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Population status and fishery potential of the mangrove crab, *Ucides cordatus* (Linnaeus, 1763) in North-eastern Brazil

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Ucides cordatus *is a semi-terrestrial crab and key species endemic to mangrove areas of eastern Americas. In North-eastern Brazil this crab holds a major socio-economic function for artisanal fisheries, as in the São Francisco River Estuary (10°30′27″S 36°23′45″W). Nevertheless, decreases in this species' stock have been reported since 2000, requiring assessments of the crab population for conservation and management purposes. This study aims at assessing the population status and the fishery potential of this species in the mangroves of this estuary and suggests strategies for its fishery and conservation, according to the guidelines of the National Management Plan for* U. cordatus *Sustainable Use. Six different sites established in 30 km² of mangroves were sampled, with the density of* U. cordatus *burrows estimated to evaluate the population structure using the measure of burrow diameters. Results show that the crab mean burrow size was 56.82 (±12.2) mm and that the medium-size crabs (40–70 mm) are the most abundant. The total mean crab density was 1.2 crabs m^{-2}, from which the density of crabs in commercial size (0.85 ± 0.55 crabs m^{-2}) was significantly higher than those in non-commercial size (0.35 ± 0.21 burrow m^{-2}). These mangroves showed a high potential for the crab fishery, with an immediate extractive potential (IEP) of 71.2% and future extractive potential (FEP) of 28.8%. Nevertheless, a lower crab density, probably due to high crab mortality, mangrove deforestation for shrimp farming and high fishery pressure, is a limiting factor for local fishery. We conclude that mangrove areas more appropriate for* U. cordatus *fishery (extractive areas) show higher mean crab size, IEP and density of commercial crabs, wherein a fixed exploitation rate or/and a fixed escapement rule should be considered. Exclusion areas, intended for the conservation, show lower values of these population parameters and higher FEP, wherein the fishery should be prohibited. These management strategies should also be considered in other Brazilian mangrove areas showing similar crab population structure, thus contributing to the National Management Plan for* U. cordatus *Sustainable Use.*

Keywords: crustaceans, population assessment, fishery management, mangrove, *Ucides cordatus*

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INTRODUCTION

Mangroves are productive coastal ecosystems that form an ideal habitat for a variety of animals, including many fishery species (Barbier, 2000; Nagelkerken *et al.*, 2008; Pinheiro *et al.*, 2008). A relevant species in this coastal environment is the mangrove crab *Ucides cordatus* (Linnaeus, 1763), an endemic crab with a semi-terrestrial life that digs burrows in the sediment up to 2 m deep and shows nocturnal habits (Alcantara-Filho, 1978; Costa, 1979; Pinheiro & Fiscarelli, 2001; Schmidt *et al.*, 2008a). This crab is distributed along the tropical and sub-tropical mangrove coasts of the eastern Americas from southern Florida to southern Brazil, in the Santa Catarina State (Bright & Hogue, 1972; Melo, 1996).

Ucides cordatus is considered a key species of mangrove ecosystems for its high biomass, its role in nutrient cycling and in the trophic structure of these ecosystems (Wolff *et al.*, 2000; Koch & Wolff, 2002; Schories *et al.*, 2003; Nordhaus *et al.*, 2006; Christofoletti *et al.*, 2013). In Brazil, due to its large size and tasty meat, *U. cordatus* has been extensively exploited (Rodrigues *et al.*, 2000; Brasil, 2011) and holds

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a major socio-economic importance for artisanal fishery, constituting the economic base of many human coastal populations (e.g. Alves & Nishida, 2003; Glaser & Diele, 2004; Alves *et al.*, 2005; Passos & Di Beneditto, 2005; Souto, 2007; Firmo *et al.*, 2011; Santos *et al.*, 2013). Since 2000 a great number of studies have been executed, revealing aspects about the population status and ecology of this crab (e.g. Schories *et al.*, 2003; Alves & Nishida 2004; Glaser & Diele, 2004; Diele *et al.*, 2005; Pinheiro *et al.*, 2005; Hattori, 2006; Nordhaus *et al.*, 2006; Schmidt *et al.*, 2008a, b; Wunderlich *et al.*, 2008; Piou *et al.*, 2009; Conti & Nalesso, 2010; Diele & Koch, 2010; Góes *et al.*, 2010; Sandrini-Neto & Lana, 2011; Leite *et al.*, 2012; Christofoletti *et al.*, 2013; Amaral *et al.*, 2014) and providing better conditions to develop an effective management strategy of this fishery resource (Diele *et al.*, 2005; Duarte *et al.*, 2014). The large size of *Ucides cordatus* suggests that this species has a high vulnerability to exploitation as it is generally correlated with slow growth, high age at maturity, long-lived (>10 years), low reproductive output and low natural mortality (Jennings *et al.*, 1998; Pauly, 1998; Pinheiro *et al.*, 2005; Diele & Koch, 2010). Declines of *U. cordatus* have been reported from many coastal regions of Brazil and were related to mangrove habitat destruction, diseases and overfishing (Maneschy, 1993; Boeger *et al.*, 2005; Diele *et al.*, 2005). Massive mortalities of *U. cordatus* have been reported by crab harvesters and biologists since 1997 throughout North-eastern Brazil, from Ceará to Espírito Santo State (Boeger *et al.*, 2005, 2007) that have decimated local stocks (Alves & Nishida, 2003; Schmidt *et al.*, 2008b; Firmo *et al.*, 2011). This mortality has generated considerable concern among specialists in regards to resulting environmental and socioeconomic impacts (Alves & Nishida, 2003; Firmo *et al.*, 2011).

This context has led to the creation of many legal guidelines by the National Environment Ministry, in order to assure strategies for the conservation and sustainable fishery of *U. cordatus* on the Brazilian coast. For example, in 2004, *U. cordatus* was included in the list of overfished or endangered species of overexploitation (Brasil, 2004). In 2011, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) published a Proposal of a National Management Plan for the Sustainable Use of this species, which aims to contribute to the maintenance and/or restoration of natural stocks of *U. cordatus*, as well as for the sustainable use of this resource, according to biological, fishery, ecological, social, economic and legal parameters (Brasil, 2011; Pinheiro & Rodrigues, 2011). This proposal is an important guideline framework for crab management, but it stills lacks regional and local studies in order to raise these parameters and to apply them to the management practices, which will be the base to build the management at the National level. Furthermore, in the end of 2014, *U. cordatus* was listed in the 'near threatened' (NT) category (Brasil, 2014) and in 2015, it has been included in the National Conservation Action Plan of Endangered Species and of Socioeconomic Importance in Mangrove Ecosystems (Brasil, 2015) as one of the nine species in the regional list of endangered species.

