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Disaster impacts on co-management networks: longitudinal and comparative analysis of Chilean small-scale fisheries

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Recent studies have highlighted the relational nature of co-management and investigated which kinds of social network structures define its possibilities to perform, adapt and deal with uncertainty and change. However, there is less understanding about the impacts of disasters and abrupt perturbations on co-management networks. Here we present a social network analysis of the impacts of the 2010 tsunami on co-management in the Chilean fishery. Based on data collected in 21 fisher organizations in the Bio-Bío region, heavily impacted by the tsunami, we assess whether and how co-management facilitating and hindering social relationships have changed after the event, as compared to 16 non-impacted organizations in the Valparaíso region. Baseline data (i.e., 2008) from both regions allows for before-after longitudinal analysis. Our findings show that after the tsunami, co-management networks in Bio-Bío present reduced fragmentation and higher levels of perceived trust among actors in comparison to the non-affected region. A slightly lower tendency towards decentralization was also observed. These findings suggest that post-disaster adjustments have occurred within the same networks. Co-management networks were flexible enough to be rewired as a consequence of abrupt perturbations triggered by the tsunami. Participatory network-based interventions, such as the Chilean MEABR co-management policy, provide a stable and at the same time adaptive setting to respond to coastal disasters.

KEYWORDS

artisanal fisheries, benthic resources, territorial user rights, hazards, adaptation, marine governance, social network analysis

1 Introduction

Collaborative management or co-management in fisheries is a particular form of marine governance that considers the participation of and power-sharing among multiple community, state and private sector actors in the use and exploitation of marine and coastal resources. Co-management is a relational institution where trust, social learning and cross-scale interactions among actors are permanently fostered and challenged (Cundill and Fabricius, 2010; Druon et al., 2023). In practice, the ways in which the relationships among the parties are established are likely to affect the mobilization of and access to key social assets and information (Crona and Bodin, 2006), and therefore to determine actors' capacity to perform and respond to increased human and natural-driven pressures and perturbations (Grafton, 2005; Bodin and Crona, 2009).

The great reliance of co-management on the structure and dynamics of underlying social relationships has fostered vast research and policy opportunities for the use of network-based frameworks and tools (Carlsson and Berkes, 2005; Sandström et al., 2014; Alexander et al., 2015; Cohen and Steenbergen, 2015; Fratsea and Papadopoulos, 2022; Gomez-Andujar et al., 2022; Zetina-Rejón et al., 2022). Recent studies have investigated which kinds of social network structures better accommodate collaborative management to deal with uncertainty and change. Sandström and Rova (2010) have argued that adaptability can be expected to be higher in co-management systems with higher levels of network closure (i.e., high density and/or centralization). Similarly, Oyanedel et al. (2016) found that collective action among heterogeneous stakeholders is facilitated by higher levels of network cohesion, which creates enhanced flows of information and resources (i.e., density; see Bodin et al., 2006) and increased coordination capacity (i.e., centralization; see Crona et al., 2011). Alexander et al. (2015) describe the potential negative effects of network fragmentation on fisheries co-management networks.

While there is growing consensus about the benefits of collaborative governance of natural resources to enable more adaptive responses to environmental change (Tompkins and Adger, 2004; Adger et al., 2005), there is less understanding on how established governance networks are impacted as a consequence of abrupt perturbations in general (Bodin and Prell, 2011), and of environmental disasters in particular (see Bodin and Nohrstedt, 2016). Environmental disasters (hereafter disasters), such as tornados, hurricanes, earthquakes and tsunamis often drive changes –e.g. threats to life, material devastation, natural resource loss, and ecosystem transformations—to which individuals, communities and agencies must respond and adapt. The rapid emergence of pressing needs vis-à-vis limited availability of relief and recovery resources, can be expected to modify the ways actors relate to and collaborate/compete with each other. Disaster contexts, representing abrupt environmental and social changes, allow investigating governance networks (e.g. Snijders, 2001), with special reference on how “actors, intentionally or not, change and adapt themselves and their relationships as a result of dynamic changes in the social and ecological contexts” (Bodin and Prell, 2011, p. 364). While some authors have suggested that adaptive

changes occur within existing networks and that these may or may not be re-wired to better respond to new challenges (Jones et al., 1997; Bodin and Crona, 2009), others have argued that actors activate dormant structures (e.g. shadow networks) or develop new networks (e.g. skunkworks) to respond to threats (Olsson et al., 2006; Goldstein, 2008; Bullock et al., 2012). In the face of unprecedented environmental transformations, addressing questions about change, response and adaptation of governance networks within social-ecological systems is a priority. Such an effort implies moving from static to dynamic assessments and gathering longitudinal network data (see Sandström and Rova, 2010; Stein et al., 2011; Bodin et al., 2019).

The aim of the study is to investigate the impacts of the 2010 tsunami on co-management networks in the small-scale benthic fishery in Chile. Therefore, we adopt a social network analysis approach (Scott, 2013) and a longitudinal and comparative research design (Menard, 2002). We draw on pre and post-tsunami data on coastal fisher organizations in Bio-Bío and Valparaíso regions, and use the latter as a non-impacted reference group in a quasi-experimental design. Although tsunami run-up was reported in southern Valparaíso, it was substantially lower than those reported in Bio-Bío (Fritz et al., 2011) and caused no damage on fisheries (Marín et al., 2010). In this context, the research objectives are to: (1) describe and compare pre and post-disaster co-management social networks –between impacted and non-impacted settings, in terms of size, composition, cohesion, levels of trust of constituting relationships, and the centrality of involved actors; (2) analyze the implications of the changes observed in terms of the long-term adaptability of the co-management arrangement to disasters. Available data offer a unique opportunity to outline lessons and open questions regarding the unexplored study of change and adaptation in resource and environmental governance networks.

