to remaining in the fishery or primarily choosing an exit response. To be clear, while 'remainers' never chose to diversify or exit across any of the hypothetical scenarios; 'diversifiers' sometimes also chose to exit (depending on the impact scenario they were presented with), and 'exiters' never diversify. Importantly however, the vast majority of diversifiers did not choose this response until reaching at least a 70% decline in profits associated with fishing. In contrast, those we classify as 'exiters' exhibit demonstrably different exiting behavior, in that most chose to exit in much lower decline scenarios (e.g., 15% decline in profits associated with fishing, Figure S1.2). For further details about these three categories see Figures S1.1-2 and Table S1.2.

Capturing the adaptive capacity domains

Based on recent developments synthesizing an interdisciplinary body of work on adaptive capacity, we developed 22 indicators to capture 7 broad domains of adaptive capacity: (1) assets, (2) flexibility, (3) learning, (4) socio-cognitive constructs, (5) agency, (6) competing concerns and (7) social organization (Table S1.2-4) (Mortreux and Barnett, 2017; Cinner et al., 2018; Cinner and Barnes, 2019).

(1) The assets people have access to or own. People are generally better able to adapt when they can access a diversity of financial, technological and service-related assets (Cinner and Barnes, 2019). Based on existing literature (Cinner et al., 2008; Cinner, 2014; Cinner et al., 2018), we used the number of *fishing assets* and *income* as indicators of this domain (Table 1).

(2) The flexibility to make changes. Individuals with more flexibility are better able to adapt to climatic impacts because they are able to access to a broader diversity of potential adaptation options (Cinner et al., 2018). For example, fishing assets (e.g. fishing gear diversity) can enable fishers to adapt to future shocks and adverse trends (Cinner et al., 2018) such as fluctuations of fishing conditions. On the flip side, fishing identity and job attachment have been associated with fishers remaining in fisheries despite deteriorating conditions and diminishing returns (Coulthard and Britton, 2015; Mortreux and Barnett, 2017; Cinner and Barnes, 2019). Age and the dependence on marine resources have also been discussed and identified as important aspects of the diversity adaptive capacity domain in recent work (Barnes et al., 2020; D'agata et al., 2020). In this domain we therefore used *fishing identity*, *job attachment*, *age*, and *dependence on marine resources* as indicators of flexibility (Table 1). We also accounted for existing *livelihood diversity* (i.e., the number of complementary income activities aside from fishing) (Cinner and Barnes, 2019; D'agata et al., 2020; Table 1).

(3) Learning to recognize change and assess response strategies. Learning in SESs can help to build awareness of environmental changes and the complex feedbacks and relationships between fishers and marine ecosystems that may underpin, or reinforce them (Cinner and Barnes, 2019). In this sense, SES thinking, and knowledge have been argued to be important determinants driving adaptation (Biggs et al., 2012; Ostrom 2009). Training activities (understood as active engagement) and fishing experience can also be important, as learning is an experiential and experimental process that enables people to frame problems (Shaffril et al., 2016; Shaffril et al., 2019; Cinner and Barnes, 2019). Here, we used *SES knowledge*, *training activities*, and *fishing experience* as indicators of learning (Table 1).

(4) The socio-cognitive constructs that can influence people's perceptions of risk, as well as the costs and benefits associated with making changes to manage risks (Cinner and Barnes, 2019). In this domain, we measured *risk attitude* as the degree of subjective risk taken in the SSF labor activity (Mortreux and Barnett, 2017; Cinner and Barnes, 2019; Barnes et al., 2020).

(5) The agency to mobilize adaptive capacities to respond to stressors. This domain refers people`s free choice, empowerment, and self-efficacy in responding to social-environmental changes (Cinner and Barnes, 2019). The household size of fishers is known to affect adaptation strategies (Coulthard and Britton, 2015; Mortreux and Barnett,

TABLE 1 Dependent and independent variables used for the multinomial multilevel logit mixed effect model.

Adaptive capacity domain	Variable/ Indicator name	Definition
–	*Diversifier*	Individual response across 10 hypothetical climate change impact scenarios: diversify at least once (1); never diversify and never exit (2); never diversify and exit at least once (3).
Assets	*Fishing assets*	Number of fishing assets that each respondent has
	Income	Range of the respondent's income from all her/his labor activities
Flexibility	*Livelihood diversity*	Number of respondent's complementary income activities
	Fisher identity	Degree of respondent's pride of being a fisher
	Job attachment	Degree of respondent's perception about her/his job attachment
	Age	Age of the respondent (years)
	Dependence on main marine resources	Number of main target resources (in relation with the main target resources in his/her community)
Learning	*SES knowledge*	Degree of respondent's knowledge about the SSF system as a SES
	Training activities	Degree of participation in the fishing community activities includes training, auction- market activities and resources improvement activities perceived by the respondent
	Fishing experience	Life-time in months spent on the SSF activity by the respondent
Agency	*Household size*	N° of members in the household of the respondent
	Participation decision making	Respondent's perception on the degree of access to decision-making in the guild
Socio-Cognitive	*Risk attitude*	Degree of risk taken in the labor activity perceived by the respondent
Competing concerns	*Inequality*	Degree of perceived inequality by the respondent between respondent's group/s and other groups in the guild
	Gender	Binary indicator (men, women) of the respondent as a proxy of biological data by his/her physical appearance
Organization	*Bonding communication*	Communication within the SSF group/s of the respondent. Proportional number based on the presence (once per year at least) or absence (never) of ties.
	Bridging communication	Communication with different SSF group/s (i.e., outside of the respondent's group/s). Proportional number based on the presence (once per year at least) or absence (never) of ties.
	Linking communication	Number of institutional profiles (community representative, government representative, secretary, guard watching, barefoot advisors and auction manager) with whom the respondent has a communication-based tie. Based on the presence (once per year at least) or absence (never) of ties.
	Bonding trust	Trust within the SSF groups the respondent belongs to. Proportional number based on the presence (any degree of trust) or absence (no degree of trust) of ties.
	Bridging trust	Trust in SSF groups the respondent does not belongs to. Proportional number based on the presence (any degree of trust) or absence (no degree of trust) of ties.
	Linking trust	Number of institutional profiles (community representative, government representative, secretary, guard watching, barefoot advisors and auction manager) with whom the respondent has a trust-based tie. Based on the presence (any degree of trust) or absence (no degree of trust) of ties.
–	*Community*	Name of the SSF community (municipality) where the respondent develops the SSF activity (random effect variable)

2017). For instance, research in farms has associated larger households with the ability to supply surplus labor to non-farm activities as an adaptation practice (Ali and Erenstein, 2017). Also, the presence of children within a household is associated with higher levels of hazard preparedness (Mortreux and Barnett, 2017). In addition, the ability to participate in decision making has been related to agency in previous studies, and affects the capacity to manage prospective situations (Cinner and Barnes, 2019; D'agata et al., 2020). In this respect, we used *Household size* and *Participation in decision making* as indicators of agency (Table 1).

(6) Competing concerns capture the effects that different priorities (i.e. the needs to fulfil) might have on adaptive behavior (Mortreux and Barnett, 2017). One way to understand competing concerns is through the lens of gender. Gender can be understood as something people do and, as such, it is a dynamic and contested identity category (Siegelman et al., 2019). In the context of adaptation, existing research suggests that women are less likely to be involved in preparedness for extreme events as they often have multiple responsibilities, and so have less time and energy to commit to household disaster preparation (Mortreux and Barnett, 2017). For this reason and

in this context the role of gender is strongly related to the conceptualization of competing concerns, despite its conventional classification as a socio-demographic feature. Unequal power relationships can also contribute to the emergence of competing concerns which influence individual adaptive capacities in the face of changes (Cinner and Barnes, 2019). In this study, we therefore included *gender* and *perceptions of inequality* as predictors of competing concerns (Table 1).