Considering this scenario, studies on the population status of *Ucides cordatus* on the coast of Brazil, such as population density and size of crabs, are extremely important for stock evaluation, estimation of population recovery and assessment of fishery potential (e.g. Hattori, 2006; Wunderlich *et al.*, 2008), and fundamental to achieve the objectives and to raise the parameters indicated by the Proposal of a National Management Plan for the Sustainable Use of this species (Brasil, 2011). Despite the existence of studies about *U. cordatus* population structure, these data are not still applied to management fishery and conservation strategies. In the present study we investigated the potential of these data to base the elaboration and suggestion of management measures, for the identification of extractive and fishery exclusion areas, an important management strategy stated by the Proposal of a National Management Plan for the species (Brasil, 2011).

In the São Francisco River Estuary (North-eastern Brazil, 10°30′27″S 36°23′45″W) *Ucides cordatus* occurs along 30 km² of mangrove forests and is the second most exploited mangrove fishery resource, constituting the major economic base for deprived human populations of eight coastal villages (Santos *et al.*, 2013, 2014). Despite its importance, decreases in this species' stock have been reported since 2000, both by local populations and research institutes (e.g. CEPENE, 2003; Santos *et al.*, 2013). Therefore, the aim of this study is to assess the population status (population density and size of crabs) and the fishery potential of *Ucides cordatus* in the mangroves of this estuary, and based on these data suggest strategies for sustainable use and conservation of this important mangrove fishery resource, according to the guidelines of the Proposal of a National Management Plan for the Sustainable Use of this species (Brasil, 2011).

MATERIALS AND METHODS

Study area

The São Francisco River is one of the most important Brazilian water resources and is considered the River of National Integration, draining seven states along its 2863 km. The river basin (636,919 km²) is divided in four sub-regions from its nascent to its estuary: high, medium, sub-medium and low São Francisco (ANA, 2005). The estuary of this river is located in the low sub-region, on the boundary of Sergipe and Alagoas States (10°30′27″S 36°23′45″W) (Figure 1), in the North-east of Brazil.

The study area corresponds to the southern part of the São Francisco River Estuary (State of Sergipe) (Figure 1C) and covers ~192.35 km² and is part of the municipalities of 'Brejo Grande' and 'Pacatuba'. This estuary shows a mangrove extent of 30.1 km², which corresponds to about 16% of the study area (Santos *et al.*, 2014). The climate in this region is tropical semi-humid with a mean annual temperature of 25°C, showing two outstanding seasons: one rainy, between April and August, and another dry, between September and March (Medeiros, 2003). This is included in the Tropical Wet & Dry (Aw) Climate, according to the Köppen Climate Classification System. The area is subject to a mid tide amplitude (between 2 and 4 m) with semi-diurnal tides (two high tides and two low tides) (Semensatto, 2004).

The study area is characterized by a remarkable lack of infrastructure, such as paved roads, hospitals, health centres, schools and commercial stores. The inhabitants are a deprived population composed of native residents whose income and subsistence depends on agricultural activities, aquaculture and mainly fishery, highlighting the fishery of the mangrove crab (Santos *et al.*, 2014). A total of eight fishery villages are

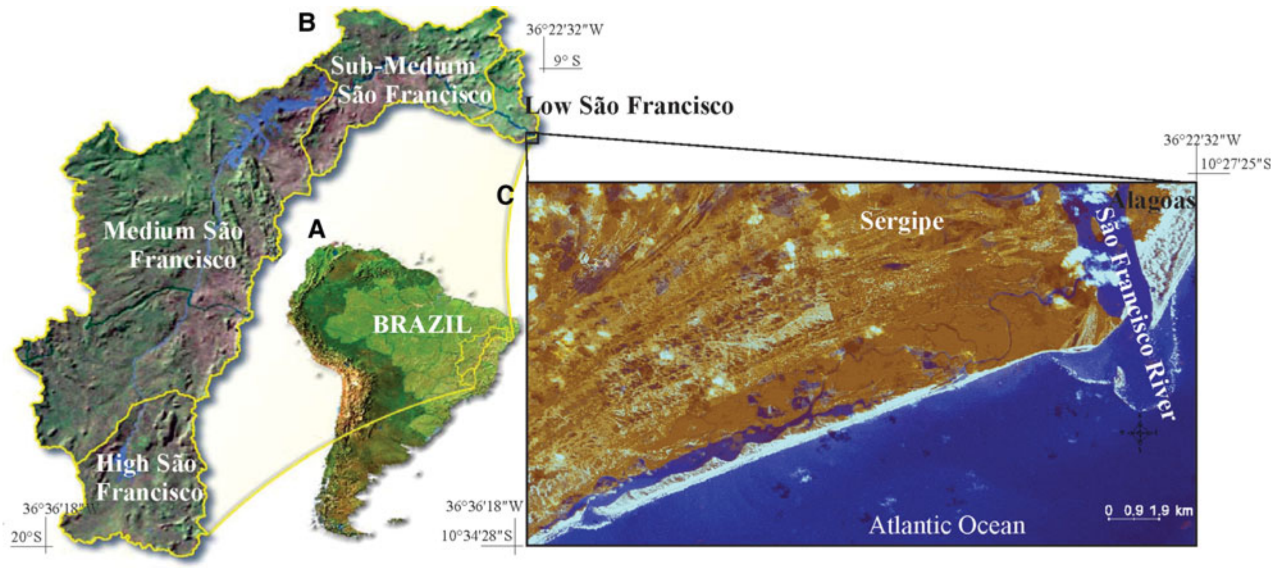

Fig. 1. (A) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (B) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (C) A close-up of the São Francisco River Estuary, the study area (tones of red are vegetation, blue is water and white is sand or clouds). (Adapted from Santos *et al.*, 2014.)

distributed in this area, characterized by artisanal fishery practices, using canoes and fishing methods such as line, net and gathering of crabs and shellfishes (CEPENE, 2003). This area is part of a State Environmental Protected Area (APA 'Litoral Norte'), a Conservation Unit of sustainable use whose objectives include the promotion of the socio-economic and sustainable development by activities that protect and conserve the ecosystems and the improvement of the life quality of the local population (Sergipe, 2004).

