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Seasonal variation in biometric parameters in a population of the endangered blue land crab (*Cardisoma guanhumi*): Indicators for assessment and management

M.C. Lima [a], C.A.M. Pereira [b], M.S.L.C. Araújo [c], G.G. Rodrigues [b], G. Nicacio [a,*]

[a] *Programa de Pós-graduação em Morfotecnologia, Centro de Biociências, Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, 1235 - Cidade Universitária, Recife – PE, CEP: 50670-901, Brazil*

[b] *Departamento de Zoologia, Centro de Biociências, Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, 1235 - Cidade Universitária, Recife – PE, CEP: 50670-901, Brazil*

[c] *Faculdade de Ciências, Educação e Tecnologia de Garanhuns, Universidade de Pernambuco, R. Cap. Pedro Rodrigues, São José, Garanhuns – PE, CEP: 55294-902, Brazil*

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ABSTRACT

Cardisoma guanhumi is a land decapod crustacean distributed along the eastern Atlantic. Currently, this species is included in the Brazilian list of aquatic species overexploited or threatened with overexploitation. This study performed biometric analysis and assessed reproductive dynamics of the blue land crab *Cardisoma guanhumi* in Acaú-Goiana Extractive Reserve, a coastal marine protected area in northeast Brazil. From January 2019 to December 2020, biometric data were evaluated from 539 captured individuals by an artisanal trap. In addition, male gonads and hepatopancreas were removed and fixed in formalin solution to analyse morphological reproductive indicators by gonadal (GSI) and hepatosomatic (HSI) index calculation. In summary, the population of blue land crab showed 322 males and 217 females. We observed a difference in variation of mean seasonal carapace width (54.73–56.67 mm). The condition factor ranged from 0.97 to 1.07, showing significant differences between the years and the seasons with high values observed in the dry season in 2019 and 2020. The weight–length relationships showed negative allometric growth for males ($b = 2.586$, $a = 0.010$) and females ($b = 2.229$, $a = 0.291$). The monthly distribution of the hepatosomatic (HSI) index did not show a clear annual pattern, but GSI differed between the months, indicating two seasonal groupings of Jan–Feb and May–August–Nov. The reproductive indicators of *C. guanhumi* evaluated here may indicate that the environmental influence and fishing pressure are the main factors that drive its reproductive seasons. Thus, it is noteworthy to indicate conservation efforts from January to April, when should be considered the breeding season for the species. In addition, long-term monitoring in the Extractive Reserve Acaú-Goiana must be considered for studies of population structure and gene flow of *Cardisoma guanhumi*, prioritizing the preservation of their habitats.

1. Introduction

Cardisoma guanhumi (Latreille, 1828) is a land decapod crustacean distributed along the eastern Atlantic, occurring from the southern coast of the United States to southern Brazil (Gifford, 1962; Hostetler et al., 2003). It has nocturnal habits and living in deep burrows near the water. The population of this species stands out in mangrove areas for its remarkable biomass and high density. The blue land crab is a significant fishing resource appreciated for its size and considerable better taste when compared to other land crabs of regional commercial value (e.g., *Ucides cordatus* and *Goniopsis cruentata*). Because of this, it has a socio-economic and high market value for the local economy of traditional communities in the Brazilian coastal zone (Joyeux et al., 2010; Firmo et al., 2012; Pereira-Júnior et al., 2019).

Considering its socio-economic significance along the eastern Atlantic, populations of this species are declining and threatened in several regions, including the Brazilian coast. *Cardisoma guanhumi* is currently also categorized as critically endangered (CR) on the IUCN (International Union for Conservation of Nature) Red List for wild species (Brasil, 2014, 2018). Thus, *C. guanhumi* is currently on the Brazilian List of species threatened by

* Corresponding author.
E-mail addresses: umamarinalima@gmail.com (M.C. Lima), claudio.prepara0@gmail.com (C.A.M. Pereira), marina.araujo@upe.br (M.S.L.C. Araújo), gilbertorodrigues.ufpe@gmail.com (G.G. Rodrigues), gilnicacio@gmail.com (G. Nicacio).

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overexploitation. This national list of species includes aquatic invertebrates and fish that are overexploited or threatened with overexploitation, mostly because of anthropogenic pressures by habitat degradation, water pollution and strong predatory fishing (Firmo et al., 2012; Brasil, 2014). Currently, researchers have highlighted the need for monitoring this species by indicators of population size variation, the minimum size for capture and establish prohibition periods for reproduction (Dias-Neto, 2011; Pereira-Júnior et al., 2019).

Along the eastern Atlantic, the decline in populational abundance and in the average size of individuals for this species has been mostly associated with predatory catching and the destruction of its habitats (Amaral and Jablonski, 2005; Govender et al., 2008). Therefore, considering this scenario in many countries, to maintain reproductive dynamics, the regulations for capture *C. guanhumi* have been established daily limits for the catch amount and a minimum carapace size to reduce the pressure on the populations. Then, for the Brazilian coast, to avoid the catch of individuals that have not achieved the minimum size of sexual maturity, current legislation established a minimum carapace size of 7 cm wide for the capture of male representatives and provided full protection for female individuals, and its capture still is prohibited (Dias-Neto, 2011; Brasil, 2018).

Populations of *C. guanhumi* in the western Atlantic have been exposed to remarkable habitat degradation and sparse effort for conservation, which highlight the need to consider monitoring local and regional contexts prior estimates minimum legal capture size for crabs (Carmona-Suárez, 2011; Govender et al., 2008). Because the variation in carapace width may be the result for a local adaptive strategy to the habitats, environments, and local fishing pressure, which are not homogeneous along regions where the species occurs (Govender and Thomlinson, 2010). In general, outside the Brazilian coast, many records for blue land crab size from other localities often have been associated with the reduction in their distribution and habitat loss (Forsee and Albrecht, 2012; Hernández-Maldonado and Campos, 2015; Cardona et al., 2019; Govender, 2019). These regions are characterized by having different efforts to control selective catch pressures and environmental problems, but still absent in studies like those performed in populations from the Brazilian coast. However, to do associations in growth and size with environmental impacts on populations of *C. guanhumi*, it is necessary to implement long-term monitoring like those recent observed in Central America (Govender, 2019).

