UNIVERSIDAD AUTÓNOMA DE BAJA CALIFORNIA

INSTITUTO DE INVESTIGACIONES OCEANOLÓGICAS

FACULTAD DE CIENCIAS FACULTAD DE CIENCIAS MARINAS

TESIS

ACOPLAMIENTO DE MODELOS DE REDES ECOLÓGICAS Y SOCIALES CON UN ENFOQUE DE SISTEMA SOCIAL-ECOLÓGICO PARA EVALUAR ESTRATEGIAS DE GESTIÓN EN PESQUERÍAS DE PEQUEÑA ESCALA BAJO ESCENARIOS DE CAMBIO CLIMÁTICO

COUPLING OF ECOLOGICAL AND SOCIAL NETWORK MODELS WITH A SOCIAL-ECOLOGICAL SYSTEM APPROACH TO EVALUATE MANAGEMENT STRATEGIES IN SMALL-SCALE FISHERIES UNDER CLIMATE CHANGE SCENARIOS

TESIS QUE PARA OBTENER EL GRADO DE

DOCTORA EN MEDIO AMBIENTE Y DESARROLLO

PRESENTA

AINOA VILALTA NAVAS

Ensenada, Baja California, México, abril 2023

Resumen

La pesca de pequeña escala (SSF, por sus siglas en inglés) es el principal medio de subsistencia en los países en desarrollo. Sin embargo, el déficit de recursos en estos países complica su gestión por falta de información. La pesca artesanal es una actividad ambientada generalmente en pequeños pueblos cuyos habitantes se han dedicado a esta actividad generación tras generación. Además, estos pueblos a menudo se encuentran en lugares aislados con bajos recursos, lo cual dificulta la obtención de información sobre el ecosistema y las pesquerías de las que sobreviven. Por eso, estas pesquerías tienen problemas con la toma de decisiones y la gestión de recursos a pesar de contribuir significativamente a las economías nacionales, los medios de vida locales y el suministro mundial de alimentos. Sin embargo, una fuente crucial de conocimiento para los pueblos pesqueros ha sido subestimada a lo largo de los años. El conocimiento ecológico local (LEK, por sus siglas en inglés) es el conocimiento, creencias o prácticas que también se obtienen a través de una amplia observación e interacción con el medio ambiente y se comparten con otros usuarios de los recursos locales. Debido a la dependencia de los pescadores de sus recursos, están en constante contacto con los ecosistemas marinos, lo que les permite obtener valiosos conocimientos locales. La zona de estudio de este trabajo se ubica en El Rosario, una comunidad pesquera en el Pacífico Nororiental de México, y es utilizada como caso de estudio ejemplar para los complejos sistemas socio-ecológicos (SES, por sus siglas en inglés) de SSF en Baja California.

El primer capítulo de este trabajo compara dos redes ecotróficas de la misma localidad. La primera red se basa en un modelo cuantitativo de balance de masas creado con el programa Ecopath con Ecosim, y utilizando datos obtenidos a través de monitoreo *in situ* del área. La segunda red se basa en un modelo cualitativo basado en LEK de los pescadores de El Rosario. Se basó en entrevistas con pescadores locales con un promedio de 14 años de experiencia en la pesca. Los resultados muestran que ambas redes responden de manera similar y representan adecuadamente el mismo ecosistema. Esto significa que las técnicas utilizadas para cada red pueden ser complementarias para generar información más específica sobre un ecosistema.

El segundo capítulo utiliza el enfoque SES para evaluar la sostenibilidad potencial de las pesquerías y mejorar las políticas y estrategias de gestión de recursos. El objetivo principal fue construir un modelo socioecológico del SSF-SES y simular los efectos de los impactos socioambientales aplicando diferentes escenarios de remoción de nodos. El capítulo concluye que afectar los nodos sociales tiene una mayor influencia en el SES que eliminar los ecológicos. Las conclusiones también destacan la importancia de los actores locales en el conjunto del SES y la importancia de mantener una buena comunicación entre ellos con los agentes externos para lograr mejores estrategias de gestión, especialmente en la SSF. A nivel mundial, la metodología utilizada puede ayudar en el análisis socioambiental para otros estudios de caso de SSF.

El tercer capítulo de este trabajo tiene como objetivo aplicar un marco conceptual desarrollado para comprender los antecedentes e identificar las acciones realizadas por SSF frente a los cambios ambientales a nuestro caso de estudio en El Rosario. Este capítulo fue desarrollado usando LEK obtenido al entrevistar a los pescadores. Este capítulo permitió identificar las fortalezas y debilidades de este sistema socio-ecológico a lo largo de los años. Los resultados muestran la resiliencia de la comunidad de El Rosario frente al cambio climático a lo largo de los años. Han sabido incorporar diferentes adaptaciones tanto en su forma de pescar como en su organización para superar las adversidades. Es importante resaltar también que algunos conceptos del marco conceptual se superponen mientras que otros son fácilmente autoidentificables al aplicarlos a un caso de estudio real. Por tanto, este esfuerzo es crucial ya que identifica y contextualiza el accionar de la cooperativa, lo que será importante a la hora de generar futuras estrategias de gestión.

Palabras clave: sistema social-ecológico, bosques de kelp, pesquería de pequeña escala

Abstract

Small-scale fisheries (SSF) are the primary means of livelihood in developing countries. Nevertheless, the resource deficit in these countries complicates their management due to a lack of information. Small-scale fishing is an activity set generally in small towns whose inhabitants have been engaged in this activity for generation after generation. Also, these villages are often in isolated locations with low resources, making it difficult to obtain information on the ecosystem and the fisheries from which they survive. Because of that, these fisheries have problems with decision-making and resource management despite significantly contributing to national economies, local livelihoods, and global food supplies. However, a crucial source of knowledge for fishing villages has been undervalued over the years. Local ecological knowledge (LEK) is knowledge, beliefs, or practices that are also obtained through extensive observation and interaction with the environment and shared with other users of local resources. Due to fishers' dependence on their resources, they are in constant contact with marine ecosystems, allowing them to obtain valuable local knowledge. Our case study is El Rosario, a fishing community in the North-East Mexican Pacific, as an exemplary case study for the complex SSF social-ecological systems (SES) in Baja California.

The first chapter of this work compares two ecotrophic networks from the same location. The first network is based on a quantitative mass-balanced model created using Ecopath with Ecosim software and was built using in situ scuba monitoring data from the area. The second network is based on a qualitative model based on LEK from the fishers of El Rosario. It was based on interviews with local fishers with an average of 14 years of fishing experience. The results show that both networks respond similarly and adequately represent the same ecosystem. This means that the techniques used for each network can be complementary to generate more specific information on an ecosystem.

The second chapter uses the SES approach to assess the potential fisheries' sustainability and improve resource management policies and strategies. The main objective was to build a social-ecological model of the SSF-SES, and simulate the effects of social-environmental impacts by applying different node removal scenarios. I conclude that affecting social nodes has a higher influence on the SES than removing ecological ones. The conclusions highlight the importance of local stakeholders in the whole SES and the importance of maintaining good communication between them with external agents to achieve better management strategies, especially in SSF. Globally, the methodology used can help in social-environmental analysis for other SSF case studies.

The third chapter of this work aims to apply a conceptual framework developed to understand the background and identify the actions made by SSF against environmental changes to our case study in El Rosario. This chapter was developed using LEK obtained by interviewing the fishers. This work allowed us to identify the strengths and weaknesses of this social-ecological system over the years. The results show El Rosario community's resilience against climate change over a few years. They have been able to incorporate different adaptations in both their way of fishing and in their organization to overcome adversity. It is important to highlight also that some concepts of the conceptual framework overlap while others are easily self-identifiable when applying them to a real case of study. Therefore, this effort is crucial since it identifies and puts the cooperative's actions in context, which will be important when generating future management strategies.

Key words: social-ecological system, kelp forest, small scale fisheries

INSTITUTO DE INVESTIGACIONES OCEANOLÓGICAS
FACULTAD DE CIENCIAS MARINAS
DOCTORADO EN MEDIO AMBIENTE Y DESARROLLO

ACOPLAMIENTO DE MODELOS DE REDES ECOLÓGICAS Y SOCIALES CON UN ENFOQUE DE SISTEMA SOCIO-ECOLÓGICO PARA EVALUAR ESTRATEGIAS DE GESTIÓN EN PESQUERÍAS DE PEQUEÑA ESCALA BAJO ESCENARIOS DE CAMBIO CLIMÁTICO

COUPLING OF ECOLOGICAL AND SOCIAL NETWORK MODELS WITH A SOCIAL-ECOLOGICAL SYSTEM APPROACH TO EVALUATE MANAGEMENTSTRATEGIES IN SMALL-SCALE FISHERIES UNDER CLIMATE CHANGE SCENARIOS

TESIS

PARA OBTENER EL GRADO DE

DOCTORA EN MEDIO AMBIENTE Y DESARROLLO

PRESENTA

AINOA VILALTA NAVAS

Aprobada por:

Rodrigo Beas

Dr. Rodrigo Beas-Luna
Director

Dr. Jose Albert Zepeda Dominguez
Co-director

Dr. Manuel Zetina Rejón
Sinodal

Lotta C. Kluger

Dra. Clara Lotta Klugger
Sinodal

Dr. Luis Malpica Cruz
Sinodal

DEDICATORIA

Per a totes aquelles persones que considero la meva família. Per deixar-me ser, per ser-hi sempre, per creure i confiar en mi, més que jo mateixa, i per acompanyar-me sempre de prop i en la distància.

AGRADECIMIENTOS

Al posgrado de Medio Ambiente y Desarrollo (IIO-UABC) por aceptarme para realizar mis estudios de doctorado y a CONACYT por brindarme el apoyo económico sin el cual no podría haber realizado este trabajo.

A mis profesores, que me ayudaron a crecer mi conocimiento y desarrollo profesional, así como al personal administrativo por siempre ayudarme en todos los tramites.

A mis directores Dr. Rodrigo Beas y Dr. José Alberto Zepeda, y a los miembros del comité, la Dra. Lotta Kluger, el Dr. Manuel Zetina y el Dr. Luis Malpica. Por el tiempo invertido en las correcciones y reuniones. Por sus preguntas y comentarios que sin duda me hicieron ver este trabajo con una perspectiva diferente.

A mi familia y amigos, que me animaron a continuar en este camino en todas y cada una de las fases de esta trayectoria.

INDICE

Introducción general 8

Capítulo I: Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems. 11

Capítulo II: Using a social-ecological network approach to simulate social and environmental impacts in small-scale fisheries 36

Capítulo III: Learned lessons based on the adaptative capacity of a small-scale fishing community to climate change in Baja California, Mexico. 61

Conclusiones generales 90

Referencias generales 92

LISTA DE FIGURAS

Figure 1.Trophic networks based on Local Ecological Knowledge (LEK, left) and Conventional Science Knowledge (CSK, right).. 18
Figure 2. Functional group level indicators (X-axis): Betweenness Centrality (BC), Closeness Centrality (CC), Degree Centrality (DI), and Eigen Centrality (EC).......... 20
Figure 3. Network indexes´ change after bottom-up (right) and top-down (left) simulations.. 21
Figure 4. Network level indicators under fishing pressure simulations. 22
Figure 5. Graphical overview of model responses amidst the bottom-up and top-down scenarios (cf. section 2.4 for details on scenarios) 24
Figure 6. Social-ecologic network model for the case of study of the small-scale fisheries social-ecological system (SSF-SES) of El Rosario, Mexico.. 40
Figure 7. Social-ecological network nodes' subgroups according to fast greedy community finding algorithm in R Studio (cf. section 2.3 for details on the method)... 41
Figure 8. Response (captured by eight network indicators, cf. Table 5) of the social network of the small-scale fisheries social-ecological system (SSF-SES) of El Rosario 42
Figure 9.Response of the eight network indicators for the Rosario Ecological network to nodes removal based on two scenarios: error/random failures (blue lines) and attack/direct impacts (red lines)... 43
Figure 10.Response of the eight network indicators for the Rosario social-ecological network to nodes removal based on two scenarios: error/random failures (blue lines) and attack/direct impacts (red lines)... 44
Figure 11. Percentage of change respect the original values of the indices analyzed in the social-ecological network, when removing particular nodes groups....................... 45
Figure 12. Conceptual framework based on Galapathithi et al., (2019)........................ 65
Figure 13.Sankey Diagram representing the basic structure information of interviewees from El Rosario fishing community 67
Figure 14. Years in which the interviewees recalled temperature anomalies (legend) and the respective species that were affected (x-axis). 68
Figure 15. Community adaptations to environmental variations (x-axis) and the respective species in which they were implemented (legend)...................................... 72

LISTA DE TABLAS

Table 1. List of network indicators used for comparative analysis, a brief description of its functioning and the respective source... 16
Table 2. Original (before disturbances) network indicators for the Local Ecological Knowledge (LEK) and Conventional Science Knowledge (CSK) models. 21
Table 3. Original (before disturbances) percentage distribution of nodes in trophic levels for each model (CSK and LEK). 19
Table 4. Stakeholder categories for grouping social nodes in the small-scale fishing social-ecological system of El Rosario, Mexican Pacific... 36
Table 5. Network indicators used to measure network's resilience, a brief description and their respective source. 39
Table 6. Definitions of the components from Galappaththi's (2019) framework and their applications to this study case. 68

GENERAL INTRODUCTION

The majority of coastal systems have some connection to fishing activities. Since marine food is one of the most important sources of animal protein, accounting for around 17% of all animal protein consumed globally, fishing is an important ecosystem service for people (Wu, 2017). Because of the widespread uncertainty caused by anthropogenic variables like overfishing and environmental fluctuation, decision-making is significantly impacted (Finkbeiner, 2015). Due to this uncertainty, small-scale fisheries (SSF) are among the most vulnerable (Defeo *et al.,* 2013). SSF produce about half of the world's seafood, yet they are disadvantaged since they lack market access and pricing power (Bindoff *et al.,* 2019). SSF exploit a great diversity of fish, invertebrates, and algae stocks and are especially important for fishing communities in developing countries like Mexico. Understanding how local environmental changes impact the availability and distribution of marine resources is essential for SSF sustainable management. Therefore, it is crucial to improve the adaptive management of fishing communities and subsequently help reduce the uncertainty resulting from these changes by understanding how coastal marine ecosystems respond to changes in natural and anthropogenic conditions.

Kelp forests are one of the world's most productive ecosystems in the word. They are formed by brown algae from the Laminariales order and are found on temperate rocky reefs with cold, clean, and nutrient-rich waters (Carr, M. H., & Reed, 2015). The macroalgae *Macrocystis pyrifera,* which may grow up to 30 m long and create three-dimensional environments, predominate on the west coast of North America (Foster & Schiel, 1985; Steneck *et al.,* 2002). A wide variety of commercially significant species are connected to kelp forests and support local fishing populations. Kelp forests are known to be substantially influenced by oceanic physical changes brought on by temperature variance brought on by El Niño events (Ladah et al., 1999), as well as by hypoxia phenomena (Micheli *et al.,* 2012), storm surge alterations (Byrnes *et al.,* 2011), and pH changes (Kroeker et al., 2013). Furthermore, a significant portion of the creatures connected to kelp forests are under anthropogenic stress from overfishing, habitat loss, and/or coastal zone pollution (Roberts *et al.,* 2017; Tegner *et al.,* 1995).

Determining how intricate, productive coastal ecosystems like kelp forests will react to changes is important, and how this will affect the fishing industry that depends on them. On the Baja California peninsula, underwater ecosystems like kelp forests coexist with terrestrial arid climates. When marine resources fail, diversification in this region is a challenging effort for SSF that depend on kelp forest resources (Álvarez et al., 2015). This region is a great illustration of how to employ social-ecological analytical methodologies because other economic alternatives to fishing, such as agriculture or tourism, are challenging to grow due to the location. To better understand complexity in the context of current and future climate change scenarios, novel and integrative analytical techniques are required. To better understand these systems' future, the combination of ecological models, social networks, and the social-ecological system method promise to be a good alternative.

Ecological network models

Ecological network models are useful for understanding how trophic systems work and conceptualizing the relationships within an ecosystem (Borrett et al., 2014). For instance, ecosystem models can produce explanations and hypotheses of a community's dynamics and structure (Thompson *et al.,* 2012), as well as forecasts of how the community would react to disturbances brought on by both natural and anthropogenic factors (Byrnes *et al.,* 2011; Pauly & Christensen, 1995). For example, ectotrophic models can be used to determine the impact of fishing on the biomass flows of giant kelp forests (Beas-Luna, 2014), or connectivity models can be used to assess marine species' distribution ranges in the Gulf of California under several climate change scenarios (Munguia-Vega *et al.,* 2018). Despite their adaptability, these models are complex, challenging to construct, and require much system knowledge.

To build these networks, knowledge can come from two different points of view: conventional scientific knowledge (CSK) or local ecological knowledge (LEK). The SCK comes from scientific studies such as experiments, in-situ observations, or other scientific papers. However, when scientific data is unavailable, LEK is becoming an important tool for understanding an ecosystem. This type of information is passed down through generations of local communities and is influenced by individual experiences (R. Hamilton et al., 2012); because of that LK has been undervalued for many years. Its importance and relevance have recently been demonstrated, increasing its use in the scientific field (Hind, 2014).

Social Network models

As well as ecosystems, we also can conceptualize society through social networks. This is an interdisciplinary method for studying social movements based on the relationships between network members (Freeman, 2004; Giuffre, 2013). Traditionally, quantitative measures of network properties (e.g., strength, direction, composition, or density) are used to analyze a social network (Heath et al., 2009). Using this network perspective, we can understand how the system's components are composed and organized and how this organization influences the system's performance (Janssen *et al.,* 2006, Luxton, 2021). Also, using this kind of network, researchers could determine, for instance, how frontier farmers in the Brazilian Amazon quickly acquired information on the natural dynamics of ecosystems as they moved from one location to another (Muchagata and Brown, 2000). Likewise, social networks have shown to be a crucial component of adaptive co-management due to the involvement of user groups in information sharing and collaborative learning regarding ecosystem management (Olsson et al., 2004).

These models are used and applied in a wide range of contexts that span many different fields. One of the key issues limiting its usage is its provenance, since the information originates from the locals. However, it is usual practice to use external sources of information (e.g., scientific data) in order to compare and supplement their knowledge.

Social-Ecological Systems Approach

Social-ecological systems (SES) are ecosystems that contain resources used by humans. Ostrom (2009) asserts that a SES is made up of four crucial components: the environmental system, the resource units, the governance system, and the resource consumers. These elements work in a sophisticated and integral way together (not linear). To fully understand them, an analysis that takes into account these interactions is required. Despite all efforts, some SESs fail because of their complexity. Therefore, to approach the problem in a multidisciplinary manner, it is required to connect social and ecological information.

The main purpose of this thesis is to ground all these concepts using a fishing community from the Baja California Peninsula as a study case. To cover all these topics, the work has been divided into three chapters:

1. Chapter I: Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems

2. Chapter II: Using a social-ecological network approach to simulate social and environmental impacts on small-scale fisheries

3. Chapter III: Learned lessons based on the adaptative capacity of a small-scale fishing community to climate change in Baja California, Mexico.

Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems.

Ainoa Vilalta-Navas[1], Rodrigo Beas-Luna[1*], Manuel J. Zetina-Rejón[2*], Gladis A. López-Ibarra[2], Luis Malpica-Cruz[3], Julio Lorda[4], José Alberto Zepeda[1], Lotta Clara Kluger[5,6]

1. Facultad de Ciencias Marinas, Universidad Autónoma de Baja California, Carretera Tijuana-Ensenada Km 103, Pedregal Playitas, 22860, Ensenada, Baja California, México
2. Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, Av. Instituto Politécnico Nacional S/N Col. Playa Palo de Sta. Rita, La Paz, BCS, 23096, México
3. Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Carretera Tijuana-Ensenada Km 103, Pedregal Playitas, 22860, Ensenada, BC, México.
4. Facultad de Ciencias, Universidad Autónoma de Baja California, Carretera Ensenada-Tijuana 3917, Fraccionamiento Playitas, 22860 Ensenada, Baja California, México
5. Center for Ocean and Society, Kiel University, Neufeldtstraße 10, 24118 Kiel, Germany
6. Department of Agricultural Economics, Kiel University, Olshausenstraße 40, 24118 Kiel, Germany

*Considered joint corresponding authors: rbeas@uabc.edu.mx (tel: +52 646 239 3581) and mzetina@ipn.mx (tel: +52 612 348 5060)

ABSTRACT

There is an urgent need to analyse and understand small-scale fisheries environment under biotic and abiotic stressors. In this work, we use a kelp forest ecosystem in Baja California, Mexico to present a novel approach comparing two network models based on different information sources. First, we developed a Conventional Scientific Knowledge network model (CSK) parameterized with in-situ observations. Secondly, we used a Local Ecological Knowledge network model (LEK) based on interviews with local fishers. Our main objectives were: a) verify if the two knowledge sources generated comparable models, b) explore model responses to disturbance scenarios. The CSK model presented greater detail at lower trophic levels, contrary to the LEK model. Additionally, we simulated top-down and bottom-up ecological disturbances. With a top-down disturbance, the groups' abundance increased following a cascade effect whereas, in the bottom-up disturbance, changes did not transfer uniformly. We also simulated anthropogenic disturbances through fishing pressure on three target species (lobsters, sea urchins and sea bass). Our findings show similar patterns with the highest degree of change when lobsters are removed. Our findings highlight the potential of model complementarity and support the relevance of ecological network models to navigate future climate and anthropogenic uncertainty.

Keywords: Ecopath and Ecosim, food-networks, ecological modelling, small scale fisheries, topological indicators, fishers' knowledge

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), most coastal ecosystems will be moderately to highly impacted by the year 2100 due to climate change (IPCC, 2021). Around 50% of all humans live within 100 km of the coast (MEA, 2005) and depend on the great diversity of services these ecosystems provide, such as coastal protection, food resources, and tourism (Wu, 2017). The forecasted environmental variability will directly affect human well-being by drastically modifying the structure and function of the ecosystems and compromise their resilience (Jackson et al., 2001). Alarmingly, ecosystems with the highest degree of impact are also those with the most complexity, such as coral reefs, macroalgae forests, mangroves, and seagrass meadows (Bindoff et al., 2019). The combination of biotic and abiotic disturbances on these complex marine ecosystems makes predicting their effects very challenging. This uncertainty can significantly affect the capacity of managers to make well informed ecosystem-based management decisions (Doney et al., 2012; Finkbeiner, 2015a). Hence, there is a need to develop analytical tools to better understand, inform and promote adaptation in these constantly changing and complex marine ecosystems.

Climate variability, in addition to overfishing, eutrophication, and invasive species, can alter the structure and function of coastal ecosystems (Overland et al., 2010). These changes can trigger cascading effects on coastal ecosystems such as "bottom-up" disturbances, which reduce nutrients or primary productivity, or "top-down" where top predators are the first affected (Bryndum-Buchholz et al., 2019). Both cases can result in various responses, with some species increasing or decreasing their abundance (Beas-Luna et al., 2020). Top-down effects are usually reflected with an inverse change in biomass between adjacent pairs of trophic levels, while bottom-up effects do not transfer up uniformly, but may omit alternate levels, generating minimal change at higher levels (Carpenter et al., 1985; Heath et al., 2014). Thus, ecosystem response to the combined effects of climate variability and anthropogenic sources of variation are not trivial to elucidate.

Network modelling is a tool used worldwide in different contexts as computer science, medicine, social sciences and ecology. It describes a system through conceptualizing actors (e.g. species, group of species or ecosystem parts) as nodes and their interactions (trophic, non-trophic) as links (Kluger et al., 2020). In ecology, network modelling is a tool generally used to provide a better understanding of the future of ecosystems. Network analysis can be used for different purposes, such as describing the ecosystem structure and function or simulating scenarios based on environmental or anthropogenic modifications (Beas Luna, 2014; Zetina-Rejón et al., 2022), and can also be based on different sources of information. For example, information based on empirical observations and practices on the interactions between living organisms, including humans, and their environment passed over generations through cultural transmission is referred to as indigenous or traditional ecological knowledge (IEK or TEK; Berkes et al., 1994). Information referred to as experts knowledge can also come from a wide variety of people such as scientists, practitioners, stakeholders and elders from a local site, that withstand due to their cumulative years of practice and experience on a particular ecosystem (Perera et al., 2011). Also, when information is gathered individually over years of empirical observations and experience interacting with a specific ecosystem it is known as local ecological knowledge (LEK; García-Quijano, 2007). Lastly, there is conventional scientific knowledge (CSK) when the information is obtained and interpreted following scientific methodologies, conceptual models and hypothesis (Gaspare et al., 2015; Mackinson, 2001). For the present study, we focus on two different sources of information, conventional scientific knowledge (CSK) and local ecological knowledge (LEK).

CSK network models are based on scientific sources that help us understand the functioning and relationships of trophic systems within an ecosystem (Borrett et al., 2014). These models can also be used to generate and test hypotheses on the dynamics and structure of communities

(Thompson et al., 2012), predict the response to disturbances due to natural and anthropogenic effects (Byrnes et al., 2011; Pauly & Christensen, 1995), or even model connectivity to estimate distribution areas of marine species under climate change scenarios (Munguia-Vega et al., 2018). Despite their versatility, these models are complex, their development is challenging and labour-intense, and require a lot of scientific information about the system, which it is not always available.

On the other hand, LEK has been undervalued for many years because it is dispersed among many fishers and is constantly changing with new observations. It is transmitted from generation to generation and varies as people experiment and adapt to the environment (R. Hamilton et al., 2012). However, its value as an information source is recently becoming increasingly recognized. In marine science, this knowledge comes from direct users or stakeholders such as fishers (Sáenz-Arroyo et al., 2005). Due to their dependence on marine resources, these people are in constant contact with their ecosystems, allowing them to obtain knowledge with a great level of detail. This knowledge includes physical aspects like currents, tides, seasonal or lunar variations, and biological elements such as behaviour, habitat, and/or feeding preferences of the species present in the ecosystem (Johannes et al., 2000). Moreover, LEK has already been proven useful in several studies. For example, it was used to adapt monitoring programs improving their efficiency (Johannes et al., 2000), identify environmental variables affecting local species recovery (Kobluk et al., 2021), and make decisions towards a better sustainability of fishing resources, MPA implementations, and seascape management (Berkström et al., 2019; Munguia-Vega et al., 2022; Stephenson et al., 2016).

Typically, in coastal fishing communities, LEK comes from fishers from small-scale fisheries (SSF). These fisheries predominate in developing countries, which is a typical expression of the well-known “problem of fit” (Folke et al., 2007). These fisheries support 22 million workers in 136 countries worldwide and supply almost half of the world's seafood (FAO, 2022). Gravely, many of these fisheries are currently threatened by multiple stressors and there is an urgent need to analyse and understand the ecosystem context where these SSFs are developed. Moreover, most fishing communities in developing countries are in a data-poor context due to their isolation and limited access to financial resources, making it difficult to obtain scientific or technical information on their ecosystems and fisheries (Saldaña et al., 2016).

Data-poor fisheries also make it difficult for SSFs to reach sustainability standards and certifications that are being applied nowadays as voluntary measures to avoid overexploitation of marine resources (Parkes et al., 2010). For example, a certification from the *Marine Stewardship Council* (MSC), ensures that a fishery meets specific quality criteria, including stock sustainability, minimizing fishery environmental impacts, and effective fisheries management (MSC, 2018). However, many developing countries and their SSFs lack the ability to gather enough scientific information on the status and functioning of the ecosystems where they occur and to cover the economic and personnel costs that the process and evaluations to obtain such certifications require (Ponte, 2012, Zepeda-Domínguez et al., 2019). As an alternative, ecosystems networks and particularly ecosystem models based on LEK are starting to be used (Bentley, Serpetti, et al., 2019; Cisneros-Montemayor et al., 2020; Zetina-Rejón et al., 2022). The information in these models comes from the fishers themselves, so the information is local and typically less expensive to generate.

Exploring and comparing the weaknesses and strengths of fisheries ecosystem network models based on CSK and LEK is warranted given the realities and limitations of data-poor fisheries. There are different ways to incorporate LEK into an ecosystem model according to the needs of the study area and the stakeholders. Different works have shown that an ecological network software such as Ecopath with Ecosim can be parameterized using LEK instead of scientific data (Bentley, Serpetti, et al., 2019; Bevilacqua et al., 2016; Rosa et al., 2014). However, they also found some limitations and suggested that variables difficult for fishers to obtain, such as biological aspects (e.g. growth rates, diet, lunar or tide-related movements) should be obtained through CSK (Johannes et al., 2000). Similarly, we can incorporate LEK to complement qualitative models based on CSK. For example, it has been shown that LEK models can improve simulation capacity in ecosystem-based management (Bentley, Serpetti, et al., 2019). Despite the high potential benefits of including CSK and LEK into network models, there hasn´t been any comparison between them on their performance under similar disturbance scenarios in the same area.

This study compares a LEK and a CSK models from a kelp forest ecosystem related to a SSF in Baja California, Mexico. Kelp forests are ecosystems that have suffered severe changes in structure and function due to climate change (Beas-Luna et al., 2020). Only a few CSK ecosystem models describe kelp forests (Beas-Luna, 2014; Vilalta-Navas et al., 2018; Schlenger et al., 2021) though they don't include Local Ecological Knowledge so far (Berkström et al., 2019). This is especially true, in data poor small-scale fisheries as in this study and elsewhere. We investigate how both types of ecological networks perform under different types of disturbances: a) top-down, b) bottom-up, and c) fishing. Particularly, we are interested in: 1) Are the CSK and LEK network properties comparable? What are the effects of these differences or similarities? and; 2) Do both models respond similarly to disturbances? With this, we aim at contributing to the ongoing scientific debates on how to combine LEK and CSK information as to improve resource management in data-poor contexts.

2. METHODOLOGY

2.1. Case study

El Rosario is a small village located near the Pacific coast within the municipality of Ensenada in the state of Baja California, Mexico. The primary sources of livelihood for the community are agriculture and fishing. Fishing is carried out by a local cooperative, "Sociedad Cooperativa de Producción Pesquera Ensenada, SCL" (from now on: Coop Ensenada), founded in 1940. The Coop Ensenada main source of income comes from the extraction of high-value benthic species associated to kelp forests, such as abalone (*Haliotis spp.*), lobsters (*Panulirus interruptus*), and sea urchins (*Strongylocentrotus franciscanus*). These products are commercialized locally and internationally. The Coop Ensenada has participated in co-management with non-governmental and scientists making it possible for us to parameterize the CSK model using the *in situ* subtidal monitoring data available. It is relevant to indicate that while this fishing community have actively been involved in these co-management efforts, their focus has mostly been on improving fishing practices and management strategies such as by establishing locally managed no-take zones, exploring mariculture strategies, catch limits, etc. Therefore, we do not expect that their involvement in these practices have influenced their empirical understanding on specific ecological interactions of the ecosystem.

The marine ecosystem area used by the Coop Ensenada is located in in Punta Baja Bay. It covers 194 km^2 and is dominated by kelp forests. This area is also under cumulative changes, affecting both predators (e.g., through fishing pressure) and primary producers (e.g., through changes in water temperature). Therefore, we chose three effects to test our network models (see also section 2.4 for details): a) bottom-up (i.e., a decrease in primary producers, e.g., as resulting from heat waves or temperature changes), b) top-down (i.e., decrease in top predator abundance, e.g., as resulting from an increase in fishing pressure), and c) removal of target species.

2.2. Model development

This work compares two models for the same case study: one quantitative and one qualitative. The quantitative model was built through Ecopath with Ecosim (EwE) software (Christensen & Walters, 2004) using Conventional Science knowledge (CSK). The qualitative model was developed by Zetina et al., (2022) through surveys using Local Ecological Knowledge (LEK) from fishers.

The CSK model in EwE used published scientific data. It describes the organization of biomass in an ecosystem and the flows of energy in its food web. Ecopath with Ecosim models are built under the premise that the ecosystem will be in balance after a particular time; that is, production is equal to consumption for each component of the system. The general equation (1) for this linear model is:

$$B_i(\mathrm{P/B})_i = \sum B_j\,(\mathrm{Q/B}_j)DC_{ji} + E_i + Y_i + BA_i + B_i * PB_i(1 - EE_i) \qquad (1)$$

Where, for a functional group *i*, B is its biomass ($t \cdot km^2$), P/B is its biomass production ratio, B_j is the predator j biomass, Q/B_j is the predator j biomass consumption ratio, DC_{ji} is the fraction of the prey *i* within the diet of the predator j, E is its total export, Y is its fishing rate, BA is its accumulated biomass. EE is the proportion of *i* used in the system called ecotrophic efficiency.

There are four basic parameters for each functional group (FG) in Ecopath: Biomass (B), production/biomass ratio (P/B), which also corresponds to the total mortality (Z), consumption/ biomass ratio (Q/B), which corresponds to the rate of food ingested from an FG with respect to its biomass in a period, and ecotrophic efficiency (EE) which means the proportion of organisms that die by predation and export. We need at least three of those four parameters for each FG to make the model work. Each FG biomass ($g \cdot m^{-2}$) was calculated from *in situ* observations (number of individuals or abundances per area). The biomass data used to build the CSK model was collected through *in situ* ecological monitoring by MexCal from the Universidad Autónoma de Baja California (UABC) during the 2012 to 2015 period. Both P/B and Q/B parameters estimate were obtained from scientific literature. In the case of fish FG, values were obtained from FishBase (Froeser & Pauly, 2016). FG formed with more than one species, the B, P/B, and Q/B values were obtained using weighted averages to the abundances of each species inside the FG.

We also developed a diet matrix based on peer-reviewed information about the feeding preferences of the model species. We looked for papers based on studies performed as close as possible to the study area, and we also used information from other EwE models developed for close ecosystems (Morales-Zárate et al., 2011; Vilalta-Navas et al., 2018). For a more details on the development of the EwE model see Beas-Luna & Ladah (2014), Vilalta-Navas et al., (2018) and Schlenger et al., (2021).

The LEK model was built by Zetina-Rejón et al. (2022) using information collected by the non-governmental environmental organization *Comunidad y Biodiversidad A.C.* (COBI) through interviews applied to fishers, the details on the construction of the LEK-based model can be found in Zetina-Rejón et al., (2022). The LEK model was based on 23 interviews with local fishers with an average of 14 years of fishing experience from November to December 2020. The interviews were made by phone and consisted of a systematic questionnaire focused on identifying the main trophic relationships in the ecosystem. The interview objectives were: 1) identifying the main biological components (species) and 2) identifying their trophic relations.

