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Spatial Analysis of a Coastal Area for Conservation and Fishery of Mangrove Edible Crab (Ucides cordatus)

Luciana C. M. Santos††*, Mario M. Rollo Jr., Tânia M. Costa†, Marcelo A. A. Pinheiro†, Farid Dahdouh-Guebas‡, and Marisa D. Bitencourt§

† Instituto de Biotecnologias, Universidade Estadual Paulista Júlio de Mesquita Filho, UNESP, Campus do Litoral Paulista, São Vicente, SP, Brasil. ‡ Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles, ULB, Bruxelles, Belgique. § Departamento de Ecologia, Instituto de Biotecnologias, Universidade de São Paulo, USP, São Paulo, SP, Brasil. *Corresponding author: santos.lucianacm@gmail.com

ABSTRACT


Mangroves are productive ecosystems of tropical coastal landscapes, constituting habitat for many commercial fisheries, as the crab Ucides cordatus. In Brazil this crab holds a major socio-economic importance for artisanal fishery, but with obvious decline on their productivity. In this study we determined and mapped the more suitable mangrove areas for the conservation and fishery of this crab in the São Francisco River Estuary (Northeastern Brazil). We applied a Multi-Criteria Evaluation (MCE) in a GIS environment. Ten criteria in total were used, including crab biotic parameters, land use/cover and social factors. Maps of each criterion were produced by GIS techniques with CBERS and SPOT images and by field data. Mangroves more suitable for the conservation of U. cordatus (9.4 km²) are near to the river mouth, due to high density and frequency of non-commercial size crabs (NCSC), low density of commercial size crabs (CSC), small crabs and low degree of use for fishery. On the other hand, the mangroves for the crab fishery occurred with a similar area (10.2 km²) located farther away from the river mouth, with a high density and frequency of CSC, low density of NCSC, big crabs, medium-high degree of use for fishery and near to the villages. These information and thematic maps can aid government agencies in delineating extractive and fishery exclusion areas, thus contributing to the management plan for this species.

ADDITIONAL INDEX WORDS: Mangrove, remote sensing, fishery management.

INTRODUCTION

Mangroves are coastal forests that occupy saline tidal areas along sheltered bays, estuaries, and inlets in the tropics and subtropics throughout the world, where they fulfill several ecological, environmental and socio-economic functions (Barbier et al., 2011; FAO, 2007). From them, it is remarkable the role of mangroves as habitats for many commercial fishery species, thus supporting small-scale fishery along the world’s (sub) tropical coast (Rönnbäck, 1999). From a diversity of fishery resources exploited in the mangrove environment, crabs are among the many commercially important species caught throughout the tropics (Macnae, 1974). In Brazil, the mangrove crab Ucides cordatus (Linnaeus, 1763), a semiterrestrial crab that lives only in mangroves (Schories et al., 2003), is a keystone species of this ecosystem and a major socio-economically important species for artisanal fishery (e.g., Magalhães et al., 2012; Cortés et al., 2014). Despite its importance, declines of U. cordatus have been reported in many regions of Brazil and were related to mangrove destruction, diseases and overfishing (Boeger et al., 2005; Diele et al., 2005). This crab shows slow growth, high age at maturity, long-lived (>10 years), low reproductive output and low natural mortality, suggesting vulnerability to exploitation (Diele et al., 2005). Since 2004 it has been included in the Brazilian National List of aquatic invertebrates species threatened with overexploitation and at risk of becoming extinct (Pinheiro and Rodrigues, 2011). This highlights the need for management strategies that allow the conservation of this resource in a sustainable fishery approach, as stated by the Proposal of a National Management Plan for the species, with the delineation of extractive and fishery exclusion areas (Brasil, 2011; Pinheiro and Rodrigues, 2011).

Considering this scenario, resource allocation for use or conservation, are also prime candidates for analysis with GIS and remote sensing techniques (Eastman, 2012). In the case of Socio-Ecological Systems (SES), as in fishery systems, where natural, human, and management systems have a complex interaction (Charles, 2001), several criteria will need to be evaluated for conservation and fishery management purposes. Therefore, it is crucial the understanding of the interrelationships among the various parts of the SES (Griffis.