In general, the populations of *C. guanhumi* have been described by slow growth, longevity and achieve sexual maturity in approximately four years, mostly with carapace size above 5 cm wide (Hostetler et al., 2003; Silva and Oshiro, 2002; Silva et al., 2014). In this prolonged period, anthropic pressures can affect mating dynamics in populations by selective pressure to capture larger individuals, even if it is juveniles and those that did not achieve sexual maturity, which become unavailable for seasonal reproduction (Shinozaki-Mendes et al., 2013). These problems can influence the reproductive biology of the species when only the smaller individuals become suitable for the reproductive periods, which can lead to a decrease in the average population size of individuals. Furthermore, seasonal reduction in the number of males available for copulation may influence population size, where females may not find males with the amount of sperm suitable for fecundation (Hines et al., 2003).

The indicators of reproductive dynamics of economically important crustacean species, such as the variation in morphological characteristics associated with reproduction, have been widely evaluated in coastal ecosystems (Castilho et al., 2008; Govender et al., 2008; Shinozaki-Mendes et al., 2013). Prior studies considered that the relationship of morphometric aspects at the macroscopic level (biometric and biomass) is essential analyses for the assessment of sexual maturity of many organisms. These approaches can be used for monitoring fisheries and proper species management. In addition, they are essential for the progress of short- and long-term management strategies. Although there was an increasing knowledge on morphology and reproduction dynamics of *Cardisoma guanhumi* from South America, some Brazilian regions still lack empirical approaches to study populational parameters of this species within protected areas. Thus, this study aimed to evaluate growth patterns and biometric indicators of reproductive dynamics in a population of *Cardisoma guanhumi* in a protected area on the Brazilian northeast coast.

2. Material and methods

2.1. Study area

The study was conducted in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) from January 2019 to December 2020. The RESEX Acaú-Goiana is a protected area located between Pernambuco and Paraíba State, northeast Brazil. The Acaú-Goiana Extractive Reserve aims to protect livelihoods and ensure the use and conservation of renewable natural resources traditionally used by the local artisanal fishing communities. The main economic activities of the RESEX Acaú-Goiana are related to fishing and collecting estuarine and marine resources.

The study area is in the municipalities of Pitimbú and Caaporã, in the state of Paraíba, and Goiana, in the state of Pernambuco. The RESEX Acaú-Goiana is inserted in the estuary areas of the rivers Goiana and Megaó, except for an area of a private company in its interior destined to carciniculture (shrimp farming), and bordering the coast, composing the "restingas", salt marsh, and the mangrove of these rivers until the proximity of the city of Goiana. These municipalities in the region surrounding the RESEX are inserted in a region characterized by the expansion of urbanization, monoculture of sugar cane, expansion of industries such as automobile and cement production. Therefore, the regional context was also characterized by a gradual reduction of vegetation cover in the region in the last three decades (Silva et al., 2020).

The sampling sites were common areas used for collecting the blue land crab and other commercial important decapod crustacean such as *Ucides cordatus* and *Goniopsis cruetanta*. These sites have a mangrove area close to a thick and dense forest and were installed towards the upstream of the Goiana River: (P1) 7°56'17"S, 34°92'81"W, (P2) 7°55'13"S, 34°89'84"W and (P3) 7°56'72"S, 34°85"77 W (Fig. 1).

The study area has different precipitation seasonality regimes, a rainy season from March to August and dry season from September to February (Fig. 2). This seasonality affects the continuity of the blue land crab harvest by decreasing harvest pressure in rainy season and increasing during the dry season.

2.2. Specimen collection

The survey was authorized and followed Brazilian guidelines for the collection of specimens (ICMBio - SISBIO process 63618-3). The collections were carried out in some months from January 2019 to December 2020. Specimens were caught by artisanal traps, manually made by local fishermen. The fishermen installed the traps at the entrance to the galleries that showed recent traces of blue land crab activity. Then, at each site, once a month, the sampling effort applied was performed by installing 50 traps per day. The traps were installed at dawn and removed after the individuals were caught (7 until 10 am).

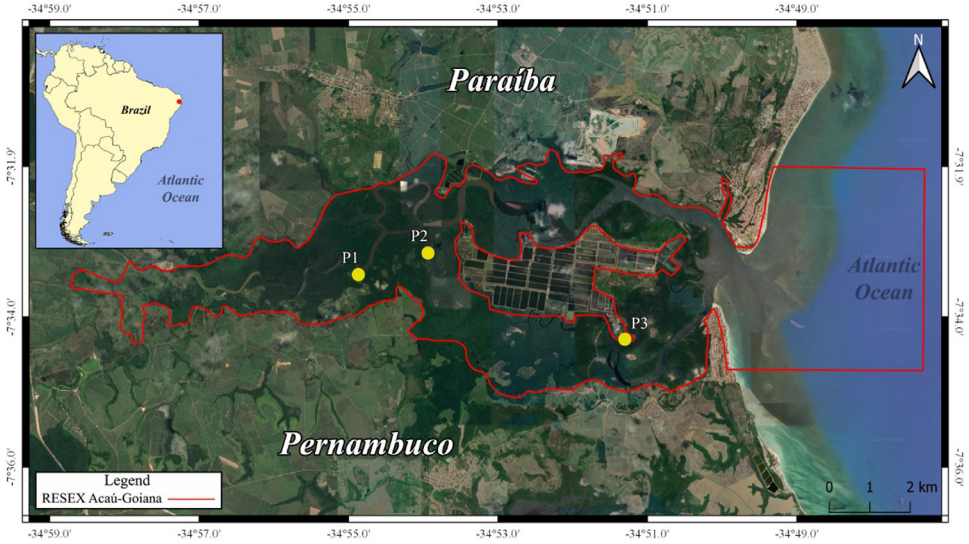

Fig. 1. The study area and the three sampling points (yellow dots) in which *Cardisoma guanhumi* was collected in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

