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REPORT

Studying common-pool resources over time: A longitudinal case study of the Buen Hombre fishery in the Dominican Republic

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Abstract Like many small-scale fishing communities around the world, the community of Buen Hombre in the Dominican Republic is dealing with a set of challenges to reconcile its fishing activities with the ecology on which it depends. Also like many such communities, this case has been examined at a particular period in time by a group of social scientists, but not over substantial lengths of time in order to examine the longitudinal validity of the conclusions made during this period. In this paper we combine data from previous anthropological work with our own primary social and ecological data to conduct a longitudinal case study of the Buen Hombre fishery. Our over-time comparison focuses on a suite of mostly social and institutional variables to explain what we find to be a continued degradation of the fishery, and we conclude the analysis by presenting a causal-loop diagram, summarizing our inferences regarding the complex interactions among these variables. We find that a mix of factors, notably changes in gear and fishing sites used, the number of fishermen and their livelihood diversity, as well as an increased connectivity between Buen Hombre and its external environment, have contributed to the decline of the condition of Buen Hombre coral reef fishery. We conclude with a discussion of what may lie ahead for this particular case and others like it.

Keywords Community-based natural resource management · Dominican Republic · Institutional analysis · Small-scale fisheries

INTRODUCTION

Small-scale fisheries employ 50 of the world's 51 million fishers and are responsible for over half of the annual marine catches around the globe (Berkes et al. 2001; Basurto 2008). The majority are located in developing countries where limited resources and a high local dependence on the natural resource make effective management both more challenging and more critical (Andrew et al. 2007).

A significant barrier to better understanding the social and ecological complexities of small-scale fisheries management is the shortage of longitudinal studies within these systems (Poteete et al. 2010; Johnson et al. 2013). Without repeated visits and analyses, we run the risk of making causal inferences that do not hold over sufficiently large time frames, which is an obvious problem when our research questions center around resource sustainability. This paper aims to address these knowledge gaps by providing an over-time comparison of an artisanal coral reef fishery in the Dominican Republic.

Between 1985 and 1995, a team of researchers led by Richard Stoffle conducted ethnographic and ecological studies on a coastal village and fishery known as Buen Hombre. The researchers reportedly observed a productive fishery being sustainably stewarded by the community (Rubino and Stoffle 1986; Stoffle et al. 1995). While overfishing and tourism had led to reef degradation in the surrounding areas, environmentally responsible local resource use was linked to superior ecological condition in the Buen Hombre fishery (Stoffle et al. 1995). Initial studies hypothesized that sustainable resource use in Buen Hombre was driven by three attributes of the community: isolation of the village, social mechanisms for adjusting the human population size of the village, and a strong marine conservation ethic among local fishermen (Stoffle et al. 1995).

Two decades after these historical studies were concluded, we began a second round of social and ecological research of the Buen Hombre community and its fishery.

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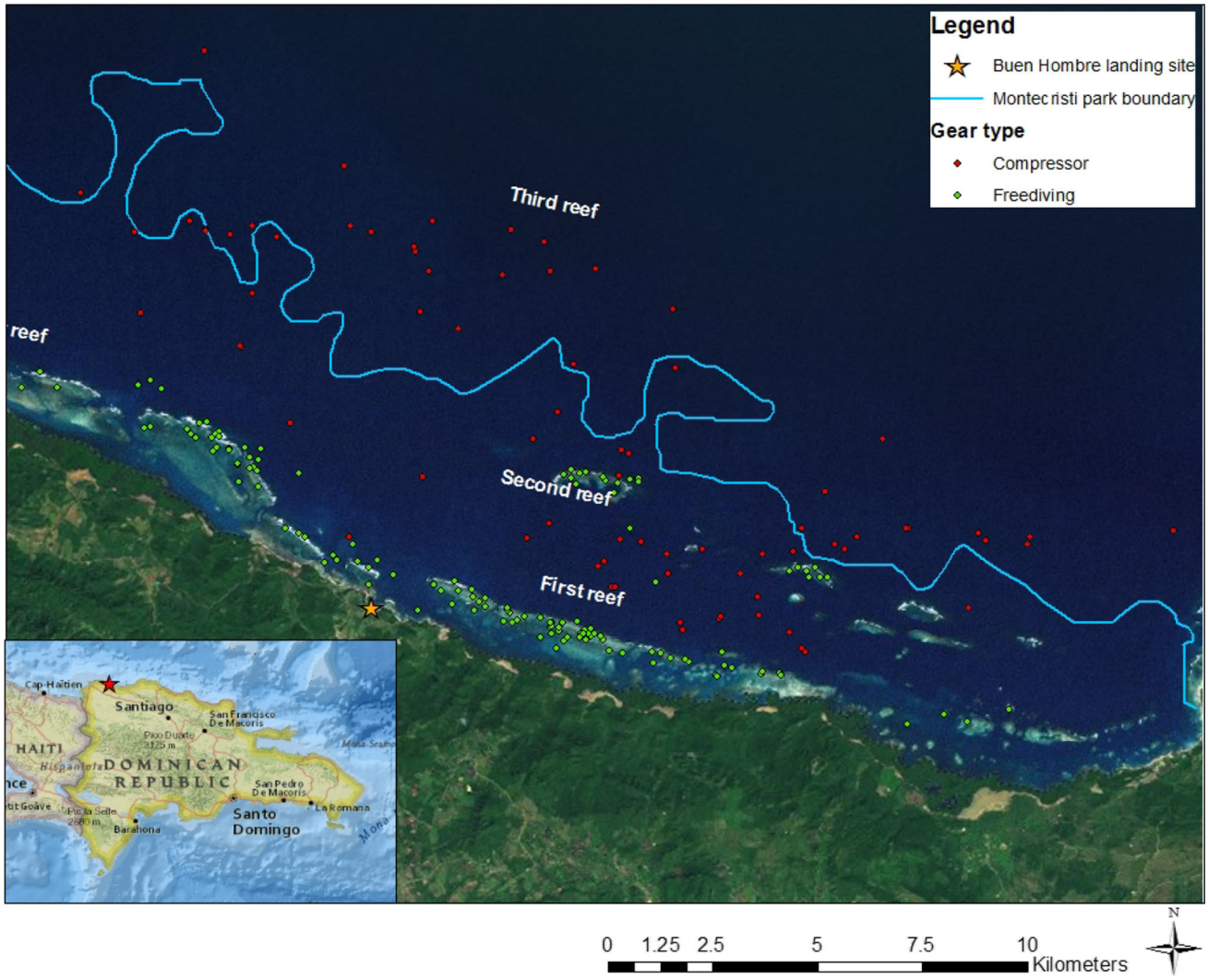

Fig. 1 Map of the study area

Here, we present a comparison of our findings with Stoffle et al.'s initial studies. First, we briefly describe the state of the fishery ecosystem. This is not a full ecological assessment, but it does provide context for our institutional analysis. Next, we assess hypotheses regarding social factors that may be driving ecological changes. We determined which variables we would incorporate into the analysis by using the social ecological systems framework (Ostrom 2007) and its previous applications in the fisheries sector (e.g., Gutiérrez et al. 2011; Basurto and Nenadovic 2012) as an informal guide. We complemented this list with our own observations of seemingly relevant factors during our initial fieldwork as well as with factors that would allow us to reevaluate the hypotheses of Stoffle et al. (1995) as they relate to present-day Buen Hombre. Together, this historical comparison and incorporation of key social variables provides a means of better understanding long-term dynamics and current status of this social–ecological system.

