Multi-criteria evaluation for the conservation of the mangrove crab *Ucides cordatus*: a case study in the São Francisco River Estuary (Northeastern Brazil)

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Abstract. Mangroves are productive coastal ecosystems that form an ideal habitat for a variety of animals, including many fishery commercial species, as the mangrove crab *Ucides cordatus*. In Brazil this crab hold a major socio-economic importance for artisanal fishery, nevertheless declines on its productivity has been reported in many regions, as in the São Francisco River Estuary (Northeastern Brazil). This study determined the most suitable mangrove areas for the conservation of the crab *Ucides cordatus* in the São Francisco River Estuary, using a Multi-Criteria Evaluation (MCE). We applied the MCE Decision Support in IDRISI Selva, considering the Weighted Linear Combination and the Analytical Hierarchy Process. A total of nine criteria were used: four biotic of the crab population parameters, three related to land use and cover and two social factors. To produce the maps of each criterion, it was applied remote sensing techniques using CBERS and SPOT images (e.g. vegetation index, pansharpening, supervised classification, distance operators) and field data. The mangrove areas more suitable for the conservation of *Ucides cordatus* are those more close to the river mouth, showing high density and frequency of crabs in non-commercial size, low density of crabs in commercial size, small crabs, low degree of use for crab fishery and dense mangrove cover. In these areas the crab fishery should be restrictive or not allowed; in order to permit the non-commercial size crabs grow to reach commercial size, as well as, for their reproduction and maintenance of the resource stock.

Key words: Geoprocessing, artisanal fishery, coastal systems, geoprocessamento, pesca artesanal, sistemas costeiros

1. Introduction

Mangroves are productive coastal ecosystems that fulfill a series of ecological, environmental and socio-economic functions. For example, mangroves form an ideal habitat for a variety of animals, including many commercial crustacean species, such as the mangrove crab *Ucides cordatus* (Linnaeus, 1763), a semiterrestrial crab and key species of these habitats (Schories et al. 2003). In Brazil, *U. cordatus* has been extensively exploited and holds a major socio-economic importance for artisanal fishery (e.g. Alves et al., 2005; Souto, 2007; Santos et al., 2013). Nevertheless, declines of *U. cordatus* have been reported in many coastal regions of Brazil and were related to mangrove habitat destruction, diseases and overfishing (Boeger et al. 2005, Diele et al., 2005).

In the São Francisco River Estuary (Sergipe State, Northeastern Brazil,) *Ucides 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 for the conservation of this crab, in order to maintain the natural stock of the resource for a sustainable fishery.

Considering this scenario, resource allocation for use or conservation, are also prime candidates for analysis with GIS and remote sensing techniques (Estman, 2012a). In the case of Socio-Ecological Complex Systems, where natural, human, and management systems have

a complex interaction (Charles 2001), such as in the fishery of the *U. cordatus* in mangrove ecosystems, several criteria will need to be evaluated for conservation and management purposes. In these cases which involve multidisciplinary knowledge bases, a GIS procedure called Multi-Criteria Evaluation (MCE) is the more appropriate (Huang et al., 2011). MCE provides a systematic methodology to combine these inputs with cost/benefit information and stakeholder views to rank project alternatives (Huang et al., 2011). MCE uses remote sensing techniques as a tool to produce the inputs of different types of criteria considered in the analysis.

This study aims to determine the most suitable mangrove areas for the conservation of the crab *Ucides cordatus* in the Estuary of the São Francisco River, using MCE, and considering a perspective that minimize the restrictions on the fishing and allow a sustainable fishery of the crab.

2. Material and Methods

2.1. Study area

The study area is part of the São Francisco River, 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 of the southern part of the São Francisco River Estuary (municipalities of "Brejo Grande" and "Pacatuba") (10º 30' 27"S, 36º 23'45"W) and covers approximately 192.35 km². This estuary shows a mangrove extent of 31.9 km^2, which corresponds to about 16% of the study area (Santos et al., 2014). Other land cover and uses presented are: sandy coastal vegetation , aquaculture and agriculture (Santos et al., 2014). A total of eight fishery villages are distributed in this area, where fishery in the mangrove areas, specially of the crab *Ucides cordatus*, is the main economic subsistence base for the local populations (Santos et al., 2013).

