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ORIGINAL ARTICLE

Coastal livelihood resilience to abrupt environmental change: the role of social capital in a Peruvian bay

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Abstract

Abrupt environmental change, such as sudden shifts in temperature or salinity, can severely alter the functioning of marine ecosystems and cause dramatic impacts on the associated social systems. Resource users, who rely on ecosystem services provided by the ocean, are particularly vulnerable to such drastic events. Functioning social relationships (social capital) have recently been suggested as a key driver for recovery after disaster. Here, we study how small-scale fishers who conduct sea-ranching of the Peruvian bay scallop *Argopecten purpuratus* in Northern Peru dealt with the literal wipe-out of their target resources caused by the Coastal El Niño (CEN) of 2017 that heavily impacted the entire region. Adopting an ego-network approach complemented by qualitative information from expert interviews, we investigated how resource users drew on their social networks to cope with the disaster. Results suggested a significant positive correlation between more desirable post-disaster trajectories and the number of helpful social links of scallop farmer associations. Disentangling the temporal aspect of this pattern, we found that social capital established *before* the disaster was driving this correlation. Importantly, both economic and non-economic links were contributing to the observed patterns. This study emphasizes the importance of social capital for dealing with the effects of disasters following natural events. Having extensive social networks increases the capacity to mobilize resources and information when needed and is associated with more efficient recovery after abrupt environmental change. Mechanisms to foster and enhance social capital are key for preventive management actions aiming to build resilience within vulnerable communities facing accelerating global change.

Keywords Mariculture · Small-scale aquaculture · Adaptive capacity · El Niño Southern Oscillation (ENSO) · Social network analysis · Disaster resilience

Introduction

Nearly half of the world's population lives in coastal areas and people derive a variety of benefits from the functions, goods, and services that marine ecosystems provide

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(Kummu et al. 2016; Barbier 2017). Abrupt environmental change, triggered by recurring natural phenomena or anthropogenic influences, can, however, severely alter the functioning of marine ecosystems (Rocha et al. 2018). The environment often normalizes after a certain period of time, yet such events can induce lasting effects on the economic development and well-being of coastal communities (Rocha et al. 2015a). Small-scale businesses that depend on marine resources are particularly vulnerable to abrupt environmental change (Marshall et al. 2013).

An advanced understanding of the factors that enhance the capacity of marine resource users to successfully cope with environmental change and disasters following natural events is urgently needed to sustain livelihoods of coastal populations in times of crises. Such knowledge is gaining particular importance as sudden environmental change and other types of extreme events are expected to increase in frequency and severity as both the impacts of climate change and resource overuse intensify (Hughes et al. 2007, 2013; IPCC 2019, 2021; Lenton et al. 2019; MEA 2005). This most likely affects the livelihoods of millions of vulnerable people in developing countries who are highly dependent on natural resources (Ferrol-Schulte et al. 2013; Cinner 2014). In this study, we investigate the role of social capital in enhancing the resilience of small-scale mariculture businesses to abrupt environmental change events. A mixed-method approach was applied to collect quantitative and qualitative empirical data from small-scale mariculture operators in a large Peruvian bay that had experienced drastic and abrupt changes in oceanic conditions and extensive infrastructural damage caused by an El Niño Southern Oscillation (ENSO) event in 2017, which heavily impacted local communities well beyond the fisheries and aquaculture sector (INDECI 2017).

Economic development and societal well-being in coastal areas are closely linked to the health of the marine ecosystems. The seafood sector — the main focus of this study — provides more than 200 million jobs globally (Teh and Sumaila 2013; FAO 2020a), and more than one-third of the human population relies on marine resources for their protein intake (FAO 2020b). Triggered by fully exploited or overexploited global fish stocks, the seafood sector increasingly turns towards aquaculture development as an alternative path to meeting increasing market demands (Ahmed and Thompson 2019). This has led to significant expansion of the global aquaculture sector, and with an annual growth rate of 5.3% (for the period 2001–2018), global aquaculture production progressively overtakes the production of the wild fisheries sector (FAO 2020a). As an example, the share of the world's scallop production originating from aquaculture increased from 10% in 1980 to more than 70% in 2019 (FAO 2021). In times of accelerating global environmental change, this development is not without risk.

Ecosystems continuously undergo gradual change. Environmental conditions, however, can also change suddenly with long-lasting socio-ecological consequences (Scheffer et al. 2001; Rocha et al. 2015b). Such abrupt changes may, for instance, alter the species composition in an ecosystem or modulate the rates at which ecological processes operate and consequently hamper the range and quality of ecosystem services provided to society (Bestelmeyer et al. 2011; Lade et al. 2013; Petraitis 2013). Typical and well-studied examples of such abrupt change events in aquatic systems are shallow lakes, in which human-induced eutrophication causes algal blooms and a shift from clear water to a turbid state (Scheffer and Jeppesen 1998; Carpenter et al. 1999). Similar large-scale shifts from one ecosystem state to another as a consequence of rapid and substantial re-organizations in complex systems are found in a variety of ecosystems (Scheffer 2009). Regarding marine environments, such abrupt changes can put fishing and aquaculture business operations into peril and cause large-scale socio-economic hardship in marine resource-dependent communities (Cinner et al. 2012; Ferrol-Schulte et al. 2013).

The concept of "resilience" has received considerable attention with the aim of mitigating socio-economic hardship in the context of environmental change (United Nations Secretary-General's High-level Panel on Global Sustainability 2012). Resilience describes the degree to which a system is able to absorb stress and reorganize while undergoing change (Holling et al. 2002). In that sense, the notion of resilience is closely linked to the capacity of a system to deal with different types of slowly or rapidly unfolding change (Holling 1973). For instance, resource-dependent coastal communities can be considered resilient, if they are able to maintain their livelihoods when faced with rapid changes in environmental conditions (Adger et al. 2005; Folke 2006; Folke et al. 2010). Hence, for this paper, we understand resilience as the degree to which a marine resource-dependent community is capable of dealing with the impacts of abrupt environmental change (adapted from Adger et al. 2005).

Social capital can play a key role for enhancing marine resource users' resilience to abrupt environmental change. The concept of social capital has received increasing attention in scholarly work in a number of academic fields (Lin et al. 2001) and very generally refers to the existence of relationships between social entities associated with a number of desirable phenomena (Portes 1998; Putnam 2000; Lin et al. 2001). The Organization for Economic Co-operation and Development (OECD) describes social capital as the norms and social relations that facilitate cooperation within and among groups to achieve desired goals (OECD 2001). The core idea is that the existence of social relationships facilitates access to valuable resources embedded in the social structure (Portes 1998; Woolcock and Narayan 2000). These resources are channeled through social relations and can be mobilized by social actors (Jones et al. 1997; Gulati and Gargiulo 1999; Burt 2003). Hence, being connected to others increases the social capital of actors and enables them to access valuable resources such as information, knowledge, and influence.

