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THE USE OF POPULATION ASPECTS OF THE GHOST CRABS AS INDICATORS OF ANTHROPOGENIC IMPACT ON URBAN BEACHES OF THE BRAZILIAN SEMIARID COAST

O uso de aspectos populacionais dos caranguejos-fantasmas como indicadores de impacto antropogênico em praias urbanas do litoral semiárido brasileiro

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ABSTRACT

To assess the effects of urbanization on populations of *Ocypode quadrata* along the semiarid Brazilian coast, four urban beaches with varying levels of usage and one rural beach as a reference were analyzed. Each beach was morphologically characterized, considering tidal range (m), beach slope, beach length (m), sand grain size (ϕ), and Urbanization Index (UI). On each beach, four transects were marked perpendicular to the waterline, each 10 meters wide and spaced 10 meters apart, extending from 5 meters below the high tide line to the base of the dune (when present) or anthropogenic structures. The burrows were counted and measured. In general, no significant differences were found in burrow abundance or mean diameter, despite the differing beach uses. Only one significant difference was observed in the mean burrow diameter of ghost crabs between Sabiaguaba and Canto Verde beaches. The heavier vehicle traffic on Sabiaguaba Beach appears to have impacted juvenile crabs. Comparing the abundance and size of burrows did not prove to be a reliable indicator of anthropogenic impacts when comparing beaches with varying levels of urbanization along the semiarid Brazilian coast.

Keywords: Sandy beach, urbanization index, bioindicator, trampling, vehicle.

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RESUMO

Para avaliar os efeitos da urbanização nas populações de Ocypode quadrata *ao longo da costa semiárida brasileira, quatro praias urbanas com diferentes níveis de uso e uma praia rural como referência foram analisadas. Cada praia foi caracterizada morfologicamente, considerando a amplitude de maré (m), declividade da praia, extensão da praia (m) e tamanho dos grãos de areia (ϕ), e índice de urbanização (UI). Em cada praia, quatro transectos foram marcados perpendicularmente à linha d'água, tendo 10 metros de largura e 10 metros de distância entre si, estendendo-se desde 5 metros abaixo da linha de maré alta até a base da duna (quando presente) ou construções antrópicas. As tocas foram contadas e medidas. Em geral, não foram encontradas diferenças significativas na abundância de tocas e no diâmetro médio, apesar dos diferentes usos das praias. Apenas uma diferença significativa foi observada entre o diâmetro médio das tocas dos caranguejos-fantasma nas praias de Sabiaguaba e Canto Verde. O tráfego de veículos mais intenso na Praia de Sabiaguaba parece ter afetado os caranguejos juvenis. A comparação da abundância e do tamanho das tocas não se mostrou um indicador de impactos antrópicos confiável ao comparar praias com diferentes níveis de urbanização na costa semiárida brasileira.*

Palavras-chave: *Praia arenosa, índice de urbanização, bioindicador, atropelamento, tráfego de veículos.*

INTRODUCTION

Sandy beaches are dynamic ecosystems dominated by physical factors such as waves, tides, and winds, which interact with the sand, determining beach slope and sediment grain size. These factors control the composition and abundance of associated organisms (McLachlan and Defeo 2017).

These ecosystems are of great ecological relevance, as they host a diverse fauna and serve as nurseries for fish, turtles, and birds (McLachlan and Defeo 2017). Some of the organisms inhabiting these environments are economically important, such as fish, polychaetes, crustaceans, and mollusks (McLachlan and Defeo 2017; Wynberg and Branch 1994; McPhee and Skilleter 2002; Defeo 2003).

Anthropogenic activities can cause changes in the environment, such as a decrease in vegetation cover in the upper parts of the beaches, increased sand compaction, and sediment displacement, thereby promoting beach erosion and disturbing the fauna (e.g., birds, turtles, interstitial invertebrates, and ghost crabs), leading to changes in behavior and population structure (McLachlan and Defeo 2017; Costa *et al.* 2019).

These threats affect different beach sectors (infralittoral, intertidal, and supralittoral), with the upper part being the most sensitive to impacts due to the presence of engineering structures and other disturbances that can affect sediment flow (McLachlan and Defeo 2017).

To assess potential impacts, ghost crabs are used as disturbance indicators, with two metrics - density and burrow diameter - generally serving as proxies (Schlacher *et al.* 2011; Costa and Zalmon 2019; Ocaña *et al.* 2020; Bal *et al.* 2021). There is a positive correlation between the number of burrows and population density, as well as between the burrow diameter and the carapace width of these crabs (Schlacher *et al.* 2016a).

Human-induced modifications on sandy beaches lead to a decrease in the density of these crabs (Machado *et al.* 2019; Barbosa *et al.* 2021; Costa *et al.* 2022). Schlacher *et al.*