(7) The organization of society through social networks of informal and formal relationships. Social organization plays a crucial role in the lives of fishers within our study communities through bonding, bridging, and linking social relationships (Macho et al., 2013; Barnes et al., 2020) that may strongly influence the adaptation process under climate change (Barnes et al., 2017b; Barnes et al., 2020). Bonding ties -ties between people of the same social group- can facilitate cooperation, reciprocity and knowledge co-production that may contribute to adapt SSF while maintaining the dominant structures (Bodin and Crona, 2009; Barnes et al., 2017b; Rockenbauch and Sakdapolrak, 2017). Bridging ties -ties between people of different social groups- are argued to provide knowledge sharing, innovation and access to external resources that may help to initiate transformations (Crona and Bodin, 2006; Bodin and Crona, 2009; Barnes et al., 2017b). And linking ties -ties between people from different levels of an organizational structure- help to leverage ideas beyond the community and promote legitimacy that may facilitate the progress towards transformations (Bodin and Crona, 2009; Barnes et al., 2017b). Here, we address our third research question by following the theoretical foundation laid out in (Barnes et al., 2017b) and testing the presence of bonding, bridging, and linking network structures (Tables 1, A1.4). We do so by distinguishing between (1) communication-based ties, which contribute to information sharing and encourage mutual learning, and thus may facilitate a range of adaptation strategies (Barnes-Mauthe et al., 2014; Gong et al., 2018); and (2) trust-based ties, which may serve to reduce the complexity of a risky situation, and may thus encourage people to adapt in ways that are distinct to communication-based ties (Terpstra, 2011; Table 1).

Further information regarding how each indicator was measured and descriptive statistics of all indicators are provided in Table 1, Appendix S1.1 and Table S1.2-4.

Modelling procedure

We used a multinomial multilevel logit mixed-effect model (Mbaru and Barnes, 2017) to test the degree to which our livelihood diversification response variable could be explained by our predictors capturing adaptive capacity domains (Cinner et al., 2018; Barnes et al., 2020; D'agata et al., 2020).

Our sample size dropped from 404 to 376 observations due to missing values. The nine communities were included in our model as a random effect ('*Community*', Table 1) to account for potential differences across sites. Results from a variance inflation factor analysis (VIF) demonstrated that there was no collinearity among our indicators (Table S1.5). The model was run with robust variance estimates to account for any potential issues of non-independence related to the manner in which our social and social/social-ecological network structures were conceptualized and calculated (Mbaru and Barnes, 2017; Barnes et al., 2017a). The model was performed in Stata/IC 16.

Ethics statement

Participation was voluntary and responses anonymized. Informed consent was obtained from all subjects and/or their legal guardian(s). The experimental protocol was approved by the University of Vigo. Also, a formal agreement with the federal Galician SSF association allow reaching the communities and the acceptance of the fisher guilds to be part of the research project. The whole process has followed the ethical guidelines and requirements set by H2020.

Results and discussion

The importance of livelihood diversification under decreasing income scenarios

According to our results, we see a pattern where a greater proportion of fishers chose to diversify their livelihoods over other options under extreme negative climate change impact scenarios. This proportion decreases to the 15% negative impact level before levelling out (Figure S1.3).

Under decreasing resource and income scenarios (Figure S1.3), the proportion of diversifiers in our sample increases from 16.83% under the current baseline status to 35.89% under the most extreme resource and income decreasing scenario (accumulative values). Our results are consistent with the work conducted by Galappaththi et al. (2020) where the authors found that livelihood diversification was an important adaptive strategy that indigenous fishing communities used to cope with adverse conditions associated with climate change, such as natural resource scarcity. Coulthard (2008) also noted that as fisheries crises worsen, fishers are increasingly under pressure to seek out new ways of living. Our research contributes to this existing body of work by empirically demonstrating that fishers are likely to choose to diversify their livelihood progressively as scarcity impacts increase, which can help to reduce the risk of livelihood failure (Coulthard, 2009; Ojea et al., 2020).

Our results show that the number of diversifiers drops under positive climate change impact scenarios, as no new fishers decide to diversify (Table S1.6), i.e., the proportion of diversifiers observed for our baseline scenario (16.83%) remains constant across all positive impact scenarios (Figure S1.3). Thus, under hypothetical scenarios of increasing biological resources, we found that fishers neither change their livelihoods nor increase their livelihood diversification strategy. Existing research regarding the role of livelihood diversification under scenarios where resources or economic profits increase is largely anecdotical, though this finding does contradict an existing study in which an increase in forest land cover at Nqabara on South Africa's Wild Coast led people to shift from large cultivated fields, which had become overgrown, to smaller gardens (Fabricius et al., 2007). In other words, changes in livelihoods were positively associated with an increase in natural resource abundance (Fabricius et al., 2007). Our results thus suggest that when faced with climate impacts, the transformative behavior of small-scale fishers may differ from that of actors in other natural resource-dependent systems; yet additional research is needed in order to confirm this hypothesis. Other possible drivers of the adaptive behavior we studied here include environmental and contextual conditions, which may also lead to different adaptation strategies in different places and sectors (e.g., fishers and farmers).

Overall, 146 (36.14%) fishers stated they would choose to diversify their livelihood by finding work outside the SSF at least once under the set of 10 climate impact scenarios, while 258 (63.86%) fishers never choose this strategy (112 remainers and 146 exiters) (Table S1.2). The somewhat low proportion of livelihood diversification responses overall for the Galician case study may be explained by several potential factors. First, fishers may not feel that they have suitable livelihood alternatives, as existing research suggests that fishers experiencing impacts on livelihoods will feel motivated to diversify and even exit the fishery when suitable alternative incomes are offered (Muallil et al., 2011). Second, fishing is often considered more than just an occupation, and fishers have strong attachments to their work (Bavinck et al., 2012). Indeed, research conducted across several countries revealed that fishers enjoy their occupation and are not often interested in alternative employment (even if catches and associated incomes fall), which tends to be contrary to the assumptions underpinning many fisheries policies (Monnereau and Pollnac, 2012). Although this second explanation could be plausible, the variables we use to measure job attachment and fisher identity (*job attachment* and *fisher identity*) do not show any level of significance in our results.

Results of the multinomial multilevel logit mixed-effect models for diversifiers are depicted in Figure 2. Generally, our findings show that flexibility enables livelihood diversification, however different aspects of learning, competing concerns and social organization play both enabling and constraining roles on this transformative process (Figure 2). Overall, compared to those who remain in the fishery without engaging in any form of livelihood diversification (remainers), those who choose to transform their livelihoods by diversifying are less likely to perceive inequality in the system, have greater livelihood diversity to begin with, depend on a greater diversity of marine species, have less bridging trust, less bonding communication and more bridging communication. Comparing diversifiers to those who choose to exit the fishery (exiters), diversifiers have greater (existing) livelihood diversity, SES knowledge, less fishing experience and lower levels of inequality perception in the system. In this comparison, fishers categorized as woman and those with trust-based linking ties were also more likely to diversify livelihoods.

In the following sections, we interpret these results in light of the research questions, looking first at the effect of adaptive capacity indicators on diversification, and second on the role of specific social-ecological network structures comprised mainly within the social organization domain.

Learning, flexibility and competing concerns as determinants of livelihood diversification

Critically, we find that having higher levels of understanding of the SSF as a SES (*SES Knowledge*) is significantly, positively (p-value = 0.021) related to decisions to diversify livelihoods rather than exit the fishery under climate impact scenarios. This finding is in line with theoretical arguments describing SES thinking and knowledge as critical elements of resilience (Biggs et al., 2012; Ostrom 2009). Cinner and Barnes (2019) argue that learning reflects people's capacity to generate, absorb, and process new information about climate change and adaptation options; and ways to live with, and manage, uncertainty. Learning may contribute to building robust decision-making capacity under adverse conditions, allowing people to engage in complementary livelihoods to reduce risk if necessary. Despite this rich literature describing the key role of learning and SES thinking to navigate uncertainties (Biggs et al., 2012), our results are the novel in empirically demonstrating the enabling role of fisher's *SES knowledge* in livelihood diversification under climate impact scenarios.

Our results also show that *Fishing experience* contributes negatively (p-value = 0.002) to diversification decisions when compared to those who primarily chose to exit (Figure 2). In other words, the more time a fisher participates in a SSF, the less likely they are to diversify as opposed to exit. This result is contrary to what we might expect since the existing literature suggests that fishing experience may be related to a strong occupational attachment, which we might expect to lead fishers to choose to diversify rather than simply exiting fisheries under climate impact scenarios (Shaffril et al., 2016; Shaffril et al., 2019).

