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"A Socioecological Resilience Approach for Evaluating Management Effectiveness of Marine Protected Areas"

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This report presents the activities developed during 10/01/2007 to11/30/2009, by the biophysical, socio-economic and governability components of the project: *Effectiveness Evaluation of Marine Protected Areas Management in the Colombian Coast: Connectivity and Resilience of Protected Coral Reefs*. The report is written as a paper since we are preparing for summiting it to publication in a high impact scientific journal.

Abstract

Coral reefs worldwide need urgent conservation action because of their high level of degradation and susceptibility. This conservation priority is more urgent in the face of current global change events, which obscure the possibility for understanding the socio-ecological systems (SESs) complex dynamics, and limits the management effectiveness of Marine Protected Areas (MPAs). To improve MPAs' effectiveness in a context of climate change and crescent anthropogenic pressures, it is necessary the use of a holistic approach that facilitates the understanding of the social and ecological relationships and helps to determine current state and potential risk faced by coral reefs SESs. In the present study we formulate an integrative model based on socioecological resilience approach to assess the management effectiveness of two MPAs located in the Southern Caribbean (Colombia). By using indexes to estimate Resilience and Human-Intervention, which are made up by indicators that reflect the social and ecological status of the system, we are able to detect specific conservation strategies and action plans to improve resilience, based on the particular conditions of the MPAs. We found that both MPAs are in a risk state characterized by low resilience and high human intervention; however, the level of risk faced differs between the two MPAs . By identifying binding indicators and variables, we show that this model might be an appropriate tool for decision-makers and reserve managers as it provides insights not only about the current status of the SESs at the MPAs , but also about what elements of the SESs should be addressed for improving MPA's protection effectiveness while mitigating the vulnerability of coral reefs ecosystems and local communities.

Keywords: Socioecological Systems, Marine Protected Areas (MPAs), Management effectiveness, Resilience, Human intervention, Coral reefs, Colombia.

Introduction

Marine Protected Areas (MPAs) have been considered as a panacea for mitigating the fast degradation of marine environments. Given that they are created especially for providing ecosystem's protection while ensuring sustainability to human populations (Agardy 1994), the scientific community has made international agreements to accomplish specific goals to improve MPAs global representation (Balmford 2004). Although these efforts have resulted in a raise in the number of MPA's, today the global MPAs system only covers 0.717% of the entire ocean surface (Spalding 2008). Furthermore, it has been highlighted that the majority of existing MPA fail to accomplish their conservation objectives (Kareiva 2006). According to Mora et al. (Mora 2006) most of the reserves cannot offer biophysical or political requirements necessary to guarantee protection; as a result, they claim that only 2% of the world's coral reefs are sheltered under successful conservation.

There are numerous aspects determining MPAs' success or failure, several of them regarding biophysical factors related to reserve design (Halpern 2003) or connectivity (Nyström & Folke 2001). Some studies illustrate the importance of reserve location for enhancing the protection of reef communities and helping to diminish external pressures coming from atmospheric, oceanic and terrestrial sources (Jameson 2002). Hence, protected areas with special physical and biological characteristics like less wave exposure and high habitat complexity seem to have healthier fish assemblages (i.e., biomass, richness) (Friedlander 2003). Likewise, connectivity among reef areas maximizes larval exchange between different populations, increasing reef genetic variation and resistance to future perturbations (Nyström & Folke 2001).

On the other hand, some authors suggest social factors as the main determinants of MPA success, arguing that participatory arrangements on MPA design, management and evaluation enhance social learning and strengths rules' legitimacy for achieving conservation goals (Friedlander 2003; Mascia 2003; Charles 2009). As an example, in New Guinea McClanahan et al. (McClanahan 2006) compared the efficiency of national parks, co-managed reserves and traditional managed areas in conserving reef resources. These authors find that traditional management, characterized by reef closures instigated and maintained by the community, provides a more efficient protection (i.e., higher fish average size and biomass) because rules reflect local understandings of human-environment interactions and provide real material benefits (McClanahan 2006). Similarly, Friedlander et al. (Friedlander 2003) incorporated stakeholder's traditional knowledge into the design of an MPA in Colombia and today this reserve has been named a "providential conservation outcome" because enclosed reefs are some of the healthiest in the Caribbean and local community is highly involved in management (Schrope 2008).

Whether biological or social, unravel the potential causes of MPA failure is a priority issue in reserves enclosing highly endangered ecosystems such as coral reefs (Bellwood 2006). Coral reefs reserves managers have to deal with the synergistic negative effects of global warming, overfishing, pollution and tourism, while ensuring local community's welfare (Hughes 2003; Bellwood 2006; Halpern 2008). For this reason, it has been shown that performing management effectiveness evaluations in existing MPAs becomes a crucial step for the improvement of management practices in order to achieve sustainable conservation results (Pomeroy 2004, Camargo 2009). Different approaches have been proposed for determining MPAs effectiveness, including protocols designed by international organizations, for example IUCN-Reef managers guides (Marshall 2006, Obura 2009, Pomeroy 2004), TNC-Reef resilience toolkit (http://www.reefresilience.org/), local institutions (National Natural Parks of Colombia-AEMAPPS (UASPNN 2007) and, Universities (Camargo 2009). Latest emerging approaches focus on *adaptability* or actor's capability to manage *resilience* of the system (Walker 2004; Hughes 2005; Camargo 2009). Resilience involves the system's capacity to absorb disturbances while retaining the same structure, identity, functionality and feedbacks, providing the ability to cope with surprises and external changes (Holling 1973; Adger 2000). In coupled complex socioecological systems (SESs) where communities directly depend on resources provided by the ecosystem, resilience has ecological and social components closely related (Adger 2000). Therefore, factors such as institutional change, economic structure, technological development, environmental hazards, natural resources distribution, demographic fluctuations and social frame, interact to determine the capability of SESs to withstand stress and shocks (Adger 2000; Ostrom 2009).

Managing resilience in SESs seems to be the most suitable approach for ensuring marine resources sustainability, despite unraveling the relationships between dynamic ecological and social components represents a big challenge (Hughes 2005).Given the multidisciplinary nature of resilience approach, difficulties arise when trying to link, conciliate and interpret findings coming from diverse sources and several methods of data collection (Ostrom 2007). The different nature of environmental and social sciences imposes very important challenges for scientists that seek to draw the connection between them for holistic analysis (Ostrom, 2009). Recent multidisciplinary approaches, supported on resilience concepts, and aimed to understand marine socio ecological systems (McClanahan and IUCN), have provided important conceptual and operative advances; however, it seems to be the time to incorporate this holistic approach as a tool for evaluating the effectiveness of a MPA as an integrated socio ecological system. The relevance of improving the effectiveness of existing MPAs for coral reef conservation, makes of the interdisciplinary and holistic assessment of MPA's management a task that needs to be done urgently as an input to develop adaptive management strategies that incorporates the complexities and uncertainties associated with coral reefs SESs. For this reason, approaches that allow to: (i) analyze simultaneously variables from diverse sources measured in different scales and techniques, (ii) combine qualitative and quantitative data into a single methodological framework and (iii) make direct comparisons in different scenarios by obtaining compatible and equivalent results, are highly needed to resolve the complexity of SESs.

Accordingly, two high priority issues in reefs' conservation come to light: i) assessing the performance of MPAs to identify aspects that need to be addressed for increasing protection efficacy (Hughes 2005) and ii) designing an approach to study MPAs systems as holistic and integrated SESs under the perspective of resilience. This study aims to design and implement a model based on the socioecological-resilience approach for assessing management effectiveness of marine protected areas. We formulate Resilience and *Human-Intervention Indexes* to estimate both, resilience of MPA's components and the degree of anthropogenic impact on them. This model was applied to a case study of two MPAs in the Colombian Caribbean, in order to determine whether current MPAs' management is having any effect increasing SESs capacity to adapt to changes. Evaluating MPAs success by identifying factors that confer socioecological resilience will provide insights for the improvement of MPA's planning and management towards achieving sustainability.

Methods

1. Conceptual Model: Interpretation

The model proposed in this study was designed by combining several frameworks found in literature and developed for understanding resilience and adaptive capacity in SESs (Pomeroy 2004; Littler 2006; Walker 2006; McClanahan 2008). Particularly, McClanahan et al. (2008) constructed an approach to establish specific conservations actions for MPAs based on their local environmental vulnerability and communities' social adaptive capacity. The present model adapts McClanahan et al. (2008, 2009) approach by relating those particular conservation actions to MPAs' socioecological resilience and degree of anthropogenic impact. Following this idea we developed a Resilience Index and Human Intervention Index. Plotting both indexes provides a four scenario space similar to McClanhan et al. (2009) in which SESs' may be located depending on their state. For each of these scenarios, different conservation strategies can take place in order to avoid phase shifts and increase capacity to overcome future perturbations and surprises (Figure 1). SESs with high Human-Intervention Index and low Resilience Index are at risk of suffering a phase shift to an ecosystem state with lower capability to offer ecological services because they lack institutional and biophysical resources for overcoming more intense anthropogenic impacts. In such cases, novel conservation actions should be directed urgently to reorganize the system by restructuring governance to reduce impact and high-dependency on natural resources (Walker 2006; McClanahan 2008). When both indexes are high, the SESs is vulnerable to internal impacts but still has the possibility to adapt and transform via innovative changes and proactive management, taking advantage of their cohesive social structure and healthy ecosystem (Walker 2006; McClanahan 2008). In the case human intervention is reduced and resilience is low, efforts should concentrate on building the capacity to strengthen the socioeconomic system and detecting critical ecological process or keystone species that enhance resilience, in order to transform management into successful protection action and to diminish current vulnerability to external perturbations and surprises (Walker 2006; McClanahan 2008). Finally, in case human intervention on SESs is low and socioecological resilience is elevated the system is in a steady state because its healthy ecosystems and flexible social structure make it robust enough to handle restrictions in resource-use and surpass unexpected changes (Walker 2006; McClanahan 2008).

