Exploring the Role of a Tropical Marine Protected Area to Mitigate Fishing Impacts on Ecosystems: A Meso-scale Spatial Simulation Approach

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ABSTRACT

Tayrona National Natural Park (TNNP) is one of the protected areas included in the Colombian governmental system. TNNP holds a high biodiversity ecosystem which registered more than 40% of the Colombian Caribbean marine species. In this area, artisanal fishing has been carried out for years, but assessments about potential effects of fishing on ecological functioning have not been achieved. A spatial simulation Ecospace model was constructed for the TNNP ecosystem to explore the potential role of the protected area to mitigate the effects of fishing on functional groups. The input parameters for the model were derived from an extensive review of published and unpublished sources. A total of 32 compartments including detritus, primary producers, invertebrates, fishes, marine mammals and birds, were defined in the model. Three scenarios were simulated for a period of 20 years considering: (1) the whole TNNP as a no-take zone, (2) the current established no-take zones, and (3) without no-take zones. In terms of predicted biomasses and catches, the scenario with a partial protection of the TNNP shows marginal difference with the one without no-take zones. In contrast, simulation of protecting the whole TNNP shows increments in predicted biomasses of several functional groups with a consequent spillover effect. According to the ecological benefit showed in the results, it is recommendable to close the TNNP to fishing. Hence the local capabilities to control the fishing effort and to provide alternative activities for the fishers should be assessed in the region.

KEY WORDS: Marine protected area, Ecospace, Caribbean Sea, Artisanal fishing.

Explorando el Papel de un Área Marina Protegida Tropical como una Medida de Mitigación del Impacto de la Pesca sobre el Ecosistema: Aproximación a Partir de Una Simulación a Escala Espacial

El Parque Nacional Natural Tayrona (PNNT) es una de las áreas protegidas incluidas en el sistema gubernamental colombiano. El PNNT posee una alta biodiversidad que registra más del 40% de especies marinas del Caribe colombiano. En esta área, por años se han llevado a cabo actividades de pesca artesanal, pero no se han realizado evaluaciones del efecto potencial de la pesca sobre el funcionamiento ecológico. Un modelo de simulación espacial fue construido del ecosistema PNNT para explorar el papel del área protegida para mitigar los efectos de la pesca sobre los grupos funcionales del ecosistema. Los parámetros de entrada del modelo fueron derivados de una extensa revisión de literatura. Un total de 32 compartimientos incluyendo detritus, productores primarios, invertebrados, peces, mamíferos marinos y aves, fueron definidos en el modelo. T res escenarios de simulación para un periodo de 20 años fueron considerados: (1) la totalidad del PNNT como área marina protegida, (2) el establecimiento de zonas intangibles, y (3) sin área protegida en el PNNT. En términos de biomasas y capturas predichas, el escenario con una parcial protección del PNNT mostro diferencias marginales con relación al escenario sin protección. En contraste, la simulación protegiendo completamente el PNNT revelo incrementos en las biomasas predichas de diferentes grupos funcionales y un efecto excedente pudo ser detectado. En concordancia con el beneficio ecológico mostrado en los resultados, es recomendable cerrar las actividades de pesca en el PNNT; por tanto es importante que la capacidad local para el control del esfuerzo pesquero y los mecanismos para proveer alternativas de sustento a las comunidades pesqueras artesanales deban ser evaluados.

PALABRAS CLAVES: Área marina protegida, Ecospace, mar Caribe, pesca artesanal

Exploration du Rôle d'une Zone Tropiale Marine Protégée Pour Atténuer Les Impacts de la Pêche Sur L'écosystème. Une Approche de Simulation D'échelle Mésoscopique Spatiale

