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Inventory

Floristics of the herbaceous-shrub vegetation in the restinga of Araoca Beach, municipality of Guimarães, Maranhão, Northeast Brazil

***José da Conceição Aguiar Penha*[1*], *Neuriane Pinheiro Ferreira Alves*[1], *Mayara Silva Nunes*[1], *Maycon Jordan Costa da Silva*[2], *Vitor Rafael Cardoso Neto*[3], *Mateus César Araújo Pestana*[4], *Alessandro Wagner Coelho Ferreira*[5] & *Raysa Valéria Carvalho Saraiva*[1]**

[1]*Universidade Federal do Maranhão, Grupo de Pesquisa em Biodiversidade e Interdisciplinaridade em Ensino de Ciências Naturais, 65200-000, Pinheiro, MA, Brasil.*
[2]*Museu Paraense Emílio Goeldi, 66077-830, Belém, PA, Brasil.*
[3]*Universidade Federal de Juiz de Fora, Programa de Pós-Graduação em Biodiversidade e Conservação da Natureza, 36036-900, Juiz de Fora, MG, Brasil.*
[4]*Universidade Federal da Grande Dourados, Programa de Pós-Graduação em Biodiversidade e Meio Ambiente, 79825-070, Dourados, MS, Brasil.*
[5]*Universidade Federal do Maranhão, Programa de Pós-Graduação em Biodiversidade e Conservação, 65085-582, São Luís, MA, Brasil.*
**Corresponding author:ca.penha@discente.ufma.com*

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Abstract: The Environmental Protection Area of Reentrâncias Maranhenses is located on the northern coast of the state of Maranhão, covering 16 municipalities and great floristic diversity. However, this biodiversity is threatened by the reduction and even extinction of species aggravated by anthropogenic action. The objectives of this study were (i) to analyze the floristic composition of the herbaceous and shrubby vegetation in the restinga ecosystem of Araoca Beach, located in the municipality of Guimarães; (ii) classify habits; (iii) to analyze pollination and seed dispersal syndromes; (iv) to categorize the physiognomies present and (v) to identify environmental impacts. Field expeditions were carried out between July 2022 to October 2023 (during the dry and rainy seasons) and plant species were recorded using the walking method. In total, 122 herbaceous and shrub species belonging to 95 genera and 50 families were cataloged. The families with the highest species richness were Fabaceae (24), Cyperaceae (10), Rubiaceae (6), and Asteraceae (5), corresponding to 37.2% of the total species collected. Herbaceous species (59), shrubs (29), sub-shrubs (21), lianas and vines (12) accounted for 48.4%, 23.8%, 17.2%, and 9.8% of the species, respectively. The survey also recorded a single species of palm (Arecaceae), corresponding to 0.8% of the species collected. As for pollination, 100 species were categorized exclusively as zoophilic and 15 as anemophilic. Concerning seed dispersal, anemochory accounted for 7.4% of the individuals (9); exclusive zoochory was present in 33.6% of the species (41); and exclusive autochory in 70 species (57.4% of the samples). Only *Pavonia cancellata* (L.) Cav. showed two types of dispersal (zoochory and autochory). The following physiognomies were described: unflooded open field, flooded open field-halophytic, unflooded closed shrubby vegetation, flooded closed shrubby vegetation, and flooded open shrubby vegetation. Araoca's plant diversity indicates a similarity to other restingas in Maranhão. The considerable amount of garbage left in the vicinity of the dunes, formation of trails, and cattle grazing areas alter the dynamics and compromise the balance of this ecosystem. Considering this scenario, the restinga of Araoca Beach is subject to loss of floristic composition, making it necessary to develop studies aimed at maintaining its diversity.
***Keywords*:** *Conservation; environmental impacts; physiognomy; Reentrâncias Maranhenses; floristic similarity.*

Florística da vegetação herbáceo-arbustiva na restinga da Praia de Araoca, município de Guimarães, Maranhão, Nordeste do Brasil

Resumo: A Área de Proteção Ambiental das Reentrâncias Maranhenses está localizada no litoral norte do estado do Maranhão, abrangendo 16 municípios e apresentando grande diversidade florística. Contudo, essa biodiversidade está ameaçada pela redução e até extinção de espécies, situação agravada pela ação antrópica. Os objetivos deste

estudo foram (i) analisar a composição florística da vegetação herbáceo-arbustiva no ecossistema de restinga da praia de Araoca, localizada no município de Guimarães; (ii) classificar hábitos; (iii) analisar síndromes de polinização e dispersão de sementes; (iv) categorizar as fitofisionomias presentes e (v) identificar os possíveis impactos ambientais. As expedições de campo foram realizadas entre julho de 2022 e outubro de 2023 (durante as estações seca e chuvosa) e as espécies vegetais foram registradas usando o método do caminhamento. No total, foram catalogadas 122 espécies herbáceo-arbustivas pertencentes a 95 gêneros e 50 famílias. As famílias com maior riqueza de espécies foram Fabaceae (24), Cyperaceae (10), Rubiaceae (6) e Asteraceae (5), correspondendo a 37, 2% do total das espécies coletadas. Quanto ao hábito, as espécies herbáceas (59) correspondem a 48,4% da amostragem, as arbustivas (29) representaram 23,8%, as subarbustivas (21) equivalem a 17,2% e as lianas/trepadeiras somaram 9,8% das espécies. O levantamento ainda registrou uma única espécie de palmeira (Arecaceae), correspondendo a 0,8% das espécies coletadas. Quanto à polinização, 100 espécies foram categorizadas exclusivamente como zoofílicas e 15 relativas à anemofilia. Em relação à dispersão, a anemocoria representou 7,4% dos indivíduos (9); a zoocoria exclusiva estava presente em 33,6% do levantamento (41); e a autocoria exclusiva em 70 espécies, somando 57,4% das amostras. Apenas *Pavonia cancellata* (L.) Cav. apresentou dois tipos de dispersão, zoocoria e autocoria, que representam 0,8% do total das síndromes de dispersão. Foram descritas fisionomias de campo aberto não inundável, campo aberto inundável-halófilo, frutíceto fechado não inundável, frutíceto fechado inundável e frutíceto aberto inundável. A diversidade vegetal de Araoca indica similaridade de restingas segundo as espécies comumente encontradas nas áreas estudadas no Maranhão. A considerável quantidade de lixo deixado nas proximidades das dunas, formação de trilhas e pastagem de bovinos em áreas de estrato arbustivo, alteram a dinâmica e comprometem o equilíbrio desse ecossistema. Considerando esse cenário, a restinga da Praia de Araoca está sujeita a perda de composição florística, sendo necessário o desenvolvimento de estudos que direcionem a manutenção de sua diversidade.
Palavras-chave: *Conservação; impactos ambientais; fisionomias; Reentrâncias Maranhenses; similaridade florística.*

Introduction

The Reentrâncias Maranhenses Environmental Protection Area (EPA) covers 16 municipalities in the state of Maranhão and 2,680,911.2 ha. The main biomes are the Amazon forest (38.3%) and coastal and marine environments (61.7%), comprising mangroves, estuaries, rivers, dunes, restingas, and lagoons, which have a rich diversity of marine and terrestrial species (ICMBIO 2017, SEMA 2023). The EPA's coastline is quite jagged and plays a role as a natural nursery for various fishing species and a landing and feeding site for migratory shorebirds from the Northern Hemisphere. In addition, the EPA protects biodiversity and preserves the ecosystems of this region, where endangered species such as manatees, groupers, dolphins, and sea turtles are found (Hazin 2008).

The state of Maranhão has the second-longest coastline in Brazil (640 km) (El-Robrini et al. 2006) and is located on the eastern portion of the northern coast, with a rich coastline of Amazonian influence, including the restinga vegetation of the state west coast and the Reentrâncias Maranhenses (Almeida Jr. et al. 2018). The restinga ecosystem has great floristic diversity, known for harboring plant species from various phytogeographic domains, including Caatinga, Atlantic Forest, Cerrado, and even Amazonia, covering around 79% of the Brazilian coast (Lacerda et al. 1993, Rabelo et al. 2024). However, this biodiversity is under constant threat due to the progressive anthropogenic activities, leading to the reduction or extinction of species (Soares et al. 2021).

Restingas are not uniform along the Brazilian coast and have a high geomorphological variety that has favored the establishment of very diverse plant and animal communities (Lacerda et al. 1984). Distinct types of vegetation can be recognized and are referred to as "restinga physiognomies" (Galvão et al. 2018): herbaceous and sub-shrub vegetation (or beach and dune vegetation), shrub vegetation, tree vegetation, low forest, and high forest (Azevedo et al. 2014). Erect herbaceous plants, shrubs of different heights and trees, and trees predominate in fields, shrubby vegetation, and forests, respectively (Silva & Britez 2005, Lima et al. 2018).

Several floristic, ecological, and conservation studies on the restinga flora have been carried out along the Northeast coast of Brazil (Costa et al. 2018, Rodrigues et al. 2019), particularly in Maranhão. Among the authors who have expanded the records on species richness and composition in restingas in this state, one can highlight the works by Amorim et al. (2016) in the dunes of Araçagi Beach, between the municipalities of São José de Ribamar and Paço do Lumiar; Almeida Jr. et al. (2018) in the Reentrâncias Maranhenses EPA; Serra et al. (2016) in the Merck restinga, in São José de Ribamar; Silva et al. (2016) in the São Marcos dunes, in São Luís; Lima & Almeida Jr. (2018) in the Panaquatira restinga, in São José de Ribamar; and Correia et al. (2020) in Alcântara. To maintain these studies over time is necessary to expand knowledge about the plant richness of the restinga ecosystem.