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*Corresponding author: santos.lucianacm@gmail.com
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and Kimball, 1996), requiring the development of analytical and operational evaluation tools for decision-making (Andalecio, 2010), that include all of these parts and aspects. In these cases which involve multidisciplinary knowledge bases, a GIS procedure called Multi-Criteria Evaluation (MCE) is the most appropriate to achieve conservation and management use purposes (Huang et al., 2011). MCE provides a systematic method to combine the inputs with cost/benefit information as well as stakeholder views to rank project alternatives (Huang et al., 2011). MCE has demonstrated its utility in many environmental issues that link economic, environmental, cultural and technical issues of management, such as in fisheries management (Andalecio, 2010).

In the São Francisco River Estuary (Sergipe State, Northeastern Brazil) U. cordatus is the second most important mangrove fishery resource (Santos et al., 2013). However, decreases in this species’ stock have been reported since 2000, requiring the definition of mangrove areas more suitable for the conservation and fishery of this crab, in order to maintain the natural stock of the resource and a sustainable fishery. This study aimed to determine the most suitable mangrove areas for the conservation and fishery of the crab U. cordatus in the Estuary of the São Francisco River, using a MCE analysis, and taking into account a perspective that minimize the restrictions on the fishing and allow a socio-ecological sustainable fishery.

METHODS

Study area

The study area is part of the São Francisco River Basin, one of the most important Brazilian water resources, and is located in the coastal zone of the Sergipe State (Northeastern Brazil) (Figure 1). The study area corresponds to the southern part of the São Francisco River Estuary (municipalities of ‘Brejo Grande’ and ‘Pacatuba’) (10°30’27”S, 36°23’45”W) and covers approximately 192.35 km². This estuary shows a mangrove extent of 31.9 km², which corresponds to about 16% of the study area (Santos et al., 2014a). Other land cover and uses present are: sandy coastal vegetation, agriculture and aquaculture (Santos et al., 2014a). A total of eight fishery villages are distributed in this area, where fishery in the mangrove areas, especially of the crab U. cordatus, is the main economic subsistence basis for the local populations (Santos et al., 2013).

Method

A Multi-Criteria Evaluation (MCE) was applied to determine the most suitable mangrove areas for the conservation and fishery of the crab U. cordatus in the São Francisco River. For this, we applied the MCE Decision Support tool in the IDRISI Selva GIS and considered the Weighted Linear Combination (WLC). The module that calculates one final weight for each criterion requires the definition of mangrove areas more suitable for the conservation and fishery of this crab, in order to maintain the natural stock of the resource and a sustainable fishery. This study aimed to determine the most suitable mangrove areas for the conservation and fishery of the crab U. cordatus in the Estuary of the São Francisco River, using a MCE analysis, and taking into account a perspective that minimize the restrictions on the fishing and allow a socio-ecological sustainable fishery.