Sample of *Ucides cordatus* burrows and population estimations

Six different sites of mangrove forests were sampled (Figure 2), from 9–11 February 2013. At each site two transects of 50 m from the channel edge towards the interior of the mangrove forest were delimited. The transects were arranged parallel to each other and separated by a distance of 5 m. Within the area bounded by transects, three quadrats of 5 × 5 m (25 m^2) were delimited (e.g. Schmidt *et al.*, 2008a; Amaral *et al.*, 2014; Pinheiro & Almeida, 2015). The first quadrant was at 5 m from the edge, the second at 25 m and the third at 45 m. In each quadrat the geographic coordinates were recorded on a GPS (Global Positioning System, Garmin eTrex Venture HC) and qualitative information about the mangrove vegetation was recorded, such as species composition, dominant arboreal mangrove species, stand stature (height) estimated as short (tree height $\leq$7 m), medium (height 7–15 m) and tall (height$\geq$15 m) (e.g. Santos *et al.*, 2014), in order to provide additional qualitative information on the structural heterogeneity of the sampled mangroves (e.g. Sandrini-Neto & Lana, 2011). A total of 18 quadrants were sampled.

Within each quadrant the diameter of burrow entrances of *U. cordatus* was measured in parallel with the sediment using a digital caliper (0.05 mm). Only active galleries, identified by the presence of fluid mud, faeces, and/or animal traces close to the opening, were considered (e.g. Sandrini-Neto & Lana, 2011; Pinheiro & Almeida, 2015). *Ucides cordatus* burrows are easily recognized in the field (Santos *et al.*, 2009) and broadly used as a proxy of crab density and size (Piou *et al.*, 2009; Sandrini-Neto & Lana, 2011; Pinheiro & Almeida, 2015). The galleries of *U. cordatus* were differentiated from other crab species by inspection of the duct and opening morphology, and its position in relation to the surface of the sediment, as described by Santos *et al.* (2009). Besides this, we are aware of the possibility that juvenile, smaller crabs can inhabit burrows that were abandoned by larger crabs, thus we only considered in our sample active galleries.

Population estimations from burrow numbers and size have been used widely for mangrove crab species (e.g. Macintosh, 1988; Warren, 1990; Skov *et al.*, 2002; Salgado Kent & McGuinness, 2006), including *U. cordatus* (e.g. Alcantra-Filho, 1978; Alves & Nishida, 2003; Alves *et al.*, 2005; Hattori, 2006; Schmidt *et al.*, 2008a; Wunderlich *et al.*, 2008, Piou *et al.*, 2009; Sandrini-Neto & Lana, 2011). Advantages of this methodology include: speed and consequent increase in sample size; conducting non-destructive sampling, which is important when work involves endangered species; and the possibility of obtaining measures of all individuals within sampling units (Schmidt *et al.*, 2008a).

Considering that each burrow of *U. cordatus* is inhabited by a single crab (Costa, 1979; Alves *et al.*, 2005), the number of burrows within the quadrats in each mangrove site was used to estimate the crab density (number of burrow m^{-2}), and the diameter of the burrow entrance was used as a proxy crab size (e.g. Alcantara-Filho, 1978; Alves & Nishida, 2004; Alves *et al.*, 2005; Hattori, 2006; Schmidt *et al.*, 2008a; Wunderlich *et al.*, 2008; Piou *et al.*, 2009; Sandrini-Neto & Lana, 2011; Pinheiro & Almeida, 2015). The data of crab burrow size was classified in eight size classes of 10 mm, from 20–30 to 90–100 mm; and histograms of the class size-frequency distribution were produced.

The burrow diameter (BD) is a measure similar to the crab carapace length (CL) which is correlated with the body size of