Despite legal conservation initiatives that have transformed some stretches of restinga into conservation units, there is still a lack of information on important ecological aspects of this ecosystem (Azevedo et al. 2014). For example, the relationships between plants and their respective pollinators or dispersers are very relevant for structuring communities and are also essential in the natural distribution of species and in the exchange of genetic material within and outside populations (Reis et al. 2012, Kuhlmann & Ribeiro 2016).

Knowledge about the relationships between organisms and the environment and the interactions between species allows for a more

qualified contribution to the definition of new conservation areas and better conservation strategies, as well as providing data for the recovery of areas that have been intensely degraded (Azevedo et al. 2014). In this context, studies on floristic composition and vegetation structure are crucial for understanding their structure and dynamics, which are basic parameters for the management and restoration of various plant communities.

This study aimed to analyze and inventory the floristic composition of the herbaceous and shrubby vegetation in the restinga of Araoca Beach in the municipality of Guimarães, in the Reentrâncias Maranhenses EPA. We categorized the physiognomies and identified the environmental impacts in this area, contributing to conservation strategies for the restinga ecosystem.

Material and Methods

1. Study area

The study was conducted in the restinga of Araoca Beach (2° 03' 03" S; 44° 29' 51" W) located in the municipality of Guimarães, part of the Reentrâncias Maranhenses EPA (ICMBIO 2023), western coast of Maranhão (Figure 1). The relief is characterized by coastal plains shaped by marine and fluvial agents and processes that give rise to beaches, mangroves, swamps, apicum (i.e., hypersaline tidal flats), lagoons, and cliffs (Ramos 2008). Coastal tablelands with higher topographic levels than those of the Maranhão lowlands (generally not exceeding 100 m in altitude) occur in this region. The regional climate is Tropical Aw, according to the Köppen classification (Alvares et al. 2013). The average annual temperature is 27ºC and the average annual rainfall is 2055 mm (Maranhão 2019). The rainy season is between November and June and the dry season is between July and October (Alvares et al. 2013).

2. Data collection

The field expeditions were conducted biannually: in July and September 2022, and in May and October 2023, covering both the dry and rainy seasons. Each expedition lasted four days and included morning and afternoon shifts (from 8:00 AM to 5:00 PM), with the participation of three researchers.

The species in the restinga areas were recorded using the free-walking method (Filgueiras et al. 1994), which consists of traversing the entire study area, identifying, collecting, and recording plant species on field datasheets. Fertile individuals were collected, pressed, and dried in an oven at 60 ºC for 72 h following the herborization techniques recommended by Fidalgo & Bononi (1984). The specimens were deposited in the Rosa Mochel Herbarium (SLUI) at the State University of Maranhão.

Species were identified according to the dichotomous keys found in specialized literature, e.g. Souza and Lorenzi (2019) and Flora e Funga do Brasil (2023), and comparison with specimens from the SLUI herbarium and virtual herbaria from the SpeciesLink and Flora e Funga do Brasil databases. In addition, taxonomists experts in Plantaginaceae, Fabaceae and Convolvulaceae were consulted. The photos were taken using a Nikon D5300 digital camera to record the vegetative and reproductive parts of the specimens in the field. Herbarium acronyms are according to Thiers (2023). The names of the authors of the species follow Brummitt & Powell (1992). The floristic list was compiled

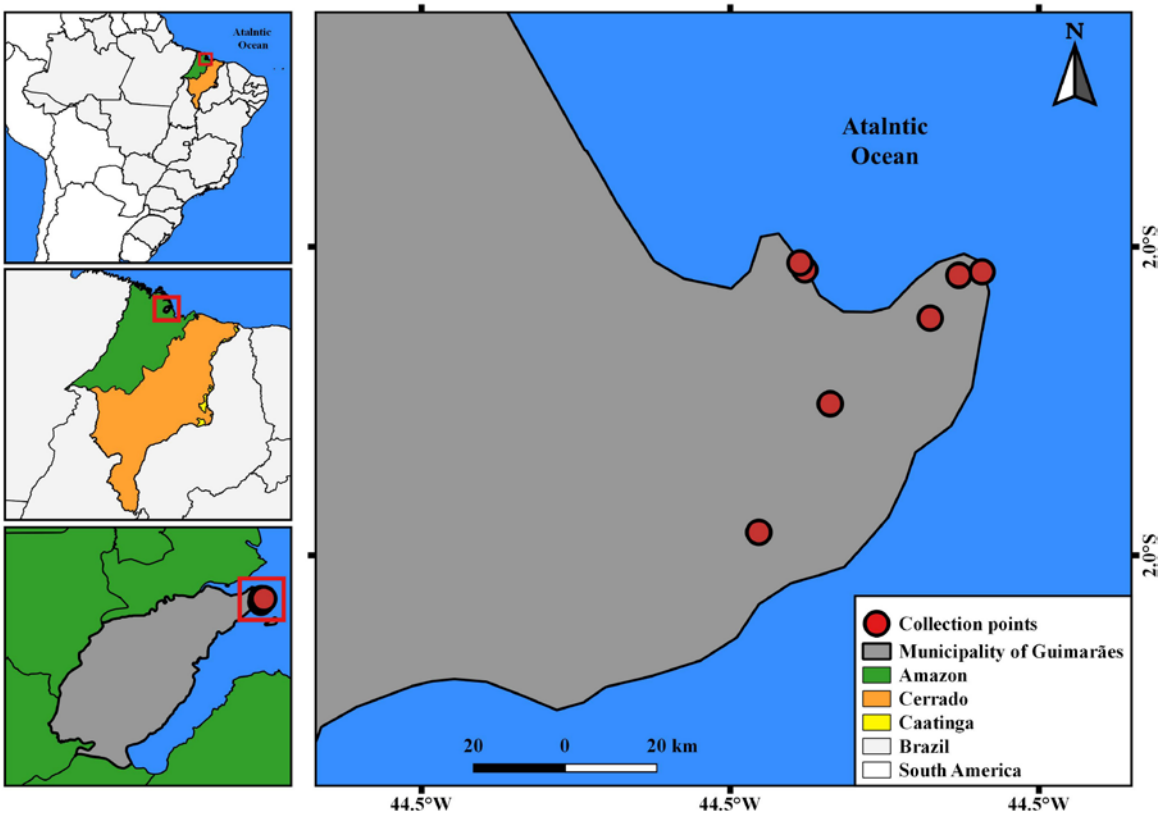


Figure 1. Map of the restinga of Araoca Beach. Red dots indicating collection locations.

according to the classification system based on APG IV (2016) and the spelling of species names and authors was confirmed by consulting the Missouri Botanical Garden database ("Tropical System", tropicos.org) and the REFLORA database (Flora e Funga do Brasil 2023).

Species were classified according to habit (Souza et al. 2013) and life form (Raunkiaer 1984). Pollination syndromes were based on Faegri & van der Pijl (1979) and van der Pijl (1972) and species were grouped into wind-pollinated species (anemophilous) and animal-pollinated species (zoophilous). The types of fruit dispersal were associated with the morphological characteristics of the diaspores of the genera described for the restinga ecosystem, which are included in the Flora e Funga do Brasil database. Species that disperse their diaspores by wind were grouped as anemochoric; species that disperse their diaspores by animals were grouped as zoochoric; and species that disperse by the plant itself were grouped as autochoric (Laurentino et al. 2016, Diniz et al. 2021).

For the classification of physiognomies, we followed the methods proposed by Silva & Britez (2005) and Nascimento-Junior (2012), considering the descriptions in Lima et al. (2017). We only considered physiognomies related to the herbaceous-shrub vegetation of the restinga, which include: 1) Field formations (characterized by herbaceous species, which can be erect, cespitose, reptant, and/or rhizomatous); and 2) Shrubby vegetation (characterized by shrub and sub-shrub species).

3. Similarity analysis

Based on the floristic list obtained in this study, a similarity analysis was conducted by comparing it with studies from restinga areas in the state of Maranhão. The following studies were selected: Lima & Almeida Jr. (2018) on Panaquatira Beach, São José de Ribamar; Correia et al. (2020) on Itatinga Beach, Alcântara; and Guterres et al. (2020) on Guia Beach, São Luís Island (Table 1). Only taxa identified to the species level were considered, while species with uncertain identifications (e.g., those marked as "cf.") and those not belonging to the stratum addressed in this study (herbaceous-shrub) were excluded from the analysis. We classified plants as herbaceous or shrubby based on their exhibited life forms during the data collection.

Subsequently, a Detrended Correspondence Analysis (DCA) was used to verify the floristic relationships of herbaceous-shrub species with the restinga areas was conducted using the Vegan package (Oksanen et al. 2023) in R software, version 4.4.2 (R Development Core Team 2024). The analysis was based on a binary matrix composed by 278 species, allowing for the visualization of similarity patterns and floristic relationships among the compared areas. The results are presented in a scatter plot, where the proximity of points indicates the floristic similarity between the analyzed areas.

Results and Discussion

We recorded 122 herbaceous and shrub species, belonging to 95 genera and 50 families, distributed in different formations and vegetations associated with the restinga of Araoca Beach (Table 2). The families with the highest species richness were Fabaceae (24), Cyperaceae (10), Rubiaceae (6), Asteraceae (5), Myrtaceae (5), Poaceae (5), Eriocaulaceae (4), Lamiaceae (4), and Plantaginaceae (4). These nine families correspond to 18% of the families sampled and accounted for 54.9% of the total species collected. The families with the highest richness were also mentioned in studies carried out on Panaquatira Beach (Lima & Almeida Jr. 2018).