2 Materials and methods

2.1 The Chilean co-management system for small-scale fisheries

This study focuses on coastal small-scale fisheries in central-south Chile and particularly on fisher organisations participating in a co-management system, called Management and Exploitation Areas for Benthic Resources (MEABR; Castilla et al., 1998). Benthic resources include mollusks, crustaceans and seaweed species, inhabiting near-shore rocky and sandy seabeds, which are extracted in Chile for commercial purposes and sold both domestically and internationally. The MEABR system was institutionalized by Law in 1991 in response to a benthic resources overexploitation crisis with highly negative social and economic effects (Castilla, 1994; Gelcich et al., 2010). The policy was formally implemented nationwide in 1997 after a trial period including several pilot cases in central Chile (Castilla, 2010). Currently, there are more than 500 operative areas along the country, with more than 16,000 formally registered users (Albornoz and Glückler, 2020). The MEABR regime allows organized small-scale fishers to apply for exclusive territorial user

rights over a portion of coastal seabed and the benthic resources within. Drawing on a base-line study and a management plan elaborated by hired fishery consultants, fisher organizations sign a four-year renewable agreement with the state. Total allowable catches (TAC), ranging from 15 to 25 percent of the total stock inside the MEABR, are established annually for specific target species in each area. The main target species exploited under the MEABR system include 'loco' (*Concholepas concholepas*), 'lapas' (*Fissurella* spp.), 'erizo' (*Loxechinus albus*), clams (*Venus antiqua*) and various species of seaweed (e.g., *Lessonia trabeculata*; *Gracilaria* sp.) (Gelcich et al., 2006; Gelcich et al., 2010; Marín et al., 2014).

MEABR users include fishers and hookah-divers operating from 5 to 8 meter deckless boats, equipped with off-board engines, and seaweed gleaners (mostly female) working either with or without boats (Marín et al., 2015a). Their activities are associated with fishing *caletas* (coves in English; see Castilla et al., 1998), referring to landing and mooring sites and to the coastal villages that develop around them (Aburto et al., 2009). *Caleta* facilities normally include basic port infrastructure (e.g., a pier or ramp, stowage for equipment and gear, and office/meeting room). In some cases, there are also restaurants, seafood/handicrafts vending stalls and tourism services administered by local fishers.

The study covers two non-adjacent administrative regions of Chile, namely Bio-Bío (36°46'S – 73°03'W) and Valparaíso (33°03'S; 71°38'W). The former is among the three most important regions in terms of small-scale fisheries in general, and of benthic resources catch in particular. The latter is the centre of national fisheries policy-making as it hosts the headquarters of SUBPESCA and the National Congress. In terms of users, in 2014 more than 23,300 fishers were registered in Bio-Bío and 5,200 in Valparaíso, representing 25 and 6% of Chile's artisanal sector, respectively. In terms of MEABR produce, between 2008 and 2014 annual average regional landings of molluscs was 254 tons in Bio-Bío (mainly 'loco', 'navajuela'/*Tagelus dombeii* and 'huepo'/*Ensis macha*) and 43 tons in Valparaíso (mainly 'loco' and 'lapas'). In the same period, annual landings of seaweed from MEABR averaged 153 tons in Bio-Bío (e.g., 'pelillo'/*Gracilaria* sp. and 'chicoria'/*Chondracanthus chamissoi*) and 502 in Valparaíso (e.g., 'huiro palo'/*Lessonia trabeculata*).

2.2 Actors of fisheries co-management governance

Original conceptions about co-management were grounded on a dyadic relationship between resource users and the State, in which management power was transferred or devolved from the authorities to organized local communities. Subsequent approaches evolved from the "Two to Tango" metaphor (Pomeroy and Berkes, 1997), to the "Three to Tango" analogy to include for instance the role of scientific/local knowledge providers and holders (Castilla, 2008)¹ and international donors (Ho et al., 2016) in co-management development. More recently, co-management representations have evolved towards a governance approach, to describe the broader and more diverse participation of stakeholder groups playing multiple roles and functions (Carlsson and Berkes, 2005; Alexander et al., 2015). Pinkerton (1989), for

instance, identifies seven functions of co-management, including data gathering; logistical decision-making (e.g., who can harvest and when); and protection of resource from environmental damage, which are often fulfilled by diverse and multiple actors.

In Chile, in addition to fisher organizations, fishery authorities, and biological consultants, many other public and private actors participate and affect the functioning and performance of MEABR (Gelcich et al., 2006; Marín et al., 2012; Rosas et al., 2014). These include national and regional fisher associations, market agents, territorial authorities, international and civil society organizations, which play important roles and provide support to fishers, for instance in regards to funding, marketing, research and development initiatives (Marín and Berkes, 2010; Albornoz and Glückler, 2020).

2.3 The coastal disaster as a driver of change

In February 2010, an 8.8 Mw earthquake struck central Chile and was followed by a tsunami (Castilla et al., 2010; Fritz et al., 2011) with devastating social and economic consequences, especially for the small-scale fishery sector. In Bio-Bío, the tsunami impacts included the reduction of up to 60% of fishing capacity due to loss of vessels and gear, port infrastructure, and commercial facilities (Marín et al., 2010).