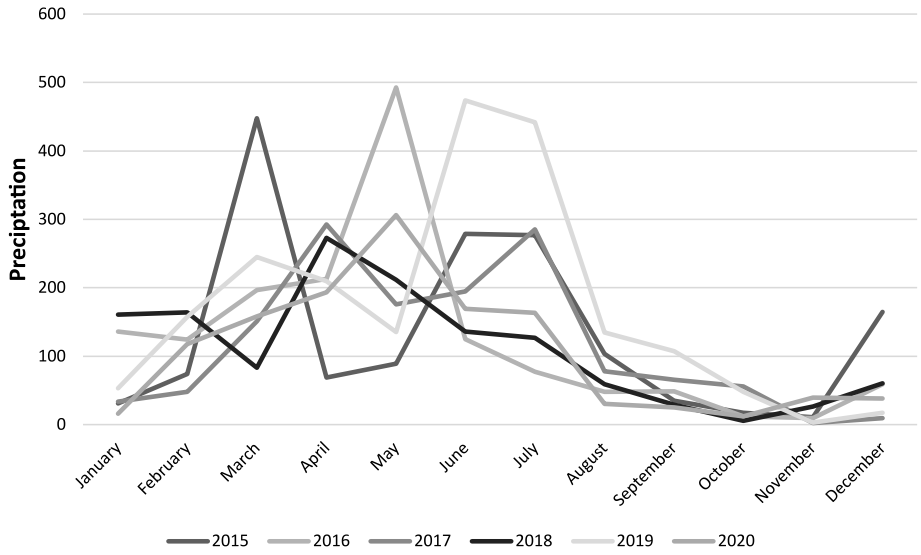

Fig. 2. Seasonal rainfall regime in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

Due to current normative restrictions for species conservation, female specimens were only analysed to record biometric data and released *in situ*. Male specimens were stored in ice for euthanasia. In the laboratory, gonads and hepatopancreas were removed and fixed for 24 h in mixed formalin and alcohol solution (Davidson's Fixative Protocol). Then, they were transferred and kept in a 70% alcohol solution.

2.3. Biometric measurements

The biometric measurements of each crab were taken as follows: carapace width (CW in mm) and length (CL) measured by using a Vernier calliper. Weight (W) was measured using a digital balance with an accuracy of 0.1 g. To determine relative growth and calculate condition factor (K) of *C. guanhumi*, the length–weight equation $W = aL^b$ was adapted to estimate the relationship between the weight (g) of the crab and carapace width (cm) (Hartnoll, 1978).

A linear model $W = aCW^b$ was applied on biometric data transformed into logarithms log (W) = a + b log (CW) and a calculation for obtaining coefficients a and b of the growth model was adapted (Froese, 2006). The coefficient a is the intercept on the y-axis. The regression coefficient b is an exponent that indicates isometric growth (b = 3), negatively allometric growth (b < 3) or positively allometric growth (b > 3).

The relative condition factor (K_n) was established to assess annually the variation in condition of *C. guanhumi* in the study area. This parameter is frequently applied in studies to evaluate variation in crab growth in response to the environment and breeding seasons (Le Cren, 1951). The K_n was applied to compare the observed weight of an individual with the average weight for the observed carapace width, through the following relationship: $K_n = Wo/W_C$. Where W_o is derived from the observed wet weight (g) and W_C is the calculated weight by growth model $W_C = aCW^b$ (Le Cren, 1951).

2.4. Morphological analyses

The morphological analyses were considered only for specimens collected in 2019 due to the restrictions imposed by COVID-19 pandemic, and all specimens collected in 2020 were released

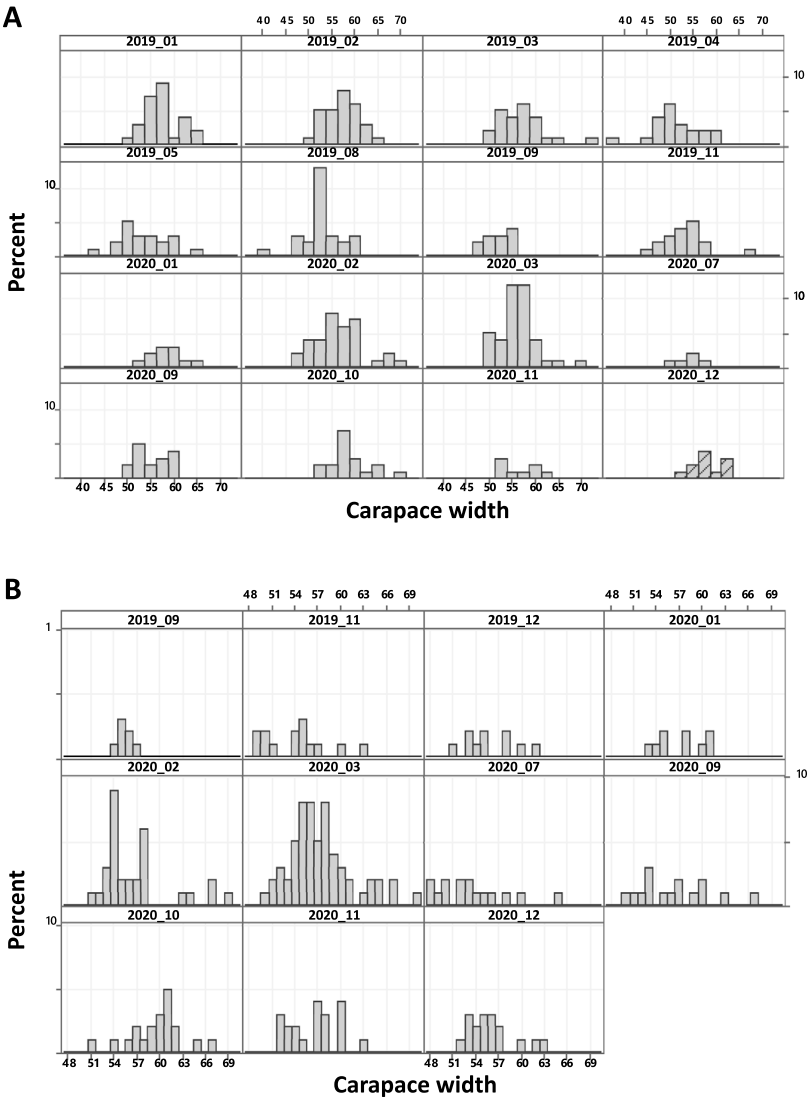

Fig. 3. Carapace size frequency for males (A) and females (B) the blue land crab (*Cardisoma guanhumi*) from the years 2019–2020 in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

into the field. Then, the analyses were applied to evaluate the variation in hepatopancreas development as a parameter associated to crab growth in response to environment and breeding seasons. To detect monthly hepatopancreas development, it was dissected out using fine forceps from each male specimen a fragment (minimum organ size 2 cm) of this organ was removed for weighing with an analytical balance (0.0001 g). Then, a correlation between hepatopancreas and individual weight was calculated by hepatosomatic index (HSI) constructed by the following equation: $HSI = (H_W/W) \times 100$. Where H_W = weight of the hepatopancreas; W = wet weight of the specimen.