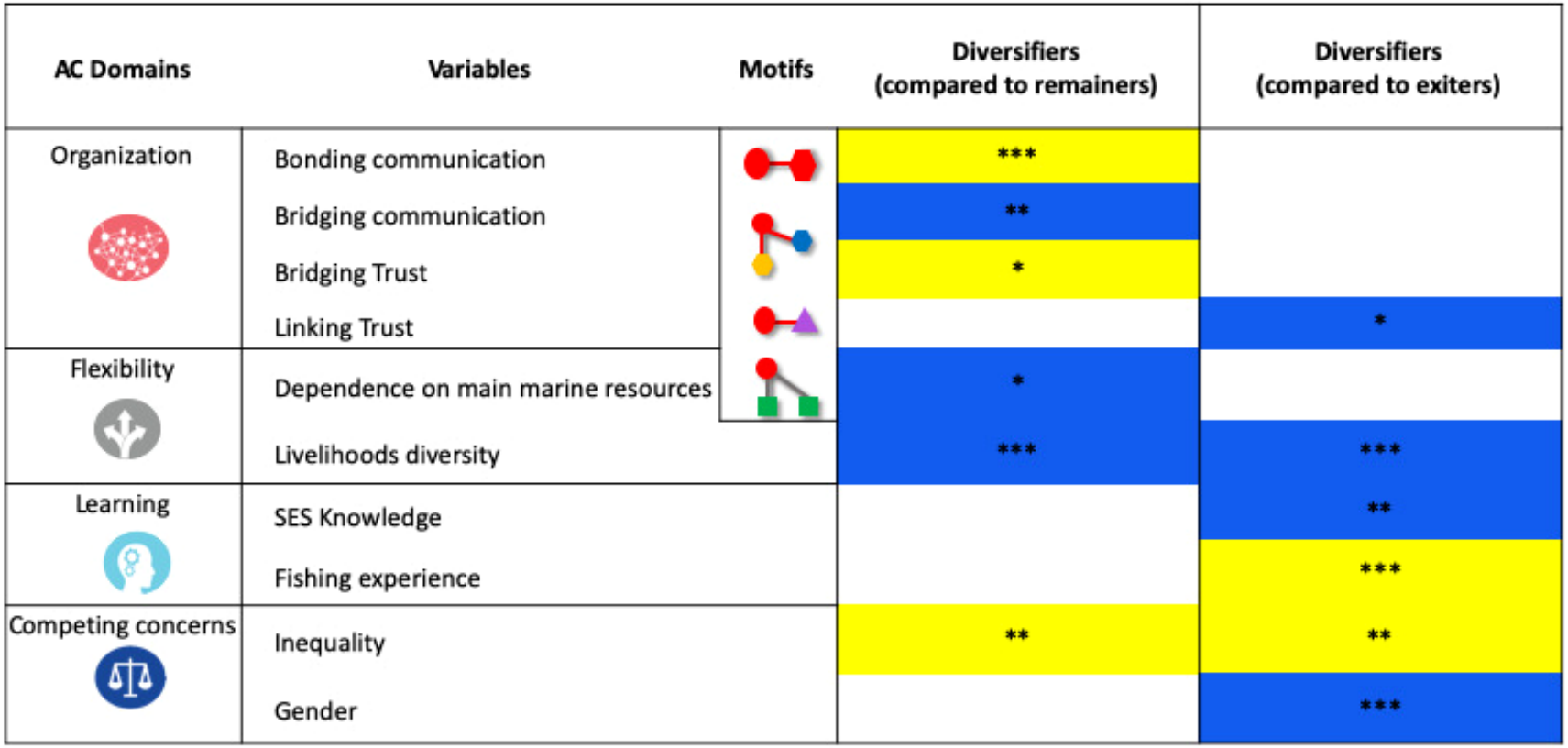

FIGURE 2
Relationships between the indicators of adaptive capacity (AC, organized by domain) that have a significant effect on the stated livelihood diversification behavior of fishers facing hypothetical climate change scenarios. Significant relationships are displayed from the results of a multinomial multilevel logit mixed-effects model which modeled three categories of fishers: diversifiers, remainers, and exiters. We were primarily interested in diversifiers, and thus diversifiers were set as the base category in order to be able to directly compare their characteristics to that of remainers and exiters. Colors indicate the type of relationship (yellow reflects a negative sign and blue captures a positive sign); presence of asterisks shows the significance level (* *p-value* <0.1, ** *p-value* <0.05, *** *p-value* <0.01) and blank cells manifest non-significant effects. This figure aims to facilitate the visualization of the variables that contribute positively and/or negatively to diversification (the base category); thus, the sign of the relationships presented here are opposite the sign of the model results. Full model results are available in Table S1.7.

10.3389/fmars.2022.888288

A simple explanation might be that more experienced fishers (who are often older) prefer to leave SSFs rather than to diversify livelihoods under impact scenarios because they may be expecting to retire. In fact, age and fishing experience (tested for multicollinearity which showed no issues between these two variables) were positively correlated in our case ($R= 0.62$, $p < 0.000$). Although age was not significant in our model, the age of exiters is significantly higher than the age of diversifiers (Table S1.8). Another potential explanation might be that the more experienced small-scale fishers are, the more knowledge they may have regarding climate-related consequences on SSFs (Mortreux and Barnett, 2017), which may cause them to see livelihood diversification as an unsuitable way to fulfill their needs and sustain their life into the future. This rationale would be consistent with Beaudreau et al. (2019), who found that contrary to portfolio theory, specializing (rather than generalizing, which would result from diversifying) was associated with stronger benefits for fishers (Beaudreau et al., 2019).

Flexibility also played an important role in livelihood diversification decisions (p-value = 0.000 compared to remainers and p-value = 0.001 compared to exiters), consistent with arguments that individuals with more flexibility may be better positioned to adapt to climatic impacts (Cinner et al., 2018). First, we found that those who are already diversifying livelihoods (*Livelihood diversity* variable) will be more likely to further diversify livelihoods under climate change scenarios rather than remain in the fishery or exit. Fishers that have already diversified their livelihoods may be more familiar with the diversification process and can apply those specific skills under future uncertainties. While this sounds intuitive, it actually stands in contrast to the results from previous studies in SSFs that found that having more occupations (i.e., greater livelihood diversity) increased the likelihood of exiting the fishery (Cinner, 2014). Empirical examples testing the role of current livelihood diversification on fisher's adaptation decisions under uncertainty are scarce; thus, more research may be needed to understand the factors that influence fisher's decisions to diversify as opposed to exit under different levels of impact or risk. We also found that fishing a more diverse portfolio of fishery resources (*Dependence on main marine resources*) was positively related to livelihood diversification compared to those whose mainly chose to remain in the fishery. We describe this result in further detail in *section The role of network structures on livelihood diversification*.

We find competing concerns as the third adaptive capacity domain that has a strong relationship with diversification. Firstly, compared to both remainers and exiters, *Inequality* is negatively related to livelihood diversification decisions (p-value of 0.037 and 0.025, respectively; Figure 2). This means that the more the fishers feel they are in an unequal situation within the SSF community, the less likely they are to diversify. This novel result is consistent with Maslow's hierarchy of needs theory which has been adapted to fisheries realms (Cinner and Pollnac, 2004). In Maslow's hierarchy, *Inequality* may reflect unfulfilled social needs such as social belonging and acceptance. According to the theory, these unfulfilled needs prevent people from focusing on reaching higher levels of the pyramid, such as esteem, cognitive and self-actualization (Cinner and Pollnac, 2004). Esteem, cognitive and self-actualization are strongly related to agency and other domains of the adaptive capacity framework which may be crucial for livelihood diversification (Cinner and Barnes, 2019). In the same line, the psychology literature describes that people have a limited capacity to worry, such that increases in worry about one issue in life will lead to a decrease in worry about other issues (Mortreux and Barnett, 2017). In this aspect, our finding is consistent with the literature that suggests that the presence of competing concerns significantly impedes adaptation, in this case through livelihood diversification, even when adaptive capacity is high (Mortreux and Barnett, 2017). Indeed, this perceived inequality could be an indicator of the existence of social-ecological traps (Cinner, 2011), where for instance, oppressing powers create a situation where marginalized groups and individuals remain locked in maladaptation, further eroding their wellbeing (Blythe et al., 2018). To solve these conflicts, deliberative processes are argued to be key (Ostrom 2009). Overall, our results suggest that equity considerations may be critical to facilitating climate adaptation and transformation in SSFs.