MATERIALS AND METHODS

Study area

The village of Buen Hombre is located on the northern coast of the Dominican Republic in Monte Cristi Province approximately 20 km east of the city of Monte Cristi and 35 km east of the Haitian border (Fig. 1). The village sits at the water's edge and is bordered to the south by the foothills of the Septentrional mountain range. There is very little rainfall or fresh groundwater, leading to dry scrub forest as the dominant biome. Archaeological evidence indicates that indigenous populations had previously inhabited Buen

Hombre's current site, though the area had been largely abandoned for over 300 years until 1887. At this time, 13 Cuban refugees arrived ashore and founded the current community (Stoffle et al. 1991; McGoodwin 2001).

The fishery is situated within Monte Cristi National Park, established in 1983 (Lopez and Silva 2012). It contains barrier and patch coral reefs interspersed with areas of sand, sea grass, and mangroves lining the coast. Fishers mostly capture finfish, with regular but lower harvests of lobster, crabs, octopus, and conch. Almost all fishing takes place in coral reef habitats, with a few fishers specializing in octopus and conch found in shallow hard-bottom or seagrass habitats and a few more targeting pelagic, offshore species. Many fish species are harvested, including, but not limited to, members of the following families (in approximate order of most to least frequently caught): parrotfishes (Scaridae), groupers (Serranidae), snappers (Lutjanidae), grunts (Haemulidae), squirrelfishes (Holocentridae), bigeyes (Priacanthidae), lionfish (Scorpaenidae), angelfishes (Pomacanthidae), morays (Muraenidae), jacks (Carangidae), and sharks and rays (Class: Chondrichthyes) (Pavlowich, unpubl.). Fishermen use spearguns, traps, nets, handlines, and boats with motors. There is also intermittent collection of bivalves from shallow, coastal seagrass beds, though we do not consider this aspect of the resource here.

Data collection

To understand if, how, and with what consequences the fishing system in Buen Hombre has changed over the past three decades, we conducted a longitudinal case study (Yin 2014). This involved the comparison of two different "snapshots," or periods of time within which we felt comfortable making inferences regarding the values of important social and ecological variables. This is thus a temporally comparative analysis. The variables we assessed are presented and defined in Table 1.

Literature review

In order to collect information about Buen Hombre in the historical snapshot, we reviewed academic and gray literature generated from previous studies of the community. We identified literature of interest through database (Web of Science) searches and by following relevant cited sources. Literature was reviewed for quantitative and qualitative information that would aid in generating values for our social and ecological variables.

Little recorded information exists about the Buen Hombre community until 1985, when Buen Hombre was chosen as a pilot site for a project implementing new spider crab (*Mithrax spinosissimus*) mariculture techniques headed by the Marine Science Lab of the Smithsonian Institute and the U.S. Agency for International Development. As the transfer of the technology had failed in the two initial pilot sites in the Turks and Caicos, both an economic and a social feasibility assessment were funded for the third site in Buen Hombre (Rubino et al. 1985; Rubino and Stoffle 1986; Stoffle 1986). While the

Table 1 Definitions of variables examined

Category	Variable	Definition
Group attributes	Population	The number of individuals residing in the Buen Hombre community
	Connectivity	Connectedness between the community and the outside world
	Number of fishermen	The number of part-time and full-time fishermen residing in the community
	Dominant livelihoods	The most commonly employed livelihoods in the community
	Livelihood diversity	Diversity of livelihood sources for fishermen
	Dependence on fishing	The importance of fishing as a livelihood for each fisherman
	Trust and cooperation	Extent to which community members act in the best interest of others and trust that others will do the same
Institutions	Association membership	The number of members of the Fishermen's Association
	Catch sold to market	The percent of catch sold as opposed to kept as subsistence
	Fishermen power in value chain	The amount of control fishermen exert or are able to exert in the value chain
	Rule effectiveness	The existence of and compliance with formal and informal rules that govern fishing activities
	User boundaries	The extent to which the Buen Hombre fishermen can effectively exclude outsiders from using their fishery
Technology	Fishing gear sophistication	The level of technological advancement of equipment used to harvest seafood
	Extractability	The quantity of fish that fishermen are capable of extracting given ecological availability using current technologies
	Expandability	The spatial range at which fishing occurs or can occur using current technologies

mariculture project was terminated less than 2 years later, a number of interdisciplinary studies continued in Buen Hombre through 1995 as part of NASA's Consortium for International Earth Science Information Network initiative (Stoffle et al. 1991; Luczkovich et al. 1993; Michalek et al. 1993; Stoffle et al. 1994). In addition, two ethnographic case studies were produced that integrated social data spanning almost 10 years (Stoffle et al. 1995; Stoffle 2001).

In addition to compiling historical information, we supplemented our own current fieldwork with recent ecological reports from the region. Between 2010 and 2012, a pilot project for developing a management plan for Monte Cristi National Park, sponsored by the United Nations Development Programme Global Environment Facility (UNDP/GEF), Dominican governmental bodies, and international non-governmental organizations, was carried out in Monte Cristi Province. Researchers and technicians performed studies on current governance and marine and coastal ecosystem status (Lopez and Silva 2012; Medina et al. 2012).

Ecological assessment

A full ecological assessment is part of our ongoing research (Pavlowich, unpubl.). Here, we rely on the reports of Stoffle and colleagues, conversations with fishermen of all ages, and our own data to make comparisons over time and with other coral reefs in the Caribbean and around the world. We focused only on the fish community because it is the resource directly relevant to fishermen and the community, it is the first component of the ecosystem to be impacted by fishing, and it is a major driver of reef ecosystem health (Pandolfi et al. 2003; Mumby et al. 2006). We conducted surveys of the fish community using underwater visual census techniques, the most commonly used methodology today (Samoilys and Carlos 2000; Lang et al. 2010). We surveyed all habitats between the shoreline mangroves and deep coral reefs within safe diving limits. Researchers scuba dove or snorkeled transects that were sited haphazardly within habitats and fishing sites across the fishery area. We identified all fish within a 30×4 m transect to species and estimated their length to the nearest centimeter. Fish lengths were used to estimate fish weights using the standard length–weight relationship, weight $= a \times$ length^b, with parameters 'a' and 'b' for each species found on Fishbase (www.fishbase.org). The sum of all fish weights per transect was calculated, converted to kg ha^{-1}, and reported as total fish biomass. Only transects conducted in windward, fore-reef habitats ($n = 46$) were used to compare fish biomass at other reefs. To compare present conditions with past conditions in Buen Hombre, we utilized qualitative statements by Stoffle and his team.