In the aftermath of the disaster, several public and private, national and international aid programs provided fishers with new or repaired vessels and equipment to resume their activity, and by the end of 2010 the Bio-Bío small-scale fishery started showing symptoms of recovery (Marín et al., 2015). In addition to the direct effects of the earthquake movement, a coseismic uplift of up to 1.6 meter triggered abrupt ecosystem transformations along Bio-Bío's coasts (Castilla et al., 2010). Associated loss of rocky intertidal ecosystems, alteration of sandy bottoms generated dramatic changes on benthic fisheries in general, and within MEABR in particular (Instituto de Fomento Pesquero – Servicio Nacional de Pesca, 2012). The latter produced uncertainty regarding coastal physical conditions and the survival and/or displacement of benthic species—with important consequences on the overall administration of MEABR. In the following years, a number of technical studies were carried out to assess post-disaster conditions of benthic ecosystems and to redefine MEABR locations, management plans and total allowable catches (IFOP, 2012). In summary, the reduction of fishing capacity, the occurrence of disasters, and the resulting socio-ecological uncertainty after the impacts, defined a temporary new scenario that challenged the functioning of MEABR and the underlying co-management network in Bio-Bío.

Co-management governance networks are likely to affect and be affected by the broader political and institutional context (Léopold et al., 2019). Other political and policy milestones in Chile marked the

¹ Castilla, J. C. (2008). Three to tango: coastal fishery paradigm shiftings in Japan and Chile. Presentation at the Resilience Alliance meeting in Chile (January 2008), (Unpublished).

period following the 2010 disaster with possible effects on the small-scale fishery sector. In March 2010, the newly elected President initiated its 4-year period with the task of reconstructing part of the country devastated by the earthquake and tsunami. The incoming government implemented new political orientations and the redesign of public policy (e.g., self-proclaimed as “the new way of governing”; see [Ikes, 2011](#)), with emphasis on spending efficiency, modernization, individual initiative and enterprise (see [Elacqua and Aninat, 2013](#)). In 2012, the 1991 Fisheries and Aquaculture Law began to be revised triggering major debates nationwide ([Witte-Lebhar, 2012](#)). Among many changes, the resulting Law (No. 20.657, 2013) instituted novel coastal management mechanisms (e.g., benthic management plans and committees for large areas) and several operational MEABR policy adjustments (e.g., abolition of the user-right fee) that directly concern the small-scale fishery sector under study.

2.4 Data collection and analysis

The study covers 21 fisher organizations in Bio-Bío and 16 in Valparaíso ([Figure 1](#)) ([Marín et al., 2015b](#)). These organizations have on average 72 members (ranging from 550 to 15) in the former, and 48 (ranging from 15 to 120) in the latter. In terms of gender, studied organizations include mostly men; however, mixed memberships are frequent and few women organizations also exist (e.g., gleaners).

Data were collected using a semi-structured questionnaire applied to the elected leaders of the organizations. The questionnaire was applied to the same sets of organizations, first in 2008 in both regions (i.e., before the tsunami) and then in 2013 in Bio-Bío and during 2013 and 2014 in Valparaíso (i.e., after the

tsunami). In 2008, a purposive sampling criterion was used to cover as many organizations as possible given time and resource limitations. At that time, the sample represented 64% and 50% of the organizations involved in the MEABR system in Valparaíso and Bio-Bío, respectively. Subsequently, in 2013, we collected data from the same organizations with comparative purposes (nearly one third of leaders were the same person as in 2008). Only one fisher organization surveyed in 2008 in Bio-Bío was excluded from the study as it no longer existed in 2013. For confidentiality, the authors decided to omit the names of the organizations; but they are available upon request for research purposes. It is important to highlight that the study is focused on inter-organizational networks around a formal and regulated activity. Therefore, fisher leaders are selected as relevant representatives and informants with respect to co-management and associated relationships (for a similar approach see [Aranda-Fragoso et al., 2020](#)).

The core questions of the survey aimed at describing relationships established by fisher organizations (i.e. the focal actors) with 26 actors at regional, national, and international levels (i.e. termed hereafter co-management counterparts) with respect to the overall functioning of their MEABR. Co-management counterparts were identified in 2008 during a qualitative-exploratory phase of the study and were subsequently included in an open-ended list presented to fisher leaders. The fisher organizations surveyed were not included in the list of counterpart actors. Interviewees were asked to respond three relational questions about the actors in the list using pre-defined response categories. First they were asked to characterize the kind of participation of each of the actors in the development of their MEABR as either “no participation”, “facilitating”, or “hindering”. The same categories have been used in other network studies to survey resource

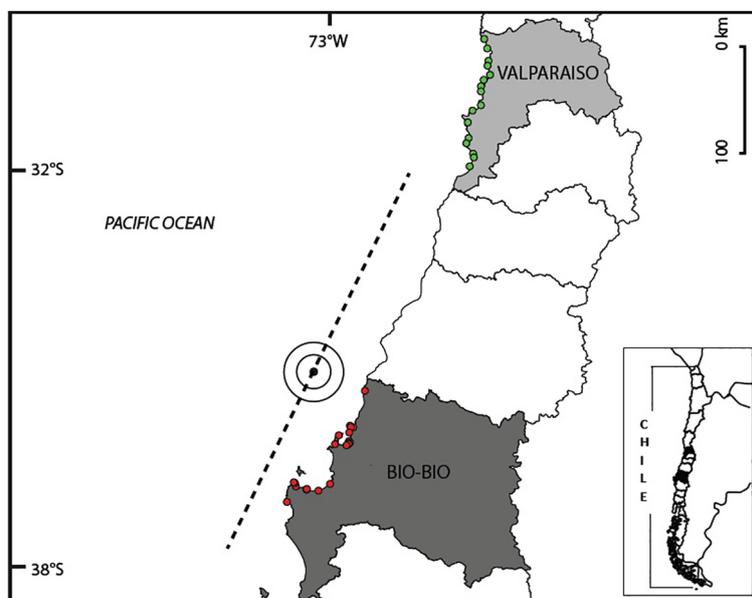


FIGURE 1

The two study regions and the thirty-seven study sites in center-south Chile. Concentric circles mark the 2010 earthquake epicenter and dotted line indicates the impact area of the associated tsunami. Red and green circles show the location of 21 and 16 fisher organizations in BioBío (impacted by the tsunami) and Valparaíso (group of reference) covered in the research, respectively.

