frontiers | Frontiers in Marine Science

ORIGINAL RESEARCH
published: 04 May 2022
doi: 10.3389/fmars.2022.802762

Resilience and Social Adaptation to Climate Change Impacts in Small-Scale Fisheries

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OPEN ACCESS

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

Received: *27 October 2021*
Accepted: *21 March 2022*
Published: *04 May 2022*

Citation:
Villasante S, Macho G, Silva MRO, Lopes PFM, Pita P, Simón A, Balsa JCM, Olabarria C, Vázquez E and Calvo N (2022) Resilience and Social Adaptation to Climate Change Impacts in Small-Scale Fisheries. Front. Mar. Sci. 9:802762. doi: 10.3389/fmars.2022.802762

Small-cale fisheries are important for livelihoods, food security, jobs and income worldwide. However, they face major challenges, including the increasing effects of climate change that pose serious risks to coastal ecosystems and fishing communities. Although scientific research on climate change impacts has increased in recent years, few studies have explored the social impacts on small-scale fisheries. Using Galicia (Spain) as a case study, we investigated individual and household-level adaptive responses to climate change among fishers in three fishing guilds (Cambados, Campelo, and Redondela). Specifically, we estimated the economic vulnerability of shellfishers and assessed the diversity of social adaptive responses used to deal with climate change. Although fishers' income strongly depends on shellfishing in all studied areas, our findings show that less fishing experience and lower engagement in fisher associations tend to increase the economic vulnerability of the fishers. The fishers' vulnerability decreases as the size of households increases, while fishers who pay a mortgage and who live in households with fewer active members tend to be more vulnerable. The findings also show that Galician shellfishers have developed a wide range of adaptation strategies to anticipate and respond to climate change impacts, namely harvesting pricier and more abundant species, reducing household expenses and increasing social involvement in shellfishery associations. Although the adaptive strategies have helped Galician fishers to deal with climate change impacts, several threats to the sustainability of shellfisheries remain, such as a decrease in the abundance of key native shellfish species, and a high dependence on public and private aid to ensure reasonable incomes for shellfisheries. These findings are of interest and relevance to other similar small-scale fisheries around the world facing similar climate change challenges.

Keywords: artisanal fisheries, climate change, vulnerability, social adaptation, Galicia, Spain

INTRODUCTION

It has been estimated that the average temperature has increased by 0.2°C per decade over the past 30 years and that by 2017, anthropogenic activities had led to an increase in temperature of 1.0°C relative to pre-industrial levels (IPBES, 2019). Recent climate change projections predict an increase in the average atmospheric and seawater temperatures as well as increases in the intensity, duration and frequency of heat waves and extreme events (Hoegh-Guldberg et al., 2018; Oliver et al., 2018). Extreme sea level events will become more frequent and more intense, leading to more coastal flooding and a shoreline retreat throughout the 21st century along sandy coasts (IPCC, 2021).

In the case of the Atlantic coast of Europe, predictions indicate an increase in the frequency and intensity of heat-waves and extreme precipitation that will modify coastal salinity (Carvalho et al., 2021), mainly affecting estuarine areas. Although total precipitation is expected to decrease in the December-February period (IPCC 2021 Regional fact sheet - Europe), predictions suggest that it is expected to increase in the most recent IPCC report on the NW Iberian Peninsula, (IPCC WGI Interactive Atlas, https://interactive-atlas.ipcc.ch). All of these predicted changes will alter terrestrial and marine ecosystems, modifying community structure and functioning in addition to causing loss of biodiversity and livelihoods (Hawkins et al., 2009; Selden and Pinsky, 2019). This is especially true in coastal areas that are exposed to the impact of both climate change-related stressors and human activities (He and Silliman, 2019). In particular, intertidal fishing beds in estuarine areas are considered among the ecosystems expected to be most affected by the effects of increases in temperature, decreases in salinity, inorganic and organic inputs, and changes in sediment dynamics and currents, among many other stressors (Mieszkowska et al., 2013).

Research is increasingly considered key to understanding the climate change adaptation practices developed and adopted by fishing communities (Shaffrill et al., 2017). In adaptation processes there is a high degree of interdependence between the various agents involved, the institutions in which they are based, and the fishery resources on which they depend (Adger et al., 2009). Adaptation processes involve the interdependence of agents through their relationships with each other, with the institutions in which they are based, and with the fishery resources on which they depend (Adger et al., 2009). There is an urgent need to understand the social-ecological processes of adaptation strategies of the various agents of change – individuals, groups and markets – to anticipate their limitations (Adger, 2010).

While adaptation in human systems is defined as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2019), adaptive capacity has been broadly defined as the conditions that underpin people's ability to anticipate and respond to change, to recover from and to minimize the consequences of change and, if possible, to take advantages of new opportunities (Smit and Wandel, 2006). Understanding the vulnerability and resilience (including social aspects) is important for the sustainability of SSFs (Folke, 2006). This could help both the scientific community and policy makers to minimize the underlying causes of social vulnerability, when dealing with social-ecological shocks and crises (Cinner et al., 2012; Villasante et al., 2021; Villasante et al., 2022).

The need to support the role of SSFs in livelihoods and food security has been recognized in various countries through adoption of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO, 2015). More recently, the United Nations launched the Decade of Ocean Science for Sustainable Development, which is expected to shed more light on the need to manage fisheries sustainably in order to support community well-being and food security (Claudet et al., 2020).

The socio-economic situation of fishers is closely related to the effects of the changing climate (Da Rocha et al., 2014), as more unpredictable or insufficient income can limit fishers' abilities to deal with impacts, such as decreasing stocks (Cinner et al., 2012; Barnes et al., 2020). Recent reviews on how marine systems and fisheries adapt to the impacts of climate change highlight the lack of examples of specific adaptation actions and measures (Miller et al., 2018). In this context, SSFs remain largely overlooked in the scientific literature (Hanich et al., 2018). Several studies have been conducted to analyze adaptation to climate change in SSFs. For example, Monirul Islam et al. (2014) examined limits and barriers in relation to restriction of fishing activities to cyclones in Bangladesh. They authors found that the limits include physical characteristics of climate and sea such as higher frequency and duration of cyclones and hidden sandbars, while barriers include, among others, inaccurate weather forecast, technologically poor boats, lack of access to credit and markets, low incomes, lack of livelihood alternatives and poor enforcement of fishing regulations. Frawley et al. (2019) also investigated the heterogeneous perceptions of social-ecological change among small-scale fishers in the central Gulf of California, and they concluded that gear ownership and target species diversification were key factors in determining the cultural models through which fishers responded to changes in the resource system. More recently, Green et al. (2021) conducted a meta-analysis to evaluate how responses to climate, environmental, and social change are influenced by domains of adaptive capacity in SSF of 20 countries, and founded that adaptive responses at the community level only occurred when the community had access to assets, in combination with other domains including diversity and flexibility, learning and knowledge, and natural capital. Galappaththi et al. (2021) also analyzed how fisheries-dependent indigenous communities respond and adapt to climate change impacts in Canada and Sri Lanka. The authors found that diversification and co-adaptive capacity were the key common main strategies adopted by artisanal fishers in indigenous communities. Finally, Gianelli et al. (2021) analyzed changes in a warming hotspot and the associated impacts on the clam fishery in Uruguay. Given the data-poor situation of most SSFs in developing countries often hinders a proper dimensioning of the extent of climate-induced changes, the study combined scientific and local ecological knowledge and found that the combination of autonomous adaptations and government-led adaptations were essential to face the challenges imposed by climate change.

Although previous studies have provided recommendations for climate change adaptation in a range of communities, few, if any, of these have focused on social adaptation in fishing groups or communities. Therefore, evidence and a better understanding of adaptation strategies for dealing with the changing climate are crucial from a policy-making perspective (Shaffrill et al., 2017).

The situation of the bivalve fisheries in Galicia (NW Spain) is representative because it is one of the most significant fishing resources in Europe in terms of landings (FAO, 2018) and, more importantly, in terms of local-scale socio-economics (Macho et al., 2013). The most important species in these fisheries are the native pullet carpet shell *Venerupis corrugata* (Gmelin 1791) and grooved carpet shell *Ruditapes decussatus* (Linnaeus 1758), the introduced Manila clam *Ruditapes philippinarum* (Adams and Reeve, 1850), and the native cockle *Cerastoderma edule* (Linnaeus 1758). These four species support the largest artisanal fishery in Spain in terms of landings and employment (~7,9 Tm of bivalves worth ~74 millions of euros and ~7,100 fishers in 2019) (www.pescadegalicia.com, accessed January 2020). However, these fisheries experience large spatial and temporal variations in catches (Juanes et al., 2012) that have been associated with strong fluctuations in environmental conditions such as temperature and salinity (Parada and Molares, 2008; Parada et al., 2012; Aranguren et al., 2014; Verdelhos et al., 2015).

Rights-based regulatory regimes, under which most of the Galician shellfishing is managed (Pita et al., 2019), seem to be relatively resilient to the consequences of climate change (Ojea et al., 2017). Nevertheless, the threats are numerous and growing. Variations in temperature and/or salinity, even within the limits of tolerance of each species, can constrain most physiological processes, such as growth and reproduction (Macho et al., 2016; Peteiro et al., 2018; Domínguez et al., 2020; Domínguez et al., 2021; Vázquez et al., 2021), and also behavior (Woodin et al., 2020). The associated constraints may lead to a recruitment failure in adult populations or delays in the time required for the species to reach commercial sizes. Future climate scenarios in Galicia predict an increase in atmospheric temperature above the world average and also an increase in the frequency and duration of extreme temperature events (Bode et al., 2009). However, no clear trends in precipitation have been observed annually (Gómez-Gesteira et al., 2011), although the average intensity of rainfall events has been projected to increase in winter and spring (Cardoso Pereira et al., 2020).

Although social and sanitary improvements can help mitigate the effects, increasingly intense heat-waves will negatively affect the health of the Galician population, especially during the summer (DeCastro et al., 2011). Summer humidity levels have also increased, and are expected to increase further, reducing outdoor comfort conditions, especially for women, who may be more sensitive to such changes (Orosa et al., 2014). Therefore, the increases in heat and humidity are expected to have strong impacts on shellfishing, which is mainly carried out by women in Galicia (Frangoudes et al., 2008; Frangoudes et al., 2013; Villasante et al., 2021). Moreover, many intertidal fishing beds are at a high risk of flooding, which will have severe effects on different bivalve populations and on the people who depend on their capture through the entire value chain (Toubes et al., 2017).