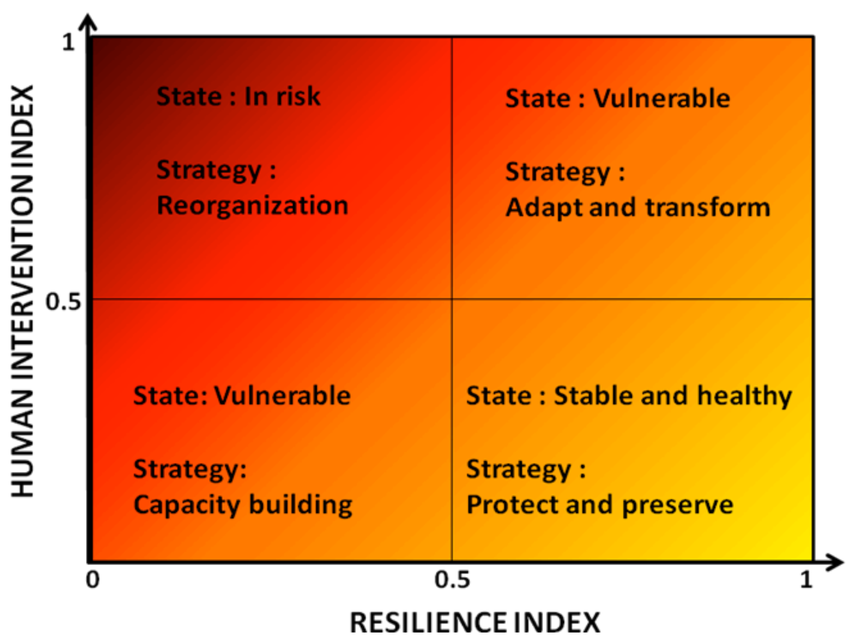

Figure 1.Theoretical model used to establish the relationship between human intervention and socioecological resilience. Plotting both indexes creates a space with four possible scenarios referring to different SESs states where particular management actions should be implemented. Lighter color represents a more desirable state. Based on McClanahan et al. (McClanahan 2008)

2. Theoretical Model: resilience and system definitions

In order to design the model, resilience was defined as the ability to resist, learn, adapt and overcome internal changes and external disturbances and shocks without losing system's identity (Folke 2002). System's *identity* is determined by (i) its *components* (i.e., human population –actors–, abiotic variables, ecosystems), (ii) the *relationships* or interactions linking them, (iii) *innovation* variables that create new solutions or diverse responses to change, and (iv) *continuity* variables that maintain identity in the space and time (Cumming 2005). By defining the current identity of the SESs under study, MPAs resilience can be evaluated in a practical and operational way by tracking and comparing the changes on specific properties of the system (Figure 2).

In this case, the identity of the MPA systems under study is defined by an ecological part constituted by corals, algae and fish communities living under specific environmental variables for each zone (i.e., water quality). In this system, biodiversity and connectivity are properties that maintain ecosystem's dynamics, promote recovery and act as innovation sources through functional redundancy (i.e., similar ecological role performed by different species) and re-seeding (Walker 1995; McClanahan 2002; Van Oppen 2006). Ecological system interacts with social system components by providing goods and services to local community (i.e., fishermen, tourists, locals), while the accessibility and usage of these natural resources is regulated by different institutions (park authorities, community organizations, informal norms and rules). A social system also has internal characteristics crucial for the development of novel solutions and responses to change like social capital (social nets, norms), financial capital (income), and human capital (education, abilities, experience), among others. In addition, relationships that describe the interactions between both systems are given by most relevant anthropogenic interventions on coral reefs: fishing, pollution and tourism. Finally, maintenance of cohesive linkages and spatiotemporal continuity of SESs' identity is given by memory, knowledge, and institutions, both formal and informal.

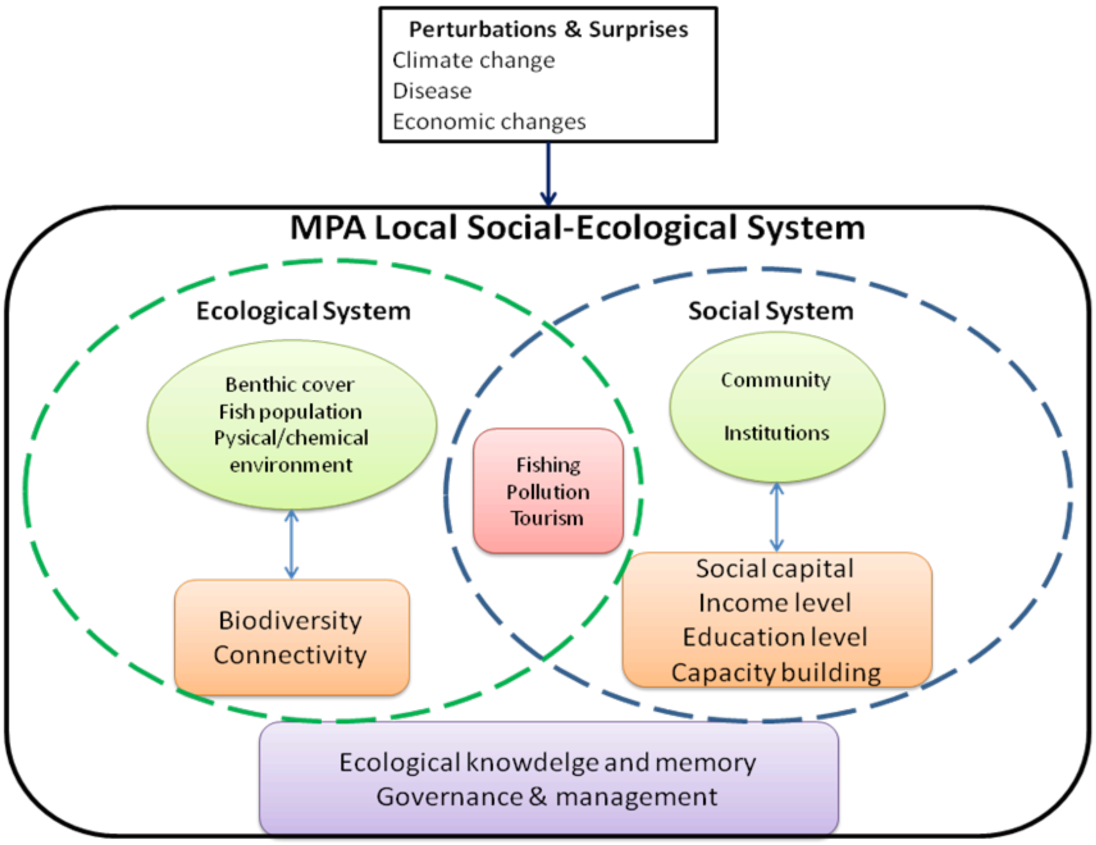

Figure 2. The scheme illustrates MPAs' identity that defines the current system to be evaluated. Colored boxes show the aspects of identity -Green: components, red: relationships between systems, orange: innovation variables, purple: continuity variables- (Based on Cumming et al., 2005)

3. Resilience and Human-intervention Indexes estimation

Resilience Index was defined as the equation 1:

(Equation 1) $$RI = (\alpha ER + \beta\, SR)/maxRI;$$

Where ER: Ecological resilience, SR: Social resilience, *α* and *β*: parameters that take values between o and 1 and reflect the weight or importance of each component. We consider each component has the same importance in the construction of the resilience Index so that *α* and *β* are assumed to be equal (1/2 each) *maxRI:* the maximum possible score in a scale. ER involved the buffer capacity of an ecosystem for withstanding shocks and for maintaining its functionality (Folke, 2006) and SR was defined as communities' ability to face, resist and overcome external shocks and disturbances (environmental, political, social, economic) (Adger, 2000).

With the purpose of constructing the RI equation 2, 3 and 4 were used as follows:

(Equation 2) $$ER \; or \; SR = \frac{1}{n_D}\sum_{D=1}^{n_D} D_i\,; \quad n_D\text{: number of drivers}$$

(Equation 3) $$D = \frac{1}{n_I}\sum_{i=1}^{n_I} I_i\,; \quad n_I\text{: number of indicators}$$

(Equation 4) $$I = \frac{1}{n_V}\sum_{i=1}^{n_V} (VS)_i\,; \quad \text{where } VS\text{: variable score} \in \{0,1,2,3\}; \; \mathrm{n_V}\text{: number of variables,}$$

Drivers (*D*) for RE and RS were identified by consulting several studies (Adger 2000; Folke 2006; Marshall 2006; Cinner 2009; Obura 2009). Subsequently, every resilience driver was divided by **Indicators (*I*)** composed, in turn, by **Variables** that estimated quantitative or qualitative aspects related to resilience (Figure 3).

