



Research

Social-ecological networks and connectivity within and between two communities of small-scale fishers in Mexico

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ABSTRACT. Aligning the ecological and social dimensions of the connections present between users that harvest a shared natural resource is a necessary step toward sustainable management. However, contrasting estimates of connectivity across disciplines is a challenging task and few empirical studies have focused on population dynamics within fish species with a complex life history. We used a collaborative approach merging citizen science, population genetics, oceanographic modeling, and interviews to collect empirical connectivity data of individual fish, fishing sites, and fishers. We integrated the data within a multilevel social-ecological network framework describing the interactions between two communities of small-scale fishers (Bahia Kino and Puerto Libertad, Sonora, Mexico) targeting leopard grouper (*Mycteroperca rosacea*). We identified two types of social-ecological links, including the use of specific fishing sites by individual fishers and the harvest of individual fish by individual fishers. Despite their fishing zones not overlapping, the ecological links between two communities located ~150 km apart were consistent and reciprocal where fishing grounds from each community acted as a source of fish to the other during the larval or juvenile/adult stages, respectively. As a result, fishers from the two communities frequently captured fish that were second-degree relatives. In contrast, the probability of social ties among fishers changed significantly depending on the type of connection and was considerably low for leadership and kinship although some communication was present. Our study highlighted how local actions (e.g., recovery from marine reserves or overfishing) are likely to impact the neighboring community as much as locally. The geographic scale and strength of key ecological process supporting fish stocks through the fish life cycle seem to be larger than those of social connections among fishers. Fishers and managers could benefit from a broader regional perspective that strengthens connections between communities about shared goals and activities. We examine some insights learned on the constraints of connectivity given different attributes of each ecological and social component and methodological challenges identified. We also discuss ways to improve collaborative management between the two communities.

Key Words: *connectivity; Gulf of California; kinship; larval dispersal; networks; small-scale fisheries; social-ecological*

INTRODUCTION

Preserving the multiple services that marine ecosystems provide is one of the main challenges of modern civilization considering the huge extent of the human footprint on aquatic environments (Pauly and Zeller 2016, FAO 2020). Multiple interdisciplinary frameworks have been proposed to match management strategies to the social and ecological contexts of environmental problems to maintain ecosystem structure and function. Some of these frameworks include ecosystem-based management (Pikitch et al. 2004), social-ecological systems (Ostrom 2009), social-ecological alignment or fit (Cumming et al. 2006), collaborative governance (Bodin 2017), among others. Common to these frameworks is the need to understand connections within and between ecological and social elements to improve management outcomes. However, comparing empirical estimates of connectivity across disciplines is not easy (Turnbull et al. 2018). Some of the difficulties include the complexity of natural and social systems, the need of transdisciplinary research tools to assess and compare connectivity, and the obstacles of matching spatial and temporal scales of measurement.

A promising method for conceptualizing social-ecological connections is representing them within a network framework (Janssen et al. 2006, Bodin et al. 2019, Sayles et al. 2019). Networks can be used to show how people interact with a common

ecological resource as a link, such as fishing (Bodin and Crona 2009). In this approach, networks are composed of nodes representing the social or ecological components and links representing their connections (Janssen et al. 2006). The social and ecological systems can be symbolized as separate but interconnected network layers in a multilevel network (Barnes et al. 2019, Bodin et al. 2019). Networks have the advantage of being flexible to represent diverse data, including for example the relationships within and between groups of people or organizations (Borgatti et al. 2009), or the export and import of fish larvae between sites driven by ocean currents (Tremblay et al. 2008). Besides explicitly accounting for the presence, intensity, and direction of connections in a spatial context, networks could reveal interdependence and feedback loops between components, and could be used to identify nodes that play key roles in the structure of the network (Turnbull et al. 2018, Sayles et al. 2019).

Social-ecological alignment or fit is accomplished when relationships between social actors are paired with links in the ecological network (Bodin 2017). Social-ecological alignment is usually associated with one or more indicators of sustainability, and contextual attributes that contribute to success are commonly identified (Epstein et al. 2015). In its simplest form, the problem of social-ecological fit could be exemplified by two sets of actors (e.g., two adjacent local communities of small-scale fisheries),

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each exploiting an ecological component (e.g., a particular fish species), which populations show strong interdependencies between them driven by the characteristics of the underlying biophysical system (e.g., ocean currents). If the actors that share the ecological component communicate with each other, it can facilitate coordination and cooperation toward sustainable management and increase the health and sustainability of the resource (Bodin 2017). This type of closed network structure could increase trust, learning, sharing of information, and enable establishing rules (Bodin et al. 2016). In contrast, the lack of social connections despite the presence of ecological links reduces the ability to address environmental problems effectively and reduces the likelihood of meeting socioeconomic and ecological long-term goals (e.g., avoid overfishing and associated loss of income due to stock depletion). A mismatch could also appear when the scales of ecological processes do not match the scales of governance structures (Cumming et al. 2006, Cumming and Dobbs 2020). Adaptive co-management of small-scale fisheries that promotes the participation of direct users, governments, and other stakeholders in decision-making processes have recently proliferated (d'Armengol et al. 2018). However, the discussion of principles for efficient governance has continued and is recognized as a key piece to overcome the underlying causes of overexploitation in fisheries (Quentin Grafton et al. 2007, Henry and Dietz 2011, Hilborn et al. 2020).

Small-scale fisheries in the Midriff Island Region (MIR) of the Gulf of California (GC), Mexico, targeting marine fish represent an ideal system to evaluate the challenges of measuring the connections between complex ecological and social systems. Most studies that simultaneously characterize ecological and social connections related to fisheries usually focus on trophic relationships among multiple species targeted by fishers (Yletyinen et al. 2018, Barnes et al. 2019, Kluger et al. 2019), or how fishing vessels interact with multiple fisheries (Fuller et al. 2017). However, ecological connections within any single one of those species are also important (Tremblay et al. 2015), but difficult to observe empirically and commonly ignored given their hidden nature. Fish populations are connected to each other via movements during different life history stages, including larvae, juvenile, and adult (Munguia-Vega et al. 2018). This type of ecological connectivity has demographic effects on population recruitment and abundance and its maintenance is crucial for the viability of local populations by shaping the metapopulation structure and resilience of a stock (Jones et al. 2009). For many species of marine fish and invertebrates, oceanographic currents mediate patterns of larval dispersal between sites, generally over a larger spatial scale compared to the movement of juveniles and adults within their home range, ontogenetic habitat shifts, or spawning migrations (Green et al. 2015, Munguia-Vega et al. 2018). Fisheries that exhibit spatial complexity where separated populations are linked via larvae and adult dispersal creates serious challenges to traditional fisheries management that assumes control of a single, spatially homogeneous stock via fishing mortality (Wilson 2006, Berger et al. 2017). Specifically, fishing could push a population across a threshold beyond which the successful reproduction is threatened, and ignoring the connections among fish populations could lead to disrupting demographic links, overexploitation, and loss of resilience of the system as a whole (Wilson 2006, Berger et al. 2017).

Fishers connect and interact with each other depending on different types of social ties, including kinship, communication, trust, reciprocity, leadership, co-occurrence of fishers in the same fishing grounds, etc. (Bodin and Crona 2009). Identifying social linkages provides channels (e.g., kinship ties, key players or leaders) for exchanging information (e.g., good fishing areas, permits, subsidies, new technologies, fisheries regulations, stock status) within and between communities in ways that could both support or hinder conservation and management efforts (Zetina-Rejón et al. 2020). Stakeholders' relationships shape the structure of social networks, which can impact governance dynamics (Hartley 2010). The term "small-scale fishery" is commonly defined mostly by its technological characteristics (i.e., type of gear and boat length) and fishing regulations tend to focus solely on the action of "fishing" (i.e., regulating fishing access or fishing methods), putting sociocultural and commercial dimensions aside (Smith and Basurto 2019, Basurto et al. 2020). The MIR fisheries are de facto open access (Cinti et al. 2014) and although all fishers should operate under permits there is limited enforcement, particularly outside existing protected areas. Like most small-scale fisheries around the world, MIR fisheries are generally self-governed through informal arrangements under cooperative or non-cooperative structures, which translates to cooperatives versus a patron-client arrangement (Lindkvist et al. 2017). To gain fishing access, fishers either work for patrons or as part of cooperatives, with both typically commercializing their catches through intermediaries (Cinti et al. 2014, Basurto et al. 2020). Although fishers are most incentivized to join cooperatives when they live in communities with high transaction costs for selling and commercializing their catch, governance arrangements seem to develop depending on their social-ecological fit, and potential for adaptation to variability (Basurto et al. 2013a).

Our study focused on fishers targeting leopard groupers (*Mycteroperca rosacea*). The species shows a complex life history including spawning aggregations, a ~28-days pelagic larval stage after which juveniles travel to *Sargassum* spp. forests and later relocate to rocky reefs as adults (Munguia-Vega et al. 2014). Leopard grouper is the most heavily targeted grouper by small-scale and recreational fisheries in the GC (Sala et al. 2003, Erisman et al. 2010), and its population status is considered to be decreasing (Erisman and Craig 2018). Leopard grouper annual landings averaged 147 tons in the GC between 1999 and 2007 (Erisman et al. 2010). The species is exploited via hand lines or spearguns with support from surface-supplied air (hookah diving; Moreno-Báez et al. 2012). This small-scale fishery operates from small skiffs (7 m long), known locally as "pangas," that are powered by outboard motors and manned by two to three fishers. The leopard grouper is part of the finfish fishery, which is managed via commercial permits that include more than 200 species exploited in Mexico, with no specific regulations regarding gear, catch, or size restrictions. No-take zones (fully protected marine reserves, fish refuges, etc.) represent the main spatial management tool implemented for leopard groupers and other finfish species in the MIR (Rife et al. 2013). Current efforts are underway to scale up the establishment of new marine reserve networks in the GC (Alvarez-Romero et al. 2018, Morzaria-Luna et al. 2020).

A first step toward evaluating the fit between social and ecological components in an environmental problem generally proceeds by

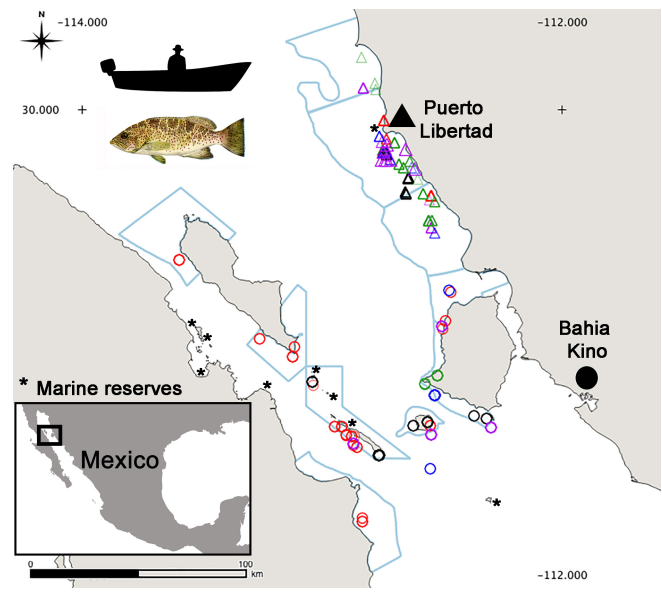
characterizing the attributes of the ecological system and then comparing these to the attributes of governing institutions (Epstein et al. 2015). To this end and to help facilitate stakeholder engagement and co-management, this study aimed to use a multilevel social-ecological network as a framework to conceptualize and analyze the ecological and social connectivity between two adjacent communities of small-scale fishers targeting the same fish species. We were interested in estimating the level of interconnectedness between populations of leopard grouper targeted by each community and measuring the level of social connections present among fishers. Our specific objectives were (1) estimate the extent of overlap in the cohorts of fish caught and fishing sites used by each community, (2) measure the presence and strength of larval and adult dispersal in fish captured within and between the fishing grounds from each community, (3) quantify the presence and level of social connections within and between fishers from each community. We identified some characteristics of these ecological and social systems that promote or inhibit connectivity and discuss how the specific biophysical characteristics of the ecological system constrain the way collaborative arrangements should ideally be devised. Our main assumption was that, if strong ecological links are present between the two communities, then management decisions that improve (e.g., marine reserves) or reduce (e.g., overfishing) the size of the shared fish stock will have impacts on the adjacent community, and thus improving communication and co-management between the two communities could help toward sustainably managing the fishery.

METHODS

Study area

The northern GC, which includes the MIR, has 45 islands and islets, and is a globally recognized marine biodiversity hot-spot (Alvarez-Romero et al. 2013). The northern GC region is of key importance for 17 communities of small-scale fishers, where nearly 80 fish and invertebrate species are targeted by > 3500 fishers using > 1600 pangas (Munguia-Vega et al. 2015). We focused our study on Puerto Libertad (PL) and Bahia Kino (BK), two communities located in the state of Sonora on the eastern shore of the GC (Fig. 1). PL is an isolated community of ~2800 inhabitants. Small-scale fishing is the main economic activity of ~200 local fishers with 119 pangas, focused on migratory species such as sharks, croakers, sierra, and yellowtail among others, along with coastal species including groupers and snappers (Espinosa-Romero et al. 2014). BK (~6000 inhabitants) is a larger and more economically diverse community, with at least 460 local fishers and 365 pangas according to a Spatial Fisheries Planning Program conducted in 2013 (Fernandez-Rivera Melo et al. 2018). Considering the ratio between the number of fishers and pangas (Johnson et al. 2017) and that there are two or three fishers per panga, the fisher population of both BK and PL is likely double or triple the reported number. BK is closest to the state capital and has access to better infrastructure than PL, including major roads in better condition that provide access to more varied market possibilities, fishing equipment, gear and supplies stores, etc. BK is also an important tourist destination (e.g., 25,000 tourists during spring break 2019).

Fig. 1. Fishing zones for leopard groupers (*Mycteroperca rosacea*) captured by fishers from Bahia Kino (circles) and Puerto Libertad (triangles) in the Gulf of California, Mexico. Fishing sites from each fisher within each community are distinguished by different colors. Lines in the background show polygons used to define eight distinct fishing zones from BK and three fishing zones from PL. The location of no-take marine reserves is indicated by asterisks (*).



Formalized fishing in this part of the MIR dates back to 1935, progressively increasing until the 1980s/1990s when the fishing activity became increasingly intensive and extensive (Frawley et al. 2019a). However, over the years, other economic activities have emerged in the community, including trade, cottage industries, crafts, tourism, and even livestock and family gardens (Moreno et al. 2005). Fishing for leopard groupers occurs during spring and summer in each community using different gear. In BK leopard groupers are caught with spearguns and hookah diving, whereas in PL the species is targeted with hand lines. Leopard grouper along with other fish (corvina, sierra, gulf coney) are the most important species in terms of economic value in PL. In BK, though the species is not the most important economically, it is found among 24 species recognized as important for its economic value or catch volume (Fernandez-Rivera Melo et al. 2018).

Fish sampling

To obtain information about the use of fishing zones and the level of ecological connectivity between the fish captured by each community, in June 2016 we established a citizen science program with five fishers from each of the two communities that target leopard groupers. Sampling focused on obtaining information about fishing sites, tissue samples of fish for genetic analyses of kinship to estimate ecological connectivity, and size of the fish to approximate its age and distinguish parent-offspring from full-sib relationships. Fishers were provided with a sampling kit that included a global positioning system (GPS) to record the sampling location of each captured fish, a ruler to measure the total length

of each organism, 1.5 ml pre-labeled screw-cap vials, ethanol, dissection scissors to collect fin clips as a source of DNA, and a water-resistant paper format to register the corresponding information. Fishers kept the contents of the sampling kit at the end of the study as an incentive for participating in the study.

To estimate the geographical extent and overlap among fishing zones within and between communities we built a geographic information system (GIS). We used the GPS coordinates of the sampling location of each individual leopard grouper collected from each fisher. We identified 11 fishing zones used by fishers of both communities based on a previously described delimitation of fishing zones of leopard grouper for the MIR (Munguia-Vega et al. 2014; Fig. 1). Fishing zones were defined by the 100 m isobath, inside which most small-scale fishing takes place, and also incorporated natural geographic features (islands) and existing marine protected areas.