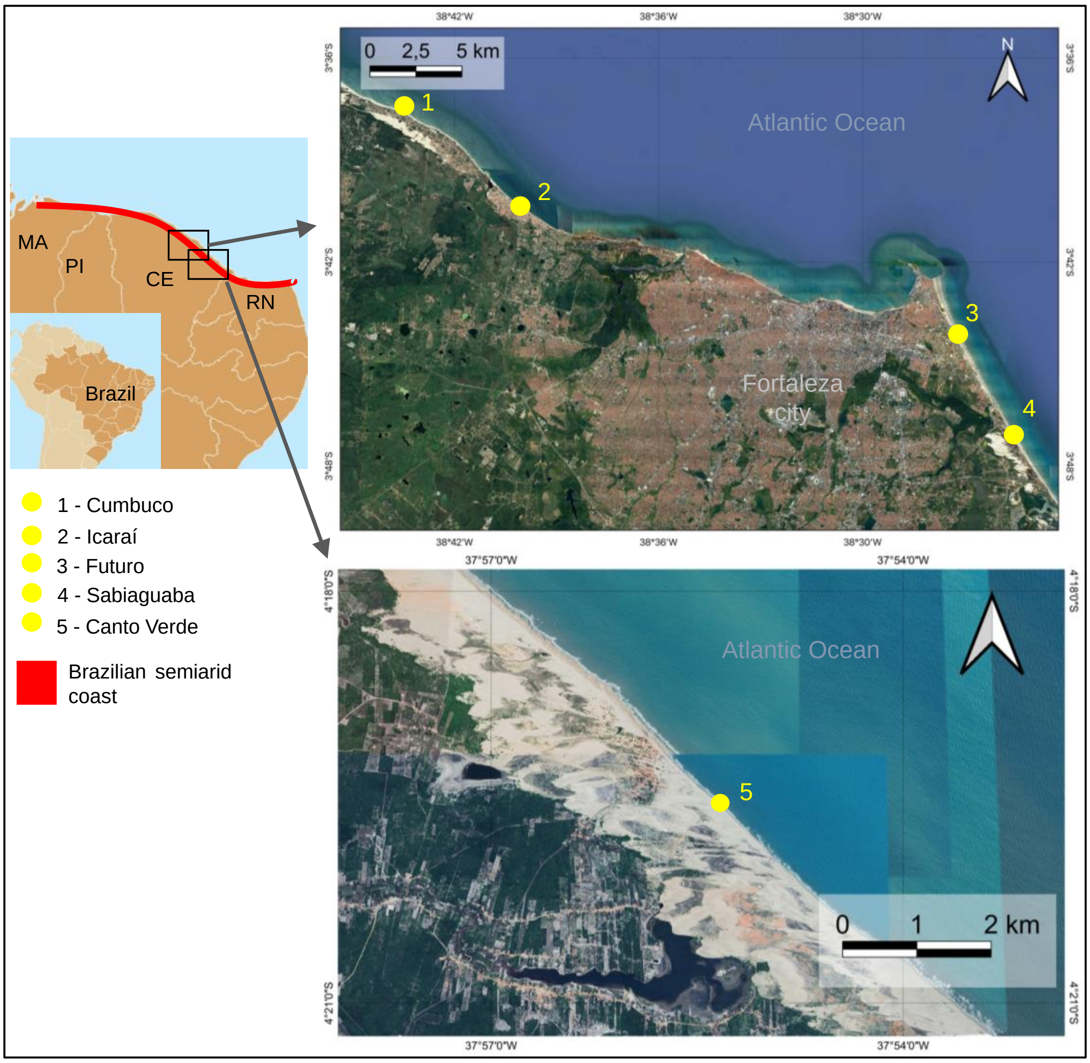
(2016b), in a meta-analysis, observed a tendency for a reduction in ghost crab burrow density in impacted environments but no effect on the mean burrow diameter. This effect on burrow density was also observed in Machado *et al.* (2019), Barbosa *et al.* (2021), and Costa *et al.* (2022).

Thus, the present work aims to characterize four urban beaches and one rural beach on the semiarid Brazilian coast regarding urbanization and their different uses, evaluate the populations of the ghost crab *Ocypode quadrata* Fabricius 1797 (Brachyura – Ocypodidae) on these beaches, and investigate whether using this crab as a bioindicator of impacts is feasible on urban beaches of this coast.

STUDY AREA

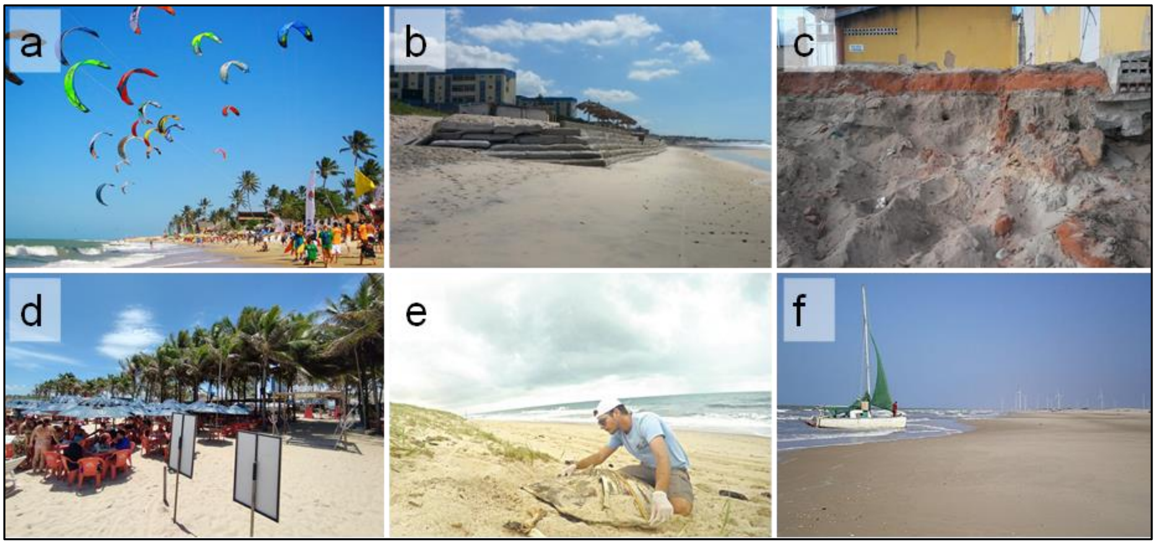
The study was conducted on five sandy beaches along the semiarid Brazilian coast (Cumbuco, Icaraí, Futuro, Sabiaguaba, and Canto Verde), all located in the state of Ceará (Figure 1). The semiarid Brazilian coast, which stretches between the states of Maranhão and Rio Grande do Norte, is a region influenced by trade winds and a hot semiarid climate, with high sea surface temperatures, low thermal variation both intra- and interannually, and two well-defined seasons: dry (July to February) and rainy (March to June) (Soares *et al.* 2021). Furthermore, the rains can concentrate in just one month (May or June), making the area prone to drought.