In this sense, a questionnaire was applied that included three basic sections. The first consisted of general data on the interviewees, such as name, years of fishing experience, fishing gear used, and species caught. The second part of the questionnaire asked them to list all those species/groups that are part of the ecosystem, including target and non-target species. Finally, in the third part of the questionnaire, they were asked to describe qualitatively the diet of each of the species/groups they had named in the second part of the questionnaire. The fishers interviewed were from Coop Ensenada and care was taken to included fishers harvesting various species (e.g., seaweed, sea cucumbers, lobsters, abalone, sea urchins, finfish and sharks) and using various types of fishing gear (e.g., handlines, gillnets, traps, diving and longlines). All fishers participated on a voluntary basis and ethical principles were followed. Once the information from the interviews was compiled, all species' common names we integrated into scientific names, grouped similar species, and verified the coherence of described trophic relationships with scientific knowledge obtained from Fishbase (https://www.fishbase.se/) and World of Marine Species (http://www.marinespecies.org/). With this information, a trophic relational matrix that represented the main species or functional groups (nodes) and their trophic interactions (links) in the food web, which served as the input for building a binary network model. This model represent the main species as functional groups (nodes) and the connections between them through trophic interactions as links (Zetina-Rejón et al., 2022).

2.3. Model Comparison

Topological analyses were used to compare qualitative and quantitative network properties at network and functional group levels (Table 1). A wide variety of analyses can be used to compare ecotrophic models. Some of the most used are ecological analyses (e.g., abundance, diet, size, etc.), which depend on quantitative data. However, since we want to compare models with different types of data (qualitative data for the LEK model and quantitative for the CSK model), we decided to use topological analyses. Unlike ecological, topological analyses can be applied to both qualitative and quantitative models. Also, topological analyses are better in line with the purpose of our work, which is to compare the performance of both models based on their network structure.

Table 1. List of network indicators used for comparative analysis, a brief description of its functioning and the respective source

Index	Description	Ecological application	Source
Network level			
Density	The proportion of potential number of connections in a network	A higher value, can indicate potential redundancy, thus, a more stable network	(Wasserman & Faust, 1994)
Average path length (APL)	Average distance in number of interactions between any pair of nodes	Describes if the energy flows efficiently in a network. The higher the value, the more efficient	(West, 1996)
Clustering coefficient	Probability that adjacent nodes are connected	Indicates the compartmentalisation or subgrouping within the network. Subgroupings compromise stability	(Wasserman & Faust, 1994)
Diameter	Longest distance between two nodes	A higher value implies longer paths resulting in a less efficient energy transfer	(Freeman, 1979)
Centrality	Measures the degree to which a node is central to the network	Network centrality can be used to identify key players in a network	(Freeman, 1979)
Connections	The number of links between all the nodes in the network	The higher the value, the more complex the network	(Wasserman & Faust, 1994)

Functional group level			
Closeness Centrality (CC)	How short is the minimal paths from a given node to all others	Shows if the connections in the network are homogeneously distributed among all the nodes	(Freeman, 1979)
Betweenness Centrality (BC)	How often a node *i* is on the shortest path between each pair of nodes *j* and *k*.	High values correspond to the most repeated nodes, meaning they have a greater importance in the network.	(Brandes, 2001; Freeman, 1979)
Eigen Centrality (EC)	Influence of a node in the network	Shows possible key nodes or essential nodes for the ecosystem.	(Bonacich, 1987)
Degree Index (D)	Number of other nodes connected directly to each node	A low value indicates homogeneous connections between nodes, and a higher value indicates the presence of nodes with higher number of connections.	(Wasserman & Faust, 1994)

2.4. Disturbance simulations

To simulate the effects of environmental and anthropogenic (fishing) disturbances (i.e., through bottom-up and top-down events) on both networks, we first classified all species in each model into five trophic groups according to their diets (for a better global vision): Primary Producers, Herbivores, Primary Consumers, Secondary Consumers and Top Predators. We then applied two scenarios for the environmental and anthropogenic disturbances: 1) eliminating the primary producers (for the bottom-up scenario) and 2) eliminating predators (for the top-down scenario). Also, as a local fishing disturbance, we chose three target species from low, intermediate and high trophic levels: lobsters, sea urchins, and sea bass. We then eliminated individually each of these species to see the response in the entire network (without trophic groups).

To analyse the ecosystem response to both environmental and fishing disturbances scenarios, we used the network indicators described in Table 1. We performed the Wilcoxon statistical analysis with the package ‘stats’ (version 3.6.3) in R studio (version 1.4.1106) to see if there were significant different responses between the CSK and LEK based models.

We are aware that the selection of scenarios, although they may occur in reality, would not be as extreme as we describe in this work. However, pushing systems – through exposing them to such extreme scenarios – to their limits and to then explore consequences on node and network level allows to understand behaviour and dynamics of the system better and to discuss potential future pathways in the face of yet unpredictable changes.

3. RESULTS

3.1. *Are the CSK and LEK network models comparable under a diverse set of network indicators? And what are the effects of these differences or similarities?*

3.1.1. Network level indicators

While the LEK network model had a greater number of nodes (52), the CSK was more complex (Figure 1), as indicated by higher density and clustering coefficients, (0.19 and 0.41 respectively) and a higher centrality (0.52). All this leads to suggest that the CSK network model had more functional groups with central nodes (Table 1).

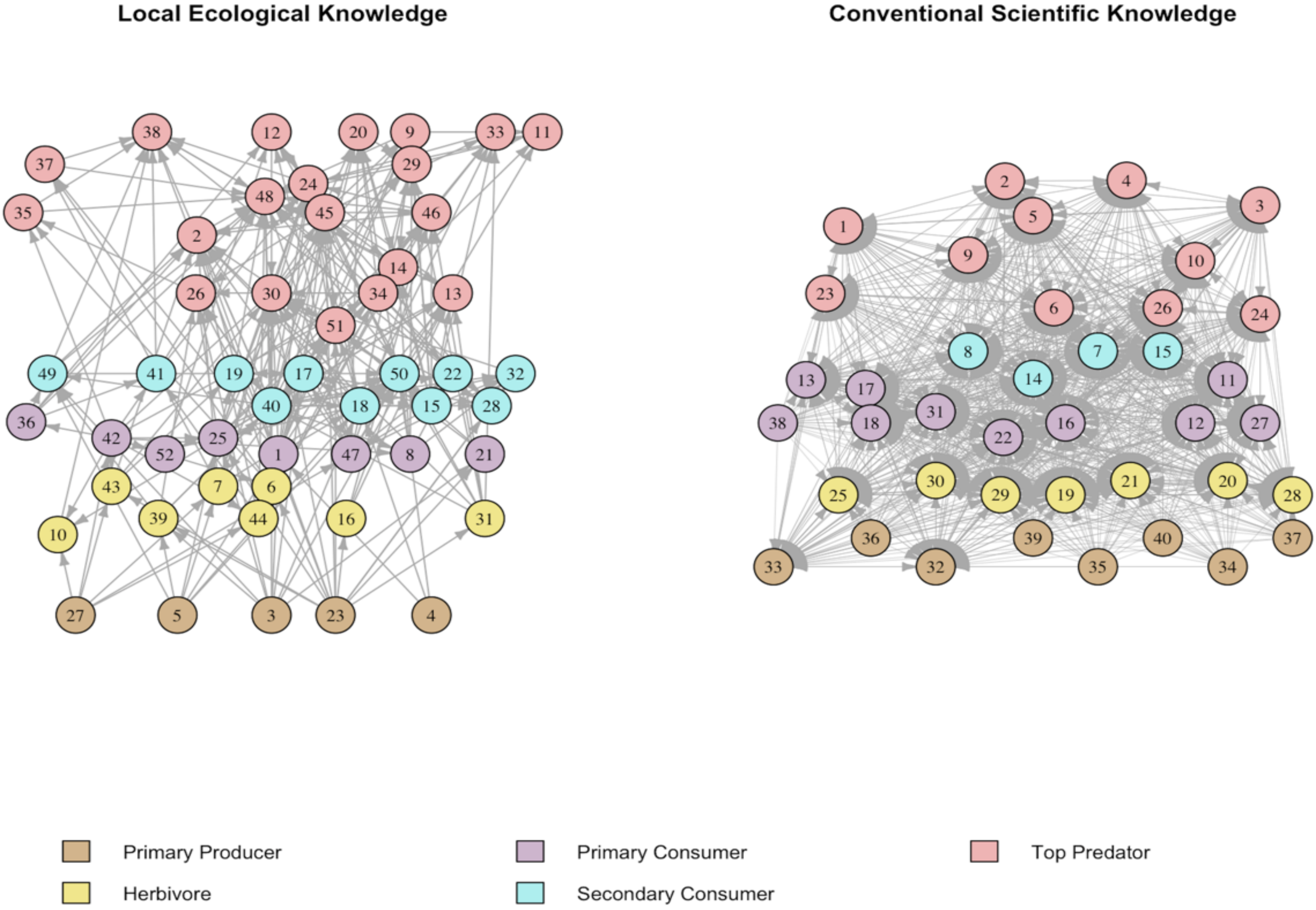


Figure 1.Trophic networks based on Local Ecological Knowledge (LEK, left) and Conventional Science Knowledge (CSK, right).

For the CSK, number nodes correspond to: 1.Abalones, 2. Sea birds, 3.Chlorophyta, 4.Rhodophytes, 5.Phaeophyceae, 6. Pismo clam, 7. Bivalves, 8.Anchovies, 9.Eels, 10.Whales, 11.Barracudas, 12.Tunas, 13.Ocean whitefish, 14.Groupers, 15.Squids, 16.Shrimps, 17.Crabs, 18.Gasteropods, 19.Triggerfishes, 20.Corvinas, 21.Chitons, 22.Doplhins, 23.Detritus, 24.Sea lions, 25.Sea urchins, 26.Starfishes, 27.Phytoplankton, 28.Swimming crab, 29.Jacks, 30.Lobsters, 31.Prawns, 32.Flatfishes, 33.Cods, 34.Mackerels, 35.Mantas, 36.Jellyfishes, 37.Sea otters, 38.Killer whales, 39.Sea cucumbers, 40.Other fishes, 41.Ocean sunfish, 42. Zooplankton, 43.Polychaetes, 44.Microcrustaceans, 45.Octopus, 46.Rockfishes, 47.Sardines, 48.Sharks, 49.Sea turtles, 50.Sand bass, 51.California sheephead , 52.Flyingfishes
For the LEK, number nodes correspond to: 1.Sea birds, 2.Marine mammals, 3.Lingcod, 4.Giant sea bass, 5.Elasmobranchia, 6.Sheepheads, 7.Ocean whitefish, 8.Rockfish microinverivore, 9.Rockfish piscivore, 10.Kelp bass, 11.Garibaldi, 12.Midwater fish, 13.Surfperch, 14.Opaleye, 15.Senoritas, 16.Understory fish, 17.Macrocrustaceans, 18.Sessile invertebrates, 19.Pink abalone, 20.Green abalone, 21.Other abalone, 22.Mobile invertebrates, 23.Octopus, 24.Lobster, 25.Sea cucumber, 26.Sea star, 27.Sea snails, 28.Purple sea urchin, 29.Black sea urchin, 30.Red sea urchin, 31.Small invertebrates, 32.Coralline incrusted algae, 33.Brown algae tall, 34.Brown algae bushy, 35.Red algae, 36.M.pyrifera, 37.Eklonia arborea, 38.Zooplankton, 39.Phytoplankton, 40.Detritus

3.1.2. Functional group level indicators

The functional groups' comparison showed differences in trophic level composition (Table 3). For the CSK model, functional groups with the highest number of nodes include Primary Consumers and Top Predators (both 25%), followed by Primary Producers (20%), Herbivores (17.5%), and finally Secondary Consumers (12.5%). In the case of the LEK model, the group with the highest number of nodes were the Top Predators (38%), followed by the Secondary Consumers (19.2%), Herbivores (17.2%), Primary Consumers (15%), and finally the Primary Producers (9.6%). While the CSK model presents more balanced percentages, the LEK model presents a remarkable difference between the Primary Producers (38%) and the Top Predators (9.6%).

Our results showed differences between the network properties of the LEK and the CSK models (Figure 2, first column): The Betweenness Centrality (BC) results showed that in the CSK network, the nodes corresponding to the Primary Producers were the most frequent within the network pathways. In contrast, the most frequent nodes in trophic pathways were the Top Predators and Secondary Consumers for the LEK. Consistently, the Degree Index (DI) results showed that the nodes with more trophic connections in the network were the Primary Producers for the CSK and Top Predators and Secondary Consumers for the LEK, concurring with the BC results.

On the other hand, Eigen Centrality (EC) results showed that Top Predator's nodes were the most influential groups for the LEK. In contrast, for the CSK, the node influence levels were homogeneous, only slightly higher for Top Predators. Finally, the Closeness Centrality (CC) results showed uniform proportions for both networks, showing homogeneous distances between nodes.

Table 2. Original (before disturbances) percentage distribution of nodes in trophic levels for each model (CSK and LEK).

Trophic Level	**Local Ecological Knowledge**	**Conventional Science Knowledge**
Primary Producer (PP)	9,6%	20 %
Herbivore (H)	17,2%	17,5 %
Primary Consumer (PC)	15%	25%
Secondary Consumer (SC)	19,2 %	12,5%
Top Predator (P)	38%	25%

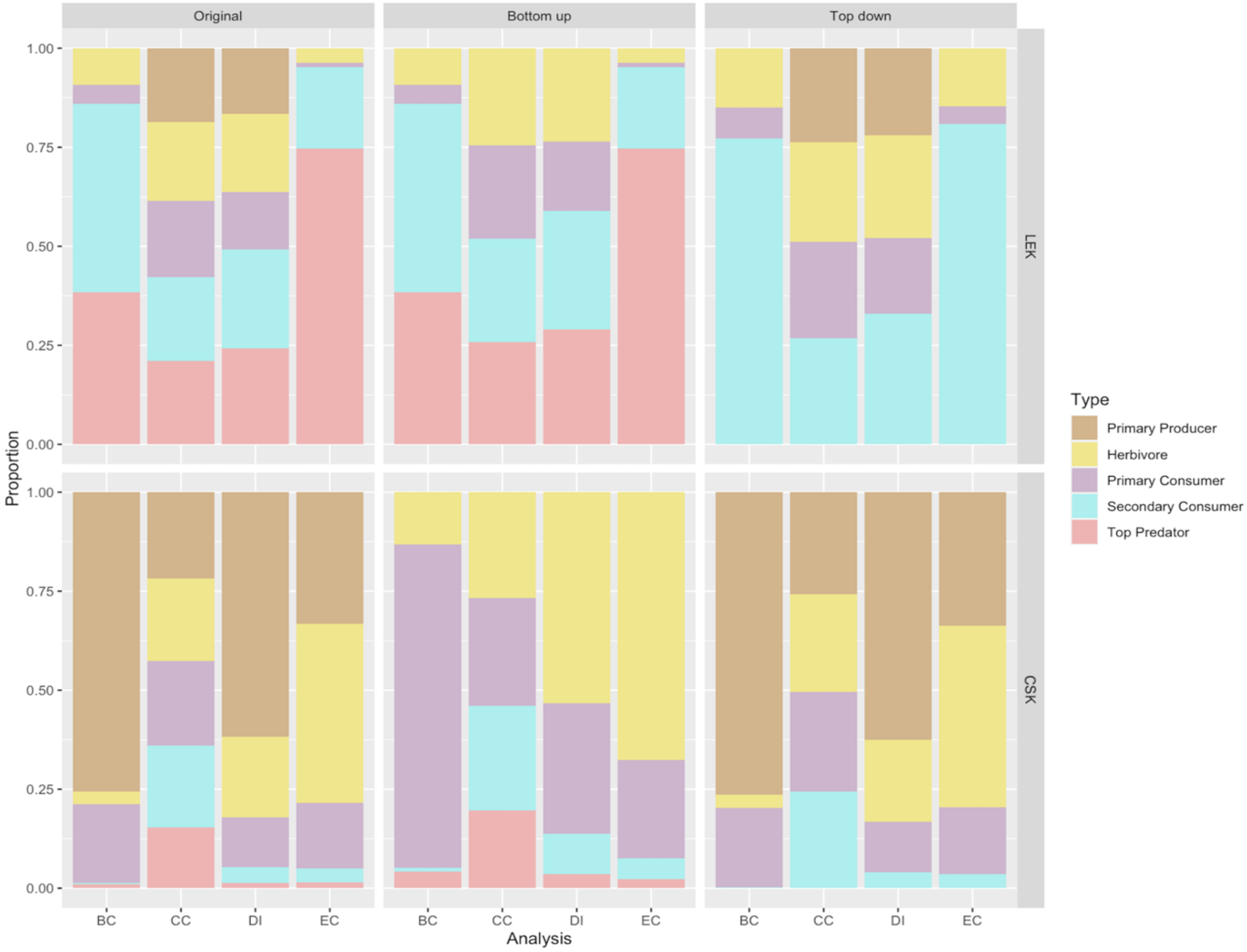


Figure 2. Functional group level indicators (X-axis): Betweenness Centrality (BC), Closeness Centrality (CC), Degree Centrality (DI), and Eigen Centrality (EC). The Y-axis shows the proportional value of each indicator for the different trophic levels. The figure is divided into two rows, the Local Ecological Knowledge (LEK) model is on top and the Conventional Science Knowledge (CSK) model on the bottom. The right column is for the original network model, the middle column the bottom-up disturbance (the Primary Producers were removed), and the right column the top-down disturbance (where the top predators were removed).

3.2. Do both models respond similarly to disturbances?

3.2.1.Environmental: Top-down & Bottom-up response in global indicators

In general, both models responded similarly under bottom-up and top-down disturbances (both increasing or decreasing) (Figure 3). Also, the Wilcoxon test indicated that there were no significant differences between the networks levels indicators (Table 2) responses to environmental disturbances (bottom-up p-value = 0.4017 and top-down p-value = 0.9375). However, in the bottom-up disturbance, we found three indexes where one model increased and the other decreased (Density, Clustering Coefficient and Diameter). The Density and Clustering Coefficient increased slightly on the LEK and decrease on the CSK. The diameter increased in the CSK while decreased in the LEK. As for the Average Path Length (APL), it increased on the CSK while it remained constant in the LEK. In the top-down disturbances, there are only two analyses in which the models responded differently, the APL and the diameter. While the

CSK diameter remained constant, it decreased in the LEK model. As for the APL, it decreased for the CSK but increased for the LEK. In most of the indexes the changes after the disturbances were less than 20%. However, the percent change on the Diameter, Connections, and Centrality, were higher than -40% in some cases for both models and disturbances.

Table 3. Original (before disturbances) network indicators for the Local Ecological Knowledge (LEK) and Conventional Science Knowledge (CSK) models.

Index	**LEK**	**CSK**
Number of nodes	52	40
Number of connections	267	297
Density	0.100	0.190
Average path length (APL)	1.934	1.641
Diameter	7	3
Clustering coefficient	0.288	0.413
Centrality	0.190	0.528

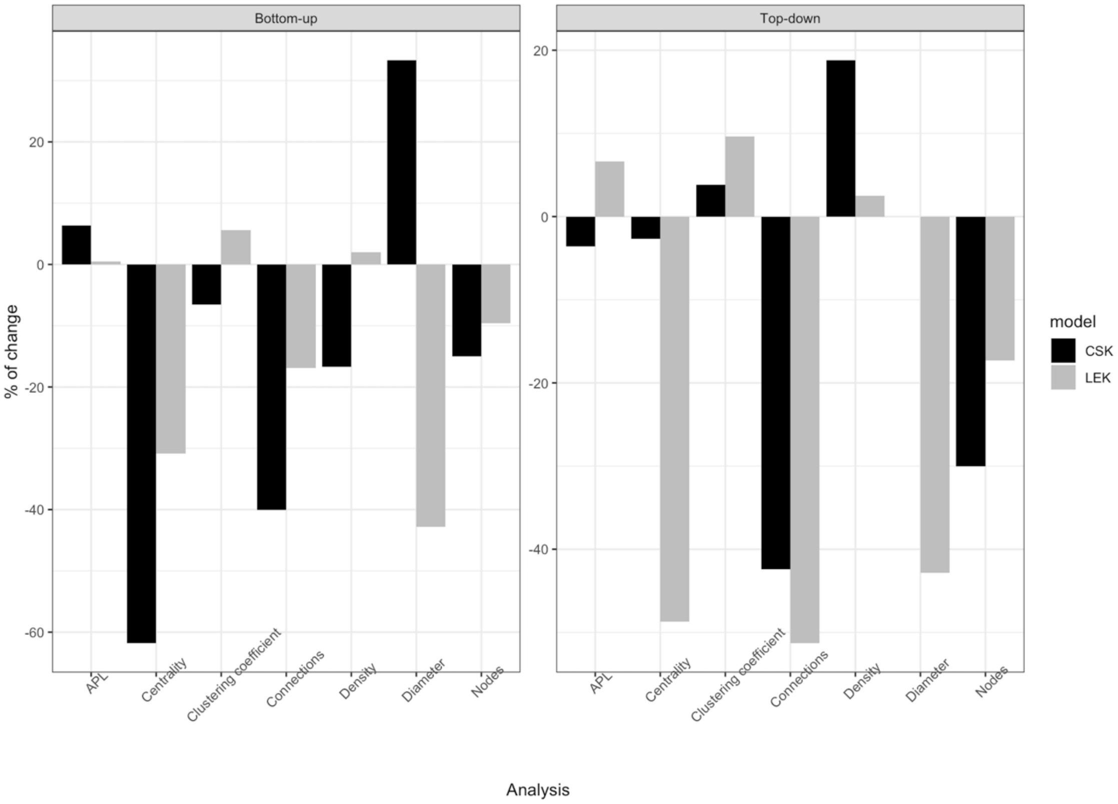


Figure 3. Network indexes´ change after bottom-up (right) and top-down (left) simulations. The Y-axis represents the percentage of change before and after each perturbation (in black for the LEK model and grey for the CSK model). The network level indexes are represented on the X-axis: Average Path Length (APL), Centrality, Connections, Density, Diameter, and Clustering coefficient.

3.2.2. Environmental: Top-down & Bottom-up response in functional group indicators

The CSK network had the most visible changes in functional group indicators: BC results changed from the most frequent nodes in trophic pathways in the network being Primary

Producers to Primary Consumers (Figure 2). BC proportions did not change for the LEK model since Primary Producers' connections were already low. In both cases, the number of connections between the nodes were homogeneous when primary producers were removed (DI). Additionally, despite the simulated disturbance, the group with the greatest influence in both models continued to be the top predators (with an influence of 30% in the CSK and 75% in the LEK).

Conversely, the LEK network showed more visible changes than the CSK network. In response to top-down disturbances in the LEK model (Figure 2), more than 75% of the trophic pathways changed to Secondary Consumers (BC), making it the group with the highest number of connections (DI). On the other hand, the redistribution of frequency in trophic pathways (BC) in the CSK model was not very visible since Top Predators were the group with the fewest connections. For the CSK, the Primary Producers continued being the most frequent group in trophic pathways and the highest number of connections (BC and DI).

3.2.3. Fishery: removal of fishing species

The greatest differences were observed for the fishing effect when lobsters were removed from the system (Figure 4). In this case, the values of all the indexes decreased their value against the original value, except for the Diameter for the LEK model.
The removal of the sea bass and sea urchin groups did only reflect on the centrality value of the LEK model (a decrease in more than 30%).

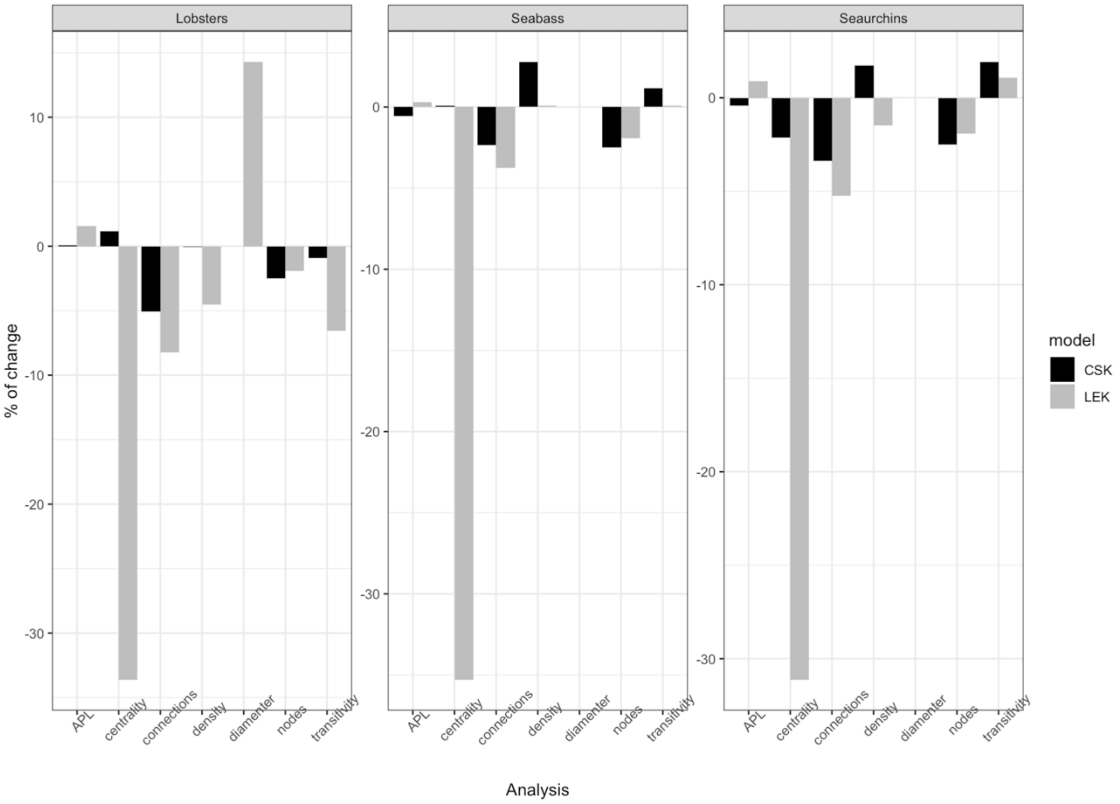


Figure 4. Network level indicators under fishing pressure simulations. The Y-axis represents the percentage of change concerning the original values once each fishing group was removed (From left to right: Lobsters, seabass and sea urchins were removed individually at each model). The network level indicators are represented on the X-axis: Average Path Length (APL), Centrality, Connections, Density, Diameter, and Clustering coefficient.

4. DISCUSSION

To our knowledge, this is the first effort to compare ecological network models from different data sources (LEK vs CSK) in the same area. This study approaches the network's structure and compare their responses to top-down and bottom-up disturbances. Overall, we found that a LEK model was performed similar to a scientific based model. Local Ecological Knowledge can be an important source of information for many data poor SSFs (Zetina-Rejón et al., 2022), however, fishers are rarely integrated into policy arenas (Finkbeiner, 2015b). Our results suggest that both LEK and CSK can be reliable sources for understanding coastal systems. In fact, the LEK model resulted with a higher number of nodes, which is directly related to a greater global vision of the fishers. This highlights the importance of this under-valued source of information to set up the system's structure drawing. We need to explore further how to better incorporate LEK from local communities into ecological research to create more solid mechanisms to face environmental and anthropogenic changes (Finkbeiner, 2015a). This work is a stepping stone to develop more robust ecological network models needed in SSF with limited data.

Data-poor context generally occur in SSF where it is not always possible to have CSK. However, our results agree with the literature that the lack of scientific knowledge does not imply a lack of knowledge in the area at all (Basurto et al., 2013; Finkbeiner, 2015a). In our results we observed that the CSK based model is more dense, complex and centralized, which means that most of the network connections are directed towards few functional groups. This could be the result of the unbalance efforts of scientific research that have focused disproportionately on some groups (e.g., those of commercial or conservation interest), resulting in a high or low network connection of groups according to the available knowledge. In contrast, the LEK network shows that connections are distributed homogeneously among all groups (Table 2). This may have some repercussions when analysing disturbances and changes in the models since the response in the network structure may vary.

The main differences between models are reflected in our results. On the one hand, local knowledge comes from daily observations at sea, or information passed from generation to generation among fishers (Johannes & Neis, 2007). Due to everyday interaction, fishers know their ecosystems well. They are very attentive to environmental changes and usually have knowledge of species fluctuations over time trough memories, observations or family stories (Rosa et al., 2014). However, fishers also target species, so most knowledge comes from organisms observed on nature or while processing the fished product. Therefore, it is expected that the upper trophic levels have greater detail than the lower ones in the LEK network, since upper trophic levels are easier to notice from a boat than lower ones.

On the other hand, academics are subject to their context also, i.e., following established scientific methods to support their observations. However, this process is time and resource consuming and therefore usually occurs less frequently than the continuous observations by the local communities. Nonetheless, scientific records are vital because they usually focus on identifying trigger mechanisms for ecological processes (Dayton, 1985; Foster & Schiel, 1985). Because of that, scientists by carefully documenting field or laboratory observations are capable to develop more detailed classifications for primary producers. For example, in this specific case, the LEK model had fewer details on primary producers. These differences between the models can point to areas of opportunity to refine LEK models that can be used for scenario analysis. In many cases in data poor localities these comparisons would not be possible. Therefore, we suggest, to first start creating LEK models in data-limited SSF areas. These models take less time and effort to create. Secondly, depending on the LEK models, create an ecological monitoring focusing on filling in the information gaps indicated by the LEK model.

We tested both network models against bottom-up and top-down effect disturbances, both of which frequently occur in the study area bioregion (Reed et al., 2011). With a top-down disturbance, the abundance of the groups increases alternately, starting with the next group after the affected one (Carpenter et al., 1985). In contrast, there is no clear pattern in bottom-up disturbances (Figure 2). For the latter, it is known that the variations in the densities of the groups are irregular and do not transfer uniformly, so that can skip alternate levels (Borer et al., 2006; Heath et al., 2014). In our analyses, we relate these patterns to the results of the EC analysis, which shows the influence of each trophic level. According to the patterns described above, these influences fluctuate for both bottom-up and top-down networks, driving cascade effects which are illustrated in Figure 5. Therefore, even though the species' distributions within the trophic levels are different between models, both networks responded similarly to these variations.

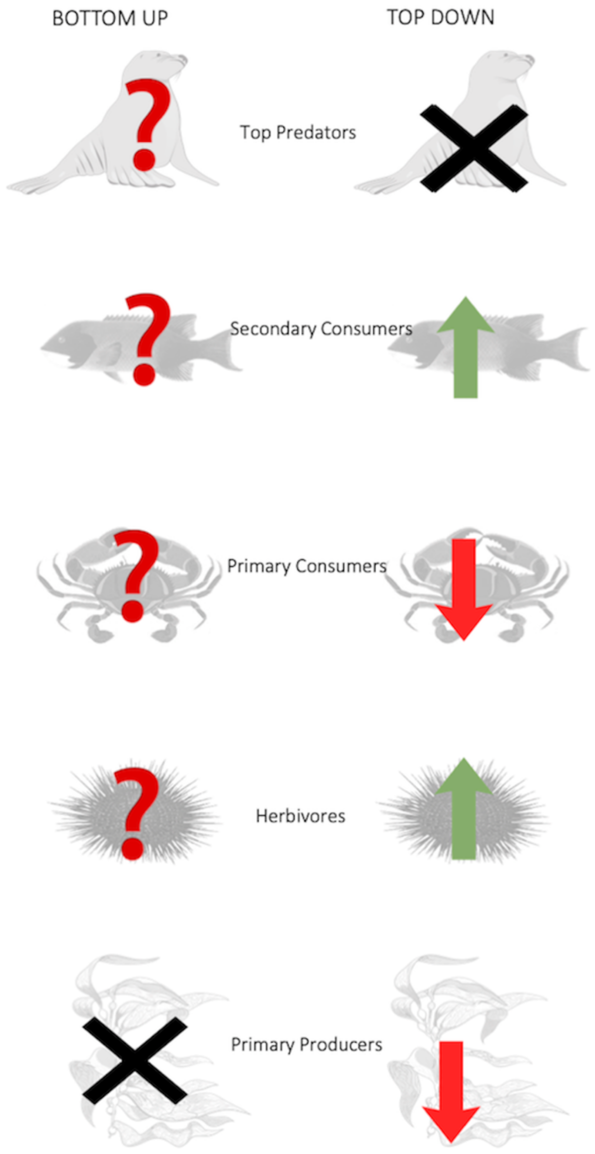


Figure 5. Graphical overview of model responses amidst the bottom-up and top-down scenarios (cf. section 2.4 for details on scenarios). This answer is based on the results obtained with the Eigen Centrality analysis.

Given that fishing is an essential activity in our study area, simulating their impacts in the models was warranted. Of the three chosen species (lobster, sea bass, and sea urchin), the removal of lobsters (its fishing) produced the most remarkable changes in both networks' global parameters, generally decreasing them. This suggests that the lobster is a key species in the trophic chain, and its elimination can lead to cascade effects (Eddy et al., 2017) with potential dramatic consequences for the entire ecosystem. This is a particularly important finding since lobster is one of the main targeted species in the area, highlighting the need to focus management attention on this species. Fortunately, lobster, as well as other species of fishing importance such as abalone, sea urchin, or snail, are under strict management regimes, including closed seasons, total allowable catches, fishing quotas, minimum catch sizes, and regulations on fishing gear (CONAPESCA, 2016), which increase the sustainability of the lobster fishery but also could be protecting the whole ecosystem. Nevertheless, ecosystems are constantly changing, and for data-poor fisheries ongoing environmental changes are less likely to be tracked /detected but management needs to be continuously adapted as to prevent deleterious ecosystem impacts (Johannes et al., 2000). Because of that, it is necessary to create adequate tools and models to forecast changes due to environmental and anthropogenic variations (Halouani et al., 2016; Johnson et al., 2017; Munguia-Vega et al., 2018).

Network modelling is a worldwide tool used to address those issues (Heymans et al., 2016). Network models have been used, among other things, to analyse possible future environmental and anthropogenic changes, identify marine reserve areas, and develop management plans (Abdou et al., 2016; Babcock et al., 2019; Romagnoni et al., 2015). In general, these models are based purely on scientific knowledge, even though they are used to make management decisions concerning fishing communities, fishers are not always involved in this process (Shabtay et al., 2018). Generating models in data-poor areas solely with scientific knowledge can lead to misleading results, since models can often be built with information from other species and/or from nearby areas (Bevilacqua et al., 2016). In addition, models based on scientific data require constant data updating, which is not always possible (Zetina-Rejón et al., 2022). This is why LEK models can be very valuable for resource managers in data-poor areas. Also, using local knowledge promotes fishers' involvement in decision-making and the design of appropriate management policies according to their resources and needs (Finkbeiner, 2015a). However, models based only on LEK also have their limitations. Coming from fishers, it is likely the amount of knowledge and its details varies depending on whether the species for which information is obtained represents a targeted species or not. Besides, it is important to review or verify the information obtained from fishers, because, just like everyone else, they can forget or mix up information (De Melo Alves Damasio et al., 2015).

