

RESEARCH ARTICLE

Connecting sea to market: Using network analysis to understand social–ecological dynamics in seafood value chains in Pisco, Southern Peru

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Handling Editor: Jacopo Baggio**Abstract**

1. Small-scale fisheries represent complex human-nature interactions, targeting different species in different locations throughout the year. On land, fishers are at the core of diverse seafood value chains that serve local and distant markets. Understanding interconnectivity and the value chain dynamics of these complex systems is key to designing meaningful resource management plans that are adaptive to changes.
2. In this article, we use network analysis to examine the multi-level social–ecological system of a Peruvian small-scale fishery. We explore the hypothesis that archetypes of different fisher adaptive strategies can be identified based on the species they target, the gear they use and market values.
3. To examine these adaptive interactions in the value chain network, we used the empirical case study of a small-scale fishery in San Andrés, Peru. Data comes from semi-structured surveys ($n = 58$) with fishers and buyers, along with historical and contextual data from qualitative interviews and literature review.
4. We visualize and analyse our data as social–ecological network interactions, which indicate patterns of adaptive behaviour among fishers with different catch and market strategies. Resilience and adaptive capacity are observed among fishers that have multiple options along the value chain. A fisher is thus more resilient to climatic and seasonal change if they fish for multiple species across different seasons. Similarly, a buyer is more resilient if buying from multiple fishers across the year and selling to a diversity of markets.
5. Findings suggest that fishers and buyers do exhibit adaptive capacity in different identifiable ways, which we interpret and explain as four adaptive fisher archetypes. This allowed us to define a theoretical fisher motif aimed at generalizing

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the structural configuration of a typical fisher who has adaptive capacity. This motif can be used as a social–ecological network model to test adaptive capacity in other fisheries. We discuss and argue that recognizing and supporting diverse value chains is key for adaptive capacity to future environmental and social changes and that fishers play a central role as agents with adaptive decision-making capacity to potentially improve overall system resilience.

KEYWORDS

adaptive capacity, ego-network, resilience, small-scale fisheries, social–ecological network analysis

1 | INTRODUCTION

Fisheries are often typified as complex social–ecological systems (SES) (Basurto et al., 2025; Kittinger et al., 2013). While being an essential element of global food production (Golden et al., 2021), fisheries provide income and livelihoods for communities worldwide (Belton et al., 2020). Small-scale fisheries (SSF) are of particular importance, as they employ over 90% of global fishers (FAO, 2024; Kittinger et al., 2013), support an estimated 500 million livelihoods worldwide (FAO, Duke University, WorldFish, 2023) and have been estimated to make up at least half of global landings (Chuenpagdee et al., 2006; FAO, 2020), contributing to both local and global markets.

The contributions of SSF to local economies and food security are intertwined with their ability to be adaptive to changing social and environmental conditions (Bassett et al., 2022; Gonzalez-Mon et al., 2021). The more adaptive they are, or can be, the more likely they are to be resilient to increasing future changes (McClanahan et al., 2013). However, the mechanisms and value chain structures that indicate adaptive capacity are less known. In this work, we principally relate to two dimensions of adaptive capacity: flexibility and social organization (Cinner et al., 2018). The flexibility domain refers to the ability of resource users to switch between potential adaptation options at different points along the value chain. This may include changing their target species, fishing location, gear type, landing dock, buyer or market to which they sell their catch. The hypothesis is that the more options a fisher has at each point, the higher the adaptive capacity. For example, changing the geographic location, that is moving towards other regions and/or countries or further away from their port in the search for fishing alternatives, is an adaptation strategy observed by fishers, for example in Peru (Kluger, Alff, et al., 2020), Senegal (Binet et al., 2012) and Costa Rica (Carrillo et al., 2019), which adds to the flexibility notion of adaptive capacity (Cinner et al., 2018). In some cases, fishers successfully transformed into entrepreneurial sea farmers to cope with environmental changes (e.g. conducting small-scale aquaculture of scallops, see Bakit et al., 2023; Kluger, Taylor, et al., 2019). The social organization domain of adaptive capacity (Cinner et al., 2018) embraces the way society and communities are organized, and how individuals' social capital shapes

the ways in which crises are confronted, and coped with (Kluger, Scotti, et al., 2019; Kriegl et al., 2022; Partelow, 2020). For example, networks promoting information exchange and cooperation can enhance communities' ability to adapt to changes in fish availability or weather patterns (Barnes et al., 2016). Access to diverse buyers can provide mutually agreed upon economic exchanges rather than powerful gatekeepers such as middlemen who regulate prices in the absence of market competition, often to the detriment of fishers (Ferrol-Schulte et al., 2014; Partelow et al., 2018). The ability to access and learn about multiple fishing gears, the ability to access knowledge or financing, or the ability to inherit fishing rights, be included in quota allocations or engage in governance processes can all influence fisher adaptive capacity (Basurto et al., 2013; Blythe, 2014).

Of the many factors influencing the resilience and adaptive capacity of fishers, external environmental changes due to climate change are increasingly important. The impacts of ocean acidification, species distributions due to increased sea surface temperatures and increased variability of regional climatic cycles are well documented (Tigheelaar et al., 2021). In Peru, fisheries have historically evolved under the conditions of the inter-annual El Niño Southern Oscillation (ENSO) (Bertrand et al., 2020; Wang & Fiedler, 2006). The warm El Niño events bring the Humboldt Current Upwelling System (HCUS) to a halt, causing an increase in sea surface temperatures (Santoso et al., 2017) and a reduction in primary production (Barber & Chavez, 1983; Pennington et al., 2006). This has drastic effects on aquatic species composition, abundance, biomass and distribution (Badjeck, 2008; Bertrand et al., 2020), with diverse and somewhat unpredictable effects for fisheries in the HCUS (Bertrand et al., 2020). However, El Niño-induced effects are not uniform. While Peruvian anchovy (*Engraulis ringens*) populations have been known to collapse due to restricted food availability (Barber & Chavez, 1983; Bertrand et al., 2020; Chavez et al., 2008), other species flourish under higher water temperatures, such as Chub mackerel (*Scomber japonicus*) and Jack mackerel (*Trachurus murphyi*) both tropical fish who have immigrated to nearshore regions (Niquen et al., 1999). Similarly, Peruvian bay scallop (*Argopecten purpuratus*) populations were observed to boom during the El Niño events of 1983/1984 and 1997/1998 in Southern Peru (Wolff, 1987, 1988; Wolff

et al., 2007; Wolff & Mendo, 2000). Although most fisheries are historically adapted to variable environmental conditions such as seasonality and species migrations, ENSO is an important external factor in understanding fishery resilience and adaptive capacity. However, amidst progressing climate change, fisheries in Peru await an uncertain future, and there is no scientific consensus on the role climate change will have on ENSO patterns yet: while a general cooling of the waters off Peru was suggested (Gutierrez et al., 2011), it is still under debate whether climate change will intensify (Bakun et al., 2010, 2015; Bakun & Weeks, 2008; Chamorro et al., 2021; Narayan et al., 2010; Xiu et al., 2018) or reduce (Barton et al., 2013) upwelling in eastern boundary upwelling systems (which include the HCUS), and whether and how this reflects in increases or decreases in ocean productivity (Salvatteci et al., 2022). Scientists are yet to agree whether global warming will cause an intensification and/or increase in frequency of occurrence of ENSO events (e.g. Bakun & Weeks, 2008; Cai et al., 2021, 2023; Collins et al., 2010; L'Heureux, 2018; Vecchi & Wittenberg, 2010), though the Intergovernmental Panel on Climate Change (IPCC) predicts an increase in El Niño and La Niña events frequencies during the next century (IPCC, 2021).

Network analysis provides a set of well-established data collection and data analysis methodologies to explore these hypotheses (Borgatti et al., 2009). Social-ecological network (SEN) analysis advances the examination of structural patterns of SES by including social and ecological variables (for recent reviews see Kluger, Gorris, et al., 2020; Sayles et al., 2019). Scholars have constructed SENs for a wide range of different human-nature interactions, including fisheries (Alexander et al., 2019; Barnes et al., 2019; Bodin, 2017; González-Mon et al., 2019; Kluger, Scotti, et al., 2019; Ortiz & Levins, 2017; Yletyinen et al., 2018; Zador et al., 2017). For example, patron-client (i.e. fisher-buyer) relationships have been assessed in a Mexican SSF by measuring fish-buyer's adaptive capacity with SENs (González-Mon et al., 2019). Patron-client relationships are well documented in SSFs literature and can impact fishers' decision-making (Miñarro et al., 2016; Nascimento et al., 2017), access to markets (Bailey et al., 2016; Ferse et al., 2012) and even livelihood security and vulnerability (Ferrol-Schulte et al., 2014). Furthermore, fish buyers are key actors in SSFs (Crona et al., 2010, 2015; González-Mon et al., 2019) and can be a direct link across social domains (i.e. fishers and markets; Crona et al., 2010). Hence, disentangling the linkages and interdependencies of fishers with target species, seafood buyers and consumer markets is important for understanding the variability of adaptive capacity and resilience at both the individual and fishery level (Nenadovic & Epstein, 2016). An explicit consideration of how social networks relate to ecological structures can help in discussing trade-offs between adaptation and transformation options within SES (Barnes et al., 2017), both being shaped by the overall network structures that facilitate learning and the internalization of ecological feedbacks (Barnes et al., 2020). This SEN approach can be complemented by a social-ecological ego-network perspective, which puts fishers as the central node of

interest (i.e. unit of analysis) in the network, with a focus on their ties to both social and ecological dimensions. Conceptualizing social capital, for example, through an ego-network perspective has proven useful to understand resource user resilience in the aftermath of environmental disasters (such as the Coastal El Niño 2017 in Northern Peru, Kriegl et al., 2022).

Archetype analysis seeks to identify patterns of SES interactions leading to specific outcomes that are similar across cases (Eisenack et al., 2021; Sietz et al., 2019). Archetypes are typically considered mid-range theories because they identify context-relevant patterns of complex interactions that may be useful to explain phenomena in systems with similar contexts but not beyond (Eisenack et al., 2021; Partelow et al., 2024). Archetype analysis can further sort out different archetypes within datasets from diverse cases. For example, cluster analysis or network configuration patterns are typically used to identify archetypes of system functioning. Archetype analysis has been applied in many environmental governance contexts including fisheries, aquaculture (Nagel et al., 2024; Partelow et al., 2025), drought adaptation (Villamayor-Tomas et al., 2020), sustainable land use (Piemontese et al., 2021) and poverty and food security (Rocha et al., 2019).

This research uses the case study of San Andrés (district in the province Pisco, Southern Peru) to examine the adaptive capacity of small-scale fishers applying a SEN approach. We focus on individual fishers as our primary unit of analysis to derive the *species-fisher-buyer-market* network as a whole, complementing discussions on diversification strategies of fishing portfolios (Barnes et al., 2019; Stoll et al., 2017) and fishers' adaptive capacity in general (González-Mon et al., 2019; Sandström & Rova, 2010). At the same time, this study also contributes to the methodological and conceptual development of SEN analysis and theory as a proof-of-concept case study. Linking both environmental and social factors together—while viewing the network structure through the lens of the individual fisher (i.e. a social-ecological ego-network perspective)—the core focus of this research is to explore the hypothesis that fish species, fishers, buyers and markets have relationships that can be structurally identified in networks to be more or less adaptive and thus more or less resilient, to future environmental changes such as ENSO.

2 | METHODS AND THEORETICAL CONTEXTUALIZATION

2.1 | Study setting: The small-scale fishery in Pisco, Peru

Peru is the world's fourth most important capture fishery producer in terms of production volumes (FAO, 2024), due to the HCUS transporting nutrient-rich waters to the ocean surface, providing high primary and fisheries productivity. While the Peruvian anchovy (*Engraulis ringens*, mainly a target of the industrial fishing fleet) is a large majority of the total catch there is a diverse