Figure 1 – Map of the Location of the Sampling Sites. Beaches: (1) Cumbuco, (2) Icaraí, (3) Futuro, (4) Sabiaguaba and (5) Canto Verde. Red line= Brazilian semiarid coast. Brazilian States: MA = Maranhão, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte



Cumbuco Beach is located in the municipality of Caucaia and encompasses approximately 9.6 km of sandy coastline, characterized by the presence of coastal dunes and no evidence of coastal erosion along most of its extent (de Paula, 2021). This beach stands out as a tourist hub, with a well-developed hospitality sector, where water sports such as windsurfing and kitesurfing serve as the main activities attracting visitors (de Paula, 2021) (Figure 2a).

Figure 2 – a) Cumbuco Beach, b) Bagwall protective wall at Icaraí Beach, c) area of Icarai Beach affected by coastal erosion, d) Beach Shack of Futuro Beach, e) A member of the Sea Turtle Protection Group (GTAR) conducting monitoring at Sabiaguaba Beach, f) Canto Verde Beach. Source: a) Viagem e Turismo (2011) (https://viagemeturismo.abril.com.br/cidades/cumbuco), b) Resmar (2014), c) Author: Tayanne Pires Ferreira, d) Author: Jadson Pinto de Lima, e) Diário do Nordeste (2016) https://diariodonordeste.verdesmares.com.br/metro/projeto-garante-protecao-na-praia-da-sabiaguaba-1.1527741, f) https://www.ferias.tur.br/fotos/10278/praia-do-canto-verde-ce.html



Icaraí Beach extends approximately 4 km and is marked by the presence of cliffs, urbanized dunes, and coastal containment works. The Icaraí coast has experienced a severe erosional process in recent decades (Farias and Maia, 2010; Paula *et al.*, 2013; Lima *et al.*, 2019), losing approximately 50 meters of coastline between 2004 and 2018 (Moreira, 2020). In 2011, with the aim of curbing the sea's advance, the Municipality of Caucaia constructed a rigid coastal protection structure in the form of a staircase, called the “Bagwall,” which has collapsed several times and proved to be largely ineffective in controlling erosion (Paula and Farrapeira Neto, 2017) (Figure 2b and 2c).

Futuro Beach is an urban beach located in Fortaleza, the capital of the state of Ceará. It extends for 8 km and is distinguished by its high tourist flow and commercial activity (Albuquerque *et al.*, 2009). This beach is known for its structures called “beach shacks,” which function as complexes offering gastronomy and leisure activities, and include additional services such as massage rooms, a water park, and stages for performances (Paula *et al.*, 2012). The services provided by these beach shacks make Futuro beach one of the most advertised and visited places in Fortaleza, receiving up to 200,000 visitors per week (Maciel, 2014; Fecomercio, 2022) (Figure 2d).

Sabiaguaba Beach, located in the eastern part of the Fortaleza coastline, comprises a stretch of beach that has not yet been intensively occupied by beach shacks and residences. It is also characterized by dunes, mangrove areas, fluviomarine plains, seasonal flood zones, and interdune lagoons (Lopes *et al.*, 2019). To minimize both current and potential future impacts, the municipality of Fortaleza established two Conservation Units in the area in 2006: the Sabiaguaba Environmental Protection Area (APA) and the Sabiaguaba Municipal Natural Park. Despite these measures, anthropogenic impacts are still visible in the region, including litter and construction debris, expansion of urban furniture, uncontrolled vehicle traffic, increased tourist influx, and the presence of animals such as dogs, cats, and horses (Lopes *et al.*, 2019) (Figure 2e).

Canto Verde Beach is located in the municipality of Beberibe, 120 km from Fortaleza, and is part of a conservation unit that includes, besides the coastal strip, fields of mobile and fixed dunes, temporary lagoons, interdune depressions and fluviolagoonal plains (Pontes and Silva, 2011; Mendonça *et al.*, 2013) (Figure 2f). Moreover, the main economic activities at Canto Verde Beach are fishing and community-based tourism (Mendonça *et al.*, 2013).

MATERIALS AND METHODS

To evaluate the density of *Ocypode quadrata* burrows, samples were collected between October 2016 and May 2017 on five sandy beaches along the coast of Ceará state. The samples were taken at dawn during the spring tide. The methodology used was adapted from Borzone *et al.* (2015). On each beach, four transects (10m wide and 10m apart) were marked perpendicular to the waterline. The transects extended from 5m below the high tide waterline to the dune base or anthropogenic constructions. Each transect was divided into continuous quadrats of 10m x 5m (50m^2), where the burrows were counted, and their diameters were measured using a caliper with 0.05mm precision.

Granulometric analyses were conducted to measure sediment characteristics. Sediment samples were collected from both the intertidal and supralittoral zones. The samples were taken to the Instituto de Ciências do Mar (LABOMAR) at Universidade Federal do Ceará (UFC), where they were dried in an oven at 60ºC, then washed using a 0.062mm mesh and dried again. Subsequently, the samples were placed in a sequence of sieves and agitated in a Rotap shaker for 10 minutes. The sediment retained in each sieve was weighed using an analytical balance, and the data were processed in SysGran 3.0 software, where the average grain size was calculated following Folk and Ward (1957), and the samples were classified according to the Wentworth scale (Suguio 1973).