Since each indicator's Variables are different among them -in terms of estimation technique and measurement units-, we standardize Variables transforming all values into a common scale of resilience ranging from 0 to 3 (0 =low, 1 =moderate low, 2 = moderate high, 3 = high) (Appendix 1). Threshold values for the Variables in this scale were defined following the existing literature and were validated by several experts in MPA's management. Following this scheme, **RI** was estimated by scoring all variables **(VS)** and calculating average scores for indicators **(I),** drivers **(D)** and social **(SR)** and ecological **(ER)** resilience components.

Regarding to ecological resilience, drivers included in the model were (i) *ecosystem condition* involving benthic cover (coral vs. algae), fish abundance and genetic connectivity among reefs, factors that provide resilience because they confer ecological integrity influencing process like coral larvae recruitment, coral-algae competition, re-seeding, herbivory, bioerosion and top-down/bottom-up control (McClanahan 2002; Elmqvist 2003; Mumby 2007); (ii) *biological diversity,* measured as coral and fish diversity, provide functional redundancy and diversity in responses after bleaching, diseases and anthropogenic impacts, increasing resistance and recover (Walker 1995; Levin 2008); finally (iii) *local physical/chemical environment* measured as water quality provide a characterization of the abiotic conditions where reef community develops, a vital factor for understanding community vulnerability to stressors (Fabricius 2005) (for a deeper revision of resilience drivers consult: (Marshall 2006; Obura 2009). Likewise, social resilience was divided in (i) *institutional management/governance* including compliance, legitimacy, enforcement and surveillance of regulations and norms governing the use of natural resources; and (ii) *adaptive capacity* to control system's response to change, learn from past, innovate and create alternatives or solutions, given by: social capital, financial capital (income level), and human capital (socioecological memory and stakeholder's education) (Adger 2000; Walker 2002).

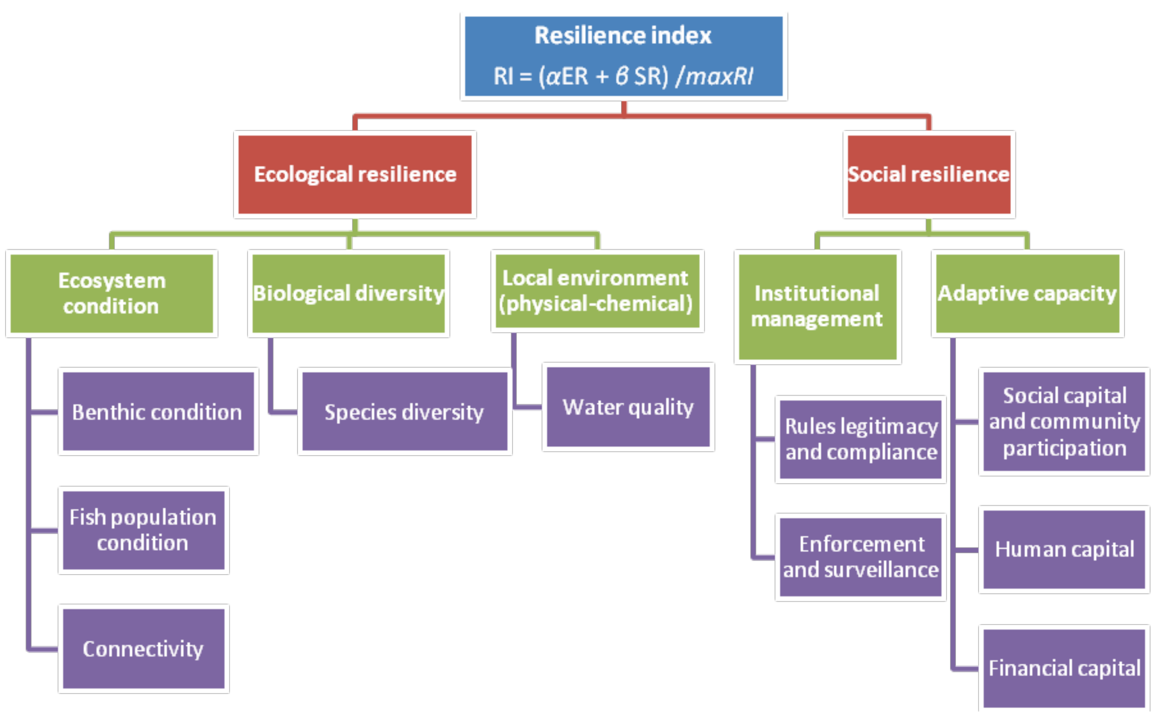

Figure 3. Resilience index components, drivers and indicators. Red box shows resilience components, green boxs correspond to resilience ecological and social drivers and purple box illustrates indicators for each driver. Formula for computing index is shown.

Additionally, to have a complete characterization of the MPAs to understand current condition of the system under study regarding the degree of human pressure on coral reefs, a *Human-Intervention Index* **(HI)** that evaluates human-ecosystem interactions was also developed (Figure 4); The *Human-Intervention Index* is defined as equation 5:

(Equation 5) $$\mathbf{HI = (\gamma\, I_1 + \delta\, I_2 + \mu\, I_3)\, /\mathit{max}HI;}$$

Where, I_1, I_2, I_3 are indicators; *max*HI is the maximum possible score and, γ, δ and μ are parameters that take values between 0 and 1 and reflect the weight of each indicator; We assume each indicator has the same importance in the construction of the resilience Index so that γ, δ and μ are equal to 1/3.

Similar to the RI methodology, we construct an intervention scale ranging from 0 to 3 (both scales were colored from red to yellow for dissemination purposes) (Appendix 2); then, the HI was estimated by scoring all variables **(VS)** and calculating average scores for indicators **(I)** as shown in Equation 6:

(Equation 6) $$I = \frac{1}{n_V}\sum_{i=1}^{n_V}(VS)_i\,;\ \text{where } VS\text{: variable score} \in \{0,1,2,3\} \text{ and } n_V\text{: number of variables}$$

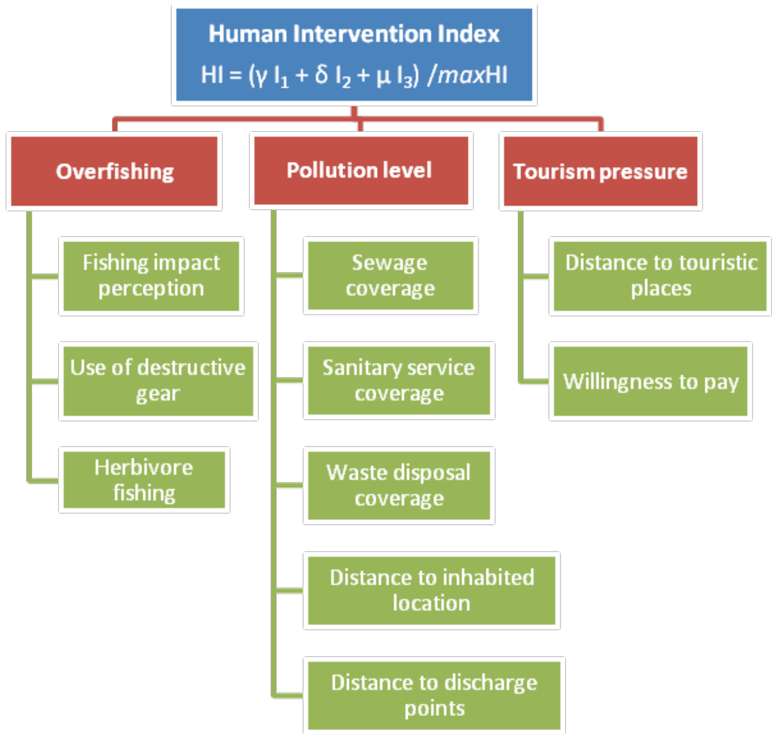

Figure 4 Human intervention index indicators and variables. Formulas for computing indexes are shown. Red box show Human Intervention indicators and green box correspond to variables measured for each indicator.

Indicators were designed based on previously proposed MPA management effectiveness evaluation approaches (Pomeroy 2004) and scientific studies (Camargo 2009). Additionally, a workshop aimed to select and discuss the relevance of indicators was conducted in Santa Marta (Colombia) on April of 2008, with a wide participation of government authorities, conservationists, researchers, local fishers and other relevant stakeholders, which guaranteed the equitable inclusion of different interests and disciplines in the discussion and selection of indicators. Following the workshop, chosen indicators were grouped for each resilience driver and intervention component (all indicators shown in Appendixes 1 and 2).