Herbaceous species (59) accounted for 48.4% of the samples, with Cyperaceae (10), Poaceae (5), Eriocaulaceae (4), and Plantaginaceae (4) standing out as the most representative families for this life form. Shrubs (29) accounted for 23.8% of the plants collected and the families with the highest shrub species richness were Myrtaceae (5), Rubiaceae (5), Fabaceae (3), and Combretaceae (2). In the sub-shrub component, 21 individuals (17.2% of the species identified) were collected from seven families: Fabaceae (12), Lamiaceae (3), Turneraceae (2), Amaranthaceae (1), Euphorbiaceae (1), Malvaceae (1), and Plumbaginaceae (1).

Lianas (4) and vines (8) accounted for 9.8% of the species sampled, grouped into seven families. The families having vines were Fabaceae (3), Passifloraceae (2), Lygodiaceae (1), Menispermaceae (1), and Vitaceae (1). The Fabaceae family also had liana species (2), followed by Araceae (1) and Euphorbiaceae (1). The survey also recorded a single palm species, *Desmoncus polyacanthos* Mart. (Arecaceae) corresponding to 0.8% of the species collected in Araoca. In the rainy season, we observed the highest number of herbaceous and shrub species blooming, while a marked decrease in blooming in the dry season (July and August).

Fabaceae were highly represented in this study (19.7% of the total species – Figure 2) as in other restinga areas in the state of Maranhão. Lima & Almeida Jr (2018) cataloged 31 species (16.3%) of Fabaceae in the Panaquatira restinga, in the municipality of São José de Ribamar, and Guterres et al. (2020) recorded 16 species of the family (20.9%) in the restinga in Guia Beach, in São Luís. In addition, Fabaceae was also predominant in the restinga of Itatinga (26 species – 17.5%), in the municipality of Alcântara (Correia et al. 2020).

Species of the Fabaceae family have a remarkable diversity of habits. Fabaceae is the family of Brazilian flora with the greatest species richness and one of the largest in the world (Lewis et al. 2005, Flora e Funga do Brasil 2023). In terms of species number, Fabaceae stands out as one of the three richest families in Brazil with approximately 3038 species (Flora e Funga do Brasil 2023).

The species *Borreria verticillata* (L.) G.Mey., *Chamaecrista diphylla* (L.) Greene, *Crotalaria retusa* L., *Turnera melochioides* Cambess., *Utricularia simulans* Pilg., were the ones with the highest number of individuals collected and were found within the entire study area. *Anacardium occidentale* L., *Byrsonima crassifolia* (L.) Kunth, *Cenostigma bracteosum* (Tul.) Gagnon & G.P.Lewis, *Chrysobalanus icaco* L, *Myrcia multiflora* (Lam.) DC., and *Myrcia splendens* (Sw.) DC. were the most common woody species.

Considering floristic studies carried out in restingas in Maranhão (Araujo et al. 2016, Lima et al. 2017, Lima & Almeida Jr 2018, Guterres et al. 2020), the families listed in our survey are the most representative in the restinga ecosystem of the state. This is due to their different habits, pollination, and dispersal strategies (Lima & Almeida Jr 2018). Pollination in the restinga is an important ecosystem service. *Byrsonima crassifolia* and *Anacardium occidentale* stand out for having flowers attractive to pollinators and contribute to less attractive plants also being potentially pollinated in their proximity (Paiva & Almeida Jr 2020).

Among the pollination syndromes, of the 122 species recorded in Araoca 100 were exclusively zoophilic and 15 were classified as anemophilous. Four species belonging to the Eriocaulaceae family had both pollination types. For zoophilic plant species, which may also have self-pollination mechanisms, only *Crotalaria retusa* (Fabaceae) stood out

Table 1. Comparative table based on species used in similarity analyses in restinga areas in the State of Maranhão, Brazil.

Site	City/State	Acronym	Number of species used	Reference
Araoca	Guimarães/Maranhão	araoca	122	Present study
Panaquatira	São José de Ribamar/Maranhão	sjriba	49	(Lima & Almeida Jr 2018)
Praia da Guia	São Luís/Maranhão	sluis	45	(Guterres et al 2020)
Itatinga	Alcântara/Maranhão	alca	54	(Correia et al. 2020)

Table 2. List of herbaceous-shrub species recorded in the floristic survey with indication of origin, habit, and pollination and dispersal syndromes, in the restinga ecosystem of Araoca Beach, Guimarães, MA. Origin: na: native; en: naturalized species. Habit: ab: shrub; ev: herbaceous; sb: subshrub; li: liana; tr: climbing plant. Pollination: zo: zoophilic; an: anemophilic; au: self-pollination. Dispersal: hi: hydrochory; zo: zoochory; au: autochory; an: anemochory. SLUI = Herbário Rosa Mochel, State University of Maranhão, São Luís.

FAMILY/Species	Origin	Habit	Pollination	Dispersal	Herbarium/Vouchers
ACANTHACEAE					
Avicennia schaueriana Stapf & Leechm. ex Moldenke	na	ab	zo	hi	SLUI 7756
Dicliptera ciliaris Juss.	na	ev	zo	au	SLUI 7835
AIZOACEAE					
Sesuvium portulacastrum (L.) L.	en	ev	zo	au	SLUI 7865
AMARANTHACEAE					
Alternanthera brasiliana (L.) Kuntze	na	sb	zo	au	SLUI 7833
Alternanthera tenella Colla	na	ev	zo	au	SLUI 7132
Blutaparon portulacoides (A.St.-Hil.) Mears	na	ev	zo	au	SLUI 6641
ANACARDIACEAE					
Anacardium occidentale L.	na	ab	zo	zo	SLUI 7831
ARACEAE					
Philodendron acutatum Schott	na	li	zo	zo	SLUI 6664
ARECACEAE					
Desmoncus polyacanthos Mart.	na	pa	zo	zo	SLUI 7509
ASTERACEAE					
Baltimora geminata (Brandegee) Stuessy	na	ev	zo	au	SLUI 7503
Elephantopus mollis Kunth	na	ev	zo	an	SLUI 7128
Emilia sonchifolia (L.) DC.	en	ev	zo	an	SLUI 7885
Sphagneticola trilobata (L.) Pruski	na	ev	zo	an	SLUI 7131
Tilesia baccata (L.) Pruski	en	ab	zo	zo	SLUI 7508
BATACEAE					
Batis maritima L.	na	ev	zo	au	SLUI 7507
HELIOTROPIACEAE					
Euploca polyphylla (Lehm.) J.I.M.Melo & Semir	na	ev	zo	au	SLUI 7830
BURMANNIACEAE					
Burmannia capitata (Walter ex J.F.Gmel.) Mart.	na	ev	zo	au	SLUI 7848
CACTACEAE					
Cereus jamacaru DC.	na	ab	zo	zo	SLUI 7873
CHRYSOBALANACEAE					
Chrysobalanus icaco L.	na	ab	zo	zo	SLUI 6649
COMBRETACEAE					
Conocarpus erectus L.	na	ab	zo	zo	SLUI 7828
Laguncularia racemosa (L.) C.F.Gaertn.	na	ab	zo	zo	SLUI 7859

FAMILY/Species	Origin	Habit	Pollination	Dispersal	Herbarium/Vouchers
COMMELINACEAE					
Murdannia nudiflora (L.) Brenan	en	ev	zo	au	SLUI 7890
CONVOLVULACEAE					
Ipomoea imperati (Vahl) Griseb.	na	ev	zo	au	SLUI 7864
CYPERACEAE					
Bulbostylis truncata (Nees) M.T.Strong	na	ev	an	au	SLUI 7866
Cyperus ligularis L.	na	ev	an	au	SLUI 7895
Cyperus obtusatus (J.Presl & C.Presl) Mattf. & Kük.	na	ev	an	au	SLUI 7867
Cyperus polystachyos Rottb.	na	ev	an	au	SLUI 7749
Cyperus sellowianus (Kunth) T.Koyama	na	ev	an	au	SLUI 7861
Eleocharis geniculata (L.) Roem. & Schult.	na	ev	an	au	SLUI 7898
Eleocharis interstincta (Vahl) Roem. & Schult.	na	ev	an	au	SLUI 7877
Fimbristylis dichotoma (L.) Vahl	na	ev	an	au	SLUI 7500
Fimbristylis cymosa R.Br.	na	ev	an	au	SLUI 6661
Scleria microcarpa Nees ex Kunth	na	ev	an	au	SLUI 7853
ERIOCAULACEAE					
Eriocaulon cinereum R.Br.	na	ev	an/zo	au	SLUI 7111
Paepalanthus subtilis Miq.	na	ev	an/zo	an	SLUI 7888
Syngonanthus gracilis (Bong.) Ruhland	na	ev	an/zo	an	SLUI 7122
Tonina fluviatilis Aubl.	na	ev	an/zo	au	SLUI 8751
EUPHORBIACEAE					
Cnidoscolus urens (L.) Arthur	na	sb	zo	zo	SLUI 7829
Dalechampia scandens L.	na	li	zo	au	SLUI 7876
Euphorbia hyssopifolia L.	na	ev	zo	au	SLUI 7098
FABACEAE					
Abrus precatorius L.	na	li	zo	au	SLUI 7471
Aeschynomene evenia C.Wright & Sauvalle	na	ev	zo	zo	SLUI 7855
Cenostigma bracteosum (Tul.) Gagnon & G.P.Lewis	na	ab	zo	au	SLUI 7102
Centrosema brasilianum (L.) Benth.	na	tr	zo	au	SLUI 7090
Chamaecrista desvauxii (Collad.) Killip	na	sb	zo	au	SLUI 7099
Chamaecrista diphylla (L.) Greene	na	sb	zo	au	SLUI 7750
Chamaecrista nictitans (L.) Moench	na	sb	zo	au	SLUI 6654
Chamaecrista tenuisepala (Benth.) H.S.Irwin & Barneby	na	sb	zo	au	SLUI 6667
Clitoria falcata Lam.	na	tr	zo	au	SLUI 7091
Clitoria simplicifolia (Kunth) Benth.	na	sb	zo	au	SLUI 7130
Crotalaria retusa L.	en	sb	zo/au	au	SLUI 7834
Desmodium barbatum (L.) Benth.	na	sb	zo	zo	SLUI 7860
Desmodium incanum (Sw.) DC.	en	sb	zo	zo	SLUI 7112
Entada polystachya (L.) DC.	na	ab	zo	au	SLUI 7759
Galactia striata (Jacq.) Urb.	na	tr	zo	au	SLUI 7872
Indigofera hirsuta L.	na	ev	zo	au	SLUI 7879
Macroptilium lathyroides (L.) Urb.	na	ev	zo	au	SLUI 7092
Macropsychanthus grandiflorus (Mart. ex Benth.) L.P.Queiroz & Snak	na	li	zo	au	SLUI 7840
Mimosa candollei R.Grether	na	ev	zo	au	SLUI 7826