The differences in gonadal development were determined to indicate sexual maturity by performing a macroscopic verification of colour, shape, and volume of male gonad. To detect seasonal differences in gonadal development, the gonadosomatic index (GSI) was calculated for males with visible gonads. Then, a correlation between gonad and individual weight was calculated by the following equation: $GSI = (G_W/W) \times 1000$. Where G_W = weight of the gonad; W = wet weight of the specimen.

Table 1
Summary of annual variation in carapace width (CW), weight (w) and relative condition factor (K_n) for females (F) and males (M) for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

Year	Parameter	Sex	Mean	SE Mean	StDev	Min	Median	Max
2019	CW	F	5.50	0.06	0.34	4.90	5.50	6.30
		M	5.47	0.04	0.50	3.86	5.50	7.26
	W	F	97.65	2.87	15.97	74.00	97.00	146.00
		M	83.18	1.65	22.05	31.00	81.00	172.00
	K_n	F	2.18	0.04	0.19	1.81	2.19	2.60
		M	1.01	0.01	0.15	0.59	0.97	1.60
2020	CW	F	5.69	0.03	0.42	4.80	5.60	7.00
		M	5.67	0.04	0.44	4.70	5.70	6.90
	W	F	93.74	1.41	19.28	60.00	90.50	156.00
		M	94.98	1.75	20.99	59.00	93.00	149.00
	K_n	F	1.93	0.01	0.16	1.47	1.91	2.36
		M	1.06	0.01	0.10	0.69	1.06	1.43

* Total 2019: 31 females and 178 males. Total 2020: 186 females and 144 males.

2.5. Male histomorphology

To detect the presence of gametes (packed in spermatophores) in the smallest male individuals with visible developed gonads (mature stage), some specimens were dissected to allow the removal of the reproductive tract. For this, fragments of the vas deferens duct (MVD) were fixed in Davidson's solution for 24 h and then kept in a 70% alcohol solution. They dehydrated in

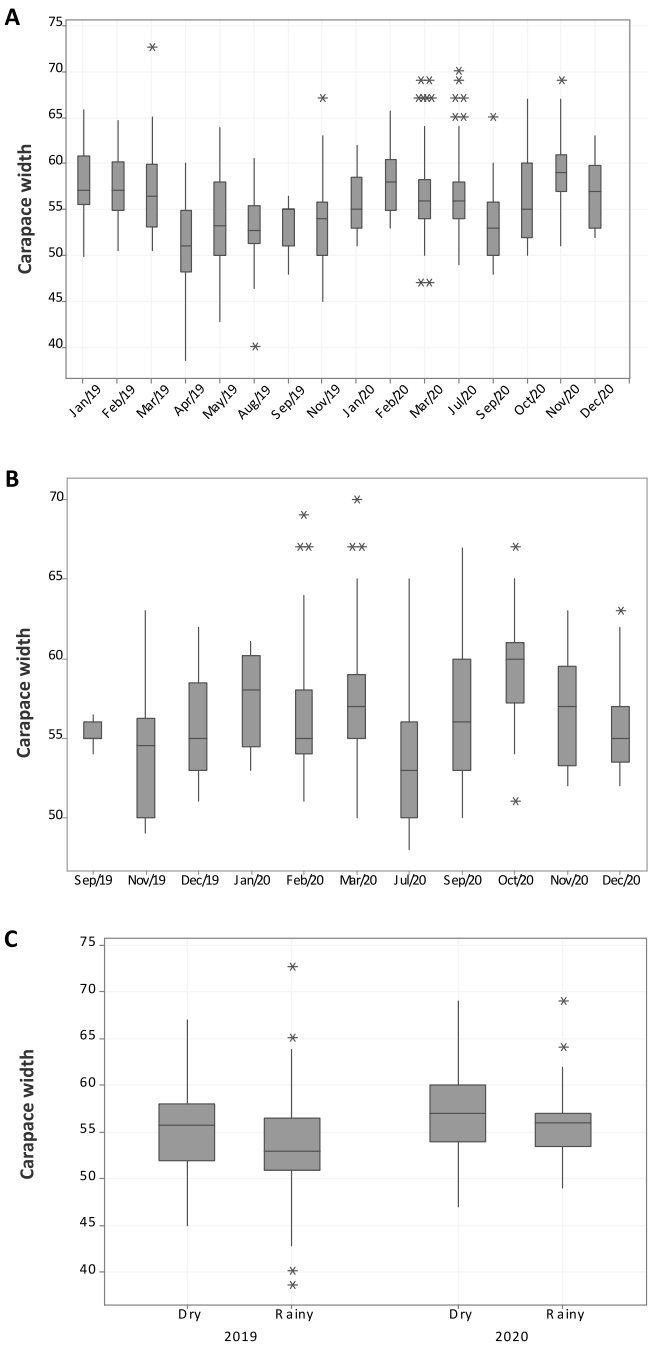

Fig. 4. Monthly and seasonal variation in carapace width (CW) for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil. (A) Males; (B) Females; (C) Males.

increasing alcohol series, diaphanized in xylene and impregnated and included in paraffin at 60 °C. Then, histological preparations were stained by Haematoxylin and Eosin (H&E).

2.6. Data analysis

To test statistically significant differences between seasonal differences in biometric data ($p < 0.05$), when appropriated a parametric (t-test) and non-parametric test (Kruskal–Wallis test) was applied to test differences in mean carapace width (CW) and relative condition factor (K_n) by sex and season. The data analysis was performed using R Statistical Software (R version 4.0.5 ; R Foundation for Statistical Computing, Vienna, Austria).