Ecological data

To obtain empirical estimates of ecological connectivity for leopard groupers, we conducted genetic analyses with the tissue samples collected by the fishers from each community. We extracted genomic DNA from fin clips using the DNeasy Blood and Tissue Kit (QIAGEN) or with the salting-out method (Aljanabi and Martinez 1997). We genotyped 13 microsatellite loci on each sample, including five loci (*Mros03*, *Mros05*, *Mros07*, *Mros11*, and *Mros12*) previously described (Jackson et al. 2014). We also analyzed eight new markers isolated during the genomic sequencing run described in Jackson et al. (2014) that were genotyped using the same PCR conditions and methods referenced above (Appendix 1, Table A1.1), including loci *Mros17*, *Mros18*, *Mros22*, *Mros25*, *Mros26*, *Mros27*, *Mros29*, and *Mros32*. We estimated deviations from Hardy-Weinberg equilibrium (HWE) and linkage disequilibrium (LD) for each combination of loci and populations using GENEPOP 4.2 with 10,000 dememorization steps, 1000 batches and 10,000 iterations (Raymond and Rousset 1995).

Based on the data collected about total fish length, we categorized individuals into age classes for the analysis of genetic kinship following intervals obtained from a previous study of age-length relationships in leopard grouper (Diaz-Uribe et al. 2001). We assigned individuals into two groups based on their age: (1) candidate parents (older individuals with total length ranging from 52 to 90 cm corresponding to > 7 to 12+ years old); and (2) candidate progeny (younger individuals with total length ranging from 20 to 43 cm corresponding to > 1 < 5 years old). These two groups were separated by an age gap equal to the time for reproductive maturity, which is estimated at two years (Diaz-Uribe et al. 2001).

We used the genetic data to estimate two measures of ecological connectivity. First, we measured kinship identifying pairs of individual fish with a probability $\geq 99.0\%$ of being first-degree relatives (e.g., parent-offspring, full sibs) or second-degree relatives (grandparent-grandchildren, half-sibs, avuncular: uncle, aunt, nephews, nieces) using the COLONY software (Jones and Wang 2010). We assumed a polygamous mating system for a diploid and dioecious species, a mutation rate for a microsatellite locus of 0.0005, and four long runs to estimate likelihood. Second, we detected first-generation migrants among the 11 fishing zones from the two communities using a Bayesian assignment method

(Rannala and Mountain 1997) implemented in GENECLASS2 (Piry et al. 2004). For each individual fish, we assessed the likelihood ratio $L_{\text{home}}/L_{\text{max}}$ using Monte Carlo resampling and simulating 10,000 individuals. Those individuals with a probability ≤ 0.01 of belonging to the population where they were sampled were identified as migrants. We constructed an asymmetric matrix among the fishing zones that represented the presence and frequency of the inferred migration events.

We estimated a third measure of ecological connectivity, namely, larval connectivity of leopard groupers driven by oceanic currents. We used the raw output of a previous study to estimate a directed larval connectivity network representing the probability of larval dispersal among the relevant fishing zones identified from the MIR (Munguia-Vega et al. 2014). Dispersal was estimated on the basis of a three-dimensional HAMSOM oceanographic model that simulated the oceanic currents during the spawning season (May and June) for a planktonic larval duration of 28 days and which accuracy was previously validated with genetic data (Munguia-Vega et al. 2014).

Social data

To identify the presence and level of social connectivity within and between fishers from BK and PL targeting leopard grouper, we used a non-probabilistic sampling based on a realistic approach (Zepeda-Dominguez et al. 2017). The realistic approach consisted of a structured interview, composed of open and closed questions, applied to 83 fishers (49 from BK and 34 from PL) that targeted leopard grouper and who represented all the different groups of interest (cooperatives, permit holders and free fishers) present within each locality (Zepeda-Dominguez et al. 2015). The number of fishers interviewed represent 10.6% (BK) and 17% (PL) based on the latest available estimates of the number of fishers targeting all species in each community. The survey sought to identify the main leopard grouper fishers of the MIR and the existing social relationships within and between the two communities. We identified five variables of interest to measure social connectivity, specifically communication, trust, reciprocity, leadership, and kinship (Bodin and Crona 2009). Communication refers to the existence of any information exchange between fishers. We considered trust as the intention to accept vulnerability based upon positive expectations of the intentions of the behavior of another person (Ostrom and Walker 2003). Reciprocity was understood as the conditional behavior depending on the perceived intentions behind the actions of others (Cox 2004). Leadership was defined as the capability of an actor to exert influence over the other fisher's decisions. These variables were ranked from bad to excellent on a numerical scale (1 being bad and 5 was excellent; see Appendix 2, Table A2.1 for details). The fishers identified in this interview were then used in a second interview to identify kinship among fishers (first- and second-degree relatives, as defined above). For the design, validation, and application, regular protocols for social research were observed: every fisher was informed about the project, including the goals, the methodology, the anonymity of the data, and the policy of not sharing any information for purposes different from those consented. We also provided channels to express any concern or refusal to include their information and a way to contact a technical person responsible for the project (Fontana and Frey 2005). With the data obtained for the five variables describing social interactions, we generated five adjacency matrices (kinship,

communication, trust, reciprocity, and leadership). Matrices represented binary data for the presence or absence of a social relationship between two fishers.

Contrasting ecological and social networks

Network analyses use graph theory to study the topological and functional relationships of nodes (Newman 2003), which in our study were represented by fish, fishing sites, and fishers, as a tool to understand the dynamics of social-ecological systems (Sayles et al. 2019). Social network analysis has been used successfully for the structural characterization of natural resource management systems (Prell et al. 2008). Two actors who share a social bond over time will influence each other, tending to increase the similarity between the two. If, in addition, this link is deep or multiple (they are friends, coworkers, close relatives), the probability of similarity will increase (Prell 2012). In the context of fisheries management, social network analysis has been used to associate structural attributes with management characteristics and their performance (Bodin and Crona 2008, Hartley 2010).

The matrices describing three ecological relationships and five social ties were analyzed and visualized using a graphic network approach with the software GEPHI (Bastian et al. 2009). In ecological networks, the nodes of the kinship network were represented by individual fish analyzed, whereas for the fish migrants and the probability of larval dispersal nodes were represented by the fishing zones used by each community and links defined by the presence/absence and intensity of ecological connectivity among them. In social networks, nodes represent individual fishers connected by the five types of social ties. To analyze the role of each node in the network structure, we used the eigen centrality index to measure the importance of each node as its positional relevance (Wasserman and Faust 1994). Eigen centrality is a measure of a node's influence on a network. For its calculation, relative scores are assigned to all the nodes in the network; a node will have a high score if it is connected to highly connected nodes, and conversely it will have a low score if it is connected to poorly connected nodes. This means that the own-vector centrality is proportional to the sum of the centralities of the nodes with which it is connected (Bonacich and Lloyd 2001).

To compare the level of connectivity within and between the two fishing communities in each ecological and social network, we estimated the density from the three ecological and five social networks. For each network, we defined density as the number of links observed divided by the maximum number of possible links (Janssen et al. 2006), while ignoring the diagonal of the matrix. Density represents the probability that any given tie between two random nodes is present (Hanneman and Riddle 2005). A network has a maximum density of 1 if all possible links among all nodes are present and a minimum density of 0 if no links are present. Estimates of density can be used to compare the level of cohesiveness or saturation among different networks and are related to some functional attributes like the level of resilience of the network (Janssen et al. 2006). All the networks were treated as directed networks. In each network, we calculated density considering links as a binary variable (i.e., present or absent) in four sub-networks to decompose the probabilities of finding a link within compared to between the two communities: (1) a subnetwork labeled *BK* including links only between nodes belonging to Bahia Kino; (2) a subnetwork labeled *PL* including

links only between nodes from Puerto Libertad; (3) a network labeled *All* including all the nodes and links; and (4) a subnetwork labeled *BK-PL* excluding the links within each community and considering only the potential ties exclusively between two nodes from different communities. We evaluated statistical differences in the observed densities of networks and subnetworks by computing the sampling variance of the estimated densities by using bootstrapping and the “Compare Densities” function in UCINET 6.718 (Borgatti et al. 2002). This method is analogous to the classical paired sample t-test for estimating the standard error of the difference. We generated a sampling distribution of density measures in 10,000 random sub-samples to account for the interdependency of network data.

RESULTS

Fishing patterns

Our citizen science program with 10 fishers allowed us to collect tissue samples, total length, and geographic coordinates from 776 leopard grouper individuals. Eight fishing zones for BK and three for PL were identified, and fishing zones used by each community did not show any overlap (Fig. 1). Fishers from BK used all the islands in the Midriff Island Region (MIR), and some individual fishers traveled up to 200 km from their community to their fishing sites. Fishers from PL exclusively fished at sites near their community and within a 50 km radius. In both communities, fishers shared between one and three fishing zones with other fishers from their community.

Each fishing community targeted fish from different cohorts that varied considerably in size. Fishers from BK captured fish that were significantly smaller (average length 45.06 cm, N = 379) than those captured by fishers from PL (average length 64.20 cm, N = 397, Fig. 2). These fish sizes corresponded to a mean age of five years for fish from BK and nine years for PL.

Fig. 2. Histogram showing the frequency distribution of total length and inferred age of 776 leopard grouper (*Mycteroperca rosacea*) individuals captured by fishers from Bahia Kino (red) and Puerto Libertad (blue).

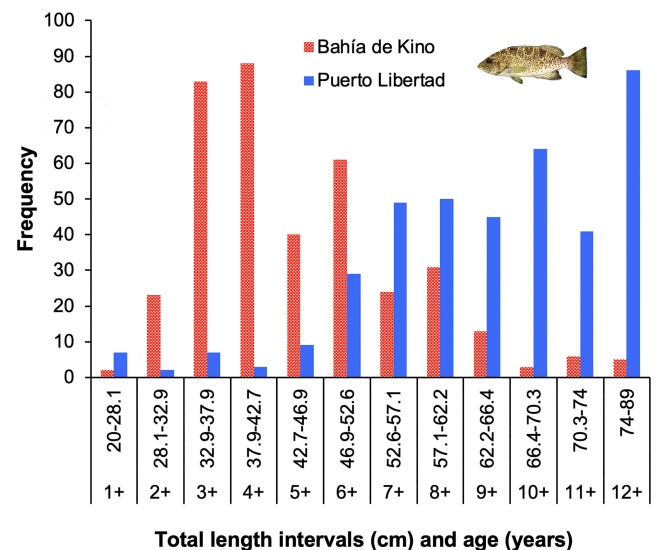


Table 1. Characteristics of three ecological (kinship, larvae, migrants) and five social (kinship, communication, trust, reciprocity, leadership) networks within and between two communities of small-scale fishers. We show the number of elements or nodes in the network (N), the maximum number of possible links, observed number of links, the average density of the network, and standard deviation (SD). We show data decomposed into four sub-networks: (1) a subnetwork labeled BK, including links only between nodes belonging to Bahia Kino; (2) a subnetwork labeled PL, including links only between nodes from Puerto Libertad; (3) a subnetwork labeled All, including all the nodes and links; and (4) a subnetwork labeled BK-PL, excluding the links within each community and considering only the potential ties exclusively between two nodes from different communities. Density represents the probability that any given tie between two random nodes is present.

Ecological Networks of fish and fishing zones					
	N	Maximum links	Observed links	Density	SD
Kinship					
BK	138	18906	79	0.0042	0.065
PL	144	20592	111	0.0054	0.073
All	282	79242	355	0.0045	0.067
BK-PL		39744	165	0.0042	
Larvae					
BK	8	56	34	0.6071	0.488
PL	3	6	3	0.5000	0.5
All	11	110	50	0.4545	0.498
BK-PL		48	13	0.2708	
Migrants					
BK	8	56	11	0.1964	0.397
PL	3	6	3	0.5000	0.5
All	11	110	29	0.2636	0.441
BK-PL		48	15	0.3125	
Social Networks of fishers					
Kinship					
BK	49	2352	30	0.0128	0.112
PL	34	1122	51	0.0455	0.208
All	83	6806	83	0.0122	0.11
BK-PL		3332	2	0.0006	
Communication					
BK	49	2352	8	0.0034	0.058
PL	34	1122	97	0.0865	0.281
All	83	6806	235	0.0345	0.183
BK-PL		3332	130	0.0390	
Trust					
BK	49	2352	9	0.0038	0.062
PL	34	1122	101	0.0900	0.286
All	83	6806	250	0.0367	0.188
BK-PL		3332	140	0.0420	
Reciprocity					
BK	49	2352	9	0.0038	0.062
PL	34	1122	102	0.0909	0.287
All	83	6806	250	0.0367	0.188
BK-PL		3332	139	0.0417	
Leadership					
BK	49	2352	127	0.0540	0.226
PL	34	1122	94	0.0838	0.277
All	83	6806	253	0.0372	0.189
BK-PL		3332	32	0.0096	

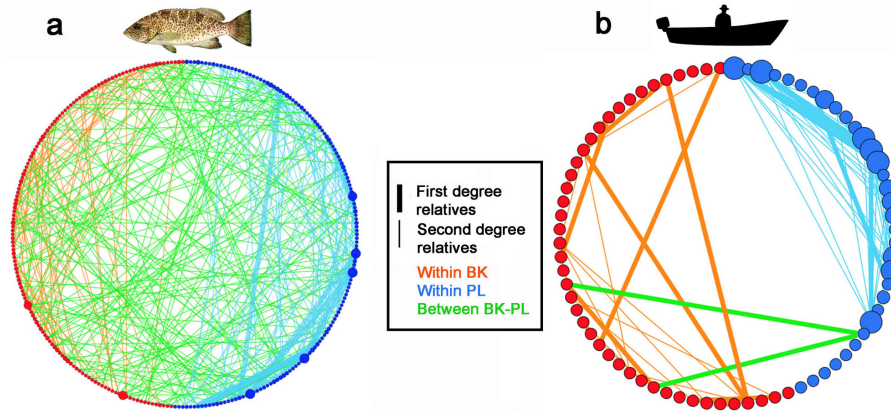
Ecological networks

Fish Kinship

Our first measure of ecological connectivity was based on genetic kinship analyses of 282 fish that passed strict quality controls (Appendices 3–6), from which 138 fish were from BK and 144 fish were from PL. We found 355 first- and second-degree relationships among the genotyped fish, of which 111 (31.26%) were from fish captured within PL fishing grounds, 79 (22.25%) were from fish captured within BK fishing grounds, and the majority (165, 46.47%) were between pairs of fish captured in the

fishing zones of two distinct communities (Table 1, Fig. 3a). From all relationships, only 4.78% (17) were between first-degree relatives. All first-degree relationships were found within the fishing zones of PL, including three parent-offspring and 14 full-sibling pairs. According to the analyses of eigenvector centrality, most of the important nodes in the network of genetic relationships were fish from PL (Fig. 3). The probability of observing a kinship link within two random fish (i.e., density) in the subnetworks within and between communities was small (< 1%) and within the same order of magnitude. Despite density

Fig. 3. Networks describing kinship (first- and second-degree relationships) among 282 leopard groupers, *Mycteroperca rosacea*, (a) and 83 fishers (b) from two communities. Nodes represent individual fish and fishers, colored according to the community to which they belong (Red = Bahia Kino, BK; blue = Puerto Libertad, PL). Node size represents the eigenvector centrality. The links show first-degree (thick lines) or second-degree relationships (thin lines). Links within BK are shown in red, links within PL are shown in blue, and green links represent relationships between nodes from different communities.



being slightly lower within BK (0.41%), we did not observe any significant difference compared to PL (0.53%), neither with the network including all fish (0.44%) or with the comparison focused between the two communities (0.41%; Fig. 4, all P values > 0.058, Appendix 7, Table A7.1).

Fish migrants

Our second measure of ecological connectivity based on the identification of first-generation fish migrants revealed 60 of the 282 fish as migrants (21.27%) whose genotypes were more likely to have originated in a different fishing zone from where they were captured (Fig. 5a, Table 1). Strong connections were observed in a southward direction indicating the migration of individuals from the central fishing zones of PL toward the fishing zones of BK in the MIR. The 60 migrants were distributed into 29 links, from which 11 (37.93%) were between BK fishing zones, 3 (10.34%) were between PL fishing zones and the bulk (15, 51.72%) were between fishing zones from two different communities. We observed the highest density in the subnetwork of migrants among PL fishing zones (50%), which was significantly higher than the value observed among BK fishing zones (19.64%, $P = 0.001$), larger than the density of the network including all fishing zones (26.36%, $P = 0.001$) and higher than the comparison between the fishing zones of the two communities (31.25%, $P = 0.025$, Fig. 4, Appendix 7, Table A7.1).

