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The challenges of local governance: Gear-based fragmentation in the Dominican fishery of Buen Hombre

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ABSTRACT

The Dominican fishing community of Buen Hombre is struggling to reconcile its fishing activities with the state of the coral reef ecosystem on which it depends. The ecosystem is showing signs of deterioration, and this seems to be resulting in large part because of the fishing activities of the Buen Hombre fishermen. The institutional arrangements of the fishermen themselves, and of relevant external organizations, have not kept pace with important technological and demographic changes that have affected the community. This paper presents the results of an analysis that unpacks these processes via a statistical analysis of fishermen behavior and a social network analysis of the "cofishing" network that these fishermen constitute. The statistical analysis shows that gear choice is very important in explaining the amount of fish caught, both as a direct factor and as a mediator of other factors such as membership in the local fishermen's association. The social network analysis complements this result by demonstrating that gear choice also serves to segment the fishermen into separate groups, with few direct linkages between them. The resulting gear-based fragmentation of the community is seen to have negative implications for the ability of the fishermen to act collectively to conserve their fishery. The paper concludes with some thoughts and suggestions for how the community might move forward, including expanding the membership of the fishermen's association and strengthening ties between fishing groups as well as ties between the community and relevant governmental agencies.

1. Introduction

Marine ecosystems around the world, including small-scale fisheries, are suffering from overfishing [28]. This trend has had specific impacts on coral reef ecosystems, where fish species play critical roles in maintaining coral health and abundance. Of particular importance are herbivorous fish that consume fleshy macroalgae that will overtake reefs if not kept in check [15]. Coral reef fisheries, therefore, must seek to sustain functional fish communities to maintain healthy coral communities.

A suite of factors drives fishing behaviors, with implications for a fishery's ecological impact on coral reef ecosystems. Many studies of coral reef fisheries use global datasets and coarse metrics of human impact, such as human population density, to explore relationships between humans and coral reefs [5]. These studies are able to identify important broad-stroke social variables and global trends in coral reef fisheries that are otherwise difficult to detect in these highly complex systems. However, this approach needs to be complemented with an understanding of the dynamics of specific fisheries to enable governance regimes that are appropriately tailored to the circumstances of such systems. In this paper one such analysis is presented of the community of Buen Hombre, Dominican Republic, and its coral reef fishery.

In a preceding paper, Wilson et al. [26] conducted a longitudinal case study of the social and ecological trends and dynamics across the Buen Hombre fishery as a whole. That case study incorporated data from ecological fieldwork in which surveys were conducted of the fish community using underwater visual census techniques. These data, combined with data from fishermen surveys, led the authors to conclude that the fish community of the coral reef ecosystem of Buen Hombre had deteriorated. Based on the predominance of fishing activities in the area, the authors also concluded that much of this deterioration was occurring as a result of these fishing activities.

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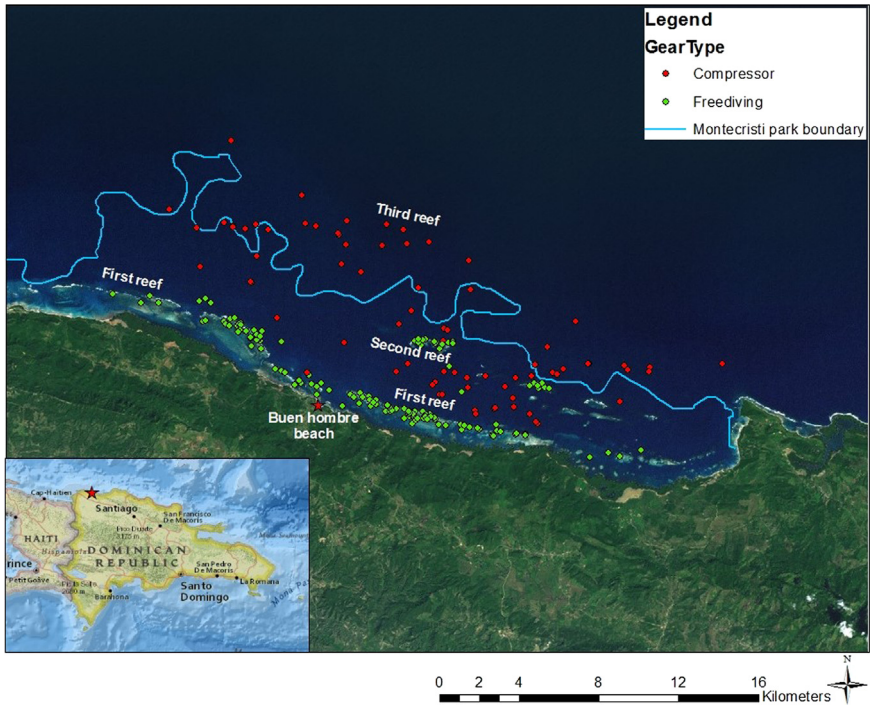

Fig. 1. Map of the Buen Hombre fishery (source: [26]).