Although the Galician population perceives climate change as a major problem and shows a willingness to address it through active policies (Arcos et al., 2011), there is relatively little evidence about the social and economic consequences of climate change, or about the ecological implications of these impacts. Available evidence on the economic impacts of climate change in coastal activities of Galician coasts includes the increase of the number of large cargo ports (León-Mateos et al., 2021) and increased tourism (Toubes et al., 2017). The socioeconomic vulnerability of some fisheries, e.g. the European pilchard *Sardina pilchardus* (Walbaum, 1792) (Pérez Muñuzuri et al., 2009; Da Rocha et al., 2014), and even some SSFs like the goose barnacle *Pollicipes pollicipes* (Gmelin, 1789) (Ruiz-Díaz et al., 2020), have also been evaluated, leading to the development of adaptation strategies. However, there is a widespread lack of attention in climate change research to many components of social-ecological systems (hereinafter SES) related to Galician SSFs, especially regarding synergies and trade-offs between socio-cultural and ecological domains (Salgueiro-Otero and Ojea, 2020; Villasante et al., 2021). The historical closeness between the Galician population and fishery resources has been able to promote strong integration of the shellfishery sector into the Galician social norms and cultural traditions-, as already observed in other regions that are highly dependent on fishing activities, such as Bretagne and the Basque Country (Villasante et al., 2021).

Despite the increasing interest in the impacts of climate change in Galician SSF (including shellfisheries), economic vulnerability and social-ecological adaptation strategies are still largely unknown. This present study addresses this research gap. The specific aims of the study were twofold: (1) to estimate the economic vulnerability of shellfishers, and (2) to assess the diversity of social adaptive responses used by shellfisheries to deal with climate change. This research will contribute to providing information about the multiple strategies that enable or hinder potential solutions towards sustainable SSF.

MATERIALS AND METHODS

Study Area

The study area, Rías Baixas, is located NW in the Iberian Peninsula between 42°30 and 42°15 N and 8°45 and 8°56 W (**Figure 1**). The rias are partially mixed estuaries with a mesotidal

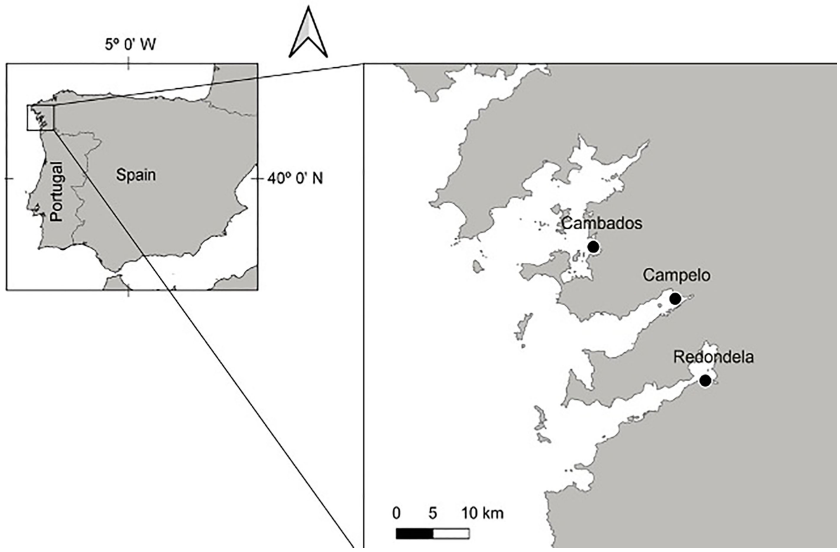

FIGURE 1 | Map of the Galician rias, highlighting the location of Cambados, Campelo and Redondela fishing guilds.

and semidiurnal regime. The hydrography in the inner part of the rías, where the fishing beds are located, is driven by two opposing processes: a continental water supply *via* the main rivers Umia and Ulla in the Ría de Arousa, Lérez in the Ría de Pontevedra and Oitavén-Verdugo in the Ría de Vigo (the mean freshwater input ranges between 20 and 26 m^3 s^{-1}, Costa et al., 2012), and an oceanic influence *via* upwelling of East North Atlantic Central Water in summer and the influence of the Iberian Poleward Current in winter (Prego et al., 2001). Important fluctuations in temperature and salinity occur as a result of these hydrographic conditions (Alvarez et al., 2005; Costa et al., 2012).

This region was chosen for study on the basis of socioeconomic and fishing aspects in order to compare the profile, economic vulnerability and fishers' adaptation strategies in different locations. We worked with three shellfishery associations, Cambados, Campelo and Redondela, which operate in the main shellfishing region in Spain and Europe (**Figure 1**). The shellfish beds exploited by these associations are located in areas where fishers must adapt their activities to the particular oceanographic conditions (temperature, current, salinity). Thus, the shellfish beds situated in the mouth of the cited rivers are more exposed than other areas to the effects of climate change in winter, because of heavy rains in winter, which cause acute decreases in salinity and because of exposure to the sun at low tide during heat-waves in summer. From a socioeconomic perspective, the three locations are strongly dependent on fishing activities, and the shellfish products are recognized as high quality, both nationally and internationally. However, the organization of the fishers' activities differ among shellfishery associations, due to their different business strategies, productive specialization and different market segmentation.

In order to prevent the overexploitation of the shellfish beds, the Spanish Regional Government limits the catches of fishers by implementing daily quotas. Thus, the fishers' incomes depend on their individual work (number of captures with the maximum daily quota) valued at the market price each day (Macho et al., 2013). The effectiveness of the extractions depends on each fisher's strategy, but also on the biophysical conditions of the environment and the organizational strategies developed by members of shellfishery associations (Villasante et al., 2021). In some associations, collaboration is usually generated almost spontaneously, while in others opportunistic behaviour is more frequent, conditioning the final performance of shellfishers. In this sense, collaboration between fishers belonging to shellfish associations has a multiplying effect, as these organizations have close links with suppliers, purification plants, restaurants and the canning industry. However, failure in adaptation to climate change can affect the economic productivity of the whole sector, and could also lead to the overexploitation and future depletion of resources, with potentially severe socio-economic consequences on vulnerable fishers' families.

Data Collection

We designed a semi-structured questionnaire to investigate the economic vulnerability and adaptation strategies used by fishers. The data were collected by the co-authors of this study between May- and July 2019 at the locations of the three shellfishery associations. The content of the questionnaire protocol was structured in four parts to collect information on key topics related to the impacts of climate change on shellfisheries (see the questionnaire in detail at Appendix I of the **Supplementary Material**):

-Part A (*Personal information and knowledge about shellfisheries*): Each interview began with questions to obtain information about years of experience working as shellfishers, and age, residence, education, occupation, household composition, income from shellfisheries, dependency on public and private aid, and main commercialized commercial species fished;

-Part B (*Adaptive strategies to deal with climate change*): shellfishers were also asked to indicate their perception of (a) biological changes in key attributes of species (e.g. mortality, length, abundance, presence of invasive species, etc.), on (b) which factors improved or worsened during the last decade (e.g. status of shellfisheries resources, contamination, organizational changes of associations, red tides, ex-vessel prices, etc.), and (c) the strategies developed by the shellfishers and their families;

-Part C (*Climate change impacts and future scenarios*): the interviewees were asked their opinion about predictions, suggesting that abundance of shellfisheries (except the Manila clam) will decrease in the near future (Domínguez et al., 2020; Domínguez et al., 2021; Vázquez et al., 2021), and what fishers would do if these predictions come true;

-Part E (*General opinion*): the interview concluded with an open, and general question to determine what other changes and/or measures could help to reduce the impacts of climate change on shellfisheries.

The questionnaire was designed in a multiple choice format with a five-point (Likert) response scale. We also designed a protocol that guided the data collection and the general procedures and rules of use, following Yin (2014). Researchers collected internal data from fishers through face to face meetings in the offices of the fishers´ associations. The researchers provided the interviewees with: (1) an initial explanation of the general purpose of the project and its academic and professional applications and (2) a copy of the questionnaire designed to investigate climate change impacts on shellfishing activities and social adaptive strategies developed by fishers. The researchers supported the interviewees by providing any clarifications required and controlled the researcher-bias during the data collection process. Fishers were randomly selected from a complete list of the members of each association previously identified by their leaders using the purposive sampling method (selection of a simple random sample from the sampling frame of each previously identified association) (Marshall, 1996; Agresti and Finaly, 2014). The participants have been selected ensuring a diverse representation of shellfishers of different ages (young and older), years of experience in roles (e.g. President, Secretary, etc.), and activity (e.g. shellfishing, seabed cleaning, surveillance, etc.) within the associations. Hence, our results should be interpreted as indicative of these areas, rather than of all fishers.

Researchers involved in the data collection process maintained the chain of evidence, following the sequence of selection of the sample, initial information and data collection. This allowed us to reconstruct the context in which the evidence was obtained (Villarreal, 2017). After the data collection phase, we classified the data, constructed a database and analyzed these data using the rules of validity, reliability and consistency recommended by Yin (2014).

Defining Fishers' Economic Vulnerability and Adaptive Responses to Climate Change

Small-scale fishers are considered among the most vulnerable socio-economic groups owing to their high exposure to certain natural, health-related and economic risks and shocks (Bennett, 2009; Silva et al., 2019). Consideration of this status provides a useful starting point for analyzing vulnerability in fishers' livelihoods, including economic vulnerability. Vulnerability can be assessed through a combination of exposure and sensitivity that represent the susceptibility to harm from a given environmental change, and the ability to cope with this change through learning (Bennet et al., 2016). Vulnerability is difficult to assess due to its complexity and context-specific nature, however, carrying out vulnerability assessments at the local level may help because this is the level where impacts are generally felt (Hinkel, 2011).

Fishers' economic vulnerability was calculated on the basis of four variables: 1) capture of the daily quota, 2) trends in income in the last 10 years, 3) trends in income considering future climate change scenarios, and 4) the minimum income leading to abandonment of shellfisheries. The variables used to estimate the economic vulnerability of fishers are summarized in **Table 1**, along with the qualitative approach used to score each variable. The summed value of those four variables was used to create an individual index of economic vulnerability, ranging from 0 (lower vulnerability) to four (higher vulnerability). The economic vulnerability increased with the value of the index.

Following the definition of the variables, the diversity of adaptive responses was identified on the basis of five adaptation situations regarding regime shifts in the shellfishery (e.g. capture of daily quota, social-ecological changes, decreasing income scenario, and abandonment of shellfishing activity). Thus, one point was awarded for each individual who chose at least one adaptation strategy in each of the five situations (see **Table 2**), and the average value was considered used as the diversity of adaptive responses. By contrast, if a fisher did not choose any strategy, no points were awarded.

Fishers were asked about the strategies used to adapt to the impacts of climate change, which included capture of daily quotas, social-ecological changes, decreasing income, and being forced to abandon shellfishing. The fishers were asked about what they would do if they were forced to abandon shellfisheries, with options including changing to another fishing activity or to a different occupation. Fishers could choose among adaptation strategies in each situation, and they could choose more than one option (**Table 2**).

