Governance Factors Affecting the Ecological Performance of Marine Reserves in the Wider Caribbean

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ABSTRACT

Marine reserve outcomes or reserve performance is related to the complexities of linked social and ecological systems. In this study, we examine the formal and informal governing arrangements linking humans and natural resources, the social and ecological context within which these arrangements are embedded, and the effect these arrangements have on the performance of marine reserves. In 2006 - 2008, a systematic survey was conducted of thirty one reserves in the wider Caribbean, all containing coral reef habitat. Ecological conditions were assessed by making SCUBA surveys of coral reefs inside each reserve and at nearby control sites. Key informant interviews, structured surveys, and documentary analysis were used to assess the political, social, and cultural conditions in the surrounding human communities. Indicators of reserve performance were developed by combining social and ecological measurements to gain a more complete understanding of overall performance. Interrelationships between data on reserve characteristics, management outputs, participatory process features, user compliance, community members' perceptions of reserve effects, and other governance factors were examined in relation to reserve outcomes. Marine reserve managers in the Caribbean can incorporate these results into on-going management programs to help reserves meet social and ecological objectives.

KEY WORDS: Marine reserves

Factores Ecológicos y Sociales que Afectan la Eficiencia de las Reservas Marinas en el Caribe

Los resultados obtenidos en el desempeño de las labores de gestión en las reservas marinas están relacionados con las complejidades de los sistemas ecólogicos y sociales existentes en éstas áreas. En este estudio, examinaremos los mecanismos formales e informales que gobiernan las relaciones que unen a las personas y los recursos naturales, el contexto social y ecológico dentro del cual estos mecanismos están incluidos, y el efecto que éstos tienen en la gestión adecuada de las reservas marinas. Entre 2006 - 2008, se condujeron una serie de encuestas estructuradas en treinta y una reservas, todas las reservas tenían ambientes arrecifales. Las condiciones ecológicas fueron analizadas realizando inmersiones en los arrecifes de coral en cada reserva y tomando puntos de control cercanos a las mismas. Se realizaron entrevistas a personas claves y expertos, además de encuestas estructuradas y análisis de documentación que fueron utilizados para valorar las condiciones políticas, sociales y culturales en las comunidades limítrofes que están influenciadas por a las reservas marinas. Los indicadores de resultados fueron escogidos combinando parámetros sociales y ecológicos que nos dieran un completo entendimiento de la eficiencia del funcionamiento de estas reservas. Las interrelaciones entre los datos característicos de cada reserva, los resultados de su gestión, los procesos de participación, el comportamiento de los usuarios, las percepciones de los miembros de las comunidades sobre los efectos causados en las reservas y otros factores relacionados con la gobernabilidad fueron examinadas en relación a los resultados obtenidos. Los gestores de las reservas en el Caribe pueden incorporar estos resultados y adaptar sus programas de gestión con el objetivo de ayudar a la mejora en la consecución de sus objetivos sociales y ecológicos.

PALABRAS CLAVES: Reservas marinas

Les Facteurs Sociaux et Écologiques Affectant la Performance des Réserves Marines au Large de la Mer des Caraïbes

Les résultats de réserve marine ou la performance de réserve sont rattachés aux complexités des systèmes sociaux et écologiques associés. Dans cette étude, nous examinons l'activité gouvernante formelle et informelle reliant des humains et des ressources minérales, le contexte social et écologique dans lequel cette activité est fixée et l'effet que cette activité a sur la performance de réserves marines. En 2006 - 2008, une enquête systématique a été conduite dans trente et une réserves au large de la mer des Caraïbes, toutes contenant un habitat de récif de corail. Les conditions écologiques ont été évaluées en faisant des enquêtes de PLONGEE des récifs de corail à l'intérieur de chaque réserve et aux sites de contrôle proches. Des interviews d'informateur principal, des enquêtes structurées et une analyse documentaire ont été utilisés pour évaluer les conditions politiques, sociales et culturelles dans les communautés humaines environnantes. Les indicateurs de performance de réserve ont été développés en combinant des mesures sociales et écologiques pour gagner une compréhension plus complète de performance totale. Les interactions entre les données sur les caractéristiques de réserve, les rendements de gestion, caractéristiques de processus participatif, la conformité d'utilisateur, les perceptions des membres de la communauté des effets de réserve et d'autres facteurs de gouvernance ont été examinées par rapport aux résultats de réserve. Les directeurs de réserve marine dans les Caraïbes peuvent incorporer ces résultats dans les programmes de gestion en cours pour aider les réserves à atteindre les objectifs sociaux et écologiques.