In this paper these processes are further unpacked via an examination of the relationship between fishing pressure and various social and technological attributes of the local fishermen. This analysis was conducted with two complementary methods: (1) a set of statistical regression analyses and (2) a basic social network analysis. The statistical analysis focuses on explaining individual-level fishermen behavior, while the network analysis examines how this behavior relates to the social structure of the fishermen.

2. Background: community-based management and social networks

This paper builds on previous work on community-based management natural resource management (CBNRM). The majority of CBNRM analyses consist of empirical case study-based examinations of particular systems where users manage an environmental commons [17,21]. The primary motivation of these studies revolves around the idea of a collective-action problem, or a divergence between individual-level and group-level interests [19]. Commons can present such problems in several ways. A commons in this discussion is a natural system the use which produces important benefits, that is available to many users, and that has properties whereby the activities of these users affect the state of the commons and therefore the welfare of others. This interdependence creates a collective-action problem. For example, a fishery commons (or more technically a common-pool resource) is difficult to enclose, and is subtractable, in that fishing activities by one set of fishermen reduce the amount of fish available to other fishermen. It is in the individual interests of each fisherman to fish as much as they can, but if they all do so, the tragedy of the commons will result and the group as a whole will suffer [11].

Much of the commons work on CBNRM has focused on identifying the factors that affect the ability of communities to resolve collective-action problems and sustainably manage their resources. There is now a long list of such factors, including characteristics of commons user groups (e.g. group size), the institutions and technologies that they use to manage a resource (e.g. property rights and fishing gear), and characteristics of the resource itself (e.g. predictability) (see [1] and [4]). Communities of natural resource users generally employ a mix of common and private property, and the literature on the commons has gone to great lengths to establish common property is a viable alternative, although this option is still sometimes under-emphasized as an institutional alternative, in favor of public or private ownership [8].

Recently, the methodology of social network analysis has been increasingly applied to the study of natural resource management, and particularly to CBNRM [2,3,13,25]. Social network analysis helps further unpack social structure and group dynamics and thereby explain social and environmental outcomes. For example, highly connected nodes in a social network of resource users are frequently leaders within a community, and leadership has been shown to be important in CBNRM settings [10].

3. Methods

This project is presented as an embedded case study [27], with a primary unit of analysis being individual fishermen, with this nested within the larger Buen Hombre fishery of which these fishermen are a part. A statistical analysis was applied at the level of the fishermen and a network analysis was applied at the broader group-level to examine the social structure that the fishermen co-create.

3.1. Study area

The town of Buen Hombre is located on the northern coast of the Dominican Republic in Montecristi Province approximately 20 km east of the city of Montecristi and 35 km east of the Haitian border (see Fig. 1). The village sits at the water's edge and is bordered to the south by the foothills of the Septentrional mountain range. Buen Hombre lies in the rain shadow of these mountains, resulting in very little rainfall or freshwater resources. The fishery is defined by the presence of coral reefs interspersed with areas of sand, sea grass, and mangroves lining the coast. The first barrier

Table 1
Descriptions of variables.

Variable	Unit	Definition
Catch	Pounds/week	The number of pounds caught per week of fishing
Native	Binary	Whether or not a respondent grew up in Buen Hombre
Experience	Years	The number of years a respondent has been fishing
Membership	Binary	Whether or not a fishermen is an association member
Dependence	Binary	Level of dependence on fishing (high, low)
Compressor	Binary	Whether or not a respondent primarily dives with compressors
Freediving	Binary	Whether or not a respondent primarily freedives
Age	Years	A respondent's age

reef is a shallow reef that parallels the coastline approximately one kilometer from shore. Farther out lies the second reef, which varies in depth from 2 to 20 m. The third reef lies approximately seven kilometers offshore in depths of over 30 m. Beyond the third reef Hispaniola's shelf drops to deep open water.

Buen Hombre is a community of about 825 people that depends primarily on fishing as a source of income and food. Farming is an important livelihood for some community members (and may have been more in the past). The fishery is a mixed gear fishery that utilizes spearfishing, hook and line fishing, traps, nets, and wading. Spearfishing is done while freediving – using only breath – or with compressors – recycled paint compressors kept at the surface on a boat and used to pressurize air down to a diver through a plastic hose.

The fishery operates with a system of pescaderías, or fish shops that will front a fisherman's daily costs in fuel, equipment and food with the understanding that the fisherman will sell their catch to that pescadería at the end of the day and pay off their debts out of their earnings. A portion of Buen Hombre fishermen are members of the local fishermen's association, which operates as an alternative to the pescadería system. Members sell their fish to the association, which then retains a portion of its profits in a fund used to pay off boat and motor costs. While some version of a fishermen's association has existed in Buen Hombre for decades, the current organization was revitalized in 2013 with the support of a local non-profit called AgroFrontera. The current association does not buy fish from compressor divers, as this is considered to be an unsafe and arguably more environmentally exploitative process.