Secondly, we find that *Gender* is strongly related to livelihood diversification decisions under climate impact scenarios; i.e., compared to those who largely chose exit responses, women are more likely to choose livelihood diversification responses (p-value = 0.007) (Figure 2). These results are consistent with the literature that describes gender as an important predictor of attitudes towards natural disasters (Ho et al., 2008; Haynes et al., 2010; Eriksen et al., 2010). Within fisheries, women have been shown to play a key role in both "endogenous strategies" (such as maintaining nets or housekeeping) and "exogenous strategies" (such as working outside of fisheries to receive a supplement income) to cover the needs of the household and contribute to buffering impacts (Coulthard and Britton, 2015). This role may contribute to vulnerabilities when faced with risks (Coulthard, 2012; Coulthard and Britton, 2015; Kawarazuka et al., 2017), e.g., women may be less able to migrate out of fisheries completely, even under extreme climate impacts (Kawarazuka et al., 2017) (Cinner, 2011). However, SSF are often a way of life; thus, fishers that are able to find ways to remain in the fishery while still adapting or transforming in the face of impacts may be better off in terms of their wellbeing (Shaffril et al., 2016; Shaffril et al., 2019). Our findings demonstrate the gendered nature of climate change adaptation in SSF. With the aim to improve this research line, we encourage further research to go beyond gender and integrate the LGTBIQA+ research in order to better understand the social diversity of SSF (Dominey-howes et al., 2014; Resurrección et al., 2019). This will help us to fully disentangle the outcomes of diversification decisions and better identify

marginalized groups and inequities, as well as good practices to combat them, when considering climate change adaptation and transformation strategies (Dominey-howes et al., 2014; Resurrección et al., 2019).

Though existing research has shown that assets, agency and socio-cognitive constructs can be important for adaptation and transformation (Barnes et al., 2020; D'agata et al., 2020; Mortreux and Barnett, 2017); we did not find evidence that they were related to livelihood diversification in our analysis of Galician SSFs under climate impact scenarios. Assets in particular are commonly considered to be one of the most important factors in building adaptive capacity (Yohe and Tol, 2002; Smit and Wandel, 2006), and as such are the focus of many adaptation programs (Lemos, 2007; Cinner et al., 2018). Here, we only included two predictors of assets: fishing assets and income. One possible reason that might explain why income and fishing assets was not significant in our models for predicting livelihood diversification responses is the coexisting conditions of a "growth-based western economy country" context, whereby every fisher is maintained above a minimum level of income and fishing assets, which may dampen the effect of income level. It is possible that other types of assets that we did not measure may have also been important, such as additional material possessions, savings, or access to credit. Similarly, we were only able to capture a limited number of predictors of agency and socio-cognitive constructs. Future research should expand on our efforts to develop a better understanding of how these domains may shape adaptive decisions.

The role of network structures on livelihood diversification

We find five network structures related to livelihood diversification. We explain these findings in five main key points. First, diversifiers show a significantly lower level of *Bonding communication* (p-value = 0.007) than remainers (Figure 2). In other words, fishers who communicate within their fishing groups are more likely to remain in the fishery than to transform by diversifying their livelihood. This is consistent with the literature that explains that bonding ties promote knowledge co-production, trust, reciprocity, and cooperation, all of which can maintain the dominant structures and function of a SES (Bodin and Crona, 2009; Berardo, 2014; Rockenbauch and Sakdapolrak, 2017). Specifically, bonding ties can provide a sense of identity and belonging, social support (in time of crisis), shared vision and mutual learning which may positively influence fishers' perceptions of remaining in fisheries through common agreements and governance practices that facilitate the adoption of technologies and adaptation strategies (Barnes-Mauthe et al., 2014; Barnes Truelove et al., 2015; Gong et al., 2018; Barnes et al., 2019; Wilson et al., 2020).

In contrast to our results on bonding communication, *Bridging communication* has a significantly positive effect (p-value = 0.033) on livelihood diversification choices (Figure 2). In other words, fishers who communicate with different people are more likely to diversify their livelihood than to remain in SSF as their only labor activity. This is consistent with the literature that explains that bridging ties between people of different groups can provide access to a diversity of external resources, enhance innovation, promote creativity, and provide new perspectives that can be crucial in times of crisis (Newman and Dale, 2005; Crona and Bodin, 2006; Bodin and Crona, 2009; Rockenbauch and Sakdapolrak, 2017). These features can enable the development of new perspectives that initiate livelihood transformations (Crona and Bodin, 2006; Bodin et al., 2006; Bodin and Crona, 2009; Rockenbauch and Sakdapolrak, 2017; Barnes et al., 2017b). Aligned with our results, Zhang et al., 2020 find in their research on the agriculture sector that people who maintain communicative bridging ties also display more progressive practices to help manage uncertainty and change.

Third, the majority of research on social networks and adaptation/transformation has focused on communication ties. Critically, in our model *Bridging trust* has a significant (p-value = 0.088) negative effect (Figure 2). In other words, those with high levels of *Bridging trust* ties are more likely to remain in the SSF rather than transform by diversifying their livelihood. Our results are consistent with literature that argues that a high level of trustful relationships may pose a barrier to transformation due to constraining social norms of mental lock-ins (Barnes et al., 2017b). In this line, this network structure combines the effect of trust (mental lock-ins) and the effect of bridging ties (the connection among different groups within SSFs), which may lead to a "we" (small-scale fishers) versus "them" (non-small-scale fishers) mentality (Dressel et al., 2020). Also, in order to reduce the complexity of the situation, trust-based ties may influence fisher's risk judgments (Terpstra, 2011; Zhang et al., 2020). Specifically, when trust is high, individual risk perception may be low, potentially causing people to perceive livelihood diversification as unnecessary (Terpstra, 2011; Wilson et al., 2020; Bodin et al., 2020). To date, little research has focused on the different types of bridging relationships and transformation in SES. Our findings demonstrate that this distinction is important, since communication-based bridging ties are positively related to livelihood diversification, whereas trust-based bridging ties are negatively related to livelihood diversification.

Fourth, *Linking trust* has a significant (p-value = 0.092) positive effect on livelihood diversification behavior compared to exiting behavior (Figure 2). In other words, fishers who trust institutional actors of the SSF community are more likely to diversify livelihoods in times of climate-induced impacts, rather than exit SSF. This is probably because (1) linking ties provide access to resources and knowledge beyond the levels of the community and can promote legitimacy (Newman and Dale,

2005; Bodin and Crona, 2009; Barnes et al., 2017b), (2) trust-based linking ties may indicate trust in leaders to manage the risks of remaining in the fishery (Terpstra, 2011), and (3) fishers may feel empowered because linking ties often enable fishers to have some agency over fishery decisions that affect them (Marín et al., 2012). Our results are consistent with previous research conducted on a Chilean coastal benthic resources co-management system which showed that the investment of small-scale fisher organizations in linking social relationships was associated with more diversified livelihoods (Marín et al., 2012).

Finally, *Dependence on main marine resources* has a significant, (p-value = 0.064) and positive effect on livelihood diversification decisions (Figure 2) compared to remaining in the SSF. In other words, fishers who fish a greater diversity of marine species are more likely to transform by diversifying their livelihood than to remain in SSF as the only labor activity when faced with climate impacts. This is consistent with the literature that explains that social-ecological ties represent the environmental knowledge and capacity acquired from the connection with different target biological marine species that may enable fishers to detect environmental changes and anticipate future change scenarios (Barnes et al., 2017b; Barnes et al., 2020). As Barnes et al., (2017b) mention, resourceful actors linked to multiple resources -targeting different main marine species- can facilitate experimentation while reducing risk, which is critical in the initial phase of transformation. Our findings demonstrating a significant positive relationship between social-ecological networks and individual livelihood diversification strategies under climate-driven impacts adds novel insight to recent advances in the SSF adaptation literature (e.g. Barnes et al., 2020).