SESs are defined by the complexity and non-linear dynamics of its relationships (Folke 2006); however, our model assumes that relationships between drivers and variables are linear in order to allow the system's characterization and had the same weights. Although this scheme represents an oversimplification of the complexity, interdependence and multiple feedbacks that characterize SESs, the linearity assumption provides the advantage of practicality and measurability for practitioners and parks officers. Similarly, since the selection of SESs' properties is highly related to the particular goals of this study, it's impossible to avoid some degree of subjectivity. Nevertheless, *RI HI* were intended to be as general as possible to ease their implementation across different MPAs. By quantifying variables associated with the properties that define systems' identity, it is possible to determine their state and then estimate the impact that humans are causing on them.

4. Empirical model: Southern Caribbean MPAs case study

Study site

This study comprises two key MPAs located in the Colombian Caribbean (Figure 5). The first is Rosario and San Bernardo Coral National Natural Park (PNNCRSB) that was established in the 70s and comprises several coral reef complexes, some of them (e.g., Isla Fuerte, Bushnell and Burbujas) incorporated as part of the MPA recently (year 2005). Nevertheless, since currently the management of the park does not include the new complexes they were excluded from the analysys. The second MPA studied, Tayrona National Natural Park (PNNT) was also established in the 70s and is characterized because it harbors a variety of fauna and flora within different tropical ecosystems. Both areas have been strongly affected by runoff and sedimentation coming from adjacent rivers, pollution originated from adjacent cities, as well as inhabitants profiting tourism, extractive handcrafting and fishing activities.

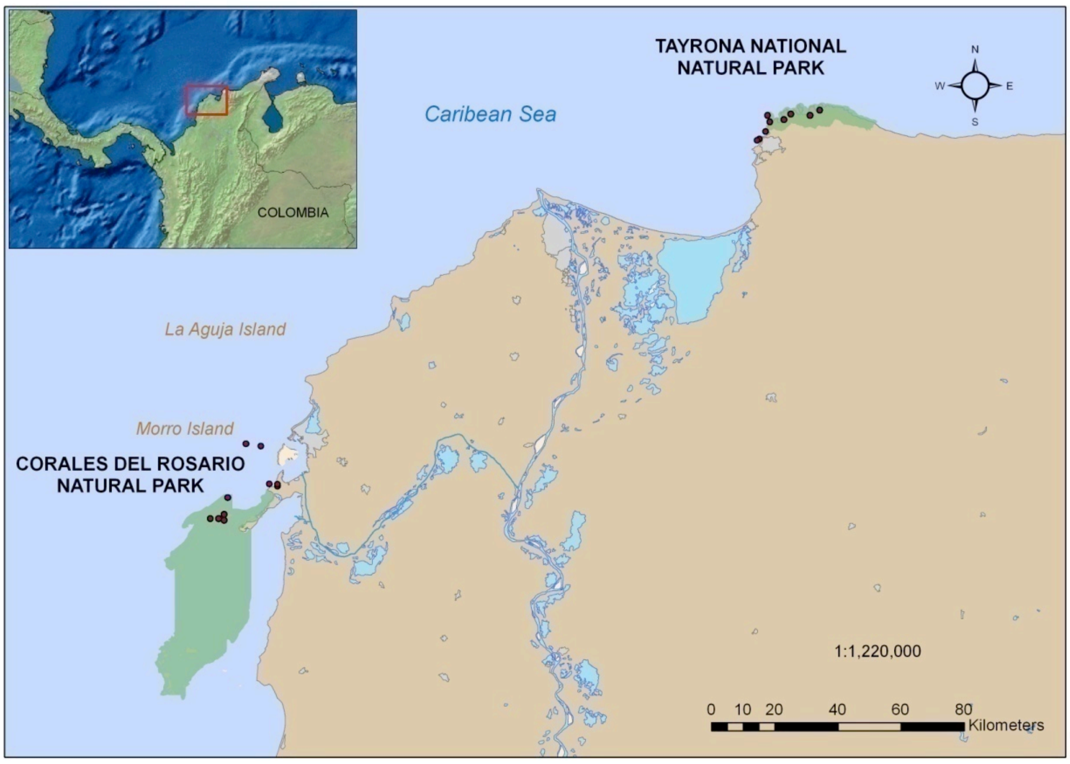

Figure 5. MPAs under study were located in southern Caribbean, Colombian coast. Biophysical survey stations are shown as dots.

Data collection

Biophysical data was collected between 2008 and 2009 in 17 sites located inside MPAs and 10 control sites outside MPAs. All sampled areas were in shallow (3 – 15m) highly developed reefs. For fish population assessments, underwater visual censuses were conducted by swimming along 2 x 50 m belt transects (100m^2) recording all individual fish of important families (Acanthuridae, Lutjanidae, Serranidae, Scaridae, Haemulidae, Carangidae, Scombridae, Sphyraenidae) and estimating total fish length. A minimum of 4 and a maximum of 10 transects were performed for each site (Table 1). Fish biomass was calculated by converting length estimates to weight using length-weight conversion equation: $W = aTL^b$; where parameters *a* and *b* are constants for each species' allometric growth equation, *TL* is the total length in centimeters and *W* is the weight in grams. In the case *a* and *b* where only available for a different length measurement types (standard length or fork length) *TL* was converted to that specific measurement using length-length regression equations. All fitting parameters were obtained from FishBase (www.fishbase.org) and parameters from similar-body congeners were used for species with no information (Friedlander 2003). Density, diversity (Shannon diversity index, Evenness and Rarefied richness) and biomass estimates were conducted for sites inside and outside MPAs. To evaluate MPA's effect on fish populations, estimated values were compared between sites by Mann-Withney U Test for non-parametric data and ANOVA for parametric data. Analysis was carried out using R software.

Relative abundance of coral, crustose coralline algae, microalgal turfs and frondose macroalgae was estimated by 1m^2 photo sequences taken from 2 x 50 m belt-transects (100m^2) (table 1). Cover percentage of each group was determined using ImageJ software, diversity estimates were calculated using PRIMER software. Values for coral-algae cover were categorized into "low – moderate low– moderate high– high" resilience having as reference existing data of the Caribbean (Rodríguez-Ramírez A. 2006; Mumby 2007) and for diversity estimates a scale provided by (Ramirez 2006) was used.

Additionally, the seawater quality database of the Colombian Caribbean (INVEMAR 2008) was consulted, for determining water quality around selected MPAs. This database provides a water quality index evaluated according to composition and concentration threshold values of physicochemical, microbiologic, hydrocarbon, pesticides and metals. To complete this information, foraminifer's community from sand samples collected in stations inside and outside the MPA was analyzed to determine species composition. Since these organisms are pollution bioindicators, the "FORAM" Index (Foraminifers in Reef Assessment and Monitoring) was calculated and interpreted following Hallock et al. (Hallock 2003).

Connectivity among coral metapopulations in the Caribbean was determined using six microsatellite loci for the coral *Montastrea annularis* designed by Severance et al. (Severance E.G. 2004), which have already been standardized and are highly polymorphic in Colombian reefs with up to 30 alleles per locus in the Rosario islands population only. Additionally, larval transport patterns were established using a model of ocean circulation (Hybrid Coordinate Ocean

Model-HYCOM) (www.hycom.org). Population genetic estimates such as genotypic diversity, Nei distance and F_{st} were determined.

Method	PNNT	PNNCRSB
Area analyzed by phototransects	800 m^2	800 m^2
Underwater visual surveys number	69	122
Foraminifer's analysis sample number	20	16
Park rangers survey	12	14
Tourists survey	160	816
Local community survey	60	235
Players in Economic Experimental Games	60	235
Participatory workshops with community	3	3
Number of workshops participants	75	66

Table 1. Methods for collecting biophysical and socioeconomic for each of the MPAs.

Information regarding socioeconomic and governance indicators was collected implementing several methodological approaches with the purpose of comparing and triangulating data obtained from the different stakeholders interacting in the MPA (Table 1). Participative rural diagnostics (PRD) were developed with several communities to identify some socioeconomic conditions characteristics and approximate their local ecological knowledge. Four PRD tools were included: (i) productive profile, to identify main income-generating activities, (ii) submarine profile to determine local knowledge about location of marine resources, (iii) institutional matrix analysis, to identify the presence of institutions (i.e., park authorities, NGOs, social assistance, academics) and the type of relationships between communities and institutions, and (iv) norms and rules matrix, to evaluate knowledge, compliance and agreement of formal regulation and informal rules and norms. Three workshops in each park for PRD activities were carried out in focal groups with about 180 participants in total.

Additionally, structured surveys were implemented to tourists, park staff, fishermen and local communities, as well as, semi-structured interviews directed to individual fishermen, tourism and fishing associations and park staff. Finally, economic experimental games (EEG) were performed to obtain information about resource users' behavior under different managements strategies, while compiling, through structured surveys, socio-economic, demographic and governance information.