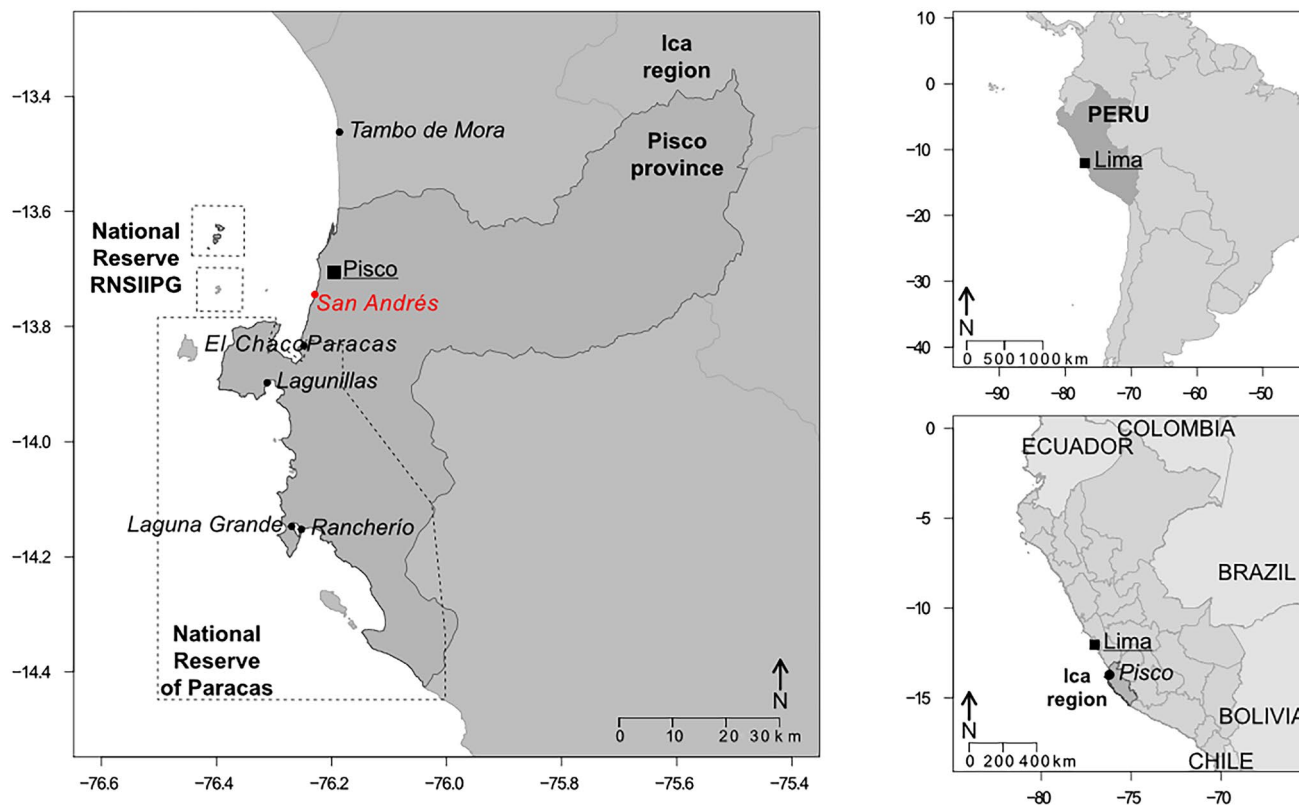


FIGURE 1 Map of study area. Top-right panel: Peru is located on the Western coast of South America, its capital Lima is indicated. Bottom-right panel: The Ica region is on the Southern coast of Peru. Left panel: The Peruvian province of Pisco (in dark grey) encompassing five of Ica's eight small-scale fisheries landing sites (including San Andrés, in red). (Marine) National Reserves are indicated (dashed lines), RNSIIPG=system of islands, islets and guano deposits; for Span. 'Reserva Nacional Sistema de Islas, Islotes y Puntas Guaneras'. For details on Figure construction and data sources see Section 2.4.

multi-gear small-scale fishery (SSF) that targets more than 300 species (Guevara-Carrasco & Bertrand, 2017). Within Peru, SSFs employ about four times more people than industrial fisheries (Alvarez, 2003) and provide one of the main sources of fish for domestic human consumption (Mendo & Wosnitza-Mendo, 2014) and supporting thousands of fishery livelihoods despite re-occurring ENSO events.

This study focuses on SSF dynamics of the Pisco province, Region of Ica, 150km south of Peru's capital Lima, and focuses here on San Andrés (Figure 1), an important fisheries hub of the province: almost all fishers from the surrounding landing sites commercialize their catch here, and San Andrés is one of the key seafood providers to the markets in Peru's capital Lima (ERM, 2002). Though semi-industrial and industrial fisheries are also present in the area, a majority of San Andrés' residents (13,757 according to national census data; INEI, 2018) have their livelihoods connected to the SSF as both fishers and fish workers, for example fish processors and cleaners, truck drivers, employees of the connected ice industry. In the desert environment of Pisco, fishing is an essential livelihood and nutrition source (Figure 2). According to Peruvian legislation, SSF is a category that encompasses every fishery operating predominantly with manual labour and with vessels with a maximum hold capacity of 32.6m³ and a

length of 15 m (DS 012-2001-PE¹). Please note that this SSF classification applied during the time of study, but was modified in 2023 as to distinguish traditional ancestral fishing (e.g. wooden raft fishing) from artisanal (i.e. small-scale) fishing Law N° 31749.²

2.2 | Data collection

This study presents a novel conceptual approach and analysis, and as such the study represents an important pilot test of these methods to demonstrate the usefulness of SE ego-networks and archetype framings for value chain analysis. Primary data collection (participatory observations, informal conversations, key informant interviews, fisher interviews) took place from September 2019 to February 2020 at or near the landing site of San Andrés (Figure 1). The research protocol and interview guides (as provided as Appendix S1) were developed and tested prior to starting the field research and followed standard ethical research principles

¹DECRETO SUPREMO No. 012-2001-PE. Available at: https://cdn.www.gob.pe/uploads/document/file/418473/Decreto_Supremo_N%C2%BA_012-2001-PE.pdf last accessed 2024-07-19.

²<https://busquedas.elperuano.pe/dispositivo/NL/2179664-1>, last accessed 2024-07-19.



FIGURE 2 The desertic coastal-marine space of the Peruvian province Pisco. Upper two pictures by LC Kluger, lower two by MA Roque-Sanchez.

throughout. This means that internal approval of the principal research institution was granted, confirming that the dignity, rights and safety of the research participants were protected and that we acted in accordance with recommendations of Peruvian colleagues on how to respect local practices and formalities. All interviews were conducted in Spanish, and interviewees were informed about the study's goals and then asked to provide prior informed consent for their participation in the study before beginning. This informed consent to participate had to be collected exclusively verbally, as all participants declined to sign any 'formal' papers in the fear of traceability and distrust expressed towards authorities. Participation was voluntary and completely anonymous, with interviewees being able to opt out at any time.

Key informants ($n=4$) were representatives of local fisheries authorities and provided initial interviewees as an entry point for the primary fisher interviews. Key informants were here defined as community members who have both extended knowledge and experience with local fisheries. Open-ended, semi-structured interviews were applied (drawing from Interviews guides as presented in [Appendix S1](#), but also being guided by topics emerging from the conversations) to explore contextual information on different fishing practices and regulations, experienced and perceived changes in the fishery over time and current challenges.

Interviews with fishers ($n=45$) were designed to gather both qualitative and quantitative data. This included questions on individual demographics (e.g. age, years fishing), the person's fishing practice (e.g. target species, gear types, seasonality) and overall fishery dynamics (e.g. satisfaction of work). Then, the fisher-buyer relations (e.g. how are buyers selected, how are relationships unfolding) and the value chain of harvested marine resources was explored. Finally, the perceptions of fishers' livelihood vulnerability and adaptive capacity to external perturbations to the fishery (e.g. ENSO events) were evaluated by providing a series of statements about perceived capacity to adapt in their social and social-ecological relationships. These statements were selected based on literature and author knowledge. For an overview of perception questions cf. [Table 4](#) in Section 3.4 (the complete questionnaire is provided in [Appendix S1](#), Interview 1). In addition, seafood buyers ($n=8$) were interviewed to gather complementary and contextual data (cf. [Appendix S1](#), Interview 2). Interviewing buyers (as key nodes) was considered crucial as they hold knowledge of both sides of the supply chain, about the fishers and the consumers/other buyers. Both interview guides were semi-structured and designed to include the same questions; nonetheless, they were formatted to suit each interviewee.

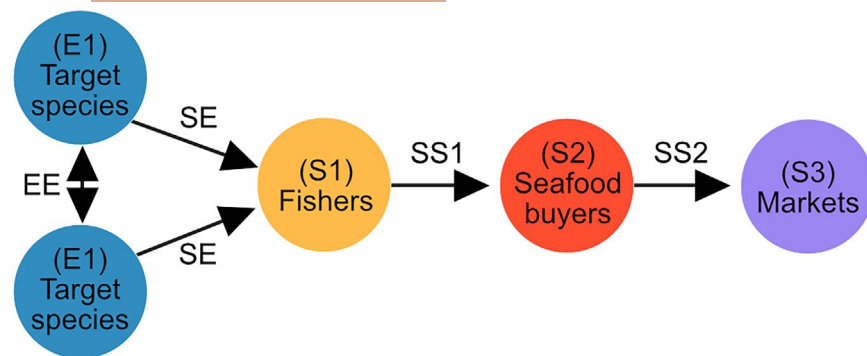


FIGURE 3 Social-ecological (SE) network conceptualization of a fishery, comprised of ecological (E1, in blue) and social nodes (S1–3, in yellow, red, violet) connected by ecological-ecological (EE), SE and social-social edges (SS) For an overview of data collection approaches and analytical foci for each network compartment compare Table 1.

2.3 | Network conceptualization and analysis

Following Bodin and Tengö (2012), a SEN combines two types of nodes (ecological (E), social (S)) through three types of links: those that link ecological nodes (ecological-ecological (EE) links), those that connect ecological with social nodes (social-ecological (SE) links) and those that combine social nodes (social-social (SS) links). The SSF-SES of San Andrés was conceptualized as including target species (E1), fishers (primary social nodes S1), seafood buyers (S2) and seafood markets (S3), as well as links between these nodes (EE1, SE1, SS1, SS2, cf. Figure 3; Table 1). From the interview data, we specifically examined fishers and their ego-network to understand and capture the human-nature interface (fish-fisher interaction). This is because fishers represent and take actions in both the social and ecological realms of the network. As such, they are key nodes linking both sides, and understanding their individual adaptive capacity and resilience will likely help to explore connectivity across the network (system). This is why the individual ego-networks were joined afterwards to derive complete networks (as further described below).

Ecological-ecological links connected species (ecological nodes) with shared seasonality. For this, each species was assigned to one of three catch season categories (i.e. 'winter', 'summer', 'all year') based on a monthly weighted score reflecting the number of interviewees who target this species in a particular month. From these score distributions, the seasonality of each species was defined, with 'summer' extending from December to March and 'winter' from May to October, and April and November being considered as 'off-season' months (i.e. neither winter nor summer). Species not following an explicit seasonality were assigned to 'all year'. These categories were then used as undirected ecological-ecological links between species within the same seasonal group. Accordingly, all species falling into a particular season are connected with each other, with no links being articulated across groups. This helps visualize the dependency of fishers to particular seasons and allows for the exploration of fishers' vulnerability to seasonal disturbance events, such as summer heatwaves.

Social-ecological links were weighted by average catch volumes per fishing event, to account for seasonal variation, reported by fishers for any target species. In instances where ranges were given, the median reported value was used for analysis. Local units of measurements were converted to their rough kilogram

equivalent, if necessary. For all reported catch species this information was obtained, except for the Peruvian eagle ray (*Myliobatis peruvianus*), which is why this species couldn't be assigned to a season category.

Social-social links capture the pathway of seafood within the respective fisheries value chains. Each interviewed fisher was asked for the destination of their products, that is to which buyers they sold and then to which markets those buyers sold. For every market a fisher reported, an unweighted social-social link (Table 1) was created between fishers, buyers and markets; with a realized link reflecting the mere presence, not the frequency of the described connection.

Archetype analysis was used as a method to identify and classify observed patterns or typologies in the network. We identified four fisher archetypes emerging from their patterns of social-ecological (SE) connectivity. We defined this SE connectivity as the ratio of SE in-degree (i.e. the number of species fishers targeted; high or low) to SS out-degree values (i.e. the number of buyers fishers worked with; high or low). This resulted in fishers with: (1) low SE in-degree and low SS out-degree ('low/low'), (2) low SE in-degree and high SS out-degree ('low/high'), (3) high SE in-degree and low SS out-degree ('high/low') and (4) high SE in-degree and high SS out-degree ('high/high'). The cut-off values were determined inductively and based on observed mean values in the data distribution: Low was defined as targeting five or fewer species (for SE in-degree) and working with less than three seafood buyers (for SS out-degree), respectively.

An archetypical average fisher motif was created to demonstrate the average San Andrés small-scale fisher's value chain, calculated from the node attribute data: Fisher in-degree reflects the average number of species per fisher, fisher node out-degree describes the average number of seafood buyers a fisher works with, and buyer node out-degree depicts the average number of markets fishery products are sold into. As a second step, node diversity within each node type of that average fisher motif was analysed by ranking individual nodes within each node type group based on the highest degree value: out-degree in case of fisheries target species (i.e. ecological nodes) and in-degree for both the seafood buyers (i.e. social nodes S2) and the seafood markets (i.e. social nodes S3).

A final step of the analysis was to derive a network representing the fisheries value chain as derived from the individual ego-networks described by fishers. This was done to visualize complex interactions and co-dependencies across fisher archetypes.

TABLE 1 Overview of network features as introduced in Section 2.3, how they were defined and conceptualized for the social–ecological network in this study. Data collection for each network part and, respectively, used question in interviews and/or surveys is provided, wherever applicable.

Network feature	ID	Defined as...	Analytical role	Data collection ^a	Question to collect data from survey	Network indicator applied ^b
Ecological node	E1	Fisheries target species ^c	Secondary unit of analysis	List of fisheries target species, derived from interviews with fishers ^d	Which species do you catch over the course of a typical year? ^e	Out-degree Weighted degree Eigenvector centrality
	S1	Fisher (individual)	Primary unit of analysis	List of interviewed fishers	-	Degree Weighted degree Eigenvector centrality
	S2	Buyer (individual)	Secondary unit of analysis	List of seafood buyers, from interviews with fishers	Which seafood buyers do you work with?	In-degree Betweenness centrality Eigenvector centrality
Social–social link	S3	Market (local, lima, other, domestic, international)	Secondary unit of analysis	List of seafood markets, from interviews with fishers	Which consumer market does your fishery product go to?	In-degree Eigenvector centrality
	SS1	Sale of fishery products from fisher to buyer	Directed link from fisher to buyer	From interviews with fishers	Which seafood buyers do you work with?	Unweighted edges between nodes S1 and S2
	SS2	Sale of fishery products buy buyer into market	Directed link from buyer to market	From interviews with fishers	Which consumer market does your fishery product go to?	Weighted edges between nodes S2 and S3
Social–ecological link	SE1	Capture of fishery resources (E1) by fisher (S1)	Directed link from species to fisher	List of fisheries target species, from interviews with fishers	Which species do you catch over the course of a typical year?	Weighted edges reflecting average catch volume
Ecological–ecological link	EE2	Shared seasonality of E1 ^f	Undirected links	From interviews with fishers	Which species do you catch over the course of a typical year? ^g	Weighted edges reflecting similarities in seasonality ^h

^aSee Section 2.2 for details on data collection.