The role of timing in climatic crises and their influence in fishers' decision making is an important point to consider. Although we did not explicitly study the time dimension, the extent of climate impacts on income could represent the extremity or acuteness of an unfolding climate crisis, with lower income impacts potentially representing a crisis unfolding more slowly (precautionary steps and proactive behaviour) *vs.* large income declines being connected to extreme events (reactive behavior). Further research is needed to explore the role of the timing and worsening conditions on adaptation, which may play an important role in how people respond.

Conclusion

The purpose of this work is to analyze the diversification of livelihoods of small-scale fishers as a transformative strategy that can contribute to helping communities face climate change. Specifically, we identify: 1) the different types of climate impact scenarios under which individual livelihood diversification takes place; 2) the aspects of adaptive capacity that contribute to, and constrain livelihood diversification choices when faced with climate impacts; and 3) the role of social-ecological structures on individual livelihood diversification responses to climate change. Our investigation combines research on adaptive capacities, network structures, perceptions of climate change scenarios and decision-making to quantify and explain fishers' livelihood diversification behavior when faced with hypothetical scenarios of climate change. We understand livelihood diversification as a transformative response (Betcherman and Marschke, 2016; Kadfak, 2020), where fishers combine income generating activities inside and outside the SSF.

First, our results show that fishers engage mainly in livelihood diversification when income decreases as a result of climate impacts at medium to high levels (50-90% declines). This novel finding demonstrates that: 1) fishers do not diversify under increasing abundance scenarios, and 2) livelihood diversification is more likely to take place at higher impact scenarios. Second, we find that fishers who are already engaged in other livelihood activities (flexibility domain) are more likely to diversify under climate change impacts. In contrast, men and fishers who perceive high levels of inequality within the SSF (competing concerns domain) are less likely to diversify livelihoods. These novel findings highlight the crucial role of personal perceptions and gender in climate change adaptation of SSF. In addition, learning played a positive role on livelihood diversification in terms of SES knowledge, while it played a constraining role in terms of SSF experience.

Regarding network structures, we find that fishers who depend on several marine species, communicate with other fishing groups and/or have trust in institutional actors within the SSF are more likely to engage in livelihood diversification. However, fishers who communicate within their fishing group and who trust different fishing groups were less likely to choose livelihood diversification options. This importantly demonstrates the differential effects of social and social-ecological ties on individual transformative responses under climate impacts. Our general findings regarding bonding, bridging, linking and social-ecological network structures empirically support the key roles of network structures in climate change adaptation frameworks (Barnes et al., 2020; Ojea et al., 2020) and adaptation continuum theory (Barnes et al., 2017b) providing people access to resources, knowledge and power (Crona and Bodin, 2006). Our findings also demonstrate that adaptation operates across scales: 1) among fishers, 2) between fishers and marine species and 3) between fishers and institutional agents (Daw et al., 2012; Ojea et al., 2020).

According to our results, further research should seek to develop a better understanding of the effects and relationships between different domains of adaptive capacity, especially in the case of learning, social organization, socio-cognitive constructs and competing concerns. In this research we find that risk attitude may constitute a potential linkage between socio-

cognitive constructs and competing concerns (Cinner et al., 2018). In previous literature, other interrelations between adaptive capacity domains have also been identified, e.g. socio-cognitive and agency (Cinner et al., 2018). In this line, agency is argued to require power and freedom to mobilize adaptive capacity domains in order to shape a desirable future (Cinner et al., 2018). Specifically, we argue that future studies should integrate a power perspective in fisheries negotiations and decision making to facilitate climate change adaptation. In this line, we recommend exploring the link between livelihood diversification, environmental conservation and equity to support adequate policies that disactivate existing barriers that may constrain adaptation pathways. Such barriers may include overexploitation in fisheries, which can have a strong effect on fisher's adaptive capacity to climate change. Further research is needed to tackle this question and shed light on the effects and feedbacks of overexploitation and climate change adaptation.

This study provides rich information about individual transformations that need to be considered in addition to other scales (i.e. households, fishing sector, communities) when considering climate change. The insights derived from this work are essential to adequately inform policy makers when transformation is discussed, designed and legislated. In addition, the identification of synergies and trade-offs of adaptation-transformation responses across scales would highly benefit sustainable SES under climate change.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Participation was voluntary and responses anonymized. Informed consent was obtained from all subjects and/or their legal guardian(s). The experimental protocol was reviewed and approved by the University of Vigo. Also, a formal agreement with the federal Galician SSF association allow reaching the communities and the acceptance of the fisher guilds to be part of the research project. The whole process has followed the ethical guidelines and requirements set by H2020.

Author contributions

DS-O, MB, and EO designed research; DS-O and EO performed research; D-SO and MB analyzed data; and D-SO, MB, and EO wrote the paper. All authors have reviewed and agreed to the submission of the final version.

Acknowledgments

We acknowledge all of the small-scale fishers and institutional members who participated in social surveys and contributed to this study sharing their knowledge and experience. Also, thanks to the Federación Galega de Confrarías de Pescadores and Xunta de Galicia that have provided information and helped to reach the target communities; Luz Eva Fernández Fernández, Laura Oubiña Acuña, Carlos Pereira Luengo, Ángela Hernández González and Gema Martínez Iglesias and Paula Barreiro Buceta for their help in the field; Elena Fontán Allende for her help with the digitalization of social surveys and Iratxe Rubio for reading the last version of this article and providing feedback. The research leading to these results has received funding from the European Research Council under the European Union's Horizon 2020 research and innovation program, ERC Starting Grant for project CLOCK (n°679812). EO also thanks GAIN from Xunta de Galicia for the Oportunius fellowship and Consellería de Educación for financial support. DS-O acknowledges funding from Xunta de Galicia, Consellería de Cultura, Educación e Ordenación Universitaria. MB acknowledges funding from the Australian Research Council (grant no. DE190101583). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.888288/full#supplementary-material

References

Adger, W. N., Huq, S., and Hulme, M. (2003). Adaptation to climate change in the developing world. *Prog. Dev. Stud.* 3, 179–195. doi: 10.1191/1464993403ps060oa

Alexander, S. M., Bodin, Ö., and Barnes, M. L. (2018). Untangling the drivers of community cohesion in small-scale fisheries. *Int. J. Commons* 12, 519–547. doi: 10.18352/ijc.843

Ali, A., and Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management* 16, 183–194. doi: 10.1016/j.crm.2016.12.001

Allison, E. H., and Ellis, F. (2001). The livelihoods approach and management of small-scale fisheries. *Mar. Policy* 25, 377–388. doi: 10.1016/S0308-597X(01)00023-9

Barnes, M. L., Arita, S., Kalberg, K., and Leung, P. S. (2017a). When does it pay to cooperate? strategic information exchange in the harvest of common-pool fishery resources. *Ecol. Econom.* 131, 1–11. doi: 10.1016/j.ecolecon.2016.08.005

Barnes, M., Bodin, Ö., Guerrero, A., Mcallister, R., Alexander, S., and Robins, G. (2017b). The social structural foundations of adaptation and transformation in social-ecological systems. *Ecol. Soc.* 22 (4), 14. doi: 10.2139/ssrn.2932575

Barnes, M. L., Bodin, Ö., McClanahan, T. R., Kittinger, J. N., Gaoue, O. G., Graham, N. A. J., et al. (2019). Social-ecological alignment and ecological conditions in coral reefs. *Nat. Commun.* 10 (1), 10. doi: 10.1038/s41467-019-09994-1

Barnes-Mauthe, M., Gray, S. A., Arita, S., Lynham, J., and Leung, P. S. (2014). What determines social capital in a social – ecological System ? insights from a network perspective. *Environ. Management* 55, 392–410. doi: 10.1007/s00267-014-0395-7

Barnes Truelove, H., Carrico, A. R., and Thabrew, L. (2015). A socio-psychological model for analyzing climate change adaptation : A case study of Sri Lankan paddy farmers. *Global Environ. Change* 31, 85–97. doi: 10.1016/j.gloenvcha.2014.12.010