Beach slope was evaluated through topographic beach profiles using leveling techniques with a surveying instrument and a level staff in the intertidal zone. The beach's morphodynamic state was determined using the "Beach Index" (BI), where BI<1.5 indicates microtidal reflective beaches, and BI>3 indicates macrotidal dissipative beaches (McLachlan and Dorvlo 2005).

To estimate the number of people and vehicles on the beach per half hour, an imaginary line perpendicular to the waterline was drawn on each beach. Each sampling session lasted 30 minutes, during which the number of people and vehicles crossing or staying on the line was counted. Samples were taken every hour for six hours, totaling six samples per beach.

To characterize the degree of urban impact on the beaches, an urbanization index (UI) adapted from Gonzales *et al.* (2014) was calculated. The UI is determined by assigning scores ranging from low (0) to high (5) for the following factors: (a) proximity to urban areas, (b) presence of constructions along the coastline, (c) beach cleanliness conditions, (d) existence of solid waste, (e) vehicle traffic along the shoreline, and (f) number of visitors. Values were determined by observing the conditions of the sandy beach during the sampling campaign. For this study, all values were determined through local observations and based on general recommendations established by Gonzales *et al.* (2014). The urbanization index was calculated using the method by Gover (Legendre and Legendre 1998):$X = \sum((X - Xmin)/(Xmax - Xmin))$, where X is the score for each category, and Xmin and Xmax are the extreme values of the score (0 – 5).

Statistical Analyses

To compare beaches with different levels of anthropogenic impact and morphological characteristics, a cluster analysis (CLUSTER) was performed based on a dissimilarity matrix using the standardized Euclidean distance method, with data on urban intervention indicators (Gonzales *et al.* 2014) and environmental indicators (tidal amplitude, grain size, beach slope, and beach extension). The cut-off point for the clusters was determined using Dunn's index.

Since the data on burrow density, burrow diameter, number of visitors, and number of vehicles did not meet the prerequisites for conducting an ANOVA, the non-parametric Kruskal - Wallis test was applied to check for differences between the sampled areas. When significant differences were found, a post-hoc Dunn test was performed, with the p-value adjusted by the Bonferroni method.

All analyses were performed using R software, with a significance level of 5%.

RESULTS

Morphological indicators

The analyzed beaches were classified according to the Beach Index (BI) as intermediate beaches, with sediment predominantly composed of medium sand, except for Canto Verde Beach, which exhibited fine sand. Regarding sediment sorting, the majority of sediments were classified as moderately sorted, whereas Canto Verde Beach, the supralittoral zone of Icaraí, and the supralittoral zone of Sabiaguaba Beach were classified as well-sorted. The beach extension ranged from 20 to 50 meters, with Cumbuco Beach being the narrowest and Canto Verde Beach the widest. The beach slope varied between 1:40.98 and 1:11.19, with Canto Verde Beach displaying a gentler slope and Futuro Beach exhibiting the steepest slope (Table 1).

Table 1 - Mean grain size (ϕ), degree of grain selection (ϕ), classification according to the Wentworth scale and percentage (%) of sand from the intertidal and supralittoral areas of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde beaches.

Beach	Zone	Mean grain size (ϕ)	Classification	Degree of selection (ϕ)	Classification	% Sand	Beach extension (m)	Slope	Beach Index (BI)
Cumbuco	Intertidal	1.8	Medium sand	0.58	Moderately sorted	99.31	20	1:13.60	1.96
	supralittoral	1.99	Medium sand	0.53	Moderately sorted	99.12			
Icaraí	Intertidal	1.79	Medium sand	0.58	Moderately sorted	99.14	40	1:23.26	2.23
	supralittoral	1.94	Medium sand	0.43	Well sorted	99.02			
Futuro	Intertidal	1.41	Medium sand	0.69	Moderately sorted	98.95	40	1:11.19	1.77
	supralittoral	1.72	Medium sand	0.58	Moderately sorted	99.38			
Sabiaguaba	Intertidal	1.46	Medium sand	0.55	Moderately sorted	99.37	30	1:14.22	1.94
	supralittoral	1.76	Medium sand	0.48	Well sorted	99.18			
Canto Verde	Intertidal	2.02	Fine sand	0.40	Well sorted	98.97	50	1:40.98	2.30
	supralittoral	2.25	Fine sand	0.38	Well sorted	98.67			

Urban Intervention indicators

Futuro Beach had the highest number of visitors, with an average of 163.33 people per 30 minutes, followed by Cumbuco Beach (126.83 people per 30 minutes), Icaraí Beach (41.50 people per 30 minutes), Sabiaguaba Beach (18.67 people per 30 minutes), and Canto Verde Beach (19.33 people per 30 minutes) (Figure 3).

In terms of the number of cars passing through the beaches, Sabiaguaba recorded the highest average (7.50 cars per 30 minutes), followed by Icaraí (2.17 cars per 30 minutes), Canto Verde (1.17 cars per 30 minutes), Futuro (0.67 cars per 30 minutes), and Cumbuco (0.33 cars per 30 minutes) (Figure 4).

The Kruskal-Wallis statistical test revealed significant differences ($p < 0.05$) in the number of people observed on the beaches (χ^2=18.118; p=0.001), as well as in the number of cars passing through the locations (χ^2=9.9756; p=0.041). The Dunn post-hoc test showed that the number of visitors differed significantly between Futuro Beach and Sabiaguaba Beach (p_{adj}=0.008), and between Futuro Beach and Canto Verde Beach (p_{adj}=0.007). Regarding the number of cars, although the Kruskal-Wallis test revealed significant differences, the Dunn post-hoc test did not show significant differences.