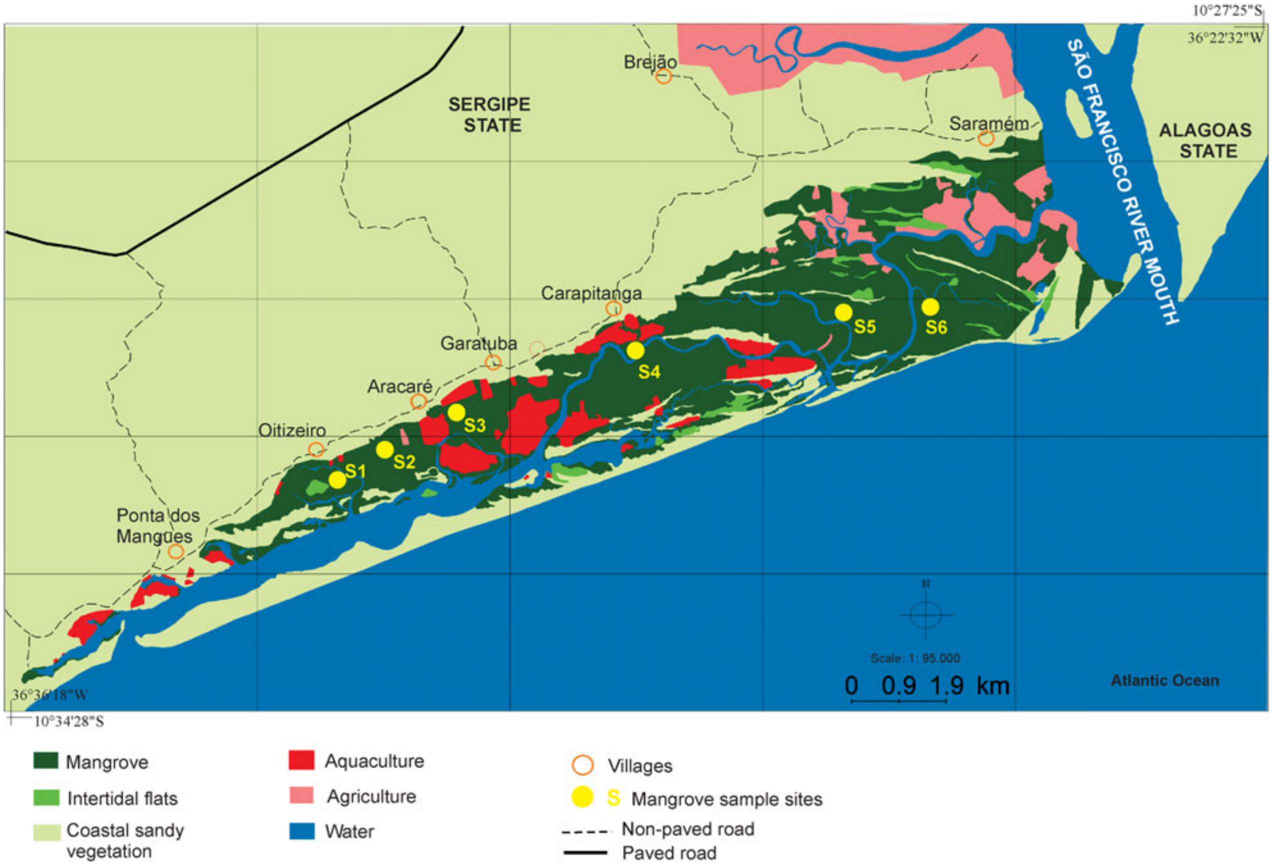

Fig. 2. Land use and cover map of study area (São Francisco River Estuary), indicating the six mangrove sample sites (S1–6).

U. cordatus, measured as the carapace width (CW) (Pinheiro & Almeida, 2015). In Brazil, the legal minimum market size of *U. cordatus* is 60 mm carapace width (IBAMA, 2003a). Schmidt *et al.* (2008a) determined that the legal market size of 60 mm carapace width (CW) corresponds to a carapace length (CL) of 46 mm which, in turn, corresponds to a burrow diameter (BD) of 51 mm. The relationship and conversion among these variables (BD to CL and then to CW) is described by Schmidt *et al.* (2008a) and Pinheiro & Almeida (2015).

Therefore, the frequency and density of crabs of commercial and non-commercial size were determined by the frequency (%) and density (number of burrow m^{-2}) of burrows with diameter size $\geq$51 mm and $<$51 mm, respectively. The Immediate Extractive Potential (IEP) was considered as the percentage of burrows above (or equal to) the size at first maturity, which corresponds to the frequency of crabs of commercial size, while the Future Extractive Potential (FEP) is the percentage of burrows below the size at first maturity, which corresponds to the frequency of crabs of non-commercial size (e.g. Wunderlich *et al.*, 2008).

The total commercial and non-commercial stocks of *U. cordatus* were estimated based on the total commercial and non-commercial densities, respectively, and the total extent of mangrove forests, calculated in our previous study (e.g. Santos *et al.*, 2014). For stock estimation, we obtained the product between the density (number of burrow m^{-2}) and the areal extension of mangroves (in m^2).

Statistical analysis

The data were tabulated and analysed in *GraphPad Prism* and *Excel* software. The analysis was carried out considering the entire mangrove forest of the São Francisco River Estuary (all sampled sites) and in relation to each mangrove site, which were compared by statistical tests. Descriptive statistics such as mean, standard deviation (SD) and frequency were calculated for crab burrow size and density. The normality of the data and homogeneity of variances were assessed by Kolmogorov–Smirnov and Bartlett tests, respectively, in order to apply parametric tests. The statistical analyses ANOVA and Tukey's Multiple Comparison test were carried out in order to compare the mean burrow diameter among the six sites of mangrove. The Kruskal–Wallis test (non-parametric ANOVA) and Dunn's Multiple Comparison Test were used to compare median crab density among the six sites of mangroves, because of the small size of this sample data. The t-test was used to verify if there was a difference in the density of the commercial and non-commercial crab burrow sizes. The χ^2 test was used to compare the frequencies of IEP and FEP between mangrove sites.

RESULTS

A total of 541 burrows of *Ucides cordatus* were measured and counted along the six sampled sites in the São Francisco River Estuary, corresponding to a total of 450 m^2 of sampled mangrove area. All sampled sites were mostly made up by *Rhizophora mangle* L. and some sites also showed the occurrence of *Avicennia schaueriana* Stapf and Leechman ex Moldenke, *Laguncularia racemosa* (L.) Gaertn.f., or both (sites 2, 3, 4 and 6). Site 6 was unique with occurrence of the mangrove-associated species *Acrostichum aureum* and dead *L. racemosa* trees infested by termites, while site 5 showed a remarkably high density of rhizophores. Mangrove stands of short stature (height <7 m) were recorded in sites 2, 3 and 6, while medium mangrove stand stature (height between 7 and 15 m) was recorded in sites 1, 4 and 5.

Considering all the six sampled sites, the overall mean burrow size of *Ucides cordatus* in the mangroves of the São Francisco River was 56.8 (±12.2) mm. Most of the crab burrows are in the class size of 50–60 mm (33.8%), followed by 60–70 mm (24%) and 40–50 mm (22.6%) (Figure 3A). Thus, medium-sized crabs (40–70 mm) are the most frequent in the mangroves of the São Francisco River Estuary. Burrows from large-sized crabs (70–80 mm: 8.3%; 80–90 mm: 4.3%; and 90–100 mm: 0.3%) and small-sized ones (20–30 mm: 0.3%; and 30–40 mm: 5.5%) are less frequent in these mangroves, but the larger are more frequent than smaller (Figure 3A).

The comparison of the six mangrove sites indicated that mean crab burrow size significantly differed among some sites ($F = 6.66$, $P < 0.0001$, Tables 1 and 2). Site 1 showed the highest mean burrow size, which significantly differed from all the other sites, apart from site 2. On the other hand, site 6 showed the lowest mean burrow size, differing from sites 1, 2 and 5. The others sites (2, 3, 4 and 5) did not differ in mean burrow size (Tables 1 and 2).

In regard to size-frequency distribution in the six mangrove sites (Figure 4), site 1, which recorded the highest mean burrow size (Table 1), also showed highest frequency of large crab burrows (70–80 mm: 17.1%; 80–90 mm: 14.6%; and 90–100 mm: 4.9%) and the lowest frequency of small crab burrows (20–30 mm: 2.4%; 30–40 mm: 2.4%). Moreover, this was the unique site that recorded all the classes of crab burrow size. Sites 2, 3, 4 and 5 showed similar size-frequency distribution, with predominance of medium-size crab burrows (40–50 to 60–70 mm), but site 4 recorded the highest frequency of burrows between 50–60 mm (44.1%). Site 6, although showing predominance of medium-size crab burrows, had a most frequent size class of 40–50 mm (31%), differing from all the other sites (Figure 4).