FAMILY/Species	Origin	Habit	Pollination	Dispersal	Herbarium/Vouchers
Stylosanthes angustifolia Vogel	na	sb	zo	zo	SLUI 7117
Zornia brasiliensis Vogel	na	sb	zo	zo	SLUI 7843
Zornia guanipensis Pittier	na	sb	zo	zo	SLUI 7498
Zornia latifolia Sm.	na	sb	zo	zo	SLUI 7093
GENTIANACEAE					
Schultesia guianensis (Aubl.) Malme	na	ev	zo	au	SLUI 7120
HELICONIACEAE					
Heliconia psittacorum L.f.	na	ev	zo	zo	SLUI 7858
IRIDACEAE					
Cipura paludosa Aubl.	na	ev	zo	au	SLUI 7849
LAMIACEAE					
Hyptis atrorubens Poit.	na	ev	zo	au	SLUI 7838
Hyptis crenata Pohl ex Benth	na	sb	zo	au	
Marsypianthes chamaedrys (Vahl) Kuntze	na	sb	zo	au	SLUI 7891
Mesosphaerum suaveolens (L.) Kuntze	na	sb	zo	au	SLUI 7856
LECYTHIDACEAE					
Gustavia augusta L	na	ab	zo	zo	SLUI 7889
LENTIBULARIACEAE					
Utricularia fimbriata Kunth	na	ev	zo	au	SLUI 7850
Utricularia simulans Pilg.	na	ev	zo	au	SLUI 7757
Utricularia subulata L.	na	ev	zo	au	SLUI 7854
LINDERNIACEAE					
Lindernia crustacea (L.) F.Muell.	na	ev	zo	au	SLUI 7845
LYGODIACEAE					
Lygodium venustum Sw.	na	tr		au	SLUI 7753
MALPIGHIACEAE					
Byrsonima crassifolia (L.) Kunth	na	ab	zo	zo	SLUI 7496
MALVACEAE					
Pavonia cancellata (L.) Cav.	na	ev	zo	zo/au	SLUI 7474
Sida ciliaris L.	na	sb	zo	zo	SLUI 7748
MELASTOMATACEAE					
Comolia villosa (Aubl.) Triana	na	ab	zo	au	SLUI 7127
Noterophila bivalvis (Aubl.) Kriebel & M.J.R.Rocha	na	ev	zo	au	SLUI 7103
MENISPERMACEAE					
Odontocarya duckei Barneby	na	tr	zo	zo	SLUI 7505
MYRTACEAE					
Eugenia flavescens DC.	na	ab	zo	zo	SLUI 6658
Eugenia punicifolia (Kunth) DC.	na	ab	zo	zo	SLUI 7096
Myrcia guianensis (Aubl.) DC.	na	ab	zo	zo	SLUI 7104
Myrcia multiflora (Lam.) DC.	na	ab	zo	zo	SLUI 7104
Myrcia splendes (Sw.) DC.	na	ab	zo	zo	SLUI 7825
OCHNACEAE					
Ouratea hexasperma	na	ab	zo	zo	SLUI 7874
ONAGRACEAE					

FAMILY/Species	Origin	Habit	Pollination	Dispersal	Herbarium/Vouchers
Ludwigia hyssopifolia (G.Don) Exell	na	ev	zo	au	SLUI 784
Ludwigia leptocarpa (Nutt.) H.Hara	na	ab	zo	au	SLUI 7842
PASSIFLORACAE					
Passiflora subrotunda Mast.	na	tr	zo	zo	SLUI 7897
Passiflora foetida L.	na	tr	zo	zo	SLUI 7868
PLANTAGINACEAE					
Bacopa angulata (Benth.) Edwall	na	ev	zo	au	SLUI 7758
Bacopa aquatica Aubl.	na	ev	zo	au	SLUI 7862
Bacopa salzmannii (Benth.) Wettst. ex Edwall	na	ev	zo	au	SLUI 7094
Bacopa sessiliflora (Benth.) Edwall	na	ev	zo	au	SLUI 7841
PLUMBAGINACEAE					
Plumbago scandens L.	na	sb	zo	zo	SLUI 7881
POACEAE					
Axonopus capillaris (Lam.) Chase	na	ev	an	an	SLUI 7824
Dactyloctenium aegyptium (L.) Willd.	en	ev	an	an	SLUI 7088
Eragrostis maypurensis (Kunth) Steud.	na	ev	an	au	SLUI 7752
Spartina alterniflora Loisel.	na	ev	an	an	SLUI 7896
Sporobolus virginicus (L.) Kunth	na	ev	an	an	SLUI 7511
POLYGALACEAE					
Senega glochidata	na	ev	zo	au	SLUI 785
POLYGONACEAE					
Coccoloba latifolia Lam.	na	ab	zo	zo	SLUI 7878
PTERIDACEAE					
Ceratopteris pteridoides (Hook.) Hieron.	na	ev		au	SLUI 7871
RHIZOPHORACEAE					
Rhizophora mangle L.	na	ab	zo	zo	SLUI 7875
RUBIACEAE					
Borreria verticillata (L.) G.Mey.	na	ev	zo	au	SLUI 7836
Chomelia obtusa Cham. & Schltdl.	na	ab	zo	zo	SLUI 7472
Chomelia ribesioides Benth. ex A.Gray	na	ab	zo	au	SLUI 7863
Cordiera sessilis (Vell.) Kuntze	na	ab	zo	zo	SLUI 7478
Isertia hypoleuca Benth.	na	ab	zo	zo	SLUI 7106
Mitracarpus strigosus (Thunb.) P.L.R.Moraes, De Smedt & Hjertson	na	ev	zo	au	SLUI 7097
Tocoyena sellowiana (Cham. & Schltdl.) K.Schum.	na	ab	zo	zo	SLUI 7882
SAPINDACEAE					
Pseudima frutescens (Aubl.) Radlk.	na	ab	zo	au	SLUI 7893
SAPOTACEAE					
Manilkara bidentata (A.DC.) A.Chev.	na	ab	zo	zo	SLUI 6651
SOLANACEAE					
Solanum stramoniifolium Jacq.	na	ab	zo	zo	SLUI 7087
TURNERACEAE					
Turnera melochioides Cambess.	na	sb	zo	zo	SLUI 7754
Turnera subulata Sm.	na	sb	zo	zo	

FAMILY/Species	Origin	Habit	Pollination	Dispersal	Herbarium/Vouchers
VIOLACEAE					
Pombalia calceolaria (L.) Paula-Souza	na	ev	zo	au	SLUI 7126
VITACEAE					
Cissus erosa Rich.	na	tr	zo	zo	SLUI 7894
XYRIDACEAE					
Xyris macrocephala Vahl	na	ev	zo	au	SLUI 7501
Xyris savanensis Miq.	na	ev	zo	au	SLUI 7847