MOTS CLÉS: Réserves marines

INTRODUCTION

Hundreds of marine protected areas (MPAs) have been established in the wider Caribbean to prevent fish stock declines, habitat degradation, and other impacts to coral reef resources (Burke and Maidens 2004). Marine reserves, a type of MPA that prohibits extractive uses inside the reserve to maintain or enhance natural resources, are rapidly gaining momentum as a conservation tool in this region. It is believed that marine reserves can improve ecological conditions, yet only a few studies have assessed governance factors influencing their biological performance (e.g., Pollnac *et al*. 2001, Halpern 2003, Micheli *et al*. 2004, McClanahan *et al*. 2006, 2008, Mora 2006, Cinner *et al*. 2009, Lester *et al*. 2009, Guidetti and Claudet 2010, Selig and Bruno 2010, Pollnac *et al*. 2010). To ensure that marine reserves achieve biological success, it is necessary to understand how governing arrangements, such as laws, administrative rules, judicial rulings, and practices that constrain or enable the allocation of natural resources (Lynn 2001), affect the performance of reserves. In this study, we examine how key governing arrangements in marine reserves in the wider Caribbean affect their ecological performance.

BACKGROUND

Marine reserve performance is comprised of desirable social and ecological characteristics of reserves and their associated human communities. Social measures of performance can include changes in well-being, community empowerment, perceptions of biological conditions, and completion of project outputs like management plans. Ecological measures of performance include fish abundance, fish biomass and diversity, spillover of adult fish from within MPA boundaries, export of larvae from within MPA boundaries, and coral cover.

Key governing arrangements affecting performance of marine reserves include design characteristics of the reserve (e.g., age, size, use zones, others), management factors associated with reserve decision making and ongoing operation (e.g., community participation, development of management plans and installation of boundary markers, formal monitoring programs, active surveillance, others), and contextual factors (e.g., level of conflict in the community, population density of adjacent community, level of socioeconomic development, others) (Table 1).

Table 1. Selected governance factors that can influence ecological performance of marine reserves

DESIGN
Size of protected area
Size of no take area
Age of protected area
Part of a political network of reserves
Different use zones
Rules on diving
Rules on fishing
MANAGEMENT
User fees charged to tourists
User fees charged to local residents
Number of visitors
Opening ceremony for reserve
Management plan developed
Informational signboards in community
MPA boundary markers
Council participates in reserve management
Council has influence over reserve decisions
Quality of decision making process
Formal monitoring program
Community members participate in monitoring
Active patrols
User compliance with reserve rules
Alternative income projects developed
CONTEXT
Population density of adjacent community
Number of communities associated with reserve
Distance of nearest town to reserve
Visibility of reserve from nearest community
Level of conflict in community
Community input in decision making
Level of community development

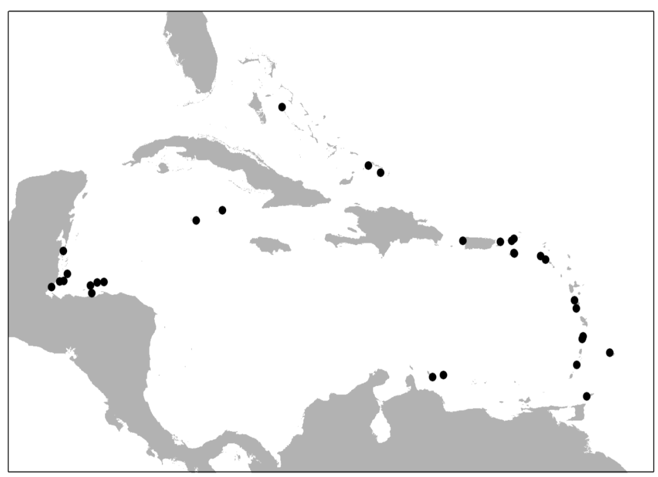

Figure 1. Marine reserve study sites in wider Caribbean

METHODS

In 2006 - 2008, we conducted a systematic survey of thirty-one marine reserves, all containing coral reef habitat, and 48 associated human communities in the wider Caribbean (Figure 1).