Table 2
Summary of t-test for test differences between carapace width (CW) for females (F) and males (M) for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

Sex	N	Mean	StDev	SE Mean	t-value	df	p-value
F	217	5.7	0.417	0.028	2.56	537	0.005
M	322	5.6	0.480	0.027			

Table 3
Summary of t-test for test seasonal differences between carapace width (CW) and relative condition factor (K_n) for males (M) for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

Parameter	Season	N	Mean	StDev	SE Mean	t-value	df	p-value
CW	Dry	185	5.649	0.452	0.033	3.97	320	0.000
	Rainy	137	5.439	0.493	0.042			
K_n	Dry	185	1.072	0.142	0.010	6.85	320	0.000
	Rainy	137	0.975	0.097	0.008			

3. Results

3.1. Biometric parameters

A total of 539 *Cardisoma guanhumi* specimens were examined. It was recorded collected 31 females and 178 males in 2019 and 186 females and 144 males in 2020 (Table 1; Table A1 - in Supplementary Material). Although applying the same sampling effort for all sites, ovigerous females were not observed during the study. The mean carapace width for the population ranged monthly from 3.9 cm to 7.3 cm, mean = 5.6 cm, StDev = 0.46 (Fig. 3). There was a significant difference in carapace width between sex and females were larger than males (Tables 1, 2). The annual patterns of biometric parameters showed monthly variations and there was a significant difference for carapace width by sex (Table 2). Besides, male carapace width and the relative condition factor (K_n) showed significant differences by season (Figs. 4, 5; Table 3). In summary, the annual mean carapace width observed were close to those values recorded in other regions in the Brazilian northeast coast but remarkable above to those observed in regional studies when comparing to recent e oldest records for the species in the region (Tables A2 and A3 in Supplementary Material).

The K_n showed significant differences between the seasons with high values observed in the dry season in 2019 and 2020 (Fig. 5; Table 3). The growth model calculated by weight–width relationship showed negative allometric growth for males ($b = 2.586$) and females ($b = 2.229$), indicating that the specimens grew more in width than in weight, which means that the carapace width may increase at a higher rate than the other body parts (Fig. 6).

3.2. Morphological analyses

Although we have made monthly catches, there were many specimens with undeveloped reproductive tract. For the males captured, those with developed hepatopancreas and gonads, the relationship between the weight of these organs and crab size did not show a clear pattern in 2019 (Fig. 7). The hepatosomatic index showed the highest values in May and November. This can indicate an investment in these organs in the middle

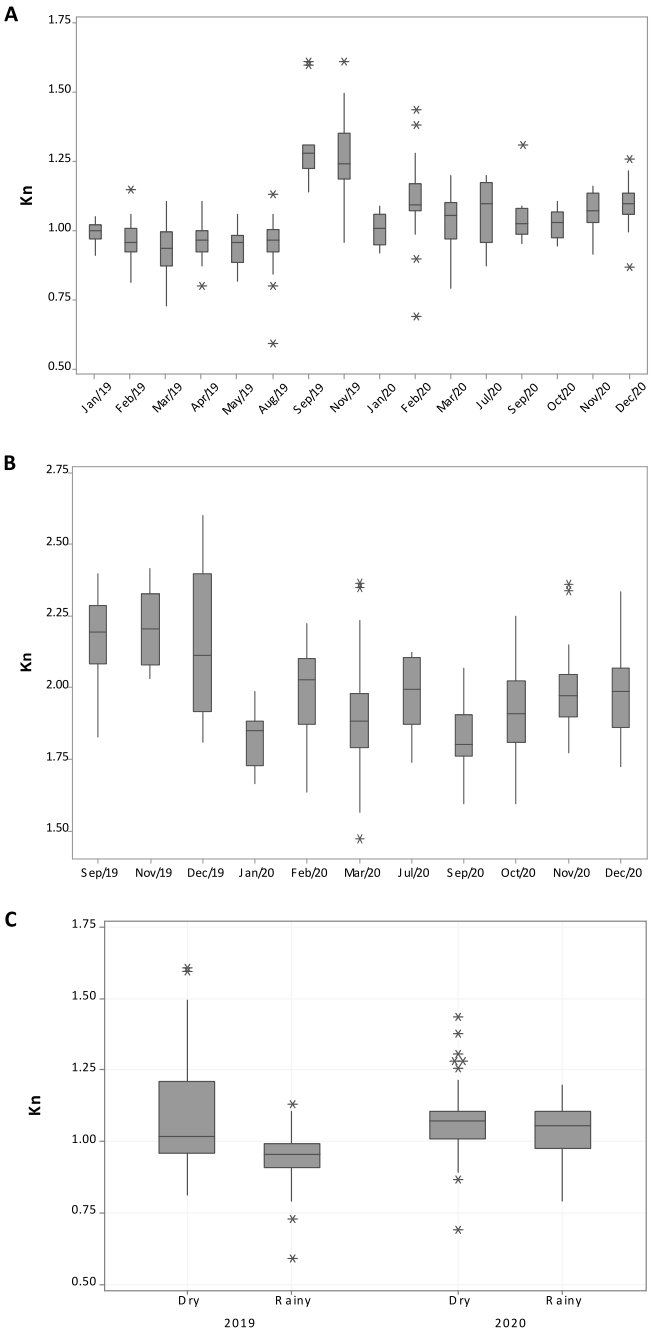

Fig. 5. Monthly and seasonal variation relative condition factor (Kn) for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil. (A) Males; (B) Females; (C) Males.

of the rainy season and dry season, respectively. Likewise, the highest value of gonadosomatic index (GSI) was observed in May and November. The monthly distribution of the GSI can highlight two seasonal male investment for reproduction (Fig. 7). In addition, the male histomorphology showed the presence of gametes (packed in spermatophores) in the smallest male individuals (Carapace width 4.8 cm; Weight = 52 g), indicating the occurrence of individuals at this size in the mature stage in the population (Fig. 8).

4. Discussion

4.1. Population and crab size

Considering our finds and the records for *Cardisoma guanhumi* along the Brazilian coast, the patterns of seasonal variations in morphological indicators and reproductive parameters observed here reinforces that there are local and regional patterns in populational structure and dynamics along the Brazilian coast. Therefore, proposes for seasonal assessment should consider the regional differences in the size of the blue land crab for conservation effort, since the species is currently exposed to different fishing pressures and environmental impacts, which can affect the patterns in the growth development of many crab species (Diele and Koch, 2010).