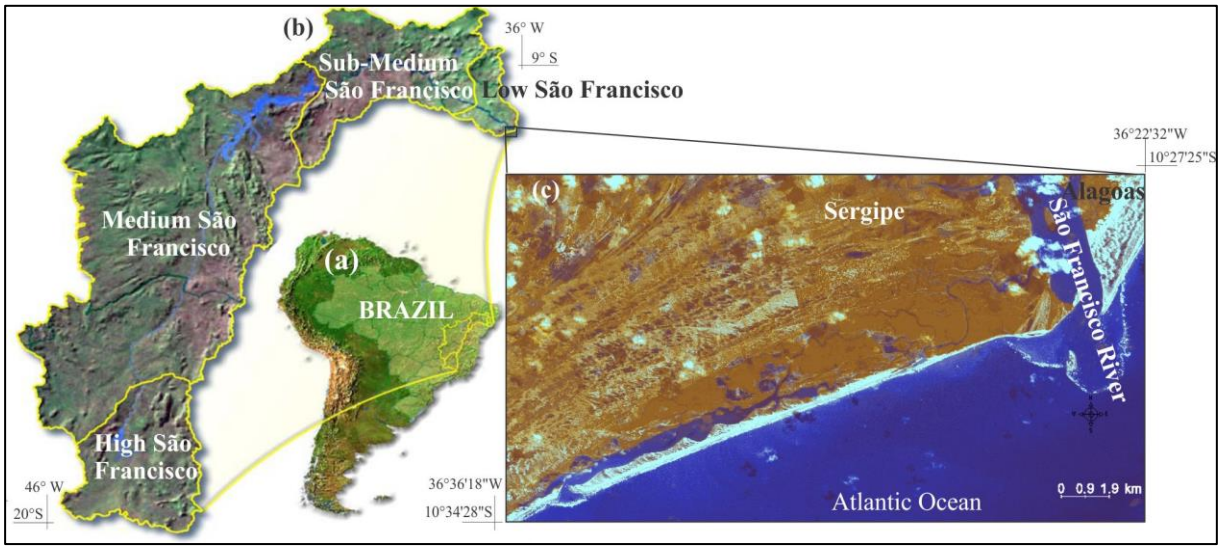

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) A close-up of the São Francisco River Estuary, the study area.

2.2. Methodology

In this study we applied a Multi-Criteria Evaluation (MCE), in order to determine the most suitable mangrove areas for the conservation of the crab *Ucides cordatus*. For this, we applied the MCE Decision Support tool in the *IDRISI Selva* and considered the Weighted

Linear Combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average (Estman, 2012a). A total of nine criteria were used in the MCE, including four biotic criteria related to the population parameters of the crab *Ucides cordatus*: 1) frequency and 2) density crabs in non-commercial size, 3) density of crabs in commercial size and 4) mean crab size; three factors related to land use and cover: 5) mangrove vegetation types, 6) distance of mangroves from fishery villages and from 7) shrimp farms, and finally, two social parameters: 8) degrees of mangrove importance for crab conservation and 9) degrees of mangrove use for crab fishery, both according to the view of the local fisherman. As a constraint, a boolean criteria that constrain (i.e., limit) the analysis to particular geographic regions (Estman, 2012b), we considered the polygons of the mangroves areas of the study site. The figure 2 synthesize the procedures carried out, in IDRISI and SPRING software, in order to produced the maps (in raster format) of each criterion, and the table 1 indicate the satellite images used in these procedures. In addition to the geoprocessing techniques, for the production of the maps of crab population parameters and mangrove types we also used field data collected in six different sites of mangroves and for the social maps, we used field data of the ethnoecological and social-economic survey carried out in five fishery villages of the study area.

