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Indicator-based management recommendations for an artisanal bottom-longline fishery in Costa Rica, Central America

Andrew B. Bystrom[*1,2,3], Helven Naranjo-Madrigal[4,5] & Ingo S. Wehrtmann[2,6]

1. Sistema Estudios de Posgrado (SEP), Universidad Estatal a Distancia, 474-2050 Mercedes de Montes de Oca, San José, Costa Rica; abystrom1@yahoo.com
2. Unidad de Investigación Pesquera y Acuicultura (UNIP), Centro de Investigación en Ciencias del Mar y Limnología (CIMAR), Universidad de Costa Rica, 11501-2060 San Pedro, San José, Costa Rica; ingowehrtmann@gmx.de, ingo.wehrtmann@ucr.ac.cr
3. Asociación Red Costarricense para el Ambiente y la Educación-ARCAE, 1376-1011 La Y-griega, San José, Costa Rica; a.bystrom@arcae.org
4. Programa de Maestría en Ciencias Marinas y Costeras. Universidad Nacional, Apdo. 86-3000, Heredia, Costa Rica; helvenn@gmail.com
5. Consultant Services Department, ALNA S.A, P.O. Box 11401, San José, Costa Rica; helvenn@gmail.com
6. Escuela de Biología, Universidad de Costa Rica, 11501-2060 San Pedro, San José, Costa Rica; ingowehrtmann@gmx.de, ingo.wehrtmann@ucr.ac.cr

* Correspondence

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Abstract: There is a growing need to strengthen the small-scale fishing sector with emerging governance methods that improve fishers' threatened livelihoods. Therefore, this study's aim was to develop management recommendations, based on easily interpreted conclusions that can be used to address the socio-ecological difficulties that the artisanal, bottom-longline fishery in Bejuco, Pacific coast of Costa Rica faces. The results of previously recorded fisher socio-ecological perceptions and an evaluation of the spotted rose snapper's, *Lutjanus guttatus*, population dynamics were assigned a measurable set of indicators in reference to the fishery's natural, human and management sub-systems. This was done via the traffic light method with easily interpreted colors based on a review of similar published fisheries studies. According to these results, a stock assessment for the fishery's target species and research to determine the composition and magnitude of the fishery's discarded species were recommended. Fisher economic dependence on bottom-longline activities led to the recommendation to develop alternative livelihood strategies. Also, the promotion of alternative markets and sustainability certification strategies for the snapper fishery are advised. Enlargement of the multi-use marine protected areas within the fishery's grounds and improvement of their management strategies is also recommended. In order for this to occur, improved resource user coordination in the form of a fisher association that has the capability to lobby for increased enforcement of the protected areas from destructive fisheries must be realized. Doing so would aid the development of a local management plan and participatory governance system. Such an initiative would justify the development of community lead marine protected area management regimes. Rev. Biol. Trop. 65 (2): 475-492. Epub 2017 June 01.

Key words: small-scale fisheries, indicator-based management, socio-ecological systems, participatory governance, traffic light method.

Small-scale fisheries (SSFs) play an important role in global food security and in the development of the global fishing effort (Swartz, Sala, Tracey, Watson, & Pauly 2010; Anticamara, Watson, Gelchu, & Pauly, 2011; Gagern & van den Bergh, 2013). Notwithstanding, increased production demands on this sector, exerted by growing coastal populations, have occurred (Mora et al., 2009; Worm et al., 2009; Andalecio, 2010; Gagern & van den Bergh, 2013). With the possibility of climate change factors also contributing to the reduced productivity of tropical coastal ecosystems (Doney et al., 2012), the application of innovative development approaches to SSFs is becoming increasingly important. Some of these include the livelihoods approach (Allison & Ellis, 2001), co-management or community-based management systems (Castilla & Fernandez, 1998; Castilla & Defeo, 2001; Defeo & Castilla, 2005), and adaptive management strategies focused on maintaining the productive capacity and resilience of SSFs (Berkes, 2003). The process of designing and implementing such a management strategy must, however, support both social and ecological processes inherent in coastal fisheries (McClanahan, Castilla, White, & Defeo, 2008).

Artisanal fishers strive to improve their general wellbeing, one associated with food security, healthy environments, quality of social relations, and cultural values, by making their livelihoods from exploiting coastal marine resources (Brook & McLachlan, 2008). This means that factors that allow fishers to meet their basic needs and valued freedoms, as well as ones that provide them with a good quality of life, are all intrinsic components of the social structure of SSFs (McGregor, McKay, & Velazco, 2007; Coulthard, Johnson, & McGregor, 2011). Because of this, fishers view their industry as more than just a job, but as a way of life (Pollnac & Poggie, 2008). It also means that fishers' wellbeing is often unrelated to their economic state (González, 2011). This being the case, there is an inherently high level of job satisfaction associated with members of this sector (Pollnac & Poggie, 2008), making wellbeing an intrinsic component to SSF governance.