management relationships and depict a more realistic representation of co-management arrangements (Mills et al., 2014; Alexander and Armitage, 2015). Second, for those actors whose participation was described as facilitating, informants were asked to qualify their relationships with them –using Likert scales– in terms of trustworthiness (i.e., 1=highly trustworthy to 4= no trustworthiness at all). Trust represents a key ingredient of social capital and collaboration in co-management governance (Fratsea and Papadopoulos, 2022). And third, fisher leaders were also able to nominate other actors originally not included in the roster.

The data collected were stored as affiliation or two-mode network matrices, and analyzed using social network analysis tools (Scott 2013). Two-mode networks represent the relationships between two sets of actors (Borgatti and Everett, 1997): 1) fisher organizations and 2) co-management counterparts. Network measures used include basic descriptive statistics (e.g., size of the networks or the number of ties), 2-mode network cohesion metrics (e.g., density, fragmentation and centralization), and 2-mode centrality indicators (e.g., in-degree centrality). The definitions and implications of these measures are presented in Table 1.

The temporal comparisons sought to identify differences in network patterns obtained before and after the occurrence of the tsunami in Bio-Bío. In parallel, the assessment of changes in Valparaíso during the same period (i.e., without tsunami impact), allowed us to assess whether the trends are more or less pronounced in Bio-Bío than in the reference group. All network analyses were done using UCINET (Borgatti et al., 2002). Network diagrams were created with NetDraw (Borgatti, 2002), using a spring embedding layout with node repulsion and equal edge length bias layout. This approach tries to pair nodes closer in a two-dimensional space, based on how similar they are to one another; thereby, nodes with more shared ties are put closer together and others are moved away.

In addition, we collected complementary qualitative information in Bio-Bío after the disaster to learn about impacts, responses and recovery challenges. We interviewed ten key informants from the public (e.g., SUBPESCA, SERNAPECSA, and Municipality), private (e.g., fishery consultants) sectors and representatives of small-scale fishery associations (e.g., Regional Federation leaders). This information was recorded and transcribed, but not systematically analyzed, and is regarded as

TABLE 1 Two-mode network measures used in the study.

	Definition/ measurement	Potential effect on co-management networks	Visual examples (*)	
			High	Low
Network level				
Density	Number of observed ties divided by the theoretical maximum number of ties.	High-density networks may benefit the spread of information and the development of trust among stakeholders, but may also lead to the homogenization of experience and knowledge (Bodin et al., 2006).		
Centralization	Extent to which a network has a highly central actor around which highly peripheral actors collect.	High centralization can be associated with increased coordination capacity, but may also lead to over-centralized decision-making (Everett and Borgatti, 2005; Crona et al., 2011)		
Fragmentation	Proportion of nodes that cannot reach each other.	Highly fragmented 2-mode networks indicate the presence of isolates and with reduced connectedness among actors' sets (Borgatti et al., 2013).		
Actor level				
Out-degree centrality	Number of relationships that an actor declares (here fisher orgs.), expressed as a proportion over the maximum.	Actors with higher out-degree have greater access to multiple sources of support, resources and information, and thus are expected to perform better than others (Borgatti et al., 2013).		
In-degree centrality	Number of relationships that an actor receives (here, co-management counterparts), expressed as a proportion over the maximum.	Actors with higher in-degree represent more prominent sources of support, information and resources; they may exercise greater influence and power over others (Borgatti et al., 2013).		

(*) In the visual examples, lines stand for social ties. Circles represent the focal points (i.e., set of actors surveyed) who provide information about their out-coming ties with others. Squares represent the second set of actors (i.e., actors nominated by focal points as having in-coming ties with them). Black colour highlight the actors to which the respective network measures refer.

part of the knowledge base applied in this study to interpret the results of the network analysis.

3 Results

Overall, when performing the longitudinal comparison of co-management social networks for both regions, changes can be observed both from an actor and a network-level perspective. We present the results focusing first on describing network size, composition and cohesion; and then, we assess centrality positions of actors within the networks. Complementarily, we use network graph lay-outs to qualitatively analyze relational patterns between fisher organizations and their counterparts.

Network size and composition

Results in [Table 2](#) show that the size of Bio-Bío's co-management network increased after the tsunami. Based on the nomination of relevant actors (i.e. nominated by informants as "other actors" to the open-ended list), results indicate that fishers in Bio-Bío report seven new actors. These include government funding and co-funding programs (e.g. FIP/FAP, Volvamos a la Mar), civil society and private initiatives (e.g. Un bote para Chile, Mar de Esperanza), and international NGOs (e.g. Red Cross, Caritas). In Valparaíso, only two new actors were mentioned in 2013/14 (i.e., MOP and FIP/FAP). These new actors added by the informants after the disaster are not included in the following network analyses for comparability reasons.