Statistical Analyses

To analyze differences in socioeconomic and fishing aspects among the study areas, non-parametric tests were performed (Neter et al., 1996). Specifically, the Kruskal-Wallis was used with Bonferroni test and Chi-square test to check for any differences in fishers' age, fishers' experience, the household size, the number of household members employed, education level, fisher and

TABLE 1 | Description of the variables used to estimate fishers' economic vulnerability.

Variable	Description	Scores
Capture of daily quota	When fishers do not catch their daily quota their earning capacity decreases (Lucchetti et al., 2014). This limited economic benefit may be seen as making it difficult for fishers to subsiste and increases their economic vulnerability.	Capture daily quota = 0 points (not vulnerable) Do not catch daily quota = 1 point (vulnerable)
Historic income trends	Fishers are socio-economically very vulnerable due to the environmental changes in coastal areas (Bhashani et al., 2021). This leads to the degradation of the local economy and further affects the earnings of many fishers. Here, fishers' classified trends in historic income trends based on the last 10 years as decreasing, no change and increasing. Considering that decreasing trends or no change in income may be associated with economic vulnerability, a score ranging from 0 (no economic vulnerability) to 1 (economic vulnerability) was associated with this quantitative categorization.	Increasing trend = 0 points No change = 0.3 points Decreasing trend = 1 point
Income change due to regime shifts	Regime shifts may influence variation in seasonality of landings due to changes in fish stocks (Barange et al., 2018; Ma et al., 2019). Uncertainty in catch rates may lead to a decrease in the fishing income (Sumaila et al., 2011), increasing the economic vulnerability of fishers. This variable was thus classified in the same way as the previous one, with scores ranging from 0 (no economic vulnerability - increasing trend) to 1 (economic vulnerability - decreasing trend).	Increasing trend = 0 points No change = 0.3 points Decreasing trend = 1 point
Minimum income leading to abandonment of shellfisheries	The three areas were classified on the basis of the lowest income cited by fishers enabling them to remain in the shellfishery sector, and on the minimum wage in Spain for the period of 2017 (ReICAZ, 2017; www.reicaz.es). The minimum wage in 2017 was 707 € and the minimum income forcing fishers to abandon shellfisheries in Cambados, Redondela and Campelo was respectively 548 €, 438 €, and 606 €. Thus, Redondela showed the highest economic vulnerability, Cambados moderate economic vulnerability and Campelo the lowest economic vulnerability.	Redondela = 1 point (high vulnerability) Cambados = 0.6 points (moderate vulnerability) Campelo = 0.3 points (low vulnerability)

Source: own data.

household shellfisheries dependencies, income trends, and daily limit achievement between the three areas. Fisher's exact test was used for small sample sizes, including zero values, as the Chi-square test is generally used for larger counts (Larntz, 1978).

Linear Mixed-Effect Models (LMMs) were used to analyze the influence of socioeconomic aspects (independent variables) on the diversity of adaptive response of fishers (dependent variable). The independent variables used were levels of income dependency on shellfishing (<50% of income, between 50% and 75% of income, and >75% of income), fishers' age, size of household, fishers' educational level, social involvement in shellfishery associations (yes = involved; no = not involved), public and/or private financial assistance, and the economic vulnerability of the fishers. The LMM allows the inclusion of random effects, which may explain a potential source of variation on the response variable (Pinheiro and Bates, 2000). Thus, the variable area, i.e. shellfishery association, was included as a random effect to prevent remaining variation due to particular site-related factors. The collinearity between explanatory variables was evaluated using the Variance Inflation Factor (VIF), which indicated low correlation between the predictors; variables with VIF < 5 were included in the final model.

Following model selection, a model averaging approach based on a subset of competing models with a cumulated weight of 95% (Burnham and Anderson, 2002) was applied to LMMs (**Appendix 2**). This procedure was used because the differences between models in the model selection procedure were small. Model averaging analysis allows examination of the relative importance values (I) of variables, which vary from zero (less important) to one (more important). This indicates the effect size of relevant variables explaining the diversity of adaptive responses of fishers in the averaged model.

Variables were checked for homogeneity of variance (Shapiro-Wilk normality test) and explanatory variables were z-standardized to allow comparisons between effect sizes. All analyses were carried out using R software (R Core Team, 2018),

FIGURE 2 | Images of **(A)** women harvesting on foot in shellfish beds located in the Galician "rias", **(B)** the rake-like fishing gear called "raño", and **(C)** the most common shellfish species manila clam, cockle, grooved carpet shell, and pullet carpet shell.

the 'lme4' package was used to fit the LMM (Bates et al., 2015), and the 'MuMIn' package was used for model averaging (Barton, 2013).

RESULTS

Fishers' Profile

We interviewed 245 shellfishers in three areas in Galicia: Cambados (N = 65; 32% of all shellfishers), Campelo (N = 125; 54%) and Redondela (N = 55; 43%) (**Figures 2A–C**). The majority of the fishers were women, only 8% of fishers were men (which is consistent with the gender distribution in the shellfishing population). The fishers were between 26 and 65 years old (48 ± 9 years), with an average fishing experience of 13 years (± 12 years).

The age of fishers differed between areas (KW=6.274, df = 2, p= 0.04); fishers in Cambados were older than those in Campelo and Redondela. However, despite the differences in age, fishers from the three areas had the same fishing experience (μ = 13.47 years). The size of households including fishers was around 3.5 members, with the average number of active members around 1.5 members. Less than half of employed members were involved in fishing activities in the three areas: 25% in Cambados, 23% in Campelo and 31% in Redondela (**Table 3**). Educational level was similar in the three areas; fishers had an average of 14 years of education. In all three areas, most fishers did not participate in shellfishery associations. The household size (KW=0.216, df = 2, p= 0.89), the number of employed members per household (KW=3.426, df = 2, p= 0.18), and fishers' educational level (Chi-squared=7.416, p=0.29) were similar in the three study areas.

The proportion of fishers who had a mortgage was about 50% in Campelo, about 34% in Cambados and 25% in Redondela. More fishers in Redondela (52%) received at least one month of economic aid (social security benefit) from the government in the last ten years, followed by the fishers in Campelo (50%) and Cambados (41%). The most important target shellfish species were Manila clams and cockles, which represented more than half of landings in the studied areas (**Table 3**). Regarding the trend in abundance of bivalve species, the findings of the study revealed the perception of an increased abundance of all four species in the last ten years by the Cambados shellfishery association. In particular, the Manila clam (*R. philippinarum*) is more abundant than the rest of the other key commercial species (**Figure 3**).

Individual fishers' dependency on income from shellfishing was similar among areas; fishers from the three areas earned more than 75% of their income from shellfisheries (**Figure 4A**). On the other hand, households' dependency on shellfishery was

TABLE 2 | Situations and adaptation strategies cited by fishers in each study area: Cambados, Campelo and Redondela.

Situation/adaptation strategies	Area			Citations (total)
	Cambados	Campelo	Redondela	
Daily catch limit achievement				
Focus on higher value species	**3**	**23**	14	40
Focus on more abundant species	2	18	**21**	**41**
Focus on species easier to catch	2	16	11	29
Other strategies	3	1	0	4
No strategy/No answer	5	17	17	39
Social-ecological changes – Fishers				
Other formal activity	6	13	7	26
Informal activity	2	16	6	24
Greater social involvement	22	17	13	52
Lower social involvement	2	2	5	9
Reduction of household expenses	**24**	**33**	**24**	**61**
Increase household expenses	1	7	3	11
Other strategies	1	2	0	3
No strategy/No answer	6	9	1	16
Social-ecological changes – Family				
Abandonment of children's further studies	0	1	0	1
Incorporation of children in shellfisheries	2	4	1	7
Incorporation of husband/wife in shellfisheries	0	1	**2**	3
Family or public financial assistance	1	**17**	**2**	**20**
Loans	**5**	13	1	19
Migration	1	2	0	3
Other strategies	5	4	4	13
No strategy/No answer	10	11	17	38
Decreasing income scenario				
Keep working on shellfisheries	**26**	11	**11**	**48**
Change target species	15	7	10	32
Change to another fishing activity	4	3	4	11
Change to a different occupation	1	**16**	7	24
Migration	0	4	1	5
Other strategies	0	0	6	6
No strategy/No answer	2	3	1	6
Forced to abandon shellfishing activity				
Change to another fishing activity	11	11	5	27
Change to a different occupation	12	**25**	**17**	**54**
Other strategies	**14**	3	4	21
No strategy/No answer	12	3	0	15

The cited strategies were divided among the five situations of adaptation to capture of daily quota, social-ecological changes, decreasing income, and forced to abandon shellfishing. The most commonly cited strategies are highlighted in bold.

different between areas: dependency on shellfishing was highest in households in Redondela (less than 50%), followed by those in Campelo and Cambados (Chi-square=9.932, df = 4, p= 0.04, **Figure 4B**). Fishers' economic vulnerability ranged from 0.3 to 3.6 (μ = 1.96); the mean score was lowest for Cambados (1.69), followed by Campelo (2.20) and Redondela (2.07). Fishers in Campelo were more vulnerable than fishers in Cambados and Redondela (KW = 10.18, df = 2, p-value = 0.006).

Captures of the daily quota also differed between shellfisheries (Chi-square =28.8, df = 2, p= 0.00, **Figure 4C**); fishers in Redondela tended to not capture the full daily quota. The fishers in Cambados explained that their income had increased in the last 10 years, but fishers in Campelo and Redondela perceived that their income had decreased, or it had not changed (Chi-square =66.56, df = 2, p= 0.00, **Figure 4D**). This was mainly due to the increasing abundance of Manila clam and pullet carpet shell in Cambados, relative to the other shellfisheries. In addition, most fishers in the three areas anticipated that their income would decrease due to the impacts of climate change on the shellfishery system (**Figure 4E**).

The Diversity of Adaptive Responses to Climate Change

In general, fishers tended to focus on catching more abundant species when they did not capture their full daily quota. When asked about social-ecological changes, fishers tended to reduce household expenses and to ask for family or public financial aid. In a scenario of decreasing income, most fishers answered that they would keep working in shellfisheries. However, some fishers suggested other strategies to deal with the lower-income situation: to apply for government aid, to catch new species, to find a better job or to retire.

More than 50% of fishers in Campelo and Redondela declared they would abandon shellfisheries if their income decreased. Fishers would abandon shellfisheries if income decreased to average values of 548 € in Cambados (minimum 300 €/maximum 800 €),

TABLE 3 | Socioeconomic and fishery aspects of shellfisheries in three study areas in Galicia: Cambados, Campelo, and Redondela. N, number of fishers; μ, Mean; ±, standard deviation. Main species landing = percentage of landing species (on foot + on boat).