Something important to keep in mind is that the LEK model combines local knowledge with scientific data. In other words, based on the information provided by the locals, the scientists need to corroborate and complement this information with the existing scientific data in the area or for the species (e.g., by translating common local species names into scientifically standardized species names). Therefore, in a way, both models are based to some extent on scientific information. However, as our results suggest local knowledge models can perform similarly to scientific-based models. This is important since it implies that, when not having enough funds and/or time to carry out scientific monitoring, it could be useful to create and use models based on interviews complemented with available scientific data.

Summing up, based on the two initial questions of this work, we have found that: first, the LEK and CSK models are comparable based on the network indicators used at the individual (node) and global (network) levels. We also demonstrate the complementarity between both models and the importance of valuing local knowledge. Second, under the disturbance simulations, both models responded according to the literature under the bottom-up and top-down scenarios. In addition, in both cases, they were sensitive to the disappearance of a key species, the lobster, which is highly important for fishing in the area.

5. CONCLUSIONS

Regardless of the knowledge source, both LEK and CSK network models proved their functionality to understand the structure and function of an ecosystem. We believe our work fills an important knowledge gap comparing both types of models form the same area. In this study, we showed how both models could be very similar topologically and respond very similarly at the onset environmental and anthropogenic disturbances. The comparison of two models of the same area, based on two different types of information, to our knowledge, has not been done before. So, until now, it was not known if the two types of models could be fully comparable and hence similarly useful. We believe that this work is a step forward to give greater credibility to LEK-informed network models, especially in data-poor settings. Additionally, we have shown that the information obtained through each of these knowledge types is somewhat complementary: The LEK network showed greater detail in upper trophic levels, while the CSK network had more resolution in lower trophic levels. Because of that, for future work, we must be careful not to overestimate the fishers' information but also not to underestimate the complexity of an ecosystem and its whole food web. Furthermore, simulations could also be made on how both networks respond to disturbances over time. This could be a useful tool for stakeholders, fishers, and managers to estimate and forecast changes at the ecosystem or species-specific level.

DATA AVAILABILITY STATEMENT

The data underlying this article will be shared on reasonable request to the corresponding author.

FUNDINGS

This work was supported by the following sources: CONACYT scholarship to AV (CVU 689916). UABC internal funds to RBL, JL, LM, JAZ. And SIP project 20221721, EDI and COFAA from Instituto Politécnico Nacional to MJZR.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENT

We want to acknowledge the help of fishers from the fishing cooperative "Sociedad Cooperativa de Producción Pesquera Ensenada, SCL" for contributing with their knowledge and collaborating with the interviews. We are grateful to COBI and all the involved who conducted the interviews. Also, we want to thank all the people involved in the MexCal long-term ecological monitoring program. The authors are grateful for financial support received from Project SIP-IPN 20221721. MJZR thanks EDI and COFAA from Instituto Politécnico Nacional. We thank SCPP Ensenada for contributing their LEK and collaborating during the interviews and SCPP 29 de Agosto, SCPP Buzos y Pescadores de la Baja California, and SCPP Ensenada for contributing fishery monitoring data. A. Romero and R. Hernández from COBI was acknowledged for applying the interviews to fishers at El Rosario, BC. And also to PRODEP-NPTC No. Folio titled "Análisis de ecoetiquetas como herramienta de agregación de valor en pesquerías de Baja California, México".

AUTHOR CONTRIBUTIONS

AV: writing the first draft and coordinating. AV, RB and MZ: conceptualization, analysis, methodology, visualization, and editing. GL: data sampling and model development. LM, JL, AZ, and LK helped develop the draft manuscript, including guidance on figures, tables, and supporting information.

REFERENCES

Abdou, K., Halouani, G., Hattab, T., Romdhane, M. S., Lasram, F. B. R., & Le Loc'H, F. (2016). Exploring the potential effects of marine protected areas on the ecosystem structure of the Gulf of Gabes using the Ecospace model. *Aquatic Living Resources*, *29*(2). https://doi.org/10.1051/alr/2016014

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography*, *79*(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Albert, R., Jeong, H., & Barabási, A. L. (2000). Error and attack tolerance of complex networks. *Nature*, *406*, 378–382. https://doi.org/10.1515/9781400841356.503

Anuario Estadístico de Acuacultura y Pesca Edición. (2020).

Argüelles-Jiménez, J., Alva-Basurto, J. C., Pérez-España, H., Zetina-Rejón, M. J., & Arias-González, J. E. (2020). The measurement of ecosystem development in Caribbean coral reefs through topological indices. *Ecological Indicators*, *110*(July 2019), 105866. https://doi.org/10.1016/j.ecolind.2019.105866

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton, E. W., & Wollenberg, E. K. (2009). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment*, *7*(2), 95–102. https://doi.org/10.1890/070089

Babcock, R. C., Bustamante, R. H., Fulton, E. A., Fulton, D. J., Haywood, M. D. E., Hobday, A. J., Kenyon, R., Matear, R. J., Plagányi, E. E., Richardson, A. J., & Vanderklift, M. A. (2019). Severe continental-scale impacts of climate change are happening now: Extreme climate events impact marine habitat forming communities along 45% of Australia's coast. *Frontiers in Marine Science*, *6*(JUL), 1–14. https://doi.org/10.3389/fmars.2019.00411

Basurto, X. (2008). Biological and ecological mechanisms supporting marine self-governance: The Seri Callo de Hacha Fishery in Mexico. *Ecology and Society*, *13*(2). https://doi.org/10.5751/ES-02587-130220

Basurto, X., Gelcich, S., & Ostrom, E. (2013). The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change*, *23*(6), 1366–1380. https://doi.org/10.1016/j.gloenvcha.2013.08.001

Bauer, J., Lorda, J., Beas-Luna, R., Malpica-Cruz, L., Lafarga-De la Cruz, F., Micheli, F., Searcy-Bernal, R., Rogers-Bennett, L., & Bracamontes-Peralta, M. (2020). The effects of depth and diet on red abalone growth and survival in cage mariculture at San Jeronimo Island, Baja California, Mexico. *Ciencias Marinas*, *46*(4), 343–357. https://doi.org/10.7773/CM.V46I4.3117

Beas-Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*. University of California in Santa Cruz.

Beas-Luna, R., & Ladah, L. B. (2014). Latitudinal, seasonal, and small-scale spatial differences of the giant kelp, macrocystis pyrifera, and an herbivore at their southern range limit in the northern hemisphere. *Botanica Marina*, *57*(2), 73–83. https://doi.org/10.1515/bot-2013-0114

Beas-Luna, R., Micheli, F., Woodson, C. B., Carr, M., Malone, D., Torre, J., Boch, C., Caselle, J. E., Edwards, M., Freiwald, J., Hamilton, S. L., Hernandez, A., Konar, B., Kroeker, K. J., Lorda, J., Montaño-Moctezuma, G., & Torres-Moye, G. (2020). Geographic variation in responses of kelp forest communities of the California Current to recent climatic changes.

Global Change Biology, *26*(11), 6457–6473. https://doi.org/10.1111/gcb.15273

Beas Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S. H., Troell, M., & Williams, M. (2016). Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence. *World Development*, *79*, 177–196. https://doi.org/10.1016/j.worlddev.2015.11.007

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, *8*(1), 123–138. https://doi.org/10.1007/s12571-015-0526-x

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Review article: resilience, poverty and development. *Journal of International Development*, *23*, 598–623. https://doi.org/10.1002/jid

Bentley, J. W., Hines, D. E., Borrett, S. R., Serpetti, N., Hernandez-Milian, G., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Combining scientific and fishers' knowledge to co-create indicators of food web structure and function. *ICES Journal of Marine Science*, *76*(7), 2218–2234. https://doi.org/10.1093/icesjms/fsz121

Bentley, J. W., Serpetti, N., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Fishers' knowledge improves the accuracy of food web model predictions. *ICES Journal of Marine Science*, *76*(4), 897–912. https://doi.org/10.1093/icesjms/fsz003

Berkes, F. (2003). Alternatives to conventional management: Lessons from small-scale fisheries. *Environments*, *31*(1), 5–20.

Berkes, F. (2012). *Sacred Ecology*. Routledge, New York.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Berkes, F., & Folke, C. (1998). *Linking social and ecological systems: management practices and social mechanisms for building resilience.*

Berkes, F., Folke, C., & Gadgill, M. (1994). Traditional Ecological Knowledge. *Biodiversity Conservation*, 269–287. https://doi.org/10.1007/978-94-007-0753-5_104248

Berkström, C., Papadopoulos, M., Jiddawi, N. S., & Nordlund, L. M. (2019). Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Frontiers in Marine Science*, *6*(MAR), 1–10. https://doi.org/10.3389/fmars.2019.00130

Bevilacqua, A. H. V., Carvalho, A. R., Angelini, R., & Christensen, V. (2016). More than anecdotes: Fishers' ecological knowledge can fill gaps for ecosystem modeling. *PLoS ONE*, *11*(5), 1–18. https://doi.org/10.1371/journal.pone.0155655

Biggs, R., Schlüter, M., & Schoon, M. L. (2015). "An introduction to the resilience approach and principles to sustain ecosystem services in social-ecological systems." In *Principles for building resilience: Sustaining ecosystem services in social–ecological systems* (pp. 1–31). https://doi.org/10.1086/696744%0Ahttps://doi.org/10.1086/696744

Bindoff, N. L., Cheung, W. W. L., Kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., Hilmi, N., Jiao, N., Karim, M. S., Levin, L., O'Donoghue, S., Cuicapusa, S. R. P., Rinkevich, B., Suga, T., Tagliabue, A., & Williamson, P. (2019). Changing Ocean, Marine Ecosystems, and Dependent Communities. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.)]. In Press.*, 447–588.

Bodin, Ö. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, *357*(6352). 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

Bonacich, P. (1987). Power and Centrality: A Family of Measures. *American Journal of Sociology*, *92*, 1170–1182.

Borer, E. T., Halpern, B. S., & Seabloom, E. W. (2006). Asymmetry in community regulation:

Effects of predators and productivity. *Ecology*, *87*(11), 2813–2820. https://doi.org/10.1890/0012-9658(2006)87[2813:AICREO]2.0.CO;2

Borrett, S. R., Moody, J., & Edelmann, A. (2014). The rise of Network Ecology: Maps of the topic diversity and scientific collaboration. *Ecological Modelling*, *293*, 111–127. https://doi.org/10.1016/j.ecolmodel.2014.02.019

Brandes, U. (2001). The Journal of Mathematical A faster algorithm for betweenness centrality. *Journal of Mathematical Sociology*, *March 2012*, 37–41.

Brown, K. (2016). Resilience, development and global change. In *Resilience, Development and Global Change*. https://doi.org/10.4324/9780203498095

Bryndum-Buchholz, A., Tittensor, D. P., Blanchard, J. L., Cheung, W. W. L., Coll, M., Galbraith, E. D., Jennings, S., Maury, O., & Lotze, H. K. (2019). Twenty-first-century climate change impacts on marine animal biomass and ecosystem structure across ocean basins. *Global Change Biology*, *25*(2), 459–472. https://doi.org/10.1111/gcb.14512

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J., & Schmitt, R. J. (2011). Climate-driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*, *17*(8), 2513–2524. https://doi.org/10.1111/j.1365-2486.2011.02409.x

Carpenter, S. R., Kitchell, J. F., & Hodgson, J. R. (1985). Fish predation and herbivory can regulate lake ecosystems. *BioScience*, *35*(10), 634–639.

Cavole, L. M., Andrade-Vera, S., Marin Jarrin, J. R., Dias, D. F., Aburto-Oropeza, O., & Barrágan-Paladines, M. J. (2020). Using local ecological knowledge of Fishers to infer the impact of climate variability in Galápagos' small-scale fisheries. *Marine Policy*, *121*(January), 1–10. https://doi.org/10.1016/j.marpol.2020.104195

Christensen, V., & Walters, C. J. (2004). Ecopath with Ecosim: Methods, capabilities and limitations. *Ecological Modelling*, *172*(2–4), 109–139. https://doi.org/10.1016/j.ecolmodel.2003.09.003

Cisneros-Montemayor, A. M., Zetina-Rejón, M. J., Espinosa-Romero, M. J., Cisneros-Mata, M. A., Singh, G. G., & Fernández-Rivera Melo, F. J. (2020). Evaluating ecosystem impacts of data-limited artisanal fisheries through ecosystem modelling and traditional fisher knowledge. *Ocean and Coastal Management*, *195*(February). https://doi.org/10.1016/j.ocecoaman.2020.105291

Clauset, A., Newman, M. E. J., & Moore, C. (2004). Finding community structure in very large networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *70*(6), 6. https://doi.org/10.1103/PhysRevE.70.066111

CONAPESCA. (2016). *Carta Nacional Pesquera, Mexico*.

Council, A. (2013). Arctic Resilience Interim Report 2013. *Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm, Pp. Ix–Xii.*

Csárdi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *Interj. Compl. Sys.* https://doi.org/10.3724/sp.j.1087.2009.02191

Dayton, P. K. (1985). Ecology of Kelp Communities. *Annual Review of Ecology and Systematics*, *16*(1985), 215–245. https://doi.org/https://doi.org/10.1146/annurev.es.16.110185.001243

De Melo Alves Damasio, L., Lopes, P. F. M., Guariento, R. D., & Carvalho, A. R. (2015). Matching Fishers' knowledge and landing data to overcome data missing in small-scale fisheries. *PLoS ONE*, *10*(7), 1–13. https://doi.org/10.1371/journal.pone.0133122

Delgado-Serrano, M. del M., Oteros-Rozas, E., Vanwildemeersch, P., Ortíz-Guerrero, C., London, S., & Escalante, R. (2015). Local perceptions on social-ecological dynamics in latin america in three community-based natural resource management systems. *Ecology and Society*, *20*(4). https://doi.org/10.5751/ES-07965-200424

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, *4*(1), 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

Eddy, T. D., Lotze, H. K., Fulton, E. A., Coll, M., Ainsworth, C. H., de Araújo, J. N., Bulman,

C. M., Bundy, A., Christensen, V., Field, J. C., Gribble, N. A., Hasan, M., Mackinson, S., & Townsend, H. (2017). Ecosystem effects of invertebrate fisheries. *Fish and Fisheries*, *18*(1), 40–53. https://doi.org/10.1111/faf.12165

Edwards, M. S., & Estes, J. A. (2006). Catastrophe, recovery and range limitation in NE Pacific kelp forests: A large-scale perspective. *Marine Ecology Progress Series*, *320*, 79–87. https://doi.org/10.3354/meps320079

Espinoza-Tenorio, A., Ehuan-Noh, R. G., Cuevas-Gómez, G. A., Narchi, N. E., Ramos-Muñoz, D. E., Fernández-Rivera Melo, F. J., Saldívar-Moreno, A., Zepeda-Domínguez, J. A., Pérez-Jiménez, J. C., Oliveto-Andrade, A., & Torre, J. (2022). Between uncertainty and hope: Young leaders as agents of change in sustainable small-scale fisheries. *Ambio*, *51*(5), 1287–1301. https://doi.org/10.1007/s13280-021-01639-2

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. In *FAO*. https://doi.org/10.4060/cc0461en

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

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

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

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio*, *31*(5), 437–440. https://doi.org/10.1579/0044-7447-31.5.437

Folke, C., Pritchard, L., Berkes, F., Colding, J., & Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-02064-120130

Foster, M., & Schiel, D. (1985). Ecology of giant kelp forests in California: a community profile. *United States Fish and Wildlife Service Biological Report*, *85*, 1–152. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5129110

Freeman, L. (1979). Centrality in networks: I: Conceptual Clarification. *Social Networks*, *1*, 215–239.

Froeser, R., & Pauly, D. (2016). *FishBase*. World Wide Web Electronic Publication.

Galappaththi, E. K., Ford, J. D., & Bennett, E. M. (2019). A framework for assessing community adaptation to climate change in a fi sheries context. *Environmental Science and Policy*, *92*(November 2018), 17–26. https://doi.org/10.1016/j.envsci.2018.11.005

García-Quijano, C. G. (2007). Fishers' Knowledge of Marine Species Assemblages: Bridging between Scientific and Local Ecological Knowledge in Southeastern Puerto Rico. *American Anthropologist*, *109*(3), 529–536. https://doi.org/10.1525/AA.2007.109.3.529.530

Gaspare, L., Bryceson, I., & Kulindwa, K. (2015). Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of groupers (Epinephelinae) fisheries around Mafia Island, Tanzania. *Ocean and Coastal Management*, *114*, 88–101. https://doi.org/10.1016/j.ocecoaman.2015.06.011

Guimerà, R., Sales-Pardo, M., & Amaral, L. A. N. (2007). Module identification in bipartite and directed networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *76*, 036102.

Guimerà, R., Stouffer, D. B., Sales-Pardo, M., Leicht, E. A., Newman, M. E. J., & Amaral, L. A. N. (2010). Origin of compartmentalization in food webs. *Ecology*, *91*(10), 2941–2951. https://doi.org/10.1890/09-1175.1

Halouani, G., Abdou, K., Hattab, T., Romdhane, M. S., Ben Rais Lasram, F., & Le Loc'h, F. (2016). A spatio-temporal ecosystem model to simulate fishing management plans: A case of study in the Gulf of Gabes (Tunisia). *Marine Policy*, *69*, 62–72. https://doi.org/10.1016/j.marpol.2016.04.002

Hamilton, R., Sadovy de Mitcheson, Y., & Aguilar-Perera, A. (2012). The Role of Local Ecological Knowledge in the Conservation and Management of Reef Fish Spawning Aggregations. In C. P. (eds) In: Sadovy de Mitcheson Y. (Ed.), *Reef Fish Spawning Aggregations: Biology, Research and Management. Fish & Fisheries Series*. Springer, Dordrecht. https://doi.org/https://doi.org/10.1007/978-94-007-1980-4_10

Hamilton, S. L., Gleason, M. G., Godoy, N., Eddy, N., & Grorud-Colvert, K. (2022). Ecosystem-based management for kelp forest ecosystems. *Marine Policy*, *136*, 104919. https://doi.org/10.1016/j.marpol.2021.104919

Heath, M. R., Speirs, D. C., & Steele, J. H. (2014). Understanding patterns and processes in models of trophic cascades. *Ecology Letters*, *17*(1), 101–114. https://doi.org/10.1111/ele.12200

Heymans, J. J., Coll, M., Link, J. S., Mackinson, S., Steenbeek, J., Walters, C., & Christensen, V. (2016). Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. *Ecological Modelling*, *331*, 173–184. https://doi.org/10.1016/j.ecolmodel.2015.12.007

Hind, E. J. (2014). A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. *ICES Journal of Marine Science*, *72*(2), 341–358. https://doi.org/10.1093/icesjms/fsu169

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

IPCC. (2014). *Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.)).

IPCC. (2021). *Climate Change 2021: The Physical Science Basis Summary for Policymakers Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, S. L. C. A. Pirani, S. B. C. Péan, Y. C. N. Caud, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & and B. Zhou (Eds.)). Cambridge University Press. In Press.

ISE. (2006). *International Society of Ethnobiology Code of Ethics (with 2008 additions).* http://ethnobiology.net/code-of-ethics/

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J., & Warner, R. R. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*, *293*, 629–637. https://doi.org/10.1126/science.1059199

Jacox, M. G., Hazen, E. L., Zaba, K. D., Rudnick, D. L., Edwards, C. A., Moore, A. M., & Bograd, S. J. (2016). *Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events*. 7072–7080. https://doi.org/10.1002/2016GL069716.Received

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01462-110115

Johannes, R. ., & Neis, B. (2007). The value of anecdote. In *Fishers' knowledge in fisheries science and management. Coastal Management Sourcebooks* (Vol. 4, Issue 3, pp. 41–58). https://doi.org/10.1016/j.avsg.2014.01.003

Johannes, R. E., Freeman, M. M. R., & Hamilton, R. J. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, *1*(3), 257–271. https://doi.org/10.1111/j.1467-2979.2000.00019.x

Johnson, A. F., Moreno-Baez, M., Giron-Nava, A., Corominas, J., Erisman, B., Ezcurra, E., &

Aburto-Oropeza, O. (2017). A spatial method to calculate small-scale fisheries effort in data poor scenarios. *PLoS ONE*, *12*(4), 1–17. https://doi.org/10.1371/journal.pone.0174064

Kluger, L. C., Gorris, P., Kochalski, S., Mueller, M. S., & Romagnoni, G. (2020). Studying human–nature relationships through a network lens: A systematic review. *People and Nature*, *2*(4), 1100–1116. https://doi.org/10.1002/pan3.10136

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*(July), 104861. https://doi.org/10.1016/j.ocecoaman.2019.104861

Kobluk, H. M., Gladstone, K., Reid, M., Brown, K., Krumhansl, K. A., & Salomon, A. K. (2021). Indigenous knowledge of key ecological processes confers resilience to a small-scale kelp fishery. *People and Nature*, *3*(3), 723–739. https://doi.org/10.1002/pan3.10211

Krause, A. E., Frank, K. A., Mason, D. M., Ulanowicz, R. E., & Taylor, W. W. (2003). Compartments revealed in food-web structure. *Nature*, *426*, 282–285.

Kroeker, K. J., Gambi, M. C., & Micheli, F. (2013). Community dynamics and ecosystem simplification in a high-CO2 ocean. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(31), 12721–12726. https://doi.org/10.1073/pnas.1216464110

Lorda, J., Beas, R., Bell, T., & Barbara, S. (2018). *Producción primaria bruta en bosques submarinos de la región Bahía Todos*. *December*.

Mackinson, S. (2001). Integrating local and scientific knowledge: An example in fisheries science. *Environmental Management*, *27*(4), 533–545. https://doi.org/10.1007/s002670010168

Marshall, N. A., & Marshall, P. A. (2007). Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-01940-120101

McCay, B. J., Micheli, F., Ponce-díaz, G., Murray, G., Shester, G., Ramirez-sanchez, S., & Weisman, W. (2014). Cooperatives , concessions , and co-management on the Paci fi c coast of Mexico. *Marine Policy*, *44*, 49–59. https://doi.org/10.1016/j.marpol.2013.08.001

McLaughlin, P., & Dietz, T. (2008). Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change*, *18*(1), 99–111. https://doi.org/10.1016/j.gloenvcha.2007.05.003

MEA. (2005). Ecosystems and human well-being: Wetland and water. In *Synthesis. Available online: http:// …*. http://millenniumassessment.org/documents/MA_wetlands&water-Chinese.pdf

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza Montes, J. A., Rossetto, M., & de Leo, G. A. (2012). Evidence that marine reserves enhance resilience to climatic impacts. *PLoS ONE*, *7*(7). https://doi.org/10.1371/journal.pone.0040832

Morales-Zárate, M. V., Lluch-Cota, S. E., Serviere-Zaragoza, E., & del Próo, S. G. (2011). Modeling an exploited rocky coastal ecosystem: Bahia Tortugas, Mexico. *Ecological Modelling*, *222*(5), 1185–1191. https://doi.org/10.1016/j.ecolmodel.2010.12.011

MSC. (2018). MSC Fisheries Standard v2.01. *Marine Stewardship Council*, *August*. https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-standard-v2-01.pdf?sfvrsn=8ecb3272_19#page=182&zoom=100,92,674

Munguia-Vega, A., Green, A. L., Suarez-Castillo, A. N., Espinosa-Romero, M. J., Aburto-Oropeza, O., Cisneros-Montemayor, A. M., Cruz-Piñón, G., Danemann, G., Giron-Nava, A., Gonzalez-Cuellar, O., Lasch, C., del Mar Mancha-Cisneros, M., Marinone, S. G., Moreno-Báez, M., Morzaria-Luna, H. N., Reyes-Bonilla, H., Torre, J., Turk-Boyer, P., Walther, M., & Weaver, A. H. (2018). Ecological guidelines for designing networks of marine reserves in the unique biophysical environment of the Gulf of California. *Reviews in Fish Biology and Fisheries*, *28*(4), 749–776. https://doi.org/10.1007/s11160-018-9529-y

Munguia-Vega, A., Zepeda-Dominguez, J. A., Perez-Alarcon, M. F., Amador-Castro, I. G., Fulton, S., Walther, M., Rodriguez-Fuentes, M., Fumero-Andreu, C. M., & Torre, J.

(2022). Social-ecological networks and connectivity within and between two communities of small-scale fishers in Mexico. *Ecology and Society*, *27*(1). https://doi.org/10.5751/es-13055-270124

Nenadović, M., Basurto, X., & Weaver, A. H. (2016). Contribution of Subsidies and Participatory Governance to Fishers' Adaptive Capacity. *Journal of Environment and Development*, *25*(4), 426–454. https://doi.org/10.1177/1070496516670448

Newman, M. E., & Girvan, M. (2004). Finding and evaluating community structure in networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *69*, 026113.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75–90. https://doi.org/10.1007/s00267-003-0101-7

Ostrom, E. (1990). *Governing the Commons: the Evolution of Institutions for Collective Action.* Cambridge University Press, New York.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*, 419–422.

Ostrom, V., Tiebout, M., & Warren, R. (1961). The Organization of Government in Metropolitan Areas : A Theoretical Inquiry. *The American Political Science Review*, *55*(4), 831–842.

Overland, J. E., Alheit, J., Bakun, A., Hurrell, J. W., Mackas, D. L., & Miller, A. J. (2010). Climate controls on marine ecosystems and fish populations. *Journal of Marine Systems*, *79*(3–4), 305–315. https://doi.org/10.1016/j.jmarsys.2008.12.009

Parkes, G., Young, J. A., Walmsley, S. F., Abel, R., Harman, J., Horvat, P., Lem, A., Macfarlane, A., Mens, M., & Nolan, C. (2010). Behind the signs-a global review of fish sustainability information schemes. *Reviews in Fisheries Science*, *18*(4), 344–356. https://doi.org/10.1080/10641262.2010.516374

Pauly, D., & Christensen, V. (1995). Primary production required to sustain global fisheries. *Nature*, *374*, 255.

Peña-Puch, A. del C., Pérez-Jiménez, J. C., & Espinoza-Tenorio, A. (2020). Advances in the study of Mexican fisheries with the social-ecological system (SES) perspective and its inclusion in fishery management policy. *Ocean and Coastal Management*, *185*(May 2019). https://doi.org/10.1016/j.ocecoaman.2019.105065

Perera, A. H., Drew, C. A., & Johnson, C. J. (Eds.). (2011). *Expert knowledge and its application in landscape ecology*. Springer Science & Business Media.

Ponte, S. (2012). The Marine Stewardship Council (MSC) and the Making of a Market for "Sustainable Fish." *Journal of Agrarian Change*, *12*(2–3), 300–315. https://doi.org/10.1111/j.1471-0366.2011.00345.x

Ramirez-Sanchez, S., & Pinkerton, E. (2009). The impact of resource scarcity on bonding and bridging social capital: The case of fishers' information-sharing networks in Loreto, BCS, Mexico. *Ecology and Society*, *14*(1). https://doi.org/10.5751/es-02841-140122

Reed, D. C., Rassweiler, A., Carr, M. H., Cavanaugh, K. C., Malone, D. P., & Siegel, D. A. (2011). Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. *Ecology*, *92*(11), 2108–2116. https://doi.org/10.1890/11-0377.1

Restrepo-Gómez, D. C., Zetina-Rejón, M. J., & Zepeda-Domínguez, J. A. (2022). Trends in marine fisheries social-ecological systems studies. *Ocean and Coastal Management*, *220*(February). https://doi.org/10.1016/j.ocecoaman.2022.106076

Revollo-Fernández, D., Aguilar-Ibarra, A., Micheli, F., & Sáenz-Arroyo, A. (2016). Exploring the role of gender in common-pool resource extraction: evidence from laboratory and field experiments in fisheries. *Applied Economics Letters*, *23*(13), 912–920. https://doi.org/10.1080/13504851.2015.1119786

Romagnoni, G., Mackinson, S., Hong, J., & Eikeset, A. M. (2015). The Ecospace model applied to the North Sea: Evaluating spatial predictions with fish biomass and fishing effort data. *Ecological Modelling*, *300*, 50–60. https://doi.org/10.1016/j.ecolmodel.2014.12.016

Rosa, R., Carvalho, A. R., & Angelini, R. (2014). Integrating fishermen knowledge and scientific analysis to assess changes in fish diversity and food web structure. *Ocean and Coastal Management*, *102*(PA), 258–268. https://doi.org/10.1016/j.ocecoaman.2014.10.004

Sáenz-Arroyo, A., Roberts, C. M., Torre, J., Cariño-Olvera, M., & Enríquez-Andrade, R. R. (2005). Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1575), 1957–1962. https://doi.org/10.1098/rspb.2005.3175

Saldaña, A., Salas, S., Arce-Ibarra, A. M., & Torres-Irineo, E. (2016). Fishing operations and adaptive strategies of small-scale fishers: insights for fisheries management in data-poor situations. *Fisheries Management and Ecology*, *24*(1), 19–32. https://doi.org/10.1111/fme.12199

Sánchez, S. R., J. McCay, B., R. Johnson, T., & Weisman, W. (2011). Surgimiento, formación y persistencia de organizaciones sociales para la pesca ribereña de la península de Baja California. *Región y Sociedad*, *23*(51). https://doi.org/10.22198/rys.2011.51.a35

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). https://doi.org/10.1088/1748-9326/ab2619

Schlenger, A. J., Beas-Luna, R., & Ambrose, R. F. (2021). Forecasting ocean acidification impacts on kelp forest ecosystems. *PLoS ONE*, *16*(4 April 2021), 1–24. https://doi.org/10.1371/journal.pone.0236218

Shabtay, A., Portman, M. E., Ofir, E., Carmel, Y., & Gal, G. (2018). Using ecological modelling in marine spatial planning to enhance ecosystem-based management. *Marine Policy*, *95*(January), 14–23. https://doi.org/10.1016/j.marpol.2018.06.018

Solano, N., Lopez-Ercilla, I., Fernandez-Rivera Melo, F. J., & Torre, J. (2021). Unveiling Women's Roles and Inclusion in Mexican Small-Scale Fisheries (SSF). *Frontiers in Marine Science*, *7*(January), 1–14. https://doi.org/10.3389/fmars.2020.617965

Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., Mackinson, S., Dankel, D. J., Brooks, K., & Benson, A. (2016). *Integrating fishers' knowledge research in science and management*. *73*, 1459–1465.

Stouffer, D. B., & Bascompte, J. (2011). Compartmentalization increases food-web persistence. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(9), 3648–3652. https://doi.org/10.1073/pnas.1014353108

Thompson, R. M., Brose, U., Dunne, J. A., Hall, R. O., Hladyz, S., Kitching, R. L., Martinez, N. D., Rantala, H., Romanuk, T. N., Stouffer, D. B., & Tylianakis, J. M. (2012). Food webs: Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution*, *27*(12), 689–697. https://doi.org/10.1016/j.tree.2012.08.005

Torre, J., Hernandez-Velasco, A., Rivera-Melo, F. F., Lopez, J., & Espinosa-Romero, M. J. (2019). Women's empowerment, collective actions, and sustainable fisheries: lessons from Mexico. *Maritime Studies*, *18*(3), 373–384. https://doi.org/10.1007/s40152-019-00153-2

Vilalta-Navas, A., Beas-Luna, R., Calderon-Aguilera, L. E., Ladah, L., Micheli, F., Christensen, V., & Torre, J. (2018). A mass-balanced food web model for a kelp forest ecosystem near its southern distributional limit in the northern hemisphere. *Food Webs*, *16*, e00091. https://doi.org/10.1016/j.fooweb.2018.e00091

Vilalta-Navas, A., Beas-Luna, R., Zetina-rejón, M. J., Lopez-Ibarra, G. A., Malpica-Cruz, L., Lorda, J., Zepeda-Dominguez, J. A., & Kluger, L. C. (2022). Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems. *ICESJournal OfMarine Science*, 1–12. https://doi.org/10.1093/icesjms/fsac225

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications.*

West, D. . (1996). Introduction to Graph Theory. *Upper Saddle River, N.J.: Prentice Hall.*

Wu, H. (2017). A Conference to #SaveOurOcean. *UN Chronicle, 54/2,.*

Yletyinen, J., Hentati-Sundberg, J., Blenckner, T., & Bodin, Ö. (2018). Fishing strategy diversification and fishers' ecological dependency. *Ecology and Society*, *23*(3). https://doi.org/10.5751/ES-10211-230328

Young, O. R., Webster, D. G., Cox, M. E., Raakjær, J., Blaxekjær, L. Ø., Einarsson, N., Virginia, R. A., Acheson, J., Bromley, D., Cardwell, E., Carothers, C., Eythórsson, E., Howarth, R. B., Jentoft, S., McCay, B. J., McCormack, F., Osherenko, G., Pinkerton, E., van Ginkel, R., … Wilson, R. S. (2018). Moving beyond panaceas in fisheries governance. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(37), 9065–9073. https://doi.org/10.1073/pnas.1716545115

Zador, S. G., Gaichas, S. K., Kasperski, S., Ward, C. L., Blake, R. E., Ban, N. C., Himes-Cornell, A., & Zachary Koehn, J. (2017). Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. *ICES Journal of Marine Science*, *74*(7), 2024–2033. https://doi.org/10.1093/icesjms/fsx054

Zepeda-Domínguez, J. A., Vergara-Rodarte, M., Gómez, A., Espinosa-Romero, M. J., Espinoza-Tenorio, A., & López-López, D. (2019). Beneficios de las ecoetique as en pesquerías en vías de desarrollo, capítulo México. *Gobernanza Pesquera:México y España*.