In the context of abrupt environmental change and coastal disasters, previous studies suggest that social capital promotes the recovery from the devastating impacts of a tsunami (Marín et al. 2015), an earthquake (Partelow 2020; Panday et al. 2021), or a cyclone (Masud-All-Kamal and Monirul Hassan 2018) and might even be more important than economic capacity or the degree of damage to explain successful recovery of groups and communities (Aldrich 2012a, b). Relevant functions of social capital that may be important in dealing with such events include an enhanced ability to, for instance, find alternative employment opportunities (Granovetter 1983) or receive social support in times of hardship (Wellman 1983). Building on this evidence, we study the role of social capital for the resilience of small-scale mariculture businesses in the context of a Peruvian bay subject to abrupt environmental change caused by an ENSO event. Specifically, we analyze (i) whether a hydro-climatic disaster induced by El Niño modulates resource users' social capital, (ii) whether social capital strengthens resilience to such abrupt environmental change, (iii) whether the timing of social capital development is an indicator for post-disaster trajectories, and (iv) whether economic relationships play a particularly prominent role in shaping how small-scale mariculture businesses cope with a disaster following a natural event.

Material and methods

Study system

The case study Peru was selected for two reasons: (1) the country is an important global player with respect to fisheries and aquaculture production and (2) the region is susceptible to the variability and impacts driven by the dynamics of the El Niño Southern Oscillation (ENSO).

In 2018, Peru ranked second (after China) on the list of major marine capture fisheries producers, with 87% of national annual catches stemming from the Peruvian anchoveta (*Engraulis ringens*) (FAO 2020b), mainly destined for fishmeal and fish oil production. The region of Piura in Northern Peru hosts the largest number of artisanal fishing vessels (> 30% of the artisanal vessels of Peru; Castillo et al. 2018) and a great part of its population depends on multi-species, multi-gear fisheries-related activities (Guevarra-Carrasco and Bertrand 2017; Kluger et al. 2019a). At the same time, the state has developed into a major (export-oriented) producer of the Peruvian bay scallop (*Argopecten purpuratus*) which is grown in bottom cultures (sea ranching) by small-scale fishers (hereafter scallop farmers). In 2013, the large bay of Sechura (Fig. 1) accounted for 83% of national (Mendo et al. 2016) and 50% of total Latin American scallop production (Kluger et al. 2019b); in 2019 Peru was — after China and Japan — the third most important scallop producer globally (FAO 2021). Overall, this sector sustains the livelihoods of more than 30,000 people in the region (Kluger et al. 2019a).

During El Niño, the warm phase of ENSO, the otherwise strong upwelling of cold, nutrient-rich waters along the Pacific coast of South America comes to a halt, and the region experiences a rise in sea surface temperatures and increased precipitation (Huyer et al. 1987). This affects the environmental dynamics and species composition of marine ecosystems. While the different phases of ENSO alternate in an irregular inter-annual cycle, individual El Niño events also vary greatly in their development from region to region, making forecasting of local effects almost impossible. For Peru, the most severe El Niño events were recorded in 1982/1983 and 1997/1998. In more recent history, a localized "Coastal El Niño" event (hereafter CEN) hit Northern Peru in February–March 2017. An increase in oceanic water temperature was the consequence, paralleled by extensive rainfall and flooding, which resulted in hypoxic conditions in the marine benthic environment as well as severe damage to the local infrastructure (Kluger et al. 2019a; Rodríguez-Morata et al. 2019, associated oceanic-physical processes presented in Echevin et al. 2018). While environmental change events may — in certain settings — create favorable oceanic conditions for specific species and thus benefit resource users who target them (*cf.* boom-and-bust cycles of certain invertebrates of Northern Chile and Southern Peru during El Niño events; Arntz and Tarazona, 1990; Wolff et al. 2007), the small-scale fisheries and particularly the scallop mariculture sector in Northern Peru were hit extremely hard by the CEN 2017 due to a literal complete die-off of the cultured scallops (Kluger et al. 2019a).

Data collection

In January 2018, face-to-face surveys were conducted with representatives of scallop farmer associations ($n = 43$, representing about 25% of all scallop farmer associations operating in the area at the time of sampling) from five villages along the coastline of Sechura Bay (Fig. 1), making sure that each survey participant spoke for a single organization (called OSPA = "Social organizations of artisanal fishers", Span. *Organizaciones Sociales de Pescadores Artesanales*; for a historical overview of scallop culture in Peru, see Kluger et al. 2019b). The parts of the survey relevant for this study can be found in the Online Resource 1. For a more detailed description of the survey protocol applied,

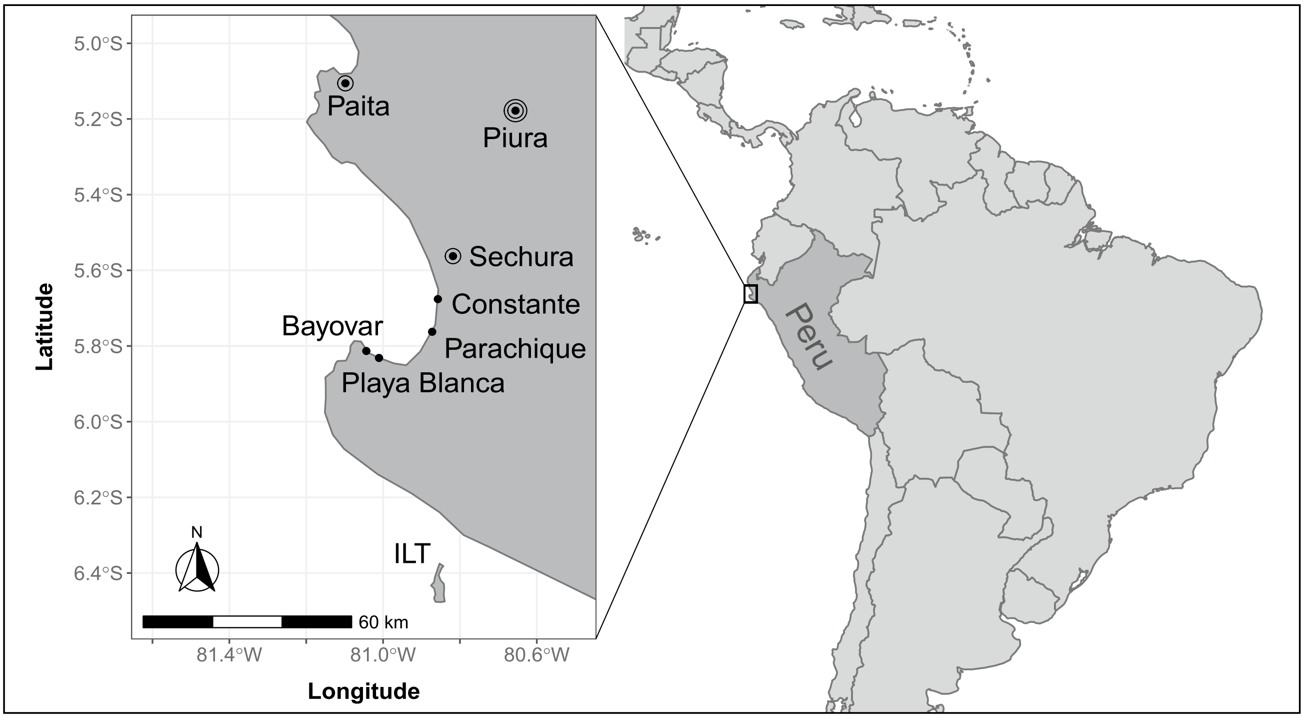

Fig. 1 Overview of the study system Sechura Bay in Northern Peru, indicating all villages in which interviews were conducted (black dots): Sechura, Constante, Parachique, Playa Blanca, Bayovar (cf. "Data collection"). ILT = Island Lobos de Tierra (modified from Fig. 1 in Kluger et al. 2019a)

refer to Online Resource 6. Out of a total of 43 conducted interviews, 35 were used in this study (8 were omitted due to incomplete information in the survey sections necessary for analysis).