Governance is the role of public and private interactions taken to solve, in this case, fisheries issues and problems (FAO, 2004; Kooiman, Bavinck, Jentoft, & Pullin, 2005). Whether formal or informal, by governments or other stakeholders, in the form of international agreements and commitments, or policies at national or local levels, governance is needed to guide actions and decisions that impact SSF management and development (FAO, 2004). Ineffective governance has plagued the fishing industry and been the catalyst for such sector dismantling activities as subsidy-fueled overcapacity and over-fishing, as well as illegal, unreported and unregulated (IUU) fishing (FAO, 2004). Overarching United Nations implementing agreements established to guide fish stock conservation strategies and the development of responsible fisheries have failed to curb over-fishing because of ineffective regional, national, and local management strategies, many of which stem from antiquated top down, command-and-control approaches (Berkes, Mahon, McConney, Pollnac, & Pomeroy, 2001). For this reason, evolving solutions are needed to strengthen governance systems, preferably, ones that focus on local perspectives and priorities (Bavinck et al., 2005; Fabinyi, Foale, & Macintyre, 2013).

Today it is widely accepted that effective fishery governance should consider aspects of human behavior (Jacobsen, 2013) including fishers' ability to self-organize within the social and ecological domain of the fishery system (Mahon, McConney, & Roy, 2008). This socio-ecological system includes not only the communities where small-scale fishers inhabit, but also the coastal marine environment within which they perform commercial activities (Van Putten et al., 2016). Therefore, the governance of these fisheries is inherently about managing resource use initiatives and the cumulative impacts that these initiatives may cause within a system where human and ecological interactions are linked (Berkes & Folke, 2002; Van Putten et al., 2016). Management of SSFs requires knowledge of the desired future state of their socio-ecological systems, as well as depends on concise goals and objectives, often times established at the community level, that specify what managers want to achieve (Bennett, Lawrence, Johnstone, & Shaw, 2005). Therefore, attracting locally initiated participation through participatory governance or co-management can be an effective strategy towards achieving sustainable environmental, social, and economic objectives (Charles, 2011; Van Putten et al., 2016).

This type of SSF community organization strategy should be enhanced through appropriate policy inputs that recognize community-based co-management systems that are people-centered, community-oriented, resource-based, and partnership-based, and the role they play in fostering the development of resilient social-ecological systems (Pomeroy, 1998; Folke, Hahn, Olsson, & Norberg, 2005; Gibbs, 2009; Biggs et al., 2012).

Indicator based-approaches to management are used to define the state of ecosystems and fisheries systems. Their aim is to monitor, assess and understand the effects of human activities on natural systems, as well as the effectiveness of management measures and other decision-making processes (Charles, 2001; Rice & Rochet, 2005). In indicator based-approaches, timely and useful information is used by decision makers to move the fishery towards sustainability (Rudd, 2003). Thus, the knowledge base for management includes indicators and qualitative predictions (Degnbol & Jarre, 2004; Degnbol, 2005). A management system such as this is based on "soft predictability", an approach that does not require a detailed understanding of the processes and the capabilities of quantitative predictions inherent to modern fishery management models basis (Degnbol & Jarre, 2004).

The traffic light method, as part of an indicator-based management approach to fisheries management, as first proposed by Caddy (1998), uses a universally recognized color-coding design (green, yellow, red) to assess a range of fishery indicators (Halliday, Fanning, & Mohn, 2001; Caddy, 2002; Trenkel, Rochet, & Mesnil, 2007). These indicators have the advantage of being based on readily available data that can be calculated with minimal technical input and provide results understood and accepted by non-technical personnel or stakeholders. They can include price and earning fluctuations, species population dynamics such as mortality rates, catch rates, or levels of by-catch, as well as fishery performance information derived from fisher ecological knowledge and traditional experiences (Caddy, 2015). Results of the color-coding assessment trigger management responses based on the number of key indicators, which have turned from green to either yellow or red and vice-versa (Caddy, 1998). Adopting such an approach to fishery management can potentially give fishers and stakeholders more control over their business and the way it is governed within the framework of a precautionary approach (FAO, 1996; Halliday et al., 2001). The traffic light method has been used as part of the management process for Northwest Atlantic shrimps and groundfish stocks (Halliday et al., 2001), the Torres Strait tropical rock lobster fishery between Australia and Papua New Guinea (Plagányi et al., 2013), and a battery of data-poor fisheries in Southern Europe (Tzanatos et al., 2013), to name a few.

Because fishery managers in developing countries have limited access to sufficient time series of data for stock assessments (Costello et al., 2012; Carruthers et al., 2014), alternative approaches that identify potential changes in the fishery and ecosystem are often more appropriate than sophisticated mathematical analysis (Caddy, 2002). These approaches, however, must also take into account not just resource and data availability, but also that complex societal structures make the governance of the ecosystems - within which these resources exist - inherently difficult (Bodin & Crona, 2009). These socio-ecological intricacies are present along Costa Rica's Pacific coast where the vast majority of the country's SSFs operate. The natural state of the coastal ecosystems in which these SSFs operate, however, is increasingly compromised by coastal development, pollution, destructive fishing gear types, and illegal fishing (Rojas, 1996a; Rojas, 1996b; Alvarado, Cortés, Esquivel, & Salas, 2012). These factors have given rise to increasing amounts of SSF community members facing economic difficulties, food security issues, and threatened livelihoods attributed to decreasing catch amounts (Rojas, 1996a; Rojas, Maravilla, & Chicas, 2004; Allison & Ellis, 2001). In this context, the need to strengthen the SSF sector with emerging governance strategies is more and more recognized (Pauly, 1997; Allison & Ellis, 2001).