Larval dispersal

Our third measure of ecological connectivity based on an oceanographic model of larval dispersal for leopard grouper (Munguia-Vega et al. 2014) showed 50 larval dispersal links, from which the majority (34, 68%) were between BK fishing grounds, followed by 13 links (26%) between different communities showing strong northward connections from the fishing zones of BK toward fishing zones from PL (Fig. 5b, Table 1). Only 3 links (6%) were observed between PL fishing zones. The density of subnetworks varied from 60.71% within BK fishing zones, to 50% within PL, and 45.45% overall, which were significantly higher than the density observed between the two communities (27.08%, all P values ≤ 0.031 , Table 1, Fig. 4, Appendix 7, Table A7.1).

Fig. 4. Probability that any given tie between two random nodes is present (density) within the ecological and social networks and subnetworks. Ecological networks (a) include larval dispersal of leopard grouper (*Mycteroperca rosacea*) among fishing zones, kinship among individual fish, and migrant fish among fishing zones. Social networks (b) include kinship, communication, and leadership among individual fishers. Subnetworks include links between nodes from BK (BK), links between nodes from PL (PL), all nodes and links (All), exclusively links between two nodes from different communities, ignoring links between nodes from the same community (BK-PL). See Appendix 7 for statistical analyses.

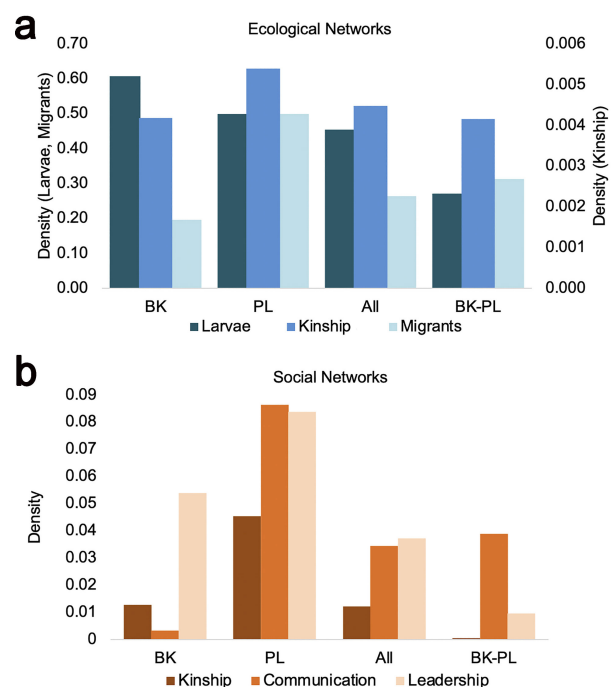
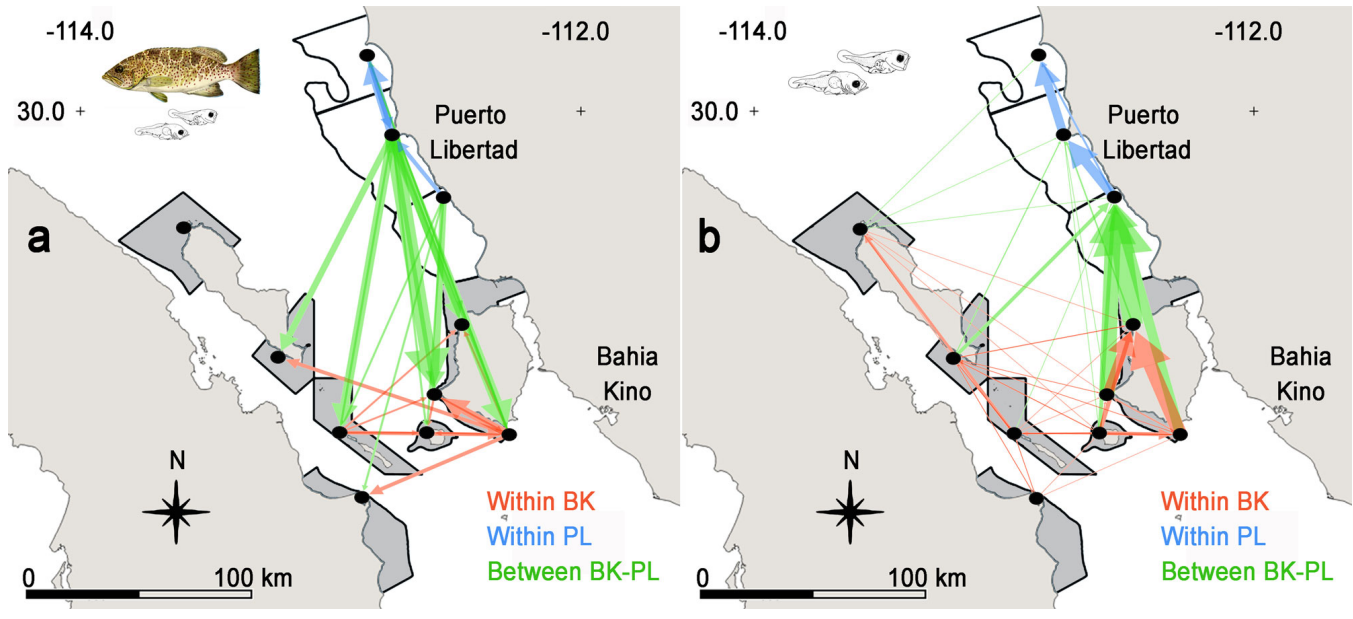


Fig. 5. Ecological networks between fishing zones from two communities in the northern Gulf of California. (a) Network showing 60 first-generation migrants that integrate larval, juvenile, and adult dispersal identified via genetic analyses among eight fishing zones from Bahia Kino (BK, gray polygons) and three fishing zones from Puerto Libertad (PL, white polygons). (b) Network showing the probability of larval dispersal among fishing zones from the two communities, based on a three-dimensional oceanographic model. Links within BK are shown in red, links within PL are shown in blue, and green links represent relationships between the two communities. Line width is proportional to the observed frequency, and the thickest lines represent the maximum values: seven migrant individuals in (a), and 27.6% probability of larval dispersal in (b).



Social networks

Fishers' kinship

From 83 fishers that were interviewed for the analyses of kinship (49 from BK and 34 from PL), our first measure of social connectivity based on kinship among fishers identified 83 connections, from which most (51, 61.44%) were among PL fishers, compared to 30 links among BK fishers (36.14%), while there were only 2 connections (2.4%) between the two communities (Table 1, Fig. 3b). From all observed relationships, 26 (31.32%) were between first-degree relatives: 13 within BK, 11 within PL, and only two between the two communities. Analysis of eigenvector centrality showed that all of the most important nodes were fishers from PL (Fig. 3b). The density of the subnetwork of kinship among fishers was significantly higher within PL (4.54%) compared to within BK (1.27%, $P = 0.001$), also higher than the overall network (1.21%, $P = 0.042$) and larger compared to the comparison between links from the two communities (0.06%, $P = 0.015$, Fig. 4, Appendix 7, Table A7.1).

Communication, trust, and reciprocity

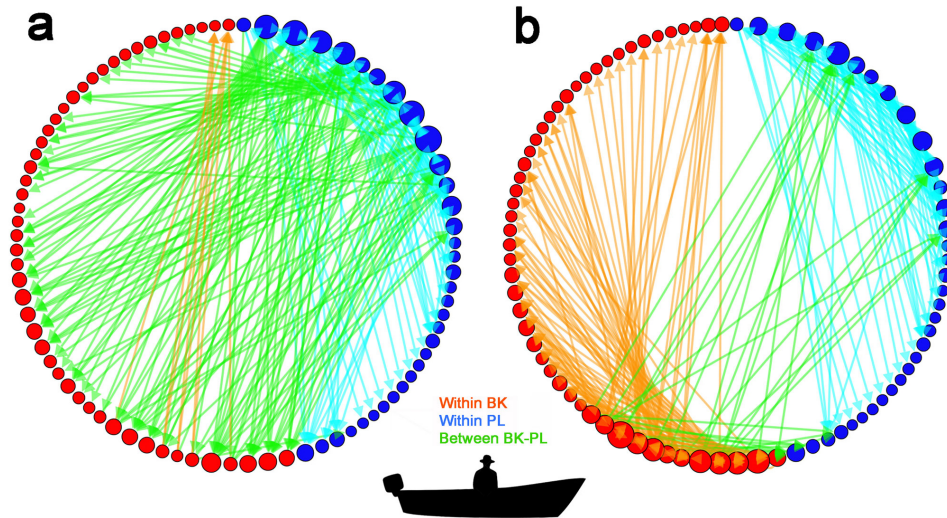
Our second, third, and fourth measures of social connectivity among fishers (communication, trust, and reciprocity) showed almost identical results among them. Social connections were more frequent within fishers from PL compared to BK, and there was a significant number of social connections between the two communities (Fig. 6a, Appendix 8, Fig. A8.1). We identified 235 communication links overall, from which 97 (41.27%) were among PL fishers, 130 (55.31%) were between fishers from distinct

communities, and only 8 (3.40%) were among BK fishers. The density of the subnetworks for communication was consistently higher within PL (8.64%), and an order of magnitude lower within BK (Fig 6a, 0.34%, $P = 0.001$, Fig. 4, Appendix 7, Table A7.1). Comparatively, the density of the overall network and the comparison between communities showed intermediate values (3.45% and 3.90%) that were significantly different from the values observed within communities (All P values ≤ 0.023). Relationships between communities for these three variables were symmetrical because communication, trust, and reciprocity were frequently observed from BK fishers toward PL fishers and vice versa. The networks contained a few isolated nodes, suggesting that some of the interviewed fishers did not communicate, trust, or have reciprocal relationships with others.

Leadership

Our fifth measure of social connectivity (leadership) showed similar levels of social connections within fishers from BK compared to PL, but a much lower frequency of social ties between the two communities (Fig. 6b). From 253 leadership ties identified, 127 (50.19%) were among BK fishers, 94 (37.15%) were among PL fishers, and only 32 (12.64%) were between fishers from the two communities. The density of the subnetwork for leadership was significantly higher within PL (8.37%) compared to within BK (5.39%, $P = 0.005$), the overall network (3.71%, $P = 0.023$) and the comparison between the two communities (0.96%, $P = 0.001$, Fig. 4, Appendix 7, Table A7.1). Notably, leadership relationships between communities were present but were completely asymmetrical. According to BK fishers, 15% of

Fig. 6. Networks describing social connectivity among 83 fishers from two communities in the northern Gulf of California: (a) Communication, (b) Leadership. Nodes represent individual fishers colored according to the community to which they belong (Red = Bahia Kino, BK; blue = Puerto Libertad, PL). Node size represents the eigenvector centrality. Links within BK are shown in red, links within PL are shown in blue, and green links represent relationships between two fishers from different communities.



the individuals identified as leaders were from PL, while the rest were fishers from BK (Fig. 6b). In contrast, fishers from PL did not recognize any leaders within BK.

Comparisons within ecological and social networks

Comparisons within BK

According to our statistical analyses, the probability of finding an ecological link within BK fishing grounds was significantly higher for larvae (60.71%) compared to fish migrants (19.64%, $P = 0.001$), and higher for fish migrants compared to fish kinship ties (0.41%, $P = 0.001$). In terms of social networks, we found a significantly higher probability of finding leadership ties (5.39%) compared to kinship ties (1.27%, $P = 0.001$), and a higher probability of kinship ties compared to communication ties (0.34%, $P = 0.025$, Fig. 4, Appendix 7, Table A7.2).

Comparisons within PL

We found that the probability of finding an ecological link within PL fishing zones was identical for larvae and fish migrants (50%), and both were significantly higher than the probability of finding fish kinship ties (0.53%, $P = 0.001$). The probability of finding any social tie among fishers within PL was not statistically different for any social measure tested (all P values ≥ 0.506 , Fig. 4, Appendix 7, Table A7.2) including kinship among fishers (4.54%), communication (8.64%), and leadership (8.37%).

Comparisons between BK and PL

When considering the entire ecological network, the probability of finding an ecological link between any fishing zone included in the analyses was not statistically different for larvae (45.45%) compared to fish migrants (26.36%, $P = 0.063$), but these two were significantly more likely than finding fish kinship ties (0.44%, $P = 0.001$). When the ecological links within each community were excluded and we focused on the potential ties exclusively between communities, the probabilities observed were also similar for

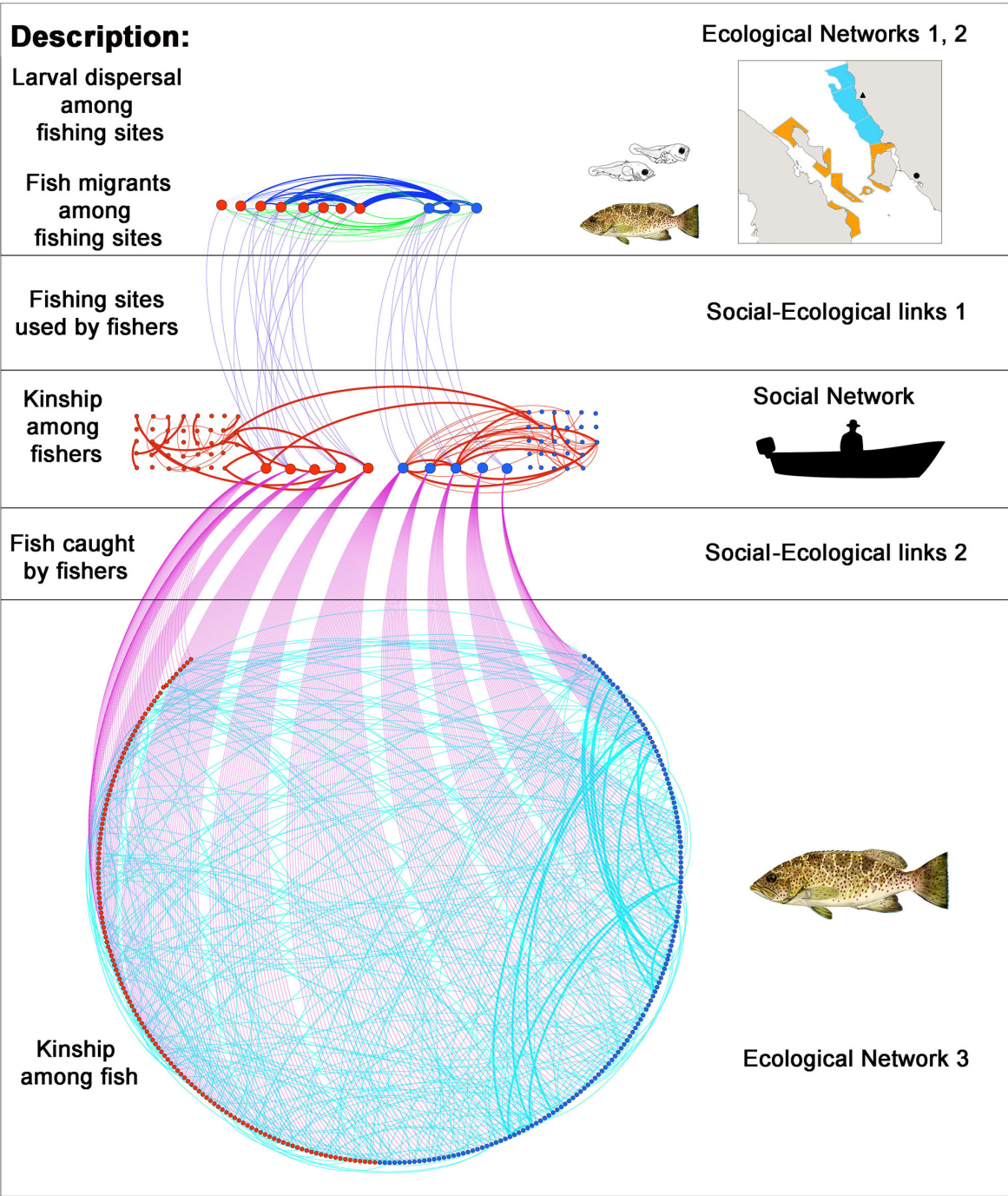
larvae (27.08%) and fish migrants (31.25%), that were more likely than finding a fish kinship tie (0.41%, Fig. 4, Appendix 7, Table A7.2).

In the social network considering all fishers and all links, it was similarly likely to find a social tie in terms of leadership (3.71%) or communication (3.45%, $P = 0.334$), and both were more likely than finding kinship ties (1.21%, $P \leq 0.007$). However, when the social links within each community were excluded and we focused on the potential ties exclusively between communities, it was much more likely to find a communication tie (3.9%) compared to leadership (0.96%) or kinship (0.06%).