Zetina-Rejón, M. J., Cabrera-Neri, E., López-Ibarra, G. A., Arcos-Huitrón, N. E., & Christensen, V. (2015). Trophic modeling of the continental shelf ecosystem outside of Tabasco, Mexico: A network and modularity analysis. *Ecological Modelling*, *313*, 314–324. https://doi.org/10.1016/j.ecolmodel.2015.07.001

Zetina-Rejón, M. J., López-Ibarra, G. A., Rocha-Tejeda, L., Flores-Guzmán, A., López-Ercilla, I., Rodríguez-Rodríguez, E., Sandoval-Jiménez, S. A., Arreguín-Sánchez, F., & Cisneros-Montemayor, A. M. (2022). A Framework for Simulating Ecosystem Effects in Data-Poor Small-Scale Fisheries Using Science-Based and Local Ecological Knowledge-Based Models. *Frontiers in Marine Science*, *8*(January), 1–14. https://doi.org/10.3389/fmars.2021.799068

Zetina-Rejón, M. J., Zepeda-Domínguez, J. A., Rodríguez-Fuentes, M., & Fumero-Andreu, C. M. (2020). Stakeholder diversity correlates with governance network performance in two artisanal fisheries in Northwest Mexico. *Ocean and Coastal Management*, *196*(March). https://doi.org/10.1016/j.ocecoaman.2020.105313

Using a social-ecological network approach to simulate social and environmental impacts in small-scale fisheries

Ainoa Vilalta-Navas[1], Rodrigo Beas-Luna[1*], Manuel J. Zetina-Rejón[2*], Lotta Clara Kluger[3,4], Luis Malpica-Cruz[5] Julio Lorda [6,7]

7. Universidad Autónoma de Baja California, Facultad de Ciencias Marinas, , Carretera Tijuana-Ensenada Km 103, Pedregal Playitas, 22860, Ensenada, Baja California, México
8. Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, Av. Instituto Politécnico Nacional S/N Col. Playa Palo de Sta. Rita, La Paz, BCS, 23096, México
9. Center for Ocean and Society, Kiel University, Neufeldtstraße 10, 24118 Kiel, Germany
10. Department of Agricultural Economics, Kiel University, Olshausenstraße 40, 24118 Kiel, Germany
11. Universidad Autónoma de Baja California,Instituto de Investigaciones Oceanológica,, Carretera Tijuana-Ensenada Km 103, Pedregal Playitas, 22860, Ensenada, Baja California, México
12. Universidad Autónoma de Baja California, Facultad de Ciencias, Carretera Tijuana-Ensenada Km 103, Pedregal Playitas, 22860, Ensenada, Baja California, México
13. Tijuana River National Estuarine Research Reserve, 311 Caspain Way, 301 Caspian Way, Imperial Beach, California, 91932, United States of America

*Considered joint corresponding authors: mzetina@ipn.mx (tel: +52 612 348 5060), and rbeas@uabc.edu.mx (tel: +52 646 239 3581)

Abstract

Small-scale fisheries (SSF) are especially important since they supply almost half of the world's seafood. Comprehending social-ecological interactions in these fisheries is key to understand how they face stochastic or directed impacts. We use a fishing village in Baja California as a case study of complex SSF social-ecological systems (SES). The aim was to 1) build a social-ecological network of the SSF-SES, and 2) simulate the effects of social-environmental impacts. We exposed the social-ecological network to two node removal simulation scenarios: One, simulating direct impacts by removing nodes based on their (high) Betweenness centrality index, and second, random failures. Our results showed, a centralized social network with well-defined subgroups. Secondly a less centralized ecological network with homogeneous connections, and thirdly a social-ecological network with well-defined subgroups highly connected. We discovered different patterns when removing nodes in a random or direct way, indicating that networks are more sensitive to direct changes. Finally, we conclude that affecting social nodes has a higher impact on the SES than removing ecological ones. We highlight the importance of local stakeholders in the whole SES and the importance of maintaining good communication between them and external agents to achieve better management strategies.

Keywords: LEK, network analysis, environmental change, Baja California, fishing impacts

1. Introduction

Current predictions indicate that climate change is expected to alter the function and progress of marine ecosystems (IPCC, 2021). Given the global trend of environmental alterations, it is necessary to assess the responses of marine ecosystems to these impacts. Particularly concerning is to understand impacts to ecosystem provisioning such as fishing. Small-scale fisheries (SSF), prevalent in the global south, supplies almost half of global seafood (FAO, 2022). These fisheries are the most vulnerable to climate change impacts given the close interdependency between the fishers (i.e. the social system) and the targeted species (i.e. the ecological system) (Berkes, 2003; Finkbeiner, 2015). Understanding social-ecological dynamics of fishing communities amidst climate change pressure and evaluations of existing and new management strategies required for adaptation and mitigation are crucial.

Local ecological knowledge (LEK) is becoming a useful tool to understand ecosystems where scientific data is scarce or not available. The knowledge about (marine) species, ecosystem structure and/or environmental dynamics is passed down between generations of local communities and is subject to individuals' experiences (Hamilton et al., 2012). Due to its empirical and not rigorous origin, LEK has been undervalued for many years. However, its importance and relevance has now been demonstrated, and its use in the scientific field has increased (Hind, 2014). Given that fishers are in daily contact with the marine environment, they can identify seasonal or annual variations, changes in currents or tides, even organisms' habitats, behavior or food preferences alterations (Johannes et al., 2000). Therefore, fishers have been recognized as the main source of local knowledge for informing marine research (Sáenz-Arroyo et al., 2005). Indeed, local knowledge is nowadays used around the world to understand SSF-SES dynamics and create fishing management strategies (Berkström et al., 2019; Saldaña et al., 2016). Given the uncertainty of climate change impacts, and the need to explore impact trajectories, incorporating LEK is critical to improve forecasts of data-limited SSF-SES. It is expected that this approach will allow us to improve our understanding on the potential impacts of climate change, not only on marine ecosystems, but also on the associated social systems.

A social-ecological systems research approach aims to improve our understanding of the interactions, inputs and outcomes between social and ecological components and to improve resource management policies and strategies to achieve sustainability (Berkes, 2003; E. Ostrom, 2009). One way to study the dynamics within a SES is through network analysis (Bodin & Tengö, 2012; Janssen et al., 2006). This is a widely used tool to understand the structure and functioning of ecosystems and social-ecological systems through capturing system entities (e.g. biological species, ecosystem parts, human actors) as nodes and their interactions (e.g. trophic or non-trophic, trust, money) as links (Janssen et al., 2006; Kluger et al., 2020; Restrepo-Gómez et al., 2022). In the past, social and ecological dimensions have been studied separately; only recently, the interaction between them (social-ecological) has gained attention in research (Restrepo-Gómez et al., 2022). Between 2006 and 2018, only 10% of the published papers including network analysis were focused on social-ecological models with social-ecological interactions (Kluger et al., 2020). However, as it has been demonstrated, environmental changes can affect human communities as much as stakeholders' decisions can have repercussions – both positive or negative – on the marine ecosystem (Zador et al., 2017). Hence the need to integrate network analysis with the SES framework, especially in cases where the social and natural components are intrinsically associated, such as with SSF-SES.

In the Northeastern Mexican Pacific, most SSF communities use valuable kelp forest associated species, such as lobsters, sea urchins, and abalones, as their main extracting resources. These kelp forest ecosystems are extremely vulnerable to climate change and their populations have suffered dramatic distribution decreases, massive mortalities and diversity losses globally, among other impacts (Eger et al., 2022; Krumhansl et al., 2016). Therefore, understanding the effect of multiple stressors on kelp forest and their resilience is key for management. Up to our knowledge, this is the first scientific effort focused on the assessment of understanding a kelp forest's-associated social-ecological system. Additionally, this study aims to evaluate the response of a kelp forest SES (the fishing village of El Rosario) in the Mexican Pacific to social-environmental disturbances. We achieved this through: a) understanding the structure and function of the social-ecological system and, b) applying disturbance simulations through removal nodes scenarios contrasting random effects and malfunction of relevant nodes.

2. Methodology

2.1. Case study

The small fishing village of El Rosario is located in the Pacific coast within the San Quintin municipality, south of Ensenada (main fishing commerce city in the state) in the state of Baja California, Mexico. Since 1940, the local fishing cooperative, "Sociedad Cooperativa de Producción Pesquera Ensenada, SCL" *Ensenada Coop* hereafter) has held territorial user fishing rights (covering 194 km along the coastline) to extract different species. Their main source of income are high-value benthic species associated with kelp forests such as lobsters (*Panulirus interruptus*) abalone (*Haliotis spp.)*, and red sea urchins (*Mesocentrotus franciscanus*) among others, which are sold at national and international markets. Its geographic location, at the end of the Southern California Bight, is near to the southern distribution limit of giant kelp, *Macrocystis pyrifera*, forests. This has caused the fishing community to face economic hardship as a consequence of dramatic temperature anomalies during events such as El Niño or the Blob (2013-2016), hypoxia events and mass mortalities of giant kelp and many other benthic species (Beas-Luna et al., 2020; S. L. Hamilton et al., 2021; Low et al., 2021).

2.2. Conceptualizing the small-scale fisheries setting as a network

According to Bodin & Tengö (2012), the first step to build a fishery as a social-ecological network (SEN), is to conceptualize and define its parts. A social-ecological network necessarily comprises two types of nodes (social and ecological) but may have three types of interactions: social-to-social (SS), ecological-to-ecological (EE) and social-to-ecological (SE) (*sensu* Bodin and Tengö, 2012). In our social-ecological network we combined two models: a) a social model (representing the fishing community social interactions) and, b) an ecotrophic model (representing the ecological trophic interactions). Each model incorporated social-to-social and ecological-to-ecological links respectively. The merging between the two models (social-to-ecological links) was made through the fishing resources, that is, between the target species (e.g., fish, lobster or abalone) and the social nodes that directly extract these resources, the fishers. The social model was built in this study, while the ecological model we used was built previously (and is reported by Zetina-Rejón et al., 2022). Both models are detailed below.

2.3. The social sub-system

In February 2021, 30 structured open-ended interviews were conducted to people directly related to the Ensenada Coop. The surveyed population included 7 women and 23 men from different job positions inside the cooperative such as fishers, surveillance, processing plant personnel, administrative and managers.

The main objective of interviews was to identify actors (i.e., from all main roles, cf. Table 1) to be included as social nodes into our network. For that, the interviewees were asked with whom they communicate most frequently inside and outside the cooperative for their particular activity related to fishing (capture, processing, marketing, management, etc.). Participation in the study was voluntary and interviewees were given the option to reserve their answers to specific questions, refuse to participate, or stop participating at any time without any associated sanctions or consequences. According to ethical procedures, participants were informed that the interviews were anonymous, that information obtained will be used exclusively for academic purposes, and that they can drop the interview at any moment and no reason would be asked.

Social nodes were grouped into different stakeholders' categories depending on their main activity (Table 1). All analyses of this work were carried out using the free R software environment (R Core Team, 2022), with the R Studio IDE (Version 1.4.1106). To identify social network compartments, we used the fast greedy community finding algorithm (Clauset et al., 2004) included in igraph package (version 1.2.11) (Csárdi & Nepusz, 2006). This algorithm finds dense communities within a network via a modularity-based maximization function that measures network divisions in modules based on the notion that there should be more intense connections within modules than between them (Guimerà et al., 2007; Newman & Girvan, 2004). Thus, modularity is used as a qualificator to identify the level of compartment division in a network.

Table 4. Stakeholder categories for grouping social nodes in the small-scale fishing social-ecological system of El Rosario, Mexican Pacific.

Category	Description
Academia	University and research organizations
Certifier	Organizations that provide some type of accreditation to the cooperative or its products
Client	Product buyers
Federal Regulation	Federal agencies that supervise the administration, regulation, and enforcement of fisheries.
Fishers	Those directly in charge of carrying out the action of fishing
Leaders	Those with a higher position within the cooperative
Local Regulation	State agencies assisting the cooperative activities.
NGO	Nongovernmental organizations who support the community.
Other employees	Employees of the cooperative who work in other sectors than those already explained
Outsiders	People who are not employees of the cooperative but live or are from the community.
Processing	Employees working in the processing section of any product
Social development	Community development agencies
Surveillance	Employees in charge of surveillance of the fishing area
Transport	People in charge of transporting the product

1.1. The ecological sub-system: The food web

From November to December 2020, 23 phone interviews were carried out with local fishers from the Ensenada Coop, with an average of 14 years of fishing experience. These interviews consisted of a systematic questionnaire focused on the trophic relationships with two main objectives to: 1) identifying the main biological components (species representing ecological nodes) and 2) identifying their trophic relations (i.e., ecological-to-ecological links). To standardize the data, common names of all species were translated into scientific names and grouped taxonomically. The coherence of described trophic relationships was verified with conventional scientific knowledge obtained from Fishbase (https://www.fishbase.se/) and World of Marine Species (http://www.marinespecies.org/). Additional details on the construction of the LEK-based model can be found in Zetina-Rejón et al., (2022).

1.2. Simulations and resilience analysis

Node removal simulations were done following the same procedure described by Albert et al. (2000). This consists of removing one node at a time and measuring the changes in the network structure through a series of indicators. A total of three types of simulations were used to remove the nodes: (1) removing the nodes at random order (as to simulate failures in the network), (2) removing nodes in a decreasing order of node relevance (as to simulate a direct attack to the network) and (3) removing specific groups nodes to simulate social-environmental disturbances. For the first two simulations, we used the Betweenness index value of each node (in the entire SEN) as a criterion to determine the node relevance for removing order in the direct attack simulations (Appendix A, following Zetina et al. 2022). This index measures how often a node *i* is located on the pathways between every pair of nodes *j* and *k* (Brandes, 2001; Freeman, 1979). To measure how the network properties changed in the simulations, we used eight topological indicators (Table 2), which have shown to be useful for measuring network resilience (Argüelles-Jiménez et al., 2020; Zetina-Rejón et al., 2022). In this study, we defined the term resilience as the ability of the network to preserve its structure and function in times of crises, i.e. during vulnerable situations / scenarios. (Béné et al., 2016).

Table 5. Network indicators used to measure network's resilience, a brief description and their respective source.

Index	Description	Source
Network level		
Density	The ratio of the number of connections	Wasserman & Faust, 1994
Average path length (APL)	Average distance in number of interactions between any pair of nodes.	West, 1996
Clustering	Probability that adjacent nodes are connected.	Wasserman & Faust, 1994
Diameter	Longest distance between two nodes.	Freeman, 1979
Centralization	A higher value means a more centralized network.	Freeman, 1979
Connectivity	The number of links between all the nodes in the network.	Wasserman & Faust, 1994
Homophyly	Nodes tendency to connect between their peers (nodes with the same labels or assigned values).	Newman M.E, 2002
Diversity	Average Shannon diversity based on the number of nodes and weights of their links	Eagle et al 2010

The random and attack (i.e., directed) scenarios were applied to the entire social-ecological network and separately to the social and ecological sub-systems. We performed simulations in this way as to explore each dimension (social and ecological) in the sense that deepening our knowledge on node behavior within each sub-dimension separately would allow us to cross-check their response to a disturbance on the global (i.e., entire network level) of the social-ecological network. This simulation strategy gives us a more realistic view of each dimension response. For the attack scenarios, the removal of nodes was always based on nodes' order of betweenness index calculated for the entire SEN.

Finally, extreme events were simulated by removing specific groups from the social-ecological network. The ecological groups removed were: primary producers (to simulate an unfavorable environmental event, e.g., Reed et al., 2011) and fished species (to simulate overfishing e.g., Jackson et al., 2001). The social groups removed were: fishers, leaders and academia; to simulate the effect that the disappearance (or a malfunction) of these specific groups would have on the social-ecologic system (e.g., McCay et al., 2014). The removal of each group was done individually, generating a new scenario every time.

1. Results

The El Rosario SEN (Figure 6) comprised 58 social nodes, 277 social links, 52 ecological nodes, 267 ecological links and 312 social-ecological links. It was structured by a total of 19 subgroups, 10 from the social dimension and 9 from the ecological one.

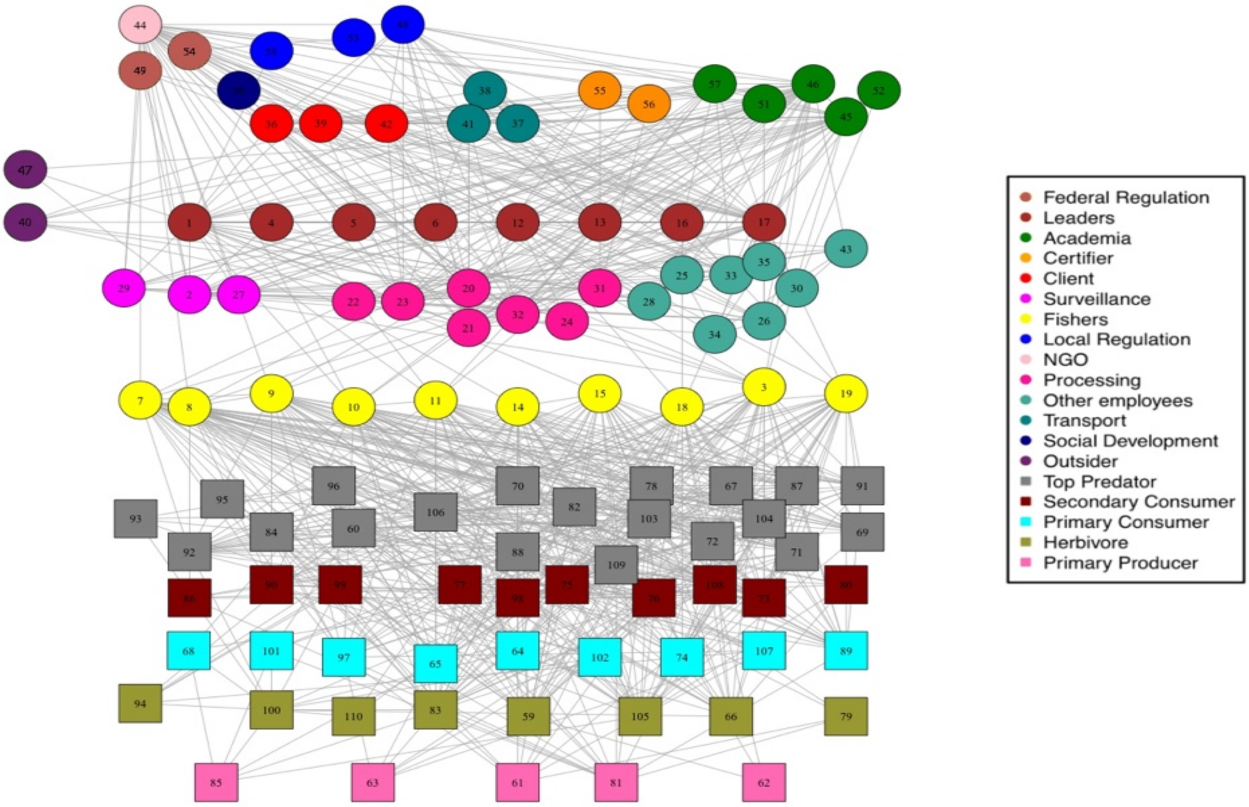


Figure 6. Social-ecologic network model for the case of study of the small-scale fisheries social-ecological system (SSF-SES) of El Rosario, Mexico. The social nodes (circles) were plotted according to their main activity (cf. Table 4) and the ecological nodes (squares) according to their trophic level estimated by Vilalta-Navas et al., (2022). Color code reflects SES-subgroups. The number correspond to the nodes described in the Appendix A.

1.1. The social sub-system

The 58 nodes of the social network were grouped into 14 actor groups (Academia, Certifier, Client, Federal Regulation, Fishers, Local Regulation, NGO, Other employees, Outsider, Processing, Social Development, Surveillance, Leaders, Transport *cf.* Table 1). According to the community finding algorithm the nodes are classified in three subgroups (Figure 7) with a modularity index of 0.27. Different types of actors fell into these subgroups Figure 7) , with one subgroup comprising comparatively much fewer (i.e. five) nodes than the other two (being formed by 25 nodes or more). Also, homogeneous connections were observed within the three subgroups with a greater connection between the large subgroups.

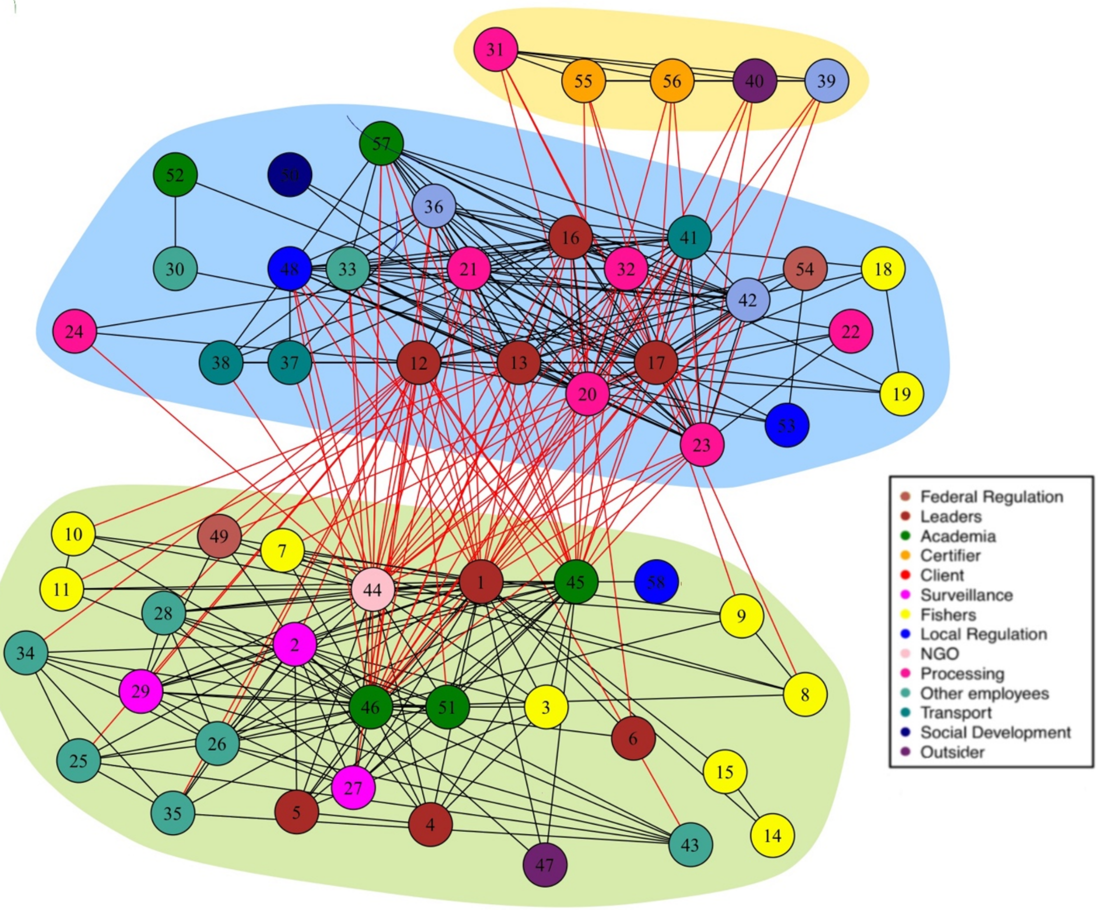
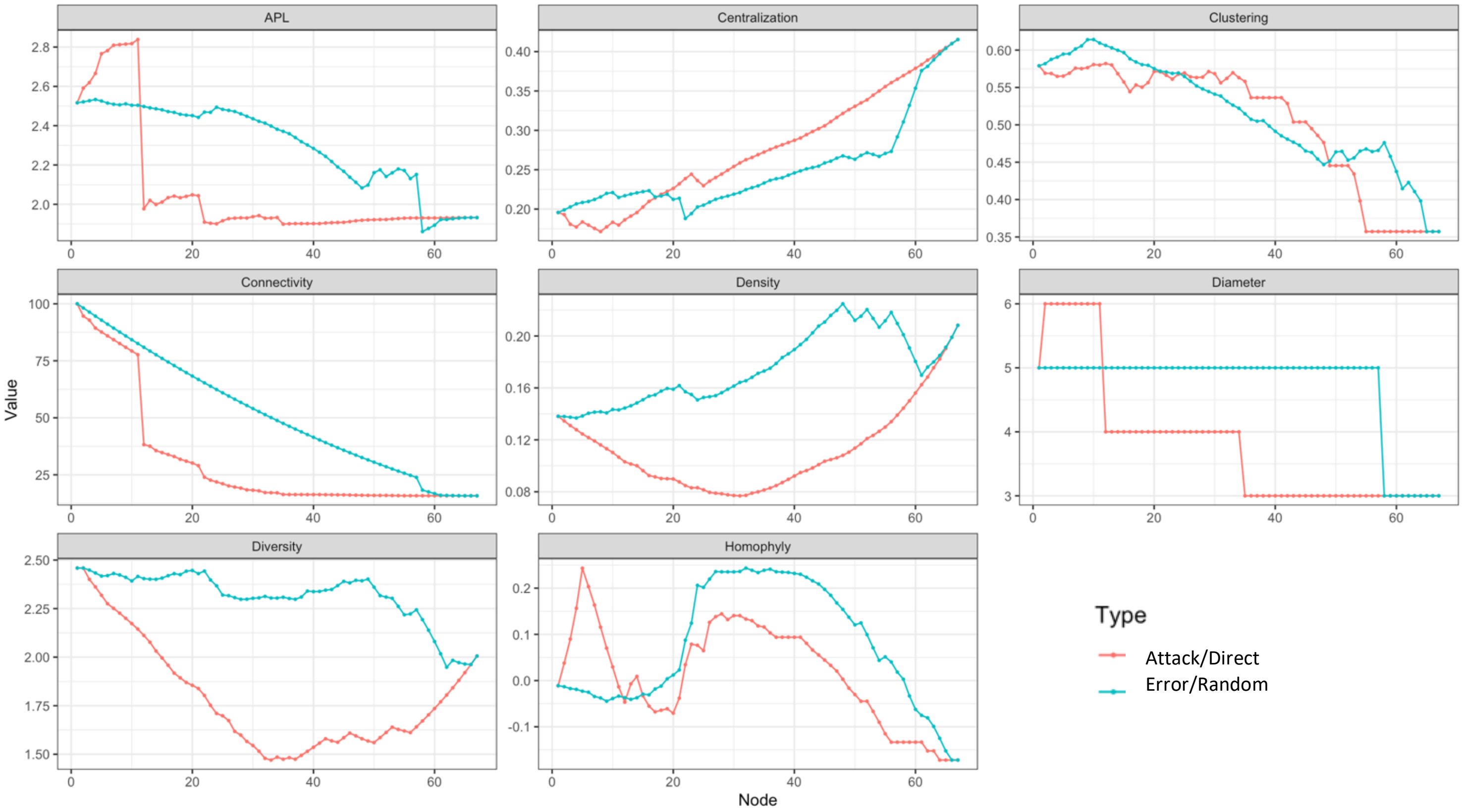


Figure 7. Subgroups containing nodes within the social subnetwork from El Rosario SEN obtained using the fast greedy community finding algorithm in R (cf. section 2.3 for details on the method). Black lines indicate interaction between nodes within the same subgroup, and red lines indicate interaction between nodes in different subgroups. The nodes numbers correspond to the same nodes names as in Figure 6.

1.1. Error and attack (directed) scenarios

1.1.1. Error and attack scenarios in the social sub-system

The node removal scenarios for the social network, showed contrasting general patterns for both error and attack scenarios in the eight network indices used (Figure 8).



Connectivity and Centralization showed opposite patterns for both scenarios. While Connectivity decreased homogeneously in the random scenario and more abruptly in the directed scenario, Centralization increased in both scenarios, being more noticeable in the directed one. Density, in turn, showed a negative parabola in the directed scenario, while in the random scenario increased homogeneously until it decreased at the end with drastic peaks. The APL and the Diameter, under the directed scenario, showed a positive peak at the beginning which decreased drastically, remaining at low values. However, the random scenario showed a monotonic decrease for the APL and a constant value in the Diameter. The Homophyly pattern generated a parabola silhouette for both scenarios, with the difference of an abrupt peak at the beginning for the directed scenario and slightly higher values in the random scenario. The Clustering showed a global decreasing tendency for both scenarios, being more homogeneous in the random scenario. Diversity, on the other hand, generates a negative parabola under the directed scenario, while the random scenario follows a slowly decreasing monotonic trend.

1.1.2. Error and attack scenarios in the ecological sub-system

All the node removal scenarios for the ecologic network showed contrasting general patterns for both error and attack scenarios in the eight indices used (Figure 9).

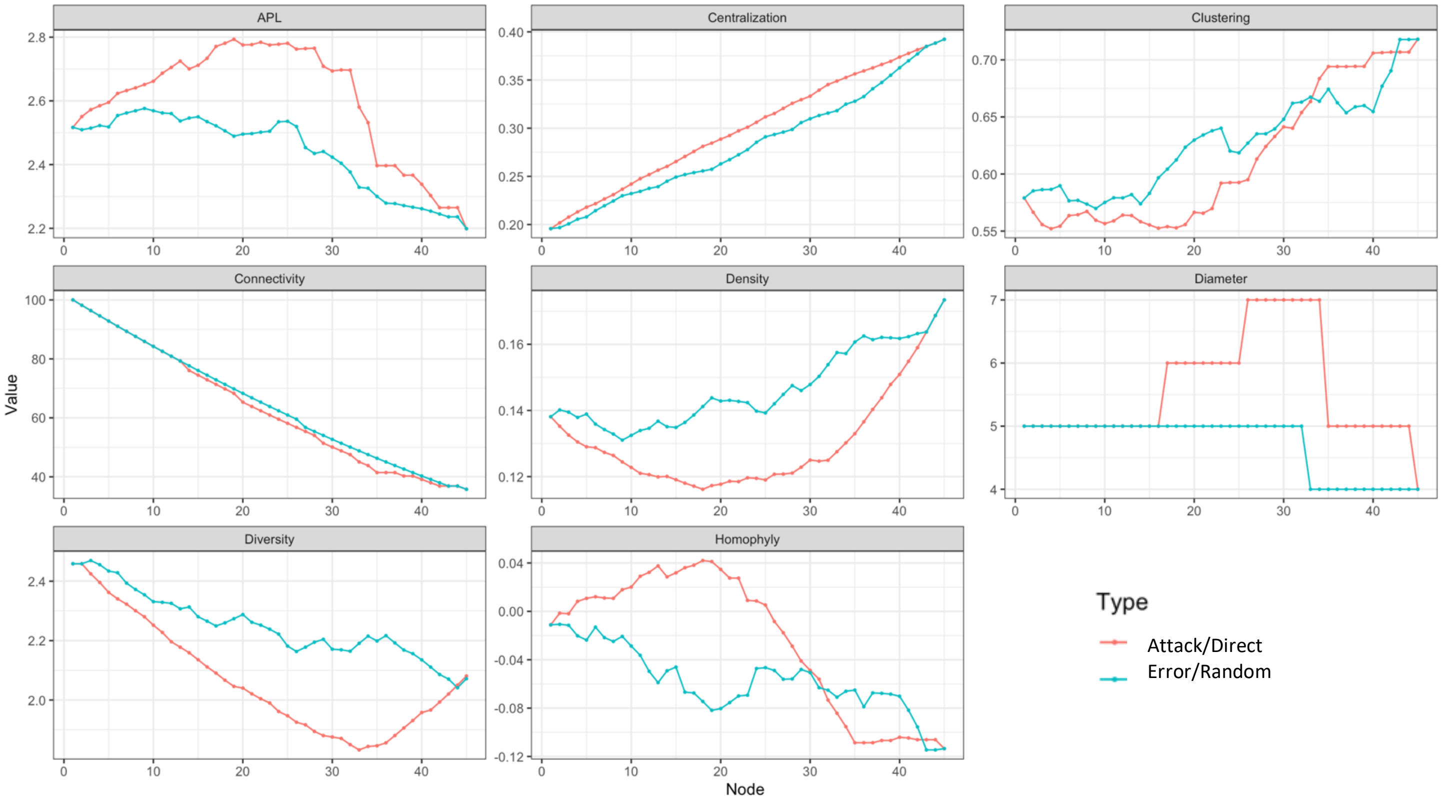


Figure 9.Response of the eight network indicators for the Rosario Ecological network to nodes removal based on two scenarios: error/random failures (blue lines) and attack/direct impacts (red lines). The removal order in the red lines, are based on the Betweenness index of the global network (Social-Ecologic network).

Connectivity and Centralization showed opposite tendencies, decreasing and increasing homogeneously respectively. On the other hand, Homophyly and Clustering also show opposite general tendencies. While Homophily decreases, Clustering increases. The Homophyly showed a parabolic movement for the directed scenario, while in the random scenario it decreases with spikes. In the Clustering, both scenarios increased gradually. Both the APL and the Diameter show higher values in the directed simulation than in the random one. The ALP in direct scenario described a parabolic movement while the random scenario decreased monotonically. The Diameter increased in the directed scenario but remained constant in the random one. In the direct simulations for both cases, the highest values coincide when removing around node 25 and then decrease. Diversity showed a decreasing homogeneous tendency in the random simulation, while the directed one followed an inverse parabolic movement. On the other hand, the Density showed a homogeneous tendency to increase in the random simulation, while the direction also followed an inverse parabolic movement. Both parabolas presented values below the values of the random simulation.

1.1.3. *Error and attack scenarios in the social-ecological system*

The social-ecological network showed contrasting general pattern for both error and attack scenarios in the eight indices used (Figure 10).

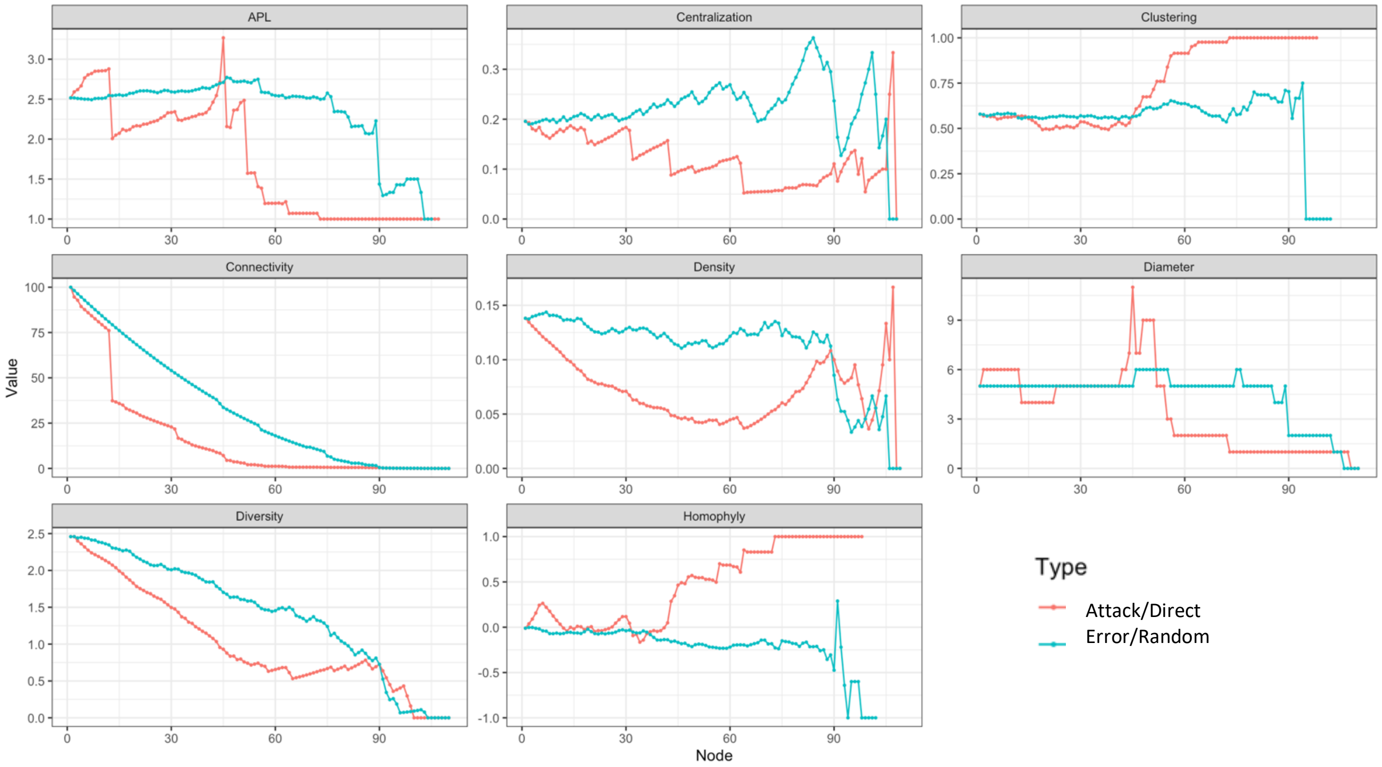


Figure 10.Response of the eight network indicators for the Rosario social-ecological network to nodes removal based on two scenarios: error/random failures (blue lines) and attack/direct impacts (red lines). The removal order in the red lines, are based on the Betweenness index value.