In general, about 71.2% of the total sampled burrows were from crabs which are of commercial size (burrow size ≥51 mm), while 28.8% are from crabs that did not reach commercial sizes (burrow size <51 mm) (Figure 3B). Therefore, in the mangroves of the study area the IEP (71.2%) of *U. cordatus* was significantly higher than the FEP (28.8%) ($\chi^2 = 21.5$, $P = 0.0006$). Sites 1 and 2 recorded the highest values of IEP (>80%) and the lowest FEP (<20%), while site 6 showed an opposite pattern (Table 1). Site 6 showed a remarkably low IEP and high FEP and it was the sole area in which IEP and FEP significantly differed from all the other areas (sites 1, 2, 3, 4 and 5) ($\chi^2 = 9$, $P = 0.0027$; $\chi^2 = 15.31$, $P < 0.0001$; $\chi^2 = 4.9$, $P = 0.028$; $\chi^2 = 12.7$, $P = 0.0004$; and $\chi^2 = 5.93$, $P = 0.015$, respectively). Sites 3, 4 and 5 showed intermediate high values of IEP (69–77%) and intermediate low values of FEP (29–31%) (Table 1), which did not statistically differ among them and among sites 1 and 2, with the exception of site 5 which showed lower IEP and higher FEP than site 2 ($\chi^2 = 3.8$, $P = 0.04$).

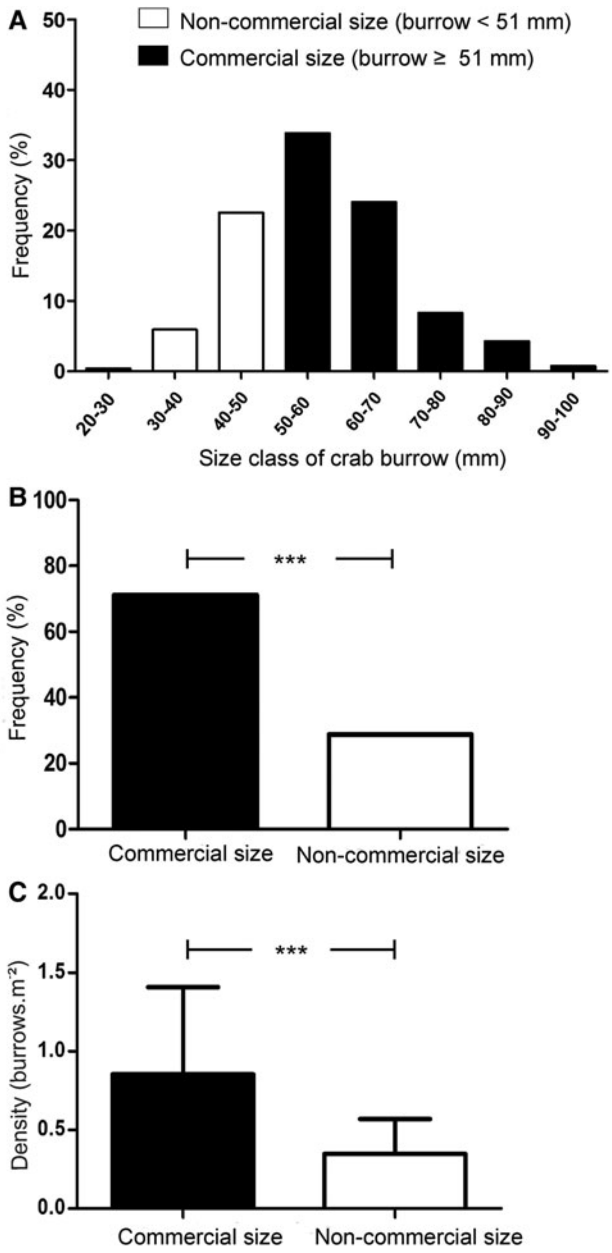

Fig. 3. Population parameters of *Ucides cordatus* based on measurement of their burrows in the mangroves of the São Francisco River Estuary. (A) Size-frequency distribution of *Ucides cordatus* by burrow's classes. (B) Frequency of the crab's burrows in commercial and non-commercial sizes. (C) Density of the crab's burrows in commercial and non-commercial sizes. (***$P < 0.001$).

The overall mean crab density in the mangrove forests of the São Francisco River Estuary was 1.2 (±0.68) burrows m^{-2}. From this, the density of burrows from crabs in commercial size (0.85 ± 0.55 burrows m^{-2}) was significantly higher than the density of crabs in non-commercial size (0.35 ± 0.21 burrows m^{-2}) ($t = 3.59$, $P < 0.0005$) (Figure 3C). Considering the total mangrove extent (30 km^2), the study area showed, in February 2013, a mean total crab stock of about 3.6×10^7 individuals, from which 2.55×10^7 individuals are crabs in commercial size, and 1.05×10^7 individuals are crabs in non-commercial size. Thus, the proportion of commercial size crab stock:non-commercial size crab stock in the mangrove of the São Francisco River Estuary is 1:0.4.

Table 1. Population parameters of *Ucides cordatus* based on measurement of their burrows in the six sampled sites mangroves in the São Francisco River Estuary.

Population parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Mean crab burrow size (mm)	64.06 (±15.73)	58.96 (±10.25)	56.33 (±13.54)	56.19 (±10.98)	57.17 (±12.09)	51.76 (±10.23)
IEP (%)	80.48%	81.48%	70.37%	76.38%	69.23%	52.50%
FEP (%)	19.52%	18.42%	29.63%	23.62%	30.77%	47.50%
Mean density of total crab burrows (burrow m^{-2})	0.56 (±0.21)	1.08 (±1.1)	1.06 (±0.70)	1.69 (±0.66)	1.73 (±0.51)	1.07 (±0.06)
Mean density of commercial crab burrow size (burrow m^{-2})	0.43 (±0.23)	0.88 (±0.87)	0.76 (±0.64)	1.29 (±0.55)	1.2 (±0.42)	0.56 (±0.11)
Mean density of non-commercial crab burrow size (burrow m^{-2})	0.13 (±0.06)	0.20 (±0.24)	0.32 (±0.26) a	0.40 (±0.14)	0.53 (±0.23)	0.51 (±0.08)

IEP, Immediate Extractive Potential; FEP, Future Extractive Potential (FEP).
Mean ± standard deviation.