[Table 2](#) shows also changes in Bio-Bío's co-management network composition after the tsunami. In 2013/14 the number of facilitating ties related to the functioning of MEABR was 10% lower than in 2008 ([Table 2](#)). Nearly 60% of facilitating ties identified after the tsunami in this region remained the same as those surveyed before the disaster. Importantly, the level of trustworthiness of the network in Bio-Bío, i.e. the qualification of facilitating ties as "highly trustworthy and trustworthy", increased from 0.8 to 0.93 during the period. In addition, the number of hindering ties, which is in general much lower than facilitating ties throughout the study period, decreased 0.41 percentage points in Bio-Bío after the tsunami.

Similar trends in Valparaíso's post-disaster co-management network can be observed in [Table 2](#) with regards to the reduction of facilitating ties (i.e., -0.09), the maintenance of pre-disaster facilitating ties (i.e., 60%), and the reduction of hindering ties (i.e., -0.81). Nevertheless, the level of trustworthiness in co-management facilitating in this region shows a different tendency. In Valparaíso the proportion of "highly trustworthy and trustworthy" ties showed no variation in 2014 as compared to 2008. All subsequent analyses are based on facilitating ties.

Network cohesion

[Table 3](#) shows the results for three co-management network cohesion measures before and after the tsunami in Bio-Bío and Valparaíso regions. Results show that network densities (i.e. the number of observed ties expressed as a proportion of the maximum number of possible ties), decreased during the period in both regions, which is consistent with the reduction in the number of relationships described above. With respect to network centralization (i.e. the extent to which a network presents a highly central actor(s) surrounded by peripheral actors), results in [Table 3](#) indicate that centralization increased in both regions. However, the increase is lower in Bio-Bío region (9%) compared to Valparaíso region (15%). In addition, results show contrasting trends in network fragmentation (i.e. the proportion of nodes that cannot reach each other) between the two regions during the study period. While in Bio-Bío the network became 66% less fragmented after the disaster, in Valparaíso the network is 48% more fragmented in 2013/14 than in 2008.

Actors' centrality

Changes were observed in in-degree centrality –or the relative prominence—of co-management counterparts in Bio-Bío during the study period ([Table 4](#)). Overall, nearly half of counterparts presented lower in-degree centrality in 2013/14 as compared to 2008. More specific changes in Bio-Bío can be identified, focusing on the most central actors in [Table 4](#). Results show that SERNAPESCA (i.e., the regional fishery authority) is the only

TABLE 2 Longitudinal comparison of co-management network size and composition in BioBio and Valparaíso.

		Facilitating ties		Hindering ties
		No.	Trustworthiness* (%)	No.
BioBío	Pre-disaster (2008)	203	0.80	22
	Post-disaster (2013)	182	0.93	13
	Variation (%)	(-0.10)	(0.13)	(-0.41)
Valparaíso	Pre-disaster (2008)	169	0.82	21
	Post-disaster (2013)	154	0.82	4
	Variation (%)	(-0.09)	(0.00)	(-0.81)

*Includes both trustworthy & highly trustworthy facilitating ties as perceived by fisher leaders interviewed.

TABLE 3 Longitudinal comparison of co-management network cohesion measures in Biobío and Valparaíso.

		Density	Centralization	Fragmentation
BioBio	Pre-disaster (2008)	0.37	0.48	0.12
	Post-disaster (2013)	0.33	0.52	0.04
	Variation (%)	(-0.10)	(0.09)	(-0.66)
Valparaíso	Pre-disaster (2008)	0.41	0.27	0.09
	Post-disaster (2013)	0.37	0.31	0.14
	Variation (%)	(-0.09)	(0.15)	(0.48)

TABLE 4 Co-management counterparts' pre/post disaster in-degree centrality in Bio-Bio and Valparaíso.

Actors	Acronym/label	Bio-Bío			Valparaíso			Function /role
		Pre	Post	Variation (%)	Pre	Post	Variation (%)	
Fisheries Undersecretary*	SUBPESCA	0.81	0.62	-0.19	0.69	0.56	-0.13	A
Marine Police*	Mar. Police	0.76	0.57	-0.19	0.63	0.94	0.31	A
Artisanal Fisheries Promotion Fund*	FFPA	0.76	0.62	-0.14	0.56	0.81	0.25	B
Regional fisher federation*	REG. FEDER.	0.76	0.48	-0.29	0.81	0.50	-0.31	C
Fishery National Service*	SERNAPESCA	0.71	0.81	0.10	0.88	0.69	-0.19	A
Universities*	UNIVS.	0.71	0.62	-0.10	0.81	0.69	-0.13	D
Technical Cooperation Service	SERCOTEC	0.52	0.29	-0.24	1.00	0.38	-0.63	B
Fisher associations' consultants	FISH. ASS. CONSULT.	0.48	0.43	-0.05	0.25	0.00	-0.25	D
Private consultants	PRIV. CONS.	0.43	0.52	0.10	0.31	0.50	0.19	D
Exporters	EXPORT.	0.38	0.43	0.05	0.25	0.06	-0.19	E
Fisheries Zonal Council	FISH. ZONAL COUN.	0.38	0.24	-0.14	0.25	0.25	0.00	F
Municipalities	MUNI.	0.38	0.38	0.00	0.50	0.69	0.19	F
Economic Development Agency	CORFO	0.33	0.10	-0.24	0.31	0.19	-0.13	B
National banks	BANKS	0.33	0.38	0.05	0.19	0.19	0.00	B
National fisher confederation	NAT. CONFED.	0.33	0.29	-0.05	0.56	0.19	-0.38	C
Independent professionals	INDEP. PROFF.	0.33	0.24	-0.10	0.56	0.56	0.00	D
Large companies (e.g., power/pulp plants)	LARGE COMP.	0.29	0.29	0.00	0.00	0.13	0.13	G
Restaurants	RESTAURANTS	0.24	0.24	0.00	0.50	0.50	0.00	E
Regional Government	REG. GOV.	0.24	0.14	-0.10	0.38	0.38	0.00	F
Fisheries Promotion Institute	IFOP	0.14	0.29	0.14	0.50	0.38	-0.13	D
Intermediaries	INTERMED.	0.14	0.14	0.00	0.06	0.31	0.25	E
Parliamentarians	PARLIAMENT.	0.14	0.19	0.05	0.19	0.44	0.25	F
Intl. organizations (incl. governments)	INT. ORGZ.	0.05	0.19	0.14	0.13	0.19	0.06	G
Ministry of the Environment	MIN. ENV.	0.00	0.05	0.05	0.13	0.13	0.00	A
Tourism Businesses	TOURISM BUS.	0.00	0.00	0.00	0.25	0.00	-0.25	E
Non-governmental organizations	NGOs	0.00	0.14	0.14	0.06	0.00	-0.06	G

