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

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ABSTRACT

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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 km^2) 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 km^2) 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; Cortês *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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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') (10º30'27"S, 36º23'45"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 presented are: sandy coastal vegetation, aquaculture and agriculture (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.

A total of ten criteria were used in the MCE, including five biotic criteria related to the population parameters of the crab: 1) frequency and 2) density of non-commercial size crabs (NCSC), 3) frequency and 4) density of commercial size crabs (CSC) and 5) mean crab size; three factors related to land use and cover: 6) mangrove vegetation types, 7) distance of mangroves from fishery villages and from 8) shrimp farms, and finally, two social parameters: 9) degrees of mangrove importance for crab conservation and 10) and for crab fishery, both in the view of the local fisherman.

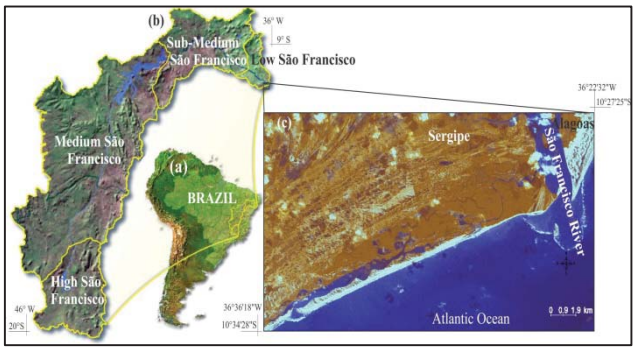

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) A close-up of the São Francisco River Estuary, the study area.

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 breading 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 ethnobiological 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 pixels values rage from 0 (unsuitable areas) to 255 (most suitable areas). Based on the pixels 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.

Table 1. *Criteria and weights in crab conservation and fishery of Ucides cordatus, according the principal eigenvector of the pairwise comparison matrix in the Analytical Hierarchy Process (AHP).*

Type of criteria	Criteria	Conservation Weights	Fishery Weights
Crab population parameters	Density of crabs in non-commercial size	0.30	0.02
	Density of crabs in commercial size	0.17	0.27
	Frequency of crabs in non-commercial size	0.24	–
	Frequency of crabs in commercial size	–	0.26
	Mean crab size	0.11	0.12
Land use and cover	Mangrove vegetation types	0.02	0.03
	Distance of mangroves from fishery villages	0.06	0.18
	Distance of mangroves from shrimp farms	0.02	–
Social parameters	Degrees of mangrove importance for crab conservation	0.02	0.05
	Degrees of mangrove use for crab fishery	0.06	0.07

RESULTS

For both objectives, conservation and fishery of the crab *U. cordatus*, the biological criteria related to the crab population parameters were those that showed the highest weights (Table 1). For the conservation purpose, the density and frequency of NCSC were the most important factors (Table 1), while density and frequency of CSC were the most important for the fishery purpose. The social criteria showed low to intermediate weights, wherein the degrees of mangrove use for crab fishery were considered more important than the degrees of mangrove importance for crab conservation (Table 1). For the land use and cover criteria, the distance of mangroves from fishery villages was the most important, mainly for the fishery purpose (Table 1). Lowest weights were given to mangrove vegetation types and distance of mangroves from shrimp farms (Table 1). Thus they were considered the less important factors to delineate areas for conservation and fishery of the crab *U. cordatus*.The most suitable mangrove areas for the conservation of the crab *U. cordatus* (classes: *extremely high*, *very high*, *high* and *moderately high*) are closest to the São Francisco River mouth (Figure 2a). On the other hand, the conservation suitability decreases as far as the mangrove areas distance themselves from the estuary mouth (Figure 2a). The most suitable classes for the crab conservation accounts together for more than 58% (18.6 km^2) of the mangroves in the study area and show important characteristics for the conservation of *U. cordatus*, such as: high density and frequency of NCSC, small sized crabs, low degree of use for crab fishery, and they are more distant areas from the fishery villages and shrimp farming. In addition to these features, the class *extremely high* exhibits mangrove vegetation type with higher green biomass and with the presence of *Laguncularia racemosa* and *Rhizophora mangle*.

The less suitable mangroves to the crab conservation (classes *medium*, *low* and *very low*) (Figure 2a) account for approximately 42% (13.3 km^2) of mangrove total area, and are closest to the fishery villages and shrimp farming, more used for the crab fishery by the local populations, and shows high density of CSC, big sized crabs and low frequency and density of NCSC. The presence (or combinations) of these features do not make them suitable as areas for the conservation of *U. cordatus*. For example, the class *medium* showed close proximity to fishery villages and shrimp farming, while the class *low* was associated with the highest density of commercial crabs and fishery use. The class *very low* showed the biggest crabs, as well as the lowest density and frequency of NCSC.