The mean density of total, commercial and non-commercial crab burrows did not statistically differ among the six sites ($H = 6.68$, $P = 0.25$; $H = 6.4$, $P = 0.27$; $H = 7.52$, $P = 0.18$, respectively). However, sites 4 and 5 showed higher values of total and commercial mean densities than sites 1, 2, 3 and 4. The lowest value of mean density was recorded in site 1 (Table 1). Site 4 was unique in that it showed similar values of commercial and non-commercial crab burrow density (Table 1), recording a proportion of ~ 1:1.

DISCUSSION

Population structure

The value of mean *Ucides cordatus* density (1.2 burrows m^{-2}) recorded in this study was similar or lower than those recorded in other mangroves along the Brazilian coast (Table 3). The most similar values were recorded in mangroves located on the north coast, in Amapá (e.g. Amaral *et al.*, 2014) and in the south coast in Santa Catarina (e.g. Branco, 1993). It is interesting to note that we registered lower values than those found in mangroves on the north-east coast, the region where the study area is located. The low values of mean crab density recorded in the mangroves of the São Francisco River Estuary can be attributed to a high mortality of the crab in this area, which started in 2000, as reported by local fishermen (e.g. Santos *et al.*, 2013), probably due to the lethargic crab disease that spread along the Brazilian North-east coast between 1997 to 2010 causing massive mortalities of *U. cordatus* (e.g. Boeger *et al.*, 2005, 2007; Firmo *et al.*, 2011). This high mortality of *Ucides cordatus* in the study area is also supported by the data of crab production which showed a large decrease since 1999 (e.g. CEPENE, 1999, 2000, 2001, 2002, 2003). The same evidence of low crab density related to crab mortality was also observed by Alves & Nishida (2004) in other mangroves on the Brazilian North-east coast. Additionally, it is remarkable that the *U. cordatus* density can vary between different mangrove areas as a result of their degradation (Pinheiro *et al.*, 2013; Duarte *et al.*, 2014), higher incidence of this extractive feature (Pinheiro & Fiscarelli, 2001), as well as due to intrinsic factors of a particular mangrove forest (primary productivity and patterns of larval recruitment, among others) (Conti & Nalesso, 2010). Since shrimp farming is the main impact causing deforestation of mangroves in the study area (Santos *et al.*, 2014), and the fishery of *U. cordatus* by the local communities is very high (Santos *et al.*, 2013), these two factors may also contribute to the lower densities recorded in the present study. In general, recent papers have registered smaller crab densities than the older studies, revealing that the crab population has been overfished, mainly due to unsustainable practices (Conti & Nalesso, 2010) without respect to their biological limitations such as slow growth (see Pinheiro *et al.*, 2005). The reduction of the crab size, weight and abundance in various mangrove areas in Brazil reveals the great pressure to which the *U. cordatus* crab population has been subject (Góes *et al.*, 2010; Brasil, 2011).

Table 2. Differences in crab burrow size (mm) among mangrove sites, using information of Tukey's Multiple Comparison Test.

Magrove sites comparison	Mean difference	Confidence interval (95%)		*q*	Significance at $P < 0.05$
		Lower	Upper		
Site1 *vs* Site 2	5.10	−1.42	11.63	3.19	No
Site 1 *vs* Site 3	7.72	1.19	14.26	4.83	Yes
Site1 *vs* Site 4	7.86	1.75	13.98	5.25	Yes
Site1 *vs* Site 5	6.88	0.79	12.98	4.61	Yes
Site 1 *vs* Site 6	12.30	5.75	18.84	7.68	Yes
Site 2 *vs* Site 3	2.62	−2.77	8.01	1.98	No
Site 2 *vs* Site 4	2.76	−2.12	7.64	2.31	No
Site 2 *vs* Site 5	1.78	−3.07	6.64	1.49	No
Site 2 *vs* Site 6	7.19	1.78	12.61	5.43	Yes
Site3 *vs* Site 4	0.13	−4.74	5.02	0.11	No
Site 3 *vs* Site 5	−0.84	−5.70	4.02	0.70	No
Site 3 *vs* Site 6	4.57	−0.83	9.98	3.45	No
Site 4 *vs* Site 5	−0.97	−5.26	3.30	0.93	No
Site 4 *vs* Site 6	4.43	−0.46	9.33	3.69	No
Site 5 *vs* Site 6	5.41	0.53	10.29	4.53	Yes

(q, studentized range q).

The mean size of *U. cordatus* recorded in this study (56.82 ± 12.2 mm) was overall similar to those recorded on the north-east coast, lower than the north and higher than the south-east and south coast (Table 3). Here we found a dominance of adult medium-size crabs (40–70 mm), mainly from the class of 50–60 mm. This pattern was also recorded in other studies about *U. cordatus* in Brazilian mangroves (e.g. Passos & Di Beneditto, 2005; Diele *et al.*, 2005; Brasil, 2011) and is in accordance with the survival curve for the species, which is characterized by high survival in