Connectivity and Diversity, followed a homogeneous decreasing pattern for both scenarios, showing lower values in the directed simulations. Connectivity's direct simulation showed a drastic decrease at the beginning and then continued to decline homogeneously. The rest of the connections showed to be homogeneous due to the monotonic decrease in both Connectivity and Diversity. Density, Diameter and APL decreased under both scenarios as a general trend, but with different patterns between directed and random scenarios. In all cases, random simulations showed a slower decrease pattern than the directed ones. For all three parameters, random value impacts remained constant or decreased monotonically except when too many nodes (>90) had been removed. On the contrary, each directed impact had its own pattern: a) In the APL and Diameter an increase is observed during the removal of the first nodes followed by a very abrupt fall. Subsequently, a second increase in the Diameter and APL is observed; b) on the Density side, it showed a homogeneous decrease until approximately the removal of half of the network nodes, followed by a homogeneous increase. The network Centralization for the random scenario showed a gradual increase that becomes more evident as more nodes were removed. On the other hand, the directed scenario, decreased in a stepwise pattern. The Clustering and Homophyly random scenario, presented a stable and monotonous decreasing tendency while the directed scenario, an increasing one (Figure 5).

2.1. Simulating social-environmental disturbances: Node group removal

The removal of each group of nodes (following the scenarios for social-environmental disturbances as described in section 2.5) within the social-ecological network showed a different response (Figure 11).

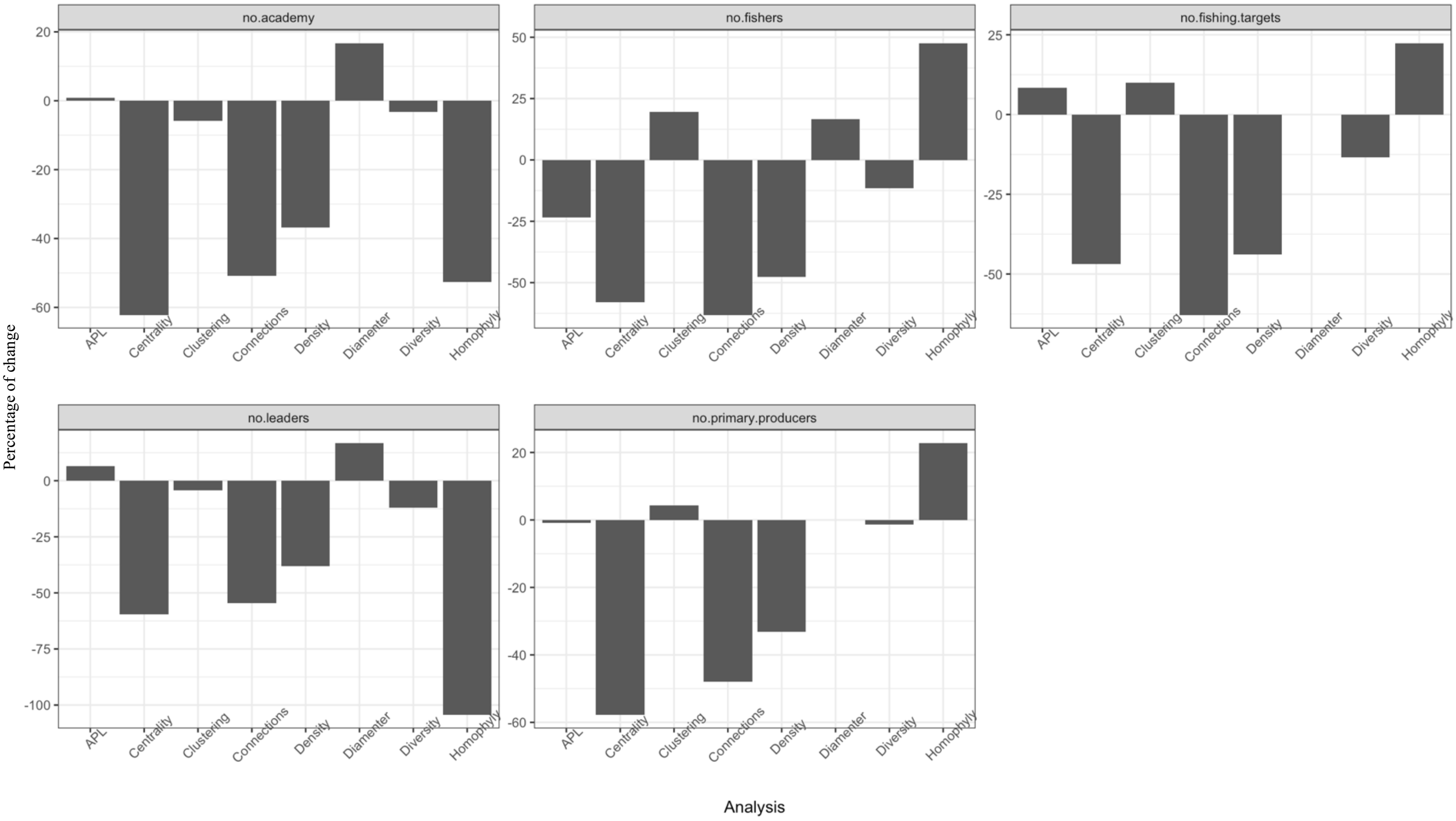


Figure 11. Percentage of change respect the original values of the indices analyzed in the social-ecological network, when removing particular nodes groups. APL = Average Path Length.

Connections, Centrality, Density and Diversity decreased in all removal scenarios, indicating that the removal of these nodes negatively affects the relationships between the remaining nodes of the network. On the other hand, APL, Clustering and Homophyly increased or decreased depending on the group removed. When the three values increased (no fishing targets), the removed nodes shortened the distance between remaining nodes grouping them among their similar ones. When APL increased, and Clustering and Homophyly decreased (no leaders, no academy), the remaining nodes were close to each other but tend to group with different nodes. When APL decreased, and Clustering and Homophyly increased (no fishers, no primary producers), the remaining nodes were separated from each other but remained grouped with their similar ones. Finally, the Diameter either increases by removing certain nodes (no academy, no fishers, no leaders) or shows no variation (no fishing targets, no primary producers) (Kluger et al., 2020; Zetina-Rejón et al., 2022).

Discussion

This work is a step forward advancing the social-ecological network theory. There are some previous references to this theory that have been made in the literature framing the basis for our work (e.g. Kluger et al., 2020; Zetina-Rejón et al., 2022). Since perturbations in the system may spread from ecological systems to humans and *vice versa*, it is well known that incorporating the human components into ecosystem-based management is challenging (Zador et al., 2017). Therefore, as this work and others have shown, the outcomes produced in simple (social or ecological networks) or combined (as a SEN) models will differ.

In addition, fishery management has broadened its focus to incorporate not only ecological and biological information but also focusing on strategies targeting fishery practices and community needs. However, at the same time, this diversification has made communities more vulnerable to poor management (Yletyinen et al., 2018). This vulnerability can be given because of the differentiation between subgroups of the same community (e.g., leaders, processing, certifier), where the lack of communication can generate incompatibilities when solving problems (Bodin, 2017). Is in that point where the novelty of this work stands out. Our research advances by examining how the social and ecological sub-systems individually as well as the whole social-ecological ecosystem respond to environmental and social disruptions pointing to the strengths and weaknesses of the SEN fishing community.

Social-ecological system glimpse

The social-ecological network representation from this work corresponds to a type III network according to the classification of Kluger et al., (2020), and to a fully articulated SEN acording to Sayles et al., (2019) . These types of networks present a high level of integration since they include social and ecological nodes as well as three types of interactions: social-social, ecological-ecological and social-ecological. Most network models include a single type of connection (social-social or ecological-ecological). Creating models that integrate these two types of interactions are relatively recent (Kluger et al., 2020; Restrepo-Gómez et al., 2022). Therefore, due to the inherent novelty of this SEN approach, we think is necessary to critically deepen our knowledge by exploring networks to understand their scopes and limitations. Social-ecological networks allows us to better delve into nature-human connections and understand how ecological indicators can influence human communities as well as elucidate how community decisions may influence the ecological system. A better understanding of social-ecological systems will allow us to generate appropriate and efficient long-term management strategies (Kluger et al., 2019; Zador et al., 2017). Fully articulated SEN allow us to understand environmental problems studying within and between social and ecological nodes. For example, Sayles et al., (2019) some of their disadvantages, such as the assumptions needed to transform the real world into a network, while highlighting some of its possible future uses since they can provide contextual richness to help address specific research questions. Also, social-ecological networks, like all networks, are dynamic and are constantly changing as nodes respond to external and internal forces (Bodin, 2017). Thus, identifying the processes that cause some nodes to interact with certain others and figuring out what makes them more or less desirable to interact with is necessary to improve our understanding of social-ecological networks dynamism.

Social sub-system glimpse

According to Stouffer and Bascompte (2011) our modularity result for the social sub-system network is within the range of compartmentalization they observed in 15 empirical food webs. The majority of studies that have analyzed modularity have done so using food chains classified into trophic levels (e.g., Krause et al., 2003; Zetina-Rejón et al., 2015). In this work, we use this analysis in a social network, that lacks trophic levels, but presents actors' groups based on their job or role within the network, which could be interpreted as a simile of trophic levels.

The presence of compartments favors the resilience of networks against disturbances since it buffers the effects on the network. Thus, identifying compartments in a network can be used for a better management of the environment (Stouffer & Bascompte, 2011). However, the presence of small compartments, or those formed by few nodes, can compromise the resilience of the ecosystem since any modification could make them quickly decrease or disappear (Guimerà et al., 2010). In our case, the smallest compartment is made up of five nodes belonging to Certifiers, Processing personnel, Outsiders and Clients. However, we observe how the connections of this subgroup with the two others are lower than the connections within the two other subgroups. In addition, four of the 5 nodes belong to external agents of the fishing cooperative (Certifiers, Outsiders and Clients). So, it could be inferred, if this subgroup were affected (or disappeared) that the effects on the community could be minimal since there are still similar external nodes, or redundancy, within the other subgroups.

Evaluating social-ecological disturbance events via error and attack scenarios

The type of simulations carried out in this work can yield different results depending on the type of model or the ecosystem's present information (Zetina-Rejón et al., 2022). In our case, both ecological and social networks were based on local ecological knowledge. The use of LEK is a great source of information especially in developing countries, where it is capable of providing different types of information such as abundances, breeding seasons, migrations or diets of different species in the same ecosystem (Johannes et al., 2000). Also, it has been demonstrated LEK's comparability with scientific data (Bentley et al., 2019; Rosa et al., 2014) and its usefulness to fill knowledge gaps (Berkström et al., 2019; Bevilacqua et al., 2016). For all this, LEK is very useful when developing management strategies adaptable to the needs of data-poor areas (Johnson et al., 2017).

In our results, the Social and Ecological networks present the same general pattern of change in all random and directed scenarios (increasing or decreasing). However, in the social-ecological network two parameters (Clustering and Homophyly) showed opposite patterns in the directed and random scenarios, meaning that the nodes move away homogeneously when the removal is random, but stick together when the removal is directed. This indicates that some of the first removed nodes, in the directed scenario, act as central nodes that, as network hubs – and once removed, the remaining ones tend to form subgroups. This goes in line with what Albert et al. 2000 suggested: targeted attacks would have a greater influence on the network than random node removal (Albert et al., 2000). However, this is also a significant outcome because it demonstrates how drastically different the effects of directed and random events may be in the same system. Since conventional science and network analyses has usually treated human actions as external to ecological system, the connections between ecosystem and social dynamics have been underestimated (Folke, 2006). Recently, the social-ecological vision of systems has gained attention, but it is still in exploratory stages (Delgado-Serrano et al., 2015; Peña-Puch et al., 2020). For instance, Munguia-Vega et al., (2022) built a qualitative SEN to analyze the likelihood of discovering ecological and social relationships using network density as a standard across various networks. On the other hand, Restrepo-Gómez et al., (2022) came to the conclusion that to use SEN effectively, it is required to implement transdisciplinary approaches (ecological, social, and political factors) as well as encourage stakeholder engagement. Therefore, this study is a step forward in understanding the dynamics of each component of a socio-ecological system as well as the system as a whole.

In general, the Social System shows to be a centralized network since the connections were concentrated to specific groups creating well defined subgroups. However, at first, the nodes approach each other but they move away drastically staying that way (e.g., APL and Diameter results). This outcome demonstrates how highly structured the cooperative is in areas such as production, administration or processing. Also, this behavior can trigger the isolation of certain nodes that do not regroup with their peers. These results show a polycentric social network, since it presents several central actors of different types. The term "polycentric" refers to many, formally independent centers of decision-making (V. Ostrom et al., 1961). Depending on the case study, they can function independently or as part of an interdependent system of relationships. This fishing community's structure, which is based on decision centers, also provides a sense of community and empowerment because they interact with actors of various types, promoting mutual learning. Using a qualitative network methodology, Zetina-Rejón et al., (2020) found that the performance of governance networks is favorably impacted by a large diversity of stakeholders. However, redundancy among stakeholders, might weaken the governance system's resilience. As our results shows, cutting too much the interactions between these social subgroups could reduce the collaboration between less connected actors and decrease the possibility of reaching agreement or promoting sustainable practices.

On the other hand, it can be seen how the Ecological Network within the SES is a less centralized network since the subgroups always would maintain connections with other nodes. A good connectivity within a network of aquatic resources can significantly improve the resilience of ecosystem functions and services. For example, when stipulating MPAs, or when conducting seascape management studies (Berkström et al., 2019). It is also believed that the presence of a large number of connections in ecological networks can help to mitigate the effects of trophic cascades (Krause et al., 2003). Thus, knowing the connections structure and status in an ecological network can be used as a management tool to promote ecosystem resilience (Hamilton et al., 2022).

Evaluating social-ecological disturbance events via node (group) removal

When removing certain groups of nodes, we found the centrality decreases in all scenarios, suggesting that the removed groups distance the others nodes groups apart. Furthermore, since the removal of node groups includes both social and ecological nodes, we can also say that the central actors within the social-ecological network correspond to different types of actors and therefore are well distributed.

Fishers and Primary Producers act as control nodes within the whole system. On the one side, Fisher's act as a bridge between the ecological and the social networks, while Primary Producers function as control nodes within the Ecological network. Also, we were able to identify that target species (all or some) may be key groups within the marine ecosystem since their disappearance separates the remaining nodes from each other and helps the formation of subgroups within the ecological network. In addition, Academia and Leaders seem to be key groups belonging to the social network, but can generate repercussions into the whole social-ecological network. This is an interesting result since Leaders are the once making decisions and, sometimes are advised or make these decisions along with Academia. However, in Mexico it appears to be disconnection between academia and policy making, which makes it difficult to implement management based on such research (Peña-Puch et al., 2020). Nonetheless, ecosystem management knowledge must continue to be generated creating useful models that can be used by fishers. We need to think of new strategies to breach from academia to policy makers, so useful scientific efforts are not lost.

Our group removals simulations allow us to take the social-ecological network to an extreme situation, in this case both from social and ecological origin. We realize that these scenarios are merely a simulation exercise and are highly unlikely to occur as described in real life. However, they are scenarios that can happen at a lower intensity (e.g., heat waves that can reduce primary producers' density or presence or disagreements in the cooperative), but in an extreme situation it is easier to identify the strengths and weaknesses of the model. We believe that this type of simulations can be very useful in data-poor scenarios since all of the information used comes from the fishers' local knowledge. Our goal with this exercise was to be able to identify the vulnerabilities and resilience of the SES and be able to eventually create co-management strategies or policies to adapt to the future. For instance, our findings imply that both the academic community and the primary producers might be leverage points. Meaning that the cooperative might target the management efforts controlling the state of primary producers for the proper functioning of the marine ecosystem. That could be achieved by encouraging cooperative leaders to uphold positive relationships with academia and use their resources to comprehend their environment. Additionally, being aware of the primary producers' annual fluctuations and, if something changes, apply management plans for this concrete future scenario. This is of great importance given the negative effects of recent warm sea surface anomalies have had on kelp forest in the area (Beas-Luna et al., 2020; Schlenger et al., 2021) and the need for funding for coordinated restoration efforts among the all stakeholders.

Conclusions/Lessons learned

This study demonstrates the importance of fishers' local knowledge in small-scale fisheries as a basis to create social, ecological and social-ecological qualitative models. These models have allowed us to understand the structure and function of each individual system and the coupled system. Also, our most notable contribution is the fact that we have proved the importance of using a network approach to simulate social-environmental impacts to identify the strengths and weaknesses of a social-ecological community.

Additionally, this work shows that each network (social, ecological or social-ecological) is vulnerable to certain groups of nodes, but each group of nodes has different repercussions on the network. Therefore, their resilience also depends on the point of view. However, identifying the resilience of each network will depend on the question we want to answer or the problem we want to reflect. Nonetheless, we have demonstrated that this model works and responds to simulations of different origins and therefore we think that it can be used in the future to generate future scenarios and management strategies with specific questions.

When comparing the Betweenness index results for each network (social and ecological), we found differences when it comes to behaving globally (e.g., greater compartmentalization in the social network, and more homogeneous connections in the ecological one). However, when we apply the Betweenness index to the merged network (social-ecological), we identified a well-defined subgroups network but with homogeneous connections, showing that the systems behave differently together. Also, our results highlight the relevant contribution of local individuals (e.g., leaders) to the whole SES. It has also been shown that external agents such academia can also influence local decisions, so it is highly important to maintain good communication to make the best management decisions. All this is relevant when generating management strategies for a social-ecological system since it emphasizes the importance of understanding both the social and ecological aspects, but also their interaction.

We believe studies like ours can inform management and can be used to plan for plausible future scenarios, especially in cases like the fishing community from El Rosario, which lives exclusively from the extraction of resources from the sea. This work, based exclusively on local ecological and social knowledge, increases the validity and scholarly of this type of knowledge, and indicates that stakeholders can be self-sufficient to manage their ecosystems within their limits. This work, more than an action guide, can be used to highlight that actors in this social-ecological network must be alert and could start to plan for future events and scenarios using social-ecological network analyses.

DATA AVAILABILITY STATEMENT

The data underlying this article will be shared on reasonable request to the corresponding author.

FUNDINGS

This work was supported by the following sources: CONACYT scholarship to AV (CVU 689916). UABC internal funds to RBL, JL, and LM. And SIP project 20230471, EDI and COFAA from Instituto Politécnico Nacional to MJZR.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENT

We thank SCPP Ensenada for contributing their LEK and collaborating during the process of this research. We are grateful to Jose Alberto Zepeda Dominguez for his support and valuable comments on early stages of the manuscript. We are grateful to UABC research group Management of Ecosystems across the Californias (http://mex-cal.org).

AUTHOR CONTRIBUTIONS

AV: writing the first draft and coordinating. AV, RB and MZ: conceptualization, analysis, methodology, visualization, and editing. LK, LM and JL helped develop the draft manuscript, including guidance on figures, tables, and supporting information.

References

Abdou, K., Halouani, G., Hattab, T., Romdhane, M. S., Lasram, F. B. R., & Le Loc'H, F. (2016). Exploring the potential effects of marine protected areas on the ecosystem structure of the Gulf of Gabes using the Ecospace model. *Aquatic Living Resources*, *29*(2). https://doi.org/10.1051/alr/2016014

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography*, *79*(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Albert, R., Jeong, H., & Barabási, A. L. (2000). Error and attack tolerance of complex networks. *Nature*, *406*, 378–382. https://doi.org/10.1515/9781400841356.503

Anuario Estadístico de Acuacultura y Pesca Edición. (2020).

Argüelles-Jiménez, J., Alva-Basurto, J. C., Pérez-España, H., Zetina-Rejón, M. J., & Arias-González, J. E. (2020). The measurement of ecosystem development in Caribbean coral reefs through topological indices. *Ecological Indicators*, *110*(July 2019), 105866. https://doi.org/10.1016/j.ecolind.2019.105866

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton, E. W., & Wollenberg, E. K. (2009). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment*, *7*(2), 95–102. https://doi.org/10.1890/070089

Babcock, R. C., Bustamante, R. H., Fulton, E. A., Fulton, D. J., Haywood, M. D. E., Hobday, A. J., Kenyon, R., Matear, R. J., Plagányi, E. E., Richardson, A. J., & Vanderklift, M. A. (2019). Severe continental-scale impacts of climate change are happening now: Extreme climate events impact marine habitat forming communities along 45% of Australia's coast. *Frontiers in Marine Science*, *6*(JUL), 1–14. https://doi.org/10.3389/fmars.2019.00411

Basurto, X. (2008). Biological and ecological mechanisms supporting marine self-governance: The Seri Callo de Hacha Fishery in Mexico. *Ecology and Society*, *13*(2).

https://doi.org/10.5751/ES-02587-130220

Basurto, X., Gelcich, S., & Ostrom, E. (2013). The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change*, *23*(6), 1366–1380. https://doi.org/10.1016/j.gloenvcha.2013.08.001

Bauer, J., Lorda, J., Beas-Luna, R., Malpica-Cruz, L., Lafarga-De la Cruz, F., Micheli, F., Searcy-Bernal, R., Rogers-Bennett, L., & Bracamontes-Peralta, M. (2020). The effects of depth and diet on red abalone growth and survival in cage mariculture at San Jeronimo Island, Baja California, Mexico. *Ciencias Marinas*, *46*(4), 343–357. https://doi.org/10.7773/CM.V46I4.3117

Beas-Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*. University of California in Santa Cruz.

Beas-Luna, R., & Ladah, L. B. (2014). Latitudinal, seasonal, and small-scale spatial differences of the giant kelp, macrocystis pyrifera, and an herbivore at their southern range limit in the northern hemisphere. *Botanica Marina*, *57*(2), 73–83. https://doi.org/10.1515/bot-2013-0114

Beas-Luna, R., Micheli, F., Woodson, C. B., Carr, M., Malone, D., Torre, J., Boch, C., Caselle, J. E., Edwards, M., Freiwald, J., Hamilton, S. L., Hernandez, A., Konar, B., Kroeker, K. J., Lorda, J., Montaño-Moctezuma, G., & Torres-Moye, G. (2020). Geographic variation in responses of kelp forest communities of the California Current to recent climatic changes. *Global Change Biology*, *26*(11), 6457–6473. https://doi.org/10.1111/gcb.15273

Beas Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S. H., Troell, M., & Williams, M. (2016). Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence. *World Development*, *79*, 177–196. https://doi.org/10.1016/j.worlddev.2015.11.007

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, *8*(1), 123–138. https://doi.org/10.1007/s12571-015-0526-x

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Review article: resilience, poverty and development. *Journal of International Development*, *23*, 598–623. https://doi.org/10.1002/jid

Bentley, J. W., Hines, D. E., Borrett, S. R., Serpetti, N., Hernandez-Milian, G., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Combining scientific and fishers' knowledge to co-create indicators of food web structure and function. *ICES Journal of Marine Science*, *76*(7), 2218–2234. https://doi.org/10.1093/icesjms/fsz121

Bentley, J. W., Serpetti, N., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Fishers' knowledge improves the accuracy of food web model predictions. *ICES Journal of Marine Science*, *76*(4), 897–912. https://doi.org/10.1093/icesjms/fsz003

Berkes, F. (2003). Alternatives to conventional management: Lessons from small-scale fisheries. *Environments*, *31*(1), 5–20.

Berkes, F. (2012). *Sacred Ecology*. Routledge, New York.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Berkes, F., & Folke, C. (1998). *Linking social and ecological systems: management practices and social mechanisms for building resilience.*

Berkes, F., Folke, C., & Gadgill, M. (1994). Traditional Ecological Knowledge. *Biodiversity Conservation*, 269–287. https://doi.org/10.1007/978-94-007-0753-5_104248

Berkström, C., Papadopoulos, M., Jiddawi, N. S., & Nordlund, L. M. (2019). Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Frontiers in Marine Science*, *6*(MAR), 1–10. https://doi.org/10.3389/fmars.2019.00130

Bevilacqua, A. H. V., Carvalho, A. R., Angelini, R., & Christensen, V. (2016). More than anecdotes: Fishers' ecological knowledge can fill gaps for ecosystem modeling. *PLoS*

ONE, *11*(5), 1–18. https://doi.org/10.1371/journal.pone.0155655

Biggs, R., Schlüter, M., & Schoon, M. L. (2015). "An introduction to the resilience approach and principles to sustain ecosystem services in social-ecological systems." In *Principles for building resilience: Sustaining ecosystem services in social–ecological systems* (pp. 1–31). https://doi.org/10.1086/696744%0Ahttps://doi.org/10.1086/696744

Bindoff, N. L., Cheung, W. W. L., Kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., Hilmi, N., Jiao, N., Karim, M. S., Levin, L., O'Donoghue, S., Cuicapusa, S. R. P., Rinkevich, B., Suga, T., Tagliabue, A., & Williamson, P. (2019). Changing Ocean, Marine Ecosystems, and Dependent Communities. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.)]. In Press.*, 447–588.

Bodin, Ö. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, *357*(6352). 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

Bonacich, P. (1987). Power and Centrality: A Family of Measures. *American Journal of Sociology*, *92*, 1170–1182.

Borer, E. T., Halpern, B. S., & Seabloom, E. W. (2006). Asymmetry in community regulation: Effects of predators and productivity. *Ecology*, *87*(11), 2813–2820. https://doi.org/10.1890/0012-9658(2006)87[2813:AICREO]2.0.CO;2

Borrett, S. R., Moody, J., & Edelmann, A. (2014). The rise of Network Ecology: Maps of the topic diversity and scientific collaboration. *Ecological Modelling*, *293*, 111–127. https://doi.org/10.1016/j.ecolmodel.2014.02.019

Brandes, U. (2001). The Journal of Mathematical A faster algorithm for betweenness centrality. *Journal of Mathematical Sociology*, *March 2012*, 37–41.

Brown, K. (2016). Resilience, development and global change. In *Resilience, Development and Global Change*. https://doi.org/10.4324/9780203498095

Bryndum-Buchholz, A., Tittensor, D. P., Blanchard, J. L., Cheung, W. W. L., Coll, M., Galbraith, E. D., Jennings, S., Maury, O., & Lotze, H. K. (2019). Twenty-first-century climate change impacts on marine animal biomass and ecosystem structure across ocean basins. *Global Change Biology*, *25*(2), 459–472. https://doi.org/10.1111/gcb.14512

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J., & Schmitt, R. J. (2011). Climate-driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*, *17*(8), 2513–2524. https://doi.org/10.1111/j.1365-2486.2011.02409.x

Carpenter, S. R., Kitchell, J. F., & Hodgson, J. R. (1985). Fish predation and herbivory can regulate lake ecosystems. *BioScience*, *35*(10), 634–639.

Cavole, L. M., Andrade-Vera, S., Marin Jarrin, J. R., Dias, D. F., Aburto-Oropeza, O., & Barrágan-Paladines, M. J. (2020). Using local ecological knowledge of Fishers to infer the impact of climate variability in Galápagos' small-scale fisheries. *Marine Policy*, *121*(January), 1–10. https://doi.org/10.1016/j.marpol.2020.104195

Christensen, V., & Walters, C. J. (2004). Ecopath with Ecosim: Methods, capabilities and limitations. *Ecological Modelling*, *172*(2–4), 109–139. https://doi.org/10.1016/j.ecolmodel.2003.09.003

Cisneros-Montemayor, A. M., Zetina-Rejón, M. J., Espinosa-Romero, M. J., Cisneros-Mata, M. A., Singh, G. G., & Fernández-Rivera Melo, F. J. (2020). Evaluating ecosystem impacts of data-limited artisanal fisheries through ecosystem modelling and traditional fisher knowledge. *Ocean and Coastal Management*, *195*(February). https://doi.org/10.1016/j.ocecoaman.2020.105291

Clauset, A., Newman, M. E. J., & Moore, C. (2004). Finding community structure in very large networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *70*(6), 6. https://doi.org/10.1103/PhysRevE.70.066111

CONAPESCA. (2016). *Carta Nacional Pesquera, Mexico*.

Council, A. (2013). Arctic Resilience Interim Report 2013. *Stockholm Environment Institute* *and Stockholm Resilience Centre, Stockholm, Pp. Ix–Xii.*

Csárdi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *Interj. Compl. Sys.* https://doi.org/10.3724/sp.j.1087.2009.02191

Dayton, P. K. (1985). Ecology of Kelp Communities. *Annual Review of Ecology and Systematics*, *16*(1985), 215–245. https://doi.org/https://doi.org/10.1146/annurev.es.16.110185.001243

De Melo Alves Damasio, L., Lopes, P. F. M., Guariento, R. D., & Carvalho, A. R. (2015). Matching Fishers' knowledge and landing data to overcome data missing in small-scale fisheries. *PLoS ONE*, *10*(7), 1–13. https://doi.org/10.1371/journal.pone.0133122

Delgado-Serrano, M. del M., Oteros-Rozas, E., Vanwildemeersch, P., Ortíz-Guerrero, C., London, S., & Escalante, R. (2015). Local perceptions on social-ecological dynamics in latin america in three community-based natural resource management systems. *Ecology and Society*, *20*(4). https://doi.org/10.5751/ES-07965-200424

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, *4*(1), 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

Eddy, T. D., Lotze, H. K., Fulton, E. A., Coll, M., Ainsworth, C. H., de Araújo, J. N., Bulman, C. M., Bundy, A., Christensen, V., Field, J. C., Gribble, N. A., Hasan, M., Mackinson, S., & Townsend, H. (2017). Ecosystem effects of invertebrate fisheries. *Fish and Fisheries*, *18*(1), 40–53. https://doi.org/10.1111/faf.12165

Edwards, M. S., & Estes, J. A. (2006). Catastrophe, recovery and range limitation in NE Pacific kelp forests: A large-scale perspective. *Marine Ecology Progress Series*, *320*, 79–87. https://doi.org/10.3354/meps320079

Espinoza-Tenorio, A., Ehuan-Noh, R. G., Cuevas-Gómez, G. A., Narchi, N. E., Ramos-Muñoz, D. E., Fernández-Rivera Melo, F. J., Saldívar-Moreno, A., Zepeda-Domínguez, J. A., Pérez-Jiménez, J. C., Oliveto-Andrade, A., & Torre, J. (2022). Between uncertainty and hope: Young leaders as agents of change in sustainable small-scale fisheries. *Ambio*, *51*(5), 1287–1301. https://doi.org/10.1007/s13280-021-01639-2

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. In *FAO*. https://doi.org/10.4060/cc0461en

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

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

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

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio*, *31*(5), 437–440. https://doi.org/10.1579/0044-7447-31.5.437

Folke, C., Pritchard, L., Berkes, F., Colding, J., & Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-02064-120130

Foster, M., & Schiel, D. (1985). Ecology of giant kelp forests in California: a community profile. *United States Fish and Wildlife Service Biological Report*, *85*, 1–152. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5129110

Freeman, L. (1979). Centrality in networks: I: Conceptual Clarification. *Social Networks*, *1*, 215–239.

Froeser, R., & Pauly, D. (2016). *FishBase*. World Wide Web Electronic Publication.

Galappaththi, E. K., Ford, J. D., & Bennett, E. M. (2019). A framework for assessing community adaptation to climate change in a fi sheries context. *Environmental Science* *and Policy*, *92*(November 2018), 17–26. https://doi.org/10.1016/j.envsci.2018.11.005

García-Quijano, C. G. (2007). Fishers' Knowledge of Marine Species Assemblages: Bridging between Scientific and Local Ecological Knowledge in Southeastern Puerto Rico. *American Anthropologist*, *109*(3), 529–536. https://doi.org/10.1525/AA.2007.109.3.529.530

Gaspare, L., Bryceson, I., & Kulindwa, K. (2015). Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of groupers (Epinephelinae) fisheries around Mafia Island, Tanzania. *Ocean and Coastal Management*, *114*, 88–101. https://doi.org/10.1016/j.ocecoaman.2015.06.011

Guimerà, R., Sales-Pardo, M., & Amaral, L. A. N. (2007). Module identification in bipartite and directed networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *76*, 036102.

Guimerà, R., Stouffer, D. B., Sales-Pardo, M., Leicht, E. A., Newman, M. E. J., & Amaral, L. A. N. (2010). Origin of compartmentalization in food webs. *Ecology*, *91*(10), 2941–2951. https://doi.org/10.1890/09-1175.1

Halouani, G., Abdou, K., Hattab, T., Romdhane, M. S., Ben Rais Lasram, F., & Le Loc'h, F. (2016). A spatio-temporal ecosystem model to simulate fishing management plans: A case of study in the Gulf of Gabes (Tunisia). *Marine Policy*, *69*, 62–72. https://doi.org/10.1016/j.marpol.2016.04.002

Hamilton, R., Sadovy de Mitcheson, Y., & Aguilar-Perera, A. (2012). The Role of Local Ecological Knowledge in the Conservation and Management of Reef Fish Spawning Aggregations. In C. P. (eds) In: Sadovy de Mitcheson Y. (Ed.), *Reef Fish Spawning Aggregations: Biology, Research and Management. Fish & Fisheries Series*. Springer, Dordrecht. https://doi.org/https://doi.org/10.1007/978-94-007-1980-4_10

Hamilton, S. L., Gleason, M. G., Godoy, N., Eddy, N., & Grorud-Colvert, K. (2022). Ecosystem-based management for kelp forest ecosystems. *Marine Policy*, *136*, 104919. https://doi.org/10.1016/j.marpol.2021.104919

Heath, M. R., Speirs, D. C., & Steele, J. H. (2014). Understanding patterns and processes in models of trophic cascades. *Ecology Letters*, *17*(1), 101–114. https://doi.org/10.1111/ele.12200

Heymans, J. J., Coll, M., Link, J. S., Mackinson, S., Steenbeek, J., Walters, C., & Christensen, V. (2016). Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. *Ecological Modelling*, *331*, 173–184. https://doi.org/10.1016/j.ecolmodel.2015.12.007

Hind, E. J. (2014). A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. *ICES Journal of Marine Science*, *72*(2), 341–358. https://doi.org/10.1093/icesjms/fsu169

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

IPCC. (2014). *Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.)).