Maps of each criterion were produced by remote sensing techniques and field data in IDRISI. The initial geodatabase was a land use and cover map of the study area produced in our previous study (e.g., Santos et al., 2014a). For the map of mangrove vegetation types the normalized difference vegetation index (NDVI) was calculated using CBERS-2B images. The maps of crab population parameters were produced based on field data of six different sites of mangroves (e.g., Santos et al., 2014b) and the social maps based on ethnoecological survey carried in villages of the study area (e.g., Santos et al., 2013). We do not consider aspects of the life cycle of this species because since 1990 there are laws of closure during the breeding and capture of females are legally prohibited at any time of year. The maps were standardized in a numeric range of 0 to 255, by a fuzzy function for quantitative maps, and reclassified for qualitative maps. The criteria weighting was developed in the module WEIGHT, which utilizes a pairwise comparison matrix, a technique developed by Saaty (1977) in the decision making process known as the Analytical Hierarchy Process (AHP) (see Eastman, 2012). In AHP the criteria are compared two at a time in terms of their importance relative to the stated objective and ratings are provided on a 9-point continuous scale. The pairwise comparison matrix was sent to researchers that work with U. cordatus in the field of biological, ecological, fishery and ethnoecological studies. The weight given by them was used in the module that calculates one final weight for each criterion (Eastman, 2012). Finally, the weighted criteria were aggregated using the Weighted Linear Combination (WLC), a method that multiplies each standardized criteria map (i.e., each raster cell within each map) by its factor weight and then sums the results. The map generated by the analysis is a raster image in which the pixel values range from 0 (unsuitable areas) to 255 (most suitable areas). Based on the pixel values, this image was reclassified to a map of seven categorical classes of mangrove suitability for the conservation and for the fishery of U. cordatus. The area of each class was determined.
The present study shows an important contribution for fishery management and specially for this plan. This methodological approach by MCE analysis produced suitability maps possible to be used by government agencies to delineate areas of extractive and fishery exclusion (conservation) along the Brazilian coast.
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mangrove areas. Moreover, the maps produced here can be used by the local government agency (Sergipe State Environmental Administration, ADEMA) in order to implement this plan in the study area. In fisheries management, developing analytical and operational evaluation tools is critical for decision-making (Andalecio, 2010). The advantage of using MCE analysis is to allow the integration of data from different fields, an important procedure in the fishery management. As an example, this study used biological parameters of the crab population structure, spatial arrangement of the landscape/land use and social data. Despite this, some limitations are found in the MCE, as standardization of qualitative criteria, the search for specialists to analyze the comparison matrix and it requires expensive tools as satellite images, geoprocessing software and field surveys, and an interdisciplinary view of the analyst.

In this study we found that the biological criteria related to the *U. cordatus* population structure (mainly density and frequency of NCSC and CSC), were more important than land/cover use and social criteria, for the delineation of the more suitable mangrove areas for the crab conservation and fishery, respectively. This fact highlights the importance to include these important variables when fishery management plans are proposed. For the crab fishery purpose, higher density of CSC was more important than the mean crab size (Table 1) since it indicates large stocks of crabs for exploitation, representing the amount of crabs per square meters and is correlated with immediate extractive potential (legal capture size) in mangroves.

The high abundance of *U. cordatus* and the large extension of its habitat make this semi-terrestrial crab a resource with a high fishery potential (Diele *et al.*, 2005). The crab stocks and therefore their capture rates and yield reflect the extent and degree of development of mangroves (Brazil, 2011). This shows the importance of the mangrove habitats for the maintenance of the fishery potential of this species. In the study area the high extent of mangrove areas (32 km²) with high developed stands (Santos *et al.*, 2014a), combined with the population structure of *U. cordatus*, as well as social and land use/cover features, indicate large areas of these mangroves with high potential to the crab fishery. According to Diele *et al.* (2005), the potential yield of *U. cordatus* is comparable to (or exceeds) other important crab fisheries worldwide, as to blue crabs (Portunidae), dungeness crabs (Cancridae), and snow crabs (Oregoniidae).
CONCLUSIONS

We concluded that the mangroves of the São Francisco River Estuary show different areas with high potential for the conservation and fishery of U. cordatus. The combination of high potential for both objectives allow the implementation of management strategies in order to achieve a sustainable fishery of this resource, as stated by the Proposal of a National Management Plan for this species. Based on the objectives of this proposal, the mangroves most suitable for the conservation of U. cordatus might be delineated as fish exclusion areas, since they show large abundance of small NCSC and are the less used for fishery. In the fishery exclusion areas the crab capture should be restrictive or not allowed, in order to permit the NCSC grow to reach the commercial size, as well as, to maintain the reproduction and resource stock viable in this area. Similarly, the mangrove areas more suitable for the crab fishery can be delineated as extractive areas, since they show large abundance of CSC, big crabs, and are closed to the fishery villages.

The combination of remote sensing, geoprocessing techniques and field surveys in a MCE was shown to be a useful tool for fishery management purposes. This fact is confirmed by the integration of different data (e.g., social, biological and geographical sciences), an essential characteristic for the analysis, resource management and conservation of socio ecological complex systems, such as fishery in coastal and marine ecosystems.

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LITERATURE CITED