EEGs were framed experiments designed to test statistically participant's behavior about the extraction of a common pooled resource (in this case a fishery). At open-access fisheries, individual fishermen only assume the private costs of their actions, ignoring the social costs, and collectively engaging in the over exploitation of a resource they perceive as "free" (Gordon 1954) ending up in what Hardin (Hardin 1968) called "the tragedy of the commons". To understand dilemmas related to the use of common pool resources, fishermen's extractive behavior was explored by applying EEGs, under four management alternatives (i.e., open access, internal cooperation, external regulation and co-management) (Maldonado 2009; Moreno-Sánchez 2009). The game was designed so that the social optimum extraction per player was one unit, while private suboptimum extraction decision was to extract eight units. The predicted outcome is that every individual player under open access extracts eight units; in practice, however, individuals deviate down from that expected behavior, reflecting collective concerns; besides, management alternatives are expected to induce reduction in the extraction decisions. The experimental game emulated real economic decisions by paying participants money depending on their individual fishing extraction decisions during the game. EEGs were carried out on 3 communities (60 participants) at PNNT and 8 communities (235 participants) at PNNCRSB.

EEGs were useful to design social capital indicators such as "proportion of reduction in extraction as a result of a co-management rule (I_1)" and "potential internal cooperation within communities (I_2)". Since EEGs' results were in extraction units, obtained values for the indicators were transformed to percentages using equation 7 and 8:

Equation 7: $I_1 = LBE - ET_1 / ET_1 - 1$; where LBE: line base extraction, ET_1: Extraction in comanagement

Equation 8: $I_2 = LBE - ET_1 / ET_1 - 1$; where LBE: line base extraction, ET_2: Extraction in internal cooperation

On the other hand, distances from reefs sample areas to cities, ports and points of discharge to the sea (waste and sewage), and tourism relevant sites (dive and beaches) were measured using the GIS software ArcGIS (version 9.1). Distance values calculated in kilometers were categorized into "low, moderate low, moderate high and high" intervention on ecosystems, following the approach of (Burke 2004). Additional information such as waste collection system, amount of population having sewage system and septic tank was obtained from the Colombia national survey data base (http://www.dane.gov.co/censo/).

Results

Resilience Index findings

Overall Resilience Index for PNNT was 0.48 and 0.29 for PNNCRSB (Tables 2 and 3). Ecological resilience was "moderate low" for both MPAs mainly because of low scores obtained for the indicators relating to ecosystem condition; for instance, reef is mainly covered by algae (PNNT= 48%, PNNCRSB=67%) instead of coral (PNNT= 22%, PNNCRSB= 23%), fish populations inside the parks were not superior in terms of density ($P>0.05$) and biomass (for herbivores $P>0.05$, for predators $P>0.05$) than populations outside the reserves without protection and, the coral species *M. annularis* was not genetically connected to populations of other areas forming closed and isolated populations adjusting to the model of isolation by distance (Mantel, $P<0.05$) (Foster in prep). Fish species diversity was higher in PNNT (H= 2.71) in comparison to PNNCRSB (H=2.56), and coral species were not very rich in PNNT (H=1.6) contrary to PNNCRSB (H=2.318). Water quality index reported excellent physical and chemical conditions for the development of coral reefs in both MPAs, and this is confirmed by the obtained FORAM indexes (PNNT= 4.29, PNNCRSB=4.0), that relate to reefs ecosystems under growing and recovering processes (Hallock et al, 2003) (Table 1 and 2) (Appendix 1)

Resilience index	Component scores	Driver scores	Indicator scores
0.48	Ecological Resilience = 0.9	Ecosystem condition = 0.3	Benthic condition = 1.0
			Fish population = 0
			Connectivity = 0
		Biological diversity = 1.0	Species diversity = 1.0
		Local environment = 2.5	Water quality = 2.5
	Social resilience = 1.8	Institutional management and governance = 1.9	Rules legitimacy and compliance = 1.6
			Enforcement and surveillance = 2.16
		Adaptive capacity = 1.6	Social capital and community participation = 2.0
			Human capital (education and training) = 1.5
			Financial capital (Income level) = 1.0

Table 2 Results of resilience-index calculation for PNNT. Scores obtained were interpreted as: 0-0.5 =low, 0.6-1.4 =moderate low, 1.5-2.5 = moderate high, 2.6-3 = high. The index value was normalized to the unit.

Resilience index	Component scores	Driver scores	Indicator scores
0.29	Ecological Resilience = 0.8	Ecosystem condition = 0.16	Benthic condition = 0.5
			Fish population = 0
			Connectivity = 0
		Biological diversity = 1	Species diversity = 1
		Local environment = 2.5	Water quality = 2.5
	Social resilience = 0.93	Institutional management and governance = 1	Rules legitimacy and compliance = 1.6
			Enforcement and surveillance = 0.66
		Adaptive capacity = 0.8	Social capital and community participation = 1
			Human capital (education and training) = 0.5
			Financial capital (Income level) = 1

Table 3 Results of resilience-index calculation for PNNCRSB. Scores obtained for components, drivers and indicators were interpreted as: 0-0.5 =low, 0.6-1.4 =moderate low, 1.5-2.5 = moderate high, 2.6-3 = high. The index value was normalized to the unit.

On the other hand, social resilience in PNNT was "moderate high" and "moderate low" in PNNCRSB. Differences in social resilience index between the MPAs are the result of both a better institutional management and a higher adaptive capacity in PNNT; the first, determined mainly by good levels of enforcement and surveillance and the second, determined by better social capital and higher levels of human capital. (Tables 2 and 3) (Appendix 1). Particularly, human capital measured as average years of formal education and informal educational activities (i.e., capacity building activities) was higher in PNNT (8 years and one activity per two weeks) compared to PNNCRSB (6 years and one activity per month). Regarding enforcement and surveillance, park-officer surveys show that the proportion of park-rangers who perceive that sanctions are easy to implement and the frequency/coverage of surveillance activities is higher for PNNT (58% and 3 days per week respectively) than for PNNCRSB (20% and once per week respectively)

With respect to social capital, Economic Experimental Games (EEG) results indicate that in a hypothetical scenario of co-management (between park authorities and local communities), fishermen would extract fewer resource units of a common pool resource in both MPAs. However, when they were asked about how resources should be managed at the MPAs, results differ between the two MPAs evaluated: 66% of EEG players at PNNT considered that resource management should be shared between community and authorities, while at PNNCRSB only 19% of players thought in the same way. Regarding other indicators associated to social capital, EEG allowed us to notice that a considerable percentage of fishermen from both MPAs extracted fewer resources when they had the possibility to communicate and build extraction strategies together (PNNT=56.40%, PNNCRSB=43.20%); indicator that we called "*potential for internal cooperation*". Moreover, the percentage of the community that report to participate in workshops related with environmental and resource issues was higher in PNNT (66%) than in PNNCRSB (43%).

Although score for Adaptive Capacity at PNNT (1.6) doubles the obtained value for PNNCRSB (0.8), this driver for both MPAs is classified as "moderate" since communities exhibit low average incomes per household compared with national standards (the minimum monthly wage is about $250 US).

Human-Intervention Index findings

The determination of the human intervention level on the ecosystem yielded a score of 0.36 for PNNT and 0.46 for PNNCRSB (Table 5). Fishing pressure was "moderate low" for PNNT and "moderate high" for PNNCRSB. Percentage of fishermen that consider fishing is highly impacting the ecosystem is 43% PNNT and 38% in PNNCRSB. The percentage of herbivore fish harvested was very low (1%) at PNNT, while at PNNCRSB herbivores represented 30% of harvest. In both areas, fishermen communities still use destructive fishing gears such as dynamite fishing even though is strictly prohibited in Colombian MPAs.

Regarding pollution indicator, it was stated as a "moderate high" intervention source for both MPAs. This result is explained since there exists a short distance between MPAs coral reefs and inhabited locations (PNNT= 9.37Km, PNNCRSB=13.18Km) and between points of waste disposal and sewage to reefs surveyed (PNNT=20.48Km, PNNCRSB=23.42Km); moreover very few locals had access to sewage system (PNNT=2.5%, PNNCRSB=5.38%) and collection of solid waste by the municipality is at best slightly above 50% for households in its rural areas (56% in PNNT and 14% in PNNCRSB). Only a minority of the population within the MPAs had access to sanitary service (PNNT=1.78%, PNNCRSB=3.71%). Tourism was considered to have a "moderate high" level of intervention, since both MPAs reefs were located relatively near touristic places (PNNT=11.17Km, PNNCRSB=5.86Km) and a low percentage of tourists were willing to pay a park entrance fee greater than $4 US (PNNT=37%, PNNCRSB=42%), indicating they do not acknowledge fully the values associated to all goods and services provides by the MPAs.

MPA	Indicator			Intervention index
	Fishing Indicator	Pollution indicator	Tourism indicator	
PNNT	1.3	2.2	1.5	0.6
PNNCRSB	1.6	2.4	2.0	0.7

Table 5. Results for indicators and intervention index in both MPAs. Scores obtained were interpreted as: 0-0.5 =low, 0.6-1.4 =moderate low, 1.5-2.5 = moderate high, 2.6-3 = high. The index value was normalized to the unit.

Obtained Resilience and Human-Intervention indexes identified the scenario in which the MPAs under study are located (Figure 6). As seen both MPAs locate in a scenario of risk, where resilience is low and human intervention is high. For the PNNT Resilience Index had a value of 0.48 and Human-Intervention Index a value of 0.6. On the other hand for the PNNCRSB, Resilience Index had a value of 0.29 and Human-Intervention Index a value of 0.7.