^bSee Section 2.3 for details on the network conceptualization and analysis and Table S2.1 in Appendix S2 and the list of additional data sources in the main manuscript.

^cSee Table S3.1 in Appendix S3 for an overview of English, Spanish and scientific names of all fisheries target species, and the list of additional data source sin the main manuscript.

^dSee Appendix S1, Interview 1 (Fisher).

^eComplemented by asking for more detailed information, for example associated bycatch, gear used, average volume caught (per fishing event).

^fSee Section 2.3.

^gData were then coded into a relative weighted scale to indicate catch species' seasonality.

^hMonthly catch frequencies were calculated from fisher responses for each catch species and then used to determine seasonality.

2.4 | Data cleaning and processing

Interview responses were digitally entered and transcribed, and if applicable, standardized and coded following an inductive approach in Microsoft Excel (MS Excel) (Microsoft Corporation, 2019). The map in Figure 1 was constructed in R (R Core Team, 2021) with the packages *maps* (Brownrigg, 2018), *sp* (Bivand et al., 2013; Pebesma & Bivand, 2005) and *sf* (Pebesma, 2018). For this, Peruvian administrative areas (region- and province-level) were retrieved from the Database of Global Administrative Areas (GADM, www.gadm.org, subdivision levels 1 and 2), and National Reserve geographic information (shape files) was downloaded from the webpage of the Peruvian National Service for Natural Protected Areas (<http://geo.sernanp.gob.pe/visorsernanp/>). Figures 3 and 6 were constructed with Affinity Designer (Serif, RRID:SCR_016952). Figures 4 and 5 were made in R (R Core Team, 2021) using the package *ggplot2* (Wickham, 2016). Figures 7 and 8 were made with Gephi 0.9.2 (Bastian et al., 2009) and afterwards modified in Affinity Designer (Serif, RRID:SCR_016952).

3 | RESULTS: THE FISHERIES SYSTEM OF SAN ANDRÉS THROUGH A NETWORK LENS

3.1 | The ecological realm: Fisheries target species and seasons

From the 28 targeted species, six were reported to be predominately caught in winter (i.e. May to October), nine were predominately caught in summer (i.e. December to March), and twelve

species were caught following no distinct seasonality (i.e. 'all year') (cf. Figure 4).

Of all ecological nodes (i.e. fisheries target species), Eastern Pacific Bonito (*S. chiliensis chiliensis*) was targeted by the highest number of interviewed fishers, as reflected by a comparatively high social-ecological out-degree of 30 (i.e. 67% of fishers targeted this species). This was followed by South Jack Mackerel (*T. murphyi*) and Pacific Chub Mackerel (*S. japonicus*) ranking second and third (SE out-degree values of 26 and 24, respectively). The average SE out-degree for all ecological nodes was 8.3.

3.2 | The social side: Seafood buyers and market

The majority of seafood buyers ($n=35$) worked with one fisher, as reflected by a social in-degree (i.e. the number of incoming links from fishers) value of 1. This is contrasted by maximum in-degree values of 18 (buyer ID C7), while 8 buyers' SS in-degree value ranged between 4 and 6.

With the exception of the Peruvian anchovy *E. ringens*, all fisheries products were destined for direct human consumption and were sold and consumed in domestic markets. The majority of seafood landed and sold at the San Andrés dock reached the country's capital Lima, as reflected by a social in-degree value of 40 (i.e. number of seafood retailers linking to this market), followed by local markets (i.e. within Pisco province, cf. Figure 1), other domestic markets (e.g. Chincha province, just north of Pisco) and international markets (in-degree values of 30, 16 and 2, respectively) (Figure 5). In these locations, seafood buyers mainly sell their product to wholesale markets (Span. *mercados*

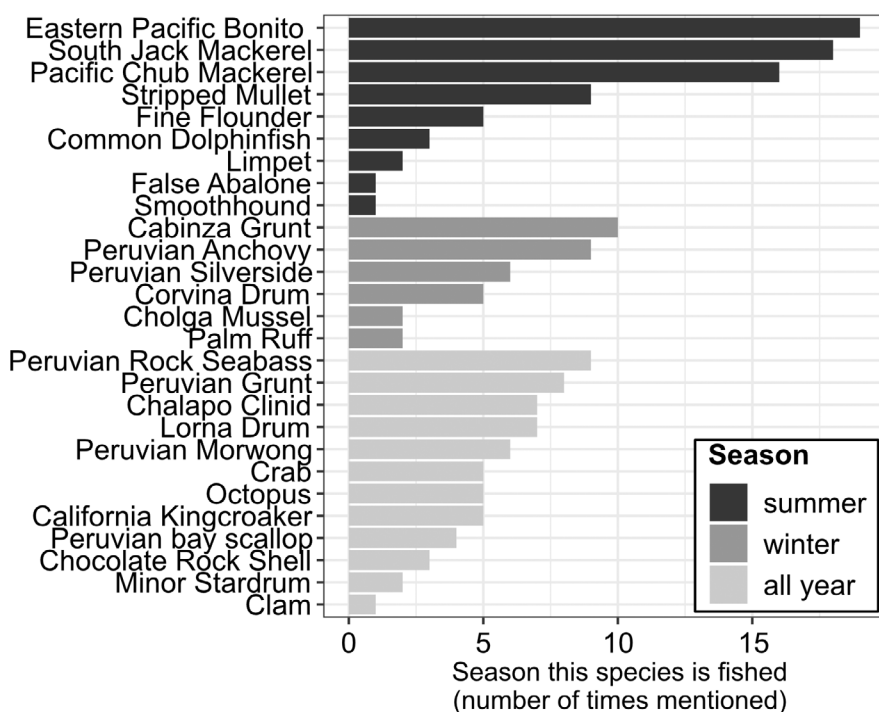
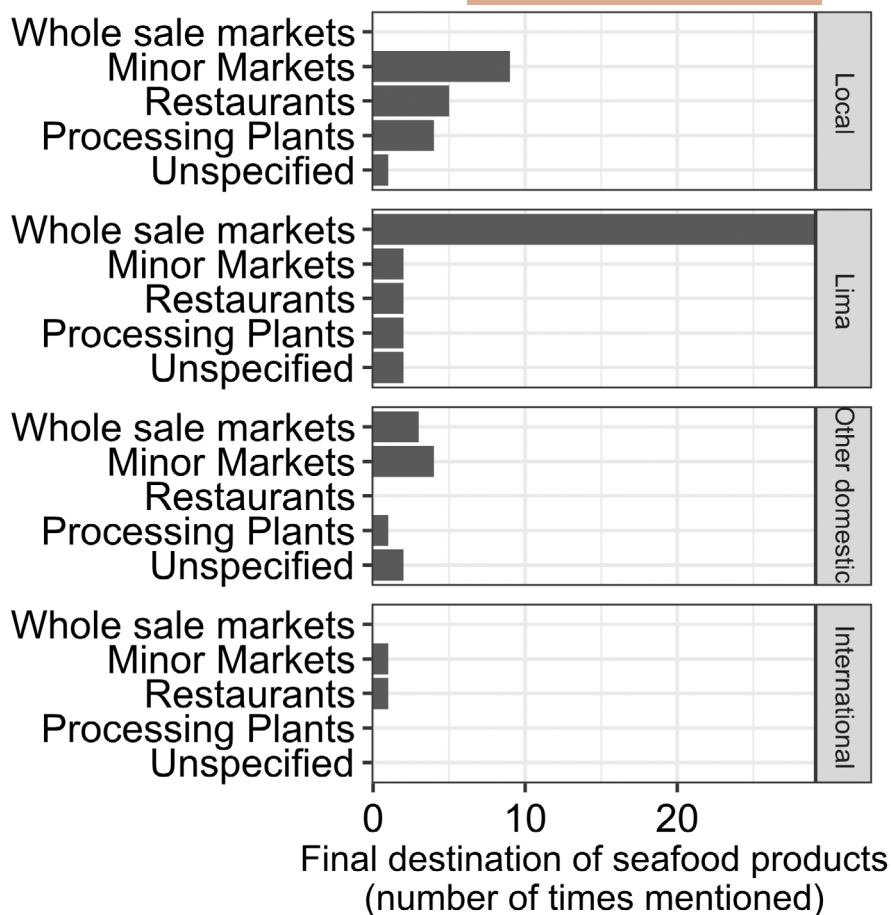


FIGURE 4 Distribution of species targeted by interviewed fishers ($n=45$), grouped by season summer, winter and all year (as defined in Section 2.3). See Table S3.1 (Appendix S3) for scientific species' names.

FIGURE 5 Distribution of seafood products landed and sold at the San Andrés dock as indicated by interviewed fishers ($n=45$), grouped by market type and destination; Local = Pisco province.



mayoristas), minor markets (Span. *mercados minoristas*), restaurants and processing (Figure 5). Wholesale markets (there are two in Lima) serve as hubs for other vendors, for example supermarkets, restaurants and smaller, local food shops. Minor markets sell directly to the public and are usually smaller, local food shops; minor markets often get some of their products from major markets. Some products ultimately end up in the international market as well after being processed (and deep-frozen) in plants within Peru, that is it is not buyers in San Andrés that sell to the international market, but rather San Andrés buyers sell to domestic processing plants who then deal with international distribution.

3.3 | The average fisher motif: Disentangling action at the human-nature interface

The average fisher motif represents the average fisher's value chain (based on average network values) depicted as an ego-network: the fisher as the ego and 5 fisheries target species (E1), 2 buyers (S2) and 2 markets (S3) as alters (Figure 6). From each node type, those with the highest degree measures (cf. preceding sections) were selected to describe the average fisher. Accordingly, the average fisher would catch Eastern Pacific Bonito (*S. chiliensis chiliensis*), South Jack Mackerel (*T. murphyi*)

and Pacific Chub Mackerel (*S. japonicus*), ranking highest in terms of social-ecological out-degree (i.e. number of fishers targeting these species). In addition, the average fisher would (for a total of five target species) catch two of the following species: Peruvian Anchovy (*E. ringens*), Cabinza Grunt (*I. conceptionis*), Stripped Mullet (*M. cephalus*) or Peruvian Silverside (*O. regia*), all of which tied for the rank of the fourth most important fisheries species. Peruvian Anchovy (*E. ringens*), Cabinza Grunt (*I. conceptionis*) and Peruvian Silverside (*O. regia*) are all predominantly caught in winter, while the other species are predominantly caught in summer. The theoretical average fisher would further work with two seafood buyers, selling into two markets: local and Lima (Figure 6).

3.4 | Fishers' perception and value chain archetypes

Archetype analysis (Table 2) allowed us to classify observed typologies in the network, with the average SE connectivity of fishers being 7.1. This analysis allows us to identify archetypes linked to particular fishing seasons. For example, all fishers with low SE in-/ high SS out-degrees target fisheries species from particular seasons, highlighting their vulnerability to seasonal impacts, for example summer heatwaves.

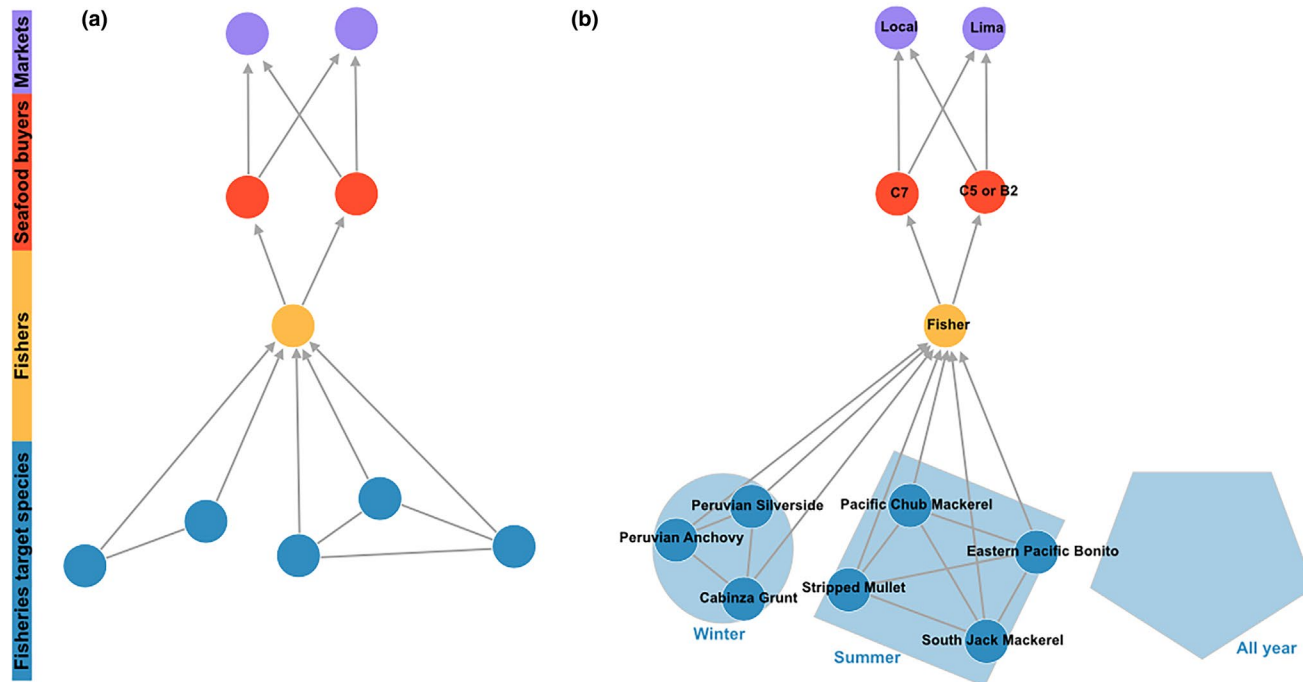


FIGURE 6 (a) Theoretical fisher motif of the fisheries system in San Andrés, looking at the fisher through an ego-network lens. (b) Average fisher motif, including diversity of nodes within each node type. Node positions reflect their occurrence in the value chain, colour represents node type: fisheries target species (E1, in blue), fishers (S1, in yellow), seafood buyers (S2, in red), markets (S3, in violet). Pacific Chub Mackerel, Eastern Pacific Bonito and South Jack Mackerel ranked highest in terms of social–ecological out-degree. Peruvian Silverside, Peruvian Anchovy, Cabinza Grunt and Stripped Mullet are all tied for the fourth most popular target species, and hence, the average fisher would in addition target two of the other species (for a total of five catch species). Light blue polygons indicate ecological node's grouping (winter=oval, summer=rhombus, all year stable=trapeze, cf. Section 2.3 for definitions). See Table S3.1 (Appendix S3) for scientific species' names.