Figure 3 – Number of beachgoers observed for 30 minutes on the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde. Black dot = mean, vertical bars = standard error. Different letters above the bars (standard error) indicate significant differences

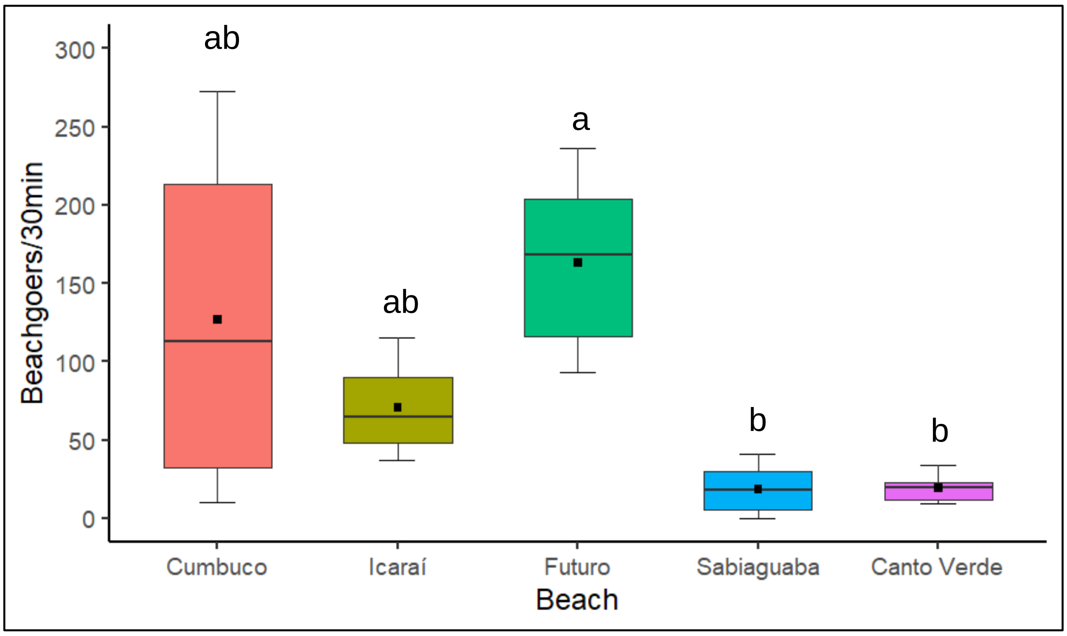
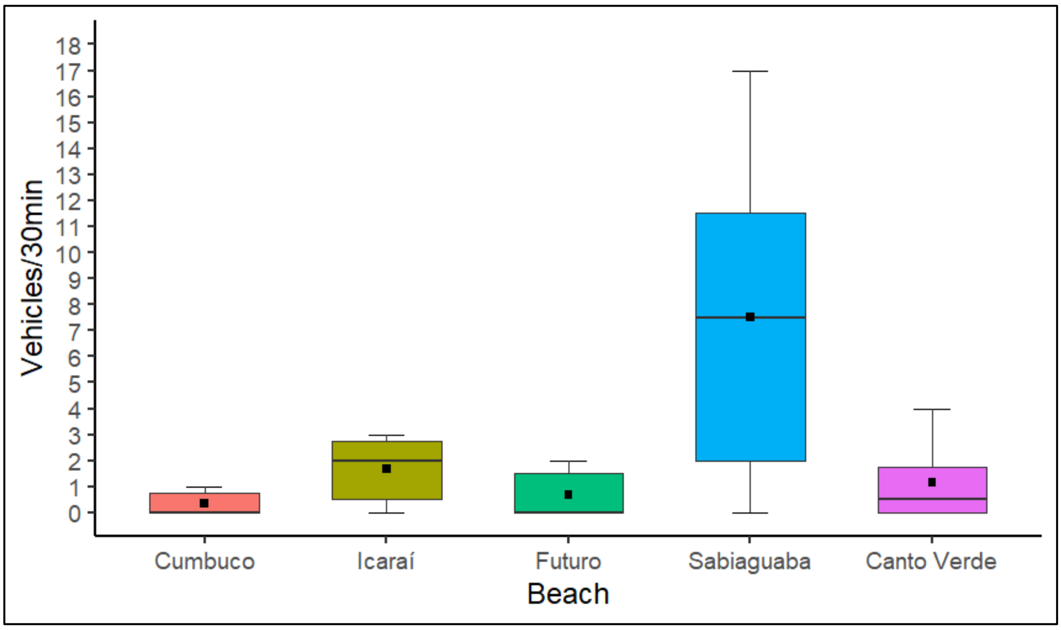


Figure 4 – Number of vehicles observed for 30 minutes on the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde. Black dot = mean, vertical bars = standard error