Representatives of the scallop farmer associations were asked about their association's relationships with 17 actors (or "alters", *cf.* "Data analysis") included in an open-ended stakeholder roster that comprised public authorities, the private sector, other resource users, advice-giving entities, and family members (Fig. 2; *cf.* Garteizgogeascoa et al. 2020 for a detailed description of the included actor groups). Interviewees had the choice to name other groups relevant for their activities but rarely used this option. While this supports the assumption that all relevant actors were included in the initial list, the few additional mentions ($n = 3$) were considered within an "Other" category (leading to a total of 18 different alters being considered for this study).

Interviewees were asked with which actors of the stakeholder roster they discuss important aspects of their work in a normal year (2015) and during El Niño (2017). Respondents were then asked how often they interact with each of the mentioned actors (*at least*: 1, "daily"; 2, "weekly"; 3, "monthly"; 4, "several times"; 5, "twice"; 6, "once") and how helpful these interactions were (1, "very helpful"; 2, "helpful"; 3, "no help"; 4, "harmful"). The applied frequency categories refer to the number of times that scallop farmers *at least* interacted with the named actors. If an interviewee indicated an interaction frequency of, for example, "every two weeks," this reply would be recorded in the category "*at least* monthly," thus fulfilling the principle of mutual exclusion and completeness in the categorization. Regarding the helpfulness of interactions, respondents were asked to rate interactions according to the best match with one of the four given categories. In case there was ambiguity in the responses during the interview, interviewers repeated these four categories and asked interviewees to indicate the category that fitted best. Furthermore, interviewees were asked whether an indicated link was of economic or non-economic nature (*cf.* Online Resource 1).

Following the proposition of Marín and colleagues (2015), we measured resilience to abrupt environmental change based on the scallop farmer associations' post-disaster trajectories by creating a five-point ordinal scale from most desirable to least desirable trajectories (i.e., in descending order from the most desirable categories "innovation" and "normalization" via "recuperation" and "stagnation" to "recession" as the least desirable option; *cf.* Online Resource 1). This approach allowed us to explore how well scallop farmers were able to cope with the abrupt environmental change brought along with the CEN (see Marín et al. 2015 for further details on this variable). The survey was complemented by qualitative information obtained between

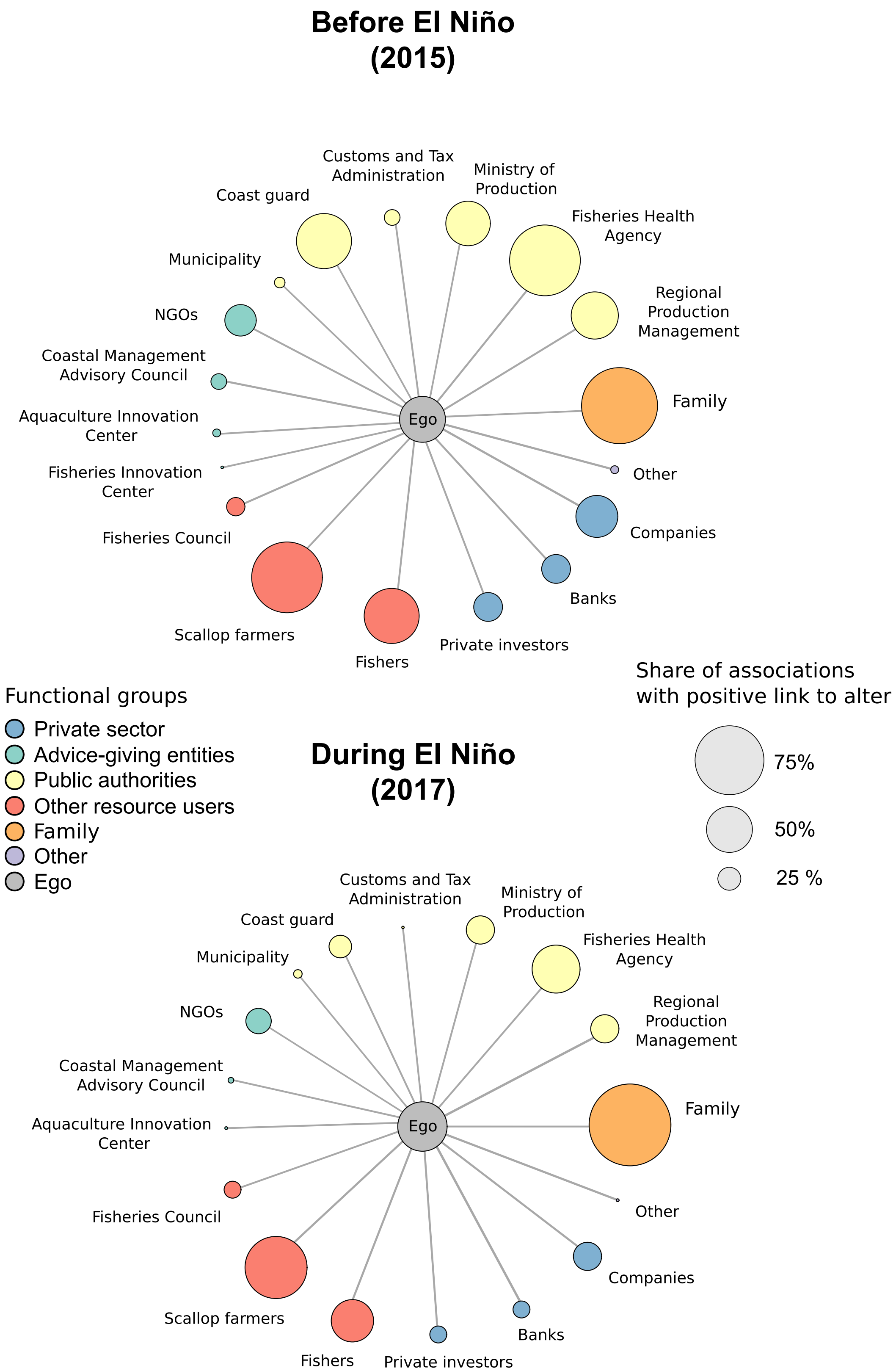

Fig. 2 Representations of scallop farmer associations' ego-networks (**a**) before (in 2015) and (**b**) during the Coastal El Niño (in 2017) with alters (circles) colored according to affiliation with functional groups. The size of the circles is scaled according to the average number of positive (i.e., very helpful and helpful) links with the respective alter across all interviewed scallop farmer associations ($n = 35$)

September 2017 and January 2018 in semi-structured expert interviews ($n = 53$) with representatives from local industry, the mariculture and fisheries sectors, and research and governmental organizations.