Other than this association, Buen Hombre is notable for its lack of formal and cross-scale institutional arrangements. While at least one Dominican agency has jurisdiction over the area, and the fishery lies within the National Park of Monte Cristi, meaningful cross-scale links to larger governing bodies are mostly absent. So while important changes have occurred here in recent years – most notably an increase in population and the introduction of compressor technologies – these have not been met by the development of new institutions to adapt to these changes, either by the fishermen themselves or along with larger governmental bodies. Buen Hombre is characterized by little collective-action to proactively conserve the resource.

3.2. Data collection

Semi-structured interviews were conducted with 72 fishermen during December 2013 and June–July 2014. Prior to this social data collection, two field seasons were spent collecting ecological data and conducting exploratory interviews and participant observation during the summers of 2012 and 2013. In sampling the local fishermen, the goal was to obtain a census via a list of 90 fishermen in the community that was compiled with the assistance of three local fishermen. Eleven fishermen either declined interviews or were not available to be interviewed because they were fishing outside of the country during the data collection period. Three fishermen were excluded from the sampling pool because they were under the age of 18. Four fishermen were unable to be reached.

Interviews with the fishermen were conducted with the aid of a questionnaire (see appendices a and b for English and Spanish versions), and lasted between half an hour and over two hours. The content of the questionnaire reflected both (1) past work on CBNRM, most succinctly summarized in Ostrom [20], in which she essentially provides a checklist of important variables to consider, and (2) experience within Buen Hombre prior to the implementation of the social science work. Topics covered in the interviews included characteristics of the fisherman and community that might be related to resource usage, including: (1) demographic information, (2) community attributes, (3) fishing practices, (4) fishing rules and regulations, (5) markets, (6) livelihoods, and (7) social capital. In addition to these topics, to collect social network information the fixed recall name generator technique was used [22]. Each respondent was asked to list up to five fishermen with whom they fished with most often in order to create the network data in this analysis.

3.3. Data analysis

The data analysis consisted of two primary stages: first, a statistical analysis at the fishermen level; and second, an analysis of the social network constituted by these same fishermen. Table 1 describes the variables that were involved in the statistical analysis, while Tables 2 and 3 provide some descriptive statistics for these variables. Table 3 breaks down the different types of gear used by the different fishermen, defining each and giving the absolute frequencies of fishermen that used each. It also provides the average of the Catch variable (the dependent variable in this analysis) for the fishermen that use each gear.

3.3.1. Main regression analysis

In order to address the research question regarding the drivers of fish catch, a statistical analysis was conducted. The first step in this process was to specify a regression equation with the Catch variable as the dependent variable. For this model the following variables were selected as independent variables to test the following hypotheses (expected relationship with Catch in parentheses):

H1. Native: Native fishermen will catch less than non-native fishermen (−)

H2. Experience: Fishermen with more experience should be able

Table 2
Summary statistics of sample.

Variable	Unit	Mean	SD	Min	Max
Catch	Pounds/week	271.73	226.41	0	735
Native	Binary	0.66	0.48	0	1
Experience	Years	21.75	16.68	0.25	70
Membership	Binary	0.28	0.45	0	1
Dependence	Binary	0.75	0.43	0	1
Compressor	Binary	0.26	0.44	0	1
Freediving	Binary	0.35	0.48	0	1
Age	Years	39.68	15.80	19.00	81

Table 3
Summary and definitions of gear types.

Gear type	Catch	Frequency	Definition
Freediving	110	25	Fishermen use a speargun and dive without equipment
Compressor	407.5	19	Fishermen use a speargun and dive with a compressor
Hook and line	291	9	Fishermen fish with a traditional hook and line system
Yolero	n/a	9	Fishermen who manage a compressor from a boat
Traps	156.5	5	Fishermen lay traps for benthic organisms
Nets	437.8	4	Fishermen lay out large nets to catch fish
Wading	160	1	Fishermen use a speargun and fish in shallow waters

to catch more (+)

H3. Membership: Members of the fishermen association will catch less (−)

H4. Dependence: Fishermen will catch more if their welfare is closely tied to fishing (+)

H5. Compressor: Compressor divers will catch more than other fishermen (+)

H6. Freediving: Freedivers will catch less than other fishermen (−)

Hypothesis one is driven by the expectation that native fishermen will be more strongly integrated into the Buen Hombre fishing community than non-native fishermen. With this integration comes a potential for increased buy-in to local norms and concerns, as well as an understanding of the state of the fishery resource, all of which could lead them to abstain from degrading the local resource. Hypothesis two is based on the observation that fishing requires a fair amount of experience to master, and thus catch should increase with the years of experience a fishermen has. Hypothesis three is based on the observation that a primary goal of the fishermen's association is to help to conserve the resource, and on the high level of social capital the association members seem to have with each other. Hypothesis four predicts that, as dependence on the resource increases, so too will individual catch as fishermen's needs to maintain their livelihoods in the short term override concerns about the resource in the long run. The final two hypotheses are based on on-site observations regarding the relative impacts that the two primary gears used in the fishery seem to have on catch and the state of the resource.