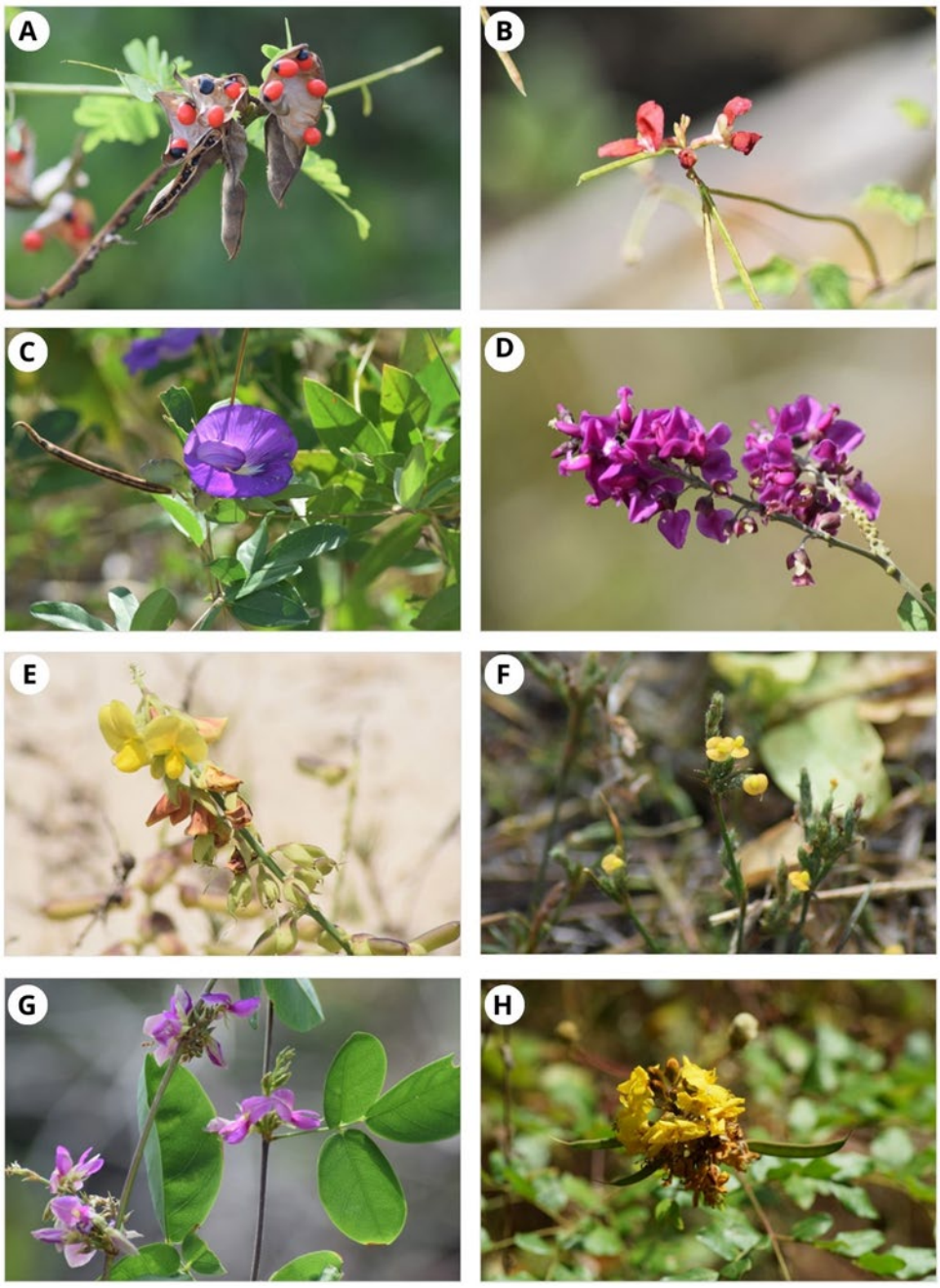


Figure 2. Some listed species of the herbaceous-shrubby vegetation of the restinga of Araoca Beach, Guimarães, MA. Fabaceae. a) *Abrus precatorius*. b) *Macroptilium lathyroides*. c) *Centrosema brasilianum*. d) *Macropsychanthus grandiflorus*. e) *Crotalaria retusa*. f) *Stylosanthes angustifolia*. g) *Galactia striata*. h) *Cenostigma bracteosum*.

in this survey. We collected two species of fern belonging to the families Lygodiaceae (*Lygodium venustum* Sw.) and Pteridaceae (*Ceratopteris pteridoides* (Hook.) Hieron.). As they belong to the group of cryptogams, they do not fit into the pollination syndromes for angiosperms.

We identified four types of dispersal syndromes: hydrocoria, considered a secondary form of dispersal, in one of the species collected (*Avicennia schaueriana* Stapf & Leechm. ex Moldenke); anemochorous in 7.4% of the individuals (9); exclusive zoochory in 33.6% of the individuals (41); and exclusive autochorous in 57.4% of the samples (70). Only *Pavonia cancellata* (L.) Cav. showed two types of dispersal, zoochory and autochorous, representing 0.8% of the total. In a study on fruit and seed dispersal in the dunes of São Marcos Beach, Pires et al. (2021) highlighted zoochory in 62.5% of the species as the main dispersal syndrome, followed by anemochorous in 26.78% and autochorous in 5.36%.

The Araoca restinga has a considerable number of native species, which account for 94.3% of the samples in this study. Fewer naturalized species were found, such as *Emilia sonchifolia* (L.) DC and *Tilesia baccata* (L.) Pruski in the dunes, *Sesuvium portulacastrum* (L.) L. and *Murdannia nudiflora* (L.) Brenan in open field; *Crotalaria retusa* in sub-shrub physiognomy, *Desmodium incanum* (Sw.) DC. and *Dactyloctenium aegyptium* (L.) Willd., both in the dunes and open field areas. These seven species account for 5.7% of the total richness.

Although the number of naturalized species collected in the study area is considered small, it indicates anthropization. However, this result cannot be used as a single parameter to assess the anthropization levels or vegetation degradation in Araoca. Future studies could cover a greater number of naturalized, exotic, or threatened species in the different phytophysiognomies of the restinga in Guimarães. Additionally, it is important to highlight that the naturalized species identified in this study are able to reproduce and maintain populations without compromising the diversity of the local flora, and do not necessarily behave as invasive species.

1. Phytophysiognomies

Araoca Beach has extensive areas of sandy strands with different restinga formations (Figure 3), varying from areas with herbaceous vegetation to trees and different anthropization levels. These formations are interspersed with areas of sediment deposition from the water table, sandy-muddy soil next to the herbaceous vegetation (further away from the seafront), flooded areas and freshwater marshes at the transition from shrub to forest vegetation, fixed dunes, and significant bands of mangrove parallel to the coast.

In the restinga, herbaceous vegetation plays an important role in stabilizing the substrate, preventing the action of erosive agents, and protecting sediments from the action of the wind. Shrub vegetation

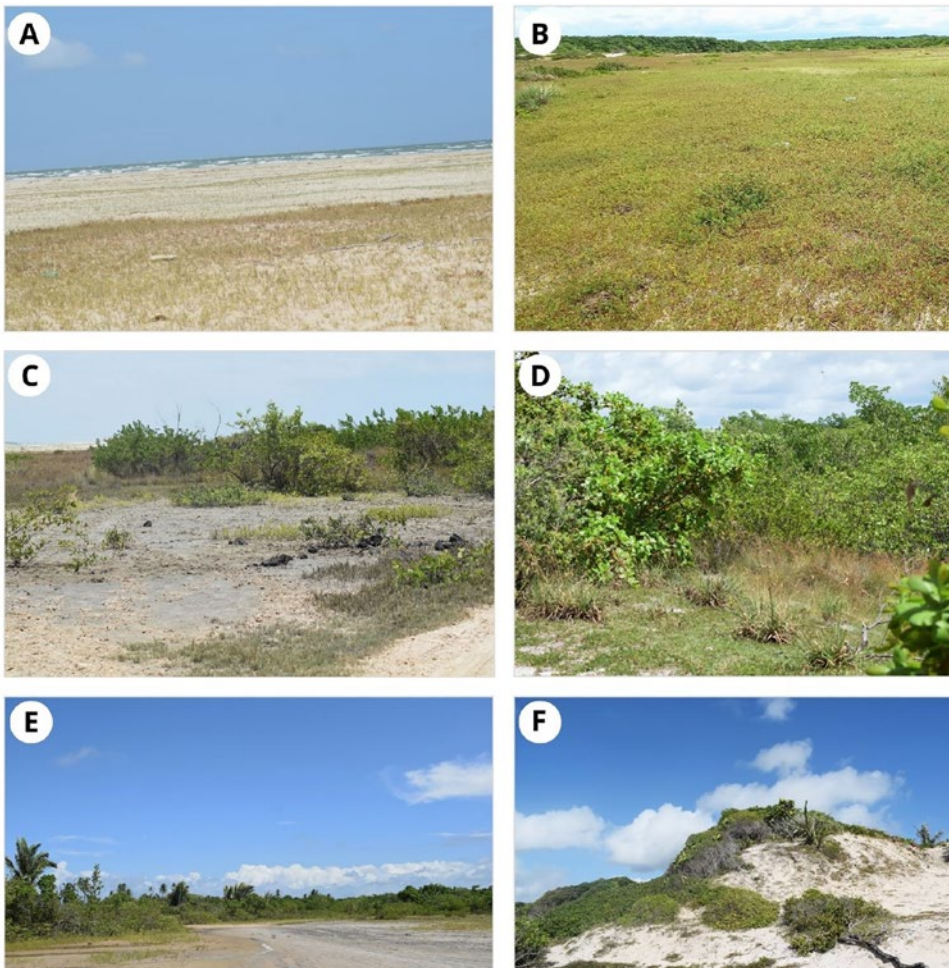


Figure 3. Phytophysiognomyes of the restinga of Araoca Beach, Guimarães, MA. a) Open, non-floodable fields in the dry period. b) Open fields that are not floodable during the rainy season. c) Open floodable fields close to mangroves, in the dry period. d) Open fruticete. e) Open floodable field, in a dry period. f) Dunes.

favors shading, greater availability of nutrients, humidity, and moderate temperatures. These conditions provided by the shrub layer contribute to plant diversity in the restinga (Assumpção & Nascimento 2000, Carvalho et al. 2018).

In the restinga of Araoca Beach, we observed dense herbaceous-shrub vegetation, physiognomies of unflooded open field, flooded open field (with halophytes), flooded closed shrubby vegetation, unflooded open shrubby vegetation. These physiognomies were also found in the works by Correia et al. (2020) and Lima & Almeida Jr (2018) for the restingas of Itatinga (in Alcântara) and Panaquatira (in São José de Ribamar).

It is important to note that the different physiognomies in restinga areas can occur irregularly in the more delimited strips, forming a mosaic-like configuration (Machado 2016). The existence of transition zones in the restinga regions of Maranhão contributes to the vegetation not having an easily recognizable identity, resulting in a mosaic of physiognomies (Castro et al. 2012, Machado 2016).