Fishermen interviews

Data for the present-day snapshot were collected during four field seasons in 2012–2014. The first two field seasons during the June–August of 2012 and June–July of 2013 were spent collecting marine ecological data and fisheries catch data as well as conducting exploratory interviews and participant observation throughout our time in the field. During the December 2013 and June 2014 site visits, semi-structured interviews were conducted with 72 of the 90 fishermen in Buen Hombre. Our sampling strategy attempted to interview each individual from a list of all fishermen in the community that we assembled with the help of two fishermen. We surveyed all fishermen who were both willing and available to be interviewed during our site visits, with the exception of four fishermen who we did not reach due to time constraints. All identified fishermen and thus all interview subjects were male. We conducted interviews in social gathering spots in various parts of town and in participants' homes. Fishermen interviews lasted between half an hour and over 2 h.

In each interview we collected information that allowed us to ascertain if and how the community and fishing system has changed over time. Interviews included questions about fishermen demographics, community attributes, fishing practices, fishing rules and regulations, markets, income and livelihoods, and social capital. Information on where fishermen fish was collected by having interviewees identify the fishing sites they currently visit most frequently and where they fished most frequently in their early fishing years on a printed satellite image of the Buen Hombre coast and surrounding areas. Fishermen were oriented with the image using key reference points before they were asked any questions regarding fishing sites.

Data synthesis

Following the data collection phase, the data from the historical and modern studies were used to code case-level variables to enable the comparison of these variables for each time period. These variables are categorized as group attributes, institutions, or technology in Table 1. Due to limitations in historical ecological data, no ecological variables were coded but instead a qualitative assessment of general trends was made with the data available.

While no spatial data were available from historical case studies, we used our fishing sites data to compare the distance each individual fisherman travels to their current fishing sites with the distance traveled to their past sites. Therefore, the past time period in this case does not necessarily refer to the 1985–1995 snapshot but instead to each individual's early fishing years. Spatial data were coded

Table 2 Comparison of variables examined between the 1985–1995 and 2012–2014 time periods

	Variable	1985–1995	2012–2014	Trend
Group attributes	Population	855	825	Decrease
	Connectivity	Low	Med	Increase
	Dominant livelihoods (in order of prevalence)	Agriculture, fishing, charcoal	Fishing, small business, agriculture	N/A
	Number of fishermen	47	90	Increase
	Livelihood diversity	High	Low	Decrease
	Dependence on fishing	Med	High	Increase
	Trust and cooperation	Med	Low	Decrease
Institutions	Association membership	98 %	27 %	Decrease
	Fishermen selling fish to Association	98 %	18 %	Decrease
	Catch sold to market	81 %	95–99 %	Increase
	Fishermen power in value chain	High	Low	Decrease
	Rule effectiveness	Med	Low	Decrease
	User boundaries	Med	Low	Decrease
Technology	Fishing gear sophistication	Low	Med	Increase
	Operating boats with motors	~6	~14	Increase
	Fishermen using dive compressors	4 %	40 %	Increase
	Extractability	Low	Med	Increase
	Expandability	Low	High	Increase
	Distance traveled to sites	6.7 km[a]	8.0 km	Increase
	Fishermen fishing abroad	0 %	32 %	Increase

[a] Past time period is not specifically 1985–1995 but instead each individual fisherman's initial years fishing

with GIS. Sites identified as points were entered as such and sites identified as ranges were entered as a geographic point in the center of the range and two points at either extreme end of the range. When calculating the average distance traveled to fishing sites per time period, we took the average of the distances from the landing beach to each site per fisherman in either the past or current time period. When calculating the average distances traveled to fishing sites by gear type, we took the average of the distances from the landing beach to each identified site associated with each gear type.

RESULTS

Here we present our findings for social and ecological changes in the Buen Hombre fishery between the historical and current snapshot. Because little quantitative ecological information was available from the historical snapshot, we could not report absolute values for the ecological changes but instead discuss trends and perceptions below. Table 2 summarizes our comparative results for changes in group attributes, institutions, and technology. Past and present values are reported quantitatively when possible, otherwise categorical values (high, medium, or low) were generated from qualitative data.

Ecological changes

When the Smithsonian project first arrived in Buen Hombre in 1985, the use of the fishery was reportedly sustainable (Stoffle et al. 1993, 1995). Luczkovich described the state of the Buen Hombre reef as "relatively pristine" (1991, p. 139), explaining that corals appeared healthy, but that the fish community showed signs of overfishing. There were few large predatory fish observed, especially in locations from shore to the first barrier reef. Luczkovich commented that macroalgae were abundant and productive in coral reef habitats, but did not express concern regarding the algal cover. He concluded that the ecosystem was in very good condition, but that artisanal fishing had the potential to degrade ecological health if not managed properly. Luczkovich provided detailed species inventories of all organisms encountered at various sampling sites throughout the fishery. Unfortunately, these data are of little use because they are incommensurate with our sampling methods, and because the presence of a species is a very coarse indicator of ecological change.

Today, fishermen of all ages in Buen Hombre unanimously report that there are fewer, smaller fish than there were in the past. Elders reminisce of how one used to be able to catch larger grouper, snapper, and lobster close to shore. Now, one must travel far from shore to the deepest

reefs to be able to catch fish like these, if at all. Even young fishermen lament how much harder fishing has gotten since they began fishing only years before.

Our quantitative data support fishermen's claims that the fish community in Buen Hombre is degraded. Fore reefs in Buen Hombre have a very low total fish biomass, with a mean of 308 kg ha^{-1} (sd = 239), on par with heavily overfished reefs in the Caribbean and elsewhere (Newman et al. 2006; MacNeil et al. 2015). MacNeil et al. (2015) estimated the global average for potential total fish biomass at unfished reefs to be 1013 kg ha^{-1} (95 % Bayesian posterior density interval = 963–1469 kg ha^{-1}). However, Sandin et al. (2008) observed much higher fish biomass estimates, up to 5000 kg ha^{-1}, at remote, pristine reefs in the Northern Line Islands (US Pacific).

Changes in group attributes

Conservation ethic

Stoffle et al. link the health of Buen Hombre's fishery to what they describe as a strong local conservation ethic (1993, 1995). It was reported that Buen Hombre fishermen "recognize the potential adverse effects of indiscriminate fishing practices on reef fish populations" (Stoffle et al. 1993, p. 271) and that they modify fishing practices in order to conserve the resource for future use. Examples of ideas held by the community to conserve the resource included refraining from taking small fish, harvesting multiple species to avoid overexploitation of a single species, not using fine-meshed seines, and generally fishing less by engaging in other livelihood activities (Stoffle and Halmo 1991).

While the historical studies place heavy emphasis on local conservation ethic, we feel that this is not a particularly clear or useful concept and do not attempt to quantify it here. Stoffle et al. use conservation ethic as a direct correlate of conservation behavior, while in reality conservation behavior integrates numerous complex factors such as perception of resource state, knowledge of how actions can affect resource state, and the means and incentives to modify these actions. Comparisons of both formal and informal interviews from 1991 and 2013 indicate that fishermen have almost identical knowledge about existing threats to the marine ecosystem and what should be done to protect and enhance the resource, yet fishing behaviors today seem to have shifted from the conservation-minded practices described in the historical time period. Fishermen today may know just as much and feel just as strongly about resource conservation yet their actions are influenced by a surplus of other factors. The remainder of our results section aims to examine these factors.