It should be noted that this study was based on respondents' accounts of their social networks at two different points in the past (i.e., retrospective design). Incomplete recall of past interactions or fade of memory may thus bias the obtained information (see, e.g., Galea et al. 2008; Moreno-Serra et al. 2022). Although it would have been ideal to assess the state of aquaculture operators' social networks independently before and during the Coastal El Niño, there was no way to predict the occurrence of this disaster. In future research, this limitation could potentially be addressed by long-term studies on the factors of livelihood resilience in the context of recurring disasters. In any case, a possible recall bias would run in one direction, e.g., in the form of an underrepresentation of interactions that lie further in the past (i.e., lower recall of interactions for 2015 than for 2017). However, such a bias would then produce patterns that run counter to the effects we observe for H1. Assuming that there is no systematic pattern in recall and/or misreporting among scallop farmer associations, a recall bias should not affect the results obtained for H2 and H3 (as well as H4), as all respondents were asked to recall interactions for the same time period and there is no direct comparison between the 2015 and 2017 survey data involved in the analysis for these hypotheses (see, e.g., Moreno-Serra et al. 2022).

Data analysis

Ego-networks were constructed for each individual scallop farmer association (ego), including all entities they interact with as alters (terminology *cf.* van Duijn and Vermunt 2006, McCarty et al. 2019; Fig. 2). Social capital was operationalized as the number of positive links scallop farmer associations had to alters (a metric called "degree centrality"). Alters were furthermore divided into five functional groups, i.e., public authorities, advice-giving entities, other resource users, family, and the private sector (Online Resource 2).

In order to characterize scallop farmers' social networks before and during the CEN, the network components (alters) and the perceived helpfulness of interactions with other actors were first analyzed descriptively ("The social capital of Peruvian scallop farmers and its evolution during the 2017 Coastal El Niño event"). Changes in the interaction frequency and perceived helpfulness of interactions from before to during the El Niño were examined using a before-and-after analysis employing a cumulative link mixed model ("The social capital of Peruvian scallop farmers and its evolution during the 2017 Coastal El Niño event"). For this analysis step, links with entities categorized as "Other" ($n = 3$, see above) were excluded because of the heterogeneity of the actors in this category. Frequency of interactions and their perceived helpfulness were treated as ordinal data and scallop farmer associations were specified as random effect. The group of fishers was used as dummy variable as the interactions with this group most closely mirrored the average interaction of scallop farmer associations with all alters.

After the description of the components and link characteristics in scallop farmer associations' social networks, we proceeded to test the hypotheses about resource users' social capital, as indicated in Table 1. For the purpose of analyzing social capital, only positive links (declared as being very helpful or helpful) were considered, following the approach by Marín and colleagues (2015). We thus excluded 51 neutral ($< 12\%$) and 3 negative ($< 1\%$) links as well as 8 links ($< 2\%$) without an associated helpfulness from the analysis.

The degree centrality for each scallop farmer association was calculated as the number of positive links an individual scallop farmer association (ego) had to other entities (alters) (a) over the entire study period, as well as separated for (b) before and (c) during the El Niño. We then tested whether the degree centrality of scallop farmer associations increased from before to during the El Niño event (Hypothesis 1) using a Wilcoxon signed-rank test ("The social capital of Peruvian scallop farmers and its evolution during the 2017 Coastal El Niño event"). For testing Hypothesis 2, 3, and 4, we could only consider scallop farmer associations that had indicated a post-disaster trajectory in the survey ($n = 33$). Spearman's rank correlation coefficients were calculated to determine whether a higher degree centrality before and/or during the CEN was associated with more desirable post-disaster trajectories (Hypotheses 2 and 3).

In a final step, the total number of links was subdivided according to the indication of whether it was an economic or a non-economic relationship (see above). Based on this division, the number of economic and non-economic links that an individual association (ego) had to other entities (alters) over the entire study period was calculated (*cf.* Online Resource 3 and Online Resource 4). With the aim to explore if positive post-disaster trajectories were more strongly correlated with the number of economic relationships than with non-economic relationships (Hypothesis 4), we tested the significance of the correlation between the number of (a) economic as well as (b) non-economic relationships and the categories of post-disaster trajectories using a Spearman's rank correlation ("Social capital positively influences post-disaster trajectories of scallop farmers").

Data handling and analysis were performed within the R environment (Version 4.0.4, R Core Team 2021). Data visualizations were realized using the *tidyverse* (particularly *ggplot2*) library (Wickham et al. 2019). For network analyses and visualizations, we used the *igraph* package (Csardi

Table 1 Hypotheses (H) addressed in this study, along with respective (network) measures

Hypothesis		Measure	Supported if …
H1	Social capital increases in times of hardship caused by an abrupt environmental change event	Change in degree centrality between 2015 and 2017 (*cf.* Fig. 5a)	Degree centrality increases from before to during the CEN event
H2	Social capital strengthens resilience to sudden environmental change	Degree centrality in relation to post-disaster trajectory (*cf.* "Social capital positively influences post-disaster trajectories of scallop farmers")	Correlation between high degree centrality and positive post-disaster trajectories
H3	Building social capital *before* a disturbance event increases resilience to sudden environmental change	Degree centrality before and during the CEN in relation to post-disaster trajectory (*cf.* Fig. 5b)	Positive post-disaster trajectories are more strongly correlated with degree centrality before the event than with degree centrality during the CEN
H4	High social capital in terms of economic relationships is key for coping with the impacts of sudden environmental change	Degree centrality of economic relationships compared to non-economic relationships in relation to post-disaster trajectories (*cf.* Fig. 5c)	Positive post-disaster trajectories are more strongly correlated with degree centrality of economic relationships than with non-economic relationships

and Nepusz 2006) and employed the *ordinal* package (Christensen 2013) for the before-after analysis.

Results

The social capital of Peruvian scallop farmers and its evolution during the 2017 Coastal El Niño event

Social networks of the interviewed scallop farmer associations were comprised of relationships with a variety of actors and entities associated with the scallop production sector (Fig. 2). While links with family members, other resource users, and various public authorities were present in almost all interviewed scallop farmer associations, other links, such as with the Aquaculture Innovation Center and the municipality, were only rarely reported (Fig. 3a). Importantly, the perceived helpfulness of relationships varied for the different alters. While the vast majority of links were regarded as positive (i.e., very helpful or helpful), some links were perceived to be of no help or even harmful (Fig. 3). Besides family ties and links among scallop farmers, the largest number of positive interactions was reported for the fisheries health agency (Fig. 3a). Key informants stated that these actors play a crucial role in the day-to-day business of scallop farmers and act as the prime information brokers within the studied system. Many scallop farmers reported that they either worked with family members in the same association, or that family members were by other means associated with the scallop production sector. At the same time, some interviewees indicated that the strong ties with family members also created additional financial challenges due to an increased urgency to provide for their relatives in times of hardship. This was further exacerbated if family members also lost their income as a consequence of the CEN.

The social fabric in which scallop farmer associations were embedded was altered by the CEN. While links with family and other scallop farmers were largely sustained from before to during the CEN, the number of positive links for all the other alters was generally reduced (Fig. 3a). The largest percentage decrease was observed for the customs and tax administration (−100%), the coastal management advisory council (−71%), and the coast guard (−62%) (Fig. 3a). This decrease is likely related to the fact that the scallop production activities were basically halted during the CEN, which drastically reduced the need to interact with the aforementioned actors.