1.1. Herbaceous physiognomy

Araoca's herbaceous vegetation is predominantly composed of halophilous, psammophilous, and stoloniferous plants, extending above the mean high tide level. The species found in this vegetation are *Alternanthera brasiliana* (L.) Kuntze, *Alternanthera tenella* Colla, *Blutaparon portulacoides* (A.St.-Hil.) Mears, *Ipomoea imperati* (Vahl) Griseb., *Sesuvium portulacastrum*, *Utricularia simulans*, and *Sporobolus virginicus* (L.) Kunth, this latter being dominant. These herbaceous species are extremely adapted to the saline soil's lack of nutrients, high temperatures, and sand mobility.

The herbaceous plants found in the open fields are under a sandy cordon along the coast, locally known as Ponta de Atins (Figure 4). This area is made up of vegetation with upright and cespitose species, and it is possible to see sparse thickets of species commonly found in mangroves, such as, *Rhizophora mangle* L., located in small dune formations, against a sandy muddy strip close to the mangrove. Still in Ponta de Atins, on Araoca Beach, there is an area of flooded open field located at the back of the mangrove line, where halophyte and cespitose species are found, such as *Batis marítima* L., *Cyperus ligularis* L., *Cyperus polystachyos* Rottb., and *Eleocharis geniculata* (L.) Roem. & Schult.

The characterization of this physiognomy, the presence of reptant species and propagules typical of mangrove species in Maranhão is close to what Lima et al. (2017) described for the Panaquatira restinga, in São José de Ribamar, and Guterres et al. (2020) for the unflooded open field of Guia Beach, on São Luís Island. Still considering the herbaceous vegetation of Araoca Beach, in unflooded formations, the herbaceous vegetation is interspersed with sub-shrub and shrub formations, where species such as *Borreria verticillata*, *Conocarpus erectus* L., *Crotalaria*

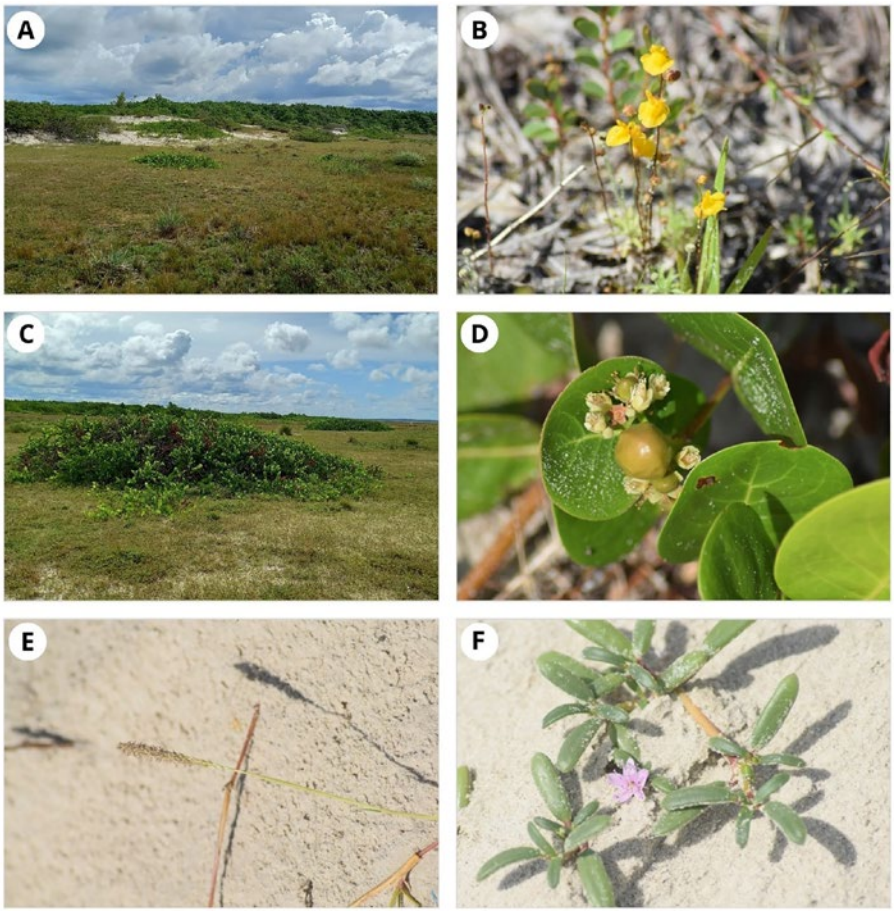


Figure 4. Restinga of Araoca Beach, Guimarães, MA. a) Ponta de Atins area, open field. b) *Utricularia simulans*, a herbaceous plant present in the open field area. c) Open field close to the mangrove area, presence of small dune formations and spaced thickets of mangrove species. d) *Chrysobalanus icaco* developing in the open field. e) S*porobolus virginicus* (Poaceae). f) *Sesuvium portulacastrum* (Aizoaceae).

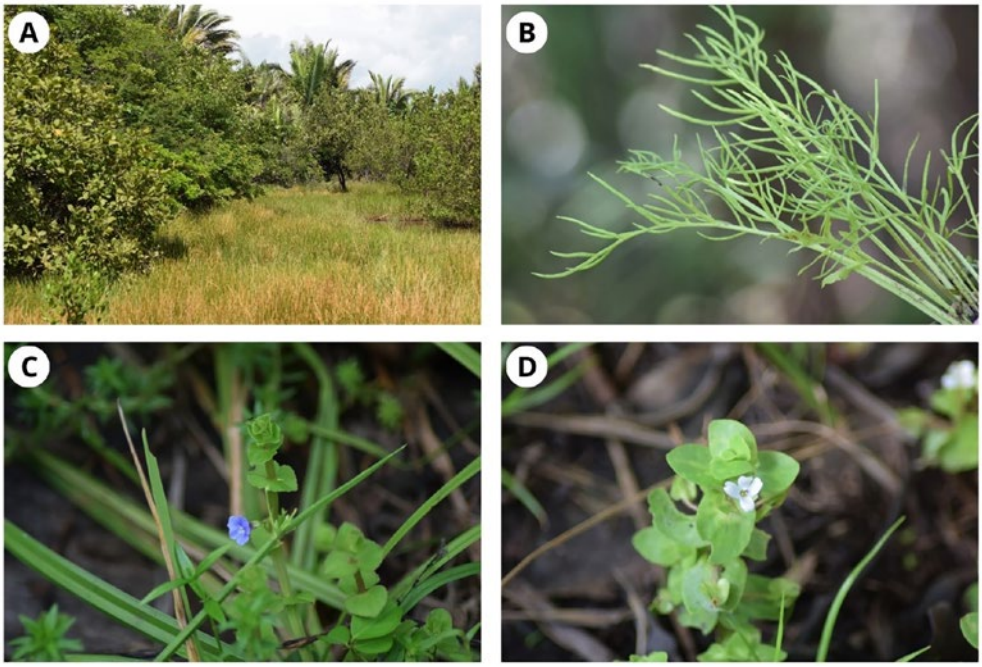


Figure 5. Restinga of Araoca Beach, Guimarães, MA. a) Phytophysiognomy of floodable closed fruticete. b) *Ceratopteris pteridoides* developing in a humid area with a closed fruticete. c) *Bacopa aubletiana* in herbaceous vegetation within a closed floodable fruticete. d) *Bacopa salzmannii* in a flooded environment with closed fruticete.

retusa, *Schultesia guianensis* (Aubl.) Malme, *Sida ciliaris* L., and *Turnera melochioides* are found.

As for the herbaceous-shrub physiognomy in the flooded closed field (Figure 5), small species predominate, such as *Axonopus capillaris* (Lam.) Chase, *Bacopa aquatica* Aubl., *Bacopa salzmannii* (Benth.) Wettst. ex Edwall, *Ceratopteris pteridoides*, *Lindernia crustacea* (L.) F.Muell., *Nepsera aquatica* (Aubl.) Naudin, *Xyris savanensis* Miq. This vegetation can be found in some stretches of marshy areas of post-beach vegetation, where there is a considerable concentration of organic matter in the soil resulting from the decomposition of leaves of shrub species such as *Anacardium occidentale*, *Cereus jamacaru* DC., and *Myrcia multiflora*, which form a favorable substrate for the establishment of these taxa.

In the Panaquatira restinga, Lima et al. (2017) categorized this set of herbaceous-shrub physiognomy in a closed flooded field as flooded closed shrubby vegetation, with *Anacardium occidentale* and *Lindernia crustacea* as one of the main shrubs and herbaceous representatives, respectively.

1.2. Shrub physiognomy

In Araoca sparse shrub thickets in different developmental stages are interspersed with open areas where herbaceous individuals are present or not, which characterizes the physiognomy of open shrubby vegetation. The vegetation is mainly composed of *Anacardium occidentale*, *Byrsonima crassifolia*, *Cenostigma bracteosum* (Tul.) Gagnon & G.P.Lewis, *Cordiera sessilis* (Vell.) Kuntze, *Chrysobalanus icaco*, *Myrcia guianensis*, *M. multiflora*, and *Solanum stramoniifolium* Jacq. Associated with this vegetation, sub-shrub species such as *Borreria verticillata*, *Mitracarpus strigosus* (Thunb.) P.L.R.Moraes, De Smedt & Hjertson, and *Crotalaria retusa* are highly abundant.

In the shrubby restinga, stretches with denser, closed vegetation can be found between sub-shrubby vegetation and sparse herbaceous vegetation. This shrubby vegetation (Figure 6) is located in a post-beach area with ecological characteristics that indicate flooding during rainy periods. Isolated, narrow strips of mangrove shrub species (*Avicennia schaueriana*, *Conocarpus erectus*, and *Rhizophora mangle*), as well as species associated with mangrove-restinga transition zones (*Chrysobalanus icaco*), are interspersed with dense herbaceous bands composed primarily of *Eleocharis interstincta* (Vahl) Roem. & Schult. In the same locality, this physiognomy gives way to less dense and more sparse bushes arranged in a strip of bare soil forming trails and cattle grazing areas modified by the constant anthropic action.