Socioeconomic and shellfishery aspects	Fishing Guilds		
	Cambados (N=65)	Campelo (N=125)	Redondela (N=55)
Age (μ years)	51 (± 8.3)	46 (± 9.2)	48 (± 8.8)
Schooling (μ years)	18 (± 2.8)	14 (± 2.6)	15 (± 2.8)
Fishing experience (μ years)	15 (± 10)	11 (± 12.7)	15 (± 14.6)
Number of people per household	3.4	3.5	3.5
Number of household members employed	1.3	1.6	2
Participation in shellfishery association (%)	20	2	17
Mortgage payment (%)	34	52	24
Social security benefits[a] (%)	41	50	52
Main species landing (%)	*Manila clam (41)*	*Cockle (36)*	*Manila clam (40)*
	Cockle (28)	*Manila clam (26)*	*Cockle (35)*
	Grooved carpet shell (18)	*Pullet carpet shell (22)*	*Pullet carpet shell (18)*
	Pullet carpet shell (12)	*Grooved carpet shell (16)*	*Grooved carpet shell (8)*

[a]*Social security benefit was calculated on the basis of the average value of the total number of months during which fishers received public assistance during the last 10 years. For the three areas, the median value was around one month. Thus, we considered one month as key assistance to the fishers for this region.*

606 € in Campelo (minimum 300 €/maximum 1000 €) and 438 € in Redondela (minimum 200 €/maximum 700 €). In addition to an unprofitable situation, fishers would abandon shellfishery activities due to illness, retirement or better job opportunities. The alternative occupations cited by the fishers if they had to abandon shellfisheries were similar between areas, with construction, teaching, politics, nursery, agriculture and tourism being the most common alternatives. In addition, fishers from the three areas cited economic issues and lack of education as important in regard to starting a new activity if they were forced to abandon the shellfisheries. Social-ecological aspects, such as the status of fishing resources, ecosystem conditions and management issues, were cited as main needs only in Campelo and Redondela.

The average LMM explained around 45% of the variation in the diversity of adaptive responses of fishers, and included area as a random effect, fishers' economic vulnerability, age and dependency on shellfishery income as the most important

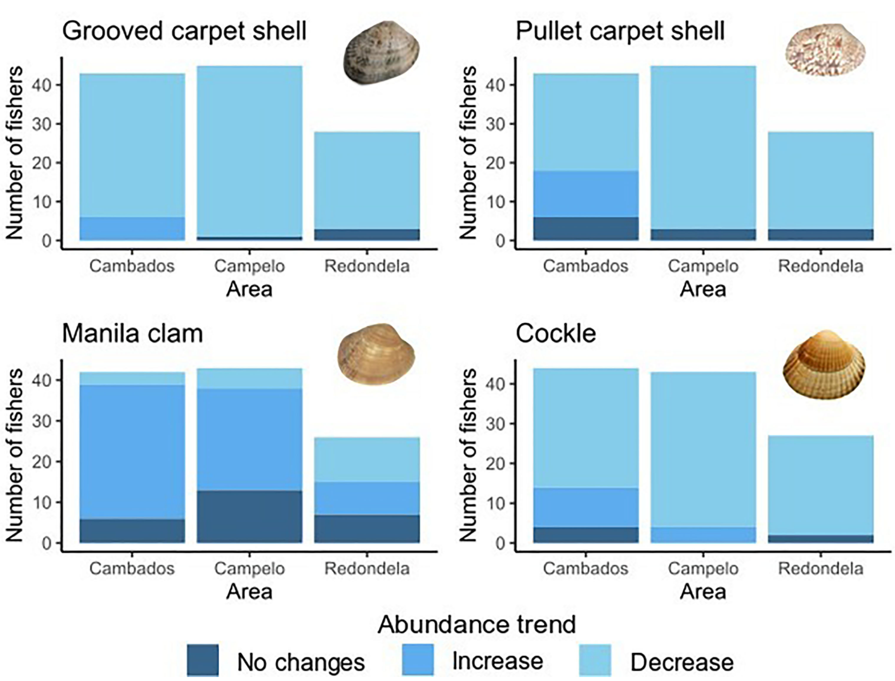

FIGURE 3 | Fishers' perceptions about the abundance of key commercial shellfish species.

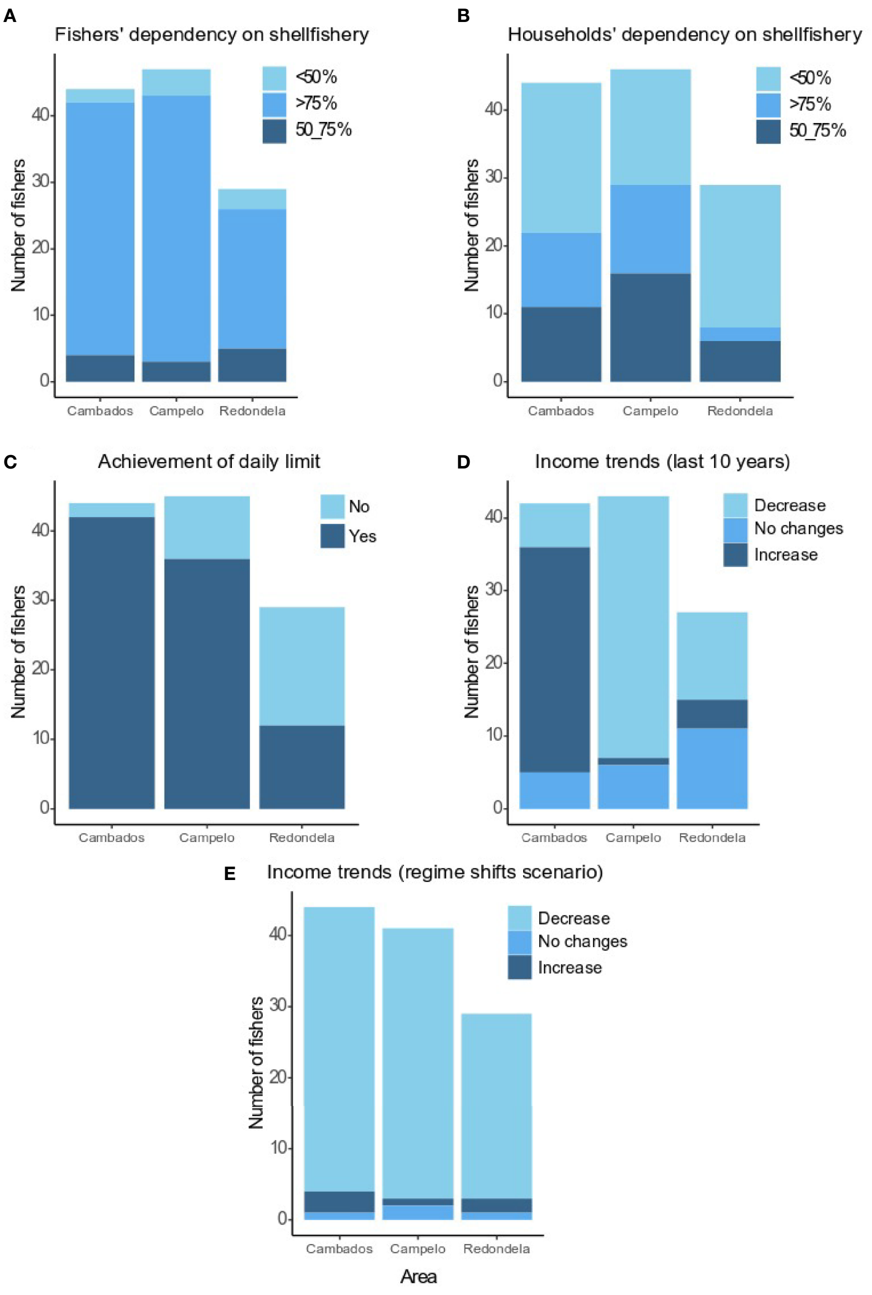

FIGURE 4 | Shellfishery dependency on **(A)** fishers and **(B)** households, and fishers' perceptions on **(C)** the capture of daily quota, **(D)** income trends (in the last 10 years), and **(E)** consideration of future climate change scenarios by area.

explanatory variables (**Figures 5A, B**). Higher economic vulnerability was associated with higher adaptation (p-value = 0.03, **Figure 6B**). The age of the fishers was inversely related to adaptation (p-value = 0.02, **Figure 6A**). Fishers who were more dependent on shellfisheries, earning more than 75% of income from shellfisheries (p-value = 0.00, **Figure 6C**) and fishers from Cambados (p-value = 0.00, **Figure 6D**), were less adaptable to changes in their social-ecological systems. Social involvement, household size, financial assistance and fishers' educational level were not significant explanatory variables in regards to the diversity of adaptive responses of fishers.

DISCUSSION

The effects on fisheries of observed and expected changes in climate are usually spatially and socially differentiated. Individuals and groups have faced risks of climatic hazards and other

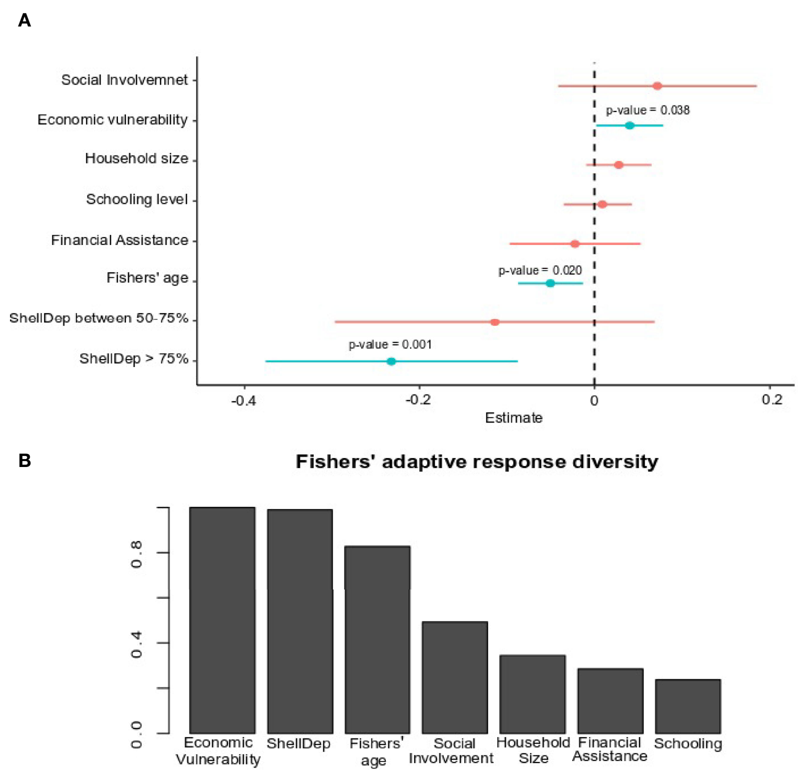

FIGURE 5 | **(A)** Coefficient estimates (± 95% CIs) showing the magnitude and direction of effects of predictors on the diversity of adaptive responses of fishers, **(B)** bar chart showing variable importance scores for the effect of each predictor. The score varies from zero (less important) to one (more important). ShellDep between 50 - 75% denotes that dependency on income from shellfisheries is between 50% and 75%, ShellDep >75% denotes that dependency on income from shellfishing is higher than 75%. Significant variables are shown in blue. Non-significant variables are indicated in red.

anthropogenic factors and they have historically been able to adapt and will continue to do so as climate is part of the wider environmental seascape of coastal development. Furthermore, human vulnerability to climate change may act as a driver for adaptive management of fishery resources (Adger, 2010).