The majority of links sustained during the evolution of the CEN did not change their characteristics in terms of perceived helpfulness (Fig. 3b). In other words, a link that was positive before the abrupt environmental change was likely to still be positive during the event. Nonetheless, about one quarter of links perceived as very helpful before the CEN subsequently deteriorated in quality (Fig. 3b). Another third of the previously established relationships were not maintained during the CEN, further illustrating the substantial decrease in the size of the social networks studied here (Fig. 3a). This comes as no surprise, as relationships are often put to test during times of crises. The fisheries health agency was the only group for which a significant decrease in the helpfulness of interactions was observed (Fig. 4). Under normal circumstances, this actor fulfills a much-needed role for sustaining the scallop production cycle through regular environmental monitoring activities (a prerequisite for access to international markets). These activities, however, were drastically reduced in the months during and after the CEN. Some of the scallop farmers perceived this as an additional barrier for their production activities and were thus displeased with this actor.

Concomitantly to a decrease in the overall number of ties with companies, the coast guard and the fisheries health

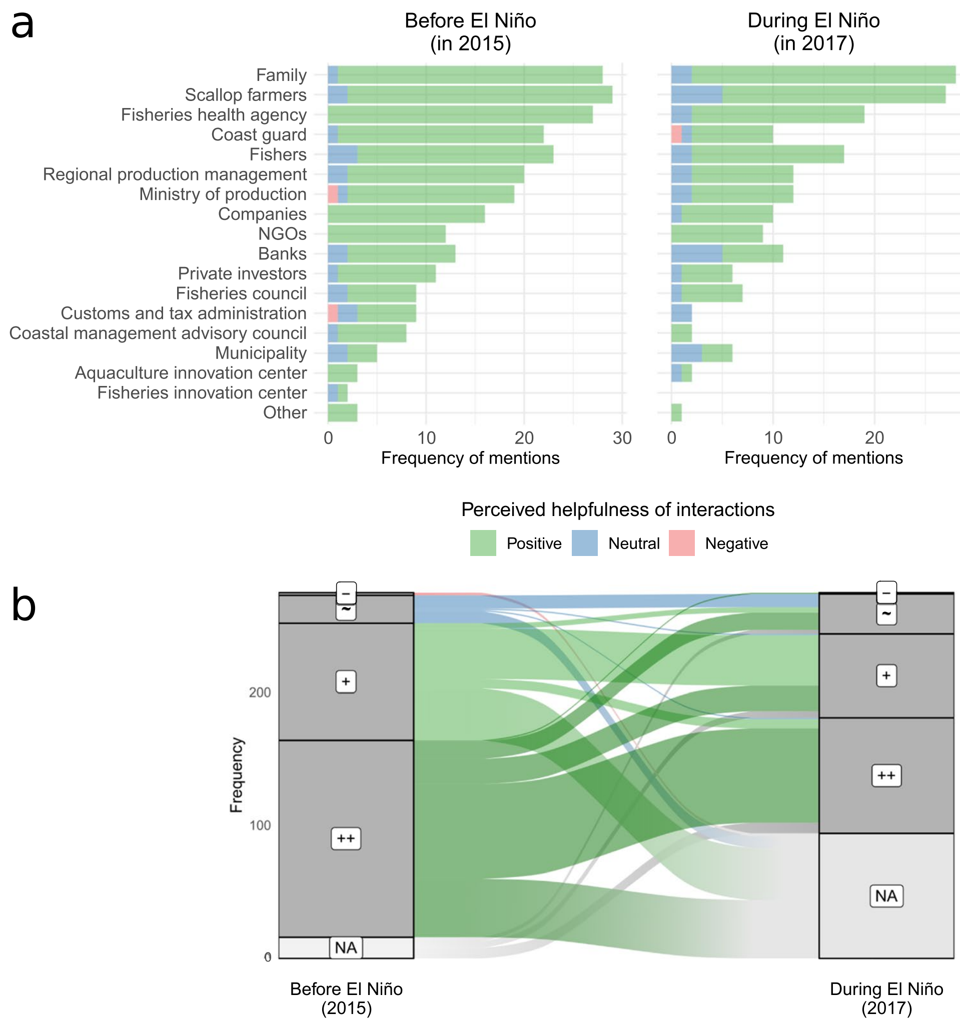

Fig. 3 **a** Bar plots showing positive (very helpful or helpful), neutral, and negative (harmful) links that scallop farmer associations ($n = 35$) had with different entities, presented separately for before the Coastal El Niño (CEN) (in 2015) and during the CEN (in 2017). **b** Alluvial plot showing the evolution of perceived helpfulness (very helpful + +, helpful +, neutral ~, harmful -; NA represents links non-existent in the respective year) of links ($n = 284$ with an attributed perceived helpfulness value in either 2015 or 2017) from before the Coastal El Niño (in 2015) to during the Coastal El Niño (in 2017). Alluvia width is proportional to the number of links in each category. Color corresponds to the perceived helpfulness in 2015 (very helpful, dark green; helpful, light green; neutral, blue; harmful, red). NA to NA links ($n = 191$) were omitted

agency (Fig. 3a), we observed that those scallop farmer associations which sustained relationships with these actors, in fact, significantly reduced the frequency of their interactions, as confirmed by the before-after analysis (Fig. 4; *cf.* Online Resource 5 illustrating the evolution of interaction frequency from 2015 to 2017). As scallop farmers stayed ashore during the CEN (due to strong rains) and were furthermore not producing and landing scallops in the months thereafter due to the die-off of their target species, certain relations became either obsolete or less important.

We had postulated that the social capital (operationalized by the number of positive relationships) of scallop farmer associations increases in times of hardship caused by an abrupt environmental change event (H1, Table 1). This was based on the rationale that resource users need enhanced support during times of crises and try to get it from others. More specifically, increasing the number of connections in scallop farmers' social networks may facilitate the access to limited resources, information, alternative coping pathways, and innovation opportunities (Marín et al. 2015). Surprisingly and contrary to our expectations, a significant reduction (by more than one-third) in the median number of positive links that scallop farmer associations exhibited was evident from 2015 to 2017 (Fig. 5a), as confirmed by a Wilcoxon test ($W = 395.5$, $p < 0.0001$). Rather than increasing, social capital decreased during the CEN event, contradicting Hypothesis 1. This result could be related to a general weakness of community support networks as well as the lack of adequate institutional assistance at the local level, especially in a disturbance scenario of this magnitude (French et al. 2020).

Social capital positively influences post-disaster trajectories of scallop farmers

In January 2018, almost 1 year after the onset of the CEN, scallop farmer associations were still struggling with the effects of the environmental disturbance, and not a single (interviewed) group had had the chance to harvest scallops at the time of the interview (*cf.* Kluger et al. 2019a). This was also reflected by the fact that none of the associations considered themselves to have reached normalization (i.e.,