Although the population of *C. guanhumi* evaluated here is found in a protected area, the species still faces the same problems of habitat degradation in the surrounding area in the region. Then, we found some population patterns with remarkable variability in the number of individuals caught between years and sexes. Therefore, it was excepted variability in abundance by sex due to the legal restriction for catching females for consumption since 2018 on Brazilian coast. Moreover, in regions with low catch pressure, the populational structure of *C. guanhumi* has been biased by sex. Thus, these patterns have been reported mostly for populations restrict on islands, where male abundance tends to markedly higher than females (Hernández-Maldonado and Campos, 2015).

However, considering selective capture pressure by size in protected and unprotected areas along the Brazilian coast, the annual mean carapace width observed here were close to those values recorded in other regions in studies for populational biology of this species, mostly in the northeast region. For instance, although studies are sparse on this species in the southernmost geographic distribution, such as Rio de Janeiro and Santa Catarina, few records of *C. guanhumi* in these regions showed mean values for carapace width longer than 6 cm (Oliveira-Neto et al., 2014; Silva and Oshiro, 2002). Moreover, in the Brazilian northeast region where the most recent and oldest studies were performed, the pattern in size-frequency for mean carapace width is like those found in prior studies in the Rio Grande do Norte (5.5 cm), Bahia (6.0 cm) and Ceará (5.5 cm) (Botelho et al., 2009; Shinozaki-Mendes et al., 2013; Silva et al., 2014; Mendes and Cruz, 2017). Therefore, considering the local population evaluated here in the regional context where species occur along the Pernambuco State coast, the values for mean carapace width is remarkable high when compared to the most recent record (4,3 cm) from the north coast (Costa and Schwamborn, 2016) and the oldest record (4,1 cm) for south coast (Botelho et al., 2001), which may highlight the need for further research to test the role of the protected areas like the Acaú-Goiana Marine Extractive Reserve for the *C. guanhumi* populations.

4.2. Weight–width relationship and the condition factor (k_n)

Assessments of growth parameters of *Cardisoma guanhumi* along the Brazilian coast still is sparse. In this study, the weight–width relationship showed a pattern growth of negative allometric type. It indicates that the growth pattern of the population prioritizes increasing the size of the carapace width that may not correlate with the growth of the total weight (Amaro Pinheiro and Fiscarelli, 2009). In addition, this type of growth is translated when throughout crab development, the length variable increases in greater proportion concerning body weight, which results in slimmer specimens as they get longer (Froese, 2006). These patterns of growth are also observed in other land crab *Cardisoma*

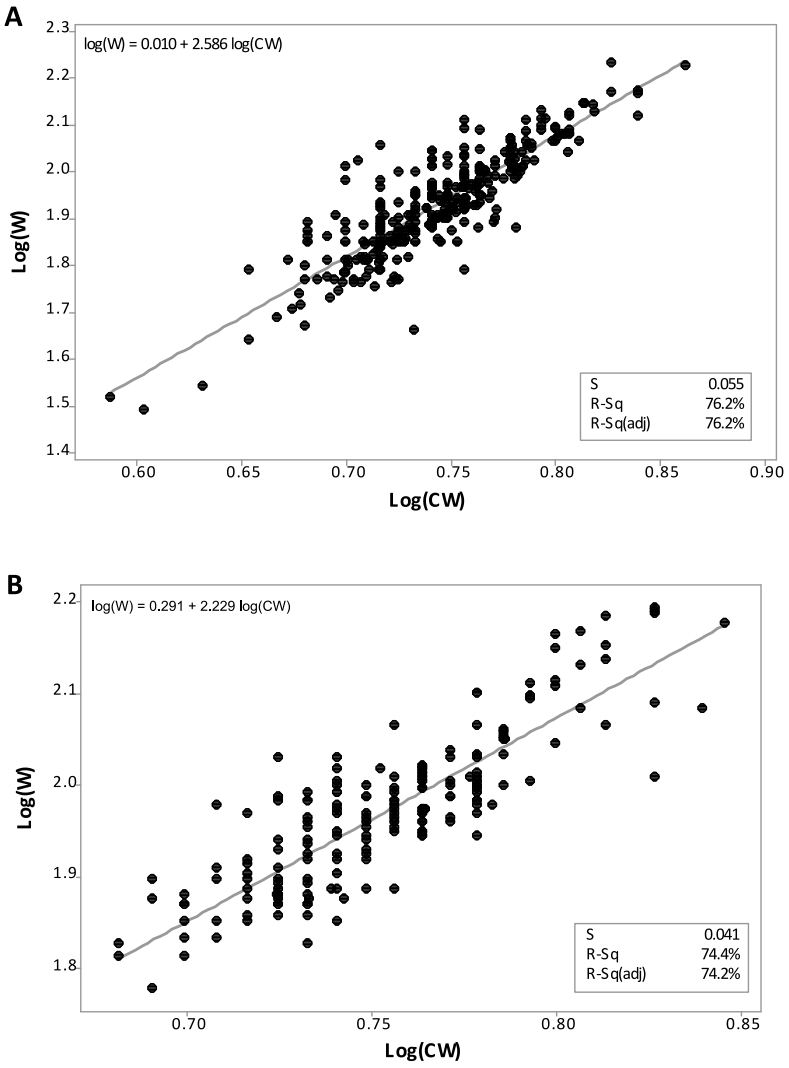

Fig. 6. The growth model calculated by weight–width relationship for the blue land crab (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil. (A) Males; (B) Females.

crassum (Vázquez-López and Ramírez-Pérez, 2015), in the mangrove crab *Ucides cordatus* (Pinheiro and Hattori, 2006); in the estuarine crab *Callinectes danae* (Branco and Thives, 1991); in the freshwater crab *Dilocarcinus pagei* (Pinheiro and Taddei, 2005); and the semi-terrestrial crab *Armases angustipes* (Kowalczuk and Masunari, 2000).

This growth strategy can highlight unfavourable conditions for growth and may indicate environmental changes and seasonal conditions where these species are exposed. As expected for *C. guanhumi* and its status along the Brazilian coast, the negative allometric growth observed in its population from our study can be considered in the local environmental context of extensive mangrove degradation in the last decades (Silva et al., 2020). Besides, the environmental degradation associated with the high capture pressure in the Brazilian northeast is not continuous along the coast but is affected by spatial and seasonal variation by increasing in the dry season (September–February) and decreasing during the rainy season (March–August). This capture pressure concurs with the beginning of the breeding season, in which large males and females are exposed for capture causing a decrease in crab populational size. Moreover, the negative allometric growth for longevous and slow-growing species highlights the need for conservation attention because efficient management effort to recover stocks is necessary for overexploited slow-growing species (Cardona et al., 2019; Silva et al., 2014).