Barnes, M. L., Wang, P., Cinner, J. E., Graham, N. A. J., Guerrero, A. M., Jasny, L., et al. (2020). Social determinants of adaptive and transformative responses to climate change. *Nat. Climate Change* 10, 823–828. doi: 10.1038/s41558-020-0871-4

Bavinck, M., Pollnac, R., Monnereau, I., and Failler, P. (2012). Introduction to the special issue on job satisfaction in fisheries in the global south. *Soc. Indic. Res.* 109, 1–10. doi: 10.1007/s11205-012-0051-7

Beaudreau, A. H., Ward, E. J., Brenner, R. E., Shelton, A. O., Watson, J. T., Womack, J. C., et al. (2019). Thirty years of change and the future of alaskan fisheries: Shifts in fishing participation and diversifiation in response to environmental, regulatory and economic pressures. *Fish. Fish.* 31, 1–19. doi: 10.1111/faf.12364

Berardo, R. (2014). The evolution of self-organizing communication networks in high-risk social-ecological systems. *Int. J. Commons* 8 (1), 236–258. doi: 10.18352/ijc.463

Betcherman, G., and Marschke, M. (2016). Coastal livelihoods in transition: how are Vietnamese housholds responding to changes in the fisheries and in the economy? *J. Rural Stud.* 45, 24–33. doi: 10.1016/j.jrurstud.2016.02.012

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., Burnsilver, S., Cundill, G., et al. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Resour.* 37, 421–448. doi: 10.1146/annurev-environ-051211-123836

Bindoff, N. L., Cheung, W. W., kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., et al (2019). Chaning ocean, marine ecosystems, and dependent communties. In *IPCC special report on the ocean and cryosphere in a changing climate* Intergoverrnmental Panel on Climate Change, pp. 477–587.

Blythe, J. L., Murray, G., and Flaherty, M. (2014). Strengthening threatened communities through adaptation: insights from coastal Mozambique. *Ecol. Soc.* 19 (2) , 1206–23. doi: 10.1111/anti.12405

Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M. L., et al. (2018). The dark side of transformation: Latent risks in contemporary sustainability discourse. *Antipode* 50 (5), 1206–1223. doi: 10.1111/anti.12405

Bode, A., Álvarez-Salgado, X. A., Ruíz-Villarreal, M., Bañón Díaz, R., Gonzalez Castro, C., Molares Vila, J., et al. (2008). "Impacto do cambio climático nas condicións oceanográficas e nos recursos mariños", in *Evidencias del cambio climático en Galicia, xunta de Galicia*, 619–636.

Bodin, Ö., Baird, J., Armitage, D., Schultz, L., and Plummer, R. (2020). The impacts of trust, cost and risk on collaboration in environmental governance. *People Nat.* 2, 734–749. doi: 10.1002/pan3.10097

Bodin, Ö., and Crona, B. (2009). The role of social networks in natural resource governance : What relational patterns make a difference? *Global Environ. Change* 19, 366–374. doi: 10.1016/j.gloenvcha.2009.05.002

Bodin, Ö., Crona, B., and Ernstson, H. (2006). Social networks in natural resource management: What is there to learn from a structural perspective? *Ecol. Soc.* 11 (2), 8. doi: 10.5751/ES-01808-1102r02

Brugère, C., Holvoet, K., and Allison, E. H. (2008). *Livelihood diversification in coastal and fishing communities: misconceptions, evidence and implications for fisheries management*. (Sustainable Fisheries Livelihoods Programme (SFLP), Rome). 1–39.

Cheung, W. W. L. (2018). The future of fishes and fisheries in the changing oceans. *J. Fish. Biol.* 92, 790–803. doi: 10.1111/jfb.13558

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., and Pauly, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish. Fish.* 10 (3), 235–251. doi: 10.1111/j.1467-2979.2008.00315.x

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., et al. (2010). Large-Scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biol.* 16, 24–35. doi: 10.1111/j.1365-2486.2009.01995.x

Cinner, J. E. (2011). Social-ecological traps in reef fisheries. *Global Environ. Change* 21 (3), 835–839. doi: 10.1016/j.gloenvcha.2011.04.012

Cinner, J. (2014). Coral reef livelihoods. *Environ. Sustainability* 7, 65–71. doi: 10.1016/j.cosust.2013.11.025

Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. L., et al. (2018). Building adaptive capacity to climate change in tropical coastal communities. *Nat. Climate Change* 8 (2), 117–123. doi: 10.1038/s41558-017-0065-x

Cinner, J. E., and Barnes, M. L. (2019). Social dimensions of resilience in social-ecological systems. *One Earth* 1 (1), 51–56. doi: 10.1016/j.oneear.2019.08.003

Cinner, J. E., and Bodin, Ö. (2010). Livelihood diversification in tropical coastal communities: A network-based approach to analyzing "livelihood landscapes". *PloS One* 5 (8), 13. doi: 10.1371/journal.pone.0011999

Cinner, J. E., Daw, T., and Clanahan, T. R. M. C. (2008). Socioeconomic factors that affect artisanal fishers. *Conserv. Biol.* 23 (1), 124–130. doi: 10.1111/j.1523-1739.2008.01041.x

Cinner, J. E., Folke, C., Daw, T., and Hicks, C. C. (2011). Responding to change : Using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. *Global Environ. Change* 21 (1), 7–12. doi: 10.1016/j.gloenvcha.2010.09.001

Cinner, J. E., and Pollnac, R. B. (2004). Poverty, perceptions and planning: why socioeconomics matter in the management of Mexican reefs. *Ocean Coast. Manage.* 47, 479–493. doi: 10.1016/j.ocecoaman.2004.09.002

Coulthard, S. (2008). Adapting to environmental change in artisanal fisheries — insights from a south Indian lagoon. *Global Environ. Change* 18, 479–489. doi: 10.1016/j.gloenvcha.2008.04.003

Coulthard, S. (2009). ""Adaptation and conflict within fisheries: insights for living with climate change"," in *Adapting to climate change: Thresholds, values, governance*. Eds. W. Neil Adger, I. Lorenzoni and K. O'Brien (Cambridge University Press.), 255–268.

Coulthard, S. (2012). Can we be both resilient and well , and what choices do people Have ? incorporating agency into the resilience debate from a fisheries. *Ecol. Soc.* 17 (1), 12. doi: 10.5751/ES-04483-170104

Coulthard, S., and Britton, E. (2015). Waving or Drowning : An exploration of adaptive strategies amongst fishing households and implications for wellbeing outcomes. *Sociol. Ruralis* 55 (3), 275–90. doi: 10.1111/soru.12093

Crona, B., and Bodin, Ö. (2006). What you know is who you know? communication patterns among resource users as a prerequisite for Co-management. *Ecol. Soc.* 11 (2), 23. doi: 10.5751/es-01793-110207

Crona, B., and Bodin, Ö. (2010). Power asymmetries in small-scale Fisheries : a barrier to governance transformability? *Ecol. Soc.* 15 (4), 16. doi: 10.5751/ES-03710-150432

D'agata, S., Darling, E. S., Gurney, G. G., McClanahan, T. R., Muthiga, N. A., Rbearisoa, A., et al. (2020). Multiscale determinants of social adaptive capacity in small-scale fishing communities'. *Environ. Sci. Policy* 108, 56–66. doi: 10.1016/j.envsci.2020.03.006

Daw, T. M., Cinner, J. E., McClanahan, T. R., Brown, K., Stead, S. M., Graham, N. A. J., et al. (2012). To fish or not to fish: Factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery'. *PloS One* 7 (2), 10. doi: 10.1371/journal.pone.0031460

Diedrich, A., Benham, C., Pandihau, L., and Sheaves, M. (2019). Social capital plays a central role in transitions to sportfishing tourism in small-scale fishing

communities in Papua new Guinea. *Ambio* 48 (4), 385–396. doi: 10.1007/s13280-018-1081-4

Dominey-howes, D., Gorman-murray, A., and McKinnon, S. (2014). Gender , place & Culture : A journal of feminist geography queering disasters : on the need to account for LGBTI experiences in natural disaster contexts. *Gender Place Cult.* 7, 905–918. doi: 10.1080/0966369X.2013.802673