Population and connectivity

One of the main features that distinguish present-day Buen Hombre from the community in 1985 is an increase in its connectivity to people and resources from outside of the community. In 1985, the road running inland from Buen hombre to the closest national highway was treacherous and seasonally impassable (Stoffle et al. 1991; Stoffle 2001). At the time, no map even identified the roads in this region, let alone the Buen Hombre village itself (Stoffle 1986). Historical work cites the isolation of the Buen Hombre community as one of the key reasons the fishery was sustainable (Stoffle et al. 1995).

The 1986 road paving that came about as a result of the mariculture project was reported to have facilitated increases in population size, tourism, and the number and frequency of fish buyers traveling to and from Buen Hombre (Stoffle et al. 1991). The population reportedly increased from approximately 825 to 1000 individuals between 1985 and 1989 (Stoffle et al. 1993). The majority of immigrants to the community reported that they moved to Buen Hombre because of the fishing opportunities it provided. Improved road access and the movement into and out of the community that it facilitated has led to a significant increase in the level of connectedness of the Buen Hombre community with the outside world. However, a severe drought in the early 90s forced many individuals to leave the community. Approximately 100 individuals were estimated to have already left the community between 1989 and 1990. A gap in population estimates prevents us from tracking subsequent changes, but population decline was reported to have continued and the road soon fell into disrepair.

Since then, the population of Buen Hombre has rebuilt to 825 individuals, almost reaching the 1985 population of 855. Improvements to community infrastructure such as occasional water provision piped from regional sources and regular domestic electricity have encouraged people to stay in or move to Buen Hombre. Marginal but existent cell-phone and internet service now connects community members with larger networks outside of the community. A major development for the community was the repaving of the road to Buen Hombre in 2013. In addition to possibly encouraging further population growth, quicker and more reliable access to Buen Hombre has already facilitated increases in tourism to the community. Most tourists are domestic tourists and come only for day trips, but international tourism around kitesurfing is also increasing. A two-story hotel was built in tandem with the restoration of the road and a small kitesurfing school was opened in 2014.

Livelihoods

While the Buen Hombre population has not changed significantly across the two time periods, the number of fishermen has increased from 47 in 1985 to 90 in 2014. In addition to this increase, the extent to which each fisherman depends on fishing has also shifted significantly. When the Smithsonian mariculture project first arrived in Buen Hombre in 1985, many of the 47 fishermen only fished part-time (Stoffle 1986). Stoffle describes community members as employing 'occupational multiplicity' (or livelihood diversity), in which individuals relied on a network of part-time livelihoods to meet their income and subsistence needs. The Buen Hombre community as a whole relied on a combination of agriculture, fishing, charcoal production, livestock, and mechanic and taxi services. Stoffle specifically points out the complementary relationship between fishing and farming for the many individuals who chose to employ both. 60 % of the local Fishermen's Association members were also members of Buen Hombre's Agricultural Association. When the seasonal demands of farming were at their peak, fishermen-farmers would reduce their pressure on the fishery. When agricultural conditions were poor, they would increase their extraction from the fishery. In this sense, fishing acted as a buffer for oscillations in agricultural productivity (Stoffle 1986).

Over the past several decades, this diversity of livelihoods has decreased, and as a result dependence on the marine resource appears to have increased significantly. As can be seen in Fig. 2, the majority of fishermen no longer rely on agriculture as a source of income. This likely resulted from a string of severe droughts in recent decades as well as from new economic policies adopted in 1990 that disproportionately burden small farmers (Greenberg 1997). Recent deforestation laws have precluded the production of charcoal as a source of income, and community concerns over livestock wandering into the road have led most to reduce or eliminate their herds. Much of the community's past reliance on these alternative livelihoods has now been shifted onto the Buen Hombre fishery, contributing to a decrease in the livelihood diversity of each fisherman, and a concomitant increase in their reliance on the fishery.

There are some exceptions to the trend of decreasing livelihood diversity and increasing dependence on fishing in Buen Hombre. For one, the viability of local businesses such as small restaurants, commodity shops, and tourism services are said to have increased with the repaving of the road in 2013 and some fishermen have begun to engage in these other activities. Also of note, many Buen Hombre fishermen have begun to fish outside of the Dominican Republic, shifting some pressure off of the Buen Hombre fishery itself. Fishing abroad occurs either on 1- to 2-day trips in dinghies from Buen Hombre or on month-long trips as part of fishing companies from outside of the community. Of the 72 fishermen interviewed, almost one-third currently engage in fishing abroad in one or both of these types of trips. Twelve of these fishermen depend highly on fishing abroad as a livelihood, and three of them fish almost exclusively abroad and do not depend on the Buen Hombre fishing resource at all. There are many risks associated with fishing abroad. For one, it is illegal and many community members have spent several months in prison on neighboring islands. On-the-water conflicts between foreign fishermen and resident fishermen and officials have escalated to gun violence in some cases. Making open water crossings without safety precautions such as back-up engines, radar, or any form of long-distance communication also comes with obvious risks and some individuals have been lost at sea. However, those who make the trips obvious perceive the rewards to be worth these risks.

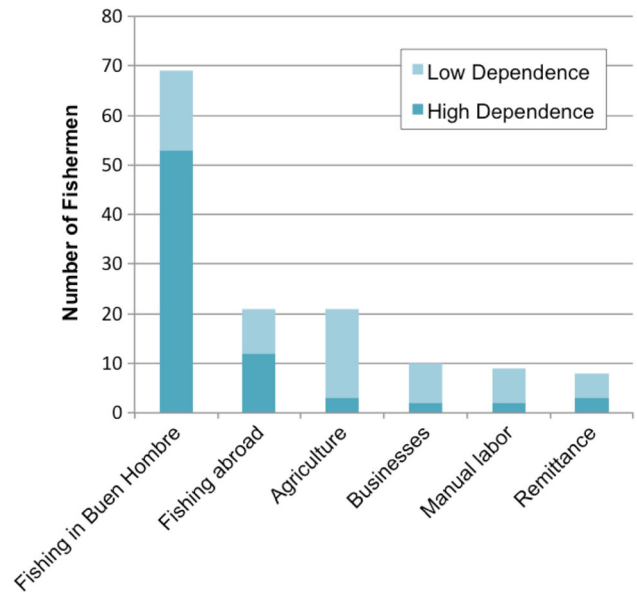

Fig. 2 Current livelihood dependencies of 72 surveyed Buen Hombre fishermen. Most fishermen in the historical period also relied on agriculture as a source of income. Now only 29 % of fishermen depend on agriculture to any extent and only 4 % consider themselves highly dependent on agriculture

Trust and cooperation

Resource users' perceptions and past experiences working in groups has an important influence on their willingness to do so in the present. Stoffle (1986) and Stoffle et al. (1995) describe a high level of cooperation and unity among Buen Hombre fishermen. Forty-six of the 47 men who were fishing out of Buen Hombre were members of the Buen Hombre Fishermen's Association, which worked to aggregate catch among fishermen as well as to provide ice

and storage for fishing equipment (Stoffle 1986). When asked about the importance of the Fishermen's Association, the majority of fishermen reported that it promotes unity and cooperation, which empowers fishermen as a whole (Stoffle et al. 1991).