For this reason, the objective of the present study was to evaluate the performance of the Bejuco artisanal fishing community located at the Pacific coast Costa Rica, Central America, with respect to management interventions (e.g size limits), stock status (e.g mortality rates), and socio-economic tendencies (e.g fishers´ perceptions). In order to accomplish this, we used the unique approach of combining questionnaire information and key primary catch data analysis spanning a seven year time period (2007-2013), with the traffic light method to assess this small-scale fishery. Finally, and after a critical revision of the results of other similar published studies, we provide a series of management recommendations.

MATERIALS AND METHODS

Study area: The present study was conducted with the bottom-longline fisher population from the district of Bejuco in the Pueblo Nuevo and the San Francisco de Coyote communities located at the Southwestern Pacific coast of Costa Rica's Nicoya Peninsula. Bejuco fishers target spotted rose snapper (*Lutjanus guttatus* (Steindachner, 1869)) and other bycatch species with economic value during nightly fishing activities. Their fishing grounds are located both within and between the Camaronal National Wildlife Refuge multi-use marine protected area (MPA) and the Caletas-Arío National Wildlife Refuge multi-use MPA (Fig. 1). These protected areas allow local community members to fish with bottom-longlines, but do not permit the use of what are considered more destructive gear types, that include gillnets and bottom trawl nets.

Target species: The use of bottom-longlines by artisanal fishers in Costa Rica occurs within a diversity of near-shore habitats. These areas include mangroves, coral and rocky reefs, areas of sub-aquatic vegetation, bays, estuaries, and islands where up to 80 commercially important fish species inhabit (Quesada-Alpízar, 2006; Cortés, 2007; Wehrtmann & Cortés, 2009). Of these commercially important fish species, *L. guttatus* is widespread, making it one of the most-fished species and therefore of high economic importance to Costa Rica's small-scale fishing communities (González et al.,

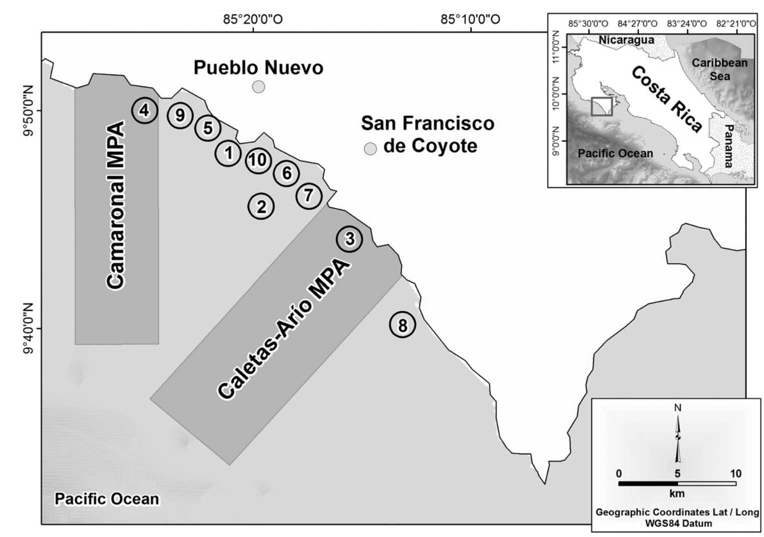

Fig. 1. Site map for data collection efforts in the Bejuco bottom-longline fishing communities of Pueblo Nuevo and San Francisco de Coyote as well at 10 fishing sites within and between the Camaronal National Wildlife Refuge multi-use marine protected area (MPA) and the Caletas-Arío National Wildlife Refuge multi-use MPA, Pacific coast, Costa Rica.

1993; Rojas, 1996a; Vargas, 1998-99; Rojas et al., 2004). The species can also be found in shallow to medium-depth subtropical coastal waters stretching from the Gulf of California, Mexico, to Peru, whereby giving it regional commercial importance as well (González et al., 1993; Fischer et al., 1995; Vargas, 1998-99; Rojo-Vásquez, Arreguín-Sánchez, Godínez-Domínguez, & Ramírez-Rodríguez, 1999; Andrade-Rodríguez, 2003; Chiappa-Carrara, Rojas, & Mascar, 2004; Rojas et al., 2004).

Traffic light technique: The present study is based on the results of Bystrom's (2015) multidisciplinary research of the Bejuco bottom-longline snapper fishery (Table 1). Components from the author's seven year (2007-2013) *L. guttatus* population dynamics (average snapper lengths, mortality and exploitations ratios) and bottom-longline catch composition and selectivity study (catch per unit of effort, size selectivity, bycatch, discards), along with his fisher socio-ecological

TABLE 1
Results of *Lutjanus guttatus* population dynamics, bottom-longline catch composition and selectivity, and socio-ecological perception studies with artisanal bottom-longline fishers in Bejuco, Pacific coast, Costa Rica (Bystrom, 2015)