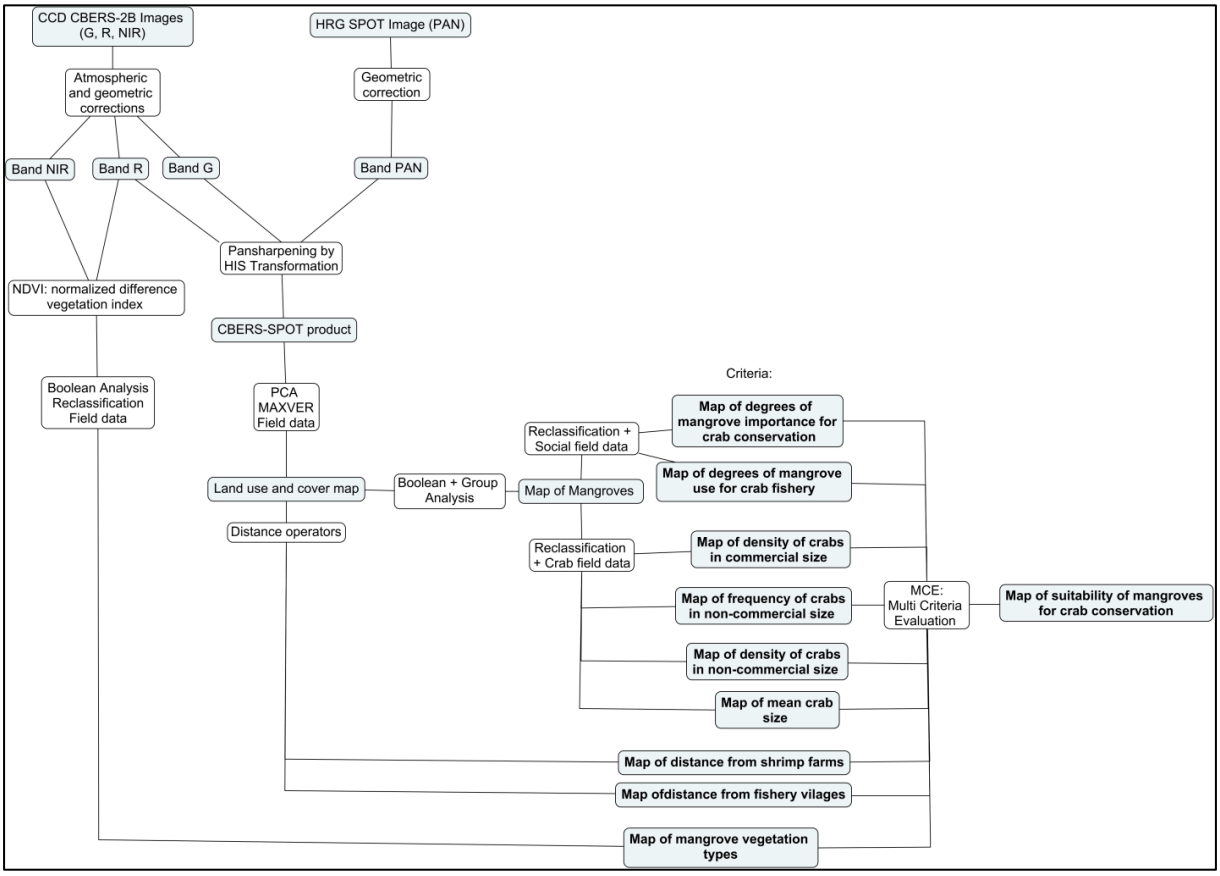

Figure 2. Summary of the geoprocessing techniques applied to produce the maps of the criteria used in the multi-criteria evaluation.

After the elaboration of the maps of each criterion, they were standardized in a numeric range of 0 to 255. In IDRISI, the module named FUZZY is provided for the standardization of quantitative factors using a whole range of fuzzy set membership functions (Estman, 2012a). The fuzzy function was used to standardize the quantitative criteria such as crab population parameters, distance from fishery villages and shrimp farms. The qualitative criteria such as mangrove vegetation types, degrees of mangrove importance for crab conservation and

mangrove use for crab fishery were standardize using the reclassification function, wherein knowing the relative suitability of each class, they were rescaled into the range 0-255 (e.g. Estman, 2012b).

Table 1. Features of the satellite images used in the study.

Satellite	Sensor	Spatial resolution (m)	Bands	Date	Path-Row
CBERS-2B	CCD	20	Blue, red and infra-red	05/14/2008	147-112
SPOT-5	HRG2	2.5	PAN	05/14/2008	731-371

The next step of the MCE was weighting the factors for aggregation, and it was carried out in the module WEIGHT of IDRISI, which utilizes a pairwise comparison matrix, technique developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (e.g. Estman, 2012a). Factors 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. After all possible combinations of two factors are compared; the module calculates a set of weights, corresponding to one weigh for each criterion (e.g. Estman, 2012b).

Finally, the weighted factors and constraint were aggregated using the Weighted Linear Combination (WCL), a method that multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results. This result is then multiplied by each of the constraints in turn to "mask out" unsuitable areas (e.g. Estman, 2012a). The final map produced is a raster image raging from 0 (unsuitable areas) to 255 (most suitable areas), this image was then reclassified to categorical classes of suitability of the mangroves for the conservation of the *Ucides cordatus* crab. The area of each class was also determined.