IPCC. (2021). *Climate Change 2021: The Physical Science Basis Summary for Policymakers Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (V. Masson-Delmotte, P. Zhai, S. L. C. A. Pirani, S. B. C. Péan, Y. C. N. Caud, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & and B. Zhou (Eds.)). Cambridge University Press. In Press.

ISE. (2006). *International Society of Ethnobiology Code of Ethics (with 2008 additions).* http://ethnobiology.net/code-of-ethics/

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J., & Warner, R. R. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*, *293*, 629–637. https://doi.org/10.1126/science.1059199

Jacox, M. G., Hazen, E. L., Zaba, K. D., Rudnick, D. L., Edwards, C. A., Moore, A. M., & Bograd, S. J. (2016). *Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events*. 7072–7080. https://doi.org/10.1002/2016GL069716.Received

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01462-110115

Johannes, R. ., & Neis, B. (2007). The value of anecdote. In *Fishers' knowledge in fisheries science and management. Coastal Management Sourcebooks* (Vol. 4, Issue 3, pp. 41–58). https://doi.org/10.1016/j.avsg.2014.01.003

Johannes, R. E., Freeman, M. M. R., & Hamilton, R. J. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, *1*(3), 257–271. https://doi.org/10.1111/j.1467-2979.2000.00019.x

Johnson, A. F., Moreno-Baez, M., Giron-Nava, A., Corominas, J., Erisman, B., Ezcurra, E., & Aburto-Oropeza, O. (2017). A spatial method to calculate small-scale fisheries effort in data poor scenarios. *PLoS ONE*, *12*(4), 1–17. https://doi.org/10.1371/journal.pone.0174064

Kluger, L. C., Gorris, P., Kochalski, S., Mueller, M. S., & Romagnoni, G. (2020). Studying human–nature relationships through a network lens: A systematic review. *People and Nature*, *2*(4), 1100–1116. https://doi.org/10.1002/pan3.10136

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*(July), 104861. https://doi.org/10.1016/j.ocecoaman.2019.104861

Kobluk, H. M., Gladstone, K., Reid, M., Brown, K., Krumhansl, K. A., & Salomon, A. K. (2021). Indigenous knowledge of key ecological processes confers resilience to a small-scale kelp fishery. *People and Nature*, *3*(3), 723–739. https://doi.org/10.1002/pan3.10211

Krause, A. E., Frank, K. A., Mason, D. M., Ulanowicz, R. E., & Taylor, W. W. (2003). Compartments revealed in food-web structure. *Nature*, *426*, 282–285.

Kroeker, K. J., Gambi, M. C., & Micheli, F. (2013). Community dynamics and ecosystem simplification in a high-CO2 ocean. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(31), 12721–12726. https://doi.org/10.1073/pnas.1216464110

Lorda, J., Beas, R., Bell, T., & Barbara, S. (2018). *Producción primaria bruta en bosques submarinos de la región Bahía Todos. December.*

Mackinson, S. (2001). Integrating local and scientific knowledge: An example in fisheries science. *Environmental Management*, *27*(4), 533–545. https://doi.org/10.1007/s002670010168

Marshall, N. A., & Marshall, P. A. (2007). Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-01940-120101

McCay, B. J., Micheli, F., Ponce-díaz, G., Murray, G., Shester, G., Ramirez-sanchez, S., & Weisman, W. (2014). Cooperatives , concessions , and co-management on the Pacific coast of Mexico. *Marine Policy*, *44*, 49–59. https://doi.org/10.1016/j.marpol.2013.08.001

McLaughlin, P., & Dietz, T. (2008). Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change*, *18*(1), 99–111. https://doi.org/10.1016/j.gloenvcha.2007.05.003

MEA. (2005). Ecosystems and human well-being: Wetland and water. In *Synthesis. Available online: http:// ...*. http://millenniumassessment.org/documents/MA_wetlands&water-Chinese.pdf

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza Montes, J. A., Rossetto, M., & de Leo, G. A. (2012). Evidence that marine reserves enhance resilience to climatic impacts. *PLoS ONE*, *7*(7). https://doi.org/10.1371/journal.pone.0040832

Morales-Zárate, M. V., Lluch-Cota, S. E., Serviere-Zaragoza, E., & del Próo, S. G. (2011). Modeling an exploited rocky coastal ecosystem: Bahia Tortugas, Mexico. *Ecological Modelling*, *222*(5), 1185–1191. https://doi.org/10.1016/j.ecolmodel.2010.12.011

MSC. (2018). MSC Fisheries Standard v2.01. *Marine Stewardship Council*, *August*. https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-standard-v2-01.pdf?sfvrsn=8ecb3272_19#page=182&zoom=100,92,674

Munguia-Vega, A., Green, A. L., Suarez-Castillo, A. N., Espinosa-Romero, M. J., Aburto-Oropeza, O., Cisneros-Montemayor, A. M., Cruz-Piñón, G., Danemann, G., Giron-Nava, A., Gonzalez-Cuellar, O., Lasch, C., del Mar Mancha-Cisneros, M., Marinone, S. G., Moreno-Báez, M., Morzaria-Luna, H. N., Reyes-Bonilla, H., Torre, J., Turk-Boyer, P., Walther, M., & Weaver, A. H. (2018). Ecological guidelines for designing networks of marine reserves in the unique biophysical environment of the Gulf of California. *Reviews in Fish Biology and Fisheries*, *28*(4), 749–776. https://doi.org/10.1007/s11160-018-9529-y

Munguia-Vega, A., Zepeda-Dominguez, J. A., Perez-Alarcon, M. F., Amador-Castro, I. G., Fulton, S., Walther, M., Rodriguez-Fuentes, M., Fumero-Andreu, C. M., & Torre, J. (2022). Social-ecological networks and connectivity within and between two communities of small-scale fishers in Mexico. *Ecology and Society*, *27*(1). https://doi.org/10.5751/es-13055-270124

Nenadović, M., Basurto, X., & Weaver, A. H. (2016). Contribution of Subsidies and Participatory Governance to Fishers' Adaptive Capacity. *Journal of Environment and Development*, *25*(4), 426–454. https://doi.org/10.1177/1070496516670448

Newman, M. E., & Girvan, M. (2004). Finding and evaluating community structure in networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *69*, 026113.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75–90. https://doi.org/10.1007/s00267-003-0101-7

Ostrom, E. (1990). *Governing the Commons: the Evolution of Institutions for Collective Action.* Cambridge University Press, New York.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*, 419–422.

Ostrom, V., Tiebout, M., & Warren, R. (1961). The Organization of Government in Metropolitan Areas : A Theoretical Inquiry. *The American Political Science Review*, *55*(4), 831–842.

Overland, J. E., Alheit, J., Bakun, A., Hurrell, J. W., Mackas, D. L., & Miller, A. J. (2010). Climate controls on marine ecosystems and fish populations. *Journal of Marine Systems*, *79*(3–4), 305–315. https://doi.org/10.1016/j.jmarsys.2008.12.009

Parkes, G., Young, J. A., Walmsley, S. F., Abel, R., Harman, J., Horvat, P., Lem, A., Macfarlane, A., Mens, M., & Nolan, C. (2010). Behind the signs-a global review of fish sustainability information schemes. *Reviews in Fisheries Science*, *18*(4), 344–356. https://doi.org/10.1080/10641262.2010.516374

Pauly, D., & Christensen, V. (1995). Primary production required to sustain global fisheries. *Nature*, *374*, 255.

Peña-Puch, A. del C., Pérez-Jiménez, J. C., & Espinoza-Tenorio, A. (2020). Advances in the study of Mexican fisheries with the social-ecological system (SES) perspective and its inclusion in fishery management policy. *Ocean and Coastal Management*, *185*(May 2019). https://doi.org/10.1016/j.ocecoaman.2019.105065

Perera, A. H., Drew, C. A., & Johnson, C. J. (Eds.). (2011). *Expert knowledge and its application in landscape ecology*. Springer Science & Business Media.

Ponte, S. (2012). The Marine Stewardship Council (MSC) and the Making of a Market for "Sustainable Fish." *Journal of Agrarian Change*, *12*(2–3), 300–315.

https://doi.org/10.1111/j.1471-0366.2011.00345.x

Ramirez-Sanchez, S., & Pinkerton, E. (2009). The impact of resource scarcity on bonding and bridging social capital: The case of fishers' information-sharing networks in Loreto, BCS, Mexico. *Ecology and Society*, *14*(1). https://doi.org/10.5751/es-02841-140122

Reed, D. C., Rassweiler, A., Carr, M. H., Cavanaugh, K. C., Malone, D. P., & Siegel, D. A. (2011). Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. *Ecology*, *92*(11), 2108–2116. https://doi.org/10.1890/11-0377.1

Restrepo-Gómez, D. C., Zetina-Rejón, M. J., & Zepeda-Domínguez, J. A. (2022). Trends in marine fisheries social-ecological systems studies. *Ocean and Coastal Management*, *220*(February). https://doi.org/10.1016/j.ocecoaman.2022.106076

Revollo-Fernández, D., Aguilar-Ibarra, A., Micheli, F., & Sáenz-Arroyo, A. (2016). Exploring the role of gender in common-pool resource extraction: evidence from laboratory and field experiments in fisheries. *Applied Economics Letters*, *23*(13), 912–920. https://doi.org/10.1080/13504851.2015.1119786

Romagnoni, G., Mackinson, S., Hong, J., & Eikeset, A. M. (2015). The Ecospace model applied to the North Sea: Evaluating spatial predictions with fish biomass and fishing effort data. *Ecological Modelling*, *300*, 50–60. https://doi.org/10.1016/j.ecolmodel.2014.12.016

Rosa, R., Carvalho, A. R., & Angelini, R. (2014). Integrating fishermen knowledge and scientific analysis to assess changes in fish diversity and food web structure. *Ocean and Coastal Management*, *102*(PA), 258–268. https://doi.org/10.1016/j.ocecoaman.2014.10.004

Sáenz-Arroyo, A., Roberts, C. M., Torre, J., Cariño-Olvera, M., & Enríquez-Andrade, R. R. (2005). Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1575), 1957–1962. https://doi.org/10.1098/rspb.2005.3175

Saldaña, A., Salas, S., Arce-Ibarra, A. M., & Torres-Irineo, E. (2016). Fishing operations and adaptive strategies of small-scale fishers: insights for fisheries management in data-poor situations. *Fisheries Management and Ecology*, *24*(1), 19–32. https://doi.org/10.1111/fme.12199

Sánchez, S. R., J. McCay, B., R. Johnson, T., & Weisman, W. (2011). Surgimiento, formación y persistencia de organizaciones sociales para la pesca ribereña de la península de Baja California. *Región y Sociedad*, *23*(51). https://doi.org/10.22198/rys.2011.51.a35

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). https://doi.org/10.1088/1748-9326/ab2619

Schlenger, A. J., Beas-Luna, R., & Ambrose, R. F. (2021). Forecasting ocean acidification impacts on kelp forest ecosystems. *PLoS ONE*, *16*(4 April 2021), 1–24. https://doi.org/10.1371/journal.pone.0236218

Shabtay, A., Portman, M. E., Ofir, E., Carmel, Y., & Gal, G. (2018). Using ecological modelling in marine spatial planning to enhance ecosystem-based management. *Marine Policy*, *95*(January), 14–23. https://doi.org/10.1016/j.marpol.2018.06.018

Solano, N., Lopez-Ercilla, I., Fernandez-Rivera Melo, F. J., & Torre, J. (2021). Unveiling Women's Roles and Inclusion in Mexican Small-Scale Fisheries (SSF). *Frontiers in Marine Science*, *7*(January), 1–14. https://doi.org/10.3389/fmars.2020.617965

Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., Mackinson, S., Dankel, D. J., Brooks, K., & Benson, A. (2016). *Integrating fishers' knowledge research in science and management*. *73*, 1459–1465.

Stouffer, D. B., & Bascompte, J. (2011). Compartmentalization increases food-web persistence. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(9), 3648–3652. https://doi.org/10.1073/pnas.1014353108

Thompson, R. M., Brose, U., Dunne, J. A., Hall, R. O., Hladyz, S., Kitching, R. L., Martinez, N. D., Rantala, H., Romanuk, T. N., Stouffer, D. B., & Tylianakis, J. M. (2012). Food webs: Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution*, *27*(12), 689–697. https://doi.org/10.1016/j.tree.2012.08.005

Torre, J., Hernandez-Velasco, A., Rivera-Melo, F. F., Lopez, J., & Espinosa-Romero, M. J. (2019). Women's empowerment, collective actions, and sustainable fisheries: lessons from Mexico. *Maritime Studies*, *18*(3), 373–384. https://doi.org/10.1007/s40152-019-00153-2

Vilalta-Navas, A., Beas-Luna, R., Calderon-Aguilera, L. E., Ladah, L., Micheli, F., Christensen, V., & Torre, J. (2018). A mass-balanced food web model for a kelp forest ecosystem near its southern distributional limit in the northern hemisphere. *Food Webs*, *16*, e00091. https://doi.org/10.1016/j.fooweb.2018.e00091

Vilalta-Navas, A., Beas-Luna, R., Zetina-rejón, M. J., Lopez-Ibarra, G. A., Malpica-Cruz, L., Lorda, J., Zepeda-Dominguez, J. A., & Kluger, L. C. (2022). Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems. *ICESJournal OfMarine Science*, 1–12. https://doi.org/10.1093/icesjms/fsac225

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications.*

West, D. . (1996). Introduction to Graph Theory. *Upper Saddle River, N.J.: Prentice Hall.*

Wu, H. (2017). A Conference to #SaveOurOcean. *UN Chronicle, 54/2,.*

Yletyinen, J., Hentati-Sundberg, J., Blenckner, T., & Bodin, Ö. (2018). Fishing strategy diversification and fishers' ecological dependency. *Ecology and Society*, *23*(3). https://doi.org/10.5751/ES-10211-230328

Young, O. R., Webster, D. G., Cox, M. E., Raakjær, J., Blaxekjær, L. Ø., Einarsson, N., Virginia, R. A., Acheson, J., Bromley, D., Cardwell, E., Carothers, C., Eythórsson, E., Howarth, R. B., Jentoft, S., McCay, B. J., McCormack, F., Osherenko, G., Pinkerton, E., van Ginkel, R., … Wilson, R. S. (2018). Moving beyond panaceas in fisheries governance. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(37), 9065–9073. https://doi.org/10.1073/pnas.1716545115

Zador, S. G., Gaichas, S. K., Kasperski, S., Ward, C. L., Blake, R. E., Ban, N. C., Himes-Cornell, A., & Zachary Koehn, J. (2017). Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. *ICES Journal of Marine Science*, *74*(7), 2024–2033. https://doi.org/10.1093/icesjms/fsx054

Zepeda-Domínguez, J. A., Vergara-Rodarte, M., Gómez, A., Espinosa-Romero, M. J., Espinoza-Tenorio, A., & López-López, D. (2019). Beneficios de las ecoetique as en pesquerías en vías de desarrollo, capítulo México. *Gobernanza Pesquera:México y España*.

Zetina-Rejón, M. J., Cabrera-Neri, E., López-Ibarra, G. A., Arcos-Huitrón, N. E., & Christensen, V. (2015). Trophic modeling of the continental shelf ecosystem outside of Tabasco, Mexico: A network and modularity analysis. *Ecological Modelling*, *313*, 314–324. https://doi.org/10.1016/j.ecolmodel.2015.07.001

Zetina-Rejón, M. J., López-Ibarra, G. A., Rocha-Tejeda, L., Flores-Guzmán, A., López-Ercilla, I., Rodríguez-Rodríguez, E., Sandoval-Jiménez, S. A., Arreguín-Sánchez, F., & Cisneros-Montemayor, A. M. (2022). A Framework for Simulating Ecosystem Effects in Data-Poor Small-Scale Fisheries Using Science-Based and Local Ecological Knowledge-Based Models. *Frontiers in Marine Science*, *8*(January), 1–14. https://doi.org/10.3389/fmars.2021.799068

Zetina-Rejón, M. J., Zepeda-Domínguez, J. A., Rodríguez-Fuentes, M., & Fumero-Andreu, C. M. (2020). Stakeholder diversity correlates with governance network performance in two artisanal fisheries in Northwest Mexico. *Ocean and Coastal Management*, *196*(March). https://doi.org/10.1016/j.ocecoaman.2020.105313

APPENDIX A

Values of the betweenness index for the nodes of the socio-ecological network.

Number	Type	Betweenness centrality index value	Network
1	Top Leaders	1.06E-01	Social
2	Surveillance	5.98E-03	Social
3	Fishers	0.00E+00	Social
4	Top Leaders	0.00E+00	Social
5	Top Leaders	0.00E+00	Social
6	Top Leaders	0.00E+00	Social
7	Fishers	6.14E-02	Social
8	Fishers	6.14E-02	Social
9	Fishers	6.14E-02	Social
10	Fishers	6.50E-02	Social
11	Fishers	6.50E-02	Social
12	Top Leaders	4.70E-02	Social
13	Top Leaders	2.25E-02	Social
14	Fishers	2.20E-02	Social
15	Fishers	2.20E-02	Social
16	Top Leaders	1.91E-02	Social
17	Top Leaders	1.81E-01	Social
18	Fishers	5.81E-02	Social
19	Fishers	5.81E-02	Social
20	Processing	1.44E-02	Social
21	Processing	3.85E-03	Social
22	Processing	0.00E+00	Social
23	Processing	1.10E-02	Social
24	Processing	0.00E+00	Social
25	Other employees	0.00E+00	Social
26	Other employees	1.81E-03	Social
27	Surveillance	0.00E+00	Social
28	Other employees	0.00E+00	Social
29	Surveillance	1.93E-04	Social
30	Other employees	0.00E+00	Social
31	Processing	0.00E+00	Social
32	Processing	0.00E+00	Social
33	Other employees	0.00E+00	Social
34	Other employees	0.00E+00	Social
35	Other employees	0.00E+00	Social
36	Client	9.58E-04	Social
37	Transport	0.00E+00	Social

38	Transport	0.00E+00	Social
39	Client	0.00E+00	Social
40	Outsider	0.00E+00	Social
41	Transport	0.00E+00	Social
42	Client	0.00E+00	Social
43	Other employees	0.00E+00	Social
44	NGO	9.07E-02	Social
45	Academia	1.23E-02	Social
46	Academia	1.16E-01	Social
47	Outsider	0.00E+00	Social
48	Local Regulaltion	9.58E-04	Social
49	Federal Regulation	3.43E-04	Social
50	Social Development	0.00E+00	Social
51	Academia	0.00E+00	Social
52	Academia	0.00E+00	Social
53	Local Regulaltion	0.00E+00	Social
54	Federal Regulation	0.00E+00	Social
55	Certifier	0.00E+00	Social
56	Certifier	0.00E+00	Social
57	Academia	0.00E+00	Social
58	Local Regulaltion	0.00E+00	Social
59	Herbivore	2.18E-02	Ecological
60	Predator	6.01E-03	Ecological
61	Primary Producer	1.75E-03	Ecological
62	Primary Producer	1.06E-05	Ecological
63	Primary Producer	5.67E-04	Ecological
64	Primary Consumer	1.58E-02	Ecological
65	Primary Consumer	1.53E-02	Ecological
66	Herbivore	7.03E-03	Ecological
67	Predator	4.91E-04	Ecological
68	Primary Consumer	5.68E-04	Ecological
69	Predator	2.45E-03	Ecological
70	Predator	1.78E-02	Ecological
71	Predator	6.53E-03	Ecological
72	Predator	8.91E-03	Ecological
73	Secondary Consumer	3.65E-03	Ecological
74	Primary Consumer	1.46E-03	Ecological
75	Secondary Consumer	1.55E-02	Ecological
76	Secondary Consumer	4.78E-03	Ecological

77	Secondary Consumer	7.93E-04	Ecological
78	Predator	1.57E-03	Ecological
79	Herbivore	6.23E-05	Ecological
80	Secondary Consumer	2.53E-04	Ecological
81	Primary Producer	5.55E-03	Ecological
82	Predator	5.55E-03	Ecological
83	Herbivore	1.91E-02	Ecological
84	Predator	1.87E-03	Ecological
85	Primary Producer	2.06E-03	Ecological
86	Secondary Consumer	2.32E-04	Ecological
87	Predator	6.53E-03	Ecological
88	Predator	3.82E-02	Ecological
89	Primary Consumer	4.52E-03	Ecological
90	Secondary Consumer	3.91E-03	Ecological
91	Predator	2.38E-03	Ecological
92	Predator	1.60E-02	Ecological
93	Predator	3.59E-04	Ecological
94	Herbivore	8.68E-04	Ecological
95	Predator	3.81E-04	Ecological
96	Predator	4.06E-03	Ecological
97	Primary Consumer	1.20E-02	Ecological
98	Secondary Consumer	2.94E-02	Ecological
99	Secondary Consumer	4.54E-04	Ecological
100	Herbivore	9.99E-03	Ecological
101	Primary Consumer	1.38E-03	Ecological
102	Primary Consumer	1.36E-03	Ecological
103	Predator	1.57E-02	Ecological
104	Predator	7.92E-03	Ecological
105	Herbivore	1.55E-02	Ecological
106	Predator	6.74E-02	Ecological
107	Primary Consumer	2.64E-03	Ecological
108	Secondary Consumer	1.69E-02	Ecological
109	Predator	1.10E-02	Ecological
110	Herbivore	1.89E-04	Ecological

Learned lessons based on the adaptative capacity of a small-scale fishing community to climate change in Baja California, Mexico.

Abstract

In light of the worldwide trend toward environmental change, it is important to investigate how marine ecosystems respond. Small-scale fisheries (SSF), are essential to many human communities but have had challenges dealing with the changing environmental circumstances throughout time. Conceptual frameworks are a widely developed tool used as an adaptative co-management vision. In this work we want to use Galappaththi et al., (2019) conceptual framework, which is focused on the social-ecological adaptations performed by SSF in response to climate change, and adapt it to a SSF study case in Baja California. We conducted 30 interviews to people directly related fishing community with different job positions and responsibilities obtain a global vision f from the most viewpoints possible, to understand the community's background such as past adverse events, how they affected the fishery. This community has faced several environmental scenarios with different levels of impact on the ecosystems over the years. Our results have shown how they have been able to incorporate different adaptations in both their way of fishing and in their organization to overcome adversity. However, we conclude that it is not easy to isolate decision making and it is necessary to tend towards a global and fluid conceptualization that can be adapted to each case of study.

Keywords: small scale fisheries, fishers' knowledge, conceptual framework, resilience, climate change

1. Introduction

For centuries, humans have struggled with environmental changes and have had to learn how to deal with the uncertainty that these continuous changes. On the other hand, humans have also learned to adapt to these changes in order to thrive. To do so, a good adaptive management approach enables communities to understand ecosystem dynamics, discover ecosystem knowledge, to later develop flexible and specific management practices (Folke et al., 2002). The adaptive co-management approach is based on a flexible governance system that is tailored to the location and its specific circumstances, involving a wide range of actors (e.g., representing individuals from the communities, stakeholders) and institutions at various levels (Armitage et al., 2009; Olsson et al., 2004). Using this integral vision helps to learn how to adapt to varying conditions and deal with uncertainty which is essential in this changing world. Currently, climate change predictions are expected to alter marine ecosystems modifing their functioning and development (IPCC, 2021). Given the global trend of environmental alterations, it is necessary to study marine ecosystems response. Applying adaptive co-management techniques successfully requires prior knowledge of the dynamics of the ecosystems, the creation of organizations or institutions that are adaptable to management processes, and the development of practices that can respond to the input of the ecosystem (Berkes & Folke, 1998; Lorda et al., 2018).

Over 850 million people worldwide live within 100 kilometers of the coast and are affected by changing coastal systems (IPCC, 2014b). Small-scale fisheries (SSF), which support over 60 million jobs and account for 40% of global fishing catch, are vital to many human communities (FAO, 2022). The shifting environmental conditions is something that SSF have had to deal with over time. When environmental changes or extreme climate events threaten a community's ability to survive, adaptive processes take place (Adger, 2003). As a result of changing environmental effects, several SSFs have been forced to shift targeted species, alter their fishing grounds, or even some ended up collapsing (Sánchez et al., 2011). However, these adaptive processes can also come from institutional outputs that anticipate environmental changes and their impacts. For future fisheries to thrive, it is crucial to keep open lines of communication and a positive working relationship between fishing communities and the organizations that assist them (Béné, Arthur, et al., 2016; Nenadović et al., 2016).

In developing countries, where funds to monitor *in situ* and get observational data are scarcer than other regions, the Local Ecological Knowledge (LEK) increases its relevance as a source of information (Saldaña et al., 2016). This knowledge comes from the accumulation of experiences and observations of fishers over time, and is passed from generation to generation (R. Hamilton et al., 2012). In isolated regions, the use of LEK has been the only source of information and has allowed many SSFs to survive over time. However, LEK has also been undervalued by the scientific community due to its inherent inconsistency given that it is usually transferred via word-of-mouth through generations. Nowadays, it has been demonstrated the validity and importance of this type of knowledge which has increased its use in scientific studies (Hind, 2014). Numerous approaches have been carried out in using LEK in scientific studies; finding marine reserves or no-fishing zones (Saldaña et al., 2016), anticipating to environmental changes (Cavole et al., 2020), laying the groundwork for novel management techniques (Berkström et al., 2019), and studying species' behavior, feeding habits, or migration patterns (Johannes et al., 2000) are just a few examples. LEK has also been used to understand and deepen the fishing communities using a social-ecological approach, since it encompasses both the social and ecological environment associated with an ecosystem (E. Ostrom, 2009).

A widely developed tool used with that vision are conceptual frameworks. They have been developed to comprehend a community's history and their adaptative capacity using general conditions (Holling, 1973). However, analytic frameworks are used to test the specific effect of certain factors (leadership, quotas, etc.) on certain variables (capture, sustainability) (E. Ostrom, 1990) . For instance, the adjustments it made in response to a catching decrease of target species as a result of environmental or human-caused events, or to pinpoint the conditional drivers of the youth involvement in fisheries (Espinoza-Tenorio et al., 2022).We particularly want to draw attention to Galappaththi et al., (2019) conceptual framework, which is focused on the social-ecological adaptations performed by SSF in response to climate change. To comprehend and analyze the success of SSF communities, this framework blends the notions of resilience and climate change adaptation. In this work we want to use their conceptual framework to take it towards an analytical framework.

Resilience is defined as the active capacity to design and implement responses in an effort to mitigate these vulnerability circumstances (Bene et al., 2016). We believe that the approach used in this conceptual framework is suitable for studying small-scale fishing communities, located in isolated areas and subject to constant environmental variations, as occurs in Mexico, where SSF are of great importance since more than 90% of the fishing fleets are dedicated to coastal fishing (*Anuario Estadístico de Acuacultura y Pesca Edición*, 2020)). Specifically, for the Baja California peninsula, fishers from most of the fishing communities have been organized through fishing cooperatives since the beginning of the 20th century. Before the Mexican revolution, fishing permits were massive and were granted mainly to foreign companies and fleets. After several demonstrations throughout the peninsula, once the Mexican revolution was over, the government promoted measures that encouraged the local fishers to conform fishing cooperatives (some of those incentives were exclusivity rights to access to some valuable fishing resources). Therefore, the cooperatives arise from the common needs among the fishers to obtain better prices in production, end the permit holders' expand limitation and ease fishing permit obtaining (Sánchez et al., 2011). In recent years, NGOs and academia have also played a relevant role in fishing cooperatives' development. They have promoted fishers' organization and fostered a sustainable vision of their products. COBI (Comunidad y Bidiversidad, local NGO), for example, has trained women from some fishing villages to conduct annual subtidal monitoring (Torre et al., 2019). Different academic institutions -both national and international- have conducted environmental studies that have helped fishers to develop management strategies, such as establishing no-fishing zones (Micheli et al., 2012), understanding the ecosystems' environmental dynamics (Kroeker et al., 2013), and also implemented mariculture and repopulation experiments (Bauer et al., 2020). However, not all of the coastal locations on the Baja California peninsula have received the same level of foreign assistance. This is a result of both, their remote location and the community's propensity to deal with external agents.

Because of that, the objective of this work is to identify the learned lessons by El Rosario fishing community regarding climate change, answering the following questions: a) How is the community structured and which is its climate change background? and b) Which collective actions were used by the community to face environmental changes? To achieve this goal we applied the Galappaththi (et al., 2019) framework to the El Rosario as study case.

2. Methodology

2.1. Case of study

El Rosario is a small fishing community located in the municipality of Ensenada, in the state of Baja California, at the northern Pacific coast of México. The local cooperative *Sociedad Cooperativa de Producción Pesquera Ensenada, SCL,* which owns the fishing rights for high value benthic and fin species encompassing 194 km of the coastline, and they have had exclusive fishing rights for this region sice 1940. Their primary source of income comes from sales of high-value benthic species linked to kelp forests (e.g.,lobster -*Panulirus interruptus*-, abalones -*Haliotis spp*.- and sea urchins -*Strongylocentrotus* spp.-), on national and -mostly- international markets. This fishing village is located on the southern limit of the California Current, which coincides with the southern limit of kelp forest distribution. Because of its geographical location, the community has experienced constant environmental variations such as drastic temperature fluctuations caused by El Niño and the Blob (2015-2016), as well as hypoxia events or mass extinctions of species. Due to its geographical position and its socioeconomic structure, the community suffers local variations (such as those mentioned above) but also regional ones (such as the reduction of the distribution limits of certain species given by climate change), which made El Rosario fishing village an interesting study case to deep our knowledge about how the societies face the social-ecological stochasticity and tendential stressors.

In order to comprehend the history of the fishing community, in February 2021, 30 interviews were conducted to people directly related to the Coop. Ensenada. The questionnaire was divided in two parts: a) The first, aimed to know the interviewees background such as their age, sex, level of education, position, and seniority within the cooperative; b) The second part, sought to understand the community's background such as past adverse events, how they affected the fishery, what they did to cope them and how they would face future changes. The surveyed population was composed by cooperative employees who played a variety of jobs (such as fishers, surveillance personnel, production sector of different organisms, administrators and managers) in order to obtain a global vision f from the most viewpoints possible. Additionally, non-participant observation were carried out to deep our understanding of the local dynamics.

MexCal has been working with this community for at least 6 years (https://mex-cal.org). Consequently, it has been feasible to watch the structural growth of the fishing village due to the regular visits over the years.

Participation in the study was voluntary and interviewees were given the option to reserve their answers to specific questions, refuse to participate, or stop participating at any time without any associated sanctions or consequences. All participants were informed that the interviews were anonymous and that the information obtained was only going to be used for the academic purposes of this work. The interviews were done following the ethical standards of informed participation of the Code of Ethics of the International Society of Ethnobiology (ISE, 2006).

2.2. Framework application

To recognize the climate change adaptations made by this community we applied Galappaththi et al., (2019) conceptual framework (Figure 12). Their work integrates resilience thinking into development studies to create a better understanding of how social-ecological changes can affect management policies specifically in small-scale fisheries. This framework is structured in three layers, and each of them integrates the concepts of one or more previous works. The details of each component are described in Table 6 (see in section 3. Results). The integrated approach they suggest emphasizes feedback and links between capabilities and place-based components while concentrating on change trajectories that ultimately result in policy creation. They characterize this framework as flexible and adaptable to accomplish transdisciplinary goals. It offers up opportunities for collaboration and gives information to create adaptive governance policy taking into account complex human-environment interactions, uncertainties, and processes.

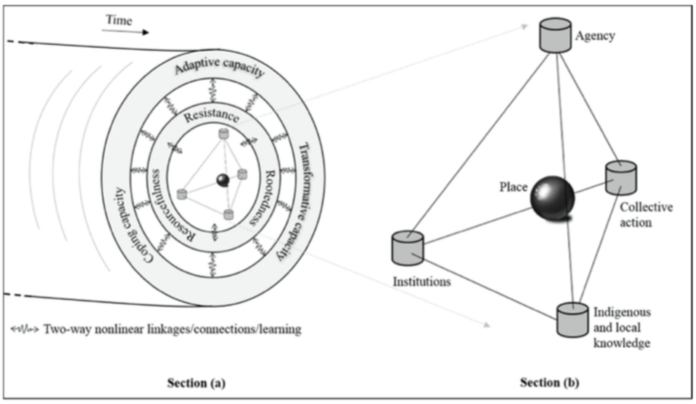


Fig. 1. Conceptual framework [building on Brown (2016) and Béné et al. (2014)].
Section (a) shows a cross-section of the tube-shaped system that grows forward in the face of SES change (for example, climate change). The cross-section represents the framework's key components, which are place-based elements, 3Rs, and 3D capacities. All three components are connected through two-way nonlinear linkages. Section (b) illustrates the network of place-based elements located in the center of the framework. The zoomed-in version shows how such conceptual elements are positioned around the 'place.'

Figure 12. Conceptual framework from on Galapathithi et al., (2019).

3. Results

3.1. How is the community structured and which is its climate change background?

From the total of 30 people interviewed (Figure 13), 7 were women and 23 men. The ages of the interviewees ranged between 20 and 70, with a greater representation from 20 to 30 years old range, and a homogeneous representation of the rest of the age ranges. Men's average study was secondary school (up to 14 years of schooling) while women's studies were homogeneously distributed between secondary school, high school and bachelor's degree (between 18 and 22 years of schooling). The interviewees are classified into three categories within the cooperative: *Socios* (6 interviewees), *Extras* (7 interviewees) or *Employees* (16 interviewees). These three categories are classified into seven jobs within the cooperative: the *socios* perform as leaders or fishers, the *extras* as fishers or industrial plant workers, and the employees as surveillance, quality control, industrial plant employees, administrative, or field work assistants. To know an independent perspective, we also interviewed the woman who runs a restaurant in the fishing village. She is not an employee of the cooperative but she has been working there for more than 40 years. The largest percentage of interviewees were done to Fishers and Employees, so we consider the extraction and processing phase are the better represented and understood. Male employees predominate with a homogeneous distribution along all sectors classified. However, women presence is lower and were situated within the production processing or quality control.