Contrast between ecological and social networks

A diagram showing a multilevel social-ecological network, including all the ecological and social components analyzed and focused on the connections between the two communities highlights at least two types of social-ecological links present in our study system (Fig. 7). The first set (social-ecological links 1) was represented by the use of fishing sites by fishers. Although fishers from each community do not show any overlap in the use of fishing zones, their fishing zones themselves show multiple ecological links based on larval dispersal and fish migrants. The second set of social-ecological links was represented by the fish caught by fishers, showing that it is common to find kinship ties between any two leopard groupers caught by fishers from distinct communities. Importantly, some social ties, for example, based on kinship among fishers, were sometimes nearly absent between the two communities. In two of our ecological variables (larval dispersal and fish migrants between fishing sites) the likelihood of finding an ecological tie was always significantly higher than finding a social tie, both within and between the two communities of fishers (Fig. 4, Appendix 7, Table A7.3). Although there were differences between the probability of finding an ecological versus a social connection, comparisons between networks of different size are a methodological challenge.

Fig. 7. Small-scale fishery targeting leopard grouper (*Mycteroperca rosacea*) in the northern Gulf of California, Mexico, as a multilevel social-ecological network. From top to bottom, Ecological Networks 1 and 2 show larval dispersal (blue links) and fish migrants (green links), respectively, identified among 11 fishing sites (nodes, see map to the right). Social Network shows first and second-degree relationships (red links) among 83 individual fishers represented by nodes. Ecological Network 3 displays kinship (teal links) among 282 individual fish represented by nodes. In all networks, nodes from Bahia Kino are coded red, and nodes from Puerto Libertad are blue. The weight of each link is proportional to the strength of the connection. Individual fishers are linked to individual fishing sites (Social-Ecological links 1) and to individual fish (Social-Ecological link 2). Note that Social-Ecological link information was available from only 10 individual fishers (larger nodes).



DISCUSSION

This study applied a collaborative approach merging citizen science, population genetics, oceanographic modeling, and interviews. We showed how empirical estimates of multiple ecological and social connections in the harvesting of a marine resource can be estimated and integrated for analysis of the interactions within the conceptual framework of multiple one-level networks that could be assembled into a multilevel social-ecological network. However, our ability to measure explicit social-ecological links was limited by the small number of fishers from whom ecological data was acquired. Also, the statistical comparison of properties of ecological and social networks displaying drastically different sizes is problematic. Below, we discuss some insights learned while comparing the level of ecological and social connectivity and challenges identified. We also examine some patterns observed on the constraints of connectivity given different attributes of each ecological and social component. Finally, we discuss how this information could be used to inform ways to improve collaborative management.

Although we showed detailed connections within ecological and social levels and between the two levels, a fully articulated social-ecological multilevel network typically considers all links simultaneously (Bodin 2017, Sayles et al. 2019). The number of fishers involved in the citizen science program in our study was limited to five fishers from each community. Thus, the information gathered about explicit social-ecological links represents only 10 individual fishers from a much larger universe. The effort to empirically characterize even a modest number of relevant social-ecological links grows exponentially with the number of fishers, fish, and fishing zones and seems daunting even for a single species and two communities. Thus, novel approaches would need to be developed in order to quickly and massively characterize ecological connections among multiple fish populations, for example, via environmental DNA metabarcoding (Sigsgaard et al. 2020; Valdivia-Carrillo et al. 2021). Additionally, we did not consider ecological connections for leopard grouper from other adjacent fishing communities (e.g., Bahía de los Angeles and Puerto Peñasco) that show significant import or export of larvae from/toward BK and PL fishing sites (Munguia-Vega et al. 2014, Jackson et al. 2015). These observations stress the problem of defining boundaries of social-ecological networks, which alter the number of nodes and the properties of the networks being studied.

Social-ecological links between communities

The scientific literature recognizes a lack of consensus about what constitutes social-ecological fit and how and at which scales it should be better measured (Bodin et al. 2019). Compared to previous studies of social-ecological networks in fisheries that focused on trophic relationships among targeted species and resource users (Yletyinen et al. 2018, Barnes et al. 2019, Kluger et al. 2019), our study highlighted source-sink metapopulation dynamics for a species with a complex life history at the level of individual fish, fishers, and fishing sites. However, even when networks are a flexible tool for investigating diverse types of data, a key challenge remains in performing quantitative analyses to compare connections in mixed social-ecological networks (Janssen et al. 2006). Our approach attempted a quantitative comparison of the likelihood of finding ecological and social links employing network density as a common measure to compare disparate networks. In our statistical analyses, ecological links

between fishing sites from the two communities were more likely to be present than any social tie among fishers. For example, in a direct comparison of the same variable (kinship) between individual fish and fishers from the two communities, kinship was an order of magnitude less likely to be present between fishers compared to fish. So, although not completely absent, social ties between the two communities were weak compared to ecological links. These results suggest little mobility of individual fishers between the two communities despite significant movement of leopard groupers through their life cycle between fishing sites. Thus, the geographic scale and strength of key ecological processes supporting fish stocks through the fish life cycle seem to be larger than those of social connections among resource users. This suggests some level of governance challenge due to a lack of network closure, where the two actors exploiting interconnected ecological resources lack strong collaboration (Bodin et al. 2016). Resource users and managers could benefit from a broader, regional perspective that connects fishers from distinct communities toward shared goals and activities, e.g., monitoring of stock status and management actions. However, a key challenge in establishing mismatches between ecological and social networks is the resolution of what the nodes and links represent in the network. For example, in our study there was an order of magnitude difference between the number of fishing sites (11), fishers (83), and fish (282). The number of nodes in the network defines the number of potential links present, thus density in a network decreases exponentially with increasing network size. This bias could also contribute to the fact that probabilities of finding ecological links among fishing sites were an order of magnitude larger than the probability of finding any social ties. Alternative analytical methods to compare social-ecological networks include motif frequency counts (e.g., of closed network structures) and exponential random graph modeling (ERGM) to test against a null model assuming a uniform likelihood of finding links between nodes (Barnes et al. 2019, Sayles et al. 2019).

Our study revealed strong leopard grouper connectivity between two communities of fishers, even when they were geographically distant (150 km apart), targeted different cohorts of the same species using distinct fishing gear, and used completely different fishing zones that do not show any spatial overlap. The latter could be explained by the presence of valuable fishing zones closer to home, the use of different fishing gear targeting distinct cohorts, and informal agreements about the traditional fishing zones of each community. Ecological links between the two communities were within the same order of magnitude and equally or more likely to be present compared to links within each community. The relevance of ecological connections between the fishing zones from the two communities varied along the life history of the fish, creating a reciprocal ecological relationship in terms of source-sink metapopulation dynamics. The ecological network based on larval dispersal showed BK fishing zones as a source of larvae for PL fishing grounds following the predominantly cyclonic circulation of oceanic currents during the spawning season of leopard groupers in the study region (Munguia-Vega et al. 2014). In contrast, the analysis of migrants suggested that larvae, juvenile, and adult fish from the fishing zones of PL also migrate to BK fishing grounds. Thus, management decisions that occur within the fishing zone of one community and that directly affect

the size and reproductive potential of the fish stock can have strong demographic impacts on the availability of leopard grouper in the other community. For example, overfishing in the fishing zones of BK could negatively impact PL by reducing larval recruitment. In contrast, the recent establishment of a marine reserve in the fishing grounds of PL (DOF 2017) could translate into a spill-over effect of migrant individuals that could directly benefit BK fishers. The recognition of how local fish populations are ecologically linked to each other is essential to maintain population resilience and avoid overexploitation (Wilson 2006, Berger et al. 2017). In terms of resilience, the high density observed in the combined ecological network could suggest high resilience of the system (Janssen et al. 2006), for example, if any particular node disappears, e.g., a particular site is overfished.

In contrast to ecological links that were consistently present between the two communities, our results showed the probability of finding a social tie among fishers changed significantly depending on the type of social connection. Strong ecological connections are not echoed by strong social ties in our study system, and fishers from the two communities do not currently have stable channels for information flow. The probability of social ties was relatively modest for communication, trust, and reciprocity, significantly lower for leadership and almost absent for kinship. The likelihood of observing communication, trust, and reciprocity between the two communities was intermediate compared to the values observed within each community. Leadership and kinship ties were significantly less likely to occur between rather than within the two communities. In contrast, a previous study of social networks conducted in 2007 in the MIR found strong kinship ties between BK and PL (Duberstein 2009), highlighting that social connections evolve and might not be static over time. However, it is also likely that, by interviewing only between 10% to 17% of all the fishers from each community, we missed documenting some social connections. Notably, leadership ties were strongly biased in terms of the recognition of leaders from the smaller community according to fishers from the larger community, but not vice versa. All other social relationships observed between the two communities were symmetrical. The asymmetry could be related to the fact that fishers from the smaller community (PL) are more likely to travel to BK than the other way around because they need to report their catches at the local fisheries office from the National Fisheries and Aquaculture Commission (CONAPESCA) in BK. Overall, leaders from the smaller community seem to play a key role in bridging barriers for communication between the two communities.

Even when the fishing zones of each community regarding leopard groupers do not overlap, they do for other fisheries including gillnets targeting Pacific sierra, Pacific angel shark, and smooth-hounds, for which fishers from both communities travel to several islands in the MIR (Moreno-Báez et al. 2012). According to Duberstein (2009), fishers from PL and BK converge at 56 fishing areas, particularly in fisheries where they use gillnets and diving as fishing techniques. This indicates that the multi-species social-ecological networks are much more complex than presented here for a single species and that patterns could vary with different fishing gear. However, our approach could in principle be scaled up to integrate multiple species, communities, and fisheries. Social-ecological systems in small-scale fisheries are complex and it may be challenging to

characterize each interaction and the effects they have on the environment considering small-scale fishers target dozens of different species (Leslie et al. 2015). These different species also show a large variation in life history, including habitats for recruitment, reproductive periods and planktonic larval durations, the presence of migratory behaviors, etc., that translate into contrasting patterns of ecological connectivity within each life history combination (Munguia-Vega et al. 2018). Because leopard groupers are also targeted by recreational fisheries, decisions made by small-scale fishers could affect effort, economic return, cost, fish population, and recruitment in this sector (Leslie et al. 2009). Further studies could provide direct evidence linking the structure of the social-ecological networks identified here and specific ecological and management outcomes that we did not measure, such as fish abundance, stock status, presence of cooperatives, etc.

Social-ecological links within each community

We identified that the spatial scale over which connectivity occurs, the size of the population from which the sample is drawn, and the spatial resolution of the analyses (defined by the number of nodes present in the networks) exerted a large influence on various aspects of social and ecological connectivity. For example, the results of kinship analyses among fishers within each community were similar to those of fish in that both showed a higher frequency of first-degree relatives within the smaller community (PL). This could be due to a general effect where kinship increases when the population size is smaller (Blouin 2003), which holds true for both fishers from PL and fish caught in their fishing zones that, comparatively, were also much smaller compared to the larger community.

The strength of the ecological connections was the result of the interaction between the geographic scales of the fished areas and the spatial scale at which leopard grouper individuals move, first as larvae, e.g., hundreds of kilometers, then as adults, e.g., tens of kilometers (Munguia-Vega et al. 2018). For example, in the eight fishing areas of BK spread over multiple islands of the MIR, ecological links based on larval dispersal were more likely to occur than links from migrants that include juvenile and adult dispersal. In contrast, both larval and migrant links were equally likely among the three adjacent fishing zones from PL. The observation of larger fishing areas in BK agrees with a previous study documenting travel distances up to 200 km, compared to the other communities in the northern GC (Duberstein 2009, Moreno-Báez et al. 2012). The higher competition within a larger community could force fishers to take longer trips to distant fishing zones if local resources have been overexploited.

We found that all different types of social connections studied, including kinship, communication, trust, reciprocity, and leadership, were all equally likely to be present in the smaller community (PL), whereas in the larger community (BK) the probability of finding distinct social ties varied significantly. This observation is consistent with several studies showing a positive relationship between the degree of cooperation within a group and the level of kinship (Smith 2014, Enke 2018), which could explain the presence of robust social ties for all types of social connections investigated within PL. In contrast, in the larger community it was more likely to find a leadership tie than a kinship tie among fishers, and comparatively it was even less likely to find

a communication, trust, or reciprocity tie. The fact that we interviewed a larger fraction of fishers in PL (17%) compared to BK (10%) could also have contributed to finding stronger social links in PL. The level of leadership could be explained by the longer investment of civil society organizations in BK into capacity building for fishers to strengthen the negotiation and conflict resolution skills of individuals and cooperatives. However, leadership in BK does not translate into the same level of communication or trust. Generally, all the types of social ties were more likely to be present among fishers from the smaller community compared to the larger one. This is also in line with small group size being a strong predictor of successful governance (Ostrom 1990). Trust among local fishers (as individuals) and members of cooperatives affect fishing patterns and fisheries sustainability. As long as cooperatives and patrons find reliable local fishers to work with, they have no need to recruit outsiders, which could otherwise increase fishing pressure and the risk of overfishing, as has been extensively documented (Basurto et al. 2020).

Besides kinship and group size, a lower level of social cohesion between fishers in a large community could be driven by other demographic processes, including recent immigration. A previous study suggested that high immigration rates in BK were associated with the presence of weak norms of trust and reciprocity, and low social capital, resulting in a challenge for fishers to develop relationships and invest in building fishing co-ops (Basurto et al. 2013a). As a result, their open access status quo has led to overharvest (Basurto et al. 2013b). Similarly, high levels of trust in smaller isolated communities could be positively associated with homogeneity with respect to ethnicity and social and economic relationships (Ostrom and Walker 2003). Other factors including lower access to information and education are likely to promote stronger local norms and lower variability within a smaller and isolated community, whereas greater individuality is expected in larger and more connected areas with higher access to education and information (McClanahan and Abunge 2018).

Implications for collaborative management

The uncovering of strong reciprocal ecological connections between two communities of small-scale fisheries in the presence of relatively weak and sometimes asymmetric social ties, highlights the importance of collaboration to plan and implement commonly agreed regulations and harvesting practices to ensure sustainability. Our data suggested that fishers from these two communities do not interact with each other at sea (at least for the leopard grouper fishery), therefore we recommend the creation of new venues for collaboration or strengthening of existing collaborative efforts.

Although some settings do exist for fishers within each community to improve governance, promote sustainable practices, and work toward a common vision, formal venues for fishers from both communities to cooperate are very limited. Both communities have community committees for fisheries and aquaculture management that represent cooperatives, permit holders, and free fishers (Espinosa-Romero et al. 2014), which do not have management authority but provide a common voice to the government to request or recommend changes. Nevertheless, the two committees do not currently interact. There is often a significant difference between communities regarding the

perceived costs and benefits of fishery restrictions such as size limits, closures, gear management, and others (McClanahan and Abunge 2018). Regional forums could provide an understanding of how both communities can manage their resources to maximize their shared benefits by identifying and communicating the nature and extent of ecological interactions (larval recruitment, spillover effects, and adult migration). Shared norms, social capital, and a shared governance of common resources, can only emerge from repeated and extended interactions that create interdependence and shared identities and interests among community members (McCay et al. 2014). It has been documented that fishers' participation in local fisheries management depends on the fishing access strategy they are associated with. As members of cooperatives, fishers are more likely to be able to create more trustworthy relationships and to participate in decision-making forums about fishing activities, financial distribution of benefits, working conditions, etc. (Basurto et al. 2020).

Social relations developed among individuals are part of their social capital, which enables network members to have access to different types of resources or benefits, including access to markets, increased income, and access to knowledge (Pedroza-Gutiérrez and Hernandez 2017). These relationships, as supported by the network exchange theory, provide a higher adaptive capacity to fishers that have a stronger and larger network, favoring those center positions compared to peripheral positions in the network (González-Mon et al. 2019). Social interactions among fishers from distinct communities are important in the face of increasing environmental variability in the Gulf of California and elsewhere (Frawley et al. 2019b). The behavior of small-scale fishers and their spatio-temporal movements respond to changes in their target fisheries (Sievanen 2014, González-Mon et al. 2021). Knowledge plays a key role in some of the most common responses of fishers to climate variability, including moving fishing locations, diversifying fisheries or occupations, or switching gear types (Sievanen 2014).