Despite the significant morphological variation between populations along the Brazilian coastal zone, there is still a high pattern of gene flow between populations of *C. guanhumi* along its distribution in north-eastern regions (Gama-Maia and Torres, 2016). Thus, it is possible to characterize that the growth pattern observed here reinforces the local effect of environmental conditions on morphological characteristics of populations. This relationship occurs because the negative allometric growth is sometimes related to the favouring of migration facilitated mainly by the reduction in body weight. Such conditions can promote reproductive events, a feature enhanced in lighter animals (Ferkau and Fischer, 2006; Vázquez-López and Ramírez-Pérez, 2015).

The seasonal variation of the condition factor (K_n) in crustaceans can be influenced by environmental characteristics, weight variation in reproductive cycles, food availability, nutritional rate, and the growth pattern of the populations (Froese, 2006; Amaro Pinheiro and Fiscarelli, 2009). Moreover, this factor may be related to the periods of ecdysis or preparation for spawning. For instance, higher values of the condition factor in land crabs throughout the year can be observed in the rainy season months for males and in the low rainfall period for females (Lira et al., 2012). In this study, the highest K_n values were observed in September and November, corresponding to the period of low rainfall. Thus, suggesting an increased investment in the weight

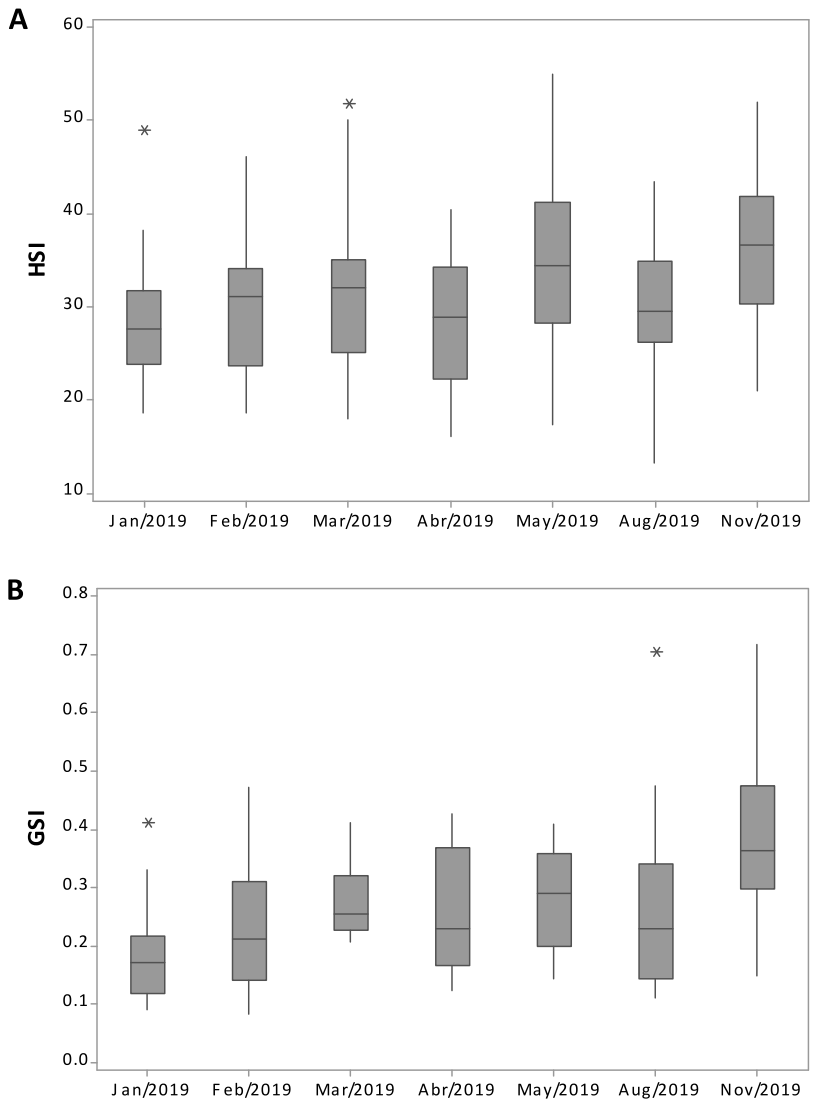

Fig. 7. Monthly variation in the hepatosomatic (A) and gonadosomatic index (B) for the blue land crab males (*Cardisoma guanhumi*) in the Acaú-Goiana Marine Extractive Reserve (RESEX Acaú-Goiana) in the northern coast of the state of Pernambuco, Brazil.

of individuals for the reproductive periods in subsequent months (Pinheiro and Taddei, 2005; Araújo et al., 2012).

4.3. Morphology and reproductive dynamics

Besides the characteristics of the external morphology, in crustaceans, several factors can also influence the internal morphology that can be evaluated through the hepatosomatic index (HIS) that can indicate developmental stages affected by seasonality, changes in environmental conditions and long periods of fasting (Augusto et al., 2018; Kennish, 1997; Strefezza et al., 2019). Despite the importance of this index with a view to decapod physiology, its overview in *C. guanhumi* is poorly explored. Despite not showing a conclusive pattern along the months, we observed here that the males of *C. guanhumi* presented their highest HSI values in the months of March, April, and May, which are the months related to the period of the reproductive seasons, when ovigerous females have already been recorded in previous studies in north-east Brazil from November to February and from March to May (Silva and Oshiro, 2002; Shinozaki-Mendes et al., 2013). Thus, an increase in HSI is indicative of growth in the hepatopancreas of male or female individuals and is closely related to the accumulation of energy and metabolic reduction that precede migration and copulation events (Augusto et al., 2018) Thus, the values observed here indicate that a reproductive investment of males of *C. guanhumi* in months preceding the rainy season in the region (March–August).