Le Tayrona National Natural Park (TNNP) est une des régions protégées comprises dans le système gouvernemental colombien. Le TNNP détient un écosystème élevé de diversité biologique qui a enregistré plus de 40 % des espèces marines antillaises colombiennes. Dans cette région, la pêche artisanale a été pratiquée pendant des années, mais les évaluations des effets potentiels de la pêche sur le fonctionnement écologique n'ont pas été effectuées. Un modèle de simulation spatiale Ecospace a été construit pour l'écosystème du TNNP pour explorer le rôle potentiel de la région protégée à atténuer les effets de la pêche sur les groupes fonctionnels. Les paramètres de contribution pour le modèle ont été tirés d'une révision étendue de sources publiées et non publiées. Un total de 32 compartiments comprenant des détritiques, des producteurs primaires, les invertébrés, des poissons, des mammifères marins et des oiseaux, a été défini dans le modèle. Trois scénarios ont été simulés pour une période de 20 ans en considérant : (1) tout le TNNP comme zone no-take, (2) les zones actuelles établies no-take et (3) sans zones no-take. En termes de biomasses prédites et de prises, le scénario avec une protection partielle du TNNP montre que la différence marginale avec celui sans zone no-take. Par contre, la simulation de protection de tout le TNNP montre des augmentations dans les biomasses prédites de plusieurs groupes fonctionnels avec un effet de débordement conséquent. Selon l'avantage écologique montré dans les résultats, il est recommandable de fermer le TNNP à la pêche; donc les capacités locales de contrôler l'effort de pêche et fournir des activités alternatives aux pêcheurs doivent être évaluées dans la région.

MOTS CLÉS: Aires marines protégées, Ecospace, mer des Caraïbes, pêcheries de petite échelle

INTRODUCTION

Marine reserves have been created to manage fishery resources with commercial importance and to preserve biodiversity in general (Pomeroy *et al*. 2004, Sobel and Dahlgren 2001). Tayrona National Natural Park (TNNP) is one of the marine protected areas included in the Colombian Caribbean, but, reporting historically artisanal fishing (Manjarrés *et al*. 2004). Research shows that fishing activities have impacts on fish population and the ecosystem (Hawkins and Roberts 2004, Mumby *et al*. 2007). However, they have impacts on important target species and equally on species of little interest, changing the ecosystem structure (Jennings *et al*. 1995, Mumby *et al*. 2007).

Protected areas are natural refuge for different species, which, helping to fishing though transport of biomass to adjacent zone (Roberts *et al*. 2001). Creating protected areas has huge responsibilities in terms of conservation and productivity that require a constant assessment of their effectiveness. Considering the species mosaic in that ecosystem, the analysis to generate conservation and manage politics should include a holistic analysis.

The ecosystem approach using Ecopath with Ecosim allows to include different system components (Christensen and Walters 2004, Pauly *et al*. 2000), presenting an analysis of the trophic interactions developed in the ecosystem; the static model (Ecopath) is used as a basis to explore the scenarios of spatial simulation (Ecospace) to assess marine protected areas effectiveness (Walters *et al*. 1998). This research aims at building the first Ecopath model of the marine area of the TNNP and achieving spatial simulations to explore different protection levels in the area to assess their effectiveness.

MATERIALS AND METHODS

TNNP (11°16'N-11°21'N and 73°53'W-74°13'W) is located on the coast of the Colombian Caribbean (Figure 1). Marine protected area of TNNP has an approximate extension of 30 km^2, including coral reefs, seagrasses, mangrove inlets, algae turfs and soft bottoms. It is featured for rocky coast, steeps, bays and islets; it is influenced by the mountainous system of the Sierra Nevada de Santa Marta. (Díaz 2000, Garzón-Ferreira and Díaz 2003).

Ecopath with Ecosim approach (version 5.1; Christensen *et al*. 2005) was used to construct a trophic model of the TNNP marine ecosystem (described in Diaz-Vesga and Duarte 2009). The input parameters for the model were derived from an extensive review of published and unpublished sources, compiling information about biomass, metabolic rates, habitats, diets and sizes of the biota in the system. The biomass information was obtained of local studies (Acero and Rivera 1992, Doncel *et al*. 2005, Navas *et al*. 2002, Olaya 2006, Rodríguez *et al*. 2003) or it was calculated to the balance solution in the model (Phytoplankton, octopus/squids, marine turtles, pelagic fishes and sharks/skates). For production and consumption metabolic rates, information available in the literature of similar tropical ecosystems was used (Garcia and Duarte 2002); or estimates from empirical equations were employed (Palomares and Pauly, 1989). Information