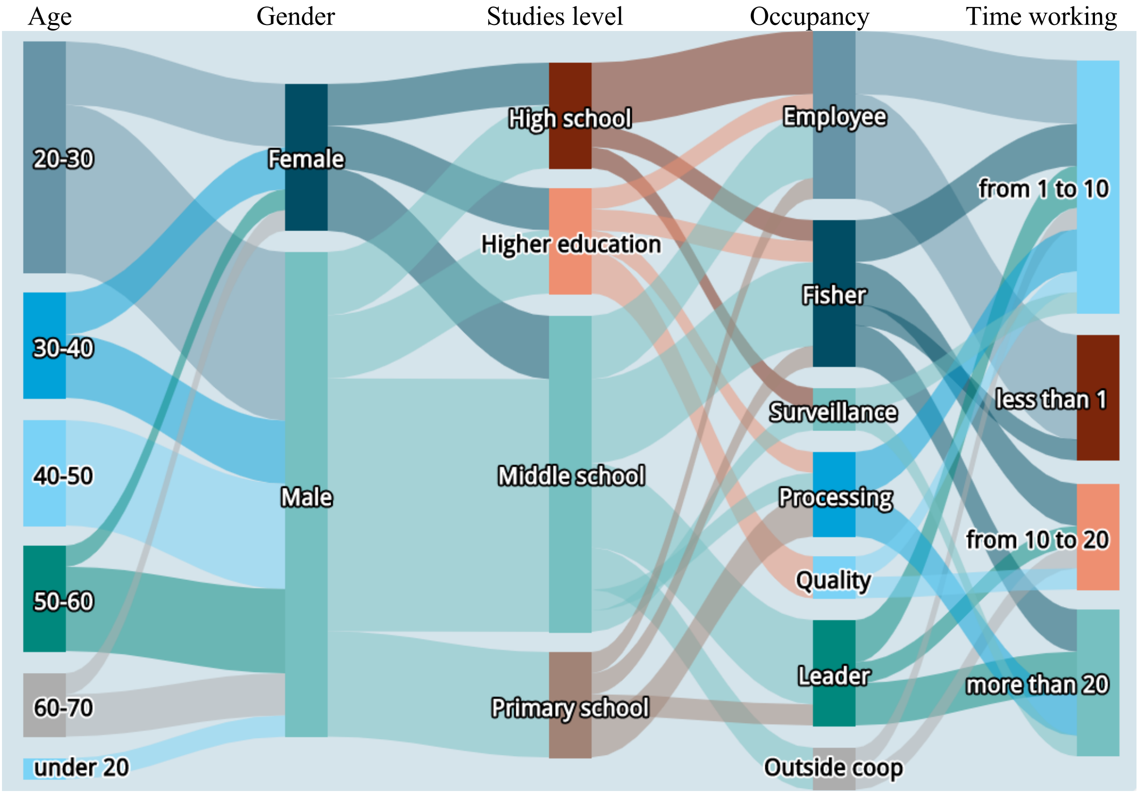


Figure 13.Sankey Diagram representing the basic structure information of interviewees from El Rosario fishing community. For the study levels, the Primary school corresponds to 6 years of schooling (from 6 to 12 years old), the Middle school corresponds to 3 years of schooling (from 12 to 15 years), the High school corresponds to 3 years of schooling (from 15 to 18 years) and the Higher education corresponds to those whom studied a bachelor's degree.

Regarding the climate change background, the 2015 anomaly was the most notorious, affecting almost all the species being the most mentioned temperature change event (Figure 14). In this period, fishers' perceptions suggest that the most affected species were abalone, sea urchins and kelp. The anomalies that occurred in 1997 and 2016 were the second most mentioned, also affecting almost all the mentioned species. In 1997 fishers recalled that the most affected species were abalone, while in 2016 were sea urchins and abalone. The anomalies of the 1990s were mentioned by interviewees over 40 years of age. The anomalies of the 2000s were mentioned by interviewees from the age of 20 onwards. Therefore, in general, all the anomalies mentioned are by individuals who lived through those environmental changes.

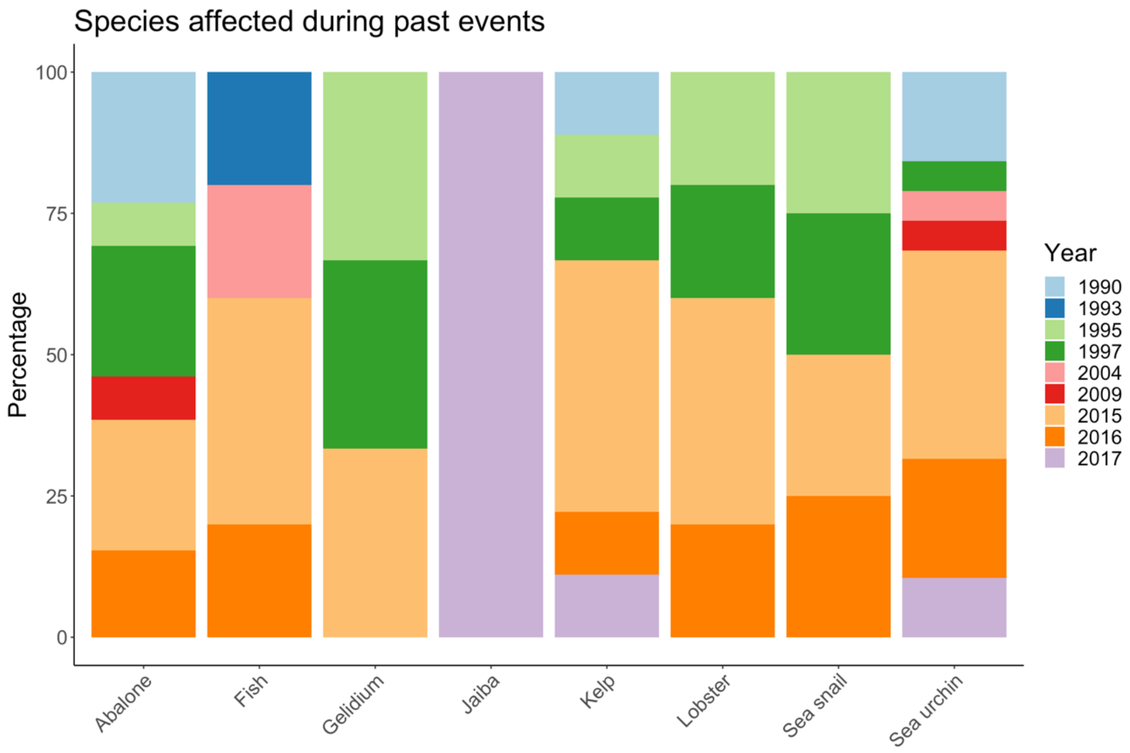


Figure 14. Years in which the interviewees recalled temperature anomalies (legend) and the respective species that were affected (x-axis). The y-axis represents the percentage of repeated responses in the interviews. All interviewees referred to anomalies that occurred at least 20 years before their current age.

3.2. *Which collective actions were used by the community?*

Through the interviews done, we identified the collective actions used to adapt to the unfavorable events that this community has faced through Galappaththi et al., (2019) conceptual framework (Table 6).

Table 6. Definitions of the components from Galappaththi's (2019) framework and their applications to this study case.

Component	Description	Application to the SES	Bibliography
Innermost layer: Place-based elements			
Place	Social and physical space that has place attachments to individuals (or cultural groups) and processors.	Rocky reef macroalgal forest	(Brown, 2016)
Agency	Individual's capacity to act independently in making his or her own decisions	Fishing cooperative	(McLaughlin & Dietz, 2008)
Institutions	Local organizations formed by the society to facilitate collective action that meets a local goal	Fishing cooperative	(E. Ostrom, 1990)

Local ecological knowledge (LEK)	Co-evolving cumulative body of knowledge (including observations, experience, lessons, and skills) belonging to a specific human-environment system (or place) and handed down through generations by cultural transmission	*Used in all decisions made by the Coop.	(Berkes, 2012)
Collective action	Actions taken together by a group of two or more people to meet a common desired objective.	*Base of the coop. and therefore, of all their actions	(E. Ostrom, 1990)
Middle layer: Katrina Brown's 3Rs of resilience			
Rootedness	Firmly associated with people, place, or space; cultural practices; social networks; and a wide range of affective ties to "home"	Fishing concession and fishing permits	(Brown, 2016)
Resistance	Ability and capacity of people to withstand external forces and to shape their own strategies.	*Includes all coping, adapting and transformative capacities actions	(Brown, 2016)
Resourcefulness	Capacity to use these resources at the right time and in the right way to harness the resources and human capacity together	Governmental bodies, national and international standardized certifications, ecolabels	(Brown, 2016)
Outermost layer: Christophe Bene's three dimensions of resilience (3D)			
Coping capacity	Actors' ability to draw on available skills, resources, and experiences as immediate responses for managing adverse stresses or shocks and maintaining persistence.	Search for new fishing sites, fish other species, fish in non-fishing areas or stop fishing temporarily	(Béné, Arthur, et al., 2016)
Adaptive capacity	Capacity to adjust and incremental changes in anticipation of or in response to change...	Modifying fishing gear, modifying "quotas" and implement tourism focus Establishing no-fishing zones, repopulation of abalone, removal of sea urchins and	(Brown, 2016)
Transformative capacity	Ability to create a new system with new fundamental characteristics when the existing system is untenable	multitrophic aquaculture, tourism focus, alternative workspaces	(Artic Council, 2013)

Starting with the innermost layer (Place-based elements), from the inside out, the first concept was the Place. In our study case we considered the marine ecosystem for this component. Specifically, local temperate rocky reefs, since most of the small-scale fishing is directly linked to species that inhabit these ecosystems. Given that these ecosystems are inherently defined by specific characteristics (e.g., rocky bottom, benthic macroalgae, etc.) they are not homogeneously distributed throughout the coast. However, the fishing cooperatives in Baja California have fishing "concessions" limiting their fishing activities to specific geographical areas, this term implies they have exclusivity for fishing specific resources in a given area, is the local term for the kind of fishing rights internationally recognized as TURF (Territorial User Rights to Fish). Therefore, the Place would be physically limited to the rocky reef ecosystems found within this concession. This limitation would also be directly related to the Rootedness of the cooperative, which we discuss later when talking about the intermediate layer.

Surrounding the Place, the framework identifies four characteristics: Institutions, Agencies, Collective Actions and Local Ecological Knowledge (LEK).

In our study case, the Institutions and the Agency can be identified with the same element: the fishing cooperative. In this fishing community, the cooperative acts as the main structural and administrative body of the small-scale fishery. It has access to different resources in order to provide new technologies and apply fishing strategies. As choices are taken collectively in assemblies, fishers may still express themselves as individuals. Therefore, fishers individually cannot make changes that affect the cooperative, but they may provide their thoughts and opinions so that they might be adopted. On the other hand, collective actions and LEK are extremely related. This community is strongly based on collective actions since the Cooperative *per se*, arises from a collective organization of the fishers themselves. The highest-ranking positions in the cooperative (e.g., President, Chief of Security or Secretary) rotate and are elected by popular vote among the members (locally known as *socios*) by two councils, the administration and the surveillance. Also, the crucial or important decisions made by the leaders are discussed in general assemblies to involve all members of the cooperative, mandatorily they need to stablish accountability mechanisms. Most of the decisions discussed and made by the cooperative are based on their daily observations and experiences with the marine ecosystem. Thus, LEK was and still is a fundamental tool in the cooperative development.

The next layer of the framework is given by Katrina Brown's 3Rs of resilience: resistance, rootedness, and resourcefulness (Brown, 2016).

Fishing cooperatives in Baja California are limited to two types of fishing rights: fishing concessions (i.e., TURF) and fishing permits (access kind). Because of that, communities are strongly attached not only to the fishing areas but also to the surrounding that allows them to monitor, maintain and watch over the ecosystems (Rootedness). In our study case, the cooperative has used surveillance sites like lighthouses and the surroundings coast of the fishing area to warn the presence of poachers (based on non-participant observations). They also have taken care of the terrestrial environment and improve common facilities such as public bathrooms, access ramp for boats, building fishers houses for the fishing seasons, constructions or material storage systems and avoiding contamination from land to the sea (based on non-participant observations) to improve the life quality in the fishing village.

Since the cooperative was stablished, the ecosystem has been affected by a wide range of environmental variations (e.g., temperature variations, heat waves, hypoxia or massive mortalities) (Resistance). The fact that the cooperative is still operational can be attributed to the ability that the fishing community has been gaining over time confronting different environmental changes. This shows the strength that the cooperative has had in decision-making to resist and adapt favorably for the community. The examples of adaptations that the cooperative has made over time are strongly linked to the most external components of the framework (outermost layer: coping, adapting and transformative capacities) and are discussed in the next paragraph.

Over the years, the cooperative has been forced to modify the way of fishing, the fishing gear (for example modifying lobster traps to be more environmentally friendly in case of loss or misplacement) or the way of processing the product (for example implementing smoked or canned products for which they needed new specific machinery) due to changes in fishing laws and regulations (Resourcefulness). To adapt, they relied on different types of organizations.
As examples of bodies responsible for compliance with fishing regulations, the interviewees mentioned CONAPESCA (*Comisión Nacional de Acuacultura y Pesca*) and SEPESCA (*Secretaria de Pesca y Acuacultura*), which are the national and state regulatory governmental bodies, respectively. These are in charge of developing plans focused on a better development of the fishing activity, promoting productivity, prevention, as well as ensuring compliance with the law on the matter. The interviewed also remarked inspections from SENASICA (*Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria*), which is in charge of carrying out epidemiological surveillance, reduction of contamination risks, and inspection of imports, exports of agricultural and fishing production.
Likewise, new forms of fishing products validation have emerged with the purpose of guaranteeing quality products that follow standardized protocols national and internationally. For example, they use NADIR (Platform for the traceability of fishery products), a platform which allows them to comply with international recommendations and access high-value markets. Furthermore, the fishing cooperative also follows a standardized business model, which supports sustainable fishing and supplies and sells exclusively responsible seafood promoting fishery improvement projects (FIP) and aquaculture improvement projects (AIP).

The outermost layer of the framework belongs to the three dimensions of resilience (3D) from Christophe Bene, who considers resilience as the combined result of coping, adapting and transforming (Béné et al., 2014). Adapting these concepts definitions to the interview responses, we have been able to identify some of the actions carried out by the cooperative over time. As coping capacities, we identified that after severe environmental changes (ENSO, Blob, etc.) , the community took the following actions: search for new fishing sites, diversify their fishing effort (fish other species), stablish some community no-fishing zones who act as reservoir that their used in some moment (fish in non-fishing areas) or stop fishing temporarily. On the other hand, as adaptive capacities, the changes made by the community include: modifying fishing gear, modifying “quotas” and implement tourism focus (Figure 3). Some transformative capacities actions taken by the cooperative were: establishing no-fishing zones, repopulation of abalone, removal of sea urchins and multitrophic aquaculture (*Figure 15*). In addition, the interviewees were asked about future possible adaptations regarding tourism in the area. Tourism is currently very low, but the area has the potential to attract tourists, especially, as they mentioned, in areas such as sport fishing, recreational diving or surfing.

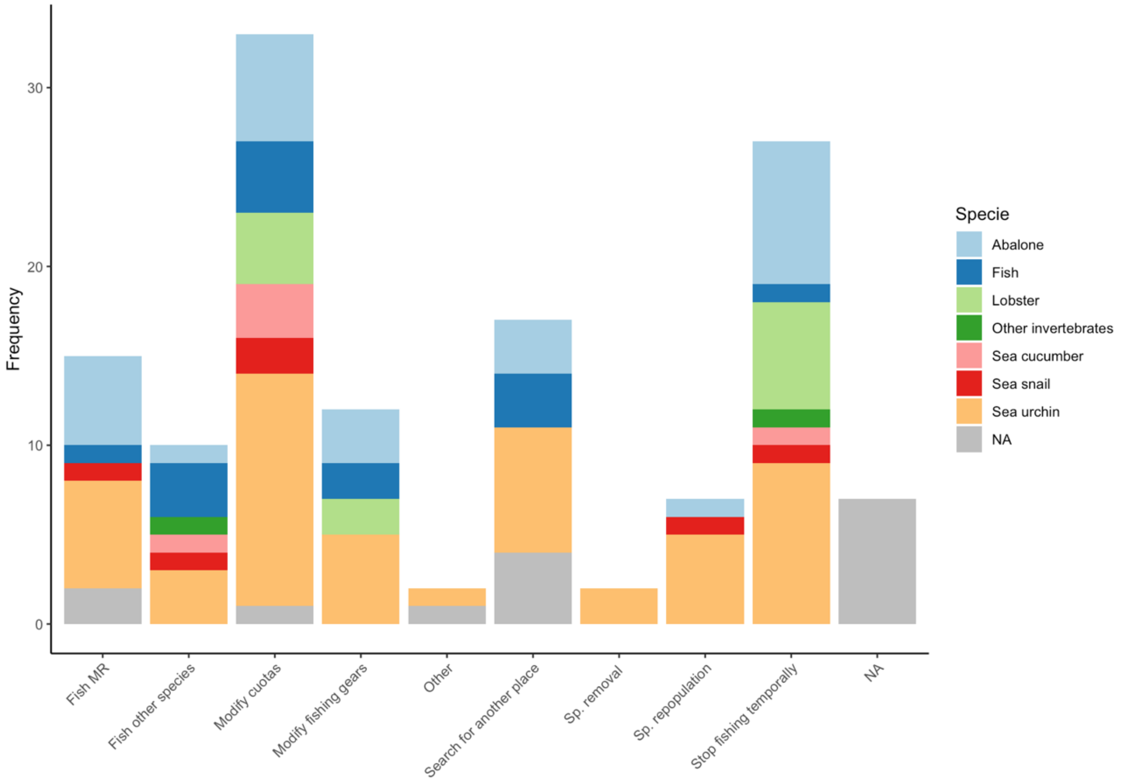


Figure 15. Community adaptations to environmental variations (x-axis) and the respective species in which they were implemented (legend). The y-axis represents the frequency of repeated responses in the interviews.

4. Discussion

4.1. How is the community structured and which is its climate change background?

This work allowed us to identify the strengths and weaknesses of this social-ecological system over the years. Some of the main findings are related with the, as was expected, low recognition of the female relevance despite its crucial role at the fishery. Another relevant issue was the youth participation, mainly relegated to manual tasks with low responsibilities and recognition. Furthermore, it is noteworthy that although the majority of respondents have a high school degree, more than half of them have been working in the cooperative for more than ten years.

Through the interviewed part of the community, we observe a male predominance. This result is not surprising since it is known that the presence of women in SSF is often ignored despite the fact that they represent 47% of the global fisheries workforce (FAO, 2022). In Mexico, women generally occupy jobs related to the pre- or post-processing of the product and have difficulties to reach positions in the decision-making arenas. This is due to the fact that women may have to divide their time with unpaid work such as housekeeping (Solano et al., 2021). On the other hand, it has been proved that when mixed-gender groups develop resources management, favors their functioning as well as the conditions of natural resources. This is consistent with what was observed in recent years, were women are becoming more involved in fishing activities that were previously strictly related to the male gender (Revollo-Fernández et al., 2016).

The average age among the interviewed people was around 30-40 years old, implying that this is a mature community where a large part of the employees has been working in the cooperative for more than 10 years. This seniority provides great cumulative knowledge about both the cooperative and the marine ecosystem functioning; or what is the same, LEK (Berkes et al., 2000). On the other hand, a mature community may imply low adaptability to new fishing methods, processing or management strategies (Marshall & Marshall, 2007). To increase the cooperative's adaptive capacity is necessary to involve the youth in the managerial tasks, not only relegate them to the manual tasks. Despite this is a very common scenario across Mexican fisheries, even those sustainable ones (Espinoza-Tenorio et al., 2022).

Regarding their climate change background, we have seen how this community has faced several environmental scenarios with different levels of impact on the ecosystems over the years. One of the most reported by the interviewees was the El Niño of 1997-1998. It came from a strong transition from the previous cold conditions (1996-1997) with the later Niña of 1998-1999 (Jacox et al., 2016). This transition generated very drastic changes in the chemistry, physics and biology of the California Current, up to the point to affect our study case community which is at the southernmost part of the influence of this current. Also, the period from 2014 to 2016, which affected all species reported by interviewees, corresponds to an unusual increase produced by the "Warm Blob" and a strong positive ENSO in the North Pacific (Beas-Luna et al., 2020). In contrast to the El Niño of 1997-1998, the one in 2015-2016 occurred when the waters of the Tropical Pacific were already abnormally warm. However, the repercussions produced in the marine environment are comparable between both events (Jacox et al., 2016). Nonetheless, the adaptive capacity that this community has shown is astonishing. According to the framework, the cooperative provides great stability to the community and its reliable governance structure has allowed innovative management schemes to be applied, such as establishing no-fishing zones, repopulation of abalone or mariculture. We believe that the use of novel methods or procedures benefits both the fishing industry and its users. It gives them new ways to make money and resources, keeps them in touch with science and the newest fields of study or concepts, and helps them communicate better among themselves and with other entities so that they can comprehend and maintain these practices.

4.2. Which collective actions were used by the community?

Understanding both social and ecological backgrounds is essential to create actions to enhance the SES capacity against uncertainty and change (Olsson et al., 2004). In this study, according to Galappathithi's conceptual framework, our results showed that the good structure of the cooperative *per se* is the key element for the success of this fishing community. As our results showed, this cooperative has adapted to both environmental and anthropogenic changes (e.g., new fishing gear, new processing techniques or new markets) always in the same area because of the fishing concessions. Because of that, fishers had to take care by themselves of the fishing concession and the adjacent land areas developing actions directly related to Rootedness (third layer of the framework). Hence, the organizational capacity of SSF extends, from the fishing aspects to environmental management strategies (Sánchez et al., 2011).

Local Ecological Knowledge (LEK) has been the main source of information for the decision-making process for this community throughout the 80 years it has been operating. It is based on the daily experiences and observations from the community members and has led them to act in different ways according to the circumstances (R. Hamilton et al., 2012). As in other SSFs (Johannes et al., 2000) through the experience and based on trial and error, users have been able to see which of the adaptations have been favorable to them or if, on the contrary, were disadvantageous.

In fact, the interviewees classified the adaptations made as favorable or unfavorable for the fishery according to their opinion. Our results remark the importance of the LEK for local decision-making, which has been mentioned in several studies across the region and other SSF worldwide (Berkström et al., 2019; R. Hamilton et al., 2012; Ramirez-Sanchez & Pinkerton, 2009). The way these decisions have been taken lead us to corroborate that the results of the adaptations carried out are context dependent (Young et al., 2018) hence the importance of the LEK for local decision-making. Since the social dynamics of this community is based on collective actions, LEK is extremely important and the fact that each individual can express their experiences enriches decision-making regarding the management of the community. This has been observed in other SSF of the region, Basurto documented the effect of collective action for the Seri fishing community (Basurto, 2008). Therefore, using LEK is an effective tool to foster the resilience of a SES in order to crate flexible management strategies (Folke et al., 2002).

However, LEK is not the only source of information that has guided the cooperative's development over the years. The use of scientific knowledge transmitted by external agents (such as academia, NGOs, or the government itself) has been increasing and improving over the years, helping the development of the community (Nenadović et al., 2016). There is a successful example of integrating research with the inhabitants on the Baja California peninsula. The study case is Isla Natividad, where inhabitants decided to establish protected marine areas. Due to their use, (Micheli et al., 2012) reported greater abalone recovery efficiency in a climate change real scenario. In our study area there are also some examples like establishment of no-fishing zones which were carried out by an initiative of the cooperative themselves with the support of COBI, a Mexican NGO (https://cobi.org.mx). Currently, the community also carries out annual subtidal monitoring and abalone repopulation (Bauer et al., 2020) , which have been initially promoted from studies by different researchers from the UABC (https://mex-cal.org/).

All the adaptations mentioned before, whether they had positive or negative effects, and developed by the Coop. or with outsiders help, are actually a set of Resistance strategies to face environmental changes. Therefore, place-based elements (fist framework's layer) such as institutions and agencies are directly linked to collective actions but also to Resistance, one of the components of the next layer of the framework. On the other hand, there are the adaptations that the community can make to fit into the world fishing standards, or the so-called Resourcefulness in this framework. These adaptations will allow to expand the market of the Coop. by following certain rules and quality standards. The main difference between these adaptations and those discussed as Resistance, is that the latter are given by environmental changes, while the Resourcefulness adaptations are given to comply with current social norms. Both types of adaptations are necessary for the proper development of communities. It is important to highlight the importance of a synergy between both types of adaptations since it favors the resilience of communities (Adger, 2003).

Finally, we identified that the three components compounding the last layer of the framework (three dimensions of resilience) differ from each other by reaction time. Coping capacity refers to immediate responses from the community to deal with variations in the ecosystem (Béné et al., 2014). While adaptation capacities refer to changes that the community can make in anticipation of these variations (Brown, 2016). Lastly, transformative capacities refer to the community's ability to transform or create new strategies when the system is unsustainable

(Artic Council, 2013). This is relevant because, when we tried to fit the adaptations made by the community in the three components, we saw that, some of the adaptations mentioned may fit into all three categories depending on the circumstances. For example, establishing no-fishing zones could have been given in anticipation of an unfavorable event (adaptation capacities), or as an immediate response to a specific environmental change (coping capacity), or as a response of the decline of the ecosystem due to continuous environmental or anthropogenic changes (transformative capacities). As a result of the compound application of adaptative, coping and transformative capacities, the cooperative has been able to open to new sources of income (e.g., abalone production) while maintaining the ecosystems' functionality (e.g., stablish no-fishing zones). This implies that the community was and still is open to new ways of adapting to current changing times. Also, the fact that they consider tourism as a future source of income is a sign that the cooperative is willing to invest time and money to diversify economically and opening up to new management and income strategies, which seems to be coherent with some frameworks that looks for promote and build the system's resilience (Biggs et al., 2015).

According to Finkbeiner (2015), resilient fisheries are those that have the ability to move between diversification and specialization strategies as they see fit. Diversification is an important factor in coping with environmental variations. Having a high capacity to diversify is more likely to benefit the community as it will allow to generate new incomes if conditions are different. On the other hand, specialization is what has positioned this community in both national and international markets due the consistency and high quality of the product. In our case of study, we have observed how over the years the community has been diversifying both in target species and the way of fishing and processing the product. However, we also consider this is a high specialized community in certain species such as lobster and abalone, since they have been performing this fishing since the cooperative was founded. Also, communities dependent on environmentally sensitive resources present a wider adaptation resources that favor their success to face environmental variations (Adger, 2003). Therefore, with all the results obtained in this work, we consider that this is a highly resilient community given its ability to adapt to unfavorable conditions while maintaining the essence and quality of their products.

Learned lessons

The community of El Rosario has shown its resilience to climate change variations over the years. They have been able to incorporate different adaptations in both their way of fishing and in their organization to overcome adversity. This work shows the learning path obtained by this community over the years, which can be extrapolated to other communities with similar characteristics. Creating an analytical framework from a conceptual one is always a difficult task. Since theoretical frameworks are generalists, we believe that this effort is a step forward in defining the notions of the conceptual framework in a specific example to identify the strengths and flaws that it may show in its application.

We believe the application of this conceptual framework is a good tool to better understand the structure of our community. It has helped us to understand the internal structure of the community, identify and see in a more organized way the actions carried out over time to adapt to changes and therefore it has allowed us to identify the lessons learned by the community. However, we conclude that it is not easy to isolate decision making or the application of new management strategies in individual concepts. Instead of an individualistic vision of the concepts, we have to tend towards a global and fluid conceptualization that can be adapted to the study case. In our particular study case, some of the concepts overlap while others are easily separable. This type of work is crucial since it identifies the actions carried out by the cooperative but also puts them in context. Therefore, it is necessary if we want to use those same adaptations again or in other similar fisheries, to understand whether they may work or not, and why.

References

Abdou, K., Halouani, G., Hattab, T., Romdhane, M. S., Lasram, F. B. R., & Le Loc'H, F. (2016). Exploring the potential effects of marine protected areas on the ecosystem structure of the Gulf of Gabes using the Ecospace model. *Aquatic Living Resources*, *29*(2). https://doi.org/10.1051/alr/2016014

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography*, *79*(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Albert, R., Jeong, H., & Barabási, A. L. (2000). Error and attack tolerance of complex networks. *Nature*, *406*, 378–382. https://doi.org/10.1515/9781400841356.503

Anuario Estadístico de Acuacultura y Pesca Edición. (2020).

Argüelles-Jiménez, J., Alva-Basurto, J. C., Pérez-España, H., Zetina-Rejón, M. J., & Arias-González, J. E. (2020). The measurement of ecosystem development in Caribbean coral reefs through topological indices. *Ecological Indicators*, *110*(July 2019), 105866. https://doi.org/10.1016/j.ecolind.2019.105866

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., Davidson-Hunt, I. J., Diduck, A. P., Doubleday, N. C., Johnson, D. S., Marschke, M., McConney, P., Pinkerton,

E. W., & Wollenberg, E. K. (2009). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment*, *7*(2), 95–102. https://doi.org/10.1890/070089

Babcock, R. C., Bustamante, R. H., Fulton, E. A., Fulton, D. J., Haywood, M. D. E., Hobday, A. J., Kenyon, R., Matear, R. J., Plagányi, E. E., Richardson, A. J., & Vanderklift, M. A. (2019). Severe continental-scale impacts of climate change are happening now: Extreme climate events impact marine habitat forming communities along 45% of Australia's coast. *Frontiers in Marine Science*, *6*(JUL), 1–14. https://doi.org/10.3389/fmars.2019.00411

Basurto, X. (2008). Biological and ecological mechanisms supporting marine self-governance: The Seri Callo de Hacha Fishery in Mexico. *Ecology and Society*, *13*(2). https://doi.org/10.5751/ES-02587-130220

Basurto, X., Gelcich, S., & Ostrom, E. (2013). The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change*, *23*(6), 1366–1380. https://doi.org/10.1016/j.gloenvcha.2013.08.001

Bauer, J., Lorda, J., Beas-Luna, R., Malpica-Cruz, L., Lafarga-De la Cruz, F., Micheli, F., Searcy-Bernal, R., Rogers-Bennett, L., & Bracamontes-Peralta, M. (2020). The effects of depth and diet on red abalone growth and survival in cage mariculture at San Jeronimo Island, Baja California, Mexico. *Ciencias Marinas*, *46*(4), 343–357. https://doi.org/10.7773/CM.V46I4.3117

Beas-Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*. University of California in Santa Cruz.

Beas-Luna, R., & Ladah, L. B. (2014). Latitudinal, seasonal, and small-scale spatial differences of the giant kelp, macrocystis pyrifera, and an herbivore at their southern range limit in the northern hemisphere. *Botanica Marina*, *57*(2), 73–83. https://doi.org/10.1515/bot-2013-0114

Beas-Luna, R., Micheli, F., Woodson, C. B., Carr, M., Malone, D., Torre, J., Boch, C., Caselle, J. E., Edwards, M., Freiwald, J., Hamilton, S. L., Hernandez, A., Konar, B., Kroeker, K. J., Lorda, J., Montaño-Moctezuma, G., & Torres-Moye, G. (2020). Geographic variation in responses of kelp forest communities of the California Current to recent climatic changes. *Global Change Biology*, *26*(11), 6457–6473. https://doi.org/10.1111/gcb.15273

Beas Luna, R. (2014). *Development and application of mass-balanced ecological network models for kelp forest ecosystems*.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S. H., Troell, M., & Williams, M. (2016). Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence. *World Development*, *79*, 177–196. https://doi.org/10.1016/j.worlddev.2015.11.007

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, *8*(1), 123–138. https://doi.org/10.1007/s12571-015-0526-x

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Review article: resilience, poverty and development. *Journal of International Development*, *23*, 598–623. https://doi.org/10.1002/jid

Bentley, J. W., Hines, D. E., Borrett, S. R., Serpetti, N., Hernandez-Milian, G., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Combining scientific and fishers' knowledge to co-create indicators of food web structure and function. *ICES Journal of Marine Science*, *76*(7), 2218–2234. https://doi.org/10.1093/icesjms/fsz121

Bentley, J. W., Serpetti, N., Fox, C., Heymans, J. J., & Reid, D. G. (2019). Fishers' knowledge improves the accuracy of food web model predictions. *ICES Journal of Marine Science*, *76*(4), 897–912. https://doi.org/10.1093/icesjms/fsz003

Berkes, F. (2003). Alternatives to conventional management: Lessons from small-scale fisheries. *Environments*, *31*(1), 5–20.

Berkes, F. (2012). *Sacred Ecology*. Routledge, New York.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Berkes, F., & Folke, C. (1998). *Linking social and ecological systems: management practices and social mechanisms for building resilience.*

Berkes, F., Folke, C., & Gadgill, M. (1994). Traditional Ecological Knowledge. *Biodiversity Conservation*, 269–287. https://doi.org/10.1007/978-94-007-0753-5_104248

Berkström, C., Papadopoulos, M., Jiddawi, N. S., & Nordlund, L. M. (2019). Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Frontiers in Marine Science*, *6*(MAR), 1–10. https://doi.org/10.3389/fmars.2019.00130

Bevilacqua, A. H. V., Carvalho, A. R., Angelini, R., & Christensen, V. (2016). More than anecdotes: Fishers' ecological knowledge can fill gaps for ecosystem modeling. *PLoS ONE*, *11*(5), 1–18. https://doi.org/10.1371/journal.pone.0155655

Biggs, R., Schlüter, M., & Schoon, M. L. (2015). "An introduction to the resilience approach and principles to sustain ecosystem services in social-ecological systems." In *Principles for building resilience: Sustaining ecosystem services in social–ecological systems* (pp. 1–31). https://doi.org/10.1086/696744%0Ahttps://doi.org/10.1086/696744

Bindoff, N. L., Cheung, W. W. L., Kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., Hilmi, N., Jiao, N., Karim, M. S., Levin, L., O'Donoghue, S., Cuicapusa, S. R. P., Rinkevich, B., Suga, T., Tagliabue, A., & Williamson, P. (2019). Changing Ocean, Marine Ecosystems, and Dependent Communities. *IPCC Special Report on the Ocean and*

Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.)]. In Press., 447–588.

Bodin, Ö. (2017). Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, *357*(6352). 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

Bonacich, P. (1987). Power and Centrality: A Family of Measures. *American Journal of Sociology*, *92*, 1170–1182.

Borer, E. T., Halpern, B. S., & Seabloom, E. W. (2006). Asymmetry in community regulation: Effects of predators and productivity. *Ecology*, *87*(11), 2813–2820. https://doi.org/10.1890/0012-9658(2006)87[2813:AICREO]2.0.CO;2

Borrett, S. R., Moody, J., & Edelmann, A. (2014). The rise of Network Ecology: Maps of the topic diversity and scientific collaboration. *Ecological Modelling*, *293*, 111–127. https://doi.org/10.1016/j.ecolmodel.2014.02.019

Brandes, U. (2001). The Journal of Mathematical A faster algorithm for betweenness centrality. *Journal of Mathematical Sociology*, *March 2012*, 37–41.