TABLE 2 Overview of the four fisher archetype categories emerging from our analysis, as defined by their social–ecological (SE) connectivity (cf. Sections 2.3 and 3.4; Figures 7 and 8). The percentage of fishers falling into each category, a description of the respective fishing portfolio and the cross-reference to the archetype visualization in Figure 7 are provided.

Archetype	Percentage of fishers	Description	Results	Figure
Low/low	69% ($n=31$)	Fishers with low SE-in and low social–social (SS) out-degree (i.e. 'low/low' SE connectivity)	The majority (51.61%, $n=16$) of this group targeted at least one species all year round, while 38.71% ($n=12$) targeted both peak summer and winter species, and 9.68% ($n=3$) target only summer species	Figure 7c
High/low	13% ($n=6$)	Fishers with a high SE in- and low SS out-degree (i.e. 'high/low' SE connectivity)	All targeted species from all three season categories	Figure 7a
Low/high	5% ($n=2$)	low SE in- and high SS out-degree (i.e. 'low/high' SE connectivity)	Caught only peak summer and winter species (i.e. no species that is caught 'all year')	Figure 7d
High/high	13% ($n=6$)	Fishers with a high SE in- and high SS out-degree (i.e. 'high/high' SE connectivity)	Caught at least one species from each peak season (i.e. winter and summer), as well as at least one species of the 'all year' category	Figure 7b

Perception data (Table 3) corroborated the interpretation of our network results. For example, all fishers with high SE-in values perceived they had many options regarding which species to fish, whereas fishers with low SE-in archetypes agreed to a lesser extent (cf. question 1 in Table 3). High SE-in/High SS-out archetype fishers showed the

highest level of agreement (i.e. 100% for all questions asked, Table 3) with respect to having options regarding which seafood buyers to sell to, receiving enough money for their catch and being able to negotiate prices. This supports the notion that fishers already exhibit adaptive capacity in both the ecological and market realms.

TABLE 3 Perception data of the four fisher archetypes characterizing the value chain, defined by their social–ecological (SE) connectivity (cf. Sections 2.3 and 3.4; Figures 7 and 8). Note that percentage values refer to the respective number of fishers per archetype category; the total number of replies per question and fisher archetype category is specified. For each question, fishers replied on a 6-point Likert scale, with 6–4 representing agreement and 3–1 disagreement to the statement; the values presented in this table are aggregated.

Survey questions	Low SE-in/low SS-out			Low SE-in/high SS-out			High SE-in/low SS-out			High SE-in/high SS-out		
	Agree	Disagree	Replies	Agree	Disagree	Replies	Agree	Disagree	Replies	Agree	Disagree	Replies
1. 'I feel I have many options regarding which species I can catch'	70% (n = 21)	30% (n = 9)	n = 30	50% (n = 1)	50% (n = 1)	n = 2	100% (n = 6)	0% (n = 0)	n = 6	100% (n = 6)	0% (n = 0)	n = 6
2. 'I feel I can easily change which species I target if I want or need'	70% (n = 21)	30% (n = 9)	n = 30	100% (n = 2)	0% (n = 0)	n = 2	67% (n = 4)	33% (n = 2)	n = 6	100% (n = 6)	0% (n = 0)	n = 6
3. 'I feel I can easily adapt my fishing gear to target other species'	77% (n = 23)	23% (n = 7)	n = 30	100% (n = 2)	0% (n = 0)	n = 2	67% (n = 4)	33% (n = 2)	n = 6	100% (n = 6)	0% (n = 0)	n = 6
4. 'I feel I have many options for buyers'	86% (n = 25)	14% (n = 4)	n = 29	50% (n = 1)	50% (n = 1)	n = 2	100% (n = 5)	0% (n = 0)	n = 5	100% (n = 6)	0% (n = 0)	n = 6
5. 'I feel the relationship with buyers is fair'	69% (n = 20)	31% (n = 9)	n = 29	50% (n = 1)	50% (n = 1)	n = 2	80% (n = 4)	20% (n = 1)	n = 5	100% (n = 6)	0% (n = 0)	n = 6
6. 'I feel I receive enough money for my catch from buyers'	69% (n = 20)	31% (n = 9)	n = 29	100% (n = 2)	0% (n = 0)	n = 2	60% (n = 3)	40% (n = 2)	n = 5	100% (n = 6)	0% (n = 0)	n = 6
7. 'I feel I have the power to negotiate with buyers'	100% (n = 29)	0% (n = 0)	n = 29	100% (n = 2)	0% (n = 0)	n = 2	80% (n = 4)	20% (n = 1)	n = 5	100% (n = 6)	0% (n = 0)	n = 6

Abbreviation: SS, social–social.

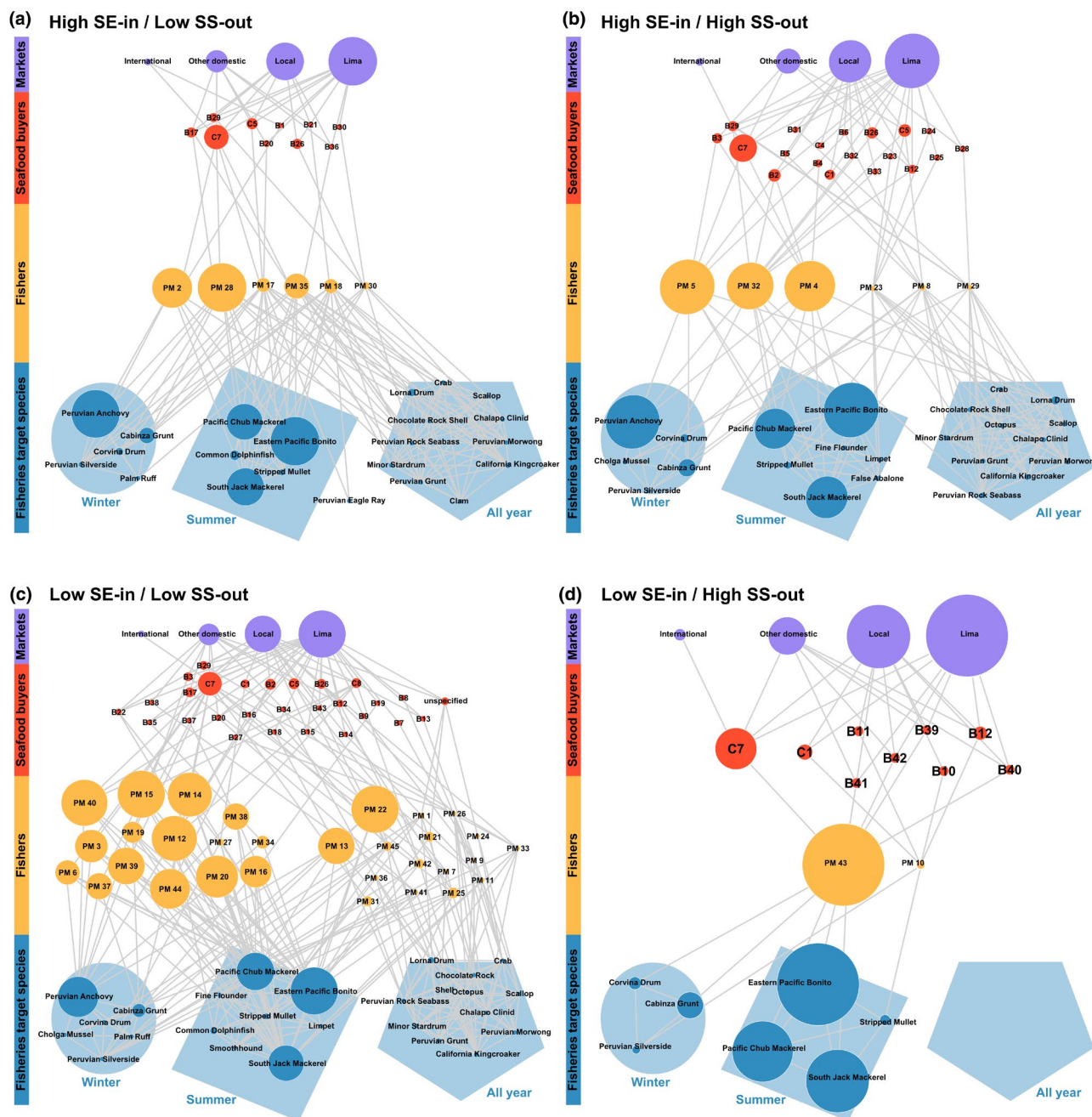


FIGURE 7 Complete social-ecological (SE) networks emerging from the different fisher archetypes and respective individual SE ego-networks: a) Fishers with a high SE in- / low SS out-degree, b) fishers with a high SE in- / high SS out-degree ratio, c) fishers with a low SE in- / low SS out-degree, d) fishers with a low SE in- / high SS out-degree. Archetypes are based on their SE connectivity (cf. Sections 2.3 and 3.4) and have been joined into complete networks to visualize dependencies of fishers to particular seasons. Node positioning represents occurrence in the fisheries value chain and colouring reflects node type: Fisheries target species' (E1, in blue, scaled proportionally to SE out-degree), fishers' (S1, in yellow, scaled proportionally to weighted SE in-degree), seafood buyers (S2, in red, proportionally to social-social [SS] in-degree) and market (S3, in violet; scaled proportionally to SS in-degree). Node grouping shows seasonality of fisheries target species (winter=oval, summer=rhombus, all year stable=trapeze, cf. Section 2.3 for definitions). See Table S3.1 (Appendix S3) for fisheries target species' scientific names.

3.5 | The whole picture: The complete SEN

The complete SEN, describing the SSF-SES in San Andrés and following the value chain of fishery products from capture to consumer market,

was derived from merging the fisher ego-networks and was then composed of 28 ecological (fisheries target species) and 98 social (fisher, seafood buyer and market) nodes, and 117 ecological-ecological, 243 social-ecological and 192 social-social links (Figure 8; Table 4).

4 | DISCUSSION

Examining the structure and adaptive capacities of fishery value chains is essential for understanding how environmental and social changes shape outcomes such as livelihood and food security. This study has provided empirical insights from San Andrés, Peru and demonstrated proof-of-concept theoretical dives into different adaptive fisher archetypes. Below, we discuss how our findings inform the development of theoretical network models of fisher adaptive capacity, which can be used to test and compare how value chain structures shape individual and system resilience in other SSF. Our theoretical motif presented in Section 3.3 (Figure 6) importantly provides a baseline for comparability and cumulative learning for future network and value chain studies on fisheries that move beyond our Peruvian case study. We believe that conceptualizing fisher's value chains as ego-networks (Figure 6a) reveals an important baseline network structure (that is contextualized) for building theory (e.g. when discussing social-ecological dependencies and repercussions of external stressors for any SSF-SES case study) and practice (e.g. when discussing concrete adaptation strategies for scenarios of species decline) through comparison with other studies. This means that for each case study an average fisher motif may emerge that is context specific, and the cross-case comparison will nourish generalizable theory development of perhaps larger and more robustly informed motifs.

4.1 | Fisher and value chain adaptive capacity and resilience

The archetype analysis allowed us to classify four adaptive strategies (cf. Section 3.4), and those expressing the highest SE connectivity (i.e. those with high SE in- / high SE out-degrees) appeared to be the most adaptive and resilient according to fisher's own perceptions. While it is difficult to identify the exact mechanisms for these observations, data linking network archetypes to outcomes, and supporting these with fisher perceptions, is a useful starting point to investigate mechanistic causes in future studies. For example, it is also evident that although adaptive capacity is possible and present, it is far from the average strategy: only 13% of all interviewed fishers fell into this group. Diverse catch portfolios have been found to positively contribute towards fisher livelihood longevity (Allison & Ellis, 2001), and many argue fishers with diverse catch have a greater adaptive capacity to absorb both economic and environmental disturbances than fishers who capture fewer and more similar species (Anderson et al., 2017; Cline et al., 2017; Alexander et al., 2019; Kluger, Scotti, et al., 2019). The opportunity to catch multiple species distributes the risk of economic and environmental stressors over time, individuals and the value chain. This is compliant with the work of Kluger, Scotti, et al. (2019) and Kluger, Kochalski, et al. (2019) who argued that single-species dependency of resource users (fishers, scallop farmers; in Sechura Bay, North Peru) made them more vulnerable to the effects of an environmental disturbance (i.e. the

Coastal El Niño 2017). And De la Puente et al. (2022) argue that the progression towards decreased catch diversity has created social-ecological traps for two fishing communities further North in Peru (El Niño, Cabo Blanco). Social-ecological traps occur when a system (here: SSF) experiences constant feedback loops that perpetuate dependency structures, and which can eventually undermine their health (e.g. overfishing a single species) instead of providing benefits to those involved (Cinner, 2011). Nonetheless, developing a diverse catch portfolio for an individual fisher may take time, with challenges such as initial financing, gear attainment and knowledge of use and repair as well as developing networks for cooperative fishing and patron-client relationships (Carrillo et al., 2019). This is an important leverage point for fisheries managers around the globe: avoiding inflexible fishing permits tying fishers to (the use of) a particular resource that potentially lowers their adaptive capacity amidst a future disturbance event. Allowing fishers to be flexible in their catch portfolio, while maintaining sustainability targets likely helps them in confronting crises. Furthermore, allowing for flexibility on the fisher level who are principle agents at the human-nature interface can enhance flexibility aspects of resilience to the overall system that is bound to the fishery-dependency.