Other initiatives that already promote some collaboration between communities also include (1) underwater monitoring groups of fishers trained in SCUBA diving to help evaluate marine reserves (Fulton et al. 2019); (2) a gender equality program where men and women from several fishing communities in Mexico, including PL and BK, are trained to promote gender equity and equality; (3) fisheries improvement project (FIP) for clams (<https://fisheryprogress.org/fip-profile/mexico-puerto-libertad-clams-hookah>), where some fishers from BK and PL participate with government agencies from the fisheries sector.

In November 2017, the results of this study were presented separately to fishers from BK and PL. Both communities were receptive and expressed the importance of having stronger communication to collaborate with fishers from the other community. The information about how an individual fish they captured at a particular fishing site was a close relative of another fish captured by a fisher from the same or adjacent community resonated the most in terms of their appreciation of social-ecological connections. This unexpected response is consistent with the presence of alternative relational values between fishers and tangible ecological elements, as opposed to theoretical or conceptual generalizations (Chan et al. 2016). They were both interested in meeting to establish agreements (i.e., pricing, size

limits, fishing effort) regarding the leopard grouper and other fisheries they share. Exchanges are well-documented tools for promoting learning, understanding, and knowledge transfer (Gardner et al. 2017, Thompson et al. 2017). However, within a particular region, they can be effective tools in creating unity, empathy, and changing the mental model about the ecological interdependence between adjacent communities. Fishers who share a resource but are unfamiliar with how neighboring communities live and work will be less likely to consider them when making decisions that affect the fishery. The recognition of some ecological interactions can significantly contribute to the understanding and management of ecosystems, thus more intensively managing these interactions, particularly for key functional taxa such as the leopard grouper, can help resource users plan local adaptations to local problems (McClanahan et al. 2009). Other examples of successful co-management exist in the region, where a concession system for benthic resources promotes cooperatives from neighboring communities to closely collaborate (McCay et al. 2014).

In the management of fisheries, as in other common property resources, there has been a shift from agreements between two sectors (fishers and government) to co-management agreements between multiple sectors involved in the use of fishery resources (Gibbs 2008, Ponce-Diaz et al. 2009). In many cases, fisheries management changed from a hierarchical to a network structure. Instead of the government agencies being the only ones that dictate the rules, the different institutions communicate with each other to reach agreements that regulate the activity (Pomeroy 2003). Thus, the current global trend in fisheries systems is toward a reticular structure. Central actors, identified in our study as fishers from PL, have more social ties than others and are well situated to execute leadership that facilitates regional collective action. Regional committees, including fishers from other fishing communities beyond PL and BK could also help create dialogue spaces for resource users at the scale at which ecological connections are present.

Responses to this article can be read online at:
<https://www.ecologyandsociety.org/issues/responses.php/13055>

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Data Availability:

The data supporting the findings of this study are available as Supplementary Material.

LITERATURE CITED

- Aljanabi, S. M., and I. Martinez. 1997. Universal and rapid salt-extraction of high quality genomic DNA for PCR-based techniques. *Nucleic Acids Research* 25:4692-4693. <https://doi.org/10.1093/nar/25.22.4692>
- Alvarez-Romero, J. G., A. Munguia-Vega, M. Beger, M. M. Mancha-Cisneros, A. N. Suárez-Castillo, G. G. Gurney, R. L. Pressey, L. R. Gerber, H. N. Morzaria-Luna, H. Reyes-Bonilla, V. M. Adams, M. Kolb, E. M. Graham, J. VanDerWal, A. H.-A. Castillo-Lopez, G. D. Petatan-Ramirez, M. Moreno-Baez, C. R. Godinez-Reyes, and J. Torre. 2018. Designing connected marine reserves in the face of global warming. *Global Change Biology* 24:e671-e691. <https://doi.org/10.1111/gcb.13989>
- Alvarez-Romero, J. G., R. L. Pressey, N. C. Ban, J. Torre-Cosio, and O. Aburto-Oropeza. 2013. Marine conservation planning in practice: lessons learned from the Gulf of California. *Aquatic Conservation: Marine and Freshwater Ecosystems* 23:483-505. <https://doi.org/10.1002/aqc.2334>
- Barnes, M. L., O. Bodin, T. R. McClanahan, J. N. Kittinger, A. S. Hoey, O. G. Gaoue, and N. A. J. Graham. 2019. Social-ecological alignment and ecological conditions in coral reefs. *Nature Communications* 10:2039. <https://doi.org/10.1038/s41467-019-09994-1>
- Bastian, M., S. Heymann, and M. Jacomy. 2009. Gephi: An open source software for exploring and manipulating networks. *Proceedings of the Third International ICWSM Conference*: 361-362.
- Basurto, X., A. Bennett, A. Hudson Weaver, S. Rodriguez-Van Dyck, and J.-S. Aceves-Bueno. 2013a. Cooperative and noncooperative strategies for small-scale fisheries' self-governance in the globalization era: implications for conservation. *Ecology and Society* 18(4):38. <https://doi.org/10.5751/ES-05673-180438>
- Basurto, X., A. Bennett, E. Lindkvist, and M. Schluter. 2020. Governing the commons beyond harvesting: an empirical illustration from fishing. *PLoS ONE* 15:e0231575. <https://doi.org/10.1371/journal.pone.0231575>
- Basurto, X., S. Gelcich, and E. Ostrom. 2013b. The social-ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. *Global Environmental Change* 23:1366-1380. <https://doi.org/10.1016/j.gloenvcha.2013.08.001>
- Berger, A. M., D. R. Goethel, P. D. Lynch, T. Quinn, S. Mormede, J. McKenzie, and A. Dunn. 2017. Space oddity: the mission for spatial integration. *Canadian Journal of Fisheries and Aquatic Sciences* 74:1698-1716. <https://doi.org/10.1139/cjfas-2017-0150>

- Blouin, M. 2003. DNA-based methods for pedigree reconstruction and kinship analysis in natural populations. *Trends in Ecology and Evolution* 18:503-511. [https://doi.org/10.1016/S0169-5347\(03\)00225-8](https://doi.org/10.1016/S0169-5347(03)00225-8)
- Bodin, Ö. 2017. Collaborative environmental governance: achieving collective action in social-ecological systems. *Science* 357(6352):eaan1114. <https://doi.org/10.1126/science.aan1114>
- Bodin, Ö., S. M. Alexander, J. Baggio, M. L. Barnes, R. Berardo, G. S. Cumming, L. E. Dee, A. P. Fischer, M. Fischer, M. Mancilla Garcia, A. M. Guerrero, J. Hileman, K. Ingold, P. Matous, T. H. Morrison, D. Nohrstedt, J. Pittman, G. Robins, and J. S. Sayles. 2019. Improving network approaches to the study of complex social-ecological interdependencies. *Nature Sustainability* 2:551-559. <https://doi.org/10.1038/s41893-019-0308-0>
- Bodin, Ö., and B. I. Crona. 2008. Management of natural resources at the community level: exploring the role of social capital and leadership in a rural fishing community. *World Development* 36:2763-2779. <https://doi.org/10.1016/j.worlddev.2007.12.002>
- Bodin, Ö., and B. I. Crona. 2009. The role of social networks in natural resource governance: what relational patterns make a difference? *Global Environmental Change* 19:366-374. <https://doi.org/10.1016/j.gloenvcha.2009.05.002>
- Bodin, Ö., G. Robins, R. R. J. McAllister, A. M. Guerrero, B. Crona, M. Tengö, and M. Lubell. 2016. Theorizing benefits and constraints in collaborative environmental governance: a transdisciplinary social-ecological network approach for empirical investigations. *Ecology and Society* 21(1):40. <https://doi.org/10.5751/ES-08368-210140>
- Bonacich, P., and P. Lloyd. 2001. Eigenvector-like measures of centrality for asymmetric relations. *Social Networks* 23:191-201. [https://doi.org/10.1016/S0378-8733\(01\)00038-7](https://doi.org/10.1016/S0378-8733(01)00038-7)
- Borgatti, S. P., M. G. Everett, and L. C. Freeman. 2002. UCINET for windows: software for social network analysis. Analytical Technologies, Harvard, Massachusetts, USA.
- Borgatti, S. P., A. Mehra, D. J. Brass, and G. Labianca. 2009. Network analysis in the social sciences. *Science* 323:892-895. <https://doi.org/10.1126/science.1165821>
- Chan, K. M., P. Balvanera, K. Benessaiah, M. Chapman, S. Diaz, E. Gomez-Baggethun, R. Gould, N. Hannahs, K. Jax, S. Klain, G. W. Luck, B. Martin-López, B. Muraca, B. Norton, K. Ott, U. Pascual, T. Satterfield, M. Tadaki, J. Taggart, and N. Turner. 2016. Opinion: Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences* 113:1462-1465. <https://doi.org/10.1073/pnas.1525002113>
- Cinti, A., J. N. Duberstein, E. Torreblanca, and M. Moreno-Báez. 2014. Overfishing drivers and opportunities for recovery in small-scale fisheries of the Midriff Islands Region, Gulf of California, Mexico: the roles of land and sea institutions in fisheries sustainability. *Ecology and Society* 19(1):15. <https://doi.org/10.5751/ES-05570-190115>
- Cox, J. C. 2004. How to identify trust and reciprocity. *Games and Economic Behavior* 46:260-281. [https://doi.org/10.1016/S0899-8256\(03\)00119-2](https://doi.org/10.1016/S0899-8256(03)00119-2)
- Cumming, G. S., D. H. M. Cumming, and C. L. Redman. 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. *Ecology and Society* 11(1):14. <https://doi.org/10.5751/ES-01569-110114>
- Cumming, G. S., and K. A. Dobbs. 2020. Quantifying social-ecological scale mismatches suggests people should be managed at broader scales than ecosystems. *One Earth* 3:251-259. <https://doi.org/10.1016/j.oneear.2020.07.007>
- d'Armengol, L., M. Prieto Castillo, I. Ruiz-Mallén, and E. Corbera. 2018. A systematic review of co-managed small-scale fisheries: social diversity and adaptive management improve outcomes. *Global Environmental Change* 52:212-225. <https://doi.org/10.1016/j.gloenvcha.2018.07.009>
- Diario Oficial de la Federación (DOF). 2017. Acuerdo por el que se establece una zona de refugio pesquero total temporal en aguas marinas de jurisdicción federal de Puerto Libertad, municipio de Pitiquito en el estado de Sonora. Diario Oficial de la Federación, México. [online] URL: http://dof.gob.mx/nota_detalle.php?codigo=5489928&fecha=12/07/2017
- Diaz-Urbe, J. G., J. F. Elorduy-Garay, and M. T. Gonzalez-Valdovinos. 2001. Age and growth of the leopard grouper, *Mycteroperca rosacea*, in the southern Gulf of California, Mexico. *Pacific Science* 55:171-182. <https://doi.org/10.1353/psc.2001.0012>
- Duberstein, J. N. 2009. The shape of the commons: social networks and the conservation of small-scale fisheries in the Northern Gulf of California, Mexico. Dissertation. School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona, USA.
- Enke, B. 2018. Kinship systems, cooperation, and the evolution of culture. CESifo Working Paper. Category 13: Behavioural Economics 6867:1-116. <https://doi.org/10.2139/ssrn.3144249>
- Epstein, G., J. Pittman, S. M. Alexander, S. Berdej, T. Dyck, U. Kreitmair, K. J. Rathwell, S. Villamayor-Tomas, J. Vogt, and D. Armitage. 2015. Institutional fit and the sustainability of social-ecological systems. *Current Opinion in Environmental Sustainability* 14:34-40. <https://doi.org/10.1016/j.cosust.2015.03.005>
- Erisman, B., and M. Craig. 2018. *Mycteroperca rosacea*. The IUCN Red List of Threatened Species. <https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T14053A100466656.en>
- Erisman, B., I. Mascarenas, G. Paredes, Y. Sadovy de Mitcheson, O. Aburto-Oropeza, and P. Hastings. 2010. Seasonal, annual, and long-term trends in commercial fisheries for aggregating reef fishes in the Gulf of California, Mexico. *Fisheries Research* 106:279-288. <https://doi.org/10.1016/j.fishres.2010.08.007>
- Espinosa-Romero, M. J., M. A. Cisneros-Mata, T. McDaniels, and J. Torre. 2014. Aplicación del enfoque ecosistémico al manejo de pesquerías artesanales. Caso de estudio: Puerto libertad, Sonora. *Ciencia Pesquera* 22:65-67.
- Fernandez-Rivera Melo, F. J., A. N. Suarez-Castillo, I. G. Amador-Castro, E. Gastelum-Nava, M. J. Espinosa-Romero, and J. Torre. 2018. Bases para el ordenamiento de la pesca artesanal con la participación del sector productivo en la región de las grandes islas, Golfo de California. *Ciencia Pesquera* 26:81-100.

- Fontana, A., and J. H. Frey. 2005. The interview: from neutral stance to political involvement. Pages 695-727 in N. K. Denzin, and Y. S. Lincoln, editors. The SAGE handbook of qualitative research. SAGE, Thousand Oaks, California, USA.
- Food and Agriculture Organization (FAO). 2020. The state of world fisheries and aquaculture 2020. FAO, Rome, Italy.
- Frawley, T. H., D. K. Briscoe, P. C. Daniel, G. L. Britten, L. B. Crowder, C. J. Robinson, W. F. Gilly, and A. Arkhipkin. 2019b. Impacts of a shift to a warm-water regime in the Gulf of California on jumbo squid (*Dosidicus gigas*). ICES Journal of Marine Science 76:2413-2426. <https://doi.org/10.1093/icesjms/fsz133>
- Frawley, T. H., E. M. Finkbeiner, and L. B. Crowder. 2019a. Environmental and institutional degradation in the globalized economy: lessons from small-scale fisheries in the Gulf of California. Ecology and Society 24(1):7. <https://doi.org/10.5751/ES-10693-240107>
- Fuller, E. C., J. F. Samhuri, J. S. Stoll, S. A. Levin, and J. R. Watson. 2017. Characterizing fisheries connectivity in marine social-ecological systems. ICES Journal of Marine Science 74:2087-2096. <https://doi.org/10.1093/icesjms/fsx128>
- Fulton, S., A. Hernández-Velasco, A. Suarez-Castillo, F. F.-R. Melo, M. Rojo, A. Sáenz-Arroyo, A. H. Weaver, R. Cudney-Bueno, F. Micheli, and J. Torre. 2019. From fishing fish to fishing data: the role of artisanal fishers in conservation and resource management in Mexico. Pages 151-175 in S. Salas, M. J. Barragan-Paladines, and R. Chuenpagdee, editors. Viability and sustainability of small-scale fisheries in Latin America and the Caribbean. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-76078-0_7
- Gardner, C. J., J. E. Latham, and S. Rocliffe. 2017. Intended and unintended outcomes in fisheries learning exchanges: lessons from Mexico and Madagascar. Marine Policy 77:219-226. <https://doi.org/10.1016/j.marpol.2016.04.040>
- Gibbs, M. T. 2008. Network governance in fisheries. Marine Policy 32:113-119. <https://doi.org/10.1016/j.marpol.2007.05.002>
- González-Mon, B., Ö. Bodin, B. Crona, M. Nenadovic, and X. Basurto. 2019. Small-scale fish buyers' trade networks reveal diverse actor types and differential adaptive capacities. Ecological Economics 164:106338. <https://doi.org/10.1016/j.ecolecon.2019.05.018>
- Gonzalez-Mon, B., Ö. Bodin, E. Lindkvist, T. H. Frawley, A. Giron-Nava, X. Basurto, M. Nenadovic, and M. Schlüter. 2021. Spatial diversification as a mechanism to adapt to environmental changes in small-scale fisheries. Environmental Science and Policy 116:246-257. <https://doi.org/10.1016/j.envsci.2020.11.006>
- Green, A. L., A. P. Maypa, G. R. Almany, K. L. Rhodes, R. Weeks, R. A. Abesamis, M. G. Gleason, P. J. Mumby, and A. T. White. 2015. Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. Biological Reviews of the Cambridge Philosophical Society 90:1215-1247. <https://doi.org/10.1111/brv.12155>
- Hanneman, R. A., and M. Riddle. 2005. Introduction to social network methods. University of California, Riverside, California, USA.
- Hartley, T. W. 2010. Fishery management as a governance network: examples from the Gulf of Maine and the potential for communication network analysis research in fisheries. Marine Policy 34:1060-1067. <https://doi.org/10.1016/j.marpol.2010.03.005>
- Henry, A. D., and T. Dietz. 2011. Information, networks, and the complexity of trust in commons governance. International Journal of the Commons 5:188-212. <https://doi.org/10.18352/ijc.312>
- Hilborn, R., R. O. Amoroso, C. M. Anderson, J. K. Baum, T. A. Branch, C. Costello, C. L. de Moor, A. Faraj, D. Hively, O. P. Jensen, H. Kurota, L. R. Little, P. Mace, T. McClanahan, M. C. Melnychuk, C. Minto, G. C. Osio, A. M. Parma, M. Pons, S. Segurado, C. S. Szuwalski, J. R. Wilson, and Y. Ye. 2020. Effective fisheries management instrumental in improving fish stock status. Proceedings of the National Academy of Sciences 117:2218-2224. <https://doi.org/10.1073/pnas.1909726116>
- Jackson, A. M., A. Munguía-Vega, R. Beldade, B. E. Erisman, and G. Bernardi. 2015. Incorporating historical and ecological genetic data for leopard grouper (*Mycteroperca rosacea*) into marine reserve design in the Gulf of California. Conservation Genetics 16:811-822. <https://doi.org/10.1007/s10592-015-0702-8>
- Jackson, A. M., A. Munguia-Vega, A. Lain, S. Stokes, A. Williams, and G. Bernardi. 2014. Isolation and characterization of fifteen microsatellite loci in leopard grouper (*Mycteroperca rosacea*) via 454 pyrosequencing. Conservation Genetics Resources 6:185-187. <https://doi.org/10.1007/s12686-013-0044-0>
- Janssen, M. A., Ö. Bodin, J. M. Anderies, T. Elmqvist, H. Ernstron, R. R. J. McAllister, P. Olsson, and P. Ryan. 2006. Toward a network perspective on the resilience of social-ecological systems. Ecology and Society 11(1):15. <https://doi.org/10.5751/ES-01462-110115>
- Johnson, A. F., M. Moreno-Báez, A. Giron-Nava, J. Corominas, B. Erisman, E. Ezcurra, and O. Aburto-Oropeza. 2017. A spatial method to calculate small-scale fisheries effort in data poor scenarios. PLoS ONE 12:e0179114. <https://doi.org/10.1371/journal.pone.0174064>
- Jones, G. P., G. R. Almany, G. R. Russ, P. F. Sale, R. S. Steneck, M. J. H. Oppen, and B. L. Willis. 2009. Larval retention and connectivity among populations of corals and reef fishes: history, advances and challenges. Coral Reefs 28:307-325. <https://doi.org/10.1007/s00338-009-0469-9>
- Jones, O. R., J. Wang. 2010. Colony: a program for parentage and sibship inference from multilocus genotype data. Molecular Ecology Resources 10:551-555. <https://doi.org/10.1111/j.1755-0998.2009.02787.x>
- Kluger, L. C., M. Scotti, I. Vivar, and M. Wolff. 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 & Coastal Management 179:104861. <https://doi.org/10.1016/j.ocecoaman.2019.104861>
- Leslie, H., X. Basurto, M. Nenadovic, L. Sievanen, K. C. Cavanaugh, J. J. Cota-Nieto, B. E. Erisman, E. Finkbeiner, G. Hinojosa-Arango, M. Moreno-Báez, S. Nagavarapu, S. M. W.