In this section we discuss the most plausible reasons for the economic vulnerability and social adaptation strategies to further advance understanding of fishers' responses to tackle impacts of climate change.

Fishers Are Highly Dependent on Shellfishing, But Also Vulnerable Depending on Financial Assistance, Experience and Size of Households

Our first key finding was the strong dependence of the fishers on shellfishing in the three study areas (Cambados, Campelo and Redondela), as fishers earned more than 75% of their monthly income from shellfishing. However, fishers depended on obtaining private loans and public financial assistance from the regional government when income from shellfish harvesting was not sufficient for subsistence.

The study findings also demonstrated that higher economic vulnerability was closely correlated with less fishing experience and the size of households. This is consistent with the findings reported by Barnes et al. (2020), who found that past experience was positively associated with willingness to develop adaptation strategies. Fishers with a long experience in working in shellfisheries have had to deal with different situations in the past, developing a diverse portfolio of solutions in their social-ecological memory. This greater vulnerability of the harvesters with less experience could discourage young people from engaging in shellfishing. As supported by the FAO (2015) in Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries, promoting government measures to economically incentivize the engagement of new people in fishing (shellfishing) activities must be highly prioritized, not only to facilitate the social-ecological memory and traditional knowledge through the current and future generations, but also to maintain the young population in coastal communities within the context of few labour opportunities.

Furthermore, lower economic vulnerability was related to a greater number of households members, because diversifying incomes from other activities (namely from small-scale and industrial fishing sectors) helped in the adaptation to climate change. Indeed, the rest of the household members generally provided complementary income from other public sources of income (e.g. public pensions for retirement, etc.). This is consistent with the findings of Green et al. (2021), who conducted a global meta-analysis to analyze impacts of climate

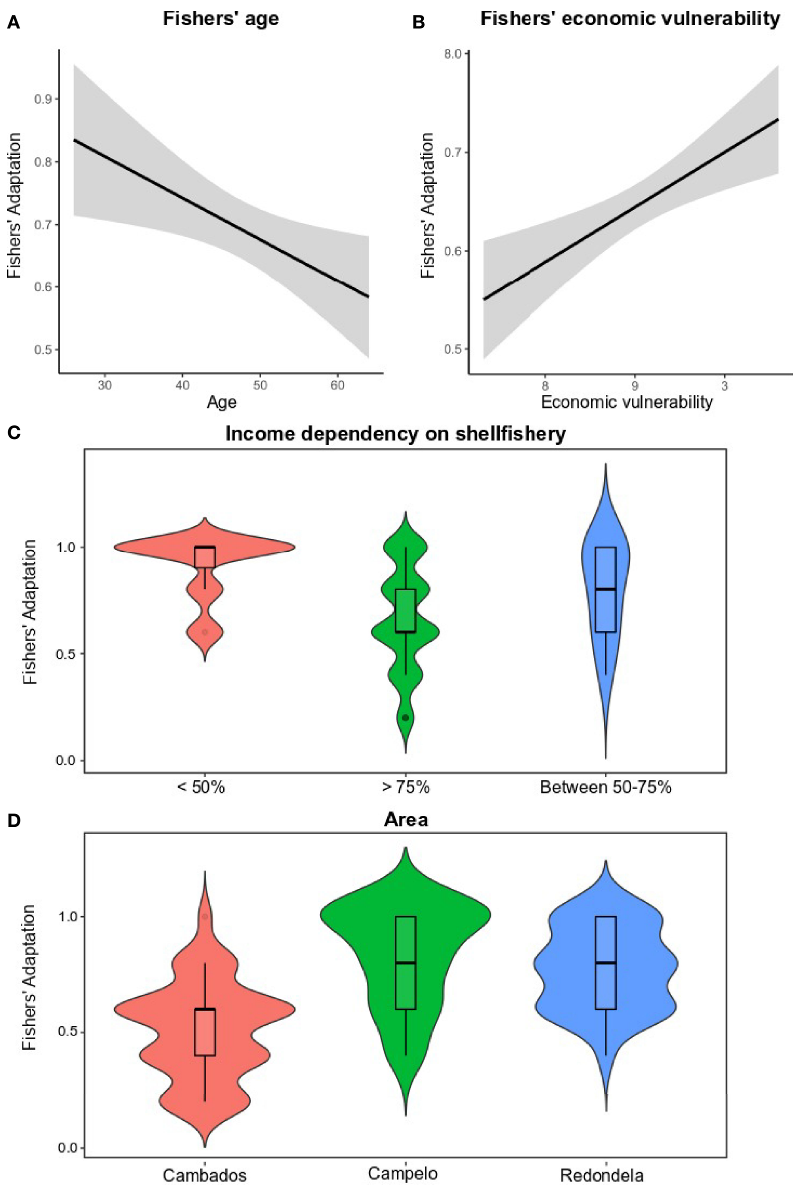

FIGURE 6 | Predictor effect of the variables from the averaged model to the fishers' adaptation to regime shifts: **(A)** fishers' age, **(B)** fishers' economic vulnerability, **(C)** dependency on income from shellfishing, and **(D)** area (area where fishing takes place).

change in SSFa and found that diversification of income was one of the key factors involved in developing diverse adaptive responses. However, in the case of Galician shellfishers, greater diversification of activities would not necessarily improve the status of fishers, given that once a certain economic threshold was reached, the fishers would be able to abandon shellfishing.

Our modelling results also predicted that economic vulnerability would be highest amongst shellfishers who were not involved in the associations. In general, our research shows that fishers perceived an improvement in the organization of their shellfishers associations. A higher involvement in the organization of shellfishers' associations allowed for a greater exchange of information on the state of the natural banks and, ultimately, led to a better socialization of the impacts of climate change. Notably, shellfishers were aware of the stronger impact of diseases and deterioration of the natural environment and worse meteorological conditions in the ecosystems.

Realizing Economic Thresholds Helps to Develop More Effective Fisheries Management

Our second key finding was the empirical demonstration, for the first time, that shellfishers' incomes must be higher than 438-606

€ per month to maintain the activity and cover fixed costs. More experienced fishers stated that they would abandon the shellfisheries earlier, which may be linked to avoid loss of income (Marshall et al., 2013).

Nevertheless, more than half of shellfishers in the three areas indicated that they would not abandon the shellfish activity, indicating the deep cultural roots of this activity. The recent increase in the minimum salary in Spain (from 707,7 € in 2017 to 965 € in 2021) (Ministry of Labour and Social Economy, 2021) could change the perception of the fishers about the minimum income needed to maintain the activity. Taking into account the trend of future increases of minimum salary, abandonment of the fishery seems to be the most likely reaction in the medium term, considering the current quotas and trends of declining catches and abundance of most of commercial shellfish species (Pita et al., 2019; Domínguez et al., 2020; Domínguez et al., 2021; Vázquez et al., 2021).

Our result is important because management strategies that explicitly include thresholds and integrating them into fisheries management policies have been shown to be more effective in achieving public policy goals than strategies that do not consider explicit thresholds (Kelly et al., 2014). Identifying economic thresholds can be extremely useful to detect early signals of regime shifts, traps or collapses, which also help to create new windows of opportunities to successfully navigate into new desirable transitions and states of shellfisheries before tipping points are reached (Biggs et al., 2009). Investigating social and economic thresholds are key to better understanding the adaptability of shellfishers to deal with climate change (Adger et al., 2009). However, it is important to highlight that limits to adaptation are endogenous in societal groups and hence also contingent on values, knowledge, attitudes to risk, ethics, and local culture, which can change over time (Adger, 2010; Villasante et al., 2021).

Fishers Adapt to Climate Change by Harvesting Available Species and Complementing Shellfisheries' Income With Other Activities

The third key finding provides evidence that adaptation strategies developed by Galician shellfishers tended to focus on harvesting the most abundant and economically valued species as the key measure to deal with climate change impacts. Our results also show that fishers adapted their individual behaviour to changes in environmental conditions by reducing household expenses and complementing shellfish with other formal or informal jobs to compensate for the economic losses. Both individual strategies would help to build resilience and adaptive capacity to deal not only climate change impacts, but also social-ecological shocks and crises such as the current COVID-19 pandemic, which has negatively impacted Galician shellfisheries by reducing their volume (-27%) and value of landings (-18%) (Villasante et al., 2021).

These results are consistent with those of Savo et al. (2017), who recently conducted a global meta-analysis of the observations of coastal subsistence-oriented fishers on climatic changes, and found that diversification is the most frequently reported adaptation strategy. At the most fundamental level, people select the available opportunities and options in relation to their personal skills and available or those that they can, afford or use.

Fishers Collectively Adapt to Climate Change by Increasing Their Involvement in Shellfishers Associations

The fourth key finding was the tendency of an increase in the social involvement of fishers in shellfishers associations. Our result is important because Galician shellfishers' associations have been experiencing a notable reduction in conflicts and mistrust between the administration and the shellfisheries sector, favouring consensus in most decisions concerning shellfishing activities (Pita et al., 2019; Villasante et al., 2021). The current co-management system in Galician shellfisheries entails the empowerment of fishers (especially women) (Pita et al., 2019), which occurs when sustainable management of the fishery resources becomes possible (Jentoft, 2005; Villasante et al., 2021)

Our result is also consistent with the fact that fishers' participation has been found to be a key pillar in a good governance system that renders social-ecological and environmental sustainability in other shellfisheries in Galicia (Aguión et al., 2022). Social trust and cooperation between agents, which are essential factors for a successful government of common resources (Ostrom, 2009), have been improved since fishers provide data and participate in monitoring programs and in designing exploitation plans.

People become empowered when they act together to form organizations and when they acquire rights and responsibilities in fisheries management (Jentoft, 2005). As Pomeroy and Viswanathan (2003) stated, successful co-management systems and meaningful partnerships can only occur when the fishing community is empowered and organized, and all participants can take advantage of short and long term benefits of cooperation. The awareness of the need for co-management leverages partner contributions, especially when the sense of urgency increases as a consequence of any crisis (Rey-García et al., 2019). Fishers who share common objectives, values, beliefs, and who trust in each other and in the group, have a better chance of realizing resilience and co-management (Grafton et al., 2019). Their adaptability to changing circumstances will be also greater because co-managers will be more willing to compromise with the group. This involvement facilitates capacity building to deal with the new challenges, reducing the cost of opportunistic behaviours (Jentoft, 2005).