The most suitable mangrove areas for the fishery of *U. cordatus* (classes: *extremely high*, *very high*, *high* and *moderately high*) are those located farther from to the river mouth, mainly along the 'Poço' and 'Carapitanga' channels (Figure 2b). The most suitable classes for the crab fishery accounts together for more than 59% (18.9 km^2) of the mangroves and show important characteristics for the crab fishery such as: high density and frequency of CSC, low density NCSC, big sized crabs, medium to high degree of use for crab fishery, and are more close to the fishery villages. The class *extremely high* exhibits higher values of CSC density than the class *very high*, which showed the biggest crabs.

The less suitable to the crab fishery (classes *medium*, *low* and *very low*) account for roughly 41% (13 km^2) of the total mangrove extent (Figure 2b) and are those more distant from the fishery villages, less used for the crab fishery by the local populations, and show high density and frequency of NCSC, small sized crabs, and mangrove vegetation with less green biomass. The presence (or combination) of these features do not make them suitable for the fishery of *U. cordatus*, but to other objectives, as for the crab conservation.

DISCUSSION

In Brazil the fishery of *U. cordatus* is a very important socioeconomic activity, but decreases in the crab stock have threatened fishing and resource. Thus, in 2011 the Brazilian Institute of the Environment (IBAMA) published a Proposal of a National Management Plan for this species, which aims to promote sustainable use of this resource, ensuring the maintenance of the crab populations at satisfactory levels and allowing the continuity of economic activity (Brasil, 2011; Pinheiro and Rodrigues, 2011). This plan states the delineation of extractive and fishery exclusion areas for achieve these objectives.

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

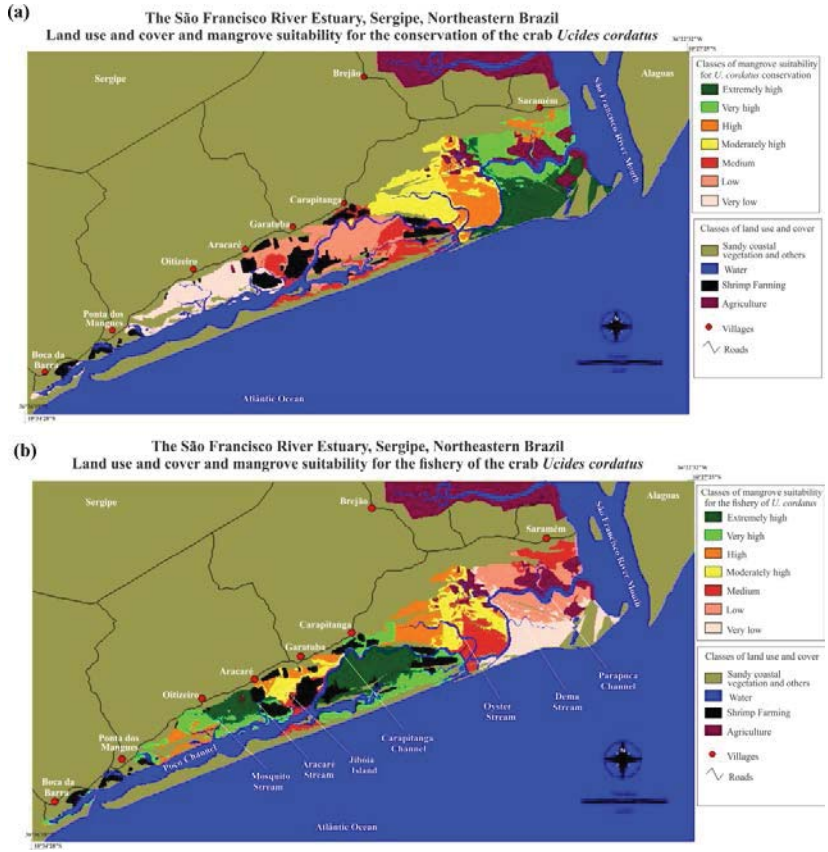

Figure 1. Map of land use/cover and mangrove suitability for the conservation (a) and fishery (b) of the crab *Ucides cordatus*, in the São Francisco River Estuary (Northeastern Brazil).

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 km^2) 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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