The physiognomy of unflooded open shrubby vegetation was also described for the restinga of Itatinga Beach, in the municipality of Alcântara. Correia et al. (2020) characterized the shrubby vegetation of Itatinga by spaced plants, mainly *Byrsonima crassifolia*, and areas of bare soil or with herbaceous vegetation such as *Crotalaria retusa* and *Cyperus ligularis*, as well as species of the genera *Zornia* and *Desmodium* (Fabaceae). Lima et al. (2017) described this same physiognomy for the Panaquatira restinga, which has *Byrsonima crassifolia* among the shrubs and the genera *Zornia* and *Desmodium* among the herbaceous. Shrub restingas can serve as ecological corridors for species in ecotonal environments and provide refuge and nursery areas (Serra et al. 2016, Costanza et al. 2017, Paiva & Almeida Jr et al. 2020).

1.3. Herbaceous-shrub physiognomy on the dune areas

The area of fixed dunes in the restinga of Araoca Beach (Figure 7) has a very diverse floristic composition compared to the herbaceous and shrubby vegetation found in the open fields of the Ponta de Atins

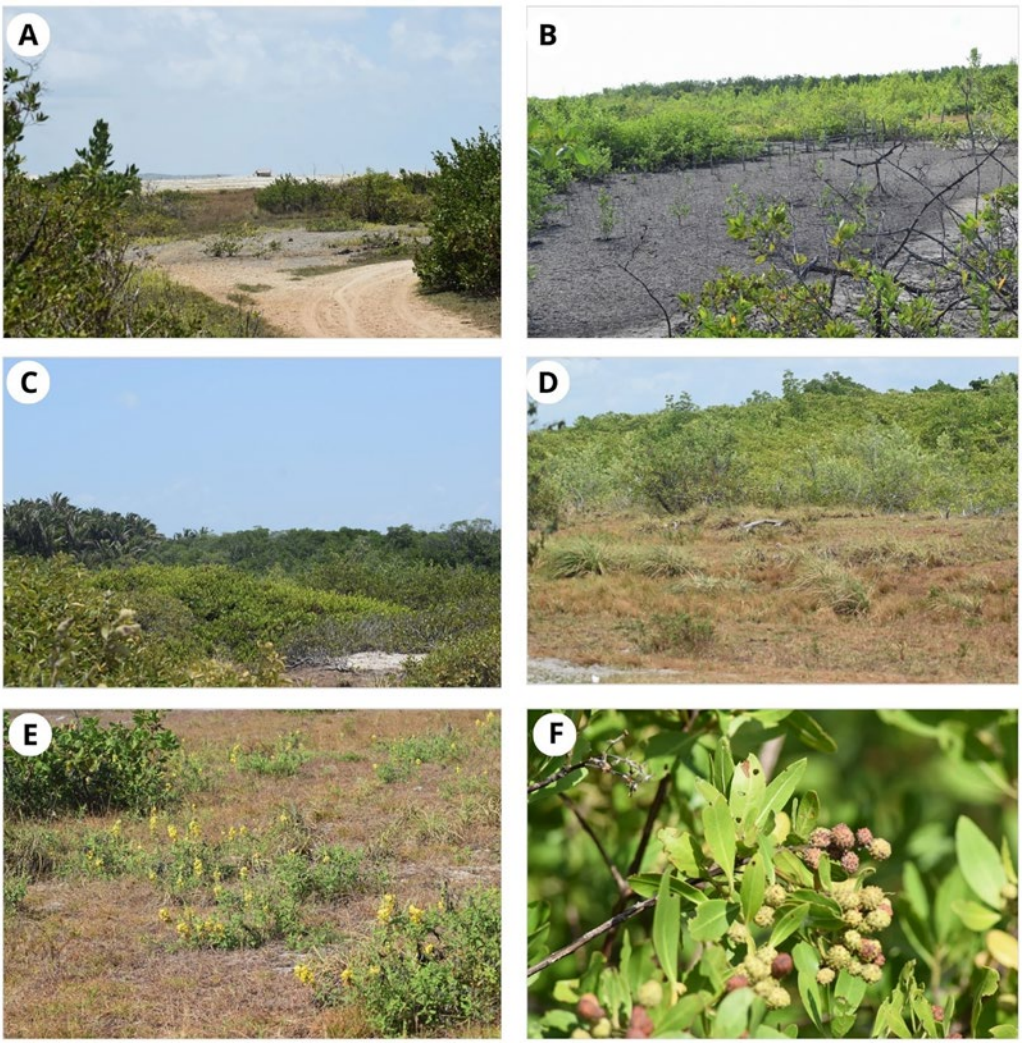


Figure 6. Restinga of Araoca Beach, Guimarães, MA. a) Phytophysiognomy of open fruit, with the presence of bare sandy soil. b) Fruticete composed of mangrove species, with a floodable area. c) Closed fruticete. d) Subshrub thickets of *Crotalaria retusa*. e) *Conocarpus erectus* (Combretaceae).

area. Shrubs dominate the dune physiognomy, with dense vegetation cover in the higher parts characterizing the closed shrubby vegetation.

The dunes have an herbaceous-shrubby vegetation rich in shrubs, herbaceous vines, lianas (woody vines), epiphytes, and halophilous and psammophilous herbs, extremely adapted to high insolation, nutrient scarcity, salinity, and sand mobility. The shrub vegetation is mostly made up of species from the Myrtaceae family (*Eugenia flavescens* DC., *E. punicifolia* (Kunth) DC., *Myrcia guianensis*, *M. multiflora*, *M. splendens* (Sw.) DC.), Rubiaceae (*Cordiera sessilis*, *Tocoyena sellowiana* (Cham. & Schltdl.) K.Schum., *Isertia hypoleuca* Benth.), Anacardiaceae (*Anacardium occidentale*), Chrysobalanaceae (*Chrysobalanus icaco*), Malpighiaceae (*Byrsonima crassifolia*), Sapindaceae (*Pseudima frutescens* (Aubl.) Radlk.), and Sapotaceae (*Manilkara bidentata* (A.DC.) A.Chev.).

Among the vines and lianas established in the dunes, we highlight species from the Passifloraceae (*Passiflora foetida* L., *P. subrotunda* Mast.), Fabaceae (*Abrus precatorius* L., *Centrosema brasilianum* (L.) Benth., *Clitoria falcata* Lam., *C. simplicifolia* (Kunth) Benth., *Entada polystachya* (L.) DC., *Galactia striata* (Jacq.) Urb.), Menispermaceae (*Odontocarya duckei* Barneby), and Vitaceae (*Cissus erosa* Rich.). Among the epiphytes, we found monilophytes such as *Lygodium venustum* (Lygodiaceae) and a species of Araceae (*Philodendron acutatum* Schott) in a denser area difficult to access.

Herbaceous plants from the Fabaceae family were found in a higher number, such as *Chamaecrista desvauxii* (Collad.) Killip, *C. diphylla*, C. *nictitans* (L.) Moench, *C. tenuisepala* (Benth.) H.S.Irwin & Barneby, *Stylosanthes angustifolia* Vogel, *Zornia brasiliensis* Vogel, *Z. guanipensis* Pittier, and *Z. latifolia* Sm. Herbaceous plants from the families Convolvulaceae (*Ipomoea imperati*), Turneraceae (*Turnera melochioides*), Boraginaceae (*Euploca polyphylla* (Lehm.) J.I.M.Melo & Semir), Eriocaulaceae (*Eriocaulon cinereum* R.Br.), and Malvaceae (*Sida ciliaris*) were also found in the lower dune areas. Among the families with the highest specific richness in this environment, Fabaceae and Rubiaceae also stood out in the study of the structural characterization and conservation status of the dunes of São Marcos Beach, in São Luís (Araujo et al. 2016).

Besides to the above-mentioned species, we also registered in Aroca Cactaceae (*Cereus jamacaru*) and Plumbaginaceae (the toxic

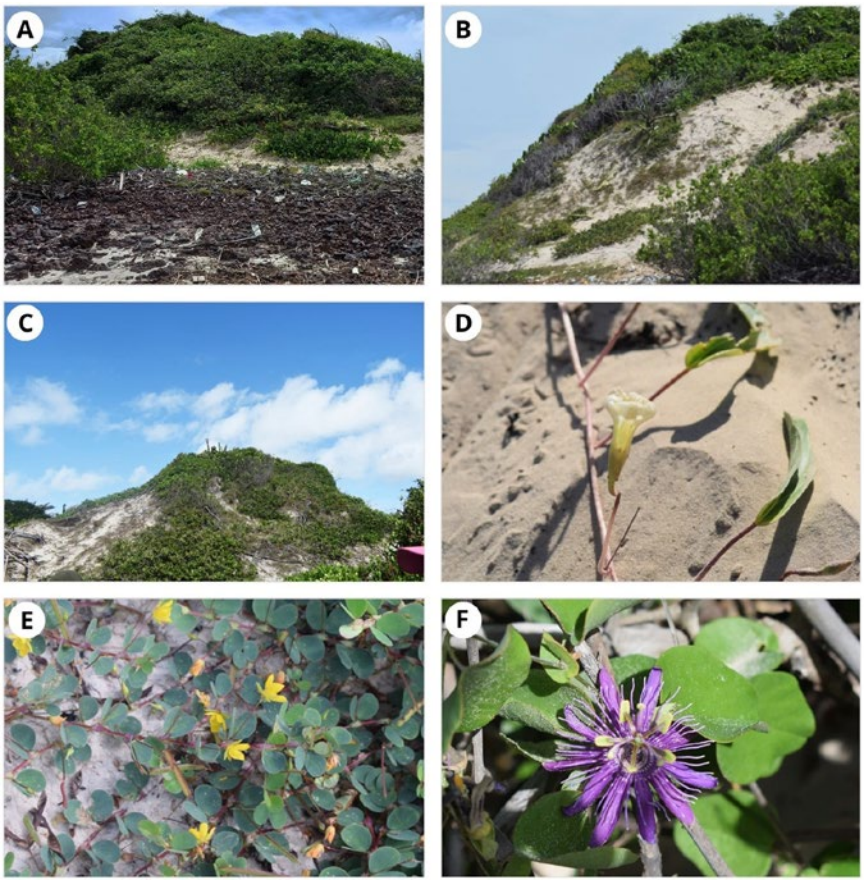


Figure 7. Restinga of Araoca Beach, Guimarães, MA. a) Dune formation in the Atins Area with rocky elements forming barriers in the lowest portion. b–c) Herbaceous-shrub phytophysiognomy of fixed dunes. d) *Ipomoea imperati* in dune areas. e) *Chamaecrista diphylla* in the lower strip of the dunes. f) *Passiflora subrotunda* in dune area.