Given the continuous nature of the Catch variable, the regression model was estimated via ordinary least squares (OLS) in the Stata software package. Regression diagnostics showed evidence of heteroskedasticity, which was corrected for. No other problems with the data were detected.

3.3.2. Mediation analysis

In addition to examining the effects of the independent variables on the Catch variable, the relationships between several of these variables were also examined, particularly the extent to which the effects of the Membership and Native variables on the Catch variable were mediated by the two binary gear variables. If this was the case, then much of the effect that Membership and Native have on Catch would be indirect, determined in large part by how these variables affected the gear variables. This relationship between gear and association membership was strongly suspected, since the members of the fishermen association had generally agreed that they would not use compressors to assist them in their diving. Thus, the effects of being an association member could be strongly mediated by the choice of gear as represented by the gear variables in the regression model.

To begin this analysis a cross-tabulations between the original categorical Gear variable and each of these variables was implemented, along with Fisher's exact test to test for the independence between the Gear variable and the other two. These showed a strong relationship between both being a member of the association and being a native and the use of certain gears. Namely, that native fishermen mostly freedive, and very few non-native fishermen freedive. Meanwhile, association members, with one exception, do not use compressors. Following this analysis, two sets of three additional regressions were conducted to examine the extent to which the effects of Membership and Native on Catch are mediated by the gear variables (see [14]). In both sets, mediation would be indicated by significant results in the first two regressions, and decreased significance for the independent variable in the final regression.

Set one:

1. Regression of Weekly Catch (Dependent) on Membership (Independent).
2. Regression of Compressor (Mediator) on Membership (Independent) via a logistic regression (since Membership is binary).
3. Regression of Weekly Catch (Dependent) on Membership (Independent) and Compressor (Mediator).

Set two:

1. Regression of Weekly Catch (Dependent) on Native (Independent).
2. Regression of Freediving (Mediator) on Native (Independent) via a logistic regression (since Native is binary).
3. Regression of Weekly Catch (Dependent) on Native (Independent) and Freediving (Mediator).

3.3.3. Social network analysis

The network that was analyzed in this paper was constituted by the individual fishermen as the nodes, with dichotomous (unweighted) ties being defined by the behavior of fishing regularly together. This “co-fishing” network is undirected, or symmetrical (since it is impossible for fisherman A to fish with fisherman B without the reverse being true).

The social network analysis was guided by the following set of hypotheses:

H7. The network will contain a low level of connectivity between the nodes.

H8. The network will be modular, containing distinct subgroups of fishermen.

H9. These subgroups will not be highly connected by “bridging ties.”

Each of these hypotheses is based on an understanding of the relationship between network properties and the ability of the community this network represents to act collectively and sustain a resource. Regarding the first hypothesis, increasing connectivity, at least to a certain point, should foster increased social capital and the ability to act collectively [3]. Since the Buen Hombre fishermen do not seem to be involved in much collective-action, it was hypothesized that their fishing network would be poorly connected.

Secondly, “the existence of subgroups can pose challenges for joint action aimed at governing a common natural resource, due to the risk of “us-and-them” attitudes among actors” [2, 368]. Thus it was hypothesized that the Buen Hombre fishing network would

contain distinct subgroups of fishermen, with comparatively high connectivity within each group and low connectivity between groups. Inter and intra-group connections are known as "bonding" and "bridging" ties, respectively. As Newman and Dale [16] state: "Bonding ties create dense network structures and strong but localized trust, but can impose strict social norms that discourage experimentation and encourage increased homophily, which is the tendency of a group to become less diverse over time, and to distrust 'others'."

Modularity then is a double-edged sword. A modular network may increase inter-group conflict, but within each group, collective-action problems may in fact be easier to resolve. The problem comes when different groups interact with the same resource, and higher-scale collective-action is required. In such situations, a modular network needs a way of bridging across subgroups in order to effectively manage a larger resource system. Such bridging is frequently done by hubs in the network, or nodes with unusually high numbers of connections (see Cox [29] for an example from irrigation systems). Hubs in a social network are frequently social leaders. In the case of Buen Hombre, again given the low levels of collective-action, it was hypothesized that there either would not be such hubs in the network, or that, if there were, they would not be playing a coordinating role across subgroups, assuming these were identified.

To test these hypotheses the co-fishing network was visually examined and several network-level statistics were calculated in order to better understand the relationships between the variables examined at the fisherman level and the properties of the network that they constitute. All of the network analysis was done in the Cytoscape network analysis package.

4. Results

4.1. Description of the sample

Table 2 shows that the majority of fishermen in Buen Hombre are native to the community. The mean age of the fishermen is about 40 years old, with an average of about 22 years of fishing experience. Of the fishermen surveyed, just over one-fourth are members of the Fishermen's Association. The Buen Hombre fishery is based primarily on spearfishing, with freedivers just outnumbering compressor divers (Table 3).