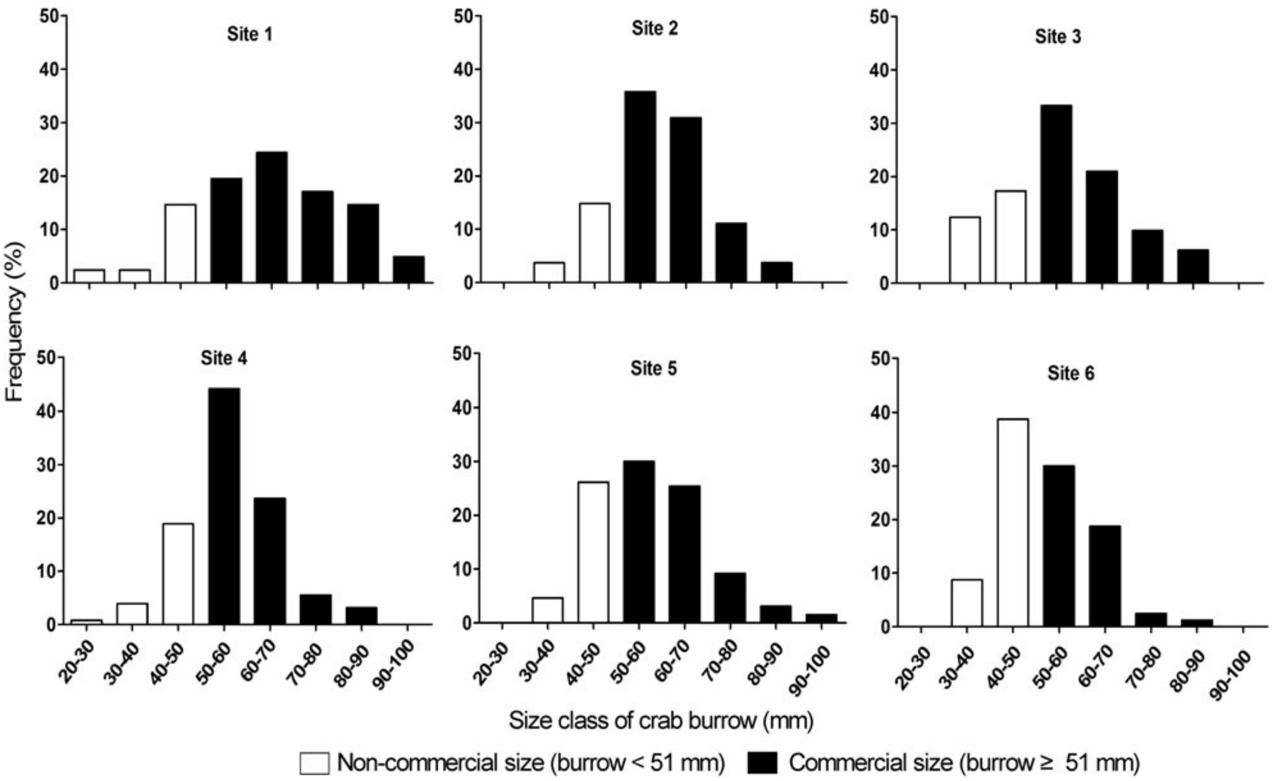

Fig. 4. Size-frequency distribution of *Ucides cordatus* based on measurement of their burrows in the six mangrove sampled sites of the São Francisco River Estuary.

intermediate age classes/sizes, followed by a decrease when close to longevity/maximum size (Leite *et al.*, 2012). Additionally, we found more frequency of larger crabs than smaller ones (Figure 3A). High frequency of large crabs is frequently found in large, long-living species, such as *U. cordatus*, where crabs accumulate in larger size classes as growth decreases with age (Hartnoll, 1982; Hartnoll & Bryant, 1990).

Differences in mean crab burrow size and in the size frequency were detected among the mangrove sites. The highest and statistically significant difference in crab size was found between site 1 (the farthest mangrove area from the estuary mouth – Figure 2), which showed the largest crabs (Figure 4, Table 1) and site 6 (the nearest from the estuary mouth – Figure 2), which showed the smallest crabs (Figure 4, Table 1). These sites have different vegetation composition, as a mono-specific mangrove forest of *Rhizophora mangle* (site 1) and a mangrove area with occurrence of *R. mangle* and *Laguncularia racemosa*, associated with *Acrostichum aureum* L. and dead *L. racemosa* trees infested by termites (site 6). Therefore, differences in crab size and size frequency between these sites can be attributed to differences in vegetation composition, a fact also verified in sex ratio

Table 3. Density and mean size of *Ucides cordatus* recorded by the literature and in the study area, in mangrove forests along the Brazilian coast.

Brazilian coast region	State	Mean density (burrows m^{-2})	Mean size (mm)	Period	Reference
North	Amapá	1.09	64.35	2008–2010	Amaral *et al.* (2014)
	Pará	6.09	52.1	2004	Piou *et al.* (2009)
	Pará	1.7	61[a], 55[b]	1997–1998	Diele *et al.* (2005)
North-east	Paraíba	1.7	56.6[a], 50.5[b]	2000–2001	Alves & Nishida (2004)
	Ceará	4.75	60.3[a], 56.9[b]	1973–1975	Alcantara-Filho (1978)
	Sergipe	1.2	56.82	2013	Present study
South-east	Espírito Santo	2.5	48.9	2004–2005	Conti & Nalesso (2010)
	Espírito Santo	3.7	54.6	1998–1999	Góes *et al.* (2010)
	São Paulo	1.8[c]	45.9[c]	2005	Hattori (2006)
	Paraná	1.35[d], 0.86[e]	–	2007	Sandrini-Neto & Lana (2011)
South	Santa Catarina	1.11	–	1987–1990	Branco (1993)
	Santa Catarina	2.02	68[a], 58.7[b]	2002–2003	Wunderlich *et al.* (2008)

[a]Male.
[b]Female.
[c]Sampled in *Rhizophora mangle* forests.
[d]Commercial size.
[e]Non-commercial size.

of *U. cordatus* by Wunderlich *et al.* (2008). According to Gomes *et al.* (2013) some mangrove crab characteristics, such as abundance and weight/size, can be significantly correlated with vegetation type. Moreover, differences in food availability (leaf litter) and/or quality could cause differential growth rates and thus crab sizes (Diele *et al.*, 2005) among mangrove areas with different vegetation structure and productivity. *Ucides cordatus* preferentially created their burrow entrances closed to *R. mangle* prop roots (Piou *et al.*, 2009). Presence of *Avicennia germinans* (L.) Stearn and *L. racemosa* in the neighbourhood was not found to favour big sizes and large numbers of crab burrows (Piou *et al.*, 2009). Thus, since *U. cordatus* mainly feeds on mangrove vegetation litter, a reduction of food availability (leaf litter) and quality in site 6 (due to the presence of *L. racemosa* associated with *Acrostichum aureum* and dead trees) could have caused the high frequency of smaller crabs. The other mangrove sites (2, 3, 4 and 5) did not differ in mean burrow size (Tables 1 and 2) and showed very similar vegetation composition, with *Rhizophora mangle* as the dominating species. These results suggest the influence of the vegetation composition on the *U. cordatus* population structure, as stated by Gomes *et al.* (2013).

We did not record significant differences in crab density among the mangrove sites. Nevertheless, it is important to highlight that the mangrove site 1, which recorded the largest crab sizes, also recorded the lowest density (Table 1). This low density with dominance of large crabs could be attributed to the occurrence of monospecific mangrove forest of *R. mangle*, the vegetation composition found in the preferred habitat of *U. cordatus* (e.g. Diele *et al.*, 2005; Hattori, 2006; Piou *et al.*, 2009). Data from previous studies (Oliveira, 2005; Wunderlich & Pinheiro, 2013) suggest that monospecific mangrove forests of *R. mangle* are those with higher levels (higher water column) or frequency of flooding during neap and spring tide and muddy, almost fluid sediment. Thus, in these areas, larger crabs are more able to rebuild their galleries after the flooding by tides. To save energy, these animals build their galleries close to the areal roots of these trees, which guarantee more stability of the adjacent sediment and therefore favour the stability of the galleries of this species.