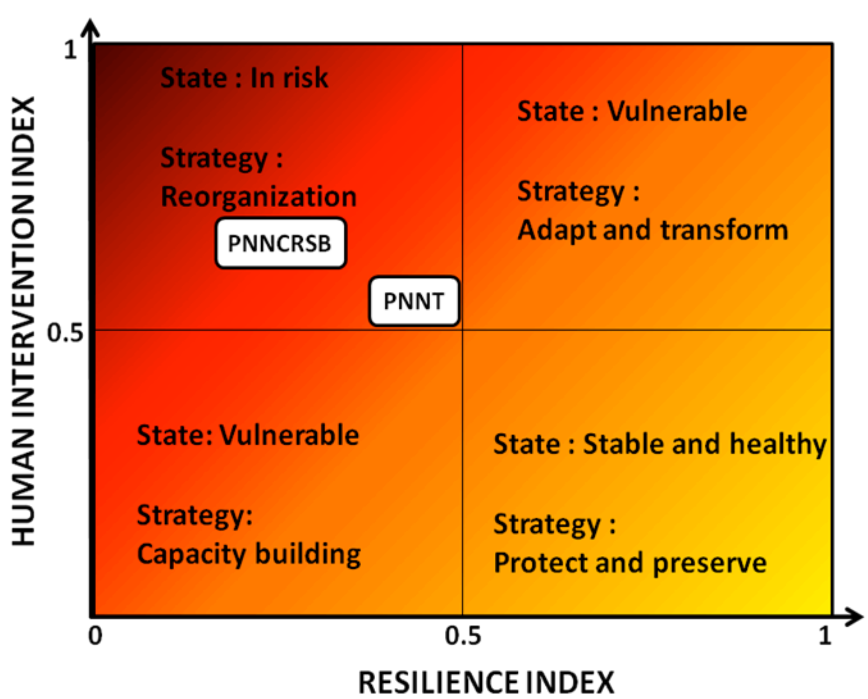

Figure 6. Location of MPAs under study along the possible scenarios given by the theoretical model used to establish the relationship between human intervention and resilience. Lighter color represents a more desirable state. Based on McClanahan et al. (McClanahan 2008)

Discussion

High-speed coral reef decline makes necessary the implementation of practical tools to estimate current resilience state to provide MPA managers with alternatives to build and improve their capacity to cope with treats, stress and surprises. It is also highly desirable that these results can be comparable across the different MPAs, to provide the MPA's authorities with a framework to identify the most relevant needs and to prioritize the conservation efforts. The Resilience and Human-intervention Indexes and interpretation implemented in this study offers a diagnosis of SESs state and allows us to understand the current local MPA context, crucial to design further actions to develop resilience and detect those resilience aspects that need to be urgently addressed and strengthen. The socioecological resilience approach used in this study can be applied in different regions since it is a practical and general tool for evaluating MPAs' performance. The standardization of data coming from different sources and scenarios (i.e., coral cover and rules compliance) and the use of color for the common scale provide a straightforward and illustrative way to deliver results, enhancing community's comprehension and facilitating its dissemination.

Southwestern Caribbean reeds represent 17% of the region's total reef area, and according to the regional analysis made by Burke & Maidens (Burke 2004), 50% of the coral reefs of this area are under significant risk. Urgent actions in these reefs should start immediately since their economic value has been estimated between US$3.1-4.6 billion annually from ecological goods and services (Burke 2004). Taking into account that economies of the zones will suffer damages if the degradation trends continue, the fact that Colombian current ecosystem status had not been properly acknowledged because of the limited financial resources available and lack of awareness of environmental protection (Castillo 2005), is an urgent issue that needs to be addressed immediately.

According to the Resilience and Human-intervention Indexes, both MPAs under study are in a "risk" state; MPAs exhibit relatively high Human-intervention and low resilience levels that made them very susceptible for an increase in internal pressures and external shocks. These results are comprehensible considering that Colombia's 46-year continuous civil war has stressed the conflict between human survival and ecosystems integrity. Developing countries commonly have local communities highly dependent of natural resources because of poverty and lack of income-generating alternatives. In the case of coastal systems, despite they are generally very diverse and can be though as resilient, maintenance of ecosystem's integrity is crucial to sustain society's multiple demands (Adger 2000). Therefore, the highly coupled and interdependent social and ecological systems make these AMPs in high risk of suffering an irreversible resilience impairment due to external hazards or an increase in current anthropogenic impacts, that is expected to happen following rapid globalization and global change trends (Hoegh-Guldberg 2007).

The evaluation of ecological resilience drivers of coral reefs studied in both MPAs showed that reefs were not in a healthy state, presenting signs of highly degraded and non-resilient habitats. Reefs benthic community was high, characterized by low coral cover, high algae cover, elevated mortality of key coral species (*Acropora cervicornis, A. palmata*) and dominance of opportunistic species (*Agaricia, Porites*, macroalgae). For fish, in addition to the fact that abundances and densities of commercial species in the areas had been recorded as very low (Olaya-Restrepo 2008; Camargo 2009), our analysis demonstrated that protection was not effective conserving few remnant fish. Considering that the Caribbean has historically shown low biodiversity (i.e., only 28% and 14% of the fish and coral species present in the Great Barrier Reef), it is evident that this zone will not have enough functional redundancy to withstand future impacts and avoid catastrophic phase shifts (Bellwood 2006). REDCAM water quality valuations declared water around MPAs was in "excellent" conditions even though rivers that flow into the Caribbean sea are among the most polluted in Colombia (Olaya-Restrepo 2008) and FI is below optimal levels in both MPAs. This evidences the lack of high resolution monitoring systems of seawater quality in Colombia. REDCAM needs to improve in coverage and sampling effort to be a fully reliable information source, meanwhile its data has to be interpreted carefully. Additionally, ocean prediction systems (i.e., HYCOM) and population genetics analysis established that connectivity between Colombia and wider Caribbean was very low. Accordingly, *M. annularis* formed self-seedling metapopulations in Colombia, meaning reefs don't receive the benefits of high levels of genetic diversity coming from external larval input (Van Oppen 2006). Further analysis of this data demonstrated that the design of PNNCRSB was not been effective since many of the important reefs that belong to this cohesive metapopulation were out of the limits of the MPA and excluded from protection (Foster in prep.). This support suggests that management is not been effective in protecting ecosystem and that it is failing to achieve stated conservation goals.

The status of the ecological system is the result of the social condition of the MPAs studied (Walker 2006). Social resilience of PNNT was "moderate high" since rules were known and understood by locals, community participation was significant and park authorities invested in surveillance. Although low levels of human and financial capital diminished communities' adaptive capacity, institutional management seemed to be good enough to confer social resilience to the system. On the other hand, PNNCRSB appeared to be in an undesirable governance situation since park authorities do not have enough capacity to enforce rules, impose sanctions and patrol the park. Social and human capitals appear to be lower in PNNCBSR; low levels of human capital are could explained because fisher communities in PNNCRSB are located in a complex of islands away from the main land and isolated from public institutions which physically limits access of people to schools and might reduce investment in education.

Although local households on both MPAs exhibit low income levels, those are inferior for households at PNNCRSB; comparing fisher villages located in the influence of PNNCRSB and PNNT it is observed that those at PNNCRSB are less developed (e.g. public and private infrastructure), physically more isolated from markets and government institutions and where people have fewer income-generating alternatives which constraints their labor mobility.

An important factor to mention is that only a small proportion of MPAs individuals followed established rules; this could be happening due to either conflicts with park authorities or communities high dependency on natural resources, which give them no option but to over-exploit resources, even knowing the existence of rules. To understand this kind of dilemmas related to the use of common pool resources, fishermen's extractive behavior was explored by applying EEGs, under two conditions of resource (i.e, abundance or scarcity) and four management alternatives (i.e., open access, internal cooperation, external regulation and co-management) (Maldonado 2009; Moreno-Sánchez 2009). The incompatibility of EEGs results in the indicators of co-management for PNNCRSB, (although most of interviewed fishers perceived that under current circumstances joint management with authorities is not desirable, EEGs results show that they are willing to reduce extraction through potential management agreements with the park authorities, might be reflecting the necessity and urgency of include local communities in processes involving MPA regulation (Moreno-Sánchez 2009). Regarding social capital, EEGs allowed to find out that fishermen of both MPAs gave up their own interest and extract less resource for common welfare when they interact under an internal cooperation situation, contrary to the expected individualistic behavior characteristic of the tragedy of the commons phenomenon (Ostrom 1990).