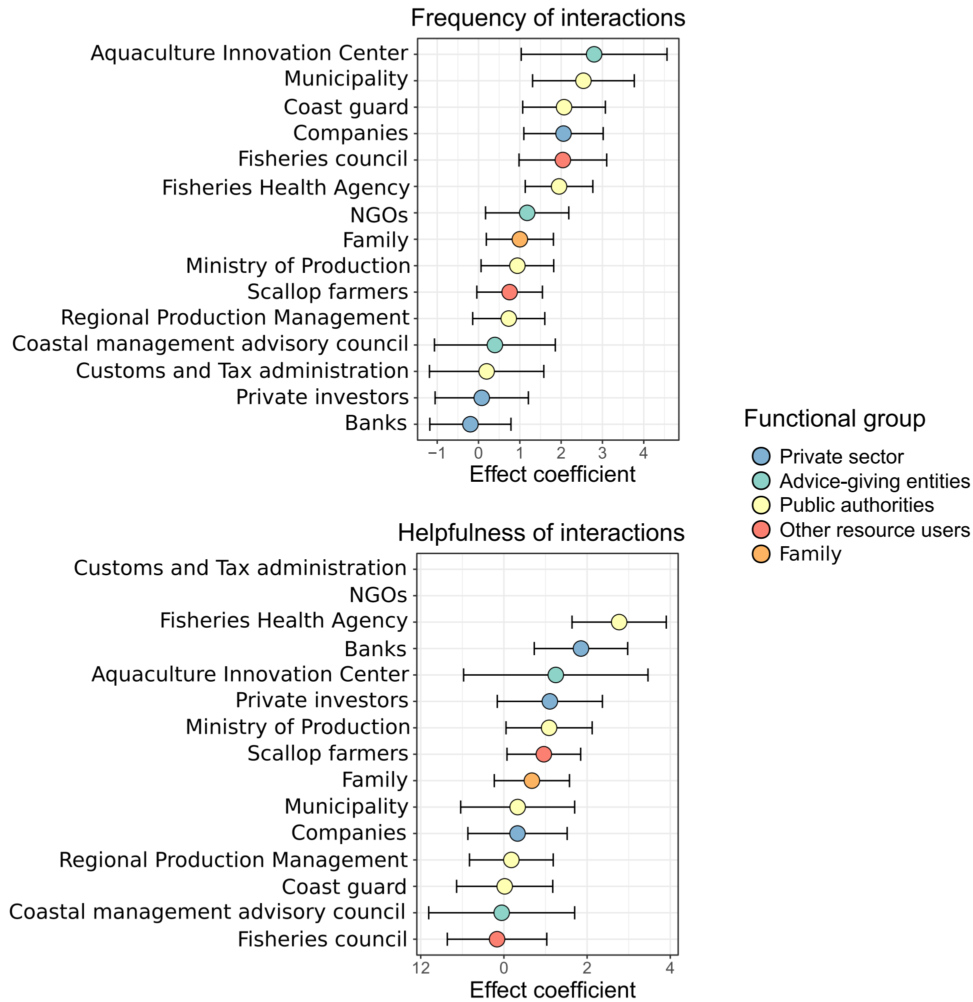

Fig. 4 Plots showing model coefficients (circles) and standard errors (bars) from cumulative link mixed models comparing relative changes in frequency (top) and helpfulness (bottom) of scallop farmer' interactions with alters from before the Coastal El Niño (in 2015) to during the Coastal El Niño (in 2017). The group of fishers was taken as a reference point for this analysis and is thus omitted (cf. "Data analysis"). Circles are colored according to functional groups of actors. Note: A positive effect coefficient corresponds to a decrease in helpfulness and interaction frequency, respectively, from 2015 to 2017

conditions comparable to before the CEN; Fig. 5b). Instead, the majority of scallop farmer associations (51.4%; $n=18$ of 35) perceived themselves to be on a recuperation pathway ("We still strive to move towards normalization") and, thus, on a positive path towards recovering pre-CEN conditions. 31.4% ($n=11$) of scallop farmer associations considered themselves to be in a state of stagnation ("We try hard, but we are still stagnant"), while 8.6% ($n=3$) of the scallop farmer associations stated that their association was in a status of recession, agreeing to the statement "There is no way we could recover." One association (2.8%) used "the opportunity to do new or different things" and was thus considered to be in a state of innovation.

We had hypothesized that social capital strengthens the resilience of scallop farmer associations to abrupt environmental change (H2, Table 1). In line with this argument, we found a significant positive relationship (Spearman's $\rho=0.570$, $p=0.0005$) between the post-disaster trajectories and degree centrality over the entire study period (Table 2). More specifically, scallop farmer associations exhibiting positive post-disaster trajectories (i.e., displaying higher resilience to the disturbance) also showed higher degrees of social capital (as operationalized by the number of positive links), supporting Hypothesis 2. This shows that scallop farmer associations that had more links before the onset of the event maintained a substantial part of their relationships throughout the evolution of the CEN and could draw upon their core network to more effectively cope with the sudden change in environmental conditions. This result is in line with evidence from the body of literature showing the importance of social capital for successful disaster recovery (from stochastic and rare events such as tsunamis and earthquakes) in various sites around the globe (Nakagawa and Shaw 2004; Duxbury and Dickinson 2007; Aldrich 2012b; McCarthy 2014; Marín et al. 2015; Panday et al. 2021). The results of this study contribute evidence on the importance of social capital for the resilience of resource users in the wake of drastic yet transient change brought along by a CEN event that occurs on a semi-regular and (comparatively) frequent basis. Hence, the findings show that social capital is an important driver not only for successful recovery from unexpected disasters for which small-scale businesses can