4.2. Statistical results

Regarding the results from the Catch regression (Table 4), each of the coefficients has the sign that was predicted except Membership for the Experience variables, neither of which were practically or statistically significant, with confidence intervals spanning 0. Regarding the other variables, all else equal, fishermen who use compressors harvest more pounds of fish, as do fishermen who are more dependent on fishing. Meanwhile, Native and Freediving are each associated with catching less. Several of the variables (both gear variables and Dependence) have fairly significant p values, particularly considering the relatively low number of observations and statistical power involved in this analysis. The Native variable is not very significant.

In terms of practical significance or effect size, the statistically significant variables, as well as the Native variable, each have substantial influence over the dependent variable. Controlling for the other independent variables, going from low fishing dependence to high fishing dependence leads to a prediction of 142 more pounds per week being caught. When compared to the mean (271) and standard deviation (226) of the Catch variable, this is clearly a substantial difference. Similarly, the coefficients for the Native (−104), Compressor (175) and Freediving (−135) variables indicate that these variable substantively affect the amount of fish caught per week.

Moving on, Table 5 illustrates an important relationship between fishermen's gear choice and their status as native fishermen and association members. Briefly, almost all of the compressor divers are non-members, and almost all of the freedivers are native fishermen. Table 6 shows the results of the six regressions that were conducted to test for the possibility that gear mediates the effects of these two independent variables. These results show that the Membership variable's effects on Catch are mostly mediated by gear (Compressor). With no other variable included in the model, the effects of the Membership variable on Catch are negative and highly significant. Additionally, the Membership variable is a highly statistically significant predictor of Compressor usage. However, when Catch is regressed on both Membership and Compressor, the significance of the Membership variable mostly disappears. Additionally, the Native variable shows a similar relationship with the Freediving variable, although its effects on Catch are only somewhat mediated by Freediving.

Finally, as shown in Fig. 2, the average age of the fishermen varies substantially by gear type, with the average age of freedivers being 37, and the average age of the compressor divers being 32, which is the lowest age of any of the groups (with the exception of a single wading fishermen who is 29). A basic t test showed that

Table 5
Cross-tabulation between Gear, Native, and Membership variables.

	Membership		Native	
Gear	**Non-member**	**Member**	**Non-native**	**Native**
Freediving	12	13	2	23
Compressor	18	1	7	11
Hook and line	6	3	6	3
Yolero	8	1	4	5
Traps	3	2	3	2
Nets	4	0	2	2
Wading	1	0	0	1
Total	20	52	47	24
	Fisher's exact $p=0.008$		Fisher's exact $p=0.005$	

Table 4
Main regression results.

Variable	B	SE	p	95% C.I.	
Native	−104.55	77.2	0.18	−260	50.8
Experience	−0.24	1.9	0.9	−4	3.5
Membership	27.13	51.8	0.60	−77	131.3
Dependence	142.37	56.4	0.015	28.9	255.8
Compressor	174.69	85.8	0.05	2.1	347.3
Freediving	−135.02	80.8	0.1	297.4	27.4
$n=55$					
$r^2=0.44$					

Table 6
Results of mediation analysis.

Model	Estimation	Dependent variable	Independent variables and significance
1	OLS	Catch	Membership (0.037)
2	ML (logit)	Compressor	Membership (0.03)
3	OLS	Catch	Membership (0.2) and compressor (0.01)
4	OLS	Catch	Native (0.00)
5	ML (logit)	Freediving	Native (0.00)
6	OLS	Catch	Native (0.07) and freediving (0.00)

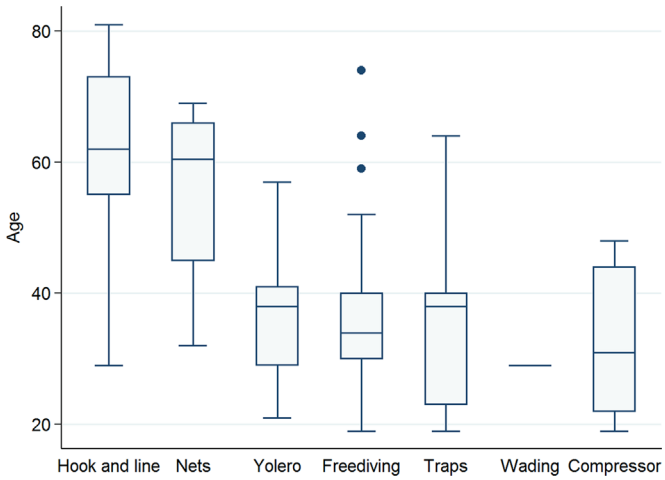

Fig. 2. Age by gear type.

the difference between the age of compressor divers and other fishermen is 10 years, and is statistically significant ($p=0.002$). Notably, the yoleros, those fishermen who manage the compressors for the compressor divers, are 37 years on average as well. Why this is important will be addressed in the next section.