Trust in specific measures adopted by the government may inhibit adaptive behaviour, which may put fishers at risk from climate-related hazards (Baan and Klijn, 2004). Given that co-management of fisheries also requires a wide range of expertise, experience and skills, Galician fishers would benefit from the social involvement in carrying out actions towards improving climate change planning and capacity building. This could translate into learning economies and provide opportunities for the members of fishing communities to put forward ideas and to adopt plans that are in line with local needs, abilities and interests (Wiseman et al., 2009).

Considering Local Fishers Knowledge Helps to Disentangle Social Adaptation Strategies

Another key result from our study is that local fishers and associations have been proactively confronting impacts of climate change. Our study contributes to giving an explicit consideration of fishers' views, perspectives and rights of local communities, their knowledge and understanding of ecosystems, and their desired future development pathways to deal with the impacts of climate change. In particular, this study highlighted that shellfishers in Galicia have also perceived increases in mortality of species, increased amounts of seaweeds on beaches and a greater presence of parasites in the intertidal zones.

When trying to adapt to these changes, our research showed (a) an increase in the medical sick leave from the beginning of shellfishing activity, (b) greater difficulties in obtaining shellfishing permits, (c) growing pressures from external poaching and (d) in some fishing guilds, an increase in the black market for shellfish. Fishers also demonstrated strong local environmental knowledge and awareness about the impacts of climate change on their activity, which is also consistent with previous research (Shaffrill et al., 2017; Pita et al., 2020). Our findings also showed that all fishers agreed with the expert opinion (Peteiro et al., 2018; Domínguez et al., 2020; Domínguez et al., 2021; Vázquez et al., 2021) about the new scenarios of climate change for the future of shellfish, and noted that these scenarios would be negative for their activity.

These findings contributed to show the diversity of responses led by local communities and the extent to which local knowledge-based measures may be transferable and beneficial across villages, cultures and environmental conditions (Forsyth, 2013). Successful adaptation to impacts of climate change are more likely when efforts are directed at promoting knowledge generation and the maintenance of different knowledge systems, including in the sciences and local knowledge, regarding shellfishing resources and their sustainable uses (IPBES, 2019).

Does Diversity of Adaptive Strategies Help to Build Social Resilience?

Socio-economic resilience of fishing communities refers to how they are able to maintain their livelihoods and desired ways of living, after undesirable shocks (Grafton, 2010). Adaptive fisheries management allows policy makers and the fisheries sector to be more effective *ex-post* in an increasingly uncertain world, while resilience provides guidance about how to manage fish stocks, ecosystems and people to adapt to undesirable shocks and crises *ex-ante* (Grafton et al., 2019).

Substantial management efforts are usually made to reverse undesirable changes, but most of these are very costly as they are implemented after shifts, traps or collapse take place, but not before them. Strategies that could be helpful in promoting resilience in a biophysical and socio-economic sense usually include lower rates of fishing mortality, larger exploitable biomass of targeted species, and increased 'no take' areas, which may provide a buffer stock in the face of unexpected shocks (Grafton and Kompas, 2005).

In general, how individuals and communities adapt to climate change depends on a diverse range of social-ecological factors including social norms and values, local environmental conditions, socio-economic status and processes of marginalization and inequality (Savo et al., 2017). However, focusing on only a few species such as the Manila clam, which is more resistant to changes in environmental conditions (Domínguez et al., 2020; Domínguez et al., 2021; Vázquez et al., 2021), can be a high-risk adaptation strategy. Manila clam (native to the Pacific), was introduced for culture in Europe in the 1970s because of its high adaptability (Latrouite and Claude, 1976; Pérez-Camacho and Cuña, 1985; Drummond et al., 2006). The increasing market pressure due to a greater national and international demand for seafood is driving shellfishers to seed this species artificially thus increasing its abundance (Pita et al., 2019; Villasante et al., 2021).

CONCLUDING REMARKS: MOVING FORWARD

The adverse effects of climate change on SSF have been predicted to increase in the future. Although scientific research on impacts of climate change has increased in recent years, few studies have explored the social dimension of the problem, in particular in the context of SSF. Our paper contributes to this research gap, and it represents a first attempt to provide empirical evidence about social adaptation strategies developed by shellfishers in Galicia. Case studies, such as that presented here, are essential to building resilience and collective adaptation to tackle impacts of climate change.

Our finding shows that there is a strong economic dependence on shellfishing, as fishers earned more than 75% of their monthly income from the activity. We also demonstrate that higher economic vulnerability was closely correlated with less fishing experience and the size of households. Fishers with a long experience in working in shellfisheries have had to deal with different situations in the past, developing a diverse portfolio of solutions.

The results of the study show that Galician shellfishers have developed a wide range of adaptive strategies to anticipate and respond to climate change, namely harvesting commercially valued species with high ex-vessel prices and also harvesting the most abundant species. Fishers have also adapted their behaviour by reducing household expenses and complementing their income from shellfishing with other formal or informal jobs to compensate for the economic losses.

Although adaptive strategies have helped to deal with impacts of climate change, several threats to the sustainability of shellfisheries remain: the decreased abundance of key native shellfisheries species and the high level of dependence on public and private aid to ensure reasonable income for shellfishers. In addition, the sector is dealing with the lack of generational transition to work in shellfisheries to ensure not only revenues, jobs and young population in coastal communities, but also to retain the traditional knowledge and social-ecological memory of associated practices, experience and values.

Key aspects such as enhancing social relationships, increasing knowledge about climate change, improving alternative skills and involving in adaptation planning are recommended to have desirable outcomes regarding social adaptation. We believe that our findings are of wide interest and relevance to other similar SSF around the world facing similar climate change challenges. We expect that the research we have conducted in this research can guide future research and policy recommendations. Future policy directions in management of these SSF should actively involve shellfishers and include their traditional and local knowledge. Such inclusion would help in the development of more effective policies as it would incorporate understanding of locally social adaptation strategies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

SV conceived the idea. SV, NC, GM, JCMB, and AS designed and performed the interviews. MROS and PFML developed the statistical analysis. All authors have equally contributed to the rest of the work.

FUNDING

This research was supported by grants CTM2014- 51935-R from the Spanish Ministerio de Economía y Competitividad to the project MARISCO and the Autonomous government Xunta de Galicia-FEDER (projects GRC2013- 004, ED431C 2017/46). SV and PP acknowledge funding from the Xunta de Galicia (RECREGES II project under Grant 1400 ED481B2018/017, and Grupo de Referencia Competitiva GI-2060 AEMI, under Grant 1401 ED431C2019/11), the H2020–European Commission project Atlantic ECOsystems assessment, forecasting & sustainability (AtlantECO, ref. 2019-PI022). SV thanks the financial support for the EQUALSEA project ERC Consolidator, under Grant Agreement n°101002784 funded by the European Research Council. GM was supported by post-doctoral contracts from projects MARISCO and PERCEBES (BiodivERsA COFUND & Spanish Agencia Estatal de Investigación; PCIN-2016-063).

ACKNOWLEDGMENTS

The authors acknowledge all shellfishers from Cambados, Campelo and Redondela who participated during the data collection and activities of the MARISCO project.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.802762/full#supplementary-material

REFERENCES

Adger, W. N. (2010). “Social Capital, Collective Action, and Adaptation to Climate Change,” in *Der Klimawandel*. Ed. M. Voss (The Netherlands: VS Verlag für Sozialwissenschaften), 327–345. doi: 10.1007/978-3-531-92258-4_19

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni,, Donald, R., et al. (2009). Are There Social Limits to Adaptation to Climate Change? *Clim. Change* 93, 335–354. doi: 10.1007/s10584-008-9520-z

Agresti, A., and Finlay, B. (2014). Statistical Methods for the Social Sciences Pearson, Harlow.

Aguión, A., Ojea, E., García-Flórez, L., Cruz, T., Garmendia, J. M., Davoult, D., et al. (2022). Establishing a Governance Threshold in Small-Scale Fisheries to Achieve Sustainability. *Ambio*. 51, 652–665 .doi: 10.1007/s13280-021-01606-x

Alvarez, I., de Castro, M., Gómez-Gesteira, M., and Prego, R. (2005). Inter and Intra-Annual Analysis of the Salinity and Temperature Evolution in the Galician Rías Baixas-Ocean Boundary (Northwest Spain). *J. Geophys. Res. C* 110, C04008. doi: 10.1029/2004JC002504

Aranguren, R., Gomez-León, J., Balseiro, P., Costa, M. M., Novoa, B., and Figueras, A. (2014). Abnormal Mortalities of the Carpet Shell Clam Ruditapes Decussatus (Linnaeus 1756) in Natural Bed Populations: A Practical Approach. *Aquacult. Res.* 45, 1303–1310. doi: 10.1111/are.1207

Arcos, F. D., Labandeira Villot, X., and Loureiro, M. L. (2011). Políticas Contra El Cambio Climático Y Preferencias Sociales En Galicia Y España. *Rev. Galega Econ.* 20, 1–20.

Baan, P. J. A., and Klijn, F. (2004). Flood Risk Perception and Implications for Flood Risk Management in the Netherlands. *Int. J. River. Basin. Manage.* 2, 113–122. doi: 10.1080/15715124.2004.9635226

Barange, M., Bahri, T., Beveridge, M. C., Cochrane, K. L., Funge-Smith, and Poulain, S. F. (2018). Impacts of Climate Change on Fisheries and Aquaculture: *Synthesis of Currrent Knowledge, Adaptation and Mitigation Options, FAO*.

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. Clim. Chang.* 10, 823–828. doi: 10.1038/s41558-020-0871-4

Barton, K. (2013). *MuMIn: Multi-Model Inference. R Package Version 0.12.2/R18*. cran.r-project.org/package=MuMIn

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting Linear Mixed-Effects Models Using Lme4. *J. Stat. Software* 67, 1–48. doi: 10.18637/jss.v067.i01

Bennett, N. J., Blythe, J., Tyler, S., and Ban, N. C. (2016). Communities and Change in the Anthropocene: Understanding Social-Ecological Vulnerability and Planning Adaptations to Multiple Interacting Exposures. *Regional Environ.* 16(4), 907–926

Bhashani, M. N., Islam, R., Ali, J., and Ghani, A. B. (2021). Assessing the Impact of Climate Change on Small-Scale Fisheries Livelihood Vulnerability Index. *Acad. Strateg. Manage. J.* 20 (4), 1–13.

Biggs, R., Peterson, G. D., and Rocha, J. C. (2018). The Regime Shifts Database: A Framework for Analyzing Regime Shifts in Social-Ecological Systems. *Ecol. Soc.* 23 (3), 9. doi: 10.5751/ES-10264-230309

Bode, A., Álvarez-Salgado, X. A., Ruiz-Villarreal, M., Bañón, R., Castro, C. G., Molares, J., et al. (2009). “Impacto do Cambio Climático Nas Condicións Oceanográficas E Nos Recursos Mariños,” in *Evidencias E Impactos do Cambio Climático En Galicia*. Eds. V. Pérez, M. Fernández and J. L. Gómez (Santiago de

Compostela: Conselleria de Medio Ambiente e Desenvolvemento Sostible), 619–636. hdl.handle.net/10508/3164

Burnham, K. P., and Anderson, D. R. (2002). *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd ed.* (New York: Springer).