Research method	Study	Component	Results
Seven year catch data analysis	*Lutjanus guttatus* population dynamics	Average snapper length (2007 - 2013)	Statistically significant increase
		Mortality rates and exploitation ratio	Natural mortality (M) = 0.43 Fishing mortality (F) = 0.34, Total mortality (Z) = 0.77 Exploitation ratio (E) = 0.44
	Bottom-longline catch composition and selectivity	Snapper catch per unit of effort (CPUE) 2007 - 2013	No significant change
		Snapper size selectivity	85 % are at or above the species' size at first maturity
		Target species selectivity	52 % of all organisms captured
		Bycatch	48 % of all organisms captured
		Discards	Estimated 10 - 20 %
Fisher questionnaire applied to entire Bejuco bottom-longline population (N=49)	Fisher socio-ecological perceptions	Economic dependence on fishery	72 % of population have not developed alternative employment options
		Present and future economic situation	96 % of population of fishers believes they have a declining economic situation and uncertain economic future.
		Job satisfaction	92 % of fishers believe they have a high quality of life in their communities
		Quantity of snappers in the past/future	94 % of fishers believe there were more snappers in the past and there will be fewer in the future
		Fishing distances have increased	47 % of fishers believe that the distances they travel to fish have increased
		Longline damage to sea bed	4 % of population believe bottom-longlines harm the environment
		Disappearance of species	53 % of the population believe that certain types of species commonly caught in the past are rarely seen today
	Governance, research, planning	Level of fisher organization	Population dispersed between three associations that include 55 % of fishers. Remaining fishers work independently
		Presence of illegal fishing (national industrial fleet)	94 % of fishers feel there is insufficient government control over illegal fishing
		Management plan	No local management strategy exists
		Catch monitoring and data collection	Entire population collaborates with researchers to collect catch data
		Participatory governance	No recognized system exists in Costa Rica
		MPA development	Two MPAs exists in the area. 100 % of focus group participants agree that illegal fishing occurs in these areas

perception (present and future economic perceptions, job satisfaction, historical catch rates, gear use impacts) and governance studies (fisher organization, management strategies, illegal fishing, and protected area development) were organized into the three major sub-systems that exist in fisheries as defined by Charles (2001): natural, human, and management. Component results were compared with the results from similar studies through a review of the published literature. Caddy's (1998) modified stoplight or traffic light approach was then used to assign easily interpreted colors that denoted component tendencies.

A green light was assigned to positive or increasing tendencies and/or a result that was more favorable than those from similar fisheries. A yellow light was assigned if no changes were noted or if there was not enough information available to confidently determine a trend, and/or comparison with other fisheries. A red light was assigned to components with negative or decreasing tendencies, and/or a result that was less favorable than those from similar fisheries. A series of management recommendations was then based on the results of this comparative analysis.

RESULTS

Green lights (positive or increasing tendencies) were assigned to both *Lutjanus guttatus* population dynamic components (Table 2) because total spotted rose snapper lengths increased significantly from 2007-2013, and the population's exploitation ratio was at an acceptable level (0.44) during this time period and lower than reported in other parts of Costa Rica (0.50). Two components analyzed in the bottom-longline catch composition and selectivity study (snapper size selectivity, target species selectivity) were also interpreted as favorable due to the percentage of mature adult snappers that were captured and the percentage of the total catch that was snapper (target species). The fisher job satisfaction and the longlines damage seabed components in the socio-ecological perceptions study also received a green light because of fishers' contentedness in their communities and desire to continue fishing with the same gear type, and their belief that their fishing gear does not negatively impact the sea floor ecosystem. The final component that received a green light (in the governance, research, and planning study) was the high level of fisher participation in catch monitoring and data collection initiatives developed by various Costa Rican universities and environmental groups.

Red lights (indicating negative or decreasing tendencies) were assigned to components regarding fishers' economic dependence on their industry, their present and perceived future economic situation, and the quantity of snappers captured in the past as compared with fisher views of the future (Table 2). All of these components were part of the socio-ecological perceptions study. A red light was also assigned to the discards component because they are above the global average for bottom-longline fisheries. Regarding the Bejuco fishery's governance study, fisher associations demonstrated a low level of organization, there was a high instance of illegal fishing from other fisheries in the area's two MPAs, and the fishery was without a management plan that clearly guided its actions. The status of these components is worsened by the lack of a nationally recognized participatory governance structure that promotes co-management governance initiatives. For these reasons the components received red lights.

All other components received yellow lights because they were found to have stayed the same or in some instances it was not possible to clearly identify their tendencies because of a lack of catch data and/or questionnaire information (Table 2). These yellow indicators were: snapper CPUE and bottom-longline bycatch (both in the bottom-longline catch category), fishing distances have increased, and the disappearance of species historically caught with bottom-longlines (both in the socio-ecological perceptions study), and illegal fishing and MPA development (both in the governance, research, planning study).