4.3. Social network results

Numerical attributes of the Buen Hombre co-fishing network are summarized in Table 7. With each fishermen fishing with slightly under three other fishermen, there is some connectivity in the network, but not a substantial amount. The clustering coefficient also indicates a degree of clustering of nodes into subgroups in the network. Finally, network heterogeneity is an indicator of the presence of hubs in the network, and shows that the network likely contains several nodes with unusually high numbers of connections.

The network itself is shown in Figs. 3–5. Each fisherman is represented as a node, and the behavior of fishing together is represented as links between nodes. While this is an undirected network (there are no arrows on the connections), the diagrams do show whether one fisherman in a linked pair identified their relationship (one line between the pair) or if both did (two lines).

Fig. 3 distinguishes nodes based on whether they were surveyed or not, while Fig. 4 distinguishes nodes based on the gear that each fisherman uses, and Fig. 5 labels nodes based on association membership. For Figs. 4 and 5, nodes that represent fishermen that were not surveyed, and thus are without any data, are left white. Each figure shows that there is one primary component with the majority of the nodes, with several much smaller components, including single-node components, shown below this main component.

These figures make it visually apparent that there is substantial clustering in the primary component of the network. To further unpack this, a basic cluster analysis was conducted in Cytoscape using an algorithm known as EAGLE, as discussed by Shen et al. [24]. This breaks the network down into clusters based on differences in the connectivity between different parts of the network. The results of this analysis are shown in Fig. 4, which assigns different shapes to the nodes of different clusters. Fig. 4 thus visually shows how this social clustering is highly correlated with the gear that fishermen use. This result was statistically confirmed with a Fisher's exact test ($p=0.00$) of the relationship between these two variables (gear and cluster, excluding fishermen that were not assigned to a cluster).

Clusters 1 and 2 are composed mostly of freedivers. Comparing cluster 1 in Fig. 4 to Fig. 5 shows that this is composed mostly association members. Clusters 3 and 4, in contrast, are constituted by some fishermen that use compressors, and others that self-identified as yoleros, which is not surprising, since the yoleros are those fishermen who stay on the boat while one or more compressor divers fish. Other than these primary clusters in the main component there are two much smaller clusters, one of which is a mix of freedivers, compressors, and a yolero, with the other being a group of five fishermen who fish with traps. The fishermen who fish with hook and line and nets are seemingly quite isolated from the rest of the fishermen, although a string of these is included in cluster 4. Finally, it is noteworthy that cluster 1, the cluster with mostly association members, is the most densely connected (with fishermen in this cluster having an average of 4.8 connections).

Table 7
Network properties.

Parameter	Value
Number of nodes	96
Average number of connections per node	2.83
Average clustering coefficient	0.23
Network heterogeneity	0.85

5. Discussion

5.1. Fishermen catch

More than anything this analysis highlights the importance of fishing gear in determining the number of pounds a fisherman catches per week. Specifically, compressor divers are associated with higher catches while freedivers are associated with lower catches. The choice of gear seems to have important ecological ramifications for the coral reef in Buen Hombre. However, it is important to remember that the regression analysis excluded the responses of individuals who operate dive compressors from the boat (yoleros). While these individuals self-identify as fishermen and divide catches and proceeds with their diver(s) at the end of each day, they are not actively harvesting fish themselves. Excluding these individuals from the analysis attributes a compressor diver's entire catch to their own efforts, resulting in higher weekly catches per individual than if the yoleros were included in the fisherman pool.

Thus these results somewhat over-value the significance of the compressor diving in terms of its effects on per capita catch. The extent of this over-valuation depends on multiple factors that are difficult to quantify. First, it depends on what the yoleros would have been doing if they were not assisting compressor divers. One hypothesis could be that the yoleros would tend to be older fishermen who no longer wanted to or could withstand the rigors of diving. However, the data showed that the average age of the yolero fishermen was 37 (Fig. 2), which is not much higher than the compressor and freedivers. Thus it seems possible that these fishermen would be actively fishing if they were not acting as yoleros. Indeed, most of the yolero fishermen reported that they also were freedivers (fishermen were asked to list their top three fishing gear strategies).

Finally, with respect to gear, it is important to note that Wilson et al. [26] observed that compressor divers fish much farther out to sea than freedivers, in deeper waters. This is also shown in Fig. 1. This is likely one large reason why they can fish more, because they are not competing with historically more depleted, shallower waters. The long-term implications of this for the fishery are complex and difficult to predict, but it can be concluded that the compressor technology has had a significant effect on the amount