The Fishermen's Association's function and membership has weakened considerably since these initial studies, and overall levels of cooperation and organization among Buen Hombre fishermen today are relatively low. At the start of the second data collection period in 2012, the Fishermen's Association was effectively inactive. AgroFrontera, a local NGO that has been working in Buen Hombre and surrounding fishing communities, has helped reinvigorate the Fishermen's Association over the past few years, but still only 27 % of Buen Hombre fishermen currently identify themselves as members and only 18 % are actively selling fish to the association as opposed to another pescadería. 44 % of non-members report concern about the potential for effective cooperation among the fishermen is the biggest deterrent from joining the Association. Past breakdowns of collective action within the fishery, including several failed aid projects where some participants were perceived to have benefited more than others, have contributed to these concerns. Almost half of these respondents cite past cooperation failures as a reason for this concern. Cooperation is a concern even among Association members, with 30 % of members reporting lack of cooperation as one of the Association's biggest issues.

Changes in institutions

Value chains and fishermen leverage

Large changes in the value chain around fishing in Buen Hombre have occurred between the two data collection periods. In 1985, a significant portion of fish was caught to meet subsistence needs. Fishermen kept around one-fifth of a normal day's catch to bring home to their families (Rubino and Stoffle 1986). During this period, fish that did go to market were sorted into classes based on catch species and size and were sold to out-of-town buyers who then transported them to inland markets. Four to six buyers of low-class fish came to Buen Hombre per week on small motorcycles, and a single buyer of higher-class fish came 2 or more days per week in a small pickup truck. An additional buyer who purchased almost exclusively lobster came to Buen Hombre every week or every other week. The Fishermen's Association was the central aggregator of fish at the landing level, and the boats, motors, and fishing gear used were owned primarily by Buen Hombre fishermen (Stoffle 1986).

The current value chain is more tightly linked to external markets and subsistence-based fishing plays less of a role compared to in the 1980s. Fish buyers estimate that upwards of 95 % of fish caught in Buen Hombre is now exported out of the community, and keeping fish for home consumption is no longer a universal practice in the community. The role of the Fishermen's Association as a primary aggregator of catch has been replaced by a network of local fish shops called *pescaderías*. The owner of each shop supplies a set of fishermen with boats, fishing gear and fuel, with the agreement that the fishermen sell their catch to that pescadería at the end of the day and that the costs for gas and equipment will come out of their earnings. Pescaderías in Buen Hombre then sell their merchandise to fish buyers and distributors who come from out of town. Fishermen have less leverage within the pescadería system than they did when operating in a central association. During the present data collection period, fishermen and a local non-profit have worked to restore the Fishermen's Association as a key player in the value chain.

Loaning and borrowing money is a common dynamic in present-day Buen Hombre and plays a particularly prominent role in the current pescadería–fisherman relationship. Unlike in the initial snapshot where many fishermen owned their own gear and sold through the Association, pescadería owners now own the majority of fishing equipment and front daily gasoline costs. As a result, fishermen who come back without enough catch to pay off costs quickly become indebted. Pescadería owners also frequently loan money to fishermen to cover food and other daily costs or emergency expenses such as medical bills or home repairs. Because fishermen are working to pay off these debts by catching fish, this indebted dynamic could potentially affect fishing behaviors.

Thirty-nine of the 50 fishermen[1] asked about borrowing behaviors reported that they borrow money at least occasionally from their pescadería. The amount borrowed per transaction is most commonly less than 12.5 % of their average weekly income but can reach up to 50 % of their average weekly income. Although these loans seem to be relatively small and short-term, fishermen incomes tend to be highly variable, with average incomes during a bad week reportedly falling at around 33.6 % of average incomes during a good week. When asked what they would do if they incurred a hypothetical emergency expense of 2000 pesos (~500 USD in 2013), 70 % of respondents reported that they would borrow money while only 18 % reported that they would turn to their savings funds first. Therefore, it is understandable that while these loans from pescaderías may be fairly small, the majority of fishermen

[1] Detailed questions regarding borrowing behaviors were only conducted with the 50 fishermen in the first round of surveys. Due to time constraints, they were not included in the second round of surveys.

who utilize them report that they are very important. Additionally, small loans tend to accumulate, eventually leading to conflict between pescadería owners and fishermen.

This borrowing behavior is a defining trait of the fisherman–pescadería dynamic today. While pescadería owners depend on their fishermen for their supply of fish, fishermen are frequently highly indebted to their pescadería owners and often overleveraged. This might reduce the ability of fishermen to make decisions that are more personally, socially, or ecologically beneficial (Crona et al. 2010).

Fishing rules and user boundaries

The Buen Hombre fishery falls under the jurisdiction of several regional and national governance institutions. The Dominican Council on Fisheries and Aquaculture and the Ministry of the Environment and Natural Resources have the authority to limit access to fisheries throughout the country if doing so is deemed necessary to protect ecosystems or their sustainable use. The coast guard (*Marina de Guerra*) is responsible for national marine traffic regulation and border patrol and has several officials stationed near Buen Hombre. The fishery area of Buen Hombre also falls within the protected area of the Monte Cristi National Park, where national legislation highlights the government's authority and responsibility to manage these designated protected areas. Legislation mandates—but has yet to prescribe—management to include regulations controlling how resources are used, including permitted gears and extractive quotas, scientific monitoring, and processes for applying sanctions against rule breakers (Medina et al. 2012).

Despite the external governance institutions in place, reports from the historical snapshot emphasize local rule development and enforcement as a defining dynamic of the community. While there is no explicit discussion of this process, most governance anecdotes cite local roots and emphasize local enforcement. Stoffle et al. (1995) report that fishermen would institute local species-specific catch bans when certain stocks appear to be low, and that a local ban on the use of tanks for fishing had also been instated. Fishermen reported that they would refrain from taking small fish and small or egg-bearing lobsters, and while it is not specified whether these were local norms or formal rules, the level of respect and compliance appears to have been high (Stoffle et al. 1995). Past studies do not mention the Monte Cristi National Park nor its implications for marine management.

In the current snapshot, the same regional and national governance institutions hold jurisdiction over the Buen Hombre fishery. However, very little local rule development and enforcement seems to be in place. The effectiveness of both formal and informal rules in the Buen Hombre fishery appears to have decreased significantly since the historical period. The criteria we used to examine the efficacy of a rule were that (1) the resource users are aware of and understand the rule, (2) there are costs to breaking this rule, (3) the rules are effectively enforced, and (4) most resource users ultimately comply with this rule. Results from the current interviews made it clear that these components are for the most part lacking for the main rules that would govern the use of the Buen Hombre fishery.

Low awareness and understanding of existing rules was inferred from the fact that there was significant variation in the rules that fishermen identified (Fig. 3). Survey responses also made it clear that existing rules were not effectively enforced. As shown in Table 3, fishermen's overall perception of the likelihood of enforcement is moderate. The average reported severity of sanctions for all identified rules was moderate to low. The lack of consensus among fishermen about sanctions, as well as the significant number who responded they did now know what the sanctions for a particular rule were, indicates that awareness of these sanctions is low.