Human-intervention index for both MPAs is high, reflecting the current pressures coral reefs in the MPSa face from fishing, tourism and pollution. It is evident that locals rely strongly on natural resources since a considerable percentage of people dedicates exclusively to fishing activities, while others to non fishing activities also dependent on the MPA resources such as handcrafting and tourism. Despite MPAs regulation prohibits destructive fishing arts (i.e., harpoon, dynamite, fishing trawls), they are of frequent used around the influence zone of the parks; however the quantification of the actual magnitude of this problem is unknown. In addition, because of overfishing commercial fish have depleted, fishermen have shifted to the exploitation of non-commercial species such as parrotfish. The extraction of keystone species such as herbivores causes serious effects in ecosystem dynamics given that big herbivores like Parrotfish species perform a critical functional role controlling algae populations that compete with corals (Lirman 2001). It has been shown that herbivores protection increase coral reef resilience by avoiding phase shifts and promoting ecosystem recovery (Hughes 2003; Hughes and Pandolfi 2006; Mumby 2007). On the other hand, since reefs are close to pollution sources, the almost null access to sewage services and proper sanitary systems for the majority of population increases the risk of affecting corals by lowering water quality (Fabricius 2005). Tourism sector constitutes a relevant source of pressure in study zones given that these two MPAs are the most visited in Colombia. Finally, it is important to mention that estimations of anthropogenic impacts on these reefs require more information to acknowledge their magnitude rigorously.

In summary, the Resilience and Human Intervention Indexes seem to be adequate to reflect an MPA current status: for the particular MPAs under study, the results suggest that current suboptimal state of ecological (i.e., coral cover, algae cover, fish abundance and biomass) and social components (i.e., community and institutions) might be a constraint for the socio-ecological system to face and recover from external shocks and disturbances. Although interactions between ecological and social systems given by human intervention activities (i.e., fishing, pollution, tourism)- are moderate, they are a real and crescent pressures in the two MPAs which weaken and erode even more the capacity of the system to recover from external perturbations (i.e., bleaching) (Carilli 2009). As a result, drivers that enhance socioecological resilience are not in a condition to reverse current damage and withstand external perturbations and surprises. MPA managers should focus on following the changes or modifications to the system's identity with the purpose of tracking SESs resilience through time. The index is a practical tool for MPAs authorities as an input to understand relationships among components system and identify those aspects related to resilience that should be addressed in MPA planning, monitoring, evaluation and decision making. The identification of key resilience drives is a vital step into adaptive management, since it allows managers to make decisions based on what they have learn about their own past (Dietz 2003, Folke 2005, Pomeroy 2004). Finally, it is worth to mention that a level of subjectivity is inevitable in resilience-based approach studies because SESs complexity lead to uncertain trajectories of change and states that are difficult to predict in practice, trying to understand and establish an expected behavior is essential to improve management strategies (Cumming 2005). Though there is no objective way to determine relative importance of each component, driver, indicator and variable for the indexes calculation, the assumption of equal weights is a conservative and practical approach that proved to function well as the results obtained for RI and HI matches the current situation of the studied zones.

The theoretical model used to interpret indexes suggests strategies to implement in MPAs. According to our SESs state, reorganization is key to improve management efficacy (McClanahan 2008). Therefore, to enhance protection effectiveness, MPAs under study should focus on creating adaptive management strategies that enhance community involvement. Part of this reorganization involves (1) increasing community involvement on MPA decision-making processes by building strong linkages and trust between institutions for nurturing self-organization (Walker 2006; Ostrom 2009), (2) developing community's learning capacity by enforcing local ecological knowledge and monitoring with educational activities and socializations (Folke 2002; Cinner 2009), and (3) promoting ecosystem monitoring of key ecosystem variables through the development of warning indicators of phase shifts and resilience loss (Folke 2002; Littler 2006). These concrete actions would reduce ecological and social vulnerability building a more suitable scenario for the conciliation between social and ecological systems.

The proposed approach complements multiple available frameworks that are emerging to understand complex SESs, in the face of new challenges to achieve a consensus between the information provided by different disciplines (i.e., biology, economy, and politics). This kind of efforts are vital to start recognizing common denominators needed to construct comparable databases of SESs from different regions and diverse contexts (Ostrom 2009). Capitalizing opportunities to improve our knowledge and refine available tools to study SESs, will allow us to explore new scenarios (i.e., co-management (Moreno-Sánchez 2009) to consolidate conservation goals, prevent coral reefs degradation and get closer to what we see today as a chimera: sustainability.

Conclusions

This research provides a better understanding of the interaction among the factors that confer social and ecological resilience, and suggest management practices to improve management effectiveness of MPAs. Empirically applying the concept of resilience is vital for understanding the current state of a system, predicting future directions and identifying which aspects (drivers and variables) are conferring resilience. Turning theory into a standard operational tool for management (i.e., Resilience- Human intervention indexes) will promote the understanding of complex SESs towards achieving sustainability.

RECOMMENDATIONS FOR MARINE PROTECTED AREAS STUDIED

Despite indicators results show in some particular cases differences between the two MPAs, we find general recommendations applicable for both areas that must be considered as stepping-stones to reframe the management in analyzed MPAs. The fundamental recommendation is to examine the actual management model characterized for being static and designed with top-down strategies. Results of our study make evident that this management model its not fostering or promoting the proper fulfillment of the conservation objectives detailed in the management plan.

Protected areas as living and changing entities subjected to uncertainty, can not be managed using rigid plans that do not allow managers to make adjusts when anthropogenic or natural perturbations generate changes in the system. Likewise, a rigid management scheme does not provide the means to correct or change strategies that result being ineffective or incorrect. In this sense, Colombia's conservation policy and particularly the administration of MPAs must understand the need to move to adaptive management schemes based on continuous learning and frequent monitoring and evaluation, developed with the support of external and neutral agents. In this final aspect, it is essential that executors of MPAs' conservation politics modify their perception of monitoring and evaluation exercises as an examination of their administration instead of seeing it as a vital step towards permanent improvement.

On the other hand, actual management scheme change also must be based on the recognition and respect for the local communities that historically have habit MPAs' influence zones, and, have traditionally used its resources as protein and economic income source to satisfy their basic needs.

Since reefs protected by both MPAs show characteristic of impacted ecosystems such as: high algae cover, presence of opportunistic species, low densities and sizes of fish, it is evident that anthropogenic disturbs as contamination, overfishing, and excessive tourism are seriously degrading reefs' health. The high levels of local impacts observed make reefs studied highly vulnerable to the effects of current global change (i.e., global warming, hurricanes). This situation is alarming since coral reefs are not isolated elements, on the contrary, they make part of a socioecological system where abiotic, biotic and social factors interact constantly. For this reason, management objectives associated to their conservation must change from dispersed and exclusively biological objectives to objectives that highlight the ecosystem's ecological interactions and recognize the relationships of the socioeconomic system surrounding them. Specifically, conservation objectives should be planned in a more integral and holistic way, searching to improve the general system functioning while reducing its vulnerability to natural and anthropogenic perturbations. This framework requires monitoring and evaluation exercises also based on multidisciplinary and integral approximations such as the socioecological resilience approach, that allows identifying ecological and socioeconomic elements key for an appropriate system functioning.

Understanding social and ecological dynamics and interactions together with the effects of them in the ecosystem's resilience, promotes the design of management strategies that fulfill previously mentioned requirements: i) flexibility and adaptability, and, ii) active participation of local communities. Natural perturbations that cause high impacts such as climate change leading to coral bleaching, impact not only reef ecosystems but also human populations because of the intrinsic dynamics of the socioecological system. Coral reef resources direct users, local communities, respond to changes with living strategies that can be sustainable or unsustainable in feedback loops that will have positive or negative effects for maintaining the stability of a desirable system's state. Consequently, it is very important not ignoring local communities' role as relevant elements in the socioecological system.

Even though the suggestions of actively involve local communities as resource users in MPAs management is not innovative, in Colombia we are far to make it a reality. Moreover, MPA's actual management lineaments in Colombia seem to direct a significant part of the conservation costs toward local communities, prohibiting the extraction without providing alternative real income sources or access to actives, that allow traditional resource users switch over other legal and desirable productive activities, without losing their well-being.

Our results show that local communities in the MPAs influence zones evaluated in this study, characterize for its low income, limited human capital, high natural resource dependence for food and financial income, and low government investment in public or communitarian infrastructure. These characteristics make that local communities generate livelihoods based almost exclusively in natural capital, sacrificing long-term sustainability, and thus, increasing their poverty vulnerability.

At the same time, surveys and Economic Experimental Games results indicate that these communities, with important differences between MPAs, have an enormous potential for the design and implementation of management strategies where the responsibility, rights and decision-making process are shared between the government, local communities, and other relevant actors of the zone. In fact, in both communities management strategies that involved internal cooperation rules and shared management achieved significant extraction reductions. In this way, social capital strength around marine and coastal resources conservation is a task that cannot be postponed, because it will promote norm and conservation attitudes legitimacy inside the communities. Then this legitimacy will foster in the middle and long-term the governance in these areas.

It worth to notice that management strategies must involve the government beyond the environmental authorities in charge of MPA management. It is necessary to count with the institutional coordination between several entities that administrate for example the availability of public communitarian infrastructure, fishing resources management, surveillance and control activities, among others. Management agreements or collaborative management resources strategies should function not only between communities and organizations, but also between organizations with spatial and functional overlaps. The coordination among the several organizations with responsibilities in the MPAs' influence zones is a key step for developing agreements with local communities, which generally require participation of diverse actors.