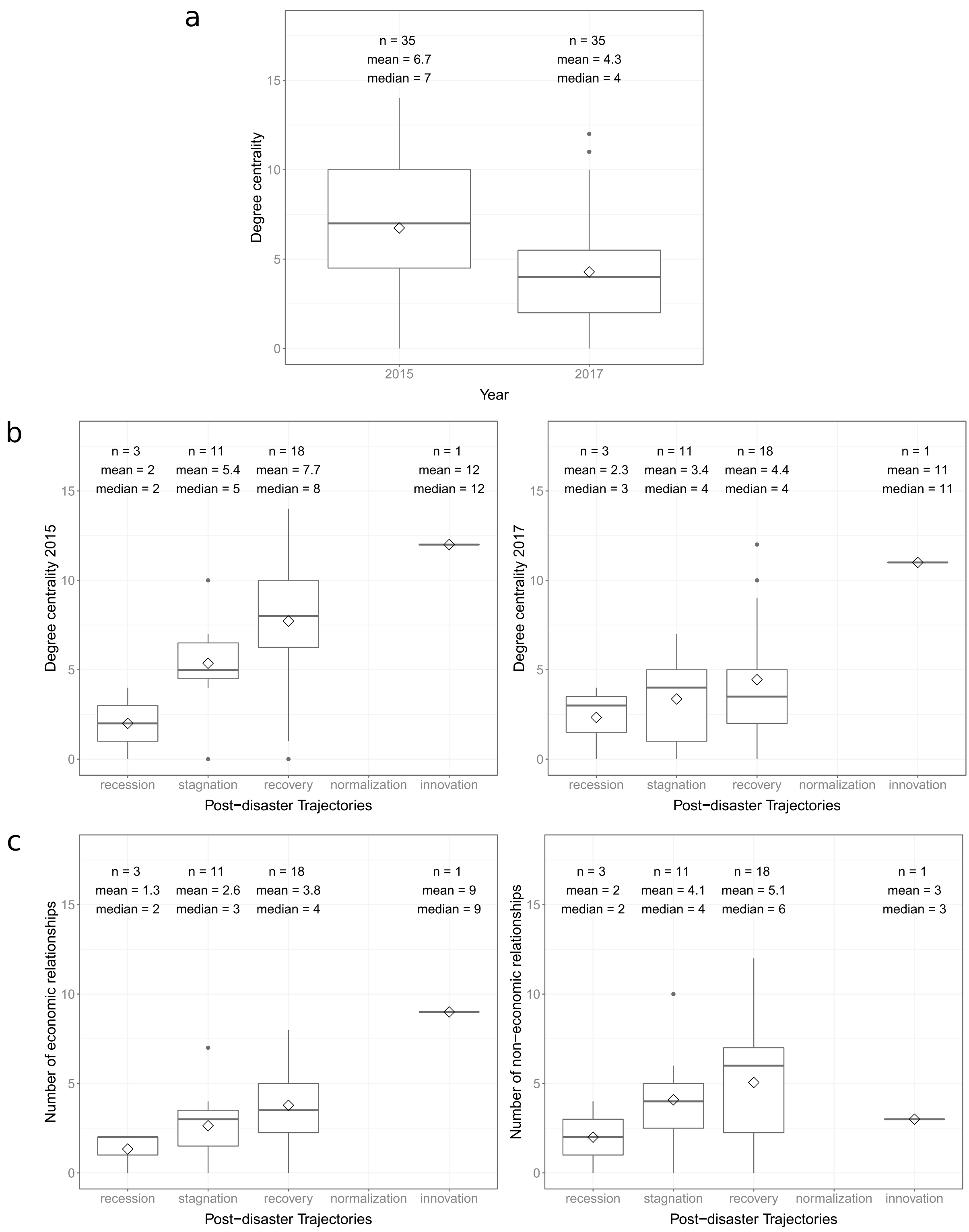

Fig. 5 Boxplots showing **a** the degree centrality (number of positive, i.e., very helpful and helpful links) of scallop farmer associations ($n=35$) before the Coastal El Niño (CEN) (in 2015) and during the CEN event (in 2017) (top), **b** the degree centrality (number of positive links) of scallop farmer associations separated by categories of post-disaster trajectories in 2015 (center left) and 2017 (center right), **c** the number of economic (bottom left) and non-economic (bottom right) links of scallop farmer associations separated by categories of post-disaster trajectories. Box extent represent quartile 1 (Q1) and quartile 3 (Q3), while whiskers indicate the minimum (Q1-1.5*interquartile range) and maximum (Q3 + 1.5*interquartile range). The median (solid line) and mean (diamond) degree centrality are given. Outliers are indicated by black dots

Table 2 Spearman rank correlation between the post-disaster trajectories of scallop farmers ($n=33$) and the degree centrality (number of positive links) (a) over the entire study period, (b) before the Coastal El Niño (in 2015), and (c) during the CEN (in 2017) as well as between post-disaster trajectories of scallop farmers ($n=33$) and the number of (d) economic and (e) non-economic links

		Spearman coeff	*p*-value
a	Degree centrality — overall	0.570	**0.0005*** **
b	Degree centrality — 2015	0.590	**0.0003*** **
c	Degree centrality — 2017	0.255	0.151
d	Degree centrality — economic	0.427	**0.013***
e	Degree centrality — non-economic	0.271	0.127

Significant correlations (* for $p < 0.05$ and *** for $p < 0.0005$) are highlighted in bold

hardly prepare, but also for unpredictable yet reoccurring environmental crisis. This highlights the importance of supporting local small-scale businesses to build-up social capital as a distinct point of leverage to increase coastal livelihood resilience in areas prone to periodical environmental disturbances.

Considering the temporal dimension of the influence of social capital on coastal livelihood resilience, we postulated that building social capital *before* a disturbance event is particularly important for scallop farmer associations to deal with abrupt environmental change (H3, Table 1). Temporally disentangling the found correlation between post-disaster trajectories and the degree of social capital (see above), we observed that it was intensified when only considering degree centrality before the CEN (Spearman's $\rho=0.590$, $p=0.0003$) and vanished when only considering the degree centrality during the CEN (Spearman's $\rho=0.255$, $p=0.151$; Fig. 5b, Table 2). That is, the number of links scallop farmer associations exhibited before the disturbance was indicative of their post-disaster trajectories, while the number of links that interviewed associations had during the CEN was not. This provides strong support for Hypothesis 3. These results show that maintaining an extensive social network under normal circumstances is a key precursor for resilience and recovery after abrupt environmental change as built relationships can be activated and drawn upon during times of crisis (e.g., to facilitate access to scarce funds and/or crucial information). Thus, building up a large set of relationships facilitates coping with the effects of sudden changes in the environment. Extending networks only in times of need is not sufficient.

These findings support the results of a previous study by Marin and colleagues (2015) who similarly investigated the evolution of social capital (operationalized by the social relationships established in the context of the local resource use setting) of fishing communities after a tsunami in Chile. The study found that extensive social networks and/or the buildup of links from before to after the disturbance event was indicative of positive post-disaster trajectories (potentially even more so than external factors such as degree of isolation or level of damage). While the second part of this finding (i.e., the buildup of links) appears to stand in contrast to our results at first glance, it is important to mention that Marin and colleagues (2015) investigated the role of social capital on the long-term recovery trajectories of fishing communities (i.e., before and 6 years after the tsunami), while our study sheds light on the short-term response (resilience) of scallop farmer associations to an El Niño–induced disaster. It is worth noting that Chilean fisher communities that showed a reduction in social capital (as was the case for most of the studied scallop farmer associations in our case) had at best reached a recovering stage even years after the tsunami hit (*cf.* Fig. 2 from Marín et al. 2015), emphasizing that recovery from disasters is often a long-term process and effective mitigation of severe impacts thus imperative. In this sense, our results complement the study by Marín et al. (2015) by highlighting the short-term effects of an El Niño-induced abrupt environmental change on resource users' social networks and demonstrating how robust and reliable social capital built before a disturbance event positively shapes proximate trajectories in times of crises and beyond. Hence, social capital is important not only for recovery from disasters in the long term (Marín et al. 2015), but also for coastal livelihood resilience to abrupt environmental change in the short term. Moreover, these findings contribute strong evidence highlighting the importance of considering a temporal dimension when studying the role of social capital in the context of abrupt environmental change and disasters (e.g., Nguyen-Trung et al. 2020). Tracking the evolution of social capital and the trajectories of scallop farmer associations in Sechura Bay over a longer timeframe would thus be an important topic of research for future studies.

Having illustrated the role of social capital of scallop farmer associations in coping with El Niño–induced abrupt environmental change in the previous sections, the question remains about the specific role of different link types: We had hypothesized that the existence of economic relationships positively influences post-disturbance trajectories when scallop farmer associations are confronted with abrupt environmental change (H4, Table 1). The degree centrality over the entire study period was therefore re-calculated for economic and non-economic links separately (Online Resource 4). We found a significant positive relationship between the number of economic links and post-disaster trajectories (Spearman's $\rho=0.427$, $p=0.013$), while no such correlation was found for non-economic relationships (Spearman's $\rho=0.271$, $p=0.127$, Fig. 5c, Table 2), supporting Hypothesis 4.

These results suggest that maintaining positive relationships with a diverse set of economic actors (rather than a single one) strengthens the resilience of small-scale aquaculture businesses, as this likely facilitates the access to funds that help re-initiating activities after abrupt environmental change (Ferrol-Schulte et al. 2013; González-Mon et al. 2019) and thus serve as a "booster" for the recovery process. Nonetheless, the role of non-economic links can certainly not be neglected and more research on the specific modes of action of specific link types is required. More specifically, strengthening relationships (e.g., with government authorities and NGOs) that, for instance, provide information to better anticipate periodic environmental change events or provide training on how to deal with such events, offer great potential to enhance the resilience of coastal communities.