* Core co-management counterparts defined by in-degree centrality scores >0.4 in Bio-Bío 2008 Bold letters used to mark emergent network actors in BioBio after the tsunami; Functions/roles: A, Power-devolution & enforcement; B, Funding; C, Fisher representative associations; D, Monitoring, research and development; E, Marketing; F, Territorial authorities; G, Private sector and civil society.

core counterpart playing a power-devolution & enforcement role with increased centrality in Bio-Bío after the disaster (+.10).

Among the other core counterparts in Bio-Bío, the highest centrality decreases correspond to Regional fisher federations, SUBPESCA (i.e., the national fishery authority), and the Marine Police, with variations of -.29, -.19, and -.19, respectively; thereby, the centrality of actors playing key roles in power-devolution & enforcement and political representation declined after the tsunami. Less pronounced centrality reductions are observed with respect to the Artisanal Fisheries Promotion Fund (i.e., -.14) and Universities (i.e., -.10), which play funding and monitoring, research and development of co-management, respectively.

Similarly, Table 4 shows that almost half of co-management counterparts present degree centrality reductions in Valparaíso during the period as well. In particular, SUBPESCA (-.13), Regional fisher federations (-.31), and Universities (-.13) present equivalent centrality decreases. Nevertheless, contrasting trends can be observed in Valparaíso, where SERNAPESCA presents considerable centrality reduction (-.19), and where the Marine Police (+.31) and FPPA (+.25) show increased prominence.

Importantly, three co-management counterparts with low or zero centrality in Bio-Bío region before the tsunami show large and positive variation during the period. Results in Table 4 indicate that, after the disaster, the Fisheries Promotion Institute (IFOP), international organizations, and NGOs increased their centrality scores in +.14. In contrast, in Valparaíso, variations in centrality of these actors are either smaller than in Bio-Bío, in the case of international organizations (+.06), or negative in the case of IFOP (-.13) and NGOs (-.06; see Table 4).

Networks' layout and relational patterns

The qualitative observation and comparison of the position and dispersal of nodes between Figures 2A, B, and between Figures 3A, B, describes overall changes in the relational patterns of co-management networks in Bio-Bío and Valparaíso after the disaster and over time. Note that the layout of the figures places nodes closer to one another based on how similar they are in terms of their relationships with others.

In Bio-Bío before the tsunami (Figure 2A) there is a core group of high centrality counterparts (i.e., colored nodes) in the middle, including actors playing various roles in co-management. After the tsunami (Figure 2B), this core appears divided in two subgroups, comprising fishery and enforcement authorities on the right-hand side versus market and civil society actors on the left-hand side. As for fisher organizations (i.e., white nodes), in 2008 they appear split in two ends of the graph: the upper-left group, which connects almost exclusively with the core counterparts; and the bottom-right group that has additional and more diversified connections with more and less prominent counterparts. By contrast, after the tsunami (Figure 2B) these two subgroups are less evident and fisher organizations are dispersed all over the network.

In Valparaíso region, in 2008 (Figure 3A) there is also a core set of co-management counterparts (i.e., colored nodes), which is still present in 2013 (Figure 3B) but looser or more dispersed. As for

fisher organizations (i.e., black nodes), trends are not very defined. However, one may note that in 2008 the visual distances among organizations are more even, with 2 or 3 regions of the graph grouping similar cases. By contrast, in 2013 (Figure 3B), the distances among nodes are less uniform and, instead of those few regions, multiple cases of pairs or triads of nodes that are closer to each other (and more distant from other groupings) can be identified.