The participation in the design and implementation of management strategies include additional relevant actors such as the touristic sector. Our interviews and surveys show that big part of the information regarding the National Parks and the established norms for its recreational use are imparted by touristic guides or tour operators according to the best information that they have. In this sense, the communitarian and enterprise touristic sector become important allies for conservation objectives fulfillment.

Tools used in rural participative diagnosis developed with communities allowed to identify the broad comprehension that they have about the natural environment surrounding them and the effects that their own and external activities generate on the ecosystems. This knowledge is fundamental to complement the scientific knowledge existing in the protected areas, representing a starting point for the integral design of rules and norms associated with the management of the diverse resources that of these MPAs.

The participation of local actors as partners of conservation its an best strategy for resources management when intrinsic characteristics of the areas (marine), budget restrictions and resources to protect (fisheries), difficult surveillance and control, as usually happens in development countries.

Under this scenario, adaptive policies of shared management, besides of sharing duties and responsibilities, should first identify the characteristics and restrictions of local communities that as resource users are obligated to generate unsustainable strategies highly dependent of natural resources. In this way, policies of shared management with communities must based in converting the strict prohibited scheme into a scheme where the benefits of conservation are also transferred to those who assume its costs. This will promote, for example, the development of alternative productive activities that will allow reducing the almost-exclusive dependence of natural capital that characterize these communities.

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Appendix 1. Resilience indicators table showing the values that were used for determining resilience scale and results. Values shown were useful for recording the score of each MPA. PT= Phototransects, UVS=Underwater visual surveys, MB=Molecular biology techniques, SI=Secondary information, FA=Foraminifer's analysis, PRS=Park ranger survey, KIS=Key informant survey, EEG=Economic experimental games.

INDICATOR	RELEVANCE	VARIABLE	RESILIENCE SCALE				VALUE PNNT	VALUE PNNCRSB	SOURCE
			HIGH=3	MOD. HIGH=2	MOD. LOW=1	LOW=0			
Benthic condition	*Tridimensional structure of corals offer the complexity for sustain all reef's organisms*	Coral cover percentage	> 50%	30 - 50%	29 - 10%	< 9%	22%	23.25%	PT
		Algae cover percentage	< 9%	29 - 10%	30 - 50%	> 50%	48%	66.81%	PT
Fish population condition	*Fish play vital ecological roles: herbivory, bioerosion, trophic control, maintaining functionality and stability*	Mann-Witney test significance for differences between fish densities inside and outside MPA Herbivore fish biomass (No.)	< 0.05			> 0.05	0.255	0.894	UVS
		ANOVA test significance for differences between herbivore fish biomass inside and outside MPA	< 0.05			> 0.05	0.6021	0.1954	UVS
		ANOVA test significance for differences between predator fish biomass inside and outside MPA	< 0.05			> 0.05	0.6383	0.5454	UVS
Connectivity	*Creates genetic variability for surviving future risks*	Mantel test significance for isolation by distance model for *M. annularis* metapopulations	> 0.05			< 0.05	p<0.05	p<0.05	MB
Species diversity	*Species diversity provides functional redundancy and diversity in responses to perturbations.*	Fish beta diversity (Shannon Index)	> 3	> 2.6 - 3	> 2.1 - 2.6	0 - 2.1	2.71	2.56	UVS
		Coral beta diversity (Shannon Index)	> 3	> 2.6 - 3	> 2.1 - 2.6	0 - 2.1	1.6	2.318	UVS
Water quality	*Inorganic nutrients have deleterious effects in coral recruitment, growth and reproduction. High concentrations promote algae fast growing.*	Water quality Index (REDCAM)	Excellent	Good	Regular	Low	Excellent	Excellent	SI
		Foram Index (FI)	>4	FI 3-4	FI 2-3	FI < 2	3.28	3.68	FA
Rule's legitimacy and compliance	*Rule's are knowledge repositories that provide system memory to maintain itself as a cohesive entity in space and time, providing continuity (Cumming et al., 2005). If rules are understood and followed management will be effective (Pomeroy, 2004)*	Percentage of park-rangers that consider rules are designed to achieve conservation objectives	80-100%	50-80%	30-50%	0-30%	69.33%	65%	PRS
		Percentage of local community surveyed that have a good perception regarding MPA existence	80-100%	50-80%	30-50%	0-30%	77%	94%	LCS
		Percentage of the community that would denounce regarding the non-compliance of informal and formal rules	80-100%	50-80%	30-50%	0-30%	52%	37%	KIS
		Percentage of community that know rules	80-100%	50-80%	30-50%	0-30%	52.75%	51.30%	KIS
		Percentage of fishermen, tourists and community that follow MPA' rules	80-100%	50-80%	30-50%	0-30%	16.66%	30%	PRS
Enforcement and surveillance	*Enforcement and surveillance activities are crucial for successful management since authorities can asses violation trends and users can be aware of non-compliance consequences (Pomeroy, 2004).*	Percentage of park-rangers and community that consider the park has capacity to enforce rules	80-100%	50-80%	30-50%	0-30%	47.50%	46%	PRS
		Percentage of park-rangers that consider the sanctions are easy to implement	80-100%	50-80%	30-50%	0-30%	58.33%	20%	PRS
		Frequency in surveillance routes and coverage of control in MPA	Every day	Three days per week	One day per week	One day every two weeks or less	3 times per week	Once a week	PRS
		Proportion of reduction in extraction as a result of a co-management rule in EEGs	80-100%	50-80%	30-50%	0-30%	81%	49.4%	EEG
		Percentage of community that consider the natural resources management must be between community and environmental authority	80-100%	50-80%	30-50%	0-30%	66%	19%	KIS
		Percentage of community that consider environmental authority has legitimacy	80-100%	50-80%	30-50%	0-30%	87.50%	50%	PRS
Social capital and community participation	*Social networking and trust guarantee the proper flow of information and the capacity to adapt to change (Walker et al., 2006)*	Potential internal cooperation within communities	80-100%	50-80%	30-50%	0-30%	56.4%	43.2%	EEG
		Percentage of community that participate in meetings and workshops with park authorities	80-100%	50-80%	30-50%	0-30%	66%	49%	KIS
Training and education Level (Human Capital)	*Training and education increase stakeholders understanding of human-nature interactions and contemplates ways*	Average years of academic studies	>10	7-9	4-6	0-3	8	6	KIS
		Frequency of informal education activities for fishermen	One activity every week	One activity every two weeks	One activity every three	One activity every month	Once every two weeks	Every month	PRS

	to improve them, elements that provide capacity to learn (Pomeroy, 2004; Cinner et al., 2009).		weeks						
Income Level (Financial Capital)	*Low income causes high resource dependence, affecting ecosystem's flexibility to unexpected changes (Cinner et al., 2009)*	Average household incomes every month	More tan US$750	US $400 - $750	US$200 - 400	Less than US$200	US$366.342	US$210.92	KIS

Appendix 2. Human-Intervention Indicator table showing the values that were used for determining impact scale. Values shown were useful for recording the score of each MPA. SI=Secondary information, PW=Participative workshop whit community, TS=Tourist survey, GIS= Geographic Information System.

INDICATOR	RELEVANCE	VARIABLE	INTERVENTION SCALE				VALUE PNNT	VALUE PNNCRSB	SOURCE
			LOW=0	MOD. LOW=1	MOD. HIGH=2	HIGH=3			
Overfishing	*Overfishing affects trophic integrity by removing top predators and creates cascades that alter other guilds. Exploiting herbivorous fish alters the dynamic between algae and corals by removing the natural control of fast growing algae populations. Destructive fishing practices damage directly the ecosystem by changing it physically and ecologically*	Percentage of fishermen that consider fishing is highly impacting the ecosystem	0-30%	30-50%	50-80%	80-100%	43%	38.00%	EEG
		Use of destructive fishing gears	No			Yes	YES	YES	PW
		Percentage of herbivores fish in harvest relative to fish surveys	0-30%	30-50%	50-80%	80-100%	3%	30.58%	SI
Pollution level	*Pollution refers to the increase in sediments, nutrient loads and water turbidity which have negative effect in the natural environment of coral reefs*	Percentage of rural households that have access to sewage system	80-100%	50-80%	30-50%	0-30%	2.5%	5.38%	SI
		Percentage of rural households that have sanitary service connected to a sewage system	80-100%	50-80%	30-50%	0-30%	1.78%	3.71%	SI
		Percentage of rural households that report municipality is in charge of waste disposal	80-100%	50-80%	30-50%	0-30%	56%	14%	SI
		Distance to inhabited location	> 15 Km	10 - 15 Km	5 - 10 Km	0 - 5 Km	9.37 Km	13.18 Km	GIS
		Distance to points of discharge to the sea (waste and sewage) and ports	> 35 Km	25 - 35 Km	10 - 25 Km	0 - 10 Km	20.48 Km	23.42 Km	GIS
Tourism pressure	*Physical damage by inexpert divers in coral colonies cause coral death and reduce growth. Resort construction and operation impacts are indirect but relevant.*	Distance to touristic places	> 15 Km	10- 15 Km	5 - 10 Km	0 - 5 Km	11.17Km	5.86 Km	GIS
		Percentage of tourists that are willing to pay more than US$4	80-100%	50-80%	30-50%	0-30%	37.40%	42.60%	TS