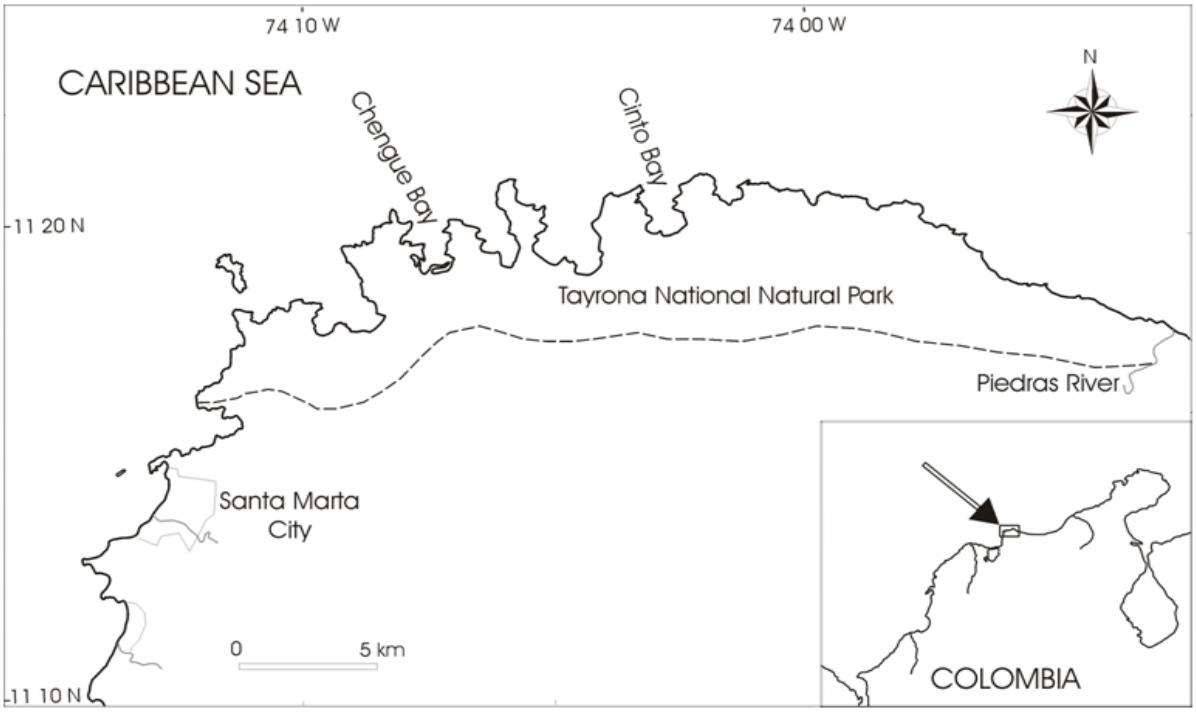

Figure 1. Location of Tayrona National Natural Park. Dotted line represents the terrestrial boundaries of the Park. Current no-take zones (Chengue and Cinto bays) are indicated.

of the diet was obtained of local studies (Duarte *et al*. 1999) or was derived from other models (Opitz 1996).

For the spatial analysis, Ecospace simulations were performed (Walters *et al*. 1999), starting with the biomass obtained in the mass-balanced model, with a simulation period of twenty years. Different habitats and functional groups were assigned in a base map of TNNP marine area developed with the Ecopace routine. Catch data of the year 2000, obtained of the Catch and Fishery Effort Information Analysis System - PICEP (Manjarrés *et al*., 2004), were used as volumes of extraction in the spatial model. Three scenarios were simulated, considering:

i) The whole TNNP as a no-take zone,
ii) The current established no-take zones (Chengue and Cinto bays), and
iii) Without no-take zones.

RESULTS

The scenario of the whole protection on TNNP predicted an increment in the biomass on the large predators (sharks/skates, pelagic carnivore fishes), a local decrease in the biomass on the echinoidea, herbivore fishes and omnivore fishes. Changes in the large predators' biomass were less evident in the current established no-take zones and without no-take zones simulations (Figure 2). Furthermore, an increment in the catch (respect to the initial volumes of the simulation) was observed in the scenarios (2) and (3). In contrast, for the simulation with whole protection was observed a reduction in the catch of 80% with respect to the initial parameters of the simulation in Ecospace.