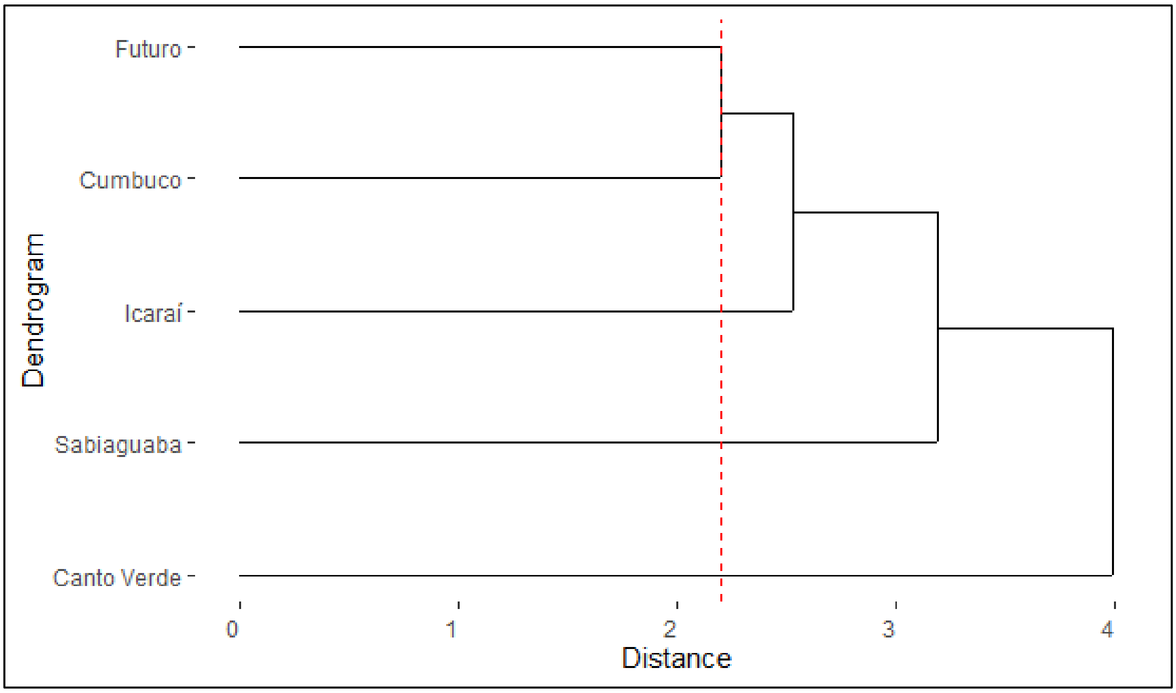
Based on field observations of the indicators—proximity to urban centers, constructions on the beach, beach cleanliness, presence of solid waste, vehicle traffic, and visitor frequency, the studied beaches exhibited urbanization levels that classify them as highly urbanized (UI > 0.6) (Futuro = 0.90, Cumbuco = 0.77 and Icaraí = 0.70), moderately urbanized (0.4 < UI < 0.6) (Sabiaguaba = 0.44), and low urbanization (UI < 0.4) (Canto Verde = 0.20) (Table 2).

Table 2 – Urbanization index (Gonzales *et al.* 2014) of the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde

Beach	Proximity to downtown	Buildings on the sand	Cleaning of the beach	Solid waste in the sand	Vehicles traffic	Demand by visitors	Mean	Urbanization index
Cumbuco	4	4	5	4	2	4	3.83	0.77
Icaraí	5	5	2	3	3	3	3.50	0.70
Futuro	5	5	5	5	2	5	4.50	0.90
Sabiaguaba	3	2	0	2	4	2	2.17	0.44
Canto Verde	0	1	0	0	3	2	1.00	0.20

From the cluster analysis (Figure 5), the presence of four groups can be observed. The first group consists of Cumbuco and Futuro beaches, characterized by a high presence of constructions on the beach, high visitor frequency, frequent beach cleaning, a significant presence of solid waste, low vehicle traffic, and steeper intertidal zones. Another group is composed of Icaraí Beach, characterized by the large presence of constructions on the beach and intermediate values for beach cleaning, visitor frequency, presence of solid waste, and a lower intertidal slope. The third group is formed by Sabiaguaba Beach, mainly characterized by the low presence of constructions, low beach cleaning frequency, few solid waste materials, few visitors, a larger beach extension, and high vehicle traffic. The fourth group consists of Canto Verde Beach, characterized by the absence of constructions, no mechanical cleaning, few solid waste materials, low visitor and vehicle frequencies.

Figure 5 – Cluster analysis of urban intervention indicators (Gonzales *et al.*, 2014) and morphological indicators (grain size, beach slope and beach extension) of the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde



Abundance (Burrows/50m²) and Mean Diameter (mm) of *Ocypode quadrata* Burrows

A total of 125 burrows of *Ocypode quadrata* were counted during the study period. Of these burrows, 9 were found on Cumbuco Beach, 5 on Icaraí Beach, 23 on Futuro Beach, 23 on Sabiaguaba Beach, and 65 on Canto Verde Beach. Regarding the number of burrows per $50m^2$, Sabiaguaba Beach had the highest average (0.96 burrows/$50m^2$), followed by Canto Verde

(0.68 burrows/50m^2), Futuro (0.64 burrows/50m^2), Cumbuco (0.38 burrows/50m^2), and Icaraí (0.31 burrows/m^2) (Figure 6).

The burrow diameter ranged from 7.13 to 46 mm, with Sabiaguaba Beach showing the highest average (38.84mm), followed by Cumbuco Beach (36.32mm), Futuro Beach (33.80mm), Icaraí Beach (29.26mm), and Canto Verde Beach (24.45mm) (Figure 7).

Figure 6 – Number of burrows/50m^2 of *Ocypode quadrata* on the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde. Black dot = mean, vertical bars = standard error