TABLE 2
Results of the traffic light approach that assigned color indicators to Bejuco bottom-longline snapper fishery components based on their trends, Pacific coast, Costa Rica

Sub-system	Study	Component, result, and color performance indicator	Reference for compared study	Fishery, target species, location, or research topic
Natural	*Lutjanus guttatus* population dynamics (catch data analysis)	Snapper average total lengths 2007-2013: increasing	Stobart et al., 2009	Trammel net, *Palinurus elephas* , Mediterranean coast, Spain
			Ault et al., 2005	Snapper-grouper complex, Florida Keys
			Shin et al., 2005	Size-based indicators to evaluate fishing impacts
		Mortality and exploitation levels: Total mortality (Z) = 0.77 Exploitation ratio (E) = 0.44	Cushing, 1968	Mortality and suitable exploitation ratios (E)
			Gulland, 1971	Mortality and suitable exploitation ratios (E)
			Amezcua et al., 2006	Shrimp trawl, *L. guttatus* Gulf of California, Mexico, age, growth, and mortality
			Vargas, 1998-99	Gillnet and bottom-longline, *L. guttatus,* Gulf of Nicoya, Costa Rica
	Bottom-longline catch composition and selectivity (catch data analysis)	Snapper catch per unit of effort (CPUE) 2007-2013 unchanged	Walters, 2003	Analysis of spatial catch per effort data
			Maunder et al., 2006	Interpreting CPUE for stock assessment
		Bottom-longline snapper size selectivity: 85 % above minimum size limit	Mongeon et al., 2013	Bottom-longline, *L. guttatus* Bejuco, Costa Rica
			Correa-Herrera & Jiménez-Segura, 2013	Artisanal hand-line, *L. guttatus*, Utría National Park, Colombia
		Target species (*L. guttatus*) selectivity: 52 % of catch are snappers	Erzini et al., 1999	Experimental longlines, *Merluccius merluccius, Conger conger, Polyprion americanus*, Algarve, Portugal
			Revolusi et al., 1999	Bottom-longline, *Lutjanus* spp., Indonesia
			Beltrano et al., 2004	Bottom-longline and gillnet, Scorpaenidae, Sepiidae, Octopodidae, Sparidae, Serranidae, Mullidae, Labridae, Egadi Islands, Italy
			Mamauag et al., 2009	Artisanal longline, *Epinephelus coioides*, Philippines
		Bycatch: 48 % of total catch	Lutchman, 2014	Use of bycatch % to develop a scoring system
		Discards: 10 - 20 % of total catch	Alverson, Freeberg, Murawski, & Pope, 1994	Global bycatch and discard ratios (FAO)
			Kelleher, 2005	Central American artisanal fishery discard rates

TABLE 2 (Continued)

Sub-system	Study	Component, result, and color performance indicator	Reference for compared study	Fishery, target species, location, or research topic
Human	Socio-ecological perceptions (fisher questionnaire)	Economic dependence on fishery: no alternative employment options: 72 %	Daw et al., 2012	Western Indian Ocean, artisanal fisher adaptive responses and alternative livelihoods
			Emmerson, 1980	Philippines, Indonesia, Sri Lanka, horizontal fishery integration: opportunities for nonfishing employment
		Present and future economic situation: declining: 96 %	FAO, 2014	Costa Rica, socio-economic pressures facing artisanal fisheries
		Job satisfaction: 92 %	Pollnac et al., 2002	Southeast Asia, fisher job satisfaction
			González, 2011	Atlantic coast, Nicaragua, artisanal fishign community wellbeing
		Quantity of snappers in the future will be fewer: 94 %	Blyth, 2013	Mozambique, Africa, social and ecological changes in coastal systems
			Ward Kirkley, Metzner, & Pascoe, 2004	Overcapacity in artisanal fisheries. FAO
			Golden, Naisilsisili, Ligairi, & Drew, 2014	Lutjanidae and others, Fiji, FEK to evaluate heavily targeted species in artisanal fisheries
		Fishing distances have increased: 47 %	Van Holt, 2012	Dive fishery, Chile loco, *Concholepas concholepas*, Chile, Traditional ecological knowledge
		Longlines damage seabed: 4 %	Sharp, Parker, & Smith, 2009	Bottom-longline, *Dissostichus mawsoni*, New Zealand benthic impact assessment,
		Disappearance of species: 53 %	FAO, 1984	A review of papers on the regulation of fishing effort
Management	Governance, research, planning (fisher questionnaire)	Fishers well organized: 45 % independent	Frangoudes, Marugán-Pintos, & Pascual-Fernández, 2008	Improving fisher community organization and social dimensions strategies
		Presence of illegal fishing: 94 %	Sumaila, Alder, & Keith, 2006	Analysis of costs, benefits, and risks of IUU fishing, global context
		Management plan: no	Jentoft, 1989	Co-management strategies for SSFs
		Catch monitoring and data collection: yes	Frangoudes et al., 2008	Shellfish, Galicia, Spain, avoiding overexploitation through data collection
		Participatory governance: no	Quesada-Alpízar, 2006	Costa Rica, encouragement for and limitations to participatory management in
			Mahon et al., 2008	Enabling self-organization, learning and adaptation for the management of complex human-in-nature systems
			Kearney, Berkes, Charles, Pinkerton, & Wiber, 2007	Canada, participatory governance for ecological sustainability and economic development
		Presence of MPAs: yes but ineffective	Halpern, 2003	Density, biomass, size of organisms, and diversity inside marine reserves Global context
			Alvarado et al., 2012	Costa Rica, coverage and threats to Costa Rican MPAs

DISCUSSION

The traffic light technique was used to evaluate the state of the Bejuco bottom-longline snapper fishery's natural, human, and management systems. The technique gave fishers a recognizable way to interpret the state of the *L. guttatus* population and bycatch species, which would have been otherwise difficult to visualize. Moreover, its results were also to develop a set of recommendations for the fishery, based on both literature and the results of recent research (Bystrom, 2015). This type of indicator-based evaluation can be replicated to other artisanal fisheries in need of management improvements.