- Reddy, A. Sánchez-Rodríguez, K. Siegel, J. J. Ulibarria-Valenzuela, A. Hudson Weaver, and O. Aburto-Oropeza. 2015. Operationalizing the social-ecological systems framework to assess sustainability. *Proceedings of the National Academy of Sciences* 112:5979-5984. <https://doi.org/10.1073/pnas.1414640112>
- Leslie, H. M., M. Schlüter, R. Cudney-Bueno, and S. A. Levin. 2009. Modeling responses of coupled social-ecological systems of the Gulf of California to anthropogenic and natural perturbations. *Ecological Research* 24:505-519. <https://doi.org/10.1007/s11284-009-0603-8>
- Lindkvist, E., X. Basurto, and M. Schluter. 2017. Micro-level explanations for emergent patterns of self-governance arrangements in small-scale fisheries: a modeling approach. *PLoS ONE* 12:e0179439. <https://doi.org/10.1371/journal.pone.0179439>
- McCay, B. J., F. Micheli, G. Ponce-Díaz, G. Murray, G. Shester, S. Ramirez-Sanchez, and W. Weisman. 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>
- McClanahan, T. R., and C. A. Abunge. 2018. Demographic variability and scales of agreement and disagreement over resource management restrictions. *Ecology and Society* 23(4):33. <https://doi.org/10.5751/ES-10544-230433>
- McClanahan, T. R., J. C. Castilla, A. T. White, and O. Defeo. 2009. Healing small-scale fisheries by facilitating complex socio-ecological systems. *Reviews in Fish Biology and Fisheries* 19:33-47. <https://doi.org/10.1007/s11160-008-9088-8>
- Moreno, C., A. Weaver, L. Bourillon, J. Torre, J. Egido, and M. Rojo. 2005. Diagnóstico ambiental y socioeconómico de la región marina-costera de Bahía de Kino, isla Tiburón, Sonora México: Documento de trabajo y discusión para promover un desarrollo sustentable. *Comunidad y biodiversidad A.C., Guaymas, Sonora, Mexico*.
- Moreno-Báez, M., R. Cudney-Bueno, B. J. Orr, W. W. Shaw, T. Pfister, J. Torre-Cosío, R. Loaiza, and M. Rojo. 2012. Integrating the spatial and temporal dimensions of fishing activities for management in the northern Gulf of California, Mexico. *Ocean & Coastal Management* 55:111-127. <https://doi.org/10.1016/j.ocecoaman.2011.10.001>
- Morzaria-Luna, H., P. Turk-Boyer, E. I. Polanco-Mizquec, C. Downton-Hoffmann, G. Cruz-Piñón, T. Carrillo-Lammens, R. Loaiza-Villanueva, P. Valdivia-Jiménez, A. Sánchez-Cruz, V. Peña-Mendoza, A. M. López-Ortiz, V. Koch, L. Vázquez-Vera, J. A. Arreola-Lizárraga, I. G. Amador-Castro, A. N. Suárez Castillo, and A. Munguia-Vega. 2020. Coastal and marine spatial planning in the northern Gulf of California, Mexico: consolidating stewardship, property rights, and enforcement for ecosystem-based fisheries management. *Ocean & Coastal Management* 197:105316. <https://doi.org/10.1016/j.ocecoaman.2020.105316>
- Munguia-Vega, A., A. L. Green, A. N. Suarez-Castillo, M. J. Espinosa-Romero, O. Aburto-Oropeza, A. M. Cisneros-Montemayor, G. Cruz-Piñón, D. G. Danemann, A. Giron-Nava, O. T. Gonzalez-Cuellar, C. Lasch, M. M. Mancha-Cisneros, S. G. Marinone, M. Moreno-Baez, H. Morzaria-Luna, H. Reyes-Bonilla, J. Torre, P. Turk-Boyer, M. Walther, and A. W. Hudson. 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* 28:749-776. <https://doi.org/10.1007/s11160-018-9529-y>
- Munguia-Vega, A., A. Jackson, S. G. Marinone, B. Erisman, M. Moreno-Baez, A. Girón-Nava, T. Pfister, O. Aburto-Oropeza, and J. Torre. 2014. Asymmetric connectivity of spawning aggregations of a commercially important marine fish using a multidisciplinary approach. *PeerJ* 2:e511. <https://doi.org/10.7717/peerj.511>
- Munguia-Vega, A., J. Torre, P. Turk-Boyer, S. G. Marinone, M. F. Lavin, T. Pfister, W. Shaw, G. Danemann, P. Raimondi, A. Castillo-López, A. Cinti, J. N. Durberstein, M. Moreno-Báez, M. Rojo, G. Soria, L. Sánchez-Velasco, H. N. Morzaria-Luna, L. Bourillon, K. Rowell, and R. Cudney-Bueno. 2015. PANGAS: An interdisciplinary ecosystem-based research framework for small-scale fisheries in the northern Gulf of California. *Journal of the Southwest* 57:337-390. <https://doi.org/10.1353/jsw.2015.0003>
- Newman, M. E. J. 2003. The structure and function of complex networks. *SIAM Review* 45:167-256. <https://doi.org/10.1137/S003614450342480>
- Ostrom, E. 1990. *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Cambridge, UK. <https://doi.org/10.1017/CBO9780511807763>
- Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. *Science* 325:419-422. <https://doi.org/10.1126/science.1172133>
- Ostrom, E., and J. Walker. 2003. *Trust and reciprocity: interdisciplinary lessons for experimental research*. Russell Sage Foundation, New York, New York, USA.
- Pauly, D., and D. Zeller. 2016. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications* 7:10244. <https://doi.org/10.1038/ncomms10244>
- Pedroza-Gutiérrez, C., and J. M. Hernandez. 2017. Social networks, market transactions, and reputation as a central resource. *The Mercado del Mar, a fish market in central Mexico*. *PLoS ONE* 12:e0186063. <https://doi.org/10.1371/journal.pone.0186063>
- Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. K. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, and K. J. Sainsbury. 2004. Ecosystem-based fishery management. *Science* 305:346-347. <https://doi.org/10.1126/science.1098222>
- Piry, S., A. Alapetite, J. M. Cornuet, D. Paetkau, L. Baudouin, and A. Estoup. 2004. GENECLASS2: a software for genetic assignment and first-generation migrant detection. *Journal of Heredity* 95:536-539. <https://doi.org/10.1093/jhered/esh074>
- Pomeroy, R. S. 2003. The government as a partner in co-management. Pages 247-261 in D. C. Wilson, J. R. Nielsen, and P. Degnbol, editors. *The fisheries co-management experience: accomplishment, challenges and prospects*. Springer, Dordrecht, The Netherlands. https://doi.org/10.1007/978-94-017-3323-6_15

- Ponce-Diaz, G., W. Weisman, and B. McCay. 2009. Co-responsibility and participation in fisheries management in Mexico: lessons from Baja California Sur. *Pesca y Conservacion* 1:1-9.
- Prell, C. 2012. *Social network analysis: history, theory & methodology*. SAGE, London, UK.
- Prell, C., K. Hubacek, C. Quinn, and M. Reed. 2008. 'Who's in the network?' When stakeholders influence data analysis. *Systemic Practice and Action Research* 21:443-458. <https://doi.org/10.1007/s11213-008-9105-9>
- Quentin Grafton, R., T. Kompas, R. McLoughlin, and N. Rayns. 2007. Benchmarking for fisheries governance. *Marine Policy* 31:470-479. <https://doi.org/10.1016/j.marpol.2006.12.007>
- Rannala, B., and J. L. Mountain. 1997. Detecting immigration by using multilocus genotypes. *Proceedings of the National Academy of Sciences* 94:9197-9201. <https://doi.org/10.1073/pnas.94.17.9197>
- Raymond, M., and F. Rousset. 1995. Genepop (version 1.2): population genetics software for exact tests and ecumenicism. *Journal of Heredity* 86:248-249. <https://doi.org/10.1093/oxfordjournals.jhered.a111573>
- Rife, A. N., B. Erisman, A. Sanchez, O. Aburto-Oropeza. 2013. When good intentions are not enough ... Insights on networks of "paper park" marine protected areas. *Conservation Letters* 6:200-212. <https://doi.org/10.1111/j.1755-263X.2012.00303.x>
- Sala, E., O. Aburto-Oropeza, G. Paredes, and G. Thompson. 2003. Spawning aggregations and reproductive behavior of reef fishes in the Gulf of California. *Bulletin of Marine Science* 72:103-121.
- Sayles, J. S., M. Mancilla Garcia, M. Hamilton, S. M. Alexander, J. A. Baggio, A. P. Fischer, K. Ingold, G. R. Meredith, and J. Pittman. 2019. Social-ecological network analysis for sustainability sciences: a systematic review and innovative research agenda for the future. *Environmental Research Letters* 14:093003. <https://doi.org/10.1088/1748-9326/ab2619>
- Sievanen, L. 2014. How do small-scale fishers adapt to environmental variability? Lessons from Baja California Sur, Mexico. *Maritime Studies* 13:9. <https://doi.org/10.1186/s40152-014-0009-2>
- Sigsgaard, E. E., M. R. Jensen, I. E. Winkelmann, P. R. Møller, M. M. Hansen, and P. F. Thomsen. 2020. Population-level inferences from environmental DNA—current status and future perspectives. *Evolutionary Applications* 13:245-262. <https://doi.org/10.1111/eva.12882>
- Smith, H., and X. Basurto. 2019. Defining small-scale fisheries and examining the role of science in shaping perceptions of who and what counts: a systematic review. *Frontiers in Marine Science* 6:236. <https://doi.org/10.3389/fmars.2019.00236>
- Smith, J. E. 2014. Hamilton's legacy: kinship, cooperation and social tolerance in mammalian groups. *Animal Behaviour* 92:291-304. <https://doi.org/10.1016/j.anbehav.2014.02.029>
- Thompson, K. R., W. D. Heyman, S. H. Peckham, and L. D. Jenkins. 2017. Key characteristics of successful fisheries learning exchanges. *Marine Policy* 77:205-213. <https://doi.org/10.1016/j.marpol.2016.03.019>
- Trembl, E. A., P. I. J. Fidelman, S. Kininmonth, J. A. Ekstrom, and Ö. Bodin. 2015. Analyzing the (mis)fit between the institutional and ecological networks of the Indo-West Pacific. *Global Environmental Change* 31:263-271. <https://doi.org/10.1016/j.gloenvcha.2015.01.012>
- Trembl, E. A., P. N. Halpin, D. L. Urban, and L. F. Pratson. 2008. Modeling population connectivity by ocean currents, a graph-theoretic approach for marine conservation. *Landscape Ecology* 23:19-36. <https://doi.org/10.1007/s10980-007-9138-y>
- Turnbull, L., M. T. Hütt, A. A. Ioannides, S. Kininmonth, R. Poeppl, K. Tockner, L. J. Bracken, S. Keesstra, L. Liu, R. Masselink, and A. J. Parsons. 2018. Connectivity and complex systems: learning from a multi-disciplinary perspective. *Applied Network Science* 3:11. <https://doi.org/10.1007/s41109-018-0067-2>
- Valdivia-Carrillo, T., A. Rocha-Olivares, H. Reyes-Bonilla, J. F. Dominguez-Contreras, and A. Munguia-Vega. 2021. Integrating eDNA metabarcoding and simultaneous underwater visual surveys to describe complex fish communities in a marine biodiversity hotspot. *Molecular Ecology Resources* 21:1558-1574. <https://doi.org/10.1111/1755-0998.13375>
- Wasserman, S., and K. Faust. 1994. *Structural analysis in the social sciences. Social network analysis: methods and applications*. Cambridge University Press, Cambridge, UK.
- Wilson, J. A. 2006. Matching social and ecological systems in complex ocean fisheries. *Ecology and Society* 11(1):9. <https://doi.org/10.5751/ES-01628-110109>
- Yletyinen, J., J. Hentati-Sundberg, T. Blenckner, and Ö. Bodin. 2018. Fishing strategy diversification and fishers' ecological dependency. *Ecology and Society* 23(3):28. <https://doi.org/10.5751/ES-10211-230328>
- Zepeda-Dominguez, J. A., G. Ponce-Diaz, and F. J. Vergara-Solana. 2017. El mapeo de actores y conformación de cuerpos de participación pesquera. *Region y Sociedad* 29:259-277. <https://doi.org/10.22198/rys.2017.68.a221>
- Zepeda-Dominguez, J. A., M. Zetina-Rejón, A. Espinoza-Tenorio, G. Ponce-Díaz, D. Lluch-Belda, M. J. Espinosa-Romero, J. Torre-Cosío, M. A. Cisneros-Mata. 2015. Mapeo topológico de los actores involucrados en el manejo de la pesquería de jaiba café *Callinectes bellicosus* en Sonora, México. *Ciencia Pesquera* 23:81-90.
- Zetina-Rejón, M. J., J. A. Zepeda-Domínguez, M. Rodríguez-Fuentes, and C. M. Fumero-Andreu. 2020. Stakeholder diversity correlates with governance network performance in two artisanal fisheries in northwest Mexico. *Ocean & Coastal Management* 196:105313. <https://doi.org/10.1016/j.ocecoaman.2020.105313>

Appendix 1

Table A1.1 Primer sequences and genetic polymorphism observed in 24 individuals from leopard grouper from Puerto Libertad among 5 microsatellite loci previously described (Jackson et al. 2014) and eight new loci described here, including repeat motif, size of the expected PCR product, range of observed allelic variation, number of observed alleles (Na), observed (Ho) and expected (He) heterozygosity and P values for deviations from Hardy-Weinberg equilibrium (HWE): * 0.05, ** 0.01, *** 0.001, NS = not significant.