Dressel, S., Johansson, M., Ericsson, G., and Sandström, C. (2020). Perceived adaptive capacity within a multi-level governance setting : The role of bonding , bridging , and linking social capital. *Environ. Sci. Policy* 104, 88–97. doi: 10.1016/j.envsci.2019.11.011

Eriksen, C., Gill, N., and Head, L. (2010). The gendered dimensions of bushfire in changing rural lanscapes in Australia. *Journal of Rural Studies* 26, 332–42. doi: 10.1016/j.jrurstud.2010.06.001

Fabinyi, M. (2020). The role of land tenure in livelihood transitions from fishing to tourism. *Maritime Stud.* 19, 29–39. doi: 10.1007/s40152-019-00145-2

Fabricius, C., Folke, C., Cundill, G., and Schultz, L. (2007). Powerless spectators , coping actors , and adaptive Co-managers : a synthesis of the role of communities in ecosystem management. *Ecol. Soc.* 12 (1), 29. doi: 10.5751/ES-02072-120129

Fedele, G., Donatti, C. I., Harvey, C. A., Hannah, L., and Hole, D. G. (2019). Transformative adaptation to climate change for sustainable social-ecological systems. *Environ. Sci. Policy* 101, 116–125. doi: 10.1016/j.envsci.2019.07.001

Finkbeiner, E. M. (2015). The role of diversification in dynamic small-scale fisheries : Lessons from Baja California sur , Mexico. *Global Environ. Change* 32, 139–152. doi: 10.1016/j.gloenvcha.2015.03.009

Free, C. M., Mangin, T., Garci, J., Burden, M., Costello, C., and Gaies, S. D. (2020). Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. *PloS One* 15, 1–21. doi: 10.1371/journal.pone.0224347

Galappaththi, E. K., Ford, J. D., and Bennett, E. M. (2019). A framework for assessing community adaptation to climate change in a fi sheries context. *Environ. Sci. Policy* 92, 17–26. doi: 10.1016/j.envsci.2018.11.005

Galappaththi, E. K., Ford, J. D., and Bennett, E. M. (2020). Climate change and adaptation to social-ecological change : the case of indigenous people and culture-based fisheries in Sri Lanka. *Climatic Change* 162, 279–300. doi: 10.1007/s10584-020-02716-3

García-Lorenzo, I., Cabaleiro-Casal, M. J., and Varela-Lafuente, M. M. (2019). Fishermen's associations of the small-scale fisheries: Study applied to the participation in the cofradías of Galicia (NW Spain). *Ocean Coast. Manage.* 178, 104841. doi: 10.1016/j.ocecoaman.2019.104841

Gong, Y., Li, H., Parks, M., Pang, J., and de Fraiture, C. (2018). The role of social capital for farmers ' climate change adaptation in lancang river basin in China. *Climate Change* 149, 75–89. doi: 10.1007/s10584-017-2057-2

Haynes, K., Handmer, J., Mcaneney, J., Tibbits, A., and Coates, L. (2010). Australian Bushfire fatalities 1900 – 2008 : exploring trends in relation to the " prepare , stay and defend or leave early " policy. *Environ. Sci. Policy* 13 (3), 185–194. doi: 10.1016/j.envsci.2010.03.002

Ho, M.-C., Shaw, D., Lin, S., and Chiu, Y.-C. (2008). How do disaster characteristics influence risk Perception? *Risk Anal.* 28 (3), 635–643. doi: 10.1111/j.1539-6924.2008.01040.x

Isaacs, M. (2012). Recent progress in understanding small-scale fisheries in southern Africa. *Curr. Opin. Environ. Sustainability* 4 (3), 338–343. doi: 10.1016/j.cosust.2012.06.002

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., et al. (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecol. Soc.* 11 (1), 15. doi: 10.5751/ES-01462-110115

Kadfak, A. (2020). More than just fishing: The formation o livelihood strategies in an urban fishing community in mangaluru, India. *J. Dev. Stud.* 56 (11), 2030–2044. doi: 10.1080/00220388.2019.1650168

Kates, R. W., Travis, W. R., and Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *PNAS* 109 (19), 7156–61. doi: 10.1073/pnas.1115521109

Kawarazuka, N., Locke, C., McDougall, C., Kantor, P., and Morgan, M. (2017). Bringing analysis of gender and social–ecological resilience together in small-scale fisheries research: Challenges and opportunities. *Ambio* 46, 201–213. doi: 10.1007/s13280-016-0814-5

Kittinger, J. N., Teneva, L. T., Koike, H., Stamoulis, K. A., Kittinger, D. S., Oleson, K. L. L., et al. (2015). From reef to table: Social and ecological factors affecting coral reef fisheries, artisanal seafood supply chains, and seafood security. *PloS One* 10 (8), 24. doi: 10.1371/journal.pone.0123856

Kooij, J., Engelhard, G. H., and Righton, D. A. (2016). Climate change and squid range expansion in the north Sea. *J. Biogeography* 43, 2285–2298. doi: 10.1111/jbi.12847

Lam, V. W. Y., Cheung, W. W. L., Reygondeau, G., and Sumaila, U. R. (2016). Projected change in global fisheries revenues under climate change. *Nat. Pub. Group* 6, 32607. doi: 10.1038/srep32607

Lam, V. W. Y., Cheung, W. W. L., and Sumaila, U. R. (2014). Marine capture fisheries in the Arctic: winners or losers under climate change and ocean acidification? *Fish. Fish.* 17 (2), 335–357. doi: 10.1111/faf.12106

Lemos, M. C. (2007). "Drought, governance and adaptive capacity in north East Brazil: A case study of ceará," in *Human development occasional papers*. (United Nations Development Programme, Michigan).

Macho, G., Naya, I., Freire, J., Villasante, S., and Molares, J. (2013). The key role of the barefoot fisheries advisors in the Co-managed TURF system of galicia (NW Spain). *Ambio* 42 (8), 1057–1069. doi: 10.1007/s13280-013-0460-0

Magnan, A. K., Schipper, E. L. F., Burket, M., Bharwani, S., Burton, I., Eriksen, S., et al. (2016). Addressing the risk of maladaptation to climate change. *WIREs Climate Change* 7 (5), 646–665. doi: 10.1002/wcc.409

Maire, E., Graham, N. A. J., Macneil, M. A., Lam, V. W. Y., Robinson, J. P., Cheung, W.W.L., et al. (2021). Micronutrient supply from global marine fisheries under climate change and overfishing. *Curr. Biol.* 31 (18), 1–7. doi: 10.1016/j.cub.2021.06.067

Marín, A., Gelcich, S., Castilla, J. C., and Berkes, F. (2012). Exploring social capital in Chile ' s coastal benthic comanagement. *Ecol. Soc.* 17 (1), 13. doi: 10.5751/ES-04562-170113

Marshall, N. A., Parks, S. E., Adger, W. N., Brown, K., and Howden, S. M. (2012). Transformational capacity and the influence of place and identity. *Environ. Res. Lett.* 7, 9. doi: 10.1088/1748-9326/7/3/034022

Mbaru, E. K., and Barnes, M. L. (2017). Key players in conservation diffusion: Using social network analysis to identify critical injection points. *Biol. Conserv.* 210, 222–232. doi: 10.1016/j.biocon.2017.03.031

Monnereau, I., and Pollnac, R. (2012). Which fishers are satisfied in the Caribbean? a comparative analysis of job satisfaction among Caribbean lobster fishers. *Soc. Indic. Res.* 109, 95–118. doi: 10.1007/s11205-012-0058-0

Mortreux, C., and Barnett, J. (2017). Adaptive capacity: exploring the research frontier. *Wiley Interdiscip. Rev.: Climate Change* 8 (4), 1–12. doi: 10.1002/wcc.467

Muallil, R. N., Cleland, D., and Aliño, P. M. (2013). Socioeconomic factors associated with fishing pressure in small-scale fisheries along the West Philippine Sea biogeographic region. *Ocean Coast. Manage.* 82, 27–33. doi: 10.1016/j.ocecoaman.2013.04.013