Snapper sizes increased from 2007-2013, which can be interpreted as an indicator that the fishery and gear type does not negatively impact the target species' stock (Ault, Smith, & Bohnsack, 2005; Shin, Rochet, Jennings, Field, & Gislason, 2005; Stobart et al., 2009). To further emphasize this point, bottom-longline snapper CPUE from 2007-2013 showed no changes (Bystrom, 2015). Based on the results of these components, the only management precaution recommended at this time regarding Bejuco bottom-longline effort is that the fishery should not increase from its current levels. This recommendation should, however, be taken with a note of caution because 94 % of fishers firmly agree that there are fewer snappers today than there were over a decade ago, and 47 % believe that the distances they travel to find snappers have increased (Bystrom, 2015). Because the Costa Rican snapper fishery's fleet dynamics include the artisanal longline and gillnet sectors, as well as the shrimp trawl fishery, it is possible that its technological interdependence is such that these different fisheries target and therefore impact different components of the snapper population's structure (Anderson & Seijo, 2010). Andrade-Rodriguez (2003) demonstrated how the Guatemalan trawl fleet captured snappers significantly smaller than the artisanal bottom-longline fishers catch, a fact that is supported through anecdotal information from the Bejuco fishers (A. Bystrom, pers. comm). Bejuco fishers also insist that gill nets capture larger snappers than bottom-longlines do (A. Bystrom, pers. comm.). For these reasons basing management recommendations on size frequencies and CPUEs alone could be problematic (Walters, 2003; Maunder et al., 2006). With this in mind, a stock assessment is recommended for the fishery's target species, *L. guttatus,* to identify reference points (Cadima, 2003) as tools for the management of this fishery. Emerging data-poor methods used to analyze fish stocks have included catch data, similar to that collected by researchers in Bejuco, to determine sustainable yields for data-poor fishery resources (Cope & Punt, 2009; MacCall, 2009; Dick & MacCall, 2011). The performance of these target reference points could then be gauged by a management strategy evaluation (Carruthers et al., 2014). While these techniques should be used to further analyze the Bejuco bottom-longline fishery's data, they should be implemented in conjunction with strategies that continue monitoring snapper catch and environmental data for future analysis.

Snapper mortality is at an acceptable level according to the criteria proposed by Cushing (1968) and Gulland (1971). By comparison, it is lower than Vargas' (1998-99) study for the species in the nearby Golfo de Nicoya and higher than the Gulf of California's stock (Amezcua, Soto-Avila, & Green-Ruiz, 2006). Because of the existence of other fisheries operating on the local snapper stock and their influence on snapper mortality, continued monitoring and enforcement measures to ensure that no illegal, unreported, and unregulated (IUU) fishing activities occur within the area's MPAs are advised. The fishery's multi-specific characteristics also attenuate this study's estimation of bottom-longline snapper mortality as an effective indicator of the stock's health because the cumulative impacts that other gear types (gill nets and trawl nets) exert on the stock were not considered. Giménez-Hurtado et al. (2005) estimated red grouper mortality in a multi-specific Mexican fishery and their methods (including the analysis of the total catch from all three fisheries targeting *Epinephelus morio*), need to be applied to Bejuco's snapper fishery in order to obtain a more accurate estimation. A closer approximation of mortality, as well as a more accurate estimation of the snapper stock's unit and status (King, 2007) could also be obtained, if the snapper fishery was homogenized to only allow one gear type. This would also make monitoring and management of this fishery more streamlined and effective.

Lutjanus guttatus represents 51.5 % of the total number of organisms caught with bottom-longlines in Bejuco, far higher than target species caught with the same gear type in other reviewed tropical and subtropical coastal fisheries (Erzini, Gonçalves, Bentes, Lino, & Ribeiro, 1999; Revolusi, Wibowo, & Sahari, 1999; Beltrano et al., 2004; Mamauag, Aliño, Gonzales, & Deocadez, 2009; Olavoa, Costa, Martins, & Ferreira, 2011). The results of Mongeon, Granek y Arauz (2013) confirmed that the hook sizes currently in use in Bejuco adequately select for mature snappers. Therefore, no changes in fishing gear and methods are necessary, as long as fishers carry out their activities in conformity with national fishing laws. Attention, however, should be paid to the fishery's bycatch amounts, which can be considered moderate according to Lutchman (2014). Since it is unclear how much of this bycatch is commercialized or consumed locally and how much is discarded, additional data are required to better determine this fishery's discard rate.