Locus	Repeat motif	Primer Sequence (5'-3')	Size (bp)	Allelic range (bp)	Na	Ho	He	HWE
Jackson et al. 2014								
<i>Mros03</i>	GT ₍₄₃₎	F: CCATCATGAAGCTTTGACCA R: TTGACTTTTATCTCCAAGGCAAAA	104–160	120-180	18	0.944	0.912	NS
<i>Mros05</i>	CA ₍₃₆₎	F: GGGACCTGAATGAGATCAACA R: ATCCTCAAGGACTGCTGGTG	117–199	159-200	14	0.786	0.890	NS
<i>Mros07</i>	GT ₍₃₆₎	F: CATTAGTGCTGCAAGGCTCA R: CAGTGAAAGGCTTGGTGTC	140–216	161-210	15	0.786	0.908	NS
<i>Mros11</i>	TCTA ₍₁₉₎	F: ATCGAGACGAAAGGATGCAG R: TCCGTCAGCAGTTTACTCCC	83–181	128-192	13	0.706	0.896	NS
<i>Mros12</i>	TAGA ₍₁₆₎	F: GTCCTGCACTCAGCTTCCTC R: TTCCATGACTGATCCAGCCT	186–302	208-289	16	0.889	0.901	NS
New loci:								
<i>Mros17</i>	AAAG ₍₁₄₎	F:CTTGTCCGAGGTAAGGCTTG R:AACAGCAGTTAAGACTGTTTCTTCA	154	157–182	6	0.778	0.793	NS
<i>Mros18</i>	AGAT ₍₁₄₎	F:TGAGATTTTACCAGATTCAAAAGTCA R:TGCTCATGAATTCCTTACCTTG	178	178–232	8	0.500	0.837	*
<i>Mros22</i>	AAAG ₍₁₂₎	F:TGGGAATTGTAGGATCTGGC R:GTACGTAAGGGGCATTCCAG	213	210–244	9	0.824	0.851	NS
<i>Mros25</i>	AGGT ₍₁₂₎	F:GAAGCTTGATTTAGAAGATCTTACCC R:GCAAGTGCATGCGAAAATTA	190	180–210	7	0.667	0.684	NS
<i>Mros26</i>	AATC ₍₁₂₎	F:TGGAGGCTTCAAACTGGAG R:TCACTGGCTATTCATGTGCAA	162	152–176	6	0.833	0.682	NS
<i>Mros27</i>	AGAT ₍₁₁₎	F:TTCTACATGTAACAAATTTCCCC R:TTGAGCCTCATGTGAAGCAG	140	144–190	8	0.889	0.855	NS
<i>Mros29</i>	AAAG ₍₁₁₎	F:GATCCCTCTAAACTGTTCTTGTTG R:CCTGACACTTTGGGTCCCT	169	172–234	8	0.778	0.793	NS
<i>Mros32</i>	AACT ₍₁₁₎	F:GACAACCTGTTCAAGCAGGCA R:TGTAAACCCATTTGGGCAAG	205	206–278	14	0.944	0.907	NS

Appendix 2

Table A2.1 General description of the structured interview applied to 83 fishers from Bahia Kino and Puerto Libertad to measure four types of social ties: communication, trust, reciprocity and leadership. The fishers identified in this interview were then used in a second interview to identify kinship.

Fisher's name	Communication			Trust ¶	Reciprocity
	Presence †	Type ‡	Frequency §		
Fisher's name or nickname (clearly enough to identify him/her with confidence) and town of residency. Names of those who I have contact with, those who I talk to and listen to, etc.	If for any reason I have any kind of interaction (talking, selling, buying, etc.)	Type of interaction, from very bad to excellent	Frequency, from very rare (those actors who I almost never interact, to very frequent (those actors I interact very frequently to)	Trust, confidence from None (I do not trust him/her at all) to Total trust (I trust him/her absolutely)	Reciprocity, from very low reciprocity (I treat him/her very different from how he/she treats me) to very high reciprocity (I treat him/her exactly as he/she treats me).
Leadership					
Please mention every fisher who can influence over your decisions or can make you change your mind	Do you have any interaction with this person?	Type of interaction, from very poor to excellent	Frequency, from very infrequent (those actors who I almost never interact, to very frequent (those actors I interact very frequently to)		

† (Yes / No)

‡ 1 (Very bad) to 5 (Excellent)

§ 1 (Very rare) to 5 (Very Frequent)

¶ 1 (None) to 5 (Total trust)

| 1 (Very Low) to 5 (Very High)

Short guide and brief instructions for the application of the interview

The formats are simple and flexible to adapt to the language of the interviewee.

General technical considerations for interviewing.

- Review the survey format to clarify the type of answers we are looking for.
- Use jargon that facilitates communication and builds confidence.
- Record start time and end time of the interview, it must last no more than 30 minutes, after this time the information tends to lose confidence.
- Type the information from the format into a digital worksheet as soon as possible to include notes about the interview.
- If possible, scan the interviews to avoid losing any information.

Equipment.

- Logbook or printed format.
- Pens

Process.

1. Begin by greeting and clarifying the institutional support to the project by Comunidad y Biodiversidad A.C.
2. It is important that all the interviewees have the same basic information. The introduction must be read to them, explaining the goals and methodology of the project “Socio-ecological Connectivity in the Midriiffs Islands of the Gulf of California”, and the need to gather information about social relationships between small-scale fishers targeting leopard grouper in the region.
3. Explicitly state that the information is anonymous, and that will be used only for academic purposes related to the goal of the project. If there is any doubt or intention to use it for another purpose, their explicit authorization will be requested.
4. It is important that interviewees understand the methodology, and is necessary to explain that they do not need to try to respond to what they think should happen, but what their personal experience is, that is to say, what happens at the moment, not in the past but now. If doubt persists, they can mention their experiences during the previous year.
5. It is key to explain the type of network being used, that is, an integral analysis of the network is carried out, which does not allow identifying who said what.
6. In case there is any specific doubt, confirm answers, that is, "then we agree that ... correct?"
7. Provide e-mail, address, and cellular phone number to contact for any questions, clarifications or complaints.
8. Finish by thanking them for their time and the information provided.

General description of the interview to gather information on social connectivity

The requested information is explained column by column. Fishers are given different options so that the interviewee responds according to what is closest to their perception.

Name. Name or nickname of the interviewee.

Town. In which village does the interviewee live?

Name every fisher with whom you have communication or contact.

Is there communication? Yes/No. If for any reason they have any contact with other actor (s), this is considered an interaction. When there is no interaction of any kind, the rest of the questions do not make sense and therefore are not asked.

i. Interaction type. Record the number associated with the answer.

1. Very bad. A very destructive relation, each one is intensely hindering the work of the other.
2. Bad. An interaction that hinders the work of the other.
3. Neutral. Interacts, but is not perceived to help or hinder.
4. Good. An interaction that favors each other's work. A supportive actor.
5. Excellent. An interaction that greatly favors each other, a very supportive actor.

ii. Frequency. Due to the unique nature of each fishery, this question was not given time units, it is only a general perception. Record the number associated with the answer.

1. Very rare. Those with whom you hardly ever interact. Keywords: very little, very rare, very occasionally.
2. Uncommon. Those actors with whom there is little interaction. Keywords: little, rare.
3. Regular or moderately frequent. Neither frequent nor infrequent. Keywords: regular, moderately, sometimes.
4. Frequent. Those with whom you interact with some regularity, frequently, often, continuously.
5. Very frequent. Those actors with whom you interact many times more than with others. Keywords: very frequently, very often, very continuously.

iii. Trust. If the actor trusts the other, he/she feels that the other is trustworthy. Record the number associated with the answer.

1. None. Keywords: nothing, no trust, never, nothing.
2. Little. Keywords: there is little trust, seldom, almost anything, very rare, very little, etc.
3. Regular. Keywords: average trust, sometimes.
4. Trust. Keywords: there is, there is trust, I have trust, I trust him/her
5. Total trust. Keywords: a lot, full confidence, always, totally, very.

iv. Reciprocity. If the interviewee treats the other actor very similar or very different from how the other actor treats the interviewee.

1. Very low. I always treat him/her very differently from how he/she treats me.
2. Low. Most of the time I treat him/her very differently from how he/she treats me.
3. Intermediate. I treat him/her more or less the same as how he/she treats me
4. High. I treat him/her as he/she treats me most of the time.
5. Very high. I always treat him/her exactly as he/she treats me.

v. Leadership. Name every fisher you consider influences your decisions or can make you change your mind?

Do you have any interaction with this person? Yes/No

Interaction type and Frequency as detailed above.

vi. Kinship. If the actor has a kinship or is a relative of other fisher (s) identified in the previous questions. Record the number associated with the answer.

1. First-degree relative (parent-offspring, full sibs).

2. Second-degree relative (grandparent-grandchildren, half-sibs, avuncular: uncle, aunt, nephews, nieces).

Appendix 3

Quality control in genetic analyses

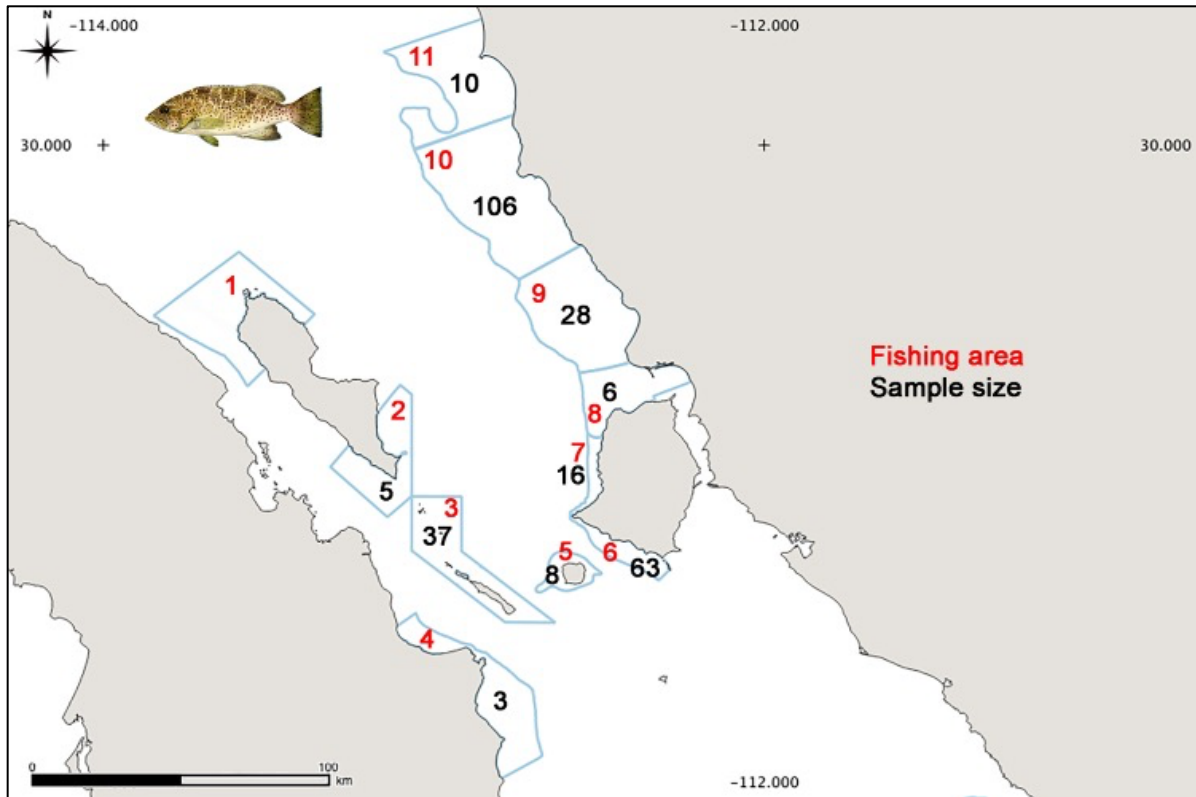
From the 776 leopard groupers sampled, we selected 500 individuals for DNA extraction and PCR amplification that met our criteria related to the candidate parents/progeny age groups, as explained in the Methods section. From these, we performed strict quality controls, since errors in genotyping and the presence of missing data can strongly bias the results of parentage and sibship analyses (Jones et al., 2010). First, we eliminated those individuals that showed low quality or quantity of genomic DNA, likely because their tissues were not properly fixed in the field and that failed to consistently amplify via PCR, as assessed by agarose gel electrophoresis. Second, we discarded individuals that failed to amplify for at least 11 microsatellite loci, those that showed more than two alleles per locus, or the presence of more than one individual DNA, indicative of DNA contamination, and those individuals for which electropherograms showed noisy or ambiguous results. Our final dataset included 282 leopard grouper individuals genotyped at 13 loci (138 from BK and 144 from PL; see Appendix 4. Figure A4.1 for sampling details and Appendix 5. Table A5.1 for the raw genotype data of each individual), with an average of 1.47% missing data. The 13 genotyped loci were highly variable, averaging 11 alleles per locus, while observed and expected heterozygosity were 0.851 and 0.825, respectively (Appendix 6. Table A6.1). Based on the level of polymorphism, the combined genotypes for the 13 loci provided a probability of individual identity 2.0^{-22} , and a probability of identifying full sibs of 4.3^{-7} . From 130 tests of HWE among the 13 loci within each population, we found only two cases of significant deviations ($P < 0.0003$). We did not find any significant instances of significant LD among 78 tests conducted between each pair of loci (all P values > 0.0006).

References:

Jones, A. G., C. M. Small, K. A. Paczolt, and N. L. Ratterman 2010. A practical guide to methods of parentage analysis. *Molecular Ecology Resources*, 10: 6-30.

Appendix 4

Figure A4.1 Number of samples of leopard groupers (shown as black numbers) collected from each of the 11 fishing areas (indicated by red numbers).



Appendix 5

Table A5.1 Genepop file with genotypes from 13 microsatellite loci in 282 individuals of leopard grouper.