Our analysis of perceptions reflected both these challenges and opportunities. A majority of fishers stated that they do have options regarding what species they catch, and they can easily change their catch species using the gear they already have (Table 3). Additionally, when asked what fishers do if their typical catch species disappear (e.g. due to an ENSO event), 64% of respondents ($n=29$) reported switching their catch species (Table 3). This suggests that fishers do have adaptive capacity and are already adapting to disturbances and fluctuating environmental conditions (e.g. seasons). This is further emphasized by the wide range (i.e. 28 different) fisheries target species, indicating functional redundancies, that is multiple nodes (catch species) that could potentially fill the role of individual nodes that may disappear in response to a particular disturbance (Blythe, 2014; Folke, 2006). The valuation of individual adaptive capacity and resilience can inform discussions on network (system) resilience by identifying crucial dependencies or the functional redundancies that could allow vulnerability reductions. For this, perceptions are essential for understanding how fishers will navigate based on what they believe their position and vulnerability to be (Bennett, 2016; Partelow et al., 2021).

When considering the fisher-buyer side, the presence of more buyers than fishers, with price being the most agreed determinant for selecting a buyer, suggests that fishers can exert power, as they can select and negotiate with buyers for the best price without fear of losing market access (González-Mon et al., 2019; Kininmonth et al., 2017). This is corroborated by fisher perception data: all fishers with a high SE in-degree perceived to have many options to whom to sell (cf. question 4 in Table 3) and the perceived power to negotiate was confirmed by all fishers interviewed (cf. question 6 in Table 3). This supports the notion that the market component of the SSF is competitive and holds adaptive capacity. As Kininmonth et al. (2017) find, having this freedom (i.e. being 'freelance' fishers

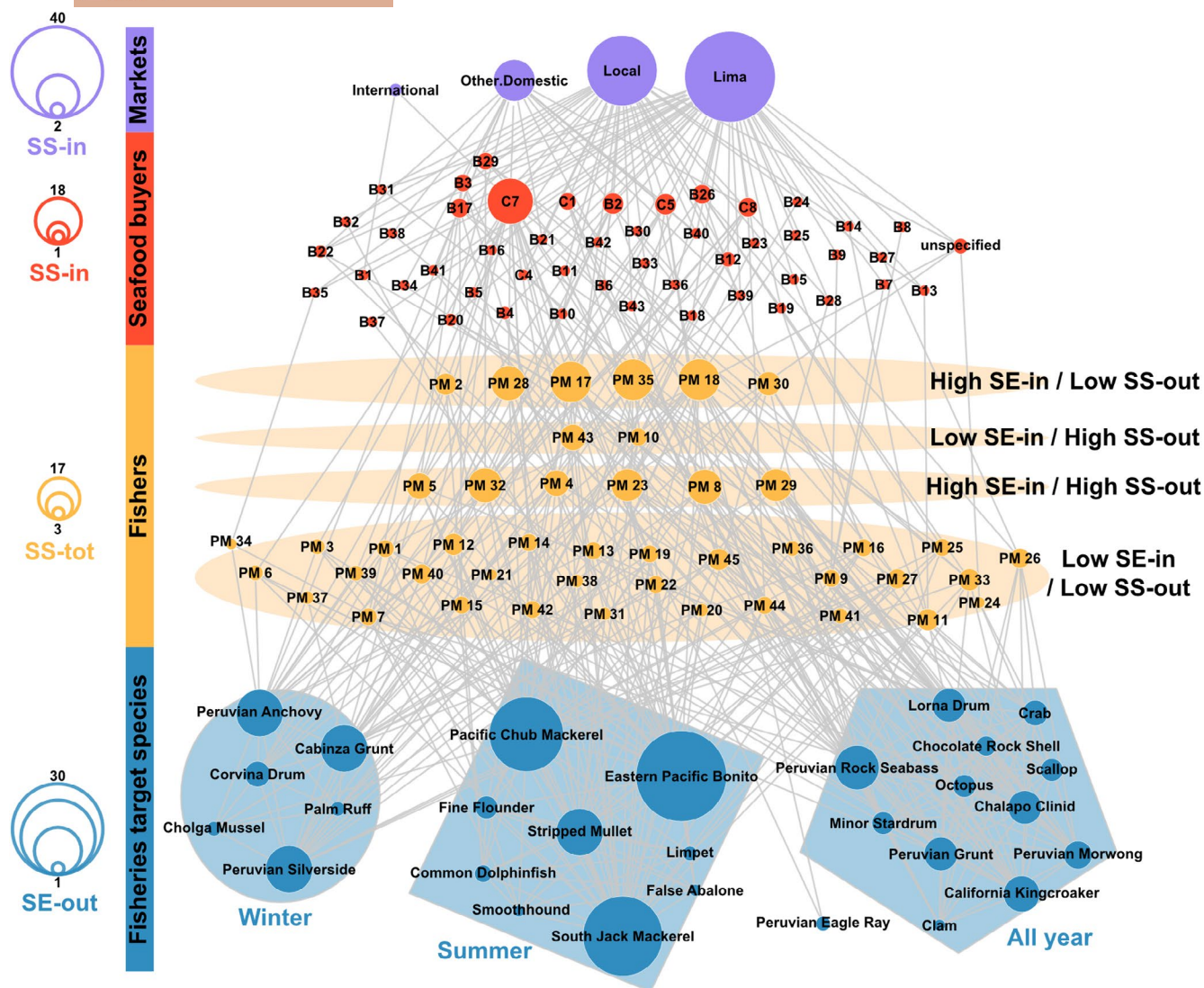


FIGURE 8 Overview of the complete social-ecological (SE) network describing the small-scale fisheries of San Andrés as derived from the individual ego-networks of fishers. Nodes (ecological ($n=28$), social ($n=98$)) are positioned along the y-axis based on their appearance in the value chain, and coloured according to node type: Fisheries target species (E1; in blue; sized proportionally to SE out-degree [SE-out]), fishers (S1; in yellow; sized proportionally to total degree [SS-tot]), seafood buyers (S2; in red; scaled proportionally to SS in-degree), markets (S3; in violet; sized proportionally to SS in-degree). Node grouping represents fisher archetypes (light yellow ovals, cf. Sections 2.3 and 3.4; Table 2) and seasonality of fisheries target species (winter=oval, summer=rhombus, all year stable=trapeze, cf. Section 2.3 for definitions). See Appendix S3, Table S3.1 for fisheries target species' scientific names. SS, social-social.

not being tied to a specific buyer requiring a specific catch species) may allow fishers greater flexibility in their fishing practices to better respond to and match both market and environmental fluctuations and disturbances. This further helps avoid dependent patron–client relationships where patrons hold the power of price and access to markets, and even loan financing and banking in some cases (Carrillo et al., 2019).

At the same time, fish buyers, in general, hold an intermediary role between fishers and markets, and thus have an ability to pass on information (Ferrol-Schulte et al., 2014) and to then potentially influence fishers' behaviour (e.g. by sharing information on market demands, which may drive fisher choice in catch species). The social dynamics of these relations can then impact fisher strategies that

are adaptive to change (González-Mon et al., 2019). Having multiple buyers and selling into multiple markets provides redundancies that act as insurance against market or buyer changes to access those markets. While some fishers do sell certain species to specific buyers, most report selling all of their catch to a single buyer they work with during that transaction; that is within the San Andrés value chains. This means that patron–client relations are not species-specific, but specific to the buyer relationship. This suggests that if a change occurs (e.g. a buyer leaves), there are others to fill its place and function, a characteristic that has been associated with resilient SESs (that are represented as SENs) (Janssen et al., 2006; Walker et al., 1999). Similarly, a majority of fishers report their products going to at least two markets, specifically Lima and Local, regardless

TABLE 4 Overview of social–ecological network components, indicating the different network features, their respective ID and definition and the number of items (*n*) in the complete network.

Network feature	ID	Defined as	<i>n</i>
Ecological node	E1	Fisheries target species	28
Social node	S1	Fishers	45
	S2	Seafood buyers	49
	S3	Markets	4
Total number of nodes			126
Ecological–ecological edges (undirected)	EE	Main fishing season	117
Social–ecological edges (directed)	SE	Fisheries target species → fishers	243
Social–social edges (directed)	SS1	Fishers → seafood buyers	104
	SS2	Seafood buyers → markets	88
Total number of links			552

of buyer. Markets are typically not species-specific. Again, this redundancy could be viewed as a sign of resilience, specifically towards disturbances that cause the removal of network links (Janssen et al., 2006). Having these redundancies may provide the opportunity for the core identity of fishers' value chains. Yet, the effects that markets impose on fisheries' and aquaculture's value chains are not to be neglected: Kluger, Taylor, et al. (2019), for example, describe how access to international markets stipulated an explosion in the production of the Peruvian bay scallop (*Argopecten purpuratus*) in Peru, how international market requirements (such as sanitary standards of the EU) shaped local production practices and how low international prices led to the exclusion of Chilean scallop producers from certain markets. And Bakit et al. (2023) describe how environmental changes in a target market (i.e. in Spain) of the same species facilitated renewed market access. Furthermore, major social changes such as the COVID-19 mobility restrictions can significantly shift how, where and in what form seafood products are distributed to different markets (Campbell et al., 2021; Kluger et al., 2023; Manlosa et al., 2021; Partelow et al., 2023).

Overall, some fishers are quite diversified in their catch and buying practices, while most are not, having relatively few catch species and buyers. However, to assess resilience, we must again contextualize these numbers and look more closely at the specific identities of the catch species and buyers connected to the fishers. There are fishers that target species with different peak catch seasons (i.e. adapting to seasonality). Likewise, fishers from all categories work with the four major buyers and sell their products to both the Lima and local markets. This suggests that fishers from within all categories are already adapting (i.e. to changing environmental factors like season) and hold additional adaptive capacity (e.g. by having redundancies in their value-chain relations). Furthermore, it is important to remember that among fishers categorized as catching a low number of species and selling to a low number of buyers, many do still have multiple options throughout their value chains. Even having 'only' two options demonstrates adaptive capacity and likely makes fishers more resilient than single species or single buyer arrangements (e.g. many industrial fishers).

Overall, it has been argued that many Peruvian small-scale fishers are diversified within the fishing sector, primarily by being flexible to fish other species (Kleisner et al., 2022). But fisher resilience (or any human, to that matter) depends, however, not only on the availability of coping mechanisms within the system but also on non-fishery livelihood options in the same location. In Peru, small-scale resource users have historically adapted to changes in species fluctuations or environmental crises by moving along the coast in search of other work (within or outside the seafood sector; Badjeck et al., 2009; Kluger, Alff, et al., 2020). Increasing individual adaptive capacity and resilience through livelihood diversification is corroborated, for example, by the findings of Pollnac et al. (2024) who explored the perception of and adaptation strategies to ENSO of about 800 fishers along the Ecuadorian coast. While this is theoretically still an option for many fishers and fish workers (with many resource user movements having been observed in the aftermath of the Coastal El Niño event; Kluger, Alff, et al., 2020; Kluger, Kochalski, et al., 2019) not all types of shocks may enable these strategies. The onset of the COVID-19 pandemic, for example, has interrupted people's ability to roam freely in search for work (e.g. Campbell et al., 2021; Kluger et al., 2023; Partelow et al., 2023; also documented for other SSF-SEs around the world), with drastic effects for fishers and fish workers.

In some occasions, aquaculture is adopted and/or promoted as a means to promote livelihood diversification and/or an alternative to traditional fisheries, for example when fishing declines render individual options within the sector difficult. However, globally there is little evidence of the so-called blue transition hypothesis until aquaculture sectors become more dominant than capture fisheries (Cottrell et al., 2021). Nonetheless, the coastal fisheries context matters. In Peru and Chile, small-scale fishers have, for example, started flourishing economic sectors such as the aquaculture of the Peruvian bay scallop (e.g. Bakit et al., 2023; Kluger, Taylor, et al., 2019); against the background of marine policies supporting aquaculture diversification in both places (Bakit et al., 2024; Garteizgogeoasoa et al., 2020). And while these farms indeed served as a lucrative income source for thousands

of locals (Kluger, Taylor, et al., 2019), it has also created what Steneck et al. (2011) termed a 'gilded trap' in times of crisis: a situation in which group actions resulting from an economically attractive activity outweigh concerns over social or ecological risks (Cumming, 2018; Steneck et al., 2011). When the Coastal El Niño 2017 hit Northern Peru, its heavy rains caused a literal die-off of scallop cultures in the region, and those farmers who were exclusively dependent on scallops were more heavily affected and had difficulties recovering (Kluger, Kochalski, et al., 2019; Kluger, Scotti, et al., 2019). In this example, the promotion of aquaculture led to increased single-species dependency rather than a livelihood diversification.