3. Results and discussion

Figure 3 shows the maps of the criteria used in the MCE analysis and the table 2 the weights derived by the AHP. The criteria related to the population parameters of the crab *Ucides cordatus* were those that showed the highest weights, wherein the density of crabs in non-commercial size was the most important factor (table 2). The maps of these parameters show that the density and frequency of non-commercial crabs increase in the direction of the São Francisco River mouth, and consequently, the smallest crabs are found in the mangroves areas near to the river mouth (Figures 3c, 3d, 3f). When considering our MCE objective, the population parameters are the most important criteria because they are directly related to the resource stock available in the study area, giving estimative of the amount of crabs available for fishery (commercial size) and those that should be conserved and not fished (non-commercial size) (e.g. Hattori, 2006; Wunderlich et al., 2008).

Lower weights were given to social and land use cover criteria (Table 2). Distance of mangroves from fishery villages and degrees of mangrove use for crab fishery showed similar weights (Table 2). They are linked criteria because both are related to the human fishery on the mangrove areas. For example, the mangrove areas more close to the fishery villages are those with very high, high and medium degrees of use. On the other hand, the mangrove areas more far from the villages are those with low degree of use (Figures 3h, 3i). This is probably because in the study area most of the fisherman reaches the mangrove areas by feet or by canoe paddle. Thus, the local populations use the mangrove areas more close to the villages where they live to fish the crab *Ucides cordatus* (Santos et al., 2013). Based on this, we considered that the suitability of the mangrove areas for the crab conservation increase with

the distance from the fishery villages, as well as, decrease with the increase of the degrees of mangrove use for fishery. The last social criterion points out the most important areas for the crab conservation in the view of the local fisherman (Figure 3g), and showed the low weight (Table 2). Since it is based on the fisherman experience, the most important areas (high and very high degree) for the crab conservation, according to them, are also those that are most used to catch the crab (Figures 3g, 3h).

The lowest weights were also given to the others two land use and cover criteria (Table 2). In relation to the distance of mangroves from shrimp farming (Figure 3j), we considered that the suitability increase with this distance, since the more distant areas are more protected from the impacts of this activity, such as mangrove deforestation and water pollution. In relation to mangrove vegetation types (Figure 3b), which is based on the values of NDVI (Normalized Difference Vegetation Index) exhibited by the mangroves, the suitability increase with NDVI, from type 1 (lowest NDVI) to type 4 (highest NDVI) . Mangrove type 1 ($0.2 \leq NDVI < 0.3$) are mangroves with exposed sediment, herbaceous vegetation (*Juncus* sp.) and *Acrostichum aureum* patches. Type 2 ($0.3 \leq NDVI < 0.45$), shows sparse mangrove vegetation and type 3 ($0.45 \leq NDVI < 0.57$) exhibits dense canopy cover, but with small gaps or spaces and it constitutes the dominant habitat in the study area. Type 4 ($0.57 \leq NDVI < 0.64$) shows dense canopy cover without gaps/spaces and occurrence of dense patches of *A. aureum* within the true mangrove vegetation (Figure 3b). The types 3 and 4, which show the highest NDVI, are those with high green leaves biomass available for the crabs feed, thus they were considered the types more suitable for the crab conservation. The vegetation type is significantly correlated to mangrove crab characteristics, abundance and weight/size (Gomes et al., 2013). Differences in food availability (leaf litter) and/or quality could have caused differential growth rates and thus crab sizes among areas (Diele et al., 2005).

Table 2. Weights derived by calculating the principal eigenvector of the pairwise comparison matrix in the Analytical Hierarchy Process (AHP).

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

The final map derived by the MCE (Figure 4) shows that the mangrove areas more suitable for the conservation of the crab *Ucides cordatus* (classes: *extremely high*, *very high*, *high* and *moderately high*) are those more close to the São Francisco River mouth. On the other hand, the suitability decreases as far as the mangrove areas are more distant form the estuary mouth (classes *medium*, *low* and *very low*) (Figure 4). The classes more suitable for the crab conservation (*extremely high*, *very high*, *high* and *moderately high*) accounts together for more than 58% of the mangroves in the study area (Table 3) and shared important characteristics such as: high density and frequency of crabs in non-commercial size, lowest density of crabs in commercial size, smallest crabs and low degree of use for crab fishery. Nevertheless, the class *extremely high* exhibits mangrove vegetation type 3 and 4, while the class *very high* showed mangrove vegetation types 1 and 2. The classes *high* and *moderately high* showed frequency of crabs in non-commercial size slightly lower than the classes

extremely high and *very high*, and density of crabs in commercial size higher than these two last classes. However, the class *high* exhibited mangrove vegetation types 3 and 4, thus it is more suitable for the crab conservation than the class *moderately high*, and was the class with highest extent (Table 3).