Fairly low levels of reported compliance (Table 3) as well as observed compliance with fisheries regulations are not surprising given low levels of awareness of rules and enforcement institutions, as well as low levels of perceived risk and cost to breaking rules. However, differences were found between the effectiveness of different rules in the fishery today. Predictably, rules that had higher likelihoods of enforcement tended to have higher rates of compliance (Pearson's $r = 0.51$, $p < 0.0001$). Similarly, rules with more severe sanctions tended to have higher rates of compliance (Pearson's $r = 0.34$, $p < 0.0001$). A confounding factor could be the potentially reduced willingness of fishermen to report noncompliance with rules that have more serious sanctions. This potential bias was minimized to the extent possible by establishing high levels of trust with respondents through working with fishermen in the community for five cumulative months before beginning the interviews. Interviewees were also assured their responses would remain confidential.

Regarding fishing territories, Buen Hombre fishermen have no legally exclusive rights to its resource, nor did they in the past. However, Stoffle reports that Buen Hombre fishermen "feel a sense of ownership of the ocean and its resources" and that they restrict access "by agreeing that generally only members of the fishermen association fish in Buen Hombre waters" (2001, p. 232). Buen Hombre fishermen aimed to exclude the majority of fishermen from other communities–especially if they were fishing with techniques that were thought to harm the marine

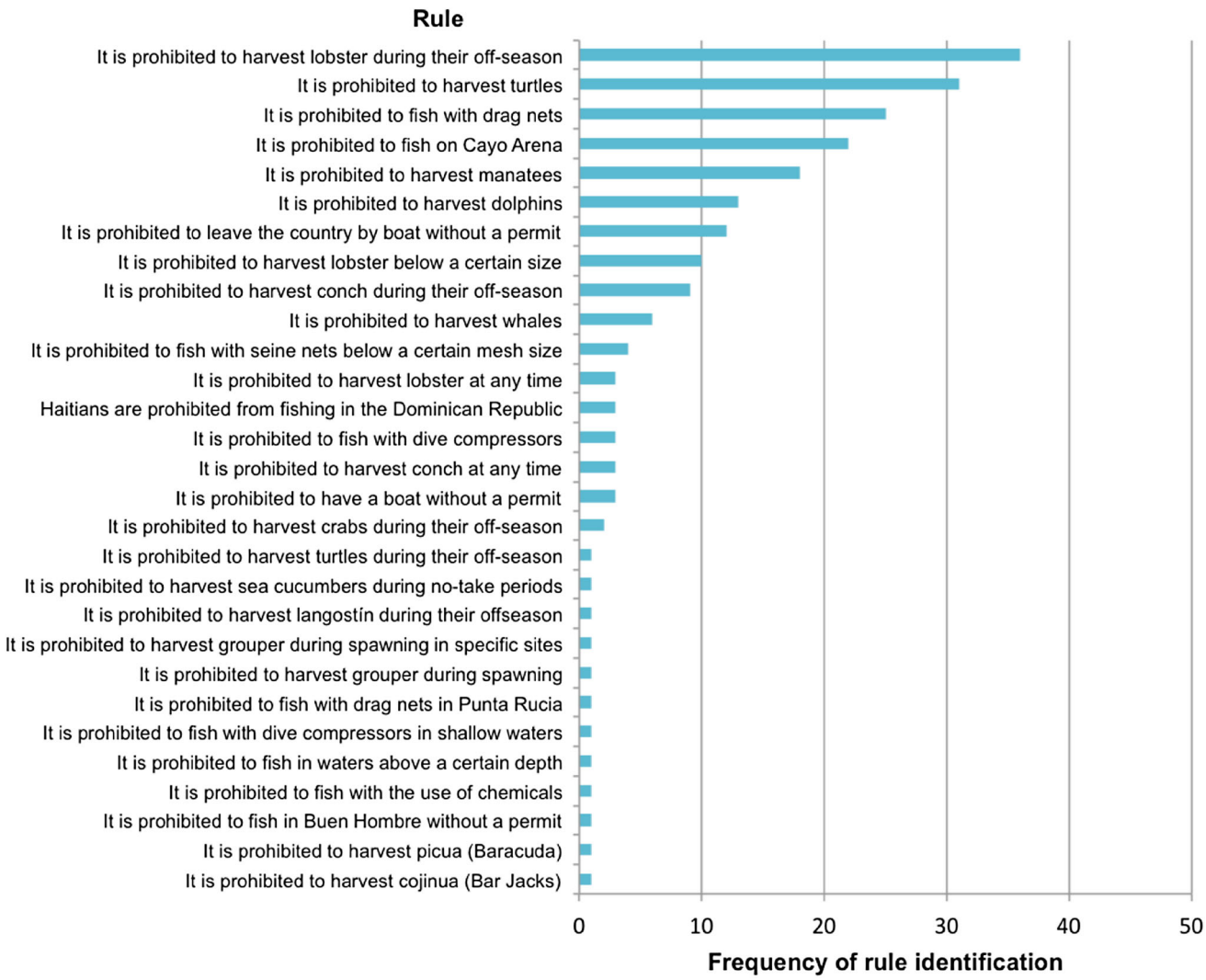

Fig. 3 Frequency of rule identification by 50 fishermen asked to report all existing rules in the fishery regarding species and size restrictions, gear restrictions, and spatial restrictions. The *y*-axis lists all reported rules and the *x*-axis indicates the number of fishermen who reported each rule. No single rule was identified by all respondents, and 22 of the 31 rules identified were reported by only three or fewer fishermen

Table 3 Average reported rule compliance (1: no user compliance; 2: moderate user compliance; 3: complete user compliance) likelihood of rule enforcement (1: improbable; 2: possible; 3: almost certain), and severity of sanctions for rule violation (1: small fine; 2: large fine and/or less than 2 years in prison; 3: 2 or more years in prison) for 50 fishermen surveyed about fishing regulations

	Mean (1–3)	SE
Compliance	1.93	0.06
Likelihood of enforcement	1.83	0.06
Severity of sanctions	1.60	0.09

environment (Stoffle 1986). Fishermen would try to work with government officials to exclude outsiders and also reportedly enforced boundaries themselves when government officials were unresponsive (Stoffle et al. 1995).

Fishermen today still feel that an informal Buen Hombre fishing territory exists and express concerns over outsiders exploiting the area—especially Haitian fishermen who cannot legally fish in Dominican waters in general. However, when asked about rules regarding access to the Buen Hombre fishermen, 46 of 50 respondents[2] reported there are not any rules effectively restricting access to the fishery by outsiders. Local efforts to exclude outsiders from this territory seem rare compared to the historical reports, although in the final months of our fieldwork momentum around resource territoriality seemed to be building. In one instance, fishermen solicited local coast guard officials to

[2] These questions were included in the rules questions that were only asked in the first survey round.

remove a group of Haitian fishermen fishing on Buen Hombre reefs.

Changes in technology

The types of gears used in Buen Hombre have shifted in the past three decades. In 1985, the majority of fishermen in Buen Hombre fished either with a speargun while freediving or with hook-and-line (Stoffle 1986). A few fishermen also set traps offshore. By 1991, two Buen Hombre fishermen as well as some fishermen in neighboring communities had begun to spearfish using a dive compressor: a recycled paint compressor that pumps air from a boat at the surface down to one to two divers below through a polymer hose. Some fishermen from neighboring communities also used beach seines and occasionally employed these nets on the reefs off of Buen Hombre. In 1995, it still did not appear that any Buen Hombre fishermen had started to use these nets (Stoffle et al. 1995).