4.2 | Advancing SEN theory

This study provides a proof-of-concept model that can be the foundation for theory building by comparing fisher and value chain adaptive capacity in other fisheries. Our findings indicate how diverse information from expert interviews and individual fisher ego-networks derived from in-depth interviews can be combined to construct a fully integrated SEN to analyse value chain structures and their changes, as well as the positioning (and thus resilience) of individual fishers. This theory-forward fisher motif presented above reflects typical value chain interactions of a resilient fisher, which can act as a basis of reference for designing future studies to test adaptive capacity in similar contexts to advance theories of resilience. We derived an average archetypal fisher motif which was based on four empirically different archetypes, each of which could be further empirically supported and lead to multiple archetype motifs in future research. Importantly, adaptive capacity can only be fully assessed by collecting and analysing data from both the social and ecological realms. Network analysis has helped examine how they are connected and interdependent. This study also makes methodological contributions to SEN theory development, which is challenged by a lack of standardized methods of (statistical) analysis across social and ecological realms (Kluger, Gorris, et al., 2020), and differentiated methods for the analysis of resilience thresholds of these inextricably linked components (Blythe, 2014). Recent reviews of SEN literature (Kluger, Gorris, et al., 2020; Sayles et al., 2019) have identified methodologies that can be utilized across fully articulated networks (i.e. reflecting social-social, social-ecological and ecological-ecological links); one such tool is motif analysis (Kluger, Gorris, et al., 2020). As such, the novel contribution of this study is the conceptual and methodological approach of using SE-networks and archetypes to understand fisheries value chains. By focusing specifically on fishers with an ego-network approach, we have been able to put forward a tentative archetypal model for future research with a clear network structure and measurable node definitions. We believe this makes clear progress towards more standardized and comparable research on SES analysis from a network perspective that combines perspectives on individual and system resilience.

While network analysis allows us to comparatively discuss system configurations, connectivity and actor interdependencies—and hence helps in advancing our understanding of SES in general—any model is also inherently reductionist, potentially limiting the generalization of results. SEN theory carries the biases of choices for data collection and individual network parametrization, but also by the method as such, one could argue. Our complete SEN was derived from joining individual ego-networks into a holistic perspective, which is different from deriving a complete network from large-scale survey data; and each approach comes with benefits and caveats. Although mechanistic drivers of archetype formation are difficult to assess in our study, we provide necessary and integrated observations linking network structures to outcomes and fishers' perceptions about those outcomes as a crucial starting point. In our opinion, it is best coupled with (other) multi-method qualitative-quantitative assessments of the system and its dynamics to deepen insights. For example, the structure of fisher-buyer relations can be observed in the network and supported by node attribute data for interpretation. Nonetheless, to fully assess patron-client social dynamics such as social capital, rich qualitative assessment needs to be added to provide meaning, interpretation and perhaps causality to observed network structures and interpretations of resilience. As external analysts, we may observe and interpret resilience in a network; however, if fishers do not perceive themselves to be resilient, but rather constrained, such factors need to be considered and unpacked through other methods.

5 | CONCLUSIONS

San Andrés small-scale fishers are diverse in their target species and gear, and reflect different adaptive strategies to value chain interactions (buyers, markets) and the environment (seasonality). We interpret our findings in a way that diverse catch portfolios represent the basis for a diverse value chain with a diversity of buyers and markets, while providing the opportunity to distribute the risk of economic and environmental stressors over time, individuals and the entire value chain. Through applying social-ecological network analysis, different fisher archetypes were identified (i.e. patterns of network structure and interactions), with fishers selling their products to buyers in a competitive market, where the main reported driving force of a sale is price (i.e. not a pre-established, asymmetric agreement with a single buyer). Fishers exhibit adaptive capacity by switching target species by season and retain the possibility to adapt because of the choices they have for catch species, buyers and markets. However, adaptive capacity was not uniform. It depends on fishers' social-ecological connectivity along the value chain, shown as different archetypes in the analysis. We aggregated these insights into a contextualized theoretical fisher motif that quantifies value chain relations and highlights the core network structure of adaptive capacity. Fishers have multiple options within each step of the value chain: (1) catching five or more different species, (2) selling to two or more different buyers and (3) selling their products into two or more

different markets. This contextual motif provides a basis for further theorizing fisheries value chain resilience through network analysis and could act as a means for broader or rapid comparison across fisheries that would have their own fisher motifs. Furthermore, this study highlights the importance of mixed method and interdisciplinary approaches to comprehensively understand SSF-SESSs and their resilience through network-based approaches.

AUTHOR CONTRIBUTIONS

Lotta Clara Kluger and Stefan Partelow conceived the ideas and designed methodology. Lotta Clara Kluger, Samantha Mercer and Máximo Antonio Roque-Sánchez collected the data. Lotta Clara Kluger and Samantha Mercer analysed the data. Lotta Clara Kluger and Stefan Partelow led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

At the time of manuscript submission and processing, Stefan Partelow was an Associate Editor for People and Nature, but was not involved in the peer review and decision-making process. Besides, no conflict of interest are to be declared.

DATA AVAILABILITY STATEMENT

As described in the method section, informed consent to participate in this study had to be collected exclusively verbally, because all participants declined to sign any 'formal' papers in the fear of traceability and distrust expressed towards authorities. Due to this study context, anonymized data for study reproduction will be made available on request, but was not stored in any publicly available database.

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REFERENCES

- Alexander, S. M., Staniczenko, P. P. A., & Bodin, Ö. (2019). Social ties explain catch portfolios of small-scale fishers in the Caribbean. *Fish and Fisheries*, 21(1), 120–131. <https://doi.org/10.1111/faf.12421>
- Allison, E. H., & Ellis, F. (2001). The livelihoods approach and Management of Small-Scale Fisheries. *Marine Policy*, 25(5), 377–388. [https://doi.org/10.1016/S0308-597X\(01\)00023-9](https://doi.org/10.1016/S0308-597X(01)00023-9)
- Alvarez, J. (2003). *Estudio sobre el impacto socioeconómico de la pesca artesanal en los Estados Miembros de la Comisión Permanente del Pacífico Sur*. Reporte preparado para la Secretaría General-Dirección de Asuntos Económicos de la CPPS, 27.
- Anderson, S. C., Ward, E. J., Shelton, A. O., Adkison, M. D., Beaudreau, A. H., Brenner, R. E., Haynie, A. C., Shriver, J. C., Watson, J. T., & Williams, B. C. (2017). Benefits and risks of diversification for individual fishers. *Proceedings of the National Academy of Sciences of the United States of America*, 114(40), 10797–10802. <https://doi.org/10.1073/pnas.1702506114>
- Badjeck, M. C. (2008). *Vulnerability of coastal fishing communities to climate change: Implications for fisheries livelihoods and management in Peru* [Doctoral thesis, Universität Bremen].
- Badjeck, M. C., Mendo, J., Wolff, M., & Lange, H. (2009). Climate variability and the Peruvian scallop fishery: The role of formal institutions in resilience building. *Climatic Change*, 94(1–2), 211–232. <https://doi.org/10.1007/s10584-009-9545-y>
- Bailey, M., Bush, S., Oosterveer, P., & Larastiti, L. (2016). Fishers, fair trade, and finding middle ground. *Fisheries Research*, 182, 59–68. <https://doi.org/10.1016/j.fishres.2015.11.027>
- Bakit, J., Burgos-Fuster, V., Abarca, A., Etchepare, I., Illanes, J. E., Villasante, S., Bonilla, E., Rojas, R., Dudouet, B., & Cortés, N. (2024). Scallop aquaculture growth: Four decades of economic policy in Chile. *Marine Policy*, 163(2024), 106139. <https://doi.org/10.1016/j.marpol.2024.106139>
- Bakit, J., Hurtado, A., Márquez, R., & Villasante, S. (2023). Navigating transformations from artisanal fishers to entrepreneurial scallop farmers in Chile. *Frontiers in Marine Science*, 10. <https://doi.org/10.3389/fmars.2023.1128527>
- Bakun, A., Black, B. A., Bograd, S. J., García-Reyes, M., Miller, A. J., Rykaczewski, R. R., & Syfeman, W. J. (2015). Anticipated effects of climate change on coastal upwelling ecosystems. *Current Climate Change Reports*, 1, 85–93. <https://doi.org/10.1007/s4064-015-0008-4>
- Bakun, A., Field, D., Redondo-Rodríguez, A., & Weeks, S. J. (2010). Greenhouse gas, upwelling-favorable winds, and the future of coastal ocean upwelling ecosystems. *Global Change Biology*, 16, 1213–1228.
- Bakun, A., & Weeks, S. J. (2008). The marine ecosystem off Peru: What are the secrets of its fishery productivity and what might its future hold? *Progress in Oceanography*, 79, 290–299. <https://doi.org/10.1016/j.pocean.2008.10.027>
- Barber, R. T., & Chavez, F. P. (1983). Biological consequences of El Niño. *Science*, 222(4629), 1203–1210. <https://doi.org/10.1126/science.222.4629.1203>
- Barnes, M. L., Bodin, Ö., Guerrero, A. M., McAllister, R. J., Alexander, S. M., & Robins, G. (2017). The social structural foundations of adaptation and transformation in social-ecological systems. *Ecology and Society*, 22(4), 16. <https://doi.org/10.5751/ES-09769-220416>
- Barnes, M. L., Bodin, Ö., McClanahan, T. R., Kittinger, J. N., Hoey, A. S., Gaoue, O. G., & Graham, N. A. J. (2019). Social-ecological alignment and ecological conditions in coral reefs. *Nature Communications*, 10(1), 2039. <https://doi.org/10.1038/s41467-019-09994-1>
- Barnes, M. L., Lynham, J., Kalberg, K., & Leung, P. (2016). Social networks and environmental outcomes. *Proceedings of the National Academy of Sciences of the United States of America*, 113, 6466–6471. <https://doi.org/10.1073/pnas.1523245111>