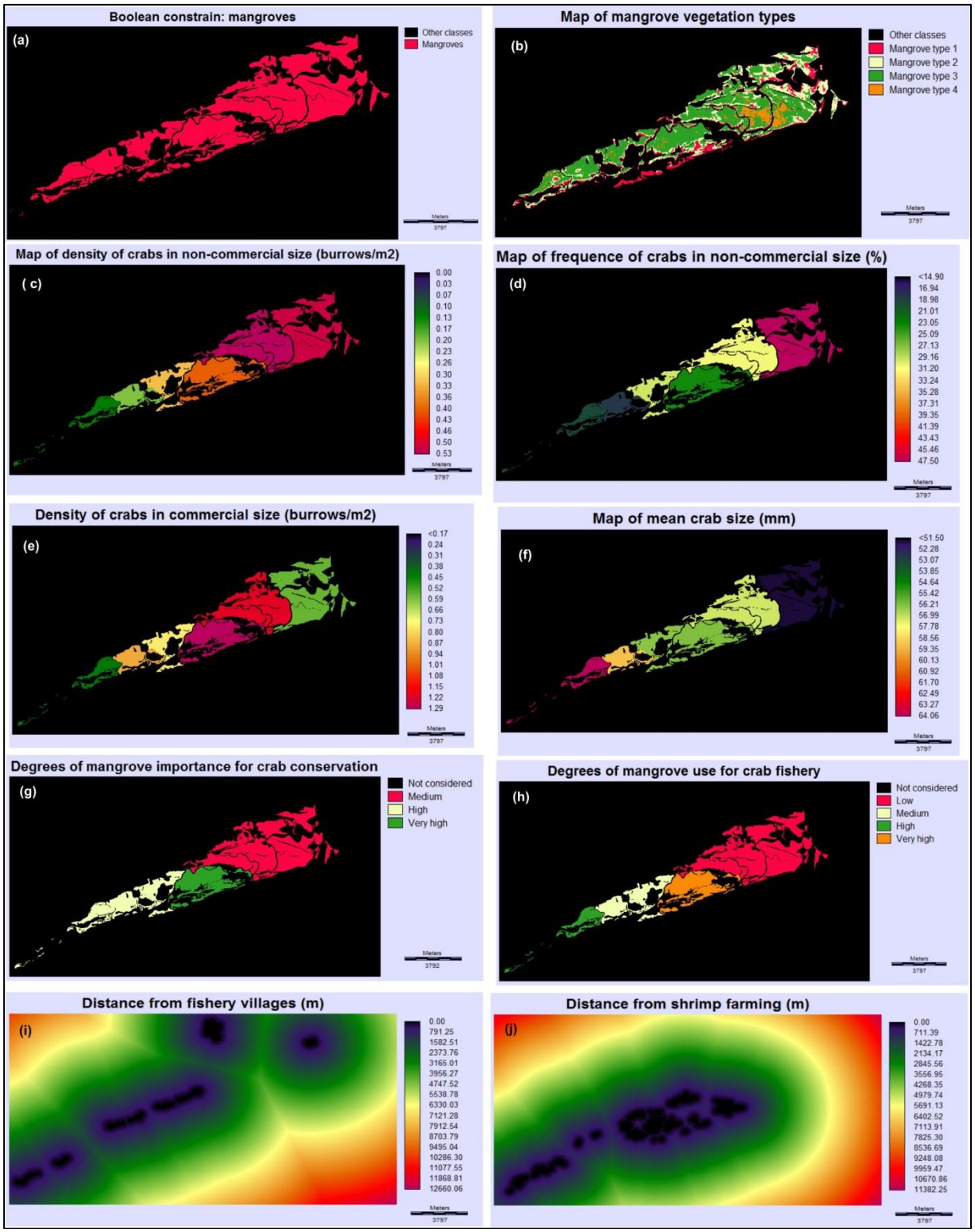

Figure 2. Maps of constrain and criteria used in the multi-criteria evaluation.