Changes in fish biomass associated with reserve establishment, a common ecological objective of marine protected areas, were used to estimate marine reserve performance. At each study site, biological surveys were conducted at 2 - 6 sites where fishing is prohibited (no take areas). Where no take areas were embedded in larger MPAs zoned to have some limits on fishing, boating, snorkeling or diving, 2 - 6 sites in those restricted areas were also sampled. Where possible, 2 - 6 sites were sampled in nearby comparable habitat outside the MPA. Divers made fish counts searching roughly 2 ha of reef for

45 min. During the 45 min. swim, divers counted all diurnal fish of species targeted by fishers that appeared to be > 25 cm in total length. The size of each fish judged > 25 cm was estimated to the nearest 5 cm. Estimates of fish body lengths were converted to mass using length-weight regressions from Fishbase (Froese and Pauly 2009). Mass estimates were summed to yield the total mass of fish per site, or fish biomass. Log-response ratio (ln*RR*) was used to measure the proportional response of fish to protection by the reserve. This was calculated as ln*RR* = ln(*inside*/*outside*), where *inside* and *outside* are the mean biomass of reef fish inside and outside the reserve, respectively.

Documentary analysis, key informant interviews, and structured surveys were used to assess governance factors of marine reserves and their associated human communities (Table 1). At each site, we examined legislation establishing the reserve and other relevant legislation and management documents. We conducted semi-structured interviews with key informants who were knowledgeable about the reserves and local communities. In structured community member surveys, we collected data on individuals' involvement in marine reserve management and planning, perceptions on changes in ecological features since reserve establishment, perceptions of rules, participation in alternative income opportunities, and others.

ANALYSIS

Table 2 includes significant correlations (Spearman's Rho) between the selected independent variables and marine reserve performance as measured by changes in fish biomass in the reserve. All relationships with changes in fish biomass were expected to be positive except for population density, visibility of reserve from the nearest community, and community conflict level, which were expected to manifest negative relationships (e.g., as the latter three variables increase, improvements in fish biomass within the reserve were expected to decrease). All correlations support these expectations and are statistically significant at the 0.05 level (one-tail tests used since direction of relationship is predicted).

We examined the combination of variables that best predict marine reserve success (increases in fish biomass in the reserve since the reserve was established) using a backwards stepwise regression. In a backwards stepwise regression, all variables are entered into the regression equation, then variables are removed in a stepwise manner with the first one removed being the variable that has the lowest partial correlation with the dependent variable (changes in fish biomass associated with the marine reserve) with all other variables controlled. After removal of the first variable, all remaining variables are entered into the regression equation and the variable that has the lowest partial correlation with the dependent variable with all other variables controlled is removed. This procedure is continued until a specified criterion is reached. In this analysis, variables with partials having probabilities > 0.05 were removed. All tolerance levels were greater than 0.10 and partials were examined at each step, both procedures indicating no problems with multi-collinearity in the final model (Table 3).

Table 2. Correlations (Spearman's Rho) between independent variables and change in fish biomass

	Fish Biomass
Size of protected area	.346*
Population density of adjacent community	-.417**
Number of communities associated with reserve	.423**
Distance of nearest town to reserve	.383*
Visibility of reserve from nearest community	-.393*
User fees charged to local residents	.397*
Different use zones	.415*
Council has influence over reserve decisions	.380*
Level of conflict in community	-.355*
Formal monitoring program	.481**
User compliance with reserve rules	.350*
Active patrols	.445**

*= $p < 0.05$ **= $p < 0.01$ (one tailed)

Table 3. Results of backwards stepwise regression analysis

Effect	**Standard Coefficient**	**t**	**p**
CONSTANT	0.000	-2.127	0.04
Number of communities associated with reserve	0.366	2.524	0.02
User compliance with reserve rules	0.338	2.278	0.03
Different use zones	0.292	2.014	0.05
Level of conflict in community	-0.297	-2.066	0.05

$R = 0.71$, $R^2 = 0.51$, adj. $R^2 = 0.43$, $F = 6.34$, df 4, 24, $p = 0.001$

3 cases deleted from analysis due to missing data on at least 1of the 4 remaining variables.