Brown, K. (2016). Resilience, development and global change. In *Resilience, Development and Global Change*. https://doi.org/10.4324/9780203498095

Bryndum-Buchholz, A., Tittensor, D. P., Blanchard, J. L., Cheung, W. W. L., Coll, M., Galbraith, E. D., Jennings, S., Maury, O., & Lotze, H. K. (2019). Twenty-first-century climate change impacts on marine animal biomass and ecosystem structure across ocean basins. *Global Change Biology*, *25*(2), 459–472. https://doi.org/10.1111/gcb.14512

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J., & Schmitt, R. J. (2011). Climate-driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*, *17*(8), 2513–2524. https://doi.org/10.1111/j.1365-2486.2011.02409.x

Carpenter, S. R., Kitchell, J. F., & Hodgson, J. R. (1985). Fish predation and herbivory can regulate lake ecosystems. *BioScience*, *35*(10), 634–639.

Cavole, L. M., Andrade-Vera, S., Marin Jarrin, J. R., Dias, D. F., Aburto-Oropeza, O., & Barrágan-Paladines, M. J. (2020). Using local ecological knowledge of Fishers to infer the impact of climate variability in Galápagos' small-scale fisheries. *Marine Policy*, *121*(January), 1–10. https://doi.org/10.1016/j.marpol.2020.104195

Christensen, V., & Walters, C. J. (2004). Ecopath with Ecosim: Methods, capabilities and limitations. *Ecological Modelling*, *172*(2–4), 109–139. https://doi.org/10.1016/j.ecolmodel.2003.09.003

Cisneros-Montemayor, A. M., Zetina-Rejón, M. J., Espinosa-Romero, M. J., Cisneros-Mata, M.

A., Singh, G. G., & Fernández-Rivera Melo, F. J. (2020). Evaluating ecosystem impacts of data-limited artisanal fisheries through ecosystem modelling and traditional fisher knowledge. *Ocean and Coastal Management*, *195*(February). https://doi.org/10.1016/j.ocecoaman.2020.105291

Clauset, A., Newman, M. E. J., & Moore, C. (2004). Finding community structure in very large networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *70*(6), 6. https://doi.org/10.1103/PhysRevE.70.066111

CONAPESCA. (2016). *Carta Nacional Pesquera, Mexico*.

Council, A. (2013). Arctic Resilience Interim Report 2013. *Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm, Pp. Ix–Xii.*

Csárdi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *Interj. Compl. Sys.* https://doi.org/10.3724/sp.j.1087.2009.02191

Dayton, P. K. (1985). Ecology of Kelp Communities. *Annual Review of Ecology and Systematics*, *16*(1985), 215–245. https://doi.org/https://doi.org/10.1146/annurev.es.16.110185.001243

De Melo Alves Damasio, L., Lopes, P. F. M., Guariento, R. D., & Carvalho, A. R. (2015). Matching Fishers' knowledge and landing data to overcome data missing in small-scale fisheries. *PLoS ONE*, *10*(7), 1–13. https://doi.org/10.1371/journal.pone.0133122

Delgado-Serrano, M. del M., Oteros-Rozas, E., Vanwildemeersch, P., Ortíz-Guerrero, C., London, S., & Escalante, R. (2015). Local perceptions on social-ecological dynamics in latin america in three community-based natural resource management systems. *Ecology and Society*, *20*(4). https://doi.org/10.5751/ES-07965-200424

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate Change Impacts on Marine Ecosystems. *Annual Review of Marine Science*, *4*(1), 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

Eddy, T. D., Lotze, H. K., Fulton, E. A., Coll, M., Ainsworth, C. H., de Araújo, J. N., Bulman, C. M., Bundy, A., Christensen, V., Field, J. C., Gribble, N. A., Hasan, M., Mackinson, S., & Townsend, H. (2017). Ecosystem effects of invertebrate fisheries. *Fish and Fisheries*, *18*(1), 40–53. https://doi.org/10.1111/faf.12165

Edwards, M. S., & Estes, J. A. (2006). Catastrophe, recovery and range limitation in NE Pacific kelp forests: A large-scale perspective. *Marine Ecology Progress Series*, *320*, 79–87. https://doi.org/10.3354/meps320079

Espinoza-Tenorio, A., Ehuan-Noh, R. G., Cuevas-Gómez, G. A., Narchi, N. E., Ramos-Muñoz, D. E., Fernández-Rivera Melo, F. J., Saldívar-Moreno, A., Zepeda-Domínguez, J. A., Pérez-Jiménez, J. C., Oliveto-Andrade, A., & Torre, J. (2022). Between uncertainty and hope: Young leaders as agents of change in sustainable small-scale fisheries. *Ambio*, *51*(5), 1287–1301. https://doi.org/10.1007/s13280-021-01639-2

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. In *FAO*. https://doi.org/10.4060/cc0461en

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

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

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

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio*, *31*(5), 437–440. https://doi.org/10.1579/0044-7447-31.5.437

Folke, C., Pritchard, L., Berkes, F., Colding, J., & Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-02064-120130

Foster, M., & Schiel, D. (1985). Ecology of giant kelp forests in California: a community profile. *United States Fish and Wildlife Service Biological Report*, *85*, 1–152. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5129110

Freeman, L. (1979). Centrality in networks: I: Conceptual Clarification. *Social Networks*, *1*, 215–239.

Froeser, R., & Pauly, D. (2016). *FishBase*. World Wide Web Electronic Publication.

Galappaththi, E. K., Ford, J. D., & Bennett, E. M. (2019). A framework for assessing community adaptation to climate change in a fi sheries context. *Environmental Science and Policy*, *92*(November 2018), 17–26. https://doi.org/10.1016/j.envsci.2018.11.005

García-Quijano, C. G. (2007). Fishers' Knowledge of Marine Species Assemblages: Bridging between Scientific and Local Ecological Knowledge in Southeastern Puerto Rico. *American Anthropologist*, *109*(3), 529–536. https://doi.org/10.1525/AA.2007.109.3.529.530

Gaspare, L., Bryceson, I., & Kulindwa, K. (2015). Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of groupers (Epinephelinae) fisheries around Mafia Island, Tanzania. *Ocean and Coastal Management*, *114*, 88–101. https://doi.org/10.1016/j.ocecoaman.2015.06.011

Guimerà, R., Sales-Pardo, M., & Amaral, L. A. N. (2007). Module identification in bipartite and directed networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *76*, 036102.

Guimerà, R., Stouffer, D. B., Sales-Pardo, M., Leicht, E. A., Newman, M. E. J., & Amaral, L. A. N. (2010). Origin of compartmentalization in food webs. *Ecology*, *91*(10), 2941–2951. https://doi.org/10.1890/09-1175.1

Halouani, G., Abdou, K., Hattab, T., Romdhane, M. S., Ben Rais Lasram, F., & Le Loc'h, F. (2016). A spatio-temporal ecosystem model to simulate fishing management plans: A case of study in the Gulf of Gabes (Tunisia). *Marine Policy*, *69*, 62–72. https://doi.org/10.1016/j.marpol.2016.04.002

Hamilton, R., Sadovy de Mitcheson, Y., & Aguilar-Perera, A. (2012). The Role of Local Ecological Knowledge in the Conservation and Management of Reef Fish Spawning Aggregations. In C. P. (eds) In: Sadovy de Mitcheson Y. (Ed.), *Reef Fish Spawning Aggregations: Biology, Research and Management. Fish & Fisheries Series*. Springer, Dordrecht. https://doi.org/https://doi.org/10.1007/978-94-007-1980-4_10

Hamilton, S. L., Gleason, M. G., Godoy, N., Eddy, N., & Grorud-Colvert, K. (2022). Ecosystem-based management for kelp forest ecosystems. *Marine Policy*, *136*, 104919. https://doi.org/10.1016/j.marpol.2021.104919

Heath, M. R., Speirs, D. C., & Steele, J. H. (2014). Understanding patterns and processes in models of trophic cascades. *Ecology Letters*, *17*(1), 101–114. https://doi.org/10.1111/ele.12200

Heymans, J. J., Coll, M., Link, J. S., Mackinson, S., Steenbeek, J., Walters, C., & Christensen, V. (2016). Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. *Ecological Modelling*, *331*, 173–184. https://doi.org/10.1016/j.ecolmodel.2015.12.007

Hind, E. J. (2014). A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. *ICES Journal of Marine Science*, *72*(2), 341–358. https://doi.org/10.1093/icesjms/fsu169

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

IPCC. (2014). *Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.)).

IPCC. (2021). *Climate Change 2021: The Physical Science Basis Summary for Policymakers*

Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (V. Masson-Delmotte, P. Zhai, S. L. C. A. Pirani, S. B. C. Péan, Y. C. N. Caud, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & and B. Zhou (Eds.)). Cambridge University Press. In Press.

ISE. (2006). *International Society of Ethnobiology Code of Ethics (with 2008 additions).* http://ethnobiology.net/code-of-ethics/

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J., & Warner, R. R. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*, *293*, 629–637. https://doi.org/10.1126/science.1059199

Jacox, M. G., Hazen, E. L., Zaba, K. D., Rudnick, D. L., Edwards, C. A., Moore, A. M., & Bograd, S. J. (2016). *Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events*. 7072–7080. https://doi.org/10.1002/2016GL069716.Received

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01462-110115

Johannes, R. ., & Neis, B. (2007). The value of anecdote. In *Fishers' knowledge in fisheries science and management. Coastal Management Sourcebooks* (Vol. 4, Issue 3, pp. 41–58). https://doi.org/10.1016/j.avsg.2014.01.003

Johannes, R. E., Freeman, M. M. R., & Hamilton, R. J. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, *1*(3), 257–271. https://doi.org/10.1111/j.1467-2979.2000.00019.x

Johnson, A. F., Moreno-Baez, M., Giron-Nava, A., Corominas, J., Erisman, B., Ezcurra, E., & Aburto-Oropeza, O. (2017). A spatial method to calculate small-scale fisheries effort in data poor scenarios. *PLoS ONE*, *12*(4), 1–17. https://doi.org/10.1371/journal.pone.0174064

Kluger, L. C., Gorris, P., Kochalski, S., Mueller, M. S., & Romagnoni, G. (2020). Studying human–nature relationships through a network lens: A systematic review. *People and Nature*, *2*(4), 1100–1116. https://doi.org/10.1002/pan3.10136

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*(July), 104861. https://doi.org/10.1016/j.ocecoaman.2019.104861

Kobluk, H. M., Gladstone, K., Reid, M., Brown, K., Krumhansl, K. A., & Salomon, A. K. (2021). Indigenous knowledge of key ecological processes confers resilience to a small-scale kelp fishery. *People and Nature*, *3*(3), 723–739. https://doi.org/10.1002/pan3.10211

Krause, A. E., Frank, K. A., Mason, D. M., Ulanowicz, R. E., & Taylor, W. W. (2003). Compartments revealed in food-web structure. *Nature*, *426*, 282–285.

Kroeker, K. J., Gambi, M. C., & Micheli, F. (2013). Community dynamics and ecosystem simplification in a high-CO2 ocean. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(31), 12721–12726. https://doi.org/10.1073/pnas.1216464110

Lorda, J., Beas, R., Bell, T., & Barbara, S. (2018). *Producción primaria bruta en bosques submarinos de la región Bahía Todos*. *December*.

Mackinson, S. (2001). Integrating local and scientific knowledge: An example in fisheries science. *Environmental Management*, *27*(4), 533–545. https://doi.org/10.1007/s002670010168

Marshall, N. A., & Marshall, P. A. (2007). Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. *Ecology and Society*, *12*(1). https://doi.org/10.5751/ES-01940-120101

McCay, B. J., Micheli, F., Ponce-díaz, G., Murray, G., Shester, G., Ramirez-sanchez, S., & Weisman, W. (2014). Cooperatives , concessions , and co-management on the Paci fi c coast of Mexico. *Marine Policy*, *44*, 49–59. https://doi.org/10.1016/j.marpol.2013.08.001

McLaughlin, P., & Dietz, T. (2008). Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change*, *18*(1), 99–111. https://doi.org/10.1016/j.gloenvcha.2007.05.003

MEA. (2005). Ecosystems and human well-being: Wetland and water. In *Synthesis. Available online: http:// …*. http://millenniumassessment.org/documents/MA_wetlands&water-Chinese.pdf

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza Montes, J. A., Rossetto, M., & de Leo, G. A. (2012). Evidence that marine reserves enhance resilience to climatic impacts. *PLoS ONE*, *7*(7). https://doi.org/10.1371/journal.pone.0040832

Morales-Zárate, M. V., Lluch-Cota, S. E., Serviere-Zaragoza, E., & del Próo, S. G. (2011). Modeling an exploited rocky coastal ecosystem: Bahia Tortugas, Mexico. *Ecological Modelling*, *222*(5), 1185–1191. https://doi.org/10.1016/j.ecolmodel.2010.12.011

MSC. (2018). MSC Fisheries Standard v2.01. *Marine Stewardship Council*, *August*. https://www.msc.org/docs/default-source/default-document-library/for-business/program-documents/fisheries-program-documents/msc-fisheries-standard-v2-01.pdf?sfvrsn=8ecb3272_19#page=182&zoom=100,92,674

Munguia-Vega, A., Green, A. L., Suarez-Castillo, A. N., Espinosa-Romero, M. J., Aburto-

Oropeza, O., Cisneros-Montemayor, A. M., Cruz-Piñón, G., Danemann, G., Giron-Nava, A., Gonzalez-Cuellar, O., Lasch, C., del Mar Mancha-Cisneros, M., Marinone, S. G., Moreno-Báez, M., Morzaria-Luna, H. N., Reyes-Bonilla, H., Torre, J., Turk-Boyer, P., Walther, M., & Weaver, A. H. (2018). Ecological guidelines for designing networks of marine reserves in the unique biophysical environment of the Gulf of California. *Reviews in Fish Biology and Fisheries*, *28*(4), 749–776. https://doi.org/10.1007/s11160-018-9529-y

Munguia-Vega, A., Zepeda-Dominguez, J. A., Perez-Alarcon, M. F., Amador-Castro, I. G., Fulton, S., Walther, M., Rodriguez-Fuentes, M., Fumero-Andreu, C. M., & Torre, J. (2022). Social-ecological networks and connectivity within and between two communities of small-scale fishers in Mexico. *Ecology and Society*, *27*(1). https://doi.org/10.5751/es-13055-270124

Nenadović, M., Basurto, X., & Weaver, A. H. (2016). Contribution of Subsidies and Participatory Governance to Fishers' Adaptive Capacity. *Journal of Environment and Development*, *25*(4), 426–454. https://doi.org/10.1177/1070496516670448

Newman, M. E., & Girvan, M. (2004). Finding and evaluating community structure in networks. *Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics*, *69*, 026113.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75–90. https://doi.org/10.1007/s00267-003-0101-7

Ostrom, E. (1990). *Governing the Commons: the Evolution of Institutions for Collective Action.* Cambridge University Press, New York.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*, 419–422.

Ostrom, V., Tiebout, M., & Warren, R. (1961). The Organization of Government in Metropolitan Areas : A Theoretical Inquiry. *The American Political Science Review*, *55*(4), 831–842.

Overland, J. E., Alheit, J., Bakun, A., Hurrell, J. W., Mackas, D. L., & Miller, A. J. (2010). Climate controls on marine ecosystems and fish populations. *Journal of Marine Systems*, *79*(3–4), 305–315. https://doi.org/10.1016/j.jmarsys.2008.12.009

Parkes, G., Young, J. A., Walmsley, S. F., Abel, R., Harman, J., Horvat, P., Lem, A., Macfarlane, A., Mens, M., & Nolan, C. (2010). Behind the signs-a global review of fish sustainability information schemes. *Reviews in Fisheries Science*, *18*(4), 344–356. https://doi.org/10.1080/10641262.2010.516374

Pauly, D., & Christensen, V. (1995). Primary production required to sustain global fisheries. *Nature*, *374*, 255.

Peña-Puch, A. del C., Pérez-Jiménez, J. C., & Espinoza-Tenorio, A. (2020). Advances in the study of Mexican fisheries with the social-ecological system (SES) perspective and its inclusion in fishery management policy. *Ocean and Coastal Management*, *185*(May 2019). https://doi.org/10.1016/j.ocecoaman.2019.105065

Perera, A. H., Drew, C. A., & Johnson, C. J. (Eds.). (2011). *Expert knowledge and its application in landscape ecology*. Springer Science & Business Media.

Ponte, S. (2012). The Marine Stewardship Council (MSC) and the Making of a Market for "Sustainable Fish." *Journal of Agrarian Change*, *12*(2–3), 300–315. https://doi.org/10.1111/j.1471-0366.2011.00345.x

Ramirez-Sanchez, S., & Pinkerton, E. (2009). The impact of resource scarcity on bonding and bridging social capital: The case of fishers' information-sharing networks in Loreto, BCS, Mexico. *Ecology and Society*, *14*(1). https://doi.org/10.5751/es-02841-140122

Reed, D. C., Rassweiler, A., Carr, M. H., Cavanaugh, K. C., Malone, D. P., & Siegel, D. A. (2011). Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. *Ecology*, *92*(11), 2108–2116. https://doi.org/10.1890/11-0377.1

Restrepo-Gómez, D. C., Zetina-Rejón, M. J., & Zepeda-Domínguez, J. A. (2022). Trends in marine fisheries social-ecological systems studies. *Ocean and Coastal Management*, *220*(February). https://doi.org/10.1016/j.ocecoaman.2022.106076

Revollo-Fernández, D., Aguilar-Ibarra, A., Micheli, F., & Sáenz-Arroyo, A. (2016). Exploring the role of gender in common-pool resource extraction: evidence from laboratory and field experiments in fisheries. *Applied Economics Letters*, *23*(13), 912–920. https://doi.org/10.1080/13504851.2015.1119786

Romagnoni, G., Mackinson, S., Hong, J., & Eikeset, A. M. (2015). The Ecospace model applied to the North Sea: Evaluating spatial predictions with fish biomass and fishing effort data. *Ecological Modelling*, *300*, 50–60. https://doi.org/10.1016/j.ecolmodel.2014.12.016

Rosa, R., Carvalho, A. R., & Angelini, R. (2014). Integrating fishermen knowledge and scientific analysis to assess changes in fish diversity and food web structure. *Ocean and Coastal Management*, *102*(PA), 258–268. https://doi.org/10.1016/j.ocecoaman.2014.10.004

Sáenz-Arroyo, A., Roberts, C. M., Torre, J., Cariño-Olvera, M., & Enríquez-Andrade, R. R. (2005). Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1575), 1957–1962. https://doi.org/10.1098/rspb.2005.3175

Saldaña, A., Salas, S., Arce-Ibarra, A. M., & Torres-Irineo, E. (2016). Fishing operations and adaptive strategies of small-scale fishers: insights for fisheries management in data-poor situations. *Fisheries Management and Ecology*, *24*(1), 19–32. https://doi.org/10.1111/fme.12199

Sánchez, S. R., J. McCay, B., R. Johnson, T., & Weisman, W. (2011). Surgimiento, formación y persistencia de organizaciones sociales para la pesca ribereña de la península de Baja California. *Región y Sociedad*, *23*(51). https://doi.org/10.22198/rys.2011.51.a35

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). https://doi.org/10.1088/1748-9326/ab2619

Schlenger, A. J., Beas-Luna, R., & Ambrose, R. F. (2021). Forecasting ocean acidification impacts on kelp forest ecosystems. *PLoS ONE*, *16*(4 April 2021), 1–24. https://doi.org/10.1371/journal.pone.0236218

Shabtay, A., Portman, M. E., Ofir, E., Carmel, Y., & Gal, G. (2018). Using ecological modelling in marine spatial planning to enhance ecosystem-based management. *Marine Policy*, *95*(January), 14–23. https://doi.org/10.1016/j.marpol.2018.06.018

Solano, N., Lopez-Ercilla, I., Fernandez-Rivera Melo, F. J., & Torre, J. (2021). Unveiling Women's Roles and Inclusion in Mexican Small-Scale Fisheries (SSF). *Frontiers in Marine Science*, *7*(January), 1–14. https://doi.org/10.3389/fmars.2020.617965

Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., Mackinson, S., Dankel, D. J., Brooks, K., & Benson, A. (2016). *Integrating fishers' knowledge research in science and management*. *73*, 1459–1465.

Stouffer, D. B., & Bascompte, J. (2011). Compartmentalization increases food-web persistence. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(9), 3648–3652. https://doi.org/10.1073/pnas.1014353108

Thompson, R. M., Brose, U., Dunne, J. A., Hall, R. O., Hladyz, S., Kitching, R. L., Martinez, N. D., Rantala, H., Romanuk, T. N., Stouffer, D. B., & Tylianakis, J. M. (2012). Food webs: Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution*, *27*(12), 689–697. https://doi.org/10.1016/j.tree.2012.08.005

Torre, J., Hernandez-Velasco, A., Rivera-Melo, F. F., Lopez, J., & Espinosa-Romero, M. J. (2019). Women's empowerment, collective actions, and sustainable fisheries: lessons from Mexico. *Maritime Studies*, *18*(3), 373–384. https://doi.org/10.1007/s40152-019-00153-2

Vilalta-Navas, A., Beas-Luna, R., Calderon-Aguilera, L. E., Ladah, L., Micheli, F., Christensen, V., & Torre, J. (2018). A mass-balanced food web model for a kelp forest ecosystem near its southern distributional limit in the northern hemisphere. *Food Webs*, *16*, e00091. https://doi.org/10.1016/j.fooweb.2018.e00091

Vilalta-Navas, A., Beas-Luna, R., Zetina-rejón, M. J., Lopez-Ibarra, G. A., Malpica-Cruz, L., Lorda, J., Zepeda-Dominguez, J. A., & Kluger, L. C. (2022). Coupling scientific and local ecological knowledge network models for temperate coastal ecosystems. *ICESJournal OfMarine Science*, 1–12. https://doi.org/10.1093/icesjms/fsac225

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications.*

West, D. . (1996). Introduction to Graph Theory. *Upper Saddle River, N.J.: Prentice Hall.*

Wu, H. (2017). A Conference to #SaveOurOcean. *UN Chronicle, 54/2,*.

Yletyinen, J., Hentati-Sundberg, J., Blenckner, T., & Bodin, Ö. (2018). Fishing strategy diversification and fishers' ecological dependency. *Ecology and Society*, *23*(3). https://doi.org/10.5751/ES-10211-230328

Young, O. R., Webster, D. G., Cox, M. E., Raakjær, J., Blaxekjær, L. Ø., Einarsson, N., Virginia, R. A., Acheson, J., Bromley, D., Cardwell, E., Carothers, C., Eythórsson, E., Howarth, R. B., Jentoft, S., McCay, B. J., McCormack, F., Osherenko, G., Pinkerton, E., van Ginkel, R., … Wilson, R. S. (2018). Moving beyond panaceas in fisheries governance. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(37), 9065–9073. https://doi.org/10.1073/pnas.1716545115

Zador, S. G., Gaichas, S. K., Kasperski, S., Ward, C. L., Blake, R. E., Ban, N. C., Himes-Cornell, A., & Zachary Koehn, J. (2017). Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. *ICES Journal of Marine Science*, *74*(7), 2024–2033. https://doi.org/10.1093/icesjms/fsx054

Zepeda-Domínguez, J. A., Vergara-Rodarte, M., Gómez, A., Espinosa-Romero, M. J., Espinoza-Tenorio, A., & López-López, D. (2019). Beneficios de las ecoetique as en pesquerías en vías de desarrollo, capítulo México. *Gobernanza Pesquera:México y España*.

Zetina-Rejón, M. J., Cabrera-Neri, E., López-Ibarra, G. A., Arcos-Huitrón, N. E., & Christensen, V. (2015). Trophic modeling of the continental shelf ecosystem outside of Tabasco, Mexico: A network and modularity analysis. *Ecological Modelling*, *313*, 314–324. https://doi.org/10.1016/j.ecolmodel.2015.07.001

Zetina-Rejón, M. J., López-Ibarra, G. A., Rocha-Tejeda, L., Flores-Guzmán, A., López-Ercilla, I., Rodríguez-Rodríguez, E., Sandoval-Jiménez, S. A., Arreguín-Sánchez, F., & Cisneros-Montemayor, A. M. (2022). A Framework for Simulating Ecosystem Effects in Data-Poor Small-Scale Fisheries Using Science-Based and Local Ecological Knowledge-Based Models. *Frontiers in Marine Science*, *8*(January), 1–14. https://doi.org/10.3389/fmars.2021.799068

Zetina-Rejón, M. J., Zepeda-Domínguez, J. A., Rodríguez-Fuentes, M., & Fumero-Andreu, C. M. (2020). Stakeholder diversity correlates with governance network performance in two artisanal fisheries in Northwest Mexico. *Ocean and Coastal Management*, *196*(March). https://doi.org/10.1016/j.ocecoaman.2020.105313

DISSERTATION GENERAL CONCLUSIONS

In this thesis, I carry out a comprehensive study of the social-ecological system of El Rosario in Baja California, Mexico, as a case study. The comparison of the two ecotrophic models in Chapter I is the first step towards valuing the residents' ecological knowledge. Then it is linked to a social network of the fishing community via the LEK-based network. To determine their relationship with one another (Chapter II). The social aspect of the community is then studied in depth, taking into account the interviewees' backgrounds as well as how the community has dealt with environmental changes through time and what adjustments have been made to keep them becoming better over time (Chapter III).

On the other hand, I combine many disciplinary perspectives in my thesis, both separately and together. I use a multidisciplinary approach in the first chapter because I compare two different forms of information, each of which derives from a distinct discipline. While LEK information originates from social science, CSK knowledge is derived from the most fundamental branch of science. However, because I examine both models using the same analyses and then adapt them so that both forms of knowledge can respond, this multidisciplinary method turns into an interdisciplinary one.

The second chapter, on the other hand, directly starts with a multidisciplinary approach as I link the social network of the fishing community with the ecotrophic web of the marine ecosystem to examine how they can interact. To provide a deeper knowledge of the structure and operation of both ecosystems and the human groups that depend on them, these kinds of techniques are crucial. As I am considering both the social and ecological components, this method is highly helpful for creating management structures and/or ecosystem management.

Finally, I take a multidisciplinary approach in the third chapter because I tie it to unfavorable environmental phenomena and how the community responds to them based on the knowledge of the locals. This has given me the opportunity to thoroughly understand the strategy that the fishing community has employed over time, and this chapter can act as a starting point for decision-making in the future.

In this thesis dissertation, there are, in my opinion, a variety of unique techniques, such as the validation of the LEK against the CSK when comparing two models from the same area. The creation of a SES network and how it responds using different environmental and social scenarios. And lastly, the use of a conceptual model to analyze a case study to determine its advantages and disadvantages. In conclusion, I believe that the complexity of this work may be utilized in the future as the basis for other works as well as a basis for developing management strategies in this particular fishing community.

CONCLUSIONES GENERALES

En esta tesis realizo un estudio integral del sistema social-ecológico de El Rosario en Baja California, México como caso de estudio. La comparación de los dos modelos ecotróficos en el Capítulo I es el primer paso para valorar el conocimiento ecológico de los residentes. Luego se vincula a una red social de la comunidad pesquera a través de la red basada en LEK. para determinar su relación entre sí (Capítulo II). Luego se estudia en profundidad el aspecto social de la comunidad, teniendo en cuenta los antecedentes de los entrevistados, así como la forma en que la comunidad ha enfrentado los cambios ambientales a lo largo del tiempo y qué ajustes se han hecho para que sigan mejorando con el tiempo. futuro (Capítulo III).

Por otro lado, combino muchas perspectivas disciplinarias en mi tesis, tanto por separado como en conjunto. Utilizo un enfoque multidisciplinario en el primer capítulo porque comparo dos formas diferentes de información, cada una de las cuales se deriva de una disciplina distinta. Mientras que la información LEK se origina en una ciencia social, el conocimiento CSK se deriva de la rama más fundamental de la ciencia. Sin embargo, debido a que examino ambos modelos utilizando los mismos análisis y luego los adapto para que ambas formas de conocimiento puedan responder, este método multidisciplinario se convierte en uno interdisciplinario.

El segundo capítulo, por otro lado, comienza directamente con un enfoque multidisciplinario ya que vinculo la red social de la comunidad pesquera con la red ecotrófica del ecosistema marino para examinar cómo pueden interactuar. Para proporcionar un conocimiento más profundo de la estructura y funcionamiento tanto de los ecosistemas como de los grupos humanos que dependen de ellos, este tipo de técnicas son cruciales. Como estoy considerando tanto los componentes sociales como los ecológicos, este método es muy útil para crear estructuras de gestión y/o gestión de ecosistemas.

Finalmente, utilizo un enfoque multidisciplinario en el tercer capítulo porque lo vinculo a los fenómenos ambientales desfavorables y cómo la comunidad responde a ellos con base en el conocimiento de los pescadores. Esto me ha dado la oportunidad de comprender a fondo la estrategia que la comunidad pesquera ha empleado a lo largo del tiempo, y este capítulo puede servir como punto de partida para la toma de decisiones en el futuro.

En esta tesis, hay, en mi opinión, una variedad de técnicas únicas, como la validación del LEK contra el CSK al comparar dos modelos de la misma área. La creación de una red SES y cómo responde utilizando diferentes escenarios ambientales y sociales. Por último, el uso de un modelo conceptual para analizar un caso de estudio para determinar sus ventajas y desventajas. Como conclusión, creo que la complejidad de este trabajo puede utilizarse en el futuro como base para otros trabajos, así como para desarrollar estrategias de gestión en esta comunidad pesquera en particular.

BIBLIOGRAFIA GENERAL

Álvarez, P., Seingier, G., Bocco, G., Espejel, I., & Noriega, J. (2015). Regional Landscape Change in Fishing Communities of the Mexican North Pacific. *Landscape Research*, *40*(7), 855–874. https://doi.org/10.1080/01426397.2015.1031095

Bindoff, N. L., Cheung, W. W. L., Kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., Hilmi, N., Jiao, N., Karim, M. S., Levin, L., O'Donoghue, S., Cuicapusa, S. R. P., Rinkevich, B., Suga, T., Tagliabue, A., & Williamson, P. (2019). Changing Ocean, Marine Ecosystems, and Dependent Communities. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (Eds.)]. In Press.*, 447–588.

Borrett, S. R., Moody, J., & Edelmann, A. (2014). The rise of Network Ecology: Maps of the topic diversity and scientific collaboration. *Ecological Modelling*, *293*, 111–127. https://doi.org/10.1016/j.ecolmodel.2014.02.019

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J., & Schmitt, R. J. (2011). Climate-driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*, *17*(8), 2513–2524. https://doi.org/10.1111/j.1365-2486.2011.02409.x

Carr, M. H., & Reed, D. C. (2015). Shallow rocky reefs and kelp forests. *Ecosystems of California. University of California Press, Berkeley, California, USA,* 311–333.

Defeo, O., Castrejón, M., Ortega, L., Kuhn, A. M., Nicolás, L., & Castilla, J. C. (2013). Impacts of Climate Variability on Latin American Small-scale Fisheries. *Ecology and Society*, *18*(4).

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

Foster, M., & Schiel, D. (1985). Ecology of giant kelp forests in California: a community profile. *United States Fish and Wildlife Service Biological Report*, *85*, 1–152. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5129110

Freeman, L. (2004). The Development of Social Network Analysis: A Study in the Sociology of Science. *Vancouver, BC: Empirical Press*.

Giuffre, K. (2013). *Communities and Networks: Using Social Network Analysis to Rethink Urban and Community Studies. Hoboken, NJ: John Wiley & Sons*. John Wiley & Sons.

Heath, S., Fuller, A., & Johnston, B. (2009). Chasing shadows: defining network boundaries in qualitative social network analysis. *Qualitative Research*, *9*(5), 645–661.

Janssen, M. A., Bodin, Ö., Anderies, J. M., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). Toward a network perspective of the study of resilience in social-ecological systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01462-110115

Kroeker, K. J., Gambi, M. C., & Micheli, F. (2013). Community dynamics and ecosystem simplification in a high-CO2 ocean. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(31), 12721–12726. https://doi.org/10.1073/pnas.1216464110

Ladah, L. B., Zertuche-González, J. A., & Hernández-Carmona, G. (1999). Giant Kelp (Macrocystis Pyrifera , Phaeophyceae) Recruitment Near Its Southern Limit in Baja California After Mass Disappearance During Enso. *Journal of Applied Phycology*, *35*, 1106–1112. https://doi.org/10.1046/j.1529-8817.1999.3561106.x

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza Montes, J. A., Rossetto, M., & de Leo, G. A. (2012). Evidence that marine reserves enhance resilience to climatic impacts. *PLoS ONE*, *7*(7). https://doi.org/10.1371/journal.pone.0040832

Muchagata, M., & Brown, K. (2000). Colonist farmers' perceptions on fertility and the frontier environment in eastern Amazonia. *Agriculture and Human Values*, *17*, 371–384.

Munguia-Vega, A., Green, A. L., Suarez-Castillo, A. N., Espinosa-Romero, M. J., Aburto-Oropeza, O., Cisneros-Montemayor, A. M., Cruz-Piñón, G., Danemann, G., Giron-Nava, A., Gonzalez-Cuellar, O., Lasch, C., del Mar Mancha-Cisneros, M., Marinone, S. G., Moreno-Báez, M., Morzaria-Luna, H. N., Reyes-Bonilla, H., Torre, J., Turk-Boyer, P., Walther, M., & Weaver, A. H. (2018). Ecological guidelines for designing networks of marine reserves in the unique biophysical environment of the Gulf of California. *Reviews in Fish Biology and Fisheries*, *28*(4), 749–776. https://doi.org/10.1007/s11160-018-9529-y

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75–90. https://doi.org/10.1007/s00267-003-0101-7

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*, 419–422.

Pauly, D., & Christensen, V. (1995). Primary production required to sustain global fisheries. *Nature*, *374*, 255.

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., Pauly, D., Sáenz-Arroyo, A., Sumaila, U. R., Wilson, R. W., Worm, B., & Castilla, J. C. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences*, *114*(24), 6167–6175. https://doi.org/10.1073/pnas.1701262114

Steneck, R. S., Graham, M. H., Bourque, B. J., Corbett, D., Erlandson, J. M., Estes, J. A., & Tegner, M. J. (2002). Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental Conservation*, *29*(04), 436–459. https://doi.org/doi:10.1017/S0376892902000322

Tegner, M. J., Dayton, P. K., Edwards, P. B., Riser, K. L., Chadwick, D. B., Dean, T. A., & Deysher, L. (1995). Effects of a large sewage spill on a kelp forest community: Catastrophe or disturbance? *Marine Environmental Research*, *40*(2), 181–224. https://doi.org/10.1016/0141-1136(94)00008-D

Thompson, R. M., Brose, U., Dunne, J. A., Hall, R. O., Hladyz, S., Kitching, R. L., Martinez, N. D., Rantala, H., Romanuk, T. N., Stouffer, D. B., & Tylianakis, J. M. (2012). Food webs: Reconciling the structure and function of biodiversity. *Trends in Ecology and Evolution*, *27*(12), 689–697. https://doi.org/10.1016/j.tree.2012.08.005

Wu, H. (2017). A Conference to #SaveOurOcean. *UN Chronicle, 54/2,*.