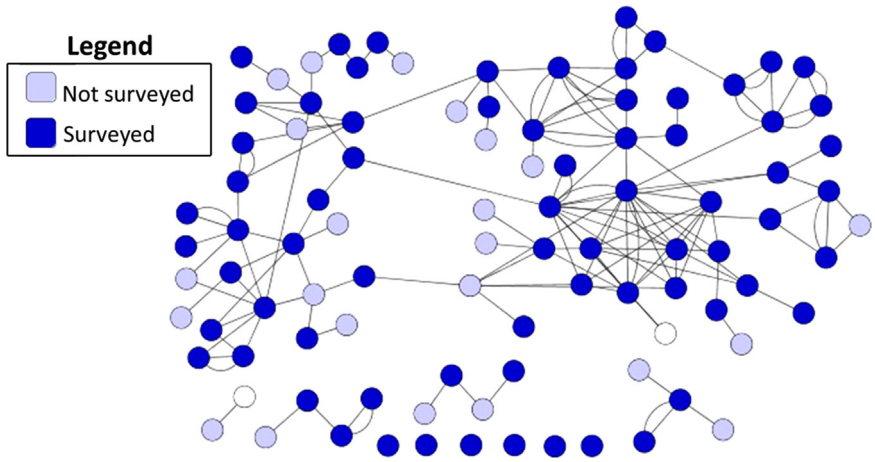

Fig. 3. Co-fishing network (surveyed vs. un-surveyed).

that fishermen catch in the Buen Hombre fishery.

Moving on, dependence on fishing was positively correlated with the pounds of fish an individual catches per week. The relationship between resource dependence and natural resource conservation is complex. Many have argued (e.g. [9]) that some level of resource dependence is in fact required for resource users to be incentivized at all to conserve. At the same time, it seems possible that excessive dependence could reduce the flexibility of users and encourage them to overuse a resource. It is important to note that all of the fishermen interviewed are at least somewhat dependent on the resource: the difference that was recorded was whether they were only somewhat dependent on the resource or highly dependent on the resource. High dependence is associated with more fishing. Another way to think about this is to suppose that the relationship between dependence and commons conservation is concave, and the dependence variable captures the range in which this relationship is negative.

This finding also has potential implications for the role of alternative livelihood sources in reducing fishing pressure. As the local agricultural sector has deteriorated, Buen Hombre community members have become more dependent on fishing. This has both increased the number of fishermen in Buen Hombre as well as increased the dependence of each fisherman on fishing [26]. A recent repaving of the road connecting Buen Hombre to inland areas has led to increased tourism in the community. While this comes with obvious concerns about environmentally harmful coastal development, it also has the potential to shift some financial dependence off of fishing and onto tourism-related industries.

Two variables that were not as significant in the regression analysis were Membership and Native. The interpretation of these, as discussed earlier, is that the effects of these on catch are either somewhat (for Native) or mostly (for Membership) indirect, being mediated by the choice of gear that a fisherman makes. The findings regarding the Native variable somewhat confirm past work on commons management that has established the importance of consistent membership and social boundaries around a user group to make sure that a resource is not overused by outsiders [6,18]. One primary concern with new members is that they may not abide by community norms, and in general their presence may lower the social capital that could be used to establish strong resource management institutions. It is possible that non-natives could have fished less, potentially because of the skill involved in catching fish via the technologies available, which is one reason that the Experience variable was included. The finding that the Membership variable indirectly affects catch is potentially very important as well, since it is this association that offers the most potential to build on current social capital to change current behaviors.

5.2. The co-fishing network

Each of the network-oriented hypotheses (H7, H8, and H9) is at least somewhat supported. The social network analysis shows that the role of gear choice is not limited to catch. There is substantial social clustering based on gear choice, with fishermen overwhelmingly fishing with the same or (in the case of compressors and yolero divers) complementary gear types. This is a similar result to the one produced by Crona and Bodin [7], although they were analyzing a communication and knowledge-sharing network rather than a co-fishing network. Nevertheless, the interpretation here is similar to theirs, in this case being that the clustering of the

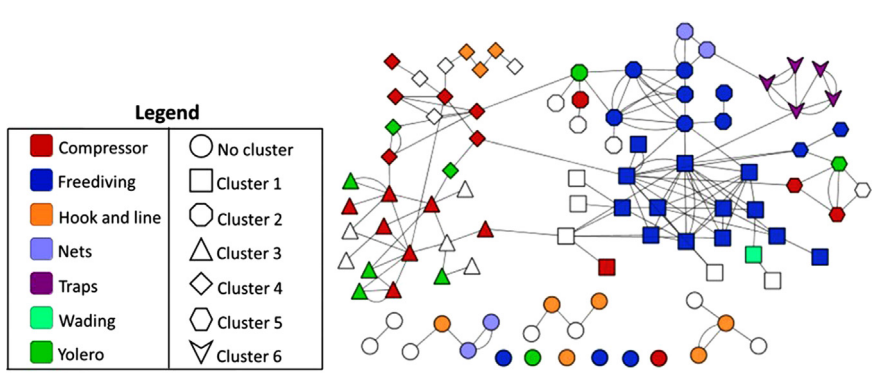

Fig. 4. Co-fishing network by cluster and gear type.