The Bejuco bottom-longline fishery is the only source of income for 71.4 % of its fishers and any negative changes to the snapper stock would endanger its ability to maintain these fishers' economic livelihoods (Bystrom, 2015). Lower-income artisanal fishers tend to be more willing to leave the fishing activity than those who earn higher wages (Daw et al., 2012). This does not seem to be the case in Bejuco where impoverished fishing community members insist they will continue to fish in the future despite their bleak economic outlook, a decision that is related to their high level of job satisfaction (Bystrom, 2015) and unrelated to their economic state. While fishers in general are apprehensive about a career change because of their limited skills and educations (Teh, Cheung, Cornish, Chu, & Sumaila, 2008), alternative employment in the marine recreation industry is a growing option for some fishers (FAO, 2014). Because of this, development of alternative livelihood options is highly recommended to improve fisher resilience to socio-ecological change, though it is questionable whether or not fishers will agree to undertake these activities (Pollnac, Pomeroy, & Harkes, 2002). Along with pursuing alternative economic options, fishers are encouraged to develop alternative markets for spotted snappers. International sustainability certifications have been shown to add value to seafood products caught with sustainable methods (MSC, 2014), and their development in Bejuco, could allow fishers at least to economically maintain their households while preserving their livelihoods.

Fishers feel there were more snappers in the past than there are now, and that there will be even fewer snappers in the future. Fisher socio-ecological perceptions as they were used to understand historic snapper and bycatch species population trends can and should also be considered in Bejuco for all management decisions (Pauly, 1995; Fischer, 2000; Gosse, Wroblewski, & Neis, 2001; Berkes & Folke, 2002; Murray, Neis, & Johnsen, 2006; Lutz & Neis, 2008; Nenadovic, Johnson, & Wilson, 2012). Because fishers have witnessed the declining population of their target species as well as catch declines of certain bycatch organisms (such as sharks, barracudas, groupers, and congers; see Bystrom, 2015), proactive management decisions that work to reverse this tendency must be immediately considered. These need to include increased enforcement of the fishing ground's protected areas, in order to curb IUU fishing, continued monitoring of catch rates and sizes, and a reduction in fisher economic dependence on this activity. Because MPAs have great potential to restore marine biodiversity at the species and community level (Jones, 2014), fishers are encouraged to lobby for cross-sectorial governance strategies that would give them more control over local resource exploitation, including the creation of a locally managed, comprehensive MPA, located in the fishing ground's unprotected areas, that would better protect the snapper stock from destructive fisheries operating in the area.

In Costa Rica there has been a general lack of *a priori* technical information used to establish the country's network of coastal MPAs (Alvarado et al., 2012). Furthermore, nearly all of these protected areas lack the inclusion of ecosystem management paradigms, including spatially coherent ecological units or ecoregions like those outlined by Spalding et al. (2007), Baker and Hollowed (2014), and Naranjo-Madrigal (2016) that highlight the importance of using the results of prior biophysical studies as a guide to developing marine spatial management tools.

In addition to Costa Rica's MPA's, the country is also implementing small-scale fishery strategies based on a system of responsible fishing areas. This marine management strategy is considered by the country's Commission for the Seas (CONAMAR) - a governmental body formed in 2013 to create a national political marine development and conservation agenda - to be uncoordinated and lacking civil society participation (CONAMAR, 2013). There is also an omnipresent lack of financial and human resources in Costa Rica that does not allow any marine managed areas to operate with enough personnel to implement a full management plan (Alvarado et al., 2012). Moreover, the country does not have a marine research vessel dedicated to the collection of fisheries data. Local fisher participatory governance and data collection strategies could relieve some of this pressure. While no systems of community-based governance exist in Costa Rica, many small-scale fishing communities, as well as national governmental organizations, are interested in promoting the creation of such systems (CONAMAR, 2013). These initiatives should continue with increasing force, as the development of local management systems has been demonstrated to be an effective institutional arrangement for small-scale Latin America fisheries, in which fishers, scientists and managers interact to improve the quality of the regulatory process (Castilla & Defeo, 2001).

In light of these governance challenges and opportunities, the Costa Rican Fisheries and Aquaculture Institute (INCOPESCA), Costa Rica's national fisheries governing entity, created a management tool called Responsible Marine Fishing Areas (RMFA) (La Gaceta, 2009). The RMFAs are based on the FAO's Code of Conduct for Responsible Fisheries (1995) and are intended to become a zoning instrument regulating SSF activities within a designated area (La Gaceta, 2009). The establishment of an RMFA in the unprotected area between the two existing MPAs inside the Bejuco fishing grounds could provide the framework for more effective fishery governance. The development of such an area, though, would need to be accompanied by a process of fisher capacity building to provide these local community members the tools and opportunities to manage their actions within the legal framework of an RMFA. Because fishers are currently dispersed among three associations (Bystrom, 2015), they are encouraged to form one association whose unified voice can more effectively advocate for capacity development assistance, national regulations, and management suggestions such as those established for RMFAs. Data collection and stock monitoring would also be facilitated, if this population of fishers would be more cohesively assembled. It is, however, not sufficient to dispose of the existing associations if a new all-inclusive entity is without the necessary capacity and authority to implement these management suggestions.