- Barnes, M. L., Wang, P., Cinner, J. E., Graham, N. A. J., Guerreo, A. M., Jasny, L., Lau, J., Sutcliffe, S. R., & Zamborain-Mason, J. (2020). Social determinants of adaptive and transformative responses to climate change. *Nature Climate Change*, 10, 823–828. <https://doi.org/10.1038/s41558-020-0871-4>
- Barton, E. D., Field, D. B., & Roy, C. (2013). Canary current upwelling: More or less? *Progress in Oceanography*, 116(2013), 167–178. <https://doi.org/10.1016/j.pocean.2013.07.007>
- Bassett, H. R., Sharan, S., Suri, S. K., Advani, S., & Giordano, C. (2022). A comparative study of small-scale fishery supply chains' vulnerability and resilience to COVID-19. *Maritime Studies*, 21(2), 173–192. <https://doi.org/10.1007/s40152-021-00231-4>
- Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. *Proceedings of the International AAAI Conference on Web and Social Media*, 3, 361–362.
- Basurto, X., Bennett, A., Weaver, A. H., & Dyck, S. R. (2013). Cooperative and noncooperative strategies for small-scale fisheries' self-governance in the globalization era: Implications for conservation. *Ecology and Society*, 18(4), 38. <https://doi.org/10.5751/ES-05673-180438>
- Basurto, X., Gutierrez, N. L., Franz, N., del Mar Mancha-Cisneros, M., Gorelli, G., Aguión, A., Funge-Smith, S., Harper, S., Mills, D. J., Nico, G., Tilley, A., Vannuccini, S., Virdin, J., Westlund, L., Allison, E. H., Anderson, C. M., Baio, A., Cinner, J., Fabinyi, M., ... Thilsted, S. H. (2025). Illuminating the multidimensional contributions of small-scale fisheries. *Nature*, 637, 875–884.
- Belton, B., Reardon, T., & Zilberman, D. (2020). Sustainable commoditization of seafood. *Nature Sustainability*, 3, 677–684. <https://doi.org/10.1038/s41893-020-0540-7>
- Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. *Conservation Biology*, 30(3), 582–592. <https://doi.org/10.1111/cobi.12681>
- Bertrand, A., Lengaigne, M., Takahashi, K., Avadí, A., Poulain, F., & Harrod, C. (2020). *El Niño Southern Oscillation (ENSO) effects on fisheries and aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 660. FAO. <https://doi.org/10.4060/ca8348en>
- Binet, T., Failer, P., & Thorpe, A. (2012). Migration of Senegalese fishers: A case for regional approach to management. *Maritime Studies*, 11(1), 1. <https://doi.org/10.1186/2212-9790-11-1>
- Bivand, R. S., Pebesma, E., & Gomez-Rubio, V. (2013). *Applied spatial data analysis with R* (2nd ed.). Springer. <https://doi.org/10.1007/978-1-4614-7618-4>
- Blythe, J. L. (2014). Resilience and social thresholds in small-scale fishing communities. *Sustainability Science*, 10(1), 157–165. <https://doi.org/10.1007/s11625-014-0253-9>
- Bodin, Ö. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, 357(6352), eaan1114. <https://doi.org/10.1126/science.aan1114>
- Bodin, Ö., & Tengö, M. (2012). Disentangling intangible social-ecological systems. *Global Environmental Change*, 22(2), 430–439. <https://doi.org/10.1016/j.gloenvcha.2012.01.005>
- Borgatti, S. P., Mehra, A., Brass, D. J., & Labianca, G. (2009). Network analysis in the social sciences. *Science*, 323, 892–895. <https://doi.org/10.1126/science.1165821>
- Brownrigg, R. (2018). *Maps: Draw geographical maps*. R package Version 3.3.0. <https://CRAN.R-project.org/package=maps>
- Cai, W., Ng, B., Geng, T., Jia, F., Wu, L., Wang, G., Liu, Y., Gan, B., Yang, K., Santoso, A., Lin, X., Li, Z., Liu, Y., Yang, Y., Jin, F. F., Collins, M., & McPhaden, M. J. (2023). Anthropogenic impacts on twentieth-century ENSO variability changes. *Nature Reviews Earth and Environment*, 4, 407–418. <https://doi.org/10.1038/s43017-023-00427-8>
- Cai, W., Santoso, A., Collins, M., Dewitte, B., Karamperidou, C., Kug, J. S., Lengaigne, M., McPhaden, M. J., Stuecker, M. F., Taschetto, A. S., Timmermann, A., Wu, L., Yeh, S. W., Wang, G., Ng, B., Jia, F., Yang, Y., Ying, J., Zheng, X. T., ... Zhong, W. (2021). Changing El Niño–Southern Oscillation in a warming climate. *Nature Reviews Earth and Environment*, 2, 628–644. <https://doi.org/10.1038/s43017-021-00199-z>
- Campbell, S. J., Jakub, R., Valdivia, A., Setiawan, H., Setiawan, A., Cox, C., Kiyo, A., Darman, Djafar, L. F., de la Rosa, E., Suherfian, W., Yuliani, A., Kushardanto, H., Muawanah, U., Rukma, A., Alimi, T., & Box, S. (2021). Immediate impact of COVID-19 across tropical small-scale fishing communities. *Ocean and Coastal Management*, 200, 105485. <https://doi.org/10.1016/j.ocecoaman.2020.105485>
- Carrillo, I. C., Partelow, S., Madrigal-Ballester, R., Schlüter, A., & Gutierrez-Montes, I. (2019). Do responsible fishing areas work? Comparing collective action challenges in three small-scale fisheries in Costa Rica. *International Journal of the Commons*, 13(1), 705–746. <https://doi.org/10.18352/ijc.923>
- Chamorro, A., Echevin, V., Dutheil, C., Tam, J., Gutiérrez, D., & Colas, F. (2021). Projection of upwelling-favorable winds in the Peruvian upwelling system under the RCP8.5 scenario using a high-resolution regional model. *Climate Dynamics*, 57, 1–16. <https://doi.org/10.1007/s00382-021-05689-w>
- Chavez, F. P., Bertrand, A., Guevara-Carrasco, R., Soler, P., & Csirke, J. (2008). The northern Humboldt current system: Brief history, present status and a view towards the future. *Progress in Oceanography*, 79(2–4), 95–105. <https://doi.org/10.1016/j.pocean.2008.10.012>
- Chuenpagdee, R., Liguori, L., Palomares, M. L. D., & Pauly, D. (2006). *Bottom-up, global estimates of small-scale marine fisheries catches*. <https://doi.org/10.14288/1.0074761>
- Cinner, J. E. (2011). Social-ecological traps in reef fisheries. *Global Environmental Change*, 21(3), 835–839. <https://doi.org/10.1016/j.gloenvcha.2011.04.012>
- Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. J., Gelcich, S., Hicks, C. C., Hughes, T. P., Lau, J., Marshall, N. A., & Morrison, T. H. (2018). Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change*, 8, 117–123. <https://doi.org/10.1038/s41558-017-0065-x>
- Cline, T. J., Schindler, D. E., & Hilborn, R. (2017). Fisheries portfolio diversification and turnover buffer Alaskan fishing communities from abrupt resource and market changes. *Nature Communications*, 8(1), 14042. <https://doi.org/10.1038/ncomms14042>
- Collins, M., An, S. I., Cai, W., Ganachaud, A., Guilyardi, E., Jin, F. F., Jochum, M., Lengaigne, M., Power, S., Timmermann, A., Vecchi, G., & Wittenberg, A. (2010). The impact of global warming on the tropical Pacific Ocean and El Niño. *Nature Geoscience*, 3, 391–397. <https://doi.org/10.1038/ngeo868>
- Cottrell, R. S., Ferraro, D. M., Blasco, G. D., Halpern, B. S., & Froehlich, H. E. (2021). The search for blue transitions in aquaculture-dominant countries. *Fish and Fisheries*, 22, 1–18. <https://doi.org/10.1111/faf.12566>
- Crona, B., Nyström, M., Folke, C., & Jiddawi, N. (2010). Middlemen, a critical social-ecological link in coastal communities of Kenya and Zanzibar. *Marine Policy*, 34(4), 761–771. <https://doi.org/10.1016/j.marpol.2010.01.023>
- Crona, B. I., Van Holt, T., Petersson, M., Daw, T. M., & Buchary, E. (2015). Using social-ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Global Environmental Change*, 35, 162–175. <https://doi.org/10.1016/j.gloenvcha.2015.07.006>
- Cumming, G. S. (2018). A review of social dilemmas and social-ecological traps in conservation and natural resource management. *Conservation Letters*, 11(1), e12376. <https://doi.org/10.1111/conl.12376>
- De la Puente, S., López de la Lama, R., Llerena-Cayo, C., Martínez, B. R., Rey-Cama, G., Christensen, V., Rivera-Ch, M., & Valdés-Velasquez, A. (2022). Adoption of sustainable low-impact fishing practices is not enough to secure sustainable livelihoods and social wellbeing in small-scale fishing communities. *Marine Policy*, 146, 105321. <https://doi.org/10.1016/j.marpol.2022.105321>

- Eisenack, K., Oberlack, C., & Sietz, D. (2021). Avenues of archetype analysis: Roots, achievements, and next steps in sustainability research. *Ecology and Society*, 26(2). <https://doi.org/10.5751/ES-12484-260231>
- ERM. (2002). *Environmental and Social Impact Assessment for the Liquids of Natural Gas Fractionation Plant and Loading Facilities Project Lobería Beach, Pisco, Peru*. PlusPetrol Peru Corporation.
- FAO. (2020). *The state of world fisheries and aquaculture 2020. Sustainability in action*. <https://doi.org/10.4060/ca9229en>
- FAO. (2024). *The state of world fisheries and aquaculture 2024. Blue transformation in action*. <https://doi.org/10.4060/cd0683en>
- FAO, Duke University, WorldFish. (2023). *Illuminating hidden harvests—The contributions of small-scale fisheries to sustainable development*. <https://doi.org/10.4060/cc4576en>
- Ferrol-Schulte, D., Ferse, S. C. A., & Glaser, M. (2014). Patron–client relationships, livelihoods and natural resource Management in Tropical Coastal Communities. *Ocean and Coastal Management*, 100, 63–73. <https://doi.org/10.1016/j.ocecoaman.2014.07.016>
- Ferse, S. C. A., Glaser, M., Neil, M., & Schwerdtner Máñez, K. (2012). To cope or to sustain? Eroding long-term sustainability in an Indonesian coral reef fishery. *Regional Environmental Change*, 14(6), 2053–2065. <https://doi.org/10.1007/s10113-012-0342-1>
- Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems. *Analyses Global Environmental Change*, 16(3), 253–267. <https://doi.org/10.1016/j.gloenvcha.2006.04.002>
- Garteizgogeoasca, M., Gonzales, I. E., Kluger, L. C., Damonte, G., & Flitner, M. (2020). *Institutional context and governance of Peruvian fisheries and aquaculture (artec-paper, 226)*. Universität Bremen, Forschungszentrum Nachhaltigkeit (artec). <https://nbn-resolving.org/urn:nbn:de:0168-ssoar-73225-8>
- Golden, C. D., Koehn, J. Z., Shepon, A., Passarelli, S., Free, C. M., Viana, D. F., Matthey, H., Eurich, J. G., Gephart, J. A., Fluet-Chouinard, E., Nyboer, E. A., Lynch, A. J., Kjelleve, M., Bromage, S., Charlebois, P., Barange, M., Vannuccini, S., Cao, L., Kleisner, K. M., ... Thilsted, S. H. (2021). Aquatic foods to nourish nations. *Nature*, 598, 315–320. <https://doi.org/10.1038/s41586-021-03917-1>
- González-Mon, B., Bodin, Ö., Crona, B., Nenadovic, M., & Basurto, X. (2019). Small-scale fish buyers' trade networks reveal diverse actor types and differential adaptive capacities. *Ecological Economics*, 164, 106338. <https://doi.org/10.1016/j.ecolecon.2019.05.018>
- Gonzalez-Mon, B., Bodin, Ö., Lindkvist, E., Frawley, T. H., Giron-Nava, A., Basurto, X., Nenadovic, M., & Schlüter, M. (2021). Spatial diversification as a mechanism to adapt to environmental changes in small-scale fisheries. *Environmental Science and Policy*, 116, 246–257. <https://doi.org/10.1016/j.envsci.2020.11.006>
- Guevara-Carrasco, R., & Bertrand, A. (2017). *Atlas de La Pesca Artesanal Del Mar Del Perú Edición IMARPE-IRD, Lima, Perú*, 183. <http://biblioiimarpe.imarpe.gob.pe/handle/123456789/3167>
- Gutierrez, D., Bouloubassi, I., Sifeddine, A., Purca, S., Goubanova, K., Graco, M., Field, D., Méjanelle, L., Velazco, F., Lorre, A., Salvatelli, R., Quispe, D., Vargas, G., Dewitte, B., & Ortlieb, L. (2011). Coastal cooling and increased productivity in the main upwelling zone off Peru since the mid-twentieth century. *Geophysical Research Letters*, 38(7), L07603. <https://doi.org/10.1029/2010GL046324>
- INEI—(Peruvian) National Institute for statistics and informatics. (2018). *Ica—Resultados Definitivos*. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1545/
- IPCC. (2021). *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change* [V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou, Eds.]. Cambridge University Press. <https://doi.org/10.1017/9781009157896.2021.2>
- Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). A network perspective on the resilience of social-ecological systems. *Ecology and Society*, 11(1), 15. <http://www.ecologyandsociety.org/vol11/iss1/art15>
- Kininmonth, S., Crona, B., Bodin, Ö., Vaccaro, I., Chapman, L. J., & Chapman, C. A. (2017). Microeconomic relationships between and among fishers and traders influence the ability to respond to social-ecological changes in a small-scale fishery. *Ecology and Society*, 22(2), art26. <https://doi.org/10.5751/ES-08833-220226>
- Kittinger, J. N., Finkbeiner, E. M., Ban, N. C., Broad, K., Carr, M. H., Cinner, J. E., Gelcich, S., Cornwell, M. L., Koeh, J. Z., Basurto, X., Fujita, R., Caldwell, M. R., & Crowder, L. B. (2013). Emerging Frontiers in social-ecological systems research for sustainability of small-scale fisheries. *Current Opinion in Environmental Sustainability*, 5(3–4), 352–357. <https://doi.org/10.1016/j.cosust.2013.06.008>
- Kleisner, K. M., Ojea, E., Battista, W., Burden, M., Cunningham, E., Fujita, R., Karr, K., Amorós, S., Mason, J., Rader, D., Rovegno, N., & Thomas-Smyth, A. (2022). Identifying policy approaches to build social-ecological resilience in marine fisheries with differing capacities and contexts. *ICES Journal of Marine Science*, 79(2), 552–572. <https://doi.org/10.1093/icesjms/fsab080>
- Kluger, L. C., Alff, H., Alfaro-Córdova, E., & Alfaro-Shigueto, J. (2020). On the move: The role of mobility and migration as a coping strategy for small-scale fishers after abrupt environmental disturbances—The empirical example of the Coastal El Niño 2017. *Global Environmental Change*, 63, 102095. <https://doi.org/10.1016/j.gloenvcha.2020.102095>
- Kluger, L. C., Garteizgogeoasca, M., Gonzales, I. E., Odar, L. A., Flitner, M., & Damonte, G. (2023). An analysis of the early impacts of COVID-19 on Peruvian fisheries and mariculture. *ICES Journal for Marine Sciences*, 80(9), 2280–2294. <https://doi.org/10.1093/icesjms/fsad140>
- Kluger, L. C., Gorris, P., Kochalski, S., Müller, M., & Romagnoni, G. (2020). Studying human-nature relationships through a network lens: A systematic review. *People and Nature*, 2, 1100–1116. <https://doi.org/10.1002/pan3.10136>
- Kluger, L. C., Kochalski, S., Aguirre-Velarde, A., Vivar, I., & Wolff, M. (2019). Coping with abrupt environmental change: The impact of the coastal El Niño 2017 on artisanal fisheries and mariculture in North Peru. *ICES Journal of Marine Science*, 76(4), 1122–1130. <https://doi.org/10.1093/icesjms/fsy171>
- Kluger, L. C., Scotti, M., Vivar, I., & Wolff, M. (2019). Specialization of fishers leads to greater impact of external disturbance: Evidence from a social-ecological network modelling exercise for Sechura Bay, northern Peru. *Ocean and Coastal Management*, 179, 104861. <https://doi.org/10.1016/j.ocecoaman.2019.104861>
- Kluger, L. C., Taylor, M. H., Wolff, M., Stotz, W., & Mendo, J. (2019). From an open-access fishery to a regulated aquaculture business: The case of the most important Latin American bay scallop (*Argopecten purpuratus*). *Reviews in Aquaculture*, 11(1), 187–203. <https://doi.org/10.1111/raq.12234>
- Kriegel, M., Kluger, L. C., Gorris, P., & Kochalski, S. (2022). Coastal livelihood resilience to abrupt environmental change: The role of social capital in a Peruvian bay. *Regional Environmental Change*, 22, 103. <https://doi.org/10.1007/s10113-022-01959-3>
- L'Heureux, L. (2018). *Exploring ENSO in Ecuador*. NOAA ENSO Blog. <https://www.climate.gov/news-features/blogs/enso/exploring-ens-ecuador>
- Manlosa, A. O., Hornidge, A. K., & Schlüter, A. (2021). Aquaculture-capture fisheries nexus under Covid-19: Impacts, diversity, and social-ecological resilience. *Maritime Studies*, 20(1), 75–85. <https://doi.org/10.1007/s40152-021-00213-6>
- McClanahan, T., Allison, E. H., & Cinner, J. E. (2013). Managing fisheries for human and food security. *Fish and Fisheries*, 16, 78–103. <https://doi.org/10.1111/faf.12045>