Cardoso Pereira, S., Marta-Almedia, M., Carvalho, A. C., and Rocha, A. (2020). Extreme Precipitation Events Under Climate Change in the Iberian Peninsula. *Int. J. Climatol.* 40, 1255–1278. doi: 10.1002/joc.6269

Carvalho, D., Cardoso Pereira, S., and Rocha, A. (2021). Future Surface Temperature Changes for the Iberian Peninsula According to EURO-CORDEX Climate Projections. *Clim. Dynam.* 56 (1-2), 123–138. doi: 10.1007/s00382-020-05472-3

Cinner, J. E., McClanahan, T. R., Graham, N. A., Daw, T. M., Maina, J., Stead, S. M., et al. (2012). Vulnerability of Coastal Communities to Key Impacts of Climate Change on Coral Reef Fisheries. *Global Environ. Change* 22 (1), 12–20. doi: 10.1016/j.gloenvcha.2011.09.018

Claudet, J., Bopp, L., Cheung, W. W. L., Devillers, R., Escobar-Briones, E., Haugan, P., et al. (2020). A Roadmap for Using the UN Decade of Ocean Science for Sustainable Development in Support of Science, Policy, and Action. *One Earth* 2 (1), 34–42. doi: 10.1016/j.oneear.2019.10.012

Costa, P., Gómez, B., Venâncio, A., Pérez, E., and Pérez-Muñuzuri, V. (2012). Using the Regional Ocean Modelling System (ROMS) to Improve the Sea Surface Temperature Predictions of the MERCARTOR Ocean System. *Sci. Mar.* 76S1, 165–175. doi: 10.3989/scimar.03614.19E

Da Rocha, J. M., Gutiérrez, M. J., and Villasante, S. (2014). Economic Effects of Global Warming Under Stock Growth Uncertainty: The European Sardine Fishery. *Reg. Environ. Change* 14, 195–205. doi: 10.1007/s10113-013-0466-y

DeCastro, M., Gomez-Gesteira, M., Ramos, A. M., and Álvarez, I. (2011). Effects of Heat Waves on Human Mortality, Galicia, Spain. *Clim. Res.* 48, 333–341. doi: 10.3354/cr00988

Domínguez, R., Olabarria, C., Woodin, S. A., Wethey, D. S., Peteiro, L. G., Macho, G., et al. (2021). Contrasting Responsiveness of Four Ecologically and Economically Important Bivalves to Simulated Heat Waves. *Mar. Environ. Res.* 164, 105229. doi: 10.1016/j.marenvres.2020.105229

Domínguez, R., Vázquez, E., Woodin, S. A., Wethey, D. S., Peteiro, L. G., Macho, G., et al. (2020). Sublethal Responses of Four Commercially Important Bivalves to Low Salinity. *Ecol. Indic.* 111, 106031. doi: 10.1016/j.ecolind.2019.106031

Drummond, L., Mulcahy, M., and Culloty, S. (2006). The Reproductive Biology of the Manila Clam, *Ruditapes Philippinarum*, From the North-West of Ireland. *Aquaculture* 254, 326–340. doi: 10.1016/j.aquaculture.2005.10.052

FAO. (2015). *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication* (Rome: IPBES). Available at: https://www.fao.org/3/i4356en/I4356EN.pdf.

FAO. (2018). "Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options," in *FAO Fisheries and Aquaculture Technical Paper 627*. Eds. M. Barenge, T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith and F. Poulain (Rome: FAO), 19–39.

Folke, C. (2006). Resilience: The Emergence of a Perspective for Social–Ecological Systems Analyses. *Global Env. Change* 16 (3), 253–267. doi: 10.1016/j.gloenvcha.2006.04.002

Forsyth, T. (2013). Community-Based Adaptation: A Review of Past and Future Challenges. *Wiley Interdiscip. Rev. Clim. Change.* 4, 439–446. doi: 10.1002/wcc.231

Frangoudes, K., Marugán-Pintos, B., and Pascual-Fernández, J. J. (2008). From Open Access to Co-Governance and Conservation: The Case of Women Shellfish Collectors in Galicia (Spain). *Mar. Policy* 32, 223–232. doi: 10.1016/j.marpol.2007.09.007

Frangoudes, K., Marugán-Pintos, B., Pascual-Fernández, J. J., and Kooiman, (2013). ""Gender in Galician Shell-Fisheries: Transforming for Governability,"," in *Governability of Fisheries and Aquaculture*. Eds. M. Bavinck, R. Chuenpagdee, S. Jentoft and J. Kooiman (Dordrecht: Springer), 241–261. doi: 10.1007/978-94-007-6107-0_13

Frawley, T. H., Crowder, L. B., and Broad, K. (2019). Heterogeneous Perceptions of Social-Ecological Change Among Small-Scale Fishermen in the Central Gulf of California: Implications for Adaptive Response. *Front. Mar. Sci.* 6, 78. doi: 10.3389/fmars.2019.00078

Galappaththi, E., Ford, J., Bennett, E., and Berkes, F. (2021). Adapting to Climate Change in Small-Scale Fisheries: Insights From Indigenous Communities in the Global North and South. *Environ. Sci. Policy.* 116, 160–170. doi: 10.1016/j.envsci.2020.11.009

Gianelli, I., Ortega, L., Pittman, J., Vasconcellos, M., and Defeo, O. (2021). Harnessing Scientific and Local Knowledge to Face Climate Change in Small-Scale Fisheries. *Glob. Environ. Change* 68, 102253. doi: 10.1016/j.gloenvcha.2021.102253

Gómez-Gesteira, M., Gimeno, L., Decastro, M., Lorenzo, M. N., Alvarez, I., Nieto, R., et al. (2011). The State of Climate in NW Iberia. *Clim. Res.* 48 (2-3), 109–144. doi: 10.3354/cr00967

Grafton, Q. (2010). Adaptation to Climate Change in Marine Capture Fisheries. *Mar. Policy* 34 (3), 606–615. doi: 10.1016/j.marpol.2009.11.011

Grafton, Q., Doyen, L., Béné, C., Borgomeo, E., Brooks, K., Chu, L., et al. (2019). Realizing Resilience for Decision-Making. *Nat. Sustain.* 2, 907–913. doi: 10.1038/s41893-019-0376-1

Grafton, Q., and Kompas, T. (2005). Uncertainty and the Active Adaptive Management of Marine Reserves. *Mar. Policy* 29, 471–479. doi: 10.1016/j.marpol.2004.07.006

Green, K. M., Selgrath, J. C., Frawley, T. H., Oestreich, W., Mansfield, E., Urteaga, J., et al. (2021). How Adaptive Capacity Shapes the Adapt, React, Cope Response to Climate Impacts: Insights From Small-Scale Fisheries. *Clim. Change* 164, 15. doi: 10.1007/s10584-021-02965-w

Hanich, Q., Wabnitz, C. C., Ota, Y., Amos, M., Donato-Hunt, C., and Huntd, A. (2018). Small-Scale Fisheries Under Climate Change in the Pacific Islands Region. *Mar. Policy* 88, 279–284. doi: 10.1016/j.marpol.2017.11.011

Hawkins, S. J., Sugden, H. E., Mieszkowska, N., Moore, P., Poloczanska, E., Leaper, R., et al. (2009). Consequences of Climate Driven Biodiversity Changes for Ecosystem Functioning of North European Rocky Shores. *Mar. Ecol. Prog. Ser.* 396, 245–259. doi: 10.3354/meps08378

He, Q., and Silliman, B. R. (2019). Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene. *Curr. Biol.* 29, 1021–1035. doi: 10.1016/j.cub.2019.08.042

Hinkel, J. (2011). Indicators of Vulnerability and Adaptive Capacity. Towards a Clarification of the Science-Policy Interface. *Glob. Environ. Change* 21, 198-208. doi: 10.1016/j.gloenvcha.2010.08.002

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., et al. (2018). "Impacts of 1.5°C Global Warming on Natural and Human Systems," in *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*. Eds. V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, et al (Geneve: World Meteorological Organization), 175–311. hdl.handle.net/10138/311749

IPBES — Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (Bonn, Germany: IPBES).

IPCC, et al. (2019). "Technical Summary", in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Eds. H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor and E. Poloczanska

IPCC, et al. (2021). "Summary for Policymakers", in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Eds. V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Peían and S. Berger (Cambridge University Press).

Jentoft, S. (2005). Fisheries Co-Management as Empowerment. *Mar. Policy* 29, 1–7. doi: 10.1016/j.marpol.2004.01.003

Juanes, J. A., Bidegain, G., Echavarri-Erasun, B., Puente, A., García, A., García, A., et al. (2012). Differential Distribution Pattern of Native *Ruditapes Decussatus* and Introduced *Ruditapes Philippinarum* Clam Populations in the Bay of Santander (Gulf of Biscay): Considerations for Fisheries Management. *Ocean Coast. Manage.* 69, 316–326. doi: 10.1016/j.ocecoaman.2012.08.007

Kelly, R. P., Erickson, A. L., Mease, L. A., Battista, W., Kittinger, J. N., and Fujita, R. (2014). Embracing Thresholds for Better Environmental Management. *Philos. Trans. R. Soc Lond. B Biol. Sci. B* 370, 20130276. doi: 10.1098/rstb.2013.0276

Larntz, K. (1978). Small-Sample Comparisons of Exact Levels for Chi-Squared Goodness-of-Fit Statistics. *J. Am. Stat. Assoc.* 73 (362), 253–263. doi: 10.2307/2286650

Latrouite, D. S., and Claude, S. (1976). Elevage En Surélévation Des Vénéridés (*Mercenaria Mercenaria, Ruditapes Decussatus, Venerupis Japonica*) En Rivière De La Trinité Sur Mer, Bretagne Sud. *ICES CM E* 7, 1–12.