The final model indicates that 43% of the variance (adjusted R-squared) in marine reserve success as measured by the fish biomass index can be accounted for by the four variables in the model: number of communities associated with the reserve, user compliance with reserve rules, presence of different use zones, and level of conflict in the community. Standardized regression coefficients indicate that number of communities associated with the marine reserve account for most of the variance while level of community conflict is negatively related to reserve performance (the greater the conflict, the lower the level of success). Overall, however, all the variables account for markedly similar levels of variance in marine reserve performance as measured here.

CONCLUSIONS

Our analysis indicates that four variables together account for about 43% of the variance in the performance measure (Table 3). The probability that this could have happened by chance alone is 1 in 1000. What does all this mean? It means that if the marine reserve in our sample:

i) Is associated with a number of communities,
ii) Manifests a high compliance rate,
iii) Has different use zones, and
iv) Is associated with a community with a low level of conflict,

it is likely to score high on the performance measure. This can be illustrated by constructing a measure reflecting the presence or absence of each of these characteristics and looking at mean fish biomass values across the groups manifesting different values on this newly constructed measure. To accomplish this, several new variables are created by dichotomizing each variable at the sample mean (use zones was already a dichotomy), assigning a value of 1 to each variable above the mean, except for conflict level which received a value of 1 if below the mean since it was negatively related to success. Scores (one or zero) for all four variables are summed, resulting in a scale with a theoretical range of 0 to 4 for each marine reserve in the sample. We refer to this variable as total number of predictor variables. If we divide the sample into five groups based on their score on this scale, we can then plot the mean value for changes in fish biomass for each group (Figure 2). It is clear that as the number of ''predictor'' variables having a ''positive'' value at a site increases up to a total of 3, so does the level of marine reserve performance as measured by changes in fish biomass. After this point, having another positive predictor variable does not seem to have any effect.

In sum, the results indicate that marine reserves in our sample are likely to have increased fish biomass within the reserve if they are associated with several communities, if they manifest a relatively high compliance rate, have zones to regulate use, and are located in a community manifesting a low level of conflict. Marine reserve managers in the Caribbean can incorporate these results into on-going management programs to increase chances of achievingmarine reserve success.

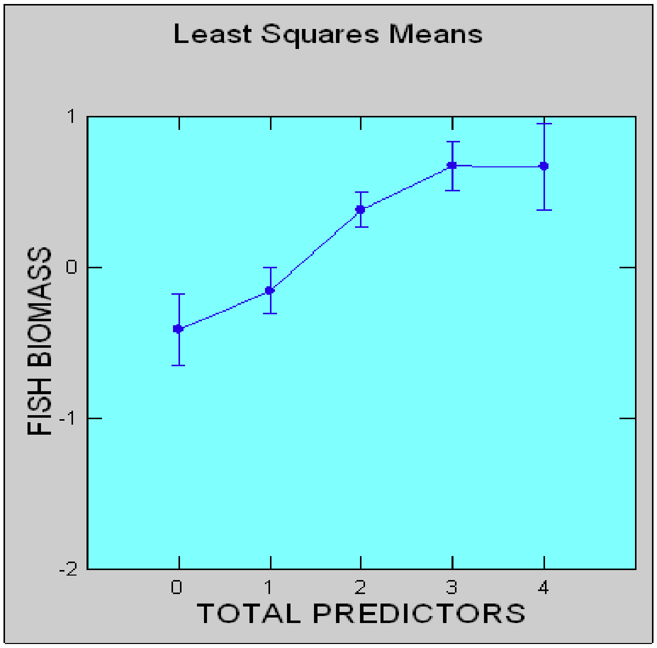

Figure 2. Mean of the change in fish biomass plotted against number of predictor variables present (bars indicate standard error)

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