- Mendo, J., & Wosnitzer-Mendo, C. (2014). *Reconstruction of Total Marine Fisheries Catches for Peru: 1950–2010*. Fisheries Centre, University of British Columbia, Vancouver, Fisheries Centre Working Paper #2014-21, 24.
- Microsoft Corporation. (2019). *Microsoft Excel*. <https://office.microsoft.com/excel>
- Miñarro, S., Navarrete Forero, G., Reuter, H., & Van Putten, I. E. (2016). The role of patron-client relations on the fishing behaviour of artisanal fishermen in the Spermonde Archipelago (Indonesia). *Marine Policy*, 69(July), 73–83. <https://doi.org/10.1016/j.marpol.2016.04.006>
- Nagel, B., Buhari, N., & Partelow, S. (2024). Archetypes of community-based pond aquaculture in Indonesia: Applying the social-ecological systems framework to examine sustainability tradeoffs. *Environmental Research Letters*, 19(4), 044026. <https://doi.org/10.1088/1748-9326/ad2e71>
- Narayan, N., Paul, A., Munitz, S., & Schulz, M. (2010). Ocean trends in coastal upwelling intensity during the late 20th century. *Ocean Science*, 6, 815–823. <https://doi.org/10.5194/os-6-815-2010>
- Nascimento, D. M., Nóbrega Alves, R. R., Duarte Barboza, R. R., Jensen Schmidt, A., Diele, K., & Silva Mourão, J. (2017). Commercial relationships between intermediaries and harvesters of the mangrove crab *Ucides cordatus* (Linnaeus, 1763) in the Mamanguape River Estuary, Brazil, and their socio-ecological implications. *Ecological Economics*, 131, 44–51. <https://doi.org/10.1016/j.ecolecon.2016.08.017>
- Nenadovic, M., & Epstein, G. (2016). The relationship of social capital and fishers' participation in multi-level governance arrangements. *Environmental Science & Policy*, 61, 77–86. <https://doi.org/10.1016/j.envsci.2016.03.023>
- Ñiquen, M., Bouchon, M., Cahuin, S., & Valdez, J. (1999). Efectos del Fenómeno "El Niño 1997–98" sobre los principales recursos pelágicos en la costa Peruana. *Revista Peruana de Biología*, 6, 85–96. <https://doi.org/10.15381/rpb.v6i3.8434>
- Ortiz, M., & Levins, R. (2017). Self-feedbacks determine the sustainability of human interventions in eco-social complex systems: Impacts on biodiversity and ecosystem health. *PLoS One*, 12(4), 1–18. <https://doi.org/10.1371/journal.pone.0176163>
- Partelow, S. (2020). Social capital and community disaster resilience: Post-earthquake tourism recovery on Gili Trawangan, Indonesia. *Sustainability Science*, 16, 203–220. <https://doi.org/10.1007/s11625-020-00854-2>
- Partelow, S., Glaser, M., Solano Arce, S., Barboza, R. S. L., & Schlüter, A. (2018). Mangroves, fishers, and the struggle for adaptive co-management: Applying the social-ecological systems framework to a marine extractive reserve (RESEX) in Brazil. *Ecology and Society*, 23, art19. <https://doi.org/10.5751/ES-10269-230319>
- Partelow, S., Jäger, A., & Schlüter, A. (2021). Linking fisher perceptions to social-ecological context: Mixed method application of the SES framework in Costa Rica. *Human Ecology*, 49(2), 187–203.
- Partelow, S., Nagel, B., Gentry, R., Gephart, J., & Rocha, J. (2025). Archetypes of aquaculture development across 150 countries. *Aquaculture*, 595(1), 741484. <https://doi.org/10.1016/j.aquaculture.2024.741484>
- Partelow, S., Nagel, B., Paramita, A. O., & Buhari, N. (2023). Seafood consumption changes and COVID-19 impact index in West Nusa Tenggara, Indonesia. *PLoS One*, 18, 1–22. <https://doi.org/10.1371/journal.pone.0280134>
- Partelow, S., Villamayor-Tomas, S., Eisenack, K., Epstein, G., Kellner, E., Roggero, M., & Tschopp, M. (2024). A meta-analysis of SES framework case studies: Identifying dyad and triad archetypes. *People and Nature*, 6, 1229–1247. <https://doi.org/10.1002/pan3.10630>
- Pebesma, E. (2018). Simple features for R: Standardized support for spatial vector data. *R Journal*, 10(1), 439–446. <https://doi.org/10.32614/RJ-2018-009>
- Pebesma, E. J., & Bivand, R. S. (2005). Classes and methods for spatial data in R. *R News*, 5, 9–13.
- Pennington, J. T., Mahoney, K. L., Kuwahara, V. S., Kolber, D. D., Calienes, R., & Chavez, F. P. (2006). Primary production in the eastern tropical Pacific: A review. *Progress in Oceanography*, 69(2–4), 285–317. <https://doi.org/10.1016/j.pocean.2006.03.012>
- Piemontese, L., Kamugisha, R. N., Tukahirwa, J. M. B., Tengberg, A., Pedde, S., & Jaramillo, F. (2021). Barriers to scaling sustainable land and water management in Uganda: A cross-scale archetype approach. *Ecology and Society*, 26(3), art6. <https://doi.org/10.5751/es-12531-260306>
- Pollnac, R., Beitzl, C. M., Vina, M. A., & Gaibor, N. (2024). Perceptions of El Niño-Southern Oscillation (ENSO) and La Niña shape fishers' adaptive capacity and resilience. *Social Sciences*, 13(7), 356. <https://doi.org/10.3390/socsci13070356>
- R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Rocha, J. C., Malmberg, K., Gordon, L. J., Brauman, K. A., & Declerck, F. (2019). Mapping social-ecological systems archetypes. *Environmental Research Letters*, 15(3), 34017. <https://doi.org/10.1088/1748-9326/ab666e>
- Salvattici, R., Schneider, R. R., Galbraith, E., Field, D., Blanz, T., Bauersachs, T., Crosta, X., Martinez, P., Echevin, V., Scholz, F., & Bertrand, A. (2022). Smaller fish species in a warm and oxygen-poor Humboldt current system. *Science*, 375, 101–104. <https://doi.org/10.1126/science.abj0270>
- Sandström, A., & Rova, C. (2010). Adaptive co-management networks: A comparative analysis of two fishery conservation areas in Sweden. *Ecology and Society*, 15(3).
- Santoso, A., Mcphaden, M. J., & Cai, W. (2017). The defining characteristics of ENSO extremes and the strong 2015/2016 El Niño: ENSO extremes reviews of geophysics, 55(4), 1079–1129. <https://doi.org/10.1002/2017RG000560>
- Sayles, J. S., Mancilla Garcia, M., Hamilton, M., Alexander, S. M., Baggio, J. A., Fischer, A. P., Ingold, K., Meredith, G. R., & Pittman, J. (2019). Social-ecological network analysis for sustainability sciences: A systematic review and innovative research agenda for the future. *Environmental Research Letters*, 14(9), 093003. <https://doi.org/10.1088/1748-9326/ab2619>
- Sietz, D., Frey, U., Roggero, M., Gong, Y., Magliocca, N., Tan, R., Janssen, P., & Václavík, T. (2019). Archetype analysis in sustainability research: Methodological portfolio and analytical frontiers. *Ecology and Society*, 24(3). <https://doi.org/10.5751/ES-11103-240334>
- Steneck, R. S., Hughes, T. P., Cinner, J. E., Adger, W. N., Arnold, S. N., Berkes, F., Boudreau, S. A., Brown, K., Folcke, C., Gunderson, L., Olsson, P., Scheffer, M., Stephenson, E., Walker, B., Wilson, J., & Worm, B. (2011). Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conservation Biology*, 25(5), 904–912. <https://doi.org/10.1111/j.1523-1739.2011.01717.x>
- Stoll, J. S., Fuller, E., & Crona, B. I. (2017). Uneven adaptive capacity among fishers in a sea of change. *PLoS One*, 12(6), e0178266. <https://doi.org/10.1371/journal.pone.0178266>
- Tigchelaar, M., Cheung, W. W. L., Mohammed, E. Y., Phillips, M. J., Payne, H. J., Selig, E. R., Wabnitz, C. C. C., Oyindola, M. A., Frölicher, T. L., Gephart, J. A., Golden, C. D., Allison, E. H., Bennett, A., Cao, L., Fanzo, J., Halpern, B. S., Lam, V. W. Y., Micheli, F., Naylor, R. L., ... Troell, M. (2021). Compound climate risks threaten aquatic food system benefits. *Nature Food*, 2, 673–682. <https://doi.org/10.1038/s43016-021-00368-9>
- Vecchi, G. A., & Wittenberg, A. T. (2010). El Niño and our future climate: Where do we stand? *WIREs Climate Change*, 1, 260–270. <https://doi.org/10.1002/wcc.33>
- Villamayor-Tomas, S., Iniesta-Arandia, I., & Roggero, M. (2020). Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. *Ecology and Society*, 25(1), art32. <https://doi.org/10.5751/ES-11329-250132>

- Walker, B., Kinzig, A., & Langridge, J. (1999). Original articles: Plant attribute diversity, resilience, and ecosystem function: The nature and significance of dominant and minor species. *Ecosystems*, 2(2), 95–113. <https://doi.org/10.1007/s100219900062>
- Wang, C., & Fiedler, P. C. (2006). ENSO variability and the eastern tropical Pacific: A review. *Progress in Oceanography*, 69(2–4), 239–266. <https://doi.org/10.1016/j.pocean.2006.03.004>
- Wickham, H. (2016). *Ggplot2: Elegant graphics for data analysis*. Springer-Verlag.
- Wolff, M. (1987). Population dynamics of the Peruvian scallop *Argopecten purpuratus* during the El Niño phenomenon of 1983. *Canadian Journal of Fisheries and Aquatic Sciences*, 44(10), 1684–1691. <https://doi.org/10.1139/f87-207>
- Wolff, M. (1988). Spawning and recruitment in the Peruvian scallop *Argopecten purpuratus*. *Marine Ecology Progress Series*, 42, 213–217.
- Wolff, M., & Mendo, J. (2000). Management of the Peruvian bay scallop (*Argopecten purpuratus*) metapopulation with regard to environmental change. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 10, 117–126. [https://doi.org/10.1002/\(SICI\)1099-0755\(200003/04\)10:2<117::AID-AQC399>3.0.CO;2-T](https://doi.org/10.1002/(SICI)1099-0755(200003/04)10:2<117::AID-AQC399>3.0.CO;2-T)
- Wolff, M., Taylor, M. H., Mendo, J., & Yamashiro, C. (2007). A catch forecast model for the Peruvian scallop (*Argopecten purpuratus*) based on estimators of spawning stock and settlement rate. *Ecological Modelling*, 209(2–4), 333–341. <https://doi.org/10.1016/j.ecolmodel.2007.07.013>
- Xiu, P., Chai, F., Curchitser, E. N., & Castruccio, F. S. (2018). Future changes in coastal upwelling ecosystems with global warming: The case of the California current system. *Scientific Reports*, 8, 2866. <https://doi.org/10.1038/s41598-018-21247-7>
- Yletyinen, J., Hentati-Sundberg, J., Blenckner, T., & Bodin, Ö. (2018). Fishing strategy diversification and fishers' ecological dependency. *Ecology and Society*, 23(3), 28. <https://doi.org/10.5751/ES-10211-230328>
- Zador, S. G., Gaichas, S. K., Kasperski, S., Ward, C. L., Blake, R. E., Ban, N. C., Himes-Cornell, A., & Koehn, J. Z. (2017). Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. *ICES Journal of Marine Science*, 74, 2024–2033. <https://doi.org/10.1093/icesjms/fsx054>
- Eider, D. (2019). *Operationalizing the social-ecological systems concept using network analysis in the context of SCUBA diving tourism on the Gili Islands, Indonesia* [Master's thesis, Universität Bremen].
- Fishbase. (2020). *Menticirrhus Undulatus Girard, 1854*. <https://www.fishbase.de/Summary/SpeciesSummary.php?ID=3587&AT=California+Kingcroaker>
- Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social Networks*, 1(3), 215–239. [https://doi.org/10.1016/0378-8733\(78\)90021-7](https://doi.org/10.1016/0378-8733(78)90021-7)
- Guía de Identificación de Peces. (n.d.). Melchorita, Peru LNG. https://perulng.com/wp-content/uploads/2016/05/Guia_identificacion_peces.pdf
- Hanneman, R. A., & Riddle, M. (2005). *Introduction to social network methods*. University of California, Riverside. <http://faculty.ucr.edu/~hanneman/>
- Nieminen, J. (1974). On the centrality in a graph. *Scandinavian Journal of Psychology*, 15(1), 332–336. <https://doi.org/10.1111/j.1467-9450.1974.tb00598.x>
- Powell, J., & Hopkins, M. (2015). Graph analytics techniques. In *A Librarian's guide to graphs, data and the semantic web* (pp. 167–174). Elsevier. <https://doi.org/10.1016/B978-1-84334-753-8.00019-1>
- SeaLifeBase. (2020). *Thaisella Chocolata Duclos, 1832*. <https://www.sealifebase.ca/summary/Thaisella-chocolata.html>
- Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge University Press.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Interview guides.

Appendix S2. Network measures applied.

Appendix S3. Fisheries target species.

DATA SOURCES

- Bonacich, P. (1987). Power and centrality: A family of measures. *American Journal of Sociology*, 92(5), 1170–1182.
- Bonacich, P. (2007). Some unique properties of eigenvector centrality. *Social Networks*, 29(4), 555–564. <https://doi.org/10.1016/j.socnet.2007.04.002>

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