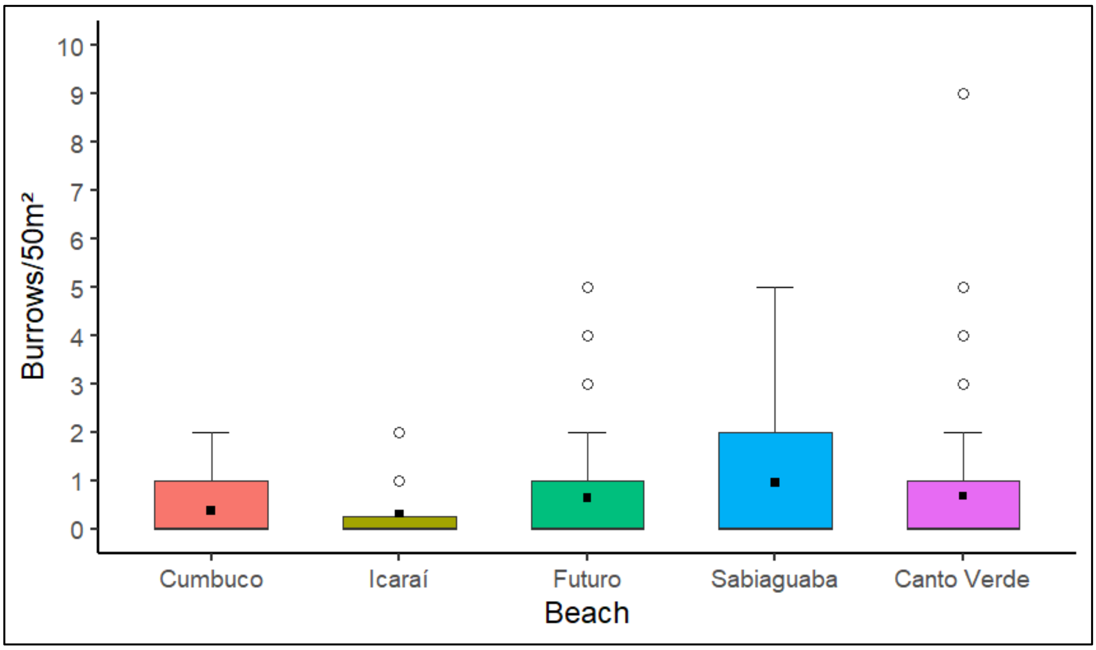
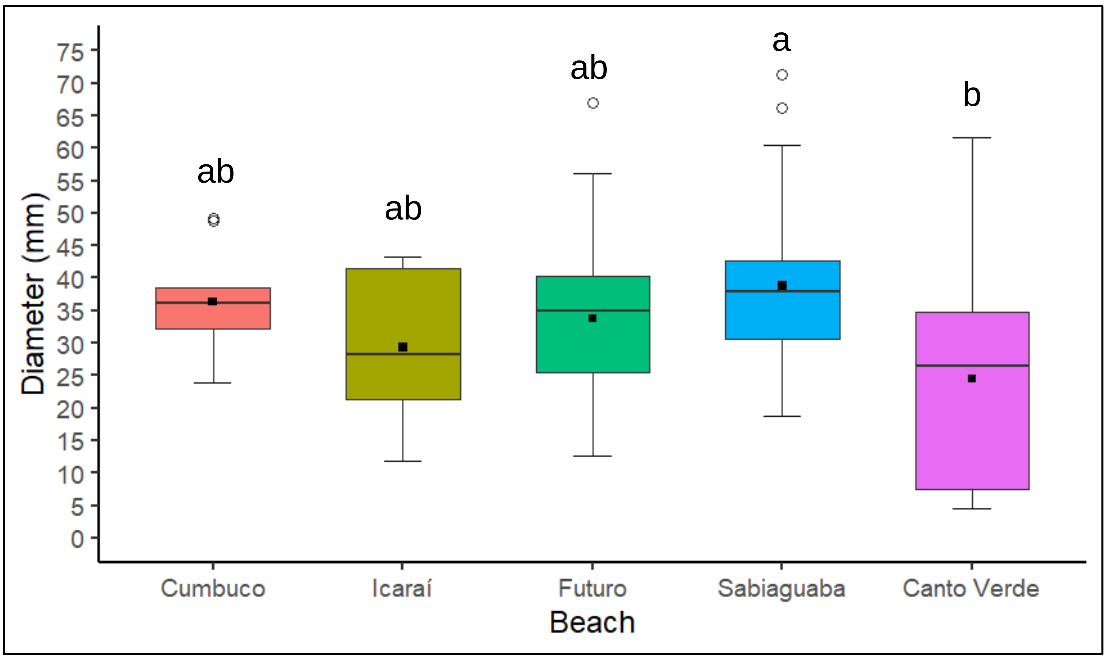


Figure 7 – Diameter (mm) of the opening of the burrows of *Ocypode quadrata* on the beaches of Cumbuco, Icaraí, Futuro, Sabiaguaba and Canto Verde. Black dot = mean, vertical bars = standard error. Different letters above the bars (standard error) indicate significant differences



The Kruskal-Wallis test showed no significant differences ($p > 0.05$) in burrow density; however, there were significant differences in the burrow diameter of *Ocypode quadrata* between the studied beaches ($p=0.0008$). The Dunn post-hoc test showed that the diameter of burrows were differed significantly between Canto Verde and Sabiaguaba Beach (p_{adj}=0.00188).

DISCUSSION

The beaches analyzed in this study exhibit varying degrees of use. Futuro and Cumbuco beaches stand out in the metropolitan region of Fortaleza as the most frequented by tourists. Icaraí Beach has been undergoing an erosive process over the past few decades (Farias and Maia 2010), which has reduced its attractiveness to tourists (Medeiros *et al.* 2016). Sabiaguaba Beach, although located within the metropolitan region of Fortaleza, lies in an environmentally protected area, lacking tourist infrastructure and therefore receiving few visitors. Canto Verde Beach is located in a conservation area with little tourist infrastructure. These differences are clearly reflected in the cluster analysis conducted during the study period.

To monitor potential negative effects of anthropogenic activities on sandy beaches, ghost crabs are often used as indicators of impacts such as trampling, erosion, and off-road vehicle use (Schlacher *et al.* 2016b; Costa *et al.* 2020). However, the use of ghost crab metrics (density and burrow diameter) to assess impacts on beaches has produced mixed results, although most studies show that more impacted areas have lower crab densities (Schlacher *et al.* 2016b).