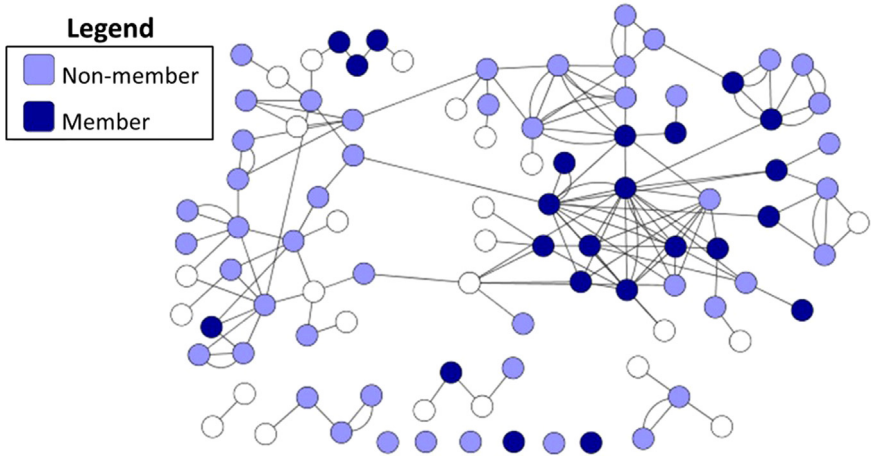

Fig. 5. Co-fishing network by membership.

network into subgroups with similar gear types likely discourages collective-action from taking place. At the same time, fishing together is not the only way in which Buen Hombre fishermen interact. Buen Hombre is a small community, and there is substantial social interaction within the village itself.

Much of the clustering is also explained by membership in the fishermen's association. It is conceivable that this association, with its enforced rule of not using compressors and high social capital (as measured by network connectivity), could serve as the basis for more collective-action in the fishery. Indeed, cluster 1 has the two most highly connected nodes in the whole network, with one of these being the president of the fishermen's association. This fisherman has a direct connection to cluster 4, one of the compressor/yolero groups. On the other hand, while this does constitute a connection, it is in fact the only such connection between a freediver and a compressor-diver in the network, and there are no comparably highly connected nodes (which might indicate comparable leaders) in any of the other clusters. Additionally, of all of the connections in the network, only three directly connect one of the freediving groups (clusters 1 and 2) to either of the compressor/yolero groups (clusters 3 and 4).

To conclude, there are two other elements to the network of interactions in Buen Hombre that were not formally analyzed, but which are relevant to mention here. First, the association members sell their fish to the association, whereas the rest of the fishermen sell their fish to one of several pescaderias on the Buen Hombre beach. So the social clustering extends to the point of sale of the fish as well. Second, there is little contact between the Buen Hombre fishermen and external governmental agencies that might enforce rules or otherwise partner with some of the fishermen to improve their ecological situation.

6. Conclusions

With few institutional arrangements and close to open-access conditions, the future state of the Buen Hombre fishery remains in doubt despite some efforts to improve the situation. In the language of social networks and commons theory, the Buen Hombre fishermen are struggling with a lack of bridging ties and strong leadership to connect different fishing groups and ameliorate the large differences in the amounts of fish these groups catch. If such ties could be strengthened, it is conceivable that informal pressures could be exerted across groups to ameliorate some of the pressure on the reef.

One very plausible avenue for such developments lies in the fishermen's association, and indeed, in similar contexts such associations have proven to be very effective [12]. It is possible that the fishermen's association could expand its membership, and this could help by increasing the proportion of fishermen who freedive in the area. One of the goals of the fishermen's association is to dis-incentivize the use of compressors by refusing to buy compressor-caught fish. However, while association membership has a clear correlation with freediving, the question remains as to whether compressor fishermen would modify their gear choices to join the association, or if the association only attracts fishermen already fishing with approved gear types. If the latter is the case, it would seem unlikely that increasing the size of the membership would have a significant effect on fishing behavior as a whole in the fishery.

In addition to stronger inter-group ties within the community, it could be helpful to develop cross-scale ties to relevant governmental agencies to form a true co-management regime, with shared responsibilities between the fishermen and governmental agencies [23]. This could prove to be particularly appropriate given some of the problems the fishermen are having with outsiders periodically fishing in their waters.

Despite the challenges it faces, the Buen Hombre fishery still has some attributes that would favor its ability to resolve the problem of overfishing. Foremost among these is the comparatively small size of the community and the number of fishermen. Group size is a central determinant in the ability of groups of resource users to resolve their differences and act collectively to preserve a common resource. Despite the social fragmentation shown in the co-fishing network, it seems very possible that social capital can be built within the village of Buen Hombre itself to overcome the gear-based fragmentation that exists in the fishery. With improved social capital as a basis for increased buy-in, the current leaders of the association may be able to pressure non-freedivers to either change their gear or otherwise limit the amount of fish they do catch with their current gear. During the fieldwork portion of this project, such efforts to build this social capital did seem to be occurring. Future fieldwork to assess and document these changes would be valuable.

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Appendix A. Supplementary material

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