The classes less suitable for the crab conservation (*medium*, *low* and *very low*) have lower extent, accounting for approximately 42 % of the mangroves (Table 3). They exhibited in

general lower density and frequency of crabs in non-commercial size, higher densities of crabs in commercial size, higher degrees of use, mangrove vegetation type 3 and are more close to fishery villages. The class *medium* showed very proximity to fishery villages and shrimp framing, while the class *low* was that which recorded the highest density of commercial crabs and use. The class *very low* showed the largest crabs as well as the lowest density and frequency of crabs in non-commercial size.

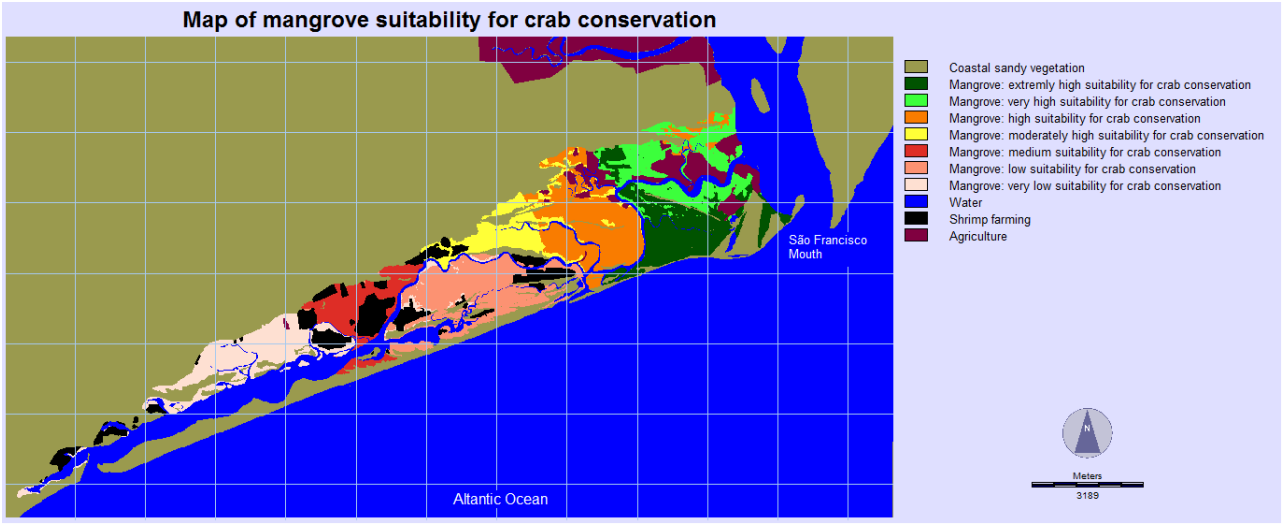

Figure 3. Map of land use and cover and mangrove suitability for the conservation of the crab *Ucides cordatus*, in the São Francisco River Estuary (Northeastern Brazil).

Table 3. Area (km^2) of the classes of mangrove suitability for the conservation of the crab *Ucides cordatus*.

Suitability	Classes of mangrove suitability	Area (km^2)	Percentage (%)
More Suitable	Extremely high	5.1	16.0
	Very high	4.3	13.5
	High	6.2	19.4
	Moderately high	3	9.4
	Sub-total	**18.6**	**58.3**
Less Suitable	Medium	2.7	8.5
	Low	5.6	17.6
	Very low	5	15.7
	Sub-total	**13.3**	**41.7**

4. Conclusions

We concluded that the mangrove areas more suitable for the conservation of the crab *Ucides cordatus* are those more close to the São Francisco River mouth, which share a combination of features with different weights, wherein biological criteria related to the crab population status were more important than land use and cover and social criteria. The areas more suitable for the crab conservation exhibit a dense mangrove vegetation cover and large stock of small of crabs. Since these areas are less used for fishery, they should be conserve, i.e., fishery should be restrictive or not allowed, in order to permit the non-commercial size crabs grow to reach the commercial size, as well as, for their reproduction and maintenance of the resource stock in the study area.

The combination of remote sensing and geoprocessing techniques and field surveys in a MCE showed to be an useful tool for conservation purposes, since it allow the integration of

different data, from social, biological and geographical sciences, thus being essential for the analysis, resource management and conservation of socio ecological complex systems, such as fishery in coastal and marine ecosystems.

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