Fishery potential and management

The study area largely shows a high potential for the fishery of *U. cordatus*, since most of the crabs are of commercial size, thus showing a high Immediate Extractive Potential (IEP – 72.1%, Figure 3B) and higher density of commercial-sized crabs (Figure 3C). Additionally, this area shows a large stock of commercial crabs (2.55×10^7 individuals) which sustains the immediate extractive potential, in addition to a stock of non commercial-size crabs (1.05×10^7 individuals), which sustains the Future Extractive Potential (FEP – 27.9%). Wunderlich *et al.* (2008) also found a similar result in mangroves of Santa Catarina State (south Brazil), recording higher IEP than FEP, which was considered of high fishery potential for *U. cordatus*.

Despite these results, *U. cordatus* is the second more explored fishery resource in the study area, and the main base of the local subsistence economy (Santos *et al.*, 2013). Thus, the fishery pressure and extractive rates of this resource are very high, requiring adequate management strategies for their sustainable use. Another important point to be highlighted is about a lower overall crab density recorded in the study area when compared with other Brazilian mangroves (Table 3). This difference could be explained by the high crab mortality that occurred in the study area and to overfishing. Considering these features, it is important to establish management strategies for conservation and a sustainable fishery of *U. cordatus* in the São Francisco River Estuary. The high exploitation and mortality of *U. cordatus* is a scenario also verified in almost the entire Brazilian coast, which highlights the importance of local and regional studies in order to apply structural population data to guide the elaboration of management strategies, in order to meet the objectives of the National Management Plan and Sustainable Use for this species (Brasil, 2011).

Due to the reduced growth rate of *U. cordatus* and intense extraction of this resource, it is necessary to foresee the laws of closure (e.g. IBAMA, 2003a, b), an intensified supervision and proper management of its natural population to provide an efficient conservation process of this species, ensuring the continuity of the extraction (Pinheiro & Fiscarelli, 2001). As a management suggestion, fishery management strategies could be considered that apply a fixed exploitation rate, in which the same percentage of stock is caught and the rest is left to reproduce and spawn. This can be calculated based on the assessment of the crab stock size and IEP which was estimated in this study for the São Francisco River Estuary. Another strategy is a fixed escapement rule which leaves the same number of crabs to spawn each year. A fixed escapement rule is a fishery management measure which aims to establish a stock after harvest. The advantage of this is to guarantee enough animals to assure the next generation and to assure the FEP. Both strategies could be considered in the study area and in other areas in Brazil showing similar population structure of *U. cordatus*. This would reinforce the importance of population structural data being applied to crab fishery management.

The Proposal of a National Management Plan for *U. cordatus* highlights the delineation of extractive and fishery exclusion areas of this resource (Brasil, 2011; Pinheiro & Rodrigues, 2011). In this view it is crucial to identify mangrove areas more suitable for fishery in which a fixed exploitation rate and/or a fixed escapement rule should be considered and other mangrove areas more suitable for conservation wherein the fishery should be prohibited in order to allow the conservation of adults crabs for reproduction, enabling the juvenile crabs to grow and reach the commercial sizes. In the present study we identified these mangrove areas, based on the crab population structure. For example, sites 1 and 2 recorded the highest IEP while sites 3, 4 and 5 recorded intermediate IEP (Table 1), indicating their high potential for crab fishery. From these, sites 4 and 5 were the most important areas for fishery due to a combined higher mean of density from commercial crabs and greater crab size. On the other hand, site 6 showed the lowest IEP and the highest FEP and thus is a more appropriate mangrove area for conservation of the *U. cordatus*.

Corroborating our finds we can mention another study (Santos *et al.*, 2013), that reveals the mangrove sites 1, 2, 3 and 4 as the most productive areas for extraction of *U. cordatus*. According to these authors, the village considered the primary crab producer (Carapitanga, Figure 2) uses mainly mangroves of site 4, where there is a remarkably high frequency of crabs in the class size of 50–60 mm, and the highest density of commercial crabs. The second most productive village (Oitizeiro, Figure 2), mainly uses mangroves of sites 1 and 2; and the third most productive village (Aracaré, Figure 2) exploits *U. cordatus* on mangroves of sites 2 and 3. Nevertheless, most attention should be direct to site 1, because although it showed the highest mean crab size, it also records the lowest density. Thus from the sites that showed potential for fishery, site 1 should be the least exploited. An alternative for this is the use of the mangrove site 5, a mixed area that combined high crab size and density, instead of the exploitation of the crab in site 1.

CONCLUSION

We concluded that the composition of mangrove vegetation can promote changes in *U. cordatus* population structure. We found larger crabs in lower density mangrove areas of monospecific mangrove forest of *Rhizophora mangle*, or dominated by this mangrove species. Moreover, mangroves associated with *Acrostichum aureum* and dead trees were linked with the occurrence of smaller crabs in high densities. These patterns show a spatial distribution wherein the density and size of crabs tend to increase in the direction to the river mouth.

Overall the São Francisco River Estuary mangroves show a high potential for the fishery of *U. cordatus*, showing a high IEP and stock in commercial size. Nevertheless, this study area showed lower densities of *U. cordatus* than other Brazilian mangrove areas. We argued that this lower density is mainly caused by a high mortality of the crab that occurred in 2000, mangrove deforestation due to shrimp farming and also to a high fishery pressure on *U. cordatus* by the local populations. This scenario reveals the need for new strategies directed for the conservation and sustainable management of *U. cordatus*. Therefore, we conclude that the mangrove areas more appropriate for *U. cordatus* fishery (extractive areas) are those that combined higher means of crab size associated with the greater densities of commercial crabs and rates of IEP. On the other hand, mangrove areas more appropriate for the conservation of *U. cordatus* (fishery exclusion areas where fishing should be prohibited) are those with smaller mean crab size combined with a higher density of non-commercial crabs and FEP.

These important management strategies were delineated based on the population structure of *U. cordatus* assessed in this study. Therefore our study and conclusions reinforce the importance of this type of data being applied to achieve the objectives of the National Management Plan and Sustainable Use for this species. These strategies (identification of extractive areas and fishery exclusion areas, fixed exploitation rate based on IEP and fixed escapement rule based on FEP) should be considered in our study area as well as in other Brazilian mangrove areas showing similar *U. cordatus* population parameters to those assessed in the present study.

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