The current ineffectiveness of the three associations is compounded by the fact that the fishery has no management plan for the spotted rose snapper or commonly caught bycatch species. Because *L. guttatus* is a species with a low growth rate, its population requires prudent management (Amezcua et al., 2006). Therefore, the recommendations of the present study should be used to develop a concise local bottom-longline management strategy that includes the definition of management reference points for the snapper stock, using the fishery's seven year catch-at-age and fishing effort data series, ecosystem impact mitigation, and fishery socio-economic development as its principal objectives. Bejuco fishers already have an advantage in this regard because they have participated for the past seven years in catch data collection activities with researchers, putting at their disposal valuable information regarding this stock's status.

The persistence of illegal shrimp trawl activity within the Bejuco fishing grounds' MPAs and the high rate of capture of juvenile snappers in trawl nets in Central America make sustainable management of the local *L. guttatus* stock a challenge no matter how much catch data is collected from bottom-longliners (Bystrom, 2015). For this reason, INCOPESCA must also improve its capacity to develop, implement, and monitor resource management measures including gear restrictions within these multi-use MPAs where bottom-longline and hand-line use is permitted but gillnets, trawl nets, and surface longlines are not. On paper, coastal MPA coverage in Costa Rica is considered to provide adequate conditions for the dispersion and exchange among populations of marine organisms (Halpern, 2003); however, few criteria or technical studies have contributed to their establishment (Alvarado et al., 2012). Because the Bejuco MPAs are marine extensions of terrestrial wildlife refuges, they do not have their own management plans (Alvarado et al., 2012), and the development of science-based fishery management plans that take into consideration any locally adopted bottom-longline management strategies (such as the one already suggested) for both of the area's MPAs is recommended as a building block towards community-lead MPA management regimes.

Insufficient financial, human, and material resources have been allocated to these protected areas by the national government, to appropriately confront instances of illegal, unreported and unregulated (IUU) fishing (Alvarado et al., 2012). Without immediate attention to the Costa Rican government's lack of capacity to enforce its marine resource conservation laws and confront instances of IUU, the number of infractions will in all likelihood continue into the foreseeable future (Bystrom, 2017).

Because of the lack of effective enforcement by government, community-based management strategies (be they formal or informal) could shoulder the responsibility and burden of ensuring rule compliance and handling conflict (Agrawal, 2001; Dietz, Ostrom, & Stern, 2003). In many instances, successfully managed common pool resources depend on the ability of users to undertake enforcement themselves (Ostrom, 2000). To this end, some coastal SSF communities in Costa Rica have acquired their own boats and realize independent patrol activities to attenuate instances of illegal fishing inside RMFAs (A. Bystrom, pers. obs.). Fishers who carry out these patrols cannot, however, arrest illegal fishers in these areas, because the only government entity legally permitted to make such arrests is the national coast guard (Costa Rica, 2000). Likewise, access to a patrol boat does not ensure fisher enforcement of resource tenure (A. Bystrom, pers. obs.), as there are other factors that influence fishers enforcement behavior, including social networks, food security, recent catch success, fisherman's age, and personal gear investment (Stevens, Frank, & Kramer, 2015). But while SSFs are complex entities to manage, there is ample evidence that supports the socio-ecological and economic benefits fostered by co-management systems that divide the authority and responsibility for management, between resource users and government agencies (Evans, Cherrett, & Pemsl, 2011).

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RESUMEN

Recomendaciones de manejo basadas en indicadores para la pesca artesanal con líneas de fondo en Costa Rica, Centroamérica. Existe una creciente necesidad de fortalecer el sector de la pesca de pequeña escala con métodos de gobernanza emergentes que mejoren las estrategias de subsistencia de los pescadores. Por lo tanto, el presente estudio se centró en el desarrollo de recomendaciones de manejo, basadas en conclusiones fácilmente interpretables, que ayuden a atender las dificultades socio-ecológicas que enfrentan los pescadores artesanales que utilizan líneas de fondo en Bejuco, Pacífico de Costa Rica. Se asignó un conjunto medible de indicadores para cada sub-sistema (natural, humano y manejo) de la pesquería a partir de los resultados de un análisis previo de las percepciones socio-ecológicas de los pescadores y una evaluación de aspectos biológico-pesqueros para el pargo manchado *Lutjanus guttatus*. Se usó la técnica de semáforo con la cual se asignaron colores para la evaluación de indicadores construidos con base en la revisión de literatura publicada. Se propusieron recomendaciones de manejo basadas en los resultados. Se sugiere un análisis del estado del stock de la principal especie objetivo de pesca y un estudio que determine la magnitud y composición de las especies descartadas. Debido a la alta dependencia económica de los pescadores, se recomienda la implementación de programas que permitan el desarrollo de opciones alternativas del empleo. Además, se recomienda promover mercados alternativos y sistemas de certificación sostenible para la captura de pargo manchado. También se recomienda la ampliación de las áreas marinas protegidas de uso múltiple de la zona. Para esto es necesario mejorar la coordinación y participación de los usuarios mediante la formación de una asociación que tenga la capacidad de vincular a la contraparte gubernamental en la solución de múltiples limitaciones y problemas (p. ej pesca ilegal) en la actividad pesquera de Bejuco. Esto facilitaría la construcción de un plan de manejo local bajo un sistema de gobernanza participativa.

Palabras clave: pesquerías artesanales de pequeña escala, manejo basado en indicadores, sistemas socio-ecológicos, gobernanza participativa, técnica de semáforo.

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