The gonadosomatic index is another indicator generally used in determining the sexual maturity and reproductive period of crustaceans (Waiho et al., 2017), since it has a consequent relationship with the size and weight of individuals (Magalhães et al., 2012). In the observed specimens, the GSI indicates that the highest frequency of males with well-developed gonads in the months of May, August, and November. In general, these variations in gonadal development in Brachyura are related to body size growth and weight, affected by environmental and habitat conditions (Leite et al., 2014). Therefore, correlations of morphology with external with gonadal development are necessary, since the gonadal and the morphometric maturity occur in parallel or consecutively (Castiglioni and Negreiros-Fransozo, 2006).

It was observed here that the main GSI peaks in May, August, and November, suggesting that these months characterize high strain and reproductive activity of *C. guanhumi*. Similarly, in other locations along the Brazilian coast, the pattern observed here for the species can be found. In the Brazilian northeast coast, prior

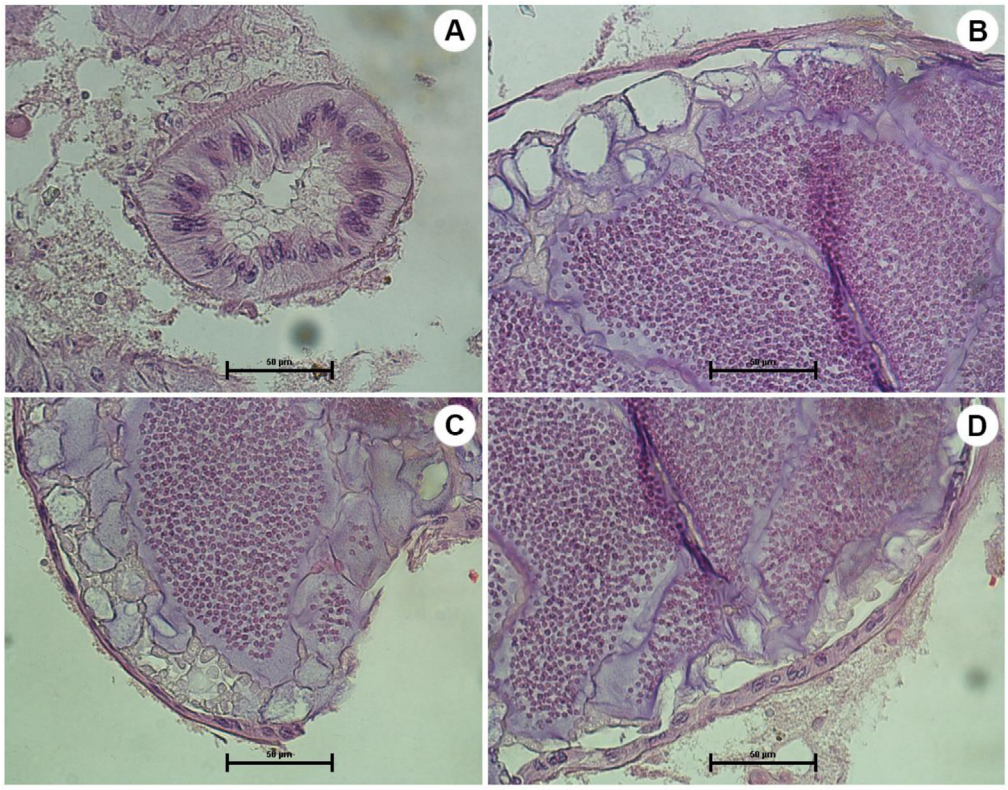

Fig. 8. Photomicrographs of *Cardisoma guanhumi* gonad sections in transverse section, showing the anterior vas deferens region (A) and regions of the middle vas deferens (B, C, D) filled with spermatophores (SPH). Bar = 50 µm HE stains.

studies showed that the highest GSI values were observed in the months of November–December–January–February, indicating periods of early reproductive and spawning seasons (Silva, 2013). For the southern coast of Pernambuco, previous studies indicate a reproductive period for *C. guanhumi* between December and February (Botelho et al., 2001). In Ceará State, there is an indication for reproductive period between November and February (Shinozaki-Mendes et al., 2008). Likewise, for Bahia State, the breeding season was indicated from December to April (Botelho et al., 2009). Then, in the southernmost geographic distribution of *C. guanhumi*, such as in Rio de Janeiro State, the reproductive period was indicated between October and March (Silva and Oshiro, 2002). Thus, considering the continental extension of the Brazilian coast it is appropriated to consider the spatial and seasonal variations in reproductive indicators, such as GSI, which may also indicate local and regional environmental conditions for breeding seasons.

5. Conclusions

The reproductive indicators of *C. guanhumi* among indicate that the environmental influence and fishing pressure are the main factors that drive its reproductive seasons. The absence of ovigerous females is similar to prior observations, mostly associated with the behaviour to prevent predator capture and energy saving. Moreover, the negative allometric growth observed for males and females highlight the response growth pattern to environmental conditions in the surrounding region, which is characterized by intense mangrove degradation and habitat reduction for this species. Besides, the similarity in carapace width by population assessed with other studies conducted in the Brazilian north-eastern coast, indicate a selective pressure for larger individuals, which were frequent in many studies. Thus, as *C. guanhumi* is a longevous and slow-growing species, the negative allometric growth highlights the need for conservation attention and management effort for long-term monitoring to recover the blue land crab stocks. Then, as observed here and in prior studies, the monthly frequency of sizes was lower than the minimum size of seven centimetres for catching, which should be reconsidered for local and regional contexts where the species occurs. Therefore, to protect and increase blue land crab size, future habitat restoration and environmental management must be considered to conserve the species, rather than only the establishment of minimum size for capture disregarding the local and regional contexts. Thus, it is noteworthy to indicate conservation efforts from January to April, when should be considered the breeding season for the species. In addition, long-term monitoring in the Extractive Reserve Acaú-Goiana must be considered for studies population structure and gene flow of *Cardisoma guanhumi*, prioritizing the preservation of their habitats.

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CRediT authorship contribution statement

M.C. Lima: Investigation, Methodology, Formal analysis, Visualization, Writing - original draft. **C.A.M. Pereira:** Methodology, Visualization, Writing - review & editing. **M.S.L.C. Araújo:** Supervision, Writing - review & editing. **G.G. Rodrigues:** Writing -

review & editing, Supervision, Project administration, Funding acquisition. **G. Nicacio:** Methodology, Formal analysis, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.101804.

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