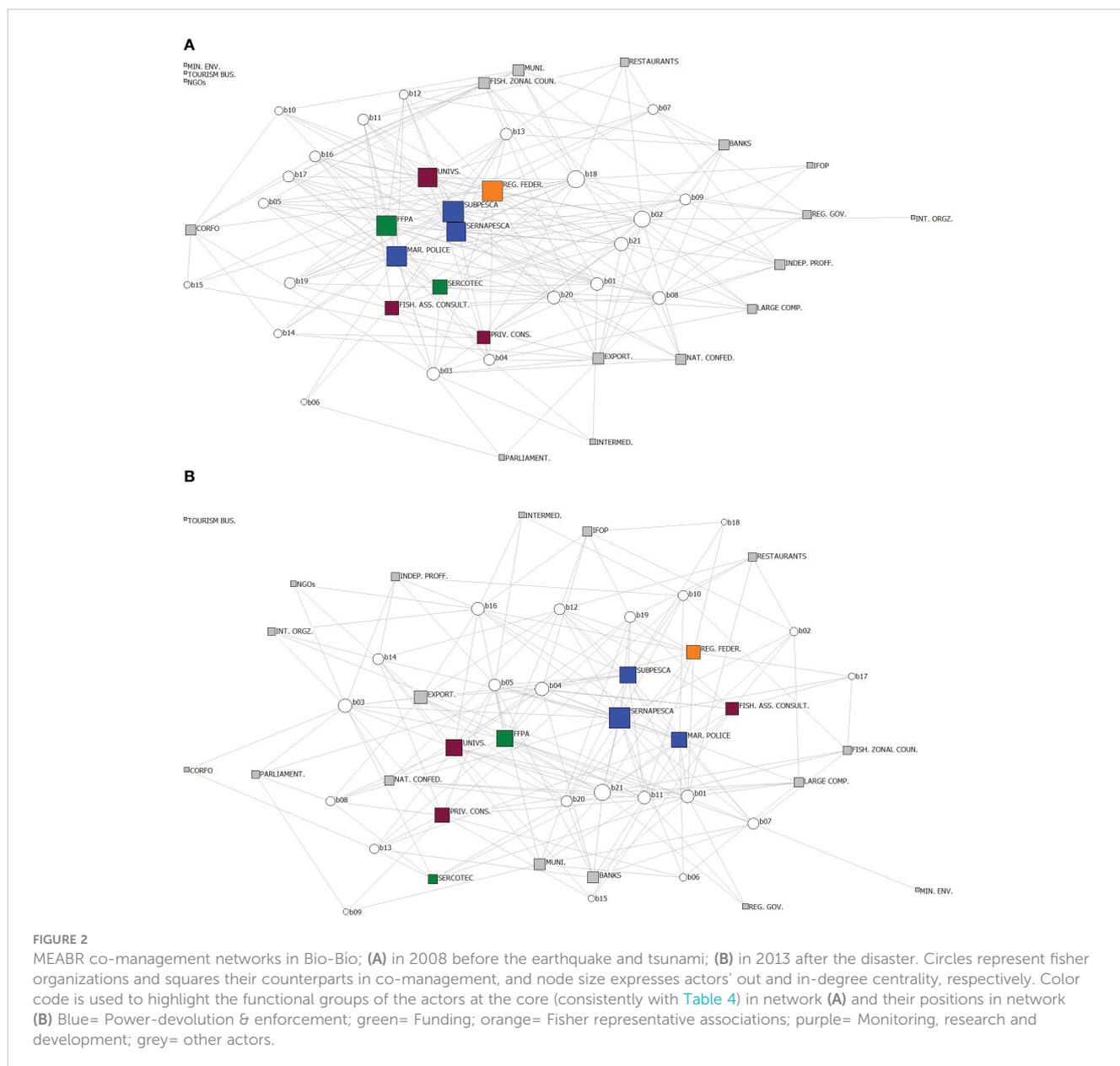
4 Discussion

The literature has emphasized two different modes of social network adaptation to large shocks and perturbations. One assumes that adaptation occurs within the same set of actors that are flexible enough to be rewired to allow for new patterns (Bodin and Crona, 2009); the other postulates that new social networks are formed to drive profound transformations (Goldstein, 2008). It is still unclear whether, and if so when, which of these modes best correspond to how resource management systems actually respond to abrupt perturbations, such as environmental disasters. To what extent can coastal disasters drive co-management networks rewiring or transformation? Which structural and relational changes are likely to occur? Which policy and decision-making implications derive from emerging conditions?

This study provides evidence supporting the idea of change and network adaptation within the same structure. In Bio-Bío, more than half of pre-disaster social relationships supporting co-management were still present after the perturbation. Without transformational changes, a number of emergent patterns described are exclusive to Bio-Bío, as compared to Valparaíso, suggesting that the tsunami had direct effects upon underlying regional networks. Our results highlight various impacts of disasters on co-management networks related to network composition, cohesion, centrality and relational patterns, which are discussed as follows.

The network observed in Bio-Bío after the disaster is larger in size and includes new counterpart actors from the private and civil society sector, both from the national and international levels. These agencies take part and are expected to play key roles and provide aid and resources for fishery and community recovery. At the same time, the overall frequency of facilitating relationships (i.e., density) decreased in Bio-Bío's network (and in Valparaíso). Reduced density may affect the spread of information among stakeholders, but may also lead to more heterogeneous experience and knowledge (Bodin et al., 2006). Although network density reduction cannot be necessarily associated with the disaster in Bio-Bío, more actors and fewer connections can be interpreted as higher focus and prioritization of relational activity during recovery times. The emergent and/or increased centrality of pre-disaster actors with fishery development and promotion goals (e.g. IFOP and NGOs) reinforces our assumption, suggesting the establishment of innovative connections that respond to specific needs.

Network-based research has indicated that high centralization can be associated with increased coordination capacity, but may also lead to over-centralized decision-making (Crona et al., 2011). In a post-disaster context, in which multiple response and recovery actions must be prioritized and implemented, higher levels of



centralization and coordination can be desirable. But, in cases where more complex coordination of resource management is demanded, overly centralized networks can be ineffective (Bodin et al., 2006). Our results show increased network centralization in Bio-Bío after the disaster, a trend that was less pronounced than in Valparaíso. The latter suggests that the co-management network in the disaster impacted region may have responded more centrally to enhance coordination capacity, without excessively reducing decision-making autonomy of more peripheral actors.