A single scallop farmer association used the difficult situation during the CEN as "an opportunity to try something new" (i.e., category "innovation"; *cf.* Fig. 5c). Interestingly, this association also exhibited the highest number of economic links among all interviewed associations. This may suggest the existence of an interdependency between financial capital and the innovative capacity of an actor. In other words, promoting the build-up of large networks with a particular emphasis on financial capital may enable small-scale coastal resource users to activate their innovative potential (Bradley et al. 2012; Kleih et al. 2013) and further increase their resilience towards changing environmental conditions and shifting management setting.

Discussion

Social capital, i.e., the value of relationships that enable effective cooperation and collaboration (Portes 1998; Putnam 2000; Lin et al. 2001), has been postulated to enhance the capacity of marine resource users to cope with disasters. Building on this idea and taking the case of a Peruvian bay influenced by multiple drivers of change (from natural to anthropogenic) and characterized by rapidly and erratically changing environmental as well as socio-economic conditions, we studied how small-scale mariculture operators coped with the effects of a severe Coastal El Niño event that unfolded in early 2017 (Kluger et al. 2019a). Adopting a longitudinal mixed-methods approach, we analyzed resource users' ego-networks to shed light on the role of social capital for the resilience of small-scale mariculture businesses in the aftermath of a disaster that turned the Sechura Bay ecosystem as well as the lives of local communities upside down.

Following the onset of the Coastal El Niño event, we observed a drastic decrease in the degree of social capital among small-scale aquaculture operators (operationalized by the amount of helpful links present in the ego-networks). About 1 year after the disaster unfolded, mariculturists embedded in extensive networks of helpful social actors were found to be on more desirable post-disaster trajectories than those with fewer connections. Results revealed that the number of relationships resource users established *before* the environmental disturbance, in fact, significantly correlated with their coping trajectories and thus presumably strengthened their resilience towards the disaster. Both economic and non-economic relationships contributed to the found patterns.

Previous studies have hypothesized that helpful social relationships can increase the resilience of the small-scale aquaculture sector but lacked the necessary data to test this assumption (López de la Lama et al. 2018). Our study fills this important knowledge gap, confirming the proposed hypothesis and substantiating it with both quantitative and qualitative data tracking the evolution of social capital of marine resource users amidst abrupt environmental change. Even though the found evidence is consistent with expectations from the literature, the proof that the observed strong linkage between degree of social capital and post-disaster trajectories is in fact a causal relation, and not mere correlation, is pending (i.e., does access to large networks make actors truly more resilient or, vice versa, are resilient actors simply better in building networks?). Nevertheless, our findings — incorporating two distinct points in time — suggest that it is indeed the social capital built *before* the event that entails the described positive effect.

An advanced understanding of the factors that foster livelihood resilience among marine resource users is urgently needed to sustain the well-being of coastal communities (Folke 2006). In this vein, this study indicates that enhancing social capital may be a powerful way of enhancing the resilience of small-scale resource users towards abrupt environmental change. Building upon the core idea that social relationships facilitate the access to valuable resources such as information, knowledge and influence (Bebbington 1999; Adger 2003), our findings entail important insights on how small-scale businesses in the fisheries and aquaculture sector can best prepare, and be best supported for dealing with erratic events of environmental change. While the impacts of each individual disaster (such as the Coastal El Niño studied here) are case-specific, vary regionally, and therefore require a tailored response, the critical role of social capital in coping with disasters appears to be consistent across different types of disasters in different geographic regions (*cf.* e.g., Marín et al. 2015; Masud-All-Kamal and Monirul Hassan 2018; Panday et al. 2021). Such knowledge is gaining particular importance as disasters around the globe are forecasted to increase in frequency and severity in the wake of advancing climate change and perpetuated resource overexploitation (Hughes et al. 2007, 2013; IPBES 2019; IPCC 2019, 2021; MEA 2005).

The evidence presented in this article is of immediate relevance for practical implementation in the studied system as well as in comparable settings: Enabling resource users to build the connections that strengthen their resilience and adaptive capacity in the event of a disaster is imperative. Establishing knowledge exchange platforms, promoting cross-level training opportunities, or supporting co-management initiatives may all constitute viable ways to kick-start exchange and connections among entities across power and/or authority gradients, with the ultimate goal of building functioning networks that persist through time.

In situations where the amount of damage inflicted by environmental disasters surpasses levels that can be cushioned by effectively operating social networks (Lohmann and Lechtenfeld 2015), the question arises whether "going back" to pre-disaster conditions is desirable, or if adaptation through innovation constitutes a more worthwhile solution. Throughout our study, we have tracked the efforts of a single association self-identifying as being on a trajectory of "innovation." The level of social capital for this association ranged among the highest values of all interviewed associations and — as opposed to the general trend laid out in this study — this group did not experience a significant reduction in the size of its social network during the evolution of the Coastal El Niño. Even though generalization from a single observation is difficult, this finding may nevertheless suggest a strong interlinkage between the ability to implement transformation processes on the one hand, and the existence of social capital (in the form of network size and stability) on the other. Further research on the factors that foster innovative capacity may yield interesting insights in this regard.

Conclusion

Our study contributes innovative insights in at least two important ways: First, while research on networks in the field of environmental governance and resource management has significantly grown in recent years (see Bodin 2017; Kluger et al. 2020), scientific understanding of the role of social capital in the context of environmental crisis is still limited. Following other studies that establish the importance of social capital for recovery from disasters (e.g., Marín et al. 2015), this research investigates different forms of social capital in the aquaculture sector and illustrates the importance of temporal dynamics in this context. We thus provide novel insights on key determinants of social capital that contribute to the resilience of marine resource-dependent livelihoods when faced with disaster. Second, the study contributes actionable knowledge of high practical relevance that can guide decision-makers in their attempt to support the resilience of coastal communities and safeguard marine food security. Specifically, the results entail important knowledge on how small-scale businesses in the fisheries and aquaculture sector can best prepare, and be best supported for dealing with disasters that are expected to increase in frequency as global environmental change accelerates (IPCC 2021).

By shedding light on the role of social capital of small-scale resource users before and shortly after the onset of an El Niño-induced disaster, we uncovered a new piece of the marine resource management puzzle. Based on our findings, we encourage decision-makers seeking to increase the resilience of the marine resource sector in the face of future disasters to invest in the creation of "spaces" (both physical and institutional) that promote meaningful exchange among stakeholders and allow coastal communities to build useful connections with relevant actors across hierarchical levels that could potentially mitigate the impacts of disasters. While our study emphasizes the importance of social capital for dealing with "blue crises" and thus pinpoints a suitable point of departure for adaptive management actions, the role of natural capital, i.e., species or ecosystems that sustain the flow of goods and services into the future, can certainly not be neglected in the decision-making process. Future research should therefore increasingly incorporate the intricate interplay between society and nature: Employing a social-ecological network approach (i.e., connecting the social and ecological domain) may be a viable way towards a holistic understanding of human-nature interactions and dependencies (for recent reviews on this topic, see Kluger et al. 2020; Sayles et al. 2019) and contribute additional facets to our understanding of resource users' resilience to environmental change in a future high-CO_2 world.

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Declarations

Conflict of interest The authors declare no competing interests.

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