In this study, in general, no significant differences in *O. quadrata* population characteristics were observed between the beaches. Despite the different uses, the synergistic effects of activities on the beaches appeared to yield similar results. Although Sabiaguaba Beach has little infrastructure and low visitor numbers, it recorded the highest maximun vehicle traffic. The impact of off-road vehicles on *Ocypode quadrata* populations is well documented (e.g., Schlacher *et al.* 2007; Hobbs *et al.* 2008; Thompson and Schlacher 2008; Schlacher and Lucrezi 2010; Schlacher *et al.* 2008), showing reduced burrow abundance in areas with heavy vehicle traffic due to increased mortality from crushing. Additionally, off-road vehicle impacts seem greater in less urbanized areas, where crabs are more abundant and active on the surface (Costa *et al.* 2020). Despite being in a conservation unit and having a low urbanization index, Sabiaguaba Beach is very close to an urban center, facilitating vehicle access. This may result in higher mortality rates of crabs due to crushing, reducing organism density on the beach and leading to no statistical difference in burrow density between this beach and more urbanized ones. This mortality may particularly affect younger crabs at Sabiaguaba Beach. The significant difference in the mean burrow opening diameter between Sabiaguaba and Canto Verde beaches could be due to the higher mortality of younger crabs on the beach with greater vehicle traffic, resulting in an increase in the mean burrow diameter at Sabiaguaba Beach.

Trampling can negatively affect benthic populations and communities, reducing the density of some species on sandy beaches (Fanini *et al.* 2005; Veloso *et al.* 2006). However, the direct effects of trampling on sandy beach fauna are difficult to measure due to the challenge of distinguishing them from other associated activities. According to Barros (2001), the number of users tends to be higher on beaches that have already undergone habitat modifications. In highly used beaches, there is also an increase in beach cleaning frequency. This activity, aimed at making the area more pleasant for users, removes macroalgae washed ashore, affecting trophic pathways and consequently ghost crab populations (McLachlan and Defeo 2017). The trampling apparently did not affect the average diameter of the burrows of *O. quadrata*. Comparing the group of urban beaches with higher levels of trampling and habitat modification (Cumbuco, Icarai, and Futuro) to the group of less urbanized beaches with lower levels of trampling (Sabiaguaba and Canto Verde), no differences were observed in the mean burrow diameter. In fact, Schlacher *et al.* (2016b), in a meta-analysis, noted that anthropogenic effects on ghost crab burrow opening size are highly variable. This variability may be due to multiple factors, including adult crabs' ability to stay in collapsed burrows longer, avoiding being trampled (Lucrezi *et al.* 2009). Furthermore, recruitment events may alter the mean burrow diameter on less impacted beaches, influencing comparisons between these areas and altered ones (Costa *et al.* 2022). The use of burrow diameter as an indicator of ecological disturbances seems to be notably variable, being more affected when multiple stressors are present (Costa *et al.* 2022), thus requiring caution when using this metric.

Urbanization significantly impacts natural communities on sandy beaches due to habitat modifications (Morteiro and Bemvenuti 2006), trampling (Comor *et al.* 2008), solid waste (Thiel *et al.* 2003; Bravo *et al.* 2009), and vehicle traffic. The studied beaches exhibited urbanization levels that classify them as highly urbanized (UI > 0.6) (Cumbuco, Icaraí, and Futuro), moderately urbanized (0.4 < UI < 0.6) (Sabiaguaba), and low urbanization (UI < 0.4) (Canto Verde). This pattern was reflected in the dissimilarity analysis, forming four groups where two were made up of highly urbanized beaches, one group comprised a moderately urbanized beach, and another a minimally urbanized beach. Despite these urbanization differences, no significant differences were observed in burrow abundance and diameter for the ghost crabs between most beach comparisons.

The low densities observed in the present study are consistent with the findings of Girão (2016). The author, analyzing 17 beaches, reported burrow densities ranging from 0.0003 to 0.0751 burrows/m^2. Other studies have also reported low densities in various locations, such as Wolcott and Wolcott (1985) (0.005–0.014 burrows/m^2), and Alberto and Fontoura (1999) (0.002–0.24 burrows/m^2). In the case of the beaches analyzed in the present study, oligotrophic waters, along with low vegetation cover, high temperatures, and constant winds (Soares *et al.*, 2021), probable reduce the productivity of ghost crabs, resulting in low burrow densities. Moreover, Girão (2016) did not observe correlations between the population aspects studied (burrow density and burrow diameter) and environmental factors such as sediment grain size, beach slope, and beach width. Thus, the impact caused by urbanization was expected to have a greater effect than environmental differences. It is likely that, due to inhabiting a highly harsh environment with limited food availability, high temperatures, and strong, constant winds, the crabs on the analyzed beaches may have adapted to more severe conditions, making it more difficult to observe potential population differences caused by anthropogenic impacts.

The results obtained in this study align with authors who emphasized that using *Ocypode quadrata* as a bioindicator of urbanization effects on beaches requires caution (Pombo and Turra, 2019). Although urbanization affects the diameter and abundance of burrows, the potential for using this species as a bioindicator is limited. It is recommended mainly for dissipative beaches with low urbanization or intermediate/reflective beaches with low or moderate urbanization (Checon *et al.* 2023). Additionally, the variance in the population parameters analyzed is influenced by both environmental and urbanization variances (Checon *et al.* 2023), which may have affected the comparison of different *O. quadrata* populations on urbanized beaches along the semiarid Brazilian coast.

CONCLUSION

The use of population parameters (abundance and burrow diameter) of the ghost crab *Ocypode quadrata* as indicators of urbanization effects by comparing different urban beaches in the Brazilian semiarid region appears to be unfeasible. To assess the viability of using ghost crabs as bioindicators of such impacts on urban beaches, further studies comparing other parameters, such as behavioral changes and body condition, are necessary.

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