In recent decades access to fishing boats and motors in the community has increased significantly. The proportion of fishermen using dive compressors has also grown to approximately 40 %, while only 35 % of fishermen are fishing while freediving. The pescadería system has largely facilitated this development as shop owners have the financial capital to invest in more expensive technologies. Only 19 % of fishermen use primarily hook-and-line or fish traps, with the majority of this group employing a combination of both gear types. This is because both typically take place farther offshore, they can be done in tandem, and traps are most effective during winter months so can be complemented by hook-and-line fishing during the rest of the year. The remaining 6 % of Buen Hombre fishermen use gillnets, although additional fishermen from neighboring towns also employ these gill nets in the Buen Hombre reefs. Much like in the past snapshot, no one from Buen Hombre currently uses beach seines but fishers from neighboring towns reportedly use them on the Buen Hombre reefs under the cover of darkness.

This shift from freediving to compressor diving as well increased access to boats and motors has had important implications for the ecological impact of fishing. First, it has increased the *extractability* of the resource, or the quantity of fish that can be harvested within a given location. Freedivers are limited in how fast they can catch fish because only one fish can be caught per breath. Compressor divers are not limited by the need to resurface for air as freedivers are, and therefore, have an increased rate at which they can capture a fish, reload their speargun, and capture another. Both of these factors lead to compressor divers catching more and often larger fish than freedivers in a given area.

Secondly, increased boats and compressors access has increased the *expandability* of the resource, or the ability of resource users to expand the area of ocean available for exploitation. Since the majority of fishermen in 1985 were freediving, their fishing sites were restricted to the inner reef and the second reef. Hook-and-line and trap fishermen could fish the third reef, but access to these farther reefs also depended on access to functioning boats and motors. As overfishing has resulted in ecological degradation in the reefs closest to shore and the community has acquired more compressors and larger, more capable boats and motors, fishermen have expanded their fishing ranges farther and farther offshore. Across all gear types, the sites that fishermen indicated they fish currently are on average 8.0 km from the landing site, while those that fishermen indicated as past sites are an average of 6.7 km from the landing site ($p < 0.001$). The spatial expansion that has come with the shift from freediving to compressor diving is visualized in Fig. 1. In addition to the site expansion occurring within the Buen Hombre fishery, many fishermen have also begun to fish outside of the country, as discussed above.

DISCUSSION

Variable implications and interactions

Understanding if and how the fishery ecosystem has changed provides the context for analyzing social and institutional changes through time. We found ample anecdotal and qualitative information regarding changes in the ecosystem, but limitations in the historical data did not allow for quantitative comparisons. Although we cannot prove nor quantify any ecosystem changes that have occurred in the past 30 years, we infer declines in ecosystem health based on qualitative historical reports and also use fish biomass comparisons to show that the Buen Hombre fishery is in poor condition relative to protected reefs in the Caribbean and elsewhere.

Our subsequent objectives were to assess changes in group attributes, institutions, and technology that may affect fishing behavior and thus the ecological condition of the marine resource. While factors other than fishing affect reef health (e.g., climate change, environmental variability, land-based anthropogenic disturbances), we focus on fishing as it is a major stressor in this and other systems and it is within the reach of resource users to act upon. Social variables can decrease catch sustainability by either directly facilitating increased catch levels, or by otherwise decreasing the incentives of fishermen to cooperate to jointly decrease their catch levels. Here, we discuss the assessed variables as they relate to fishing incentives and

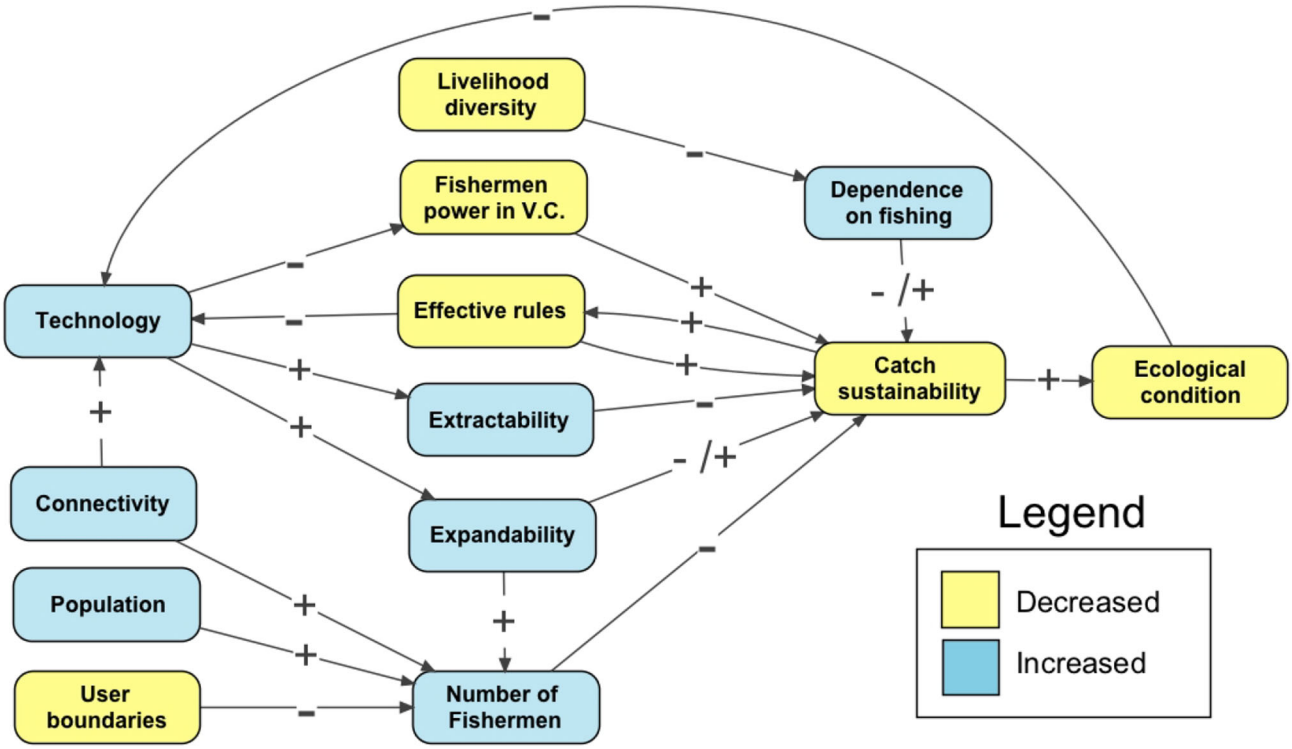

Fig. 4 Systems dynamics representation of interactions between social variables assessed in this study (Table 1) and their implications for the ecological condition of the fishery. *Variable color* reflects the direction of change between the first and second data collection period (Table 2). *Arrow symbols* indicate whether an increase in the level of the affecting variable increases (*plus*), decreases (*minus*), or has a mixed effect on (*plus or minus*) the level of the affected variable. The assessed variables affect catch sustainability, which in turn affects the ecological condition of the resource

practices and complete our assessment with a discussion of interconnectedness among variables and the feedbacks that can occur (Fig. 4).