Muallil, R. N., Geronimo, R. C., Cleland, D., Cabral, R. B., Victoria Doctor, M., Cruz-Trinidad, A., et al. (2011). Willingness to exit the artisanal fishery as a response to scenarios of declining catch or increasing monetary incentives. *Fish. Res.* 111 (1–2), 74–81. doi: 10.1016/j.fishres.2011.06.013

Newman, L., and Dale, A. (2005). Network structure , diversity , and proactive resilience Building : a response to Tompkins and adger. *Ecol. Soc.* 10 (1), 0–4. doi: 10.5751/ES-01396-1001r02

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., et al. (2020). Principles for knowledge co-production in sustainability research. *Nat. Sustainability* 3, 182–190. doi: 10.1038/s41893-019-0448-2

Ojea, E., Lester, S. E., and Salgueiro-Otero, D. (2020). Adaptation of fishing communities to climate-driven shifts in target species. *One Earth* 2 (6), 544–556. doi: 10.1016/j.oneear.2020.05.012

Olale, E., and Henson, S. (2012). Determinants of income diversification among fishing communities in Western Kenya. *Fish. Res.* 125–126, 235–42. doi: 10.1016/j.fishres.2012.02.029

Osbahr, H., Twyman, C., Adger, W. N., and Thomas, D. S. G. (2010). Evaluating Succesful Livelihood Adaptation to Climate Variabiliaty and Change in Southern Africa. *Ecology and Society* 15 (2):27.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325 (5939), 419–22. doi: 10.1126/science.1172133

Pinsky, M. L., Worm, B., Fogarty, M. J., Sarmiento, J. L., and Levin, S. A. (2013). Marine taxa track local climate velocities. *Science* 341, 1239–1242. doi: 10.1126/science.1239352

Pita, C., Dickey, H., Graham, J. P., Mente, E., and Theodossiou, I. (2010). Fishermen, willingness for mobility amongst European. *J. Rural Stud.* 26, 11. doi: 10.1016/j.jrurstud.2010.02.004

Pita, P., Fernández-Márquez, D., Antelo, M., Nacho, G., and Villasante, S. (2019). Socioecological changes in data-poor s-fisheries: A hidden shellfisheries crisis in Galicia (NW Spain). *Mar. Policy* 101, 208–224. doi: 10.1016/j.marpol.2018.09.018

Poloczanska, E. S., Brown, C. J., Sydeman, W. J., Kiessling, W., Schoeman, D. S., Moore, P. J., et al. (2013). Global imprint of climate change on marine life. *Nat. Climate Change* 3, 919–925. doi: 10.1038/nclimate1958

Poloczanska, E. S., Burrows, M. T., Brwon, C. J., Garcia, J., Halpern, B. S., Hoegh-Guldberg, O., et al. (2016). Responses of marine organisms to climate change across oceans. *Front. Mar. Sci.* 3, 1–21. doi: 10.3389/fmars.2016.00062

Resurrección, B. P., Bee, B. A., Dankelman, I., Park, C. M. Y., Haldar, M., and McMullen, C. P. (2019). "Gender-transformative climate change adaptation: advancing social equity," in *Background paper to the 2019 report of the global commission on adaptation*. (Stockholm Environment Institute:Rotterdam and Washington, DC). Available at: www.gca.org.

Rockenbauch, T., and Sakdapolrak, P. (2017). Social networks and the resilience of rural communities in the global south: a critical review and conceptual reflections. *Ecol. Soc.* 22 (1), 32. doi: 10.5751/ES-09009-220110

Rogers, L. A., Griffin, R., Young, T., Fuller, E., Martin, K., and Pinsky, M. L. (2019). Shifting habitats expose fishing communities to risk under climate change. *Nat. Climate Change* 9, 512–18. doi: 10.1038/s41558-019-0503-z

Salgueiro-Otero, D., and Ojea, E. (2020). A better understanding of social-ecological systems is needed for adapting fisheries to climate change. *Mar. Policy* 122, 9. doi: 10.1016/j.marpol.2020.104123

Savo, V., Lepofsky, D., Benner, J. P., Kohfeld, K. E., Bailey, J., and Lertzman, K. (2016). Observations of climate change among subsistence-oriented communities around the world. *Nat. Climate Change* 6 (5), 462–473. doi: 10.1038/nclimate2958

Schwermer, H., Aminpour, P., Reza, C., Funk, S., Möllmann, C., and Gray, S. (2021). Modeling and understanding social – ecological knowledge diversity. *Conserv. Sci. Pract.* 3 (5), 1–11. doi: 10.1111/csp2.396

Shaffril, H. A. M., Hamzah, A., D'silva, J. L., Samah, B. A., and Samah, A. A. (2016). Individual adaptive capacity of small-scale fishermen living in vulnerable areas towards the climate change in Malaysia. *Climate Dev.* 5529, 12. doi: 10.1080/17565529.2016.1145100

Shaffril, H. A. M., Samah, A. A., Samsuddin, S. F., and Ali, Z. (2019). Mirror-mirror on the wall , what climate change adaptation strategies are practiced by the Asian 's fishermen of all? *J. Cleaner Prod.* 232, 104–117. doi: 10.1016/j.jclepro.2019.05.262

Siegelman, B., Haenn, N., and Basurto, X. (2019). "Lies build trust": Social capital, masculinity, and community-based resource management in a Mexican fishery'. *World Dev.* 123, 12. doi: 10.1016/j.worlddev.2019.05.031

Sievanen, L., Crawford, B., Pollnac, R., and Lowe, C. (2005). Weeding through assumptions of livelihood approaches in ICM : Seaweed farming in the Philippines and Indonesia. *Ocean Coast. Manage.* 48 (3-69), 297–313. doi: 10.1016/j.ocecoaman.2005.04.015

Slater, M. J., Napigkit, F. A., and Stead, S. M. (2013). Resource perception , livelihood choices and fi shery exit in a coastal resource management area. *Ocean Coast. Manage.* 71, 326–333. doi: 10.1016/j.ocecoaman.2012.11.003

Smit, B., and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environ. Change* 16, 282–292. doi: 10.1016/j.gloenvcha.2006.03.008

Teh, L. C. L., and Sumaila, U. R. (2011). Contribution of marine fisheries to worldwide employment. *Fish. Fish.* 14 (1), 1–12. doi: 10.1111/j.1467-2979.2011.00450.x

Terpstra, T. (2011). Emotions , trust , and perceived Risk : Affective and cognitive routes to flood preparedness behavior. *Risk Anal.* 31 (10), 1658–1675. doi: 10.1111/j.1539-6924.2011.01616.x

Tzanatos, E., Somarakis, S., Tserpes, G., and Koutsikopoulos, C. (2006). Identifying and classifying small-scale fisheries métiers in the Mediterranean: A case study in the patraikos gulf, Greece. *Fish. Res.* 81 (2–3), 158–168. doi: 10.1016/j.fishres.2006.07.007

Villasante, S., Antelo, M., Christou, M., Fauconnet, L., Frangoudes, K., Maynou, F., et al. (2019). "The implementation of the landing obligation in small-scale fisheries of southern European union countries", in *The European landing obligation: Reducing discards in complex, multi-species and multi-jurisdictional fisheries*. Eds. S. S. Uhlmann, C. Ulrich and S. J. Kennelly (Springer Open: Switzerland), 438.

Walker, B., and Holling, C. S. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecol. Soc.* 9 (2), 9. doi: 10.5751/ES-00650-090205

Wilson, R. S., Herziger, A., Hamilton, M., and Brooks, J. S. (2020). From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. *Nat. Climate Change* 10, 200–208. doi: 10.1038/s41558-020-0691-6

Yohe, G., and Tol, R. S. J. (2002). Indictors for social and economic coping capacity - moving toward a working definition of adaptive capacity. *Global Environemntal Change* 12 (1), 25–40. doi: 10.1016/S0959-3780(01)00026-7

Zhang, A. J., Matous, P., and Tan, D. K. Y. (2020). Forget opinion leaders : the role of social network brokers in the adoption of innovative farming practices in north-western Cambodia forget opinion leaders : the role of social network brokers in the adoption. *Int. J. Agric. Sustainability* 18(4), 266–284. doi: 10.1080/14735903.2020.1769808