Studies have suggested that reduced network density may also affect the development of trust among stakeholders (Bodin et al., 2006). However, our results show that in Bio-Bío after the disaster, the network became stronger in terms of perceived levels of trust of facilitating ties. Trust among actors has been considered a basic requisite for collective action and co-management (Berkes, 2007; Armitage et al., 2008). An increase of trust in Bio-Bío's network can

be explained by a prompt and adequate responsiveness of co-management counterparts with respect to fishing communities' material losses and recovery needs. In addition, the Bio-Bío co-management network became less fragmented after the disaster. Fragmentation refers to isolation of actors and disconnection of the flow and access to resources and information (Borgatti et al., 2013). Results show the annexation of previously isolated counterparts from regional, national and international levels that provided aid and supported the recovery of tsunami impacted coastal communities. In this case, these actors imply also higher levels of heterogeneity, which has been considered a determinant feature of co-management adaptability. Higher diversity of players engaged increases the access to more varied sources of knowledge, ideas and resources (Sandström and Rova, 2010).

In Bio-Bío, a more dispersed and diversified pattern of relationships between parties is evident, where more fisher

(Marín and Berkes, 2010; Holt et al., 2012; Gelcich et al., 2013; Oyanedel et al., 2016). We speculate the reduced levels of conflict around co-management can be attributed either to the effect of time and experience of actors and the consequent accommodation of roles in the system, or of the disaster and the flexibilization of regulations and enforcement criteria (e.g., as a way of making things easier). However, the reduction in levels of conflict is much more evident in Valparaíso than in Bio-Bío, discarding the latter interpretation. Time and learning are key components of adaptive co-management and are likely to iron out the differences among actors. The latter was exposed to the impacts of the disaster and to recovery challenges. Competition and conflict is likely to be exacerbated in a context of increased needs and limited resources, which makes it more difficult for relationships and roles to stabilize.

Methodologically, the study highlights the importance of having a baseline and a reference group for assessing longitudinal changes in co-management social networks after major shocks. Without pre-disaster data and without the case of Valparaíso, it would have been impossible to identify whether network changes in Bio-Bío region (e.g. reduced density) could be attributed to the effects of the tsunami or to other factors affecting Chile's small-scale fisheries at large. Further, without a baseline and the non-impacted case it would have been hard to judge the relative size of the changes (e.g. reduced centralization) observed in the impacted region, or whether a whole new configuration had emerged. The study highlights the potential of longitudinal and comparative studies to move from static to dynamic network-based assessments in marine environments and more broadly.

The changes observed in co-management networks in response to the environmental disaster have several policy implications for the long-term adaptability of the system to abrupt shocks. It is worth mentioning that a limitation of the study is the lack of co-management performance indicators. Such data would allow assessing the extent to which the Bio-Bío social network in 2013 is better suited to support the sustainability of co-management than it was in 2008 (or than the Valparaíso network). However, we can draw lessons and infer policy implications based on the opportunities and threats identified in the study. When observing the differences between the latest networks in both regions, one may expect the Bio-Bío region to be better prepared to confront large challenges than Valparaíso, due to network enlargement, the maintenance of network cohesion, the enforcement of central actors' positions, and most importantly the strengthening of trust among stakeholders. The structural changes resulting from the 2010 tsunami reported here and are based on data gathered in 2008 and 2014. Follow-up studies are needed to assess later evolutions of these networks. Other studies interested in assessing disaster impacts on co-management could further explore network changes from a more qualitative approach, including also horizontal connections between fisher organizations and interpersonal relationships among fishers. These elements may open new questions for future research on network-based approaches in marine environments.

Small-scale fisheries under participatory and co-management approaches are more and more common worldwide. At the same time, coastal co-managed fisheries are becoming increasingly vulnerable to coastal disasters due to global changes (Prieto-Carolino et al., 2018; Nurzaman et al., 2020; Steenbergen et al., 2022). Based on the Bio-Bío case, our findings suggest the importance of sustaining

coherence among fisher organizations and their relationships with counterparts. Relying on temporary enhanced levels of trust, and allowing for autonomy and variability of engagement styles and objectives can reactivate collective action processes of co-management in the face of disasters and other coastal perturbations. The study suggests that participatory network-based interventions, such as the Chilean MEABR co-management policy, provide a stable and at the same time adaptive setting which may increase fishery resilience to coastal environmental disasters and perturbations.

5 Conclusions

The networks studied show an aggregated representation of how fisher organizations conceive the institutional environment from which they obtain support, resources and information relevant to co-management during normal times and in the aftermath of a massive coastal disaster. From the point of view of individual fisher organizations, these networks describe engagement strategies pursued and more broadly, they illustrate co-management governance networks. After an abrupt and major environmental disaster, co-management governance networks are likely to evolve to adapt to multiple social and ecological changes. Network rewiring vis-à-vis transformation can be better regarded as the ends of a continuum. Our results show that although important changes were observed in post-disaster co-management networks, these changes emerged within the same overall co-management governance network. New actors became involved in post-disaster emergency and recovery to respond to specific needs, suggesting some kind of transformation, but these interventions have not created new permanent networks. The majority of actors and connections were the same as before the 2010 tsunami; but the quality and strength of relationships was different. In Chile, after a major coastal perturbation, the co-management governance network has mostly shown symptoms of being re-wired. As abrupt and massive coastal disasters due to climate change threaten the viability and sustainability of small-scale fishing communities worldwide, an increased attention to changing governance networks can help identify key leverage points to support, taking advantage of and integrating post-disaster emerging relationships in decision-making processes.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Stockholm University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AM: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft. ÖB: Conceptualization, Formal Analysis, Supervision, Writing – review & editing. SG: Resources, Supervision, Writing – review & editing. JC: Writing – review & editing.

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Conflict of interest

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

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