While the community population has remained relatively constant, a significant decrease in livelihood diversity has lead to an increase in the number of fishermen and an increased dependence of each fisherman on the marine resource. The Fishermen's Association has been largely replaced by a *pescadería* system that disempowers fishermen within the value chain and fuels fisherman debt. The shift away from the Fishermen's Association model is reflected in lower levels of trust and cooperation among fishermen, and the effectiveness of fishing rules and boundaries has also decreased significantly. The current market system corresponds with higher connectivity between Buen Hombre and outside communities and higher proportions of catch being exported out of the community than reported in the historical snapshot. Access to increased fishing technology—namely dive compressors and boat engines—has significantly increased both the extractability and expandability of the resource.

As introduced above, fishing technology has important implications for resource extractability and expandability and thus for catch sustainability and ecological condition. In turn, ecological condition has important implications for fishing technology. As ecological condition and resource availability declines, the incentive to use fishing technologies increases. This is especially the case when financial investments have been made in fishing technologies and intensified extraction is required to pay off these investments. This creates a reinforcing feedback loop, or a social–ecological trap (Steneck 2009; Cinner 2011) in which increased technology leads to ecological degradation and vice versa.

Of note are the contradictions that arise when examining the effects of resource expandability on catch sustainability. Increased access to better boats and motors, as well as the rise of compressor use, has enabled fishermen to fish and intensely exploit areas that were previously not fished or only lightly fished. In the Buen Hombre fishery, one could argue that this has positive environmental implications, as fishing pressure is now distributed throughout a greater area rather than concentrated on the shallow areas accessible by freediving. However, a concern here is that this initial relief in fishing pressure in inner reef areas might lower the incentives fishermen have to cooperate

with each other, and ultimately encourage additional fishermen to enter the system and fish these now less-exploited areas.

Additional complexities arise when examining the paradoxical implications of fishing dependence on the marine resource. Increasing resource dependence would presumably increase the value of the resource to the user, and therefore, the user's incentives to make individual sacrifices that benefit the resource. The key dynamic here is that resource users can be expected to have strong incentives to care for their own welfare (at the individual or group level or both), and we can thus expect them to care for a resource insofar as there is a strong connection between the state of the resource and this welfare. At the same time, users who are extremely dependent on one resource are often unable to act to conserve it, as their wellbeing is so tightly tied to the use of that resource and they have few other livelihood options. As this resource becomes degraded, users become embedded in a poverty trap where they have no option but to continue exploiting this resource (Cinner 2011). To conserve a resource users need both the incentive and the ability to conserve, implying an overall trend in which conservation behaviors peak at a moderate level of resource dependence. More than a finding, this understanding of resource dependence is a hypothesis we draw from our work that will need to be tested with additional data in the future.

Longitudinal data challenges

It is important to also acknowledge the possibility that fishing practices in Buen Hombre may never have actually been sustainable. Luczkovich warns of this possibility when he states that quantitative stock assessments would have been needed to definitively determine the status and trends of the fishery (1991). Many of Stoffle et al.'s (1995) assessments of the Buen Hombre community during the first data collection period were qualitative and to some extent subjective, making it difficult to assess whether the community's values and behaviors were actually as aligned with the sustainable management of the fishery as was assumed. In 1992, fishermen were already reporting that yields had declined over the past 20 years, suggesting a downward trajectory. Furthermore, lags in the ecosystem's dynamics could delay any feedback from the fishing pressure being applied to it and could explain why it might have appeared "relatively pristine" (e.g., Jackson et al. 2001; Hughes et al. 2013). In fact, much of the coral reef still appears to be in fairly good condition, despite the fact that fish abundance and biomass are very low. Ecological dynamics occurring on differing timescales from those in which management decisions are made may have been and still be obscuring the severity of an unsustainable fishing system (Gunderson and Holling 2002).

Future outlook for the Buen Hombre fishery

There are both causes for concern and reasons for optimism regarding the future of the Buen Hombre fishery. If current trends continue, the fishery would be expected to experience further declines and the reef ecosystem could eventually crash. Shifting the fishery away from this trajectory is not an easy task. Fishermen are so highly dependent on the fishery and have such little economic leverage within the current market structure that they often have very little power to shift their behaviors to more sustainable practices. Possible decreases in alternative livelihoods would lead to further increases in fisherman dependence. For example, agricultural conditions could further decline, as could the feasibility of fishing abroad as neighboring countries begin to crack down on border patrol and enforcement. Tourism developments occurring as a result of the repaved road have the potential to increase livelihood options in the community and shift pressure away from the fishery. However, this also comes with some strong concerns about the detrimental effects of tourism on both communities and natural resources that have been documented elsewhere (Scheyvens 1999; Wyles et al. 2014). The Dominican government has not yet been able to maintain rules that effectively manage the number of fishermen in Buen Hombre, the gear types employed, and the types and quantities of marine organisms harvested. With high fishing dependencies and a lack of effective rules, fishermen will probably continue to harvest whatever they can get with the correct perception that if they do not take something, someone else will.

Despite these challenges, not all is lost in Buen Hombre and there are several reasons for hope. First, the coral reef ecosystem has not shifted to a completely degraded state, despite historical fishing and an intensification of these pressures in recent decades that is reflected in the current fish populations. Recruitment of coral and fish, the persistence of some large coral colonies, and local recovery of long-spined sea urchins (*Diadema antillarum*) after the Caribbean-wide mortality event in 1983–1984 (Lessios 1988) are all signals of resilience that will be indispensible for reef recovery. Second, AgroFrontera has taken steps to improve the ecological and social status of Buen Hombre by addressing the same systemic issues that are preventing the community from implementing a successful management regime. They are making interventions in the fish commodity chain to establish incentives for sustainable fishing, improving organizational capacity of fishermen, changing the dynamic between fishermen and fish buyers, working to shift the gear types used by fishermen, and engaging the government to encourage their participation. Hopefully AgroFrontera's work will help the community find their way toward a sustainable fishing system in a less

isolated, more technologically advanced future. Future research can help examine the extent to which this is the case.

CONCLUSION

Limited historical ecological data prevent us from making quantitative comparisons between the past and current state of the Buen Hombre fishery. However, our current ecological assessments indicate overfishing and fishermen's perceptions imply declines in ecosystem health since the historical snapshot. This longitudinal case study identifies critical changes in group attributes, institutions, and technology that have important implications for the health and sustainability of the Buen Hombre fishery. Historical studies emphasize local conservation ethic as primary driver of sustainable resource use. Here we show how other factors are driving current fishing practices, regardless of the fact that fishermen are still aware of the detrimental effects of fishing on the resource. We identify a greater dependence on fishing as a livelihood, shifts in the fishing value chain and fisherman organization, and increased access to fishing technologies as particularly significant drivers of increased fishing pressure in the Buen Hombre fishery. Efforts to better manage the Buen Hombre fishery must address these critical social drivers.

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