DISCUSSION

The ecosystem approach enables the use of the marine protected areas and offers tools to generate effective measures of manage and conservation (Walters *et al*., 1999). The simulations of the spatial protection scenarios observed an increase of the biomass of the large predators predicting a top-down effect, *i.e.* an increase of the biomass in the top predators and a decrease of the biomass in preys (Cury *et al*. 2003). This effect generates conditions in the ambient affecting positively or negatively some ecosystem groups, but stabilizing properties of predation have been suggested in the ecosystem dynamics (McCann 2000).

The exploration of changes in the catch during the Ecospace simulation suggests that a partial protection in the marine area of TNNP shows marginal differences with relation to the scenario without protection, *i.e.* with an open access scheme for the resources use. Walters (2000) suggest that marine protected areas should not be small fractions of the ecosystems since it is required to guarantee the integral supporting of species and mosaics in the system. The potential benefit of a small protected area should be transformed in a negative effect on the ecosystem, as a consequence of the increment in the fishing effort near its boundaries. In fact, high movements rates of preys that attract predators outside of the protected area can increase the availability of target species to fishing gears.

According to simulations results, a complete protection (close to fishing) of TNNP is required to preserve the resources for the ecosystem sustainability. Hence the local capabilities to control the fishing effort should be assessed in the region. However, such ecological goal should be accompanied with economical alternatives for the artisanal fishers in order to avoid negative social impacts. Participatory management schemes involving National Natural Park administrators, governmental organizations, industries, tourism operators, scientists and local communities appear to be a sound option.

ACKNOWLEDGEMENTS

This study was supported by the Departamento Administrativo de Ciencias, Tecnología e Innovación - Colciencias (Young Researchers and Innovators Program Grant 090-2007 and Grant 1117-335-18591), Universidad del Magdalena and UAESPNN.

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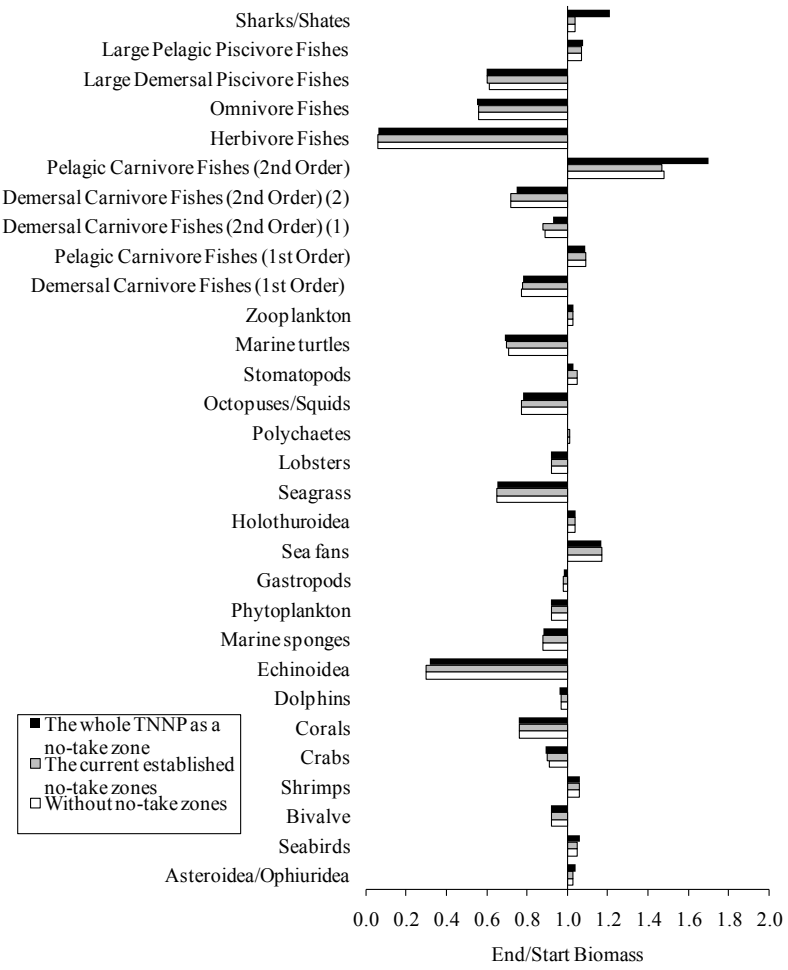

Figure 2. Changes of the functional groups biomass predicted in the three scenarios of spatial simulation.

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