M12

M29

M32

M03

M27

M7

M18

M17

M22

M25

M11

M5

M26

Pop

FA2, 0207 0708 1010 0708 0506 1927 0608 0307 0103 0404 1117 1526 0404

FA2, 0811 0506 0813 0815 0610 0618 0815 0506 0507 0507 1116 0818 0203

FA2, 0608 0506 0414 1717 0505 2323 0611 0508 0608 0410 2021 1212 0101

FA2, 1518 0212 0405 1212 0712 0816 0608 0409 0207 0103 1919 1116 0103

FA2, 0208 0607 0913 1626 0609 1425 1010 0707 0204 0206 1218 1016 0102

Pop

FA3, 0414 0507 0713 1314 0610 0519 0411 0607 0406 0408 2323 1426 0102

FA3, 1017 0507 0611 0410 0508 0733 0914 0505 0607 0206 1519 1226 0304

FA3, 1015 0404 0505 1010 0606 0612 1011 0407 0405 0507 1118 1521 0103

FA3, 0917 0510 0505 2529 0810 2125 1112 0305 0507 0407 1920 0420 0101

FA3, 0204 0510 0417 1112 0611 0623 0309 0506 0406 0505 1115 1515 0103

FA3, 1931 0910 0515 1012 1115 2323 0607 0405 0507 0406 1921 2123 0101

FA3, 0814 0204 0418 1119 0506 2029 1111 0506 0811 0404 1221 2325 0202

FA3, 0407 0404 1015 1417 0810 1427 0811 0406 0204 0407 1818 1526 0202

FA3, 0415 0412 0507 0411 0707 2026 0000 0405 0405 0607 1718 0808 0102

FA3, 0404 0508 0314 1213 0815 2425 0811 0505 0507 0404 0923 0411 0202

FA3, 1113 0509 0713 1225 0816 2035 0611 0306 0304 0304 1422 1521 0102

FA3, 0407 0608 0505 1012 0506 2131 0710 0405 0409 0404 1417 1919 0103

FA3, 0708 0512 1016 1619 1012 2530 0000 0707 0404 0107 0115 1024 0203

FA3, 0812 0106 0513 0414 0910 1723 0610 0407 0409 0104 1417 1424 0104

FA3, 0313 0505 0404 0410 0510 1722 1010 0407 0405 0710 1119 1427 0102

FA3, 1216 0506 0412 1229 0512 0509 0717 0204 0405 0707 1819 1315 0102

FA3, 0210 0211 0610 1214 0810 0217 1013 0406 0709 0104 1623 0320 0102

FA3, 0509 0708 1414 1229 0311 0206 1015 0507 0407 0407 1214 2424 0103

FA3, 0414 0204 0407 1429 0608 1617 1014 0506 0404 0405 0000 0927 0202

FA3, 1317 0606 0813 1012 0510 0615 0610 0509 0406 0404 1618 2222 0202

FA3, 0417 0410 1216 1012 0625 0612 1016 0305 0609 0405 1622 1722 0203

FA3, 0912 0206 0810 1314 0911 2122 0715 0204 0507 0407 0116 1521 0304
 FA3, 0607 0202 1213 1415 0910 1227 0911 0306 0407 0107 1724 1725 0206
 FA3, 0708 0405 0405 0812 0909 1221 0711 0507 0208 0305 1723 1823 0101
 FA3, 0810 0607 0515 0420 0809 0924 0405 0305 0409 0506 0220 1619 0202
 FA3, 1014 0207 0508 1114 0816 2434 0106 0404 0709 0408 1316 1418 0101
 FA3, 0304 0507 0715 0418 0508 0221 1213 0505 0409 0409 1826 1216 0102
 FA3, 0809 0406 0507 1717 0810 2628 0606 0506 0506 0101 1620 2428 0209
 FA3, 0210 0712 0913 0809 0610 0616 0808 0405 0507 0405 0114 1927 0101
 FA3, 0709 0607 0412 0808 0609 2525 0709 0406 0204 0305 2121 1113 0102
 FA3, 0808 0505 1213 0414 1020 2528 1212 0305 0509 0406 1520 1417 0102
 FA3, 1319 0609 0611 1216 0513 1016 0507 0304 0203 0404 1421 1624 0204
 FA3, 0409 0407 1114 1113 0609 0621 0417 0506 0510 0304 1220 1426 0102
 FA3, 0608 0410 1216 0812 0911 1829 1116 0207 0405 0406 0817 1924 0102
 FA3, 1215 0404 0513 0414 0510 0617 0712 0305 0507 0304 1820 1419 0102
 FA3, 0717 0708 0410 1013 0306 0917 0211 0405 0607 0304 1620 2225 0204
 FA3, 0412 0506 0517 1012 0710 2427 0404 0405 0608 0304 1218 1121 0202

Pop

FA4, 0511 0708 0405 0410 1414 2836 0819 0506 0204 0505 1819 1515 0104
 FA4, 0416 0607 1014 0810 1015 1922 0303 0000 0410 0104 1116 1232 0000
 FA4, 1013 0407 0614 1114 0311 0920 0611 0607 0407 0505 1619 0317 0103

Pop

FA5, 0409 0000 0505 0913 1120 2125 0407 0507 0405 0408 1616 1020 0101
 FA5, 1418 0407 0506 1619 0311 2526 0812 0505 0207 0505 0909 1924 0204
 FA5, 0517 0607 0712 1017 1116 0527 0707 0505 0607 0404 2121 1416 0103
 FA5, 1617 0607 0505 1029 0614 0823 0308 0304 0707 0405 1620 1313 0102
 FA5, 1014 0406 1212 0716 0910 3132 0410 0406 0508 0404 2324 2126 0101
 FA5, 0810 0711 0913 1831 0514 2122 0709 0404 0204 0405 1818 1719 0109
 FA5, 0817 0611 0710 0910 0510 2935 0915 0405 0507 0405 1320 1421 0103
 FA5, 0511 0106 0511 0410 0717 1728 0111 0304 0607 0506 1415 1717 0101

Pop

FA6, 0413 0506 0517 0811 0811 2429 0000 0507 0809 0406 0218 0000 0203
 FA6, 0000 0000 0000 1016 0915 1118 0209 0304 0206 0304 1822 0917 0203
 FA6, 0422 0507 1417 1012 0507 0625 0808 0405 0510 0104 0000 1724 0204
 FA6, 1114 0507 0912 0728 1111 2223 0810 0304 0307 0406 1618 1320 0104
 FA6, 0810 0204 0509 0910 0610 0000 0000 0406 0404 0405 1820 0000 0101
 FA6, 0409 0606 0713 1316 0612 0918 0808 0405 0708 0405 1717 1726 0203
 FA6, 1117 0207 0709 1213 0510 0620 0708 0506 0405 0107 1819 2123 0104
 FA6, 1111 0405 0612 0414 1011 0617 0313 0407 0406 0104 0918 1024 0104
 FA6, 0922 0405 0512 1213 0810 2531 0608 0506 0105 0305 1111 1825 0102
 FA6, 0000 0205 0608 1112 0508 2125 0608 0205 0306 0105 1721 1518 0106
 FA6, 0407 0607 0514 1019 0611 0220 0713 0506 0506 0304 0115 1418 0104
 FA6, 0516 0518 1313 0114 0608 2023 0609 0406 0305 0404 2022 1727 0102
 FA6, 0613 0506 1113 2628 0609 2331 1414 0509 0204 0407 1520 2032 0202
 FA6, 0910 0506 0709 0914 0808 0825 0000 0708 0507 0406 2022 1025 0101
 FA6, 0512 0407 0316 1314 0810 1718 0416 0405 0506 0204 1619 0714 0102
 FA6, 0207 0205 0811 1227 0910 0206 0707 0407 0204 0406 1820 1423 0102

FA6, 0821 0607 0713 1116 0509 0202 0614 0405 0606 0304 0913 0719 0202
FA6, 0811 0305 0506 1015 0306 0000 0214 0507 0407 0106 0000 2530 0103
FA6, 0507 0406 0506 0911 0306 2226 0305 0404 0204 0404 1216 1317 0203
FA6, 0613 0606 1415 1427 0709 0925 0306 0405 0303 0404 1717 2139 0107
FA6, 1315 0606 0406 0411 0915 2135 0202 0407 0404 0404 1822 0713 0101
FA6, 1010 0505 0511 0808 0810 1637 0311 0505 0304 0406 1315 1121 0202
FA6, 0814 0406 0512 1213 1111 1617 0606 0406 0406 0305 2024 0424 0101
FA6, 0815 0506 0913 0920 0709 2328 0712 0307 0208 0408 0119 1426 0101
FA6, 0210 0408 0505 1019 0309 1619 0909 0306 0505 0304 1617 0121 0103
FA6, 0508 0404 0612 0812 0608 2028 0507 0405 0405 0405 2121 1122 0203
FA6, 0608 0207 0414 0418 0608 1329 0411 0406 0404 0404 1418 1519 0103
FA6, 1022 0610 0507 0723 0809 0819 0409 0509 0407 0405 1620 1127 0102
FA6, 0307 0512 0412 1424 0811 0823 1212 0306 0407 0510 1016 1515 0104
FA6, 0215 0408 0407 0812 0509 2728 0909 0408 0404 0404 1317 0831 0102
FA6, 0102 0506 0307 1414 0511 2125 1111 0405 0202 0204 1118 1621 0101
FA6, 0613 0407 0414 0715 0511 0823 0613 0405 0202 0505 1217 1420 0104
FA6, 0916 0404 1112 1318 0912 2223 0912 0505 0304 0409 0000 1217 0101
FA6, 0813 0405 0816 1012 2428 1722 0312 0507 0305 1017 0922 1420 0101
FA6, 0410 0204 1212 1214 0913 0000 0812 0103 0204 0505 1618 1919 0102
FA6, 0810 0607 0911 1023 0929 0120 0404 0405 0608 0507 1717 1924 0102
FA6, 0513 0505 0811 1314 0508 1728 0314 0406 0404 0304 1317 1118 0101
FA6, 0410 0607 0509 0913 0810 0923 1414 0508 0410 0304 1020 0718 0204
FA6, 0413 0709 0713 1212 0607 0616 1010 0305 0205 0505 0217 1717 0203
FA6, 0505 0206 0610 1016 0910 0607 0713 0505 0406 0304 1116 1625 0101
FA6, 0914 0404 0714 0810 1010 1723 0914 0505 0508 0610 2424 1624 0104
FA6, 1011 0609 0510 0715 0710 2426 0417 0405 0708 0404 2123 1525 0202
FA6, 0507 0404 1116 0810 0506 1422 1217 0505 0405 0407 1122 1414 0202
FA6, 0407 0404 0416 1010 0510 0818 0310 0507 0408 0404 1519 2424 0101
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Appendix 6

Table A6.1 Genetic diversity (average and standard error) observed in leopard grouper individuals sampled at 10 fishing areas, including sample size (N), number of alleles (Na), number of effective alleles (Ne), observed and expected heterozygosity (Ho and He, respectively).

Fishing Area		N	Na	Ne	Ho	He
FA2	Mean	5.000	6.923	5.916	0.815	0.822
	SE	0.000	0.383	0.377	0.036	0.013
FA3	Mean	36.769	15.000	9.550	0.868	0.863
	SE	0.166	1.747	1.321	0.022	0.023
FA4	Mean	2.846	4.462	3.956	0.872	0.720
	SE	0.104	0.291	0.348	0.060	0.027
FA5	Mean	7.923	8.385	6.482	0.808	0.798
	SE	0.077	0.859	0.878	0.052	0.032
FA6	Mean	61.692	16.538	10.473	0.853	0.866
	SE	0.347	1.973	1.559	0.027	0.025
FA7	Mean	15.923	11.000	7.514	0.865	0.841
	SE	0.077	1.138	0.831	0.032	0.021
FA8	Mean	5.923	7.385	6.224	0.869	0.812
	SE	0.077	0.712	0.690	0.051	0.022
FA9	Mean	27.692	14.000	9.692	0.867	0.862
	SE	0.175	1.710	1.348	0.025	0.024
FA10	Mean	104.154	18.308	10.650	0.827	0.864
	SE	0.912	2.240	1.525	0.028	0.028
FA11	Mean	9.923	8.385	6.011	0.866	0.800
	SE	0.077	0.828	0.702	0.037	0.028
Total	Mean	27.785	11.038	7.647	0.851	0.825
	SE	2.721	0.567	0.373	0.012	0.008

Appendix 7

Statistical analyses conducted with the software UCINET 6.718 comparing the density within and between ecological and social networks and subnetworks.

Table A7.1. P values resulting from the statistical analyses comparing the density between subnetworks. Statistically significant values ($P \leq 0.05$) are shown in bold and indicate the two networks being compared have densities that are statistically different from each other.

	Ecological networks		Social networks			
	Larvae	Migrants	Kinship	Kinship	Communi- cation	Leader- ship
BK vs. PL	0.152	0.001	0.063	0.001	0.001	0.005
BK vs. All	0.087	0.729	0.089	0.387	0.001	0.096
PL vs. All	0.687	0.001	0.131	0.042	0.013	0.023
BK vs. BK-PL	0.001	0.093	0.058	0.008	0.001	0.001
PL vs. BK-PL	0.031	0.025	0.073	0.015	0.023	0.001
All vs. BK-PL	0.019	0.697	0.073	0.003	0.715	0.001

Table A7.2. P values resulting from the statistical analyses comparing the density within ecological and within social networks. Statistically significant values ($P \leq 0.05$) are shown in bold and indicate the two networks being compared have densities that are statistically different from each other.

Ecological network	BK	PL	All
Larvae vs. Migrants	0.001	1	0.063
Larvae vs. Kinship	0.001	0.001	0.001
Migrants vs. Kinship	0.001	0.001	0.001
Social network			
Kinship vs. Communication	0.025	0.050	0.007
Kinship vs. Leadership	0.001	0.078	0.001
Communication vs. Leadership	0.001	0.668	0.334

Table A7.3. P values resulting from the statistical analyses comparing the density between ecological and social networks. Statistically significant values ($P \leq 0.05$) are shown in bold and indicate the two networks being compared have densities that are statistically different from each other.

Ecological network	Social network	BK	PL	All
Larvae vs.	Kinship	0.001	0.001	0.001
	Communication	0.001	0.001	0.001
	Leadership	0.001	0.001	0.001
Migrants vs.	Kinship	0.001	0.001	0.005
	Communication	0.001	0.001	0.008
	Leadership	0.001	0.001	0.005
Kinship vs.	Kinship	0.001	0.025	0.001
	Communication	0.563	0.001	0.001
	Leadership	0.001	0.001	0.001

Appendix 8

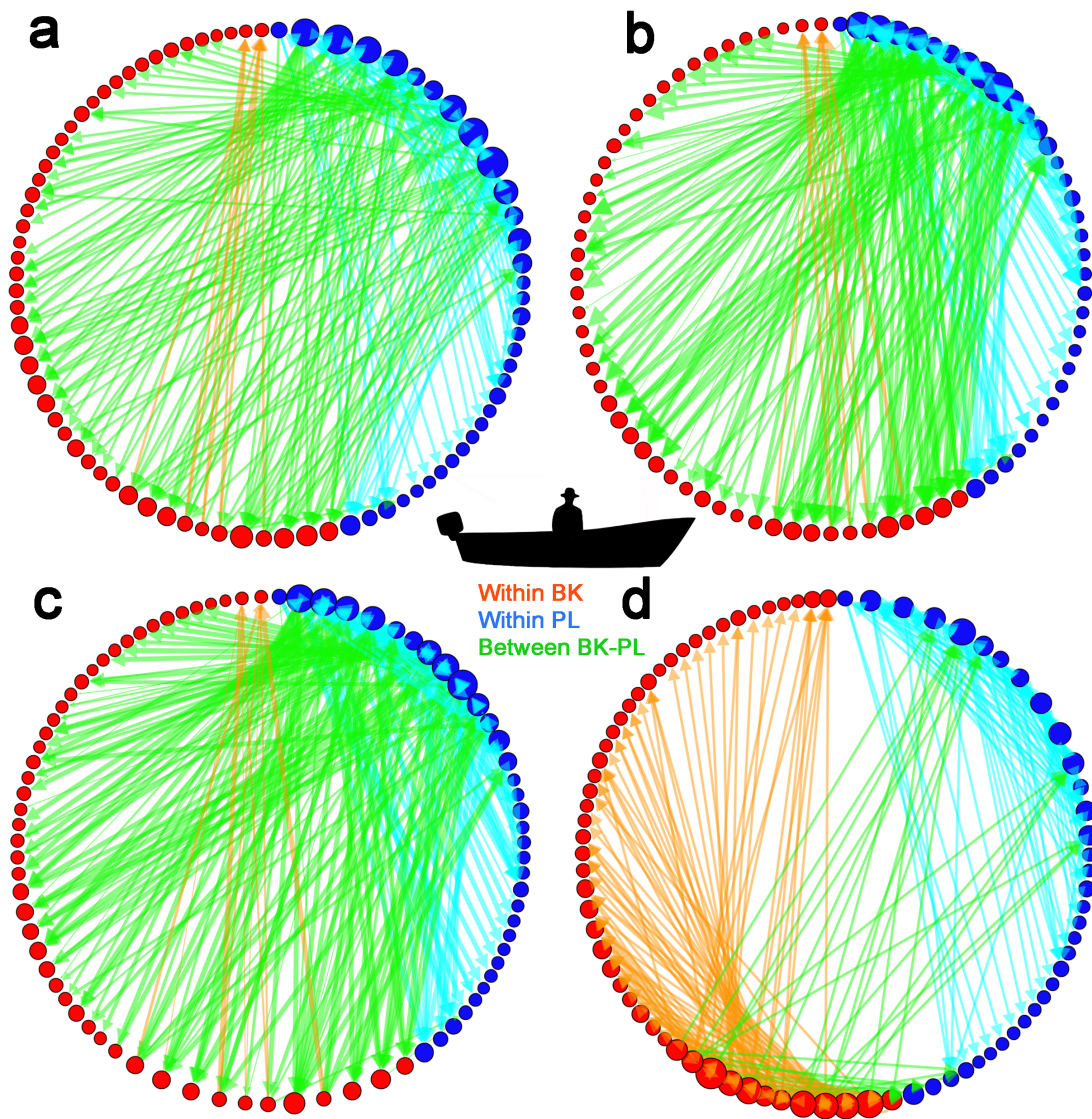


Figure A8.1 Networks describing social connectivity among 83 fishers from two communities in the Northern Gulf of California: a) Communication, b) Trust, c) Reciprocity, d) Leadership. Nodes represent individual fishers colored according to the community to which they belong (Red = Bahia Kino or BK; blue = Puerto Libertad or PL). Node size represents the eigenvector centrality. Links within BK are shown in red, links within PL are shown in blue, and green links represent relationships between the two communities.