León-Mateos, F., Sartal, A., López-Manuel, L., and Quintás, M. A. (2021). Adapting Our Sea Ports to the Challenges of Climate Change: Development and Validation of a Port Resilience Index. *Mar. Policy* 130, 104573. doi: 10.1016/j.marpol.2021.104573

Lucchetti, A., Piccinetti, C., Meconi, U., Frittelloni, C., Marchesan, M., Palladino, S., et al. (2014). Transferable Fishing Concessions (TFC): A Pilot Study on the Applicability in the Mediterranean Sea. *Mar. Pol.* 44, 438–447. doi: 10.1016/j.marpol.2013.10.009

Ma, S., Cheng, J., Li, J., Liu, Y., Wan, R., and Tian, Y. (2019). Interannual to Decadal Variability in the Catches of Small Pelagic Fishes From China Seas and its Responses to Climatic Regime Shifts. *Deep Sea Res. Part II: Topical Stud. Oceanography* 159, 112–129. doi: 10.1016/j.dsr2.2018.10.005

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, 1057–1069. doi: 10.1007/s13280-013-0460-0

Macho, G., Woodin, S. A., Wethey, D. S., and Vázquez, E. (2016). Impacts of Sublethal and Lethal High Temperatures on Clams Exploited in Europeanfisheries. *J. Shellfish Res.* 35, 405–419. doi: 10.2983/035.035.0215

Marshall, M. N. (1996). Sampling for Qualitative Research. *Fam. Pract.* 13, 522–526. doi: 10.1093/fampra/13.6.522

Marshall, N. A., Tobin, R. C., Marshall, P. A., Gooch, M., and Hobday, A. J. (2013). Social Vulnerability of Marine Resource Users to Extreme Weather Events. *Ecosystems* 16, 797–809. doi: 10.1007/s10021-013-9651-6

Mieszkowska, N., Firth, L., and Bentley, M. (2013). Impacts of Climate Change on Intertidal Habitats. *MCCIP Sci. Rev.* 2013, 180–192. doi: 10.14465/2013.arc19.180-192

Miller, D. D., Ota, Y., Sumaila, U. R., Cisneros-Montemayor, A. M., and Cheung, W. W. L. (2018). Adaptation Strategies to Climate Change in Marine Systems. *Glob. Change Biol.* 24, 1–14. doi: 10.1111/gcb.13829

Ministry of Labour and Social Economy. (2021). *Real Decreto 817/2021, De 28 De Septiembre, Por El Que Se Fija El Salario Mínimo Interprofesional Para 2021. BOE N° 233*. Available at: https://www.boe.es/eli/es/rd/2021/09/28/817/con.

Islam, M. Md., Sallu, S., Hubacek, K., and Paavolaa, J. (2014). Limits and Barriers to Adaptation to Climate Variability and Change in Bangladeshi Coastal Fishing Communities. *Mar. Pol.* 43, 208–216. doi: 10.1016/j.marpol.2013.06.007

Neter, J., Kutner, M. H., Nachtsheim, C. J., and Wasserman, W. (1996). *Applied Linear Statistical Models. 4th Edition* (New York: McGraw-Hill).

Ojea, E., Pearlman, I., Gaines, S. D., and Lester, S. E. (2017). Fisheries Regulatory Regimes and Resilience to Climate Change. *Ambio* 46, 399–412. doi: 10.1007/s13280-016-0850-1

Oliver, E. C. J., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., et al. (2018). Longer and More Frequent Marine Heatwaves Over the Past Century. *Nat. Commun.* 9, 1324. doi: 10.1038/s41467-018-03732-9

Orosa, J. A., Costa, Á.M., Rodríguez-Fernández, Á., and Roshan, G. (2014). Effect of Climate Change on Outdoor Thermal Comfort in Humid Climates. *J. Environ. Heal. Sci. Eng.* 12, 1–9. doi: 10.1186/2F2052-336X-12-46

Parada, J. M., and Molares, J. (2008). Natural Mortality of the Cockle Cerastoderma Edule (L.) From the Ria of Arousa (NW Spain) Intertidal Zone. *Rev. Biol. Mar. Oceanogr.* 43, 501–511. doi: 10.4067/S0718-19572008000300009

Parada, J. M., Molares, J., and Otero, X. (2012). Multispecies Mortality Patterns of Commercial Bivalves in Relation to Estuarine Salinity Fluctuation. *Estuar. Coast* 35, 132–142. doi: 10.1007/s12237-011-9426-2

Pérez-Camacho, A., and Cuña, M. (1985). First Data on Raft Culture of Manila Clam (*Ruditapes Philippinarum*) in the Ría De Arosa (NW Spain). *Int. Council Explor. Sea C.M.* 43, 21.

Pérez Muñuzuri, V., Fernández Cañamero, M., and Gómez Gesteira, J. L. (2009). *Evidencias E Impactos do Cambio Climático En Galicia. Santiago De Compostela: Xunta De Galicia. Consellería De Medio Ambiente E Desenvolvemento Sostible*. (Xunta de Galicia, City: Santiago de Compostela).

Peteiro, L. G., Woodin, S., Wethey, D., Costas-Costas, D., Martínez-Casal, A., Olabarria, C., et al. (2018). Responses to Salinity Stress in Bivalves: Evidence of Ontogenetic Changes in Energetic Physiology on *Cerastoderma Edule*. *Sci. Rep.* 8, 8329. doi: 10.1038/s41598-018-26706-9

Pinheiro, J. C., and Bates, D. M. (2000). Linear Mixed-Effects Models: Basic Concepts and Examples. *Mixed-effects Models S S-Plus*, 3–56. doi: 10.1007/b98882

Pita, P., Antelo, M., Hyder, K., Vingada, J., and Villasante, S. (2020). The Use of Recreational Fishers' Ecological Knowledge to Assess the Conservation Status of Marine Ecosystems. *Front. Mar. Sci.* 7, 242. doi: 10.3389/fmars.2020.00242

Pita, P., Fernández-Márquez, D., Antelo, M., Macho, G., and Villasante, S. (2019). Social-Ecological 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

Pomeroy, R. S., and Viswanathan, K. K. (2003). "). Experiences With Fisheries Co-Management in Southeast Asia and Bangladesh," in *The Fisheries Co-Management Experience* (Dordrecht: Springer), 99–117.

Prego, R., deCastro, M., Gómez-Gesteira, M., Taboada, J. J., Montero, P., and Pérez-Villar, V. (2001). Micro-Scale Hydrography of the Pontevedra Ría (NW Spain). *J. Geophys. Res.* 106, 845–19,857. doi: 10.1029/2000JC000775

R Core Team. (2018). *R: A Language and Environment for Statistical Computing* (Vienna, Austria: The R Foundation for Statistical Computing). Available at: https://www.R-project.org.

ReICAZ – Real e Ilustre Colegio de Abogados de Zaragoza. (2017). *Tablas Anuales Del Salario Mínimo Interprofesional*. Available at: http://www.reicaz.org/normaspr/tablasdi/tblsalmi.htm.

Rey-García, M., Calvo, N., and Mato-Santiso, V. (2019). Collective Social Enterprises for Social Innovation: Understanding the Potential and Limitations of Cross-Sector Partnerships in the Field of Work Integration. *Manage. Decision* 57 (6), 1415–1440. doi: 10.1108/MD-01-2017-0091

Ruiz-Díaz, R., Liu, X., Aguión, A., Macho, G., DeCastro, M., Gómez-Gesteira, M., et al. (2020). Social-Ecological Vulnerability to Climate Change in Small-Scale Fisheries Managed Under Spatial Property Rights Systems. *Mar. Policy* 121, 104192. doi: 10.1016/j.marpol.2020.104192

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, 104123. doi: 10.1016/j.marpol.2020.104123

Savo, V., Morton, C., and Lepofsky, D. (2017). Impacts of Climate Change for Coastal Fishers and Implications for Fisheries. *Fish. Fish.* 18 (5), 877–889. doi: 10.1111/faf.12212

Selden, R., and Pinsky, M. (2019). "Chapter 20- Climate Change Adaptation and Spatial Fisheries Management," in *Predicting Future Oceans*. Eds. A. M. Cisneros-Montemayor, W. W. L. Cheung and Y. Ota (Amsterdam: Elsevier Inc), 207–214. doi: 10.1016/B978-0-12-817945-1.00023-X

Shaffrill, H., Samaha, A., and D'Silva, J. (2017). Climate Change: Social Adaptation Strategies for Fishermen. *Mar. Policy* 81, 256–261. doi: 10.1016/j.marpol.2017.03.031

Silva, M., Pennino, M., and Lopes, P. (2019). Social-Ecological Trends: Managing the Vulnerability of Coastal Fishing Communities. *Ecol. Soc* 24(4).

Smit, B, and Wandel, J (2006). Adaptation, Adaptive Capacity and Vulnerability. *Global Environ. Change* 16(3), 282–292.

Sumaila, U. R., Cheung, W. W., Lam, V. W., Pauly, D., and Herrick, S. (2011). Climate Change Impacts on the Biophysics and Economics of World Fisheries. *Nat. Clim. Change* 1 (9), 449–456. doi: 10.1038/nclimate1301

Team, R.D.C. (2018). "R: A Language and Environment for Statistical Computing," in *Vienna: R Foundation for Statistical Computing*.

Toubes, D. R., Gössling, S., Hall, C. M., and Scott, D. (2017). Vulnerability of Coastal Beach Tourism to Flooding: A Case Study of Galicia, Spain. *Environments* 4, 83. doi: 10.3390/environments4040083

Vázquez, E., Woodin, S. A., Wethey, D. S., Peteiro, L. G., and Olabarria, C. (2021). Reproduction Under Stress: Effect of Low Salinities and Heat Waves on Reproductive Cycle of Four Ecologically and Commercially Important Bivalves. *Front. Mar. Sci.* 8, 685282. doi: 10.3389/fmars.2021.685282

Verdelhos, T., Marques, J. C., and Anastácio, P. (2015). Behavioral and Mortality Responses of the Bivalves *Scrobicularia Plana* and *Cerastoderma Edule* to Temperature, as Indicator of Climate Change's Potential Impacts. *Ecol. Indic.* 58, 95–103. doi: 10.1016/j.ecolind.2015.05.042

Villarreal, O. (2017). Is it Desirable, Necessary and Possible to Perform Research Using Case Studies? *Cuad. Gestión* 17, 147–172.

Villasante, S., Gianelli, I., Castrejón, M., Ortega, L., Nahuelhual, L., Sumaila, R., et al. (2022). Social-Ecological Shifts, Traps and Collapses in Small-Scale Fisheries: Envisioning a Way Forward to Transformative Changes. *Mar. Pol.* 136, 104933. doi: 10.1016/j.marpol.2021.104933

Villasante, S., Tubío, A., Gianelli, I., Pita, P., and García-Allut, A. (2021). Ever Changing Times: Sustainability Transformations of Galician Small-Scale Fisheries. *Front. Mar. Sci.* doi: 10.3389/fmars.2021.712819

Wiseman, J., Wlliamson, L., and Fritze, J. (2009). Community Engagement and Climate Change: Learning From Recent Australian Experience. *Int. J. Clim. Change Strateg. Manage.* 2 (2), 134–147. doi: 10.1108/17568691011040399

Woodin, S. A., Wethey, D. S., Olabarria, C., Vázquez, E., Domínguez, R., Macho, G., et al. (2020). Behavioral Responses of Three Venerid Bivalves to Fluctuating Salinity Stress. *J. Exp. Mar. Biol. Ecol.* 522, 151256. doi: 10.1016/j.jembe.2019.151256

Yin, R. K. (2014). *Case Study Research Design and Methods (5th Ed.)* (Thousand Oaks, CA: Sage).

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