and ornamental plant *Plumbago scandens* L.), this latter spread in the dunes through human action. We also identified a large amount of plastic, glass, and rubber waste (including packaging, bottles, and bags) in the dunes and surrounding areas. As dunes act as sediment stocks on the beach strip in erosive episodes (Amorim et al. 2023), this scenario represents a threat to the sedimentary dynamics. Paiva & Almeida Jr (2020) reinforced the role of dunes as a natural protection for the adjacent coastal zone.

The floristic survey of the dunes of São Marcos Beach carried out by Silva et al. (2016) listed the predominance of herbaceous species influenced by abiotic variables. Most of these herbaceous species have rhizome and stolon structures that play an important role in storing water and essential nutrients and reproduce asexually often via clonal reproduction, which facilitates their rapid growth and favors their effective occupation of the dune substrate (Seeliger 1998, Silva et al. 2016).

2. Floristic similarity

Based on our analysis, the floristic similarity between Araoca Beach and Guia Beach was 36.8%, with 45 species shared between the two areas: 21 herbaceous species in 13 families, 11 shrub species in 10 families, 9 sub-shrubs, 3 climbers, and 1 liana (Guterres et al. 2020). Fabaceae, Asteraceae, Lamiaceae, and Rubiaceae were the most common families in both areas. When comparing Panaquatira restinga with Araoca, the similarity was 40.1%, with 49 species (31 herbaceous) distributed in 25 families. *Utricularia simulans* should be highlighted, as it is one of the most widely distributed herbaceous plants in the Araoca restinga which was also present in Panaquatira.

In the comparison with the Itatinga restinga, 54 species were listed in common with Araoca, which represents a percentage similarity of 44.2%. This result was expected, considering the geographical proximity between the municipalities of Guimarães and Alcântara. Correia et al. (2020) listed 22 herbaceous species, 19 shrubs, 7 sub-shrubs, 4 vines, and 2 lianas in Araoca Beach within the physiognomies of unflooded open field, unflooded open shrubby vegetation, and unflooded closed shrubby vegetation.

The DCA analysis demonstrated the segregation of plant communities on Araoca beach in relation to other restinga areas on the DCA 1 axis (Eigenvalue= 0.4963). On the DCA 2 axis (Eigenvalue= 0.3588), Araoca beach has greater floristic proximity to Itatinga and Panaquatira beaches (Figure 8), which is in line with the similarity percentages observed.

Besides, climatic conditions and the biomes may also be significant factors influencing the levels of floristic similarity among the compared restinga areas (Rabelo et al. 2024). The Maranhão Amazon, located in a region characterized by a humid climate with little to no water deficiency (Martins & Oliveira 2011), contributes to the colonization

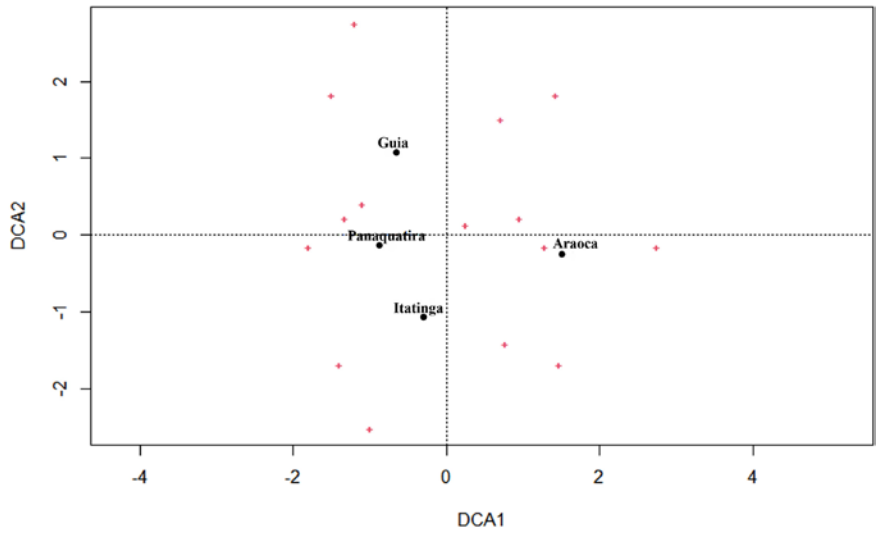


Figure 8. The results of the DCA analysis showed the following lengths of the two main axes: DCA1 = 2.5055 (eigenvalue = 0.4963) and DCA2 = 2.1326 (eigenvalue = 0.3588).

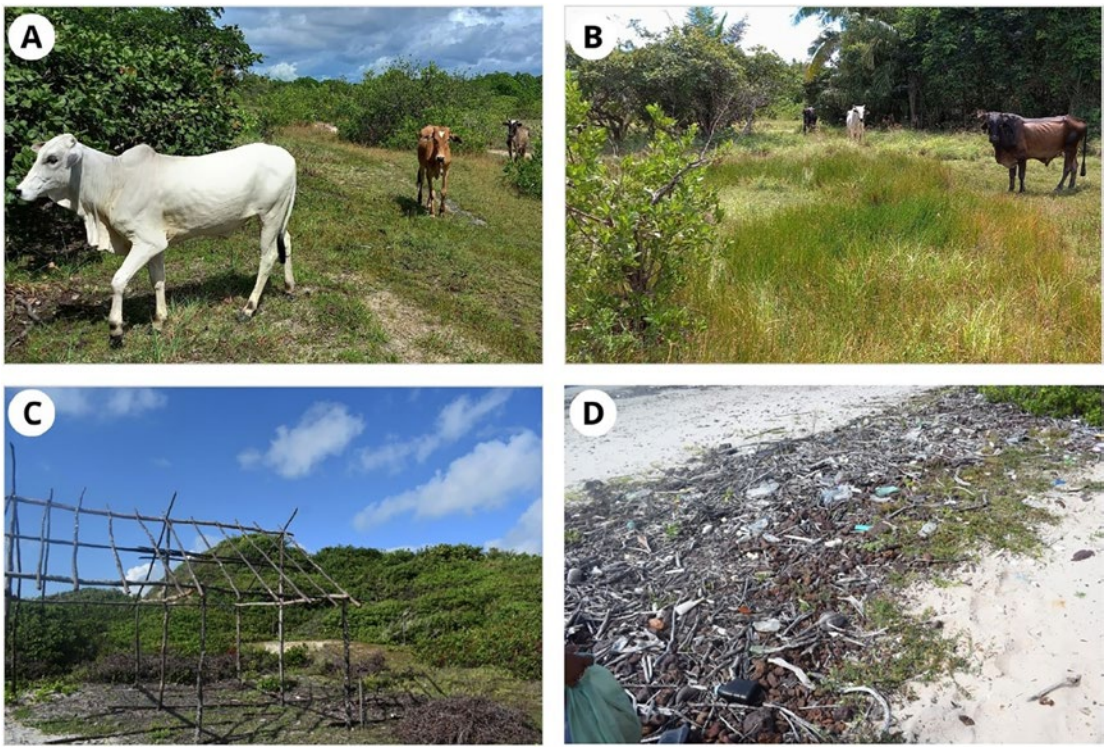


Figure 9. Records of environmental impacts on the restinga of Araoca Beach, Guimarães, MA. a–b) Cattle grazing in herbaceous and shrub fields. c) Burning in an area near the dunes for the construction of huts. d) Solid waste deposited on the lower strip of the dunes, with the growth of herbaceous species.

of the Maranhão coastal restingas by species from the Amazon biome (Serra et al. 2016, Lima & Almeida Jr. 2018).

3. Environmental impacts and restinga conservation

The resolutions of the National Environment Council (CONAMA) (No. 07/1996, No. 303/2002, and No. 417/2009) and the New Forest Code (Federal Law No. 12,651 of May 25, 2012) legitimize restingas as Permanent Protection Areas. Restingas provide ecological services that contribute to maintaining biodiversity (Darold & Irigaray 2018). Even so, the restinga is considered a fragile ecosystem, constantly threatened and degraded mainly due to unsustainable extractivism. Among the activities contributing to its degradation are illegal practices for sand extraction, expansion of agriculture, invasion of exotic species, and real estate speculation.

The different plant formations of the Araoca restinga are biologically rich, with important species in this ecosystem. The typical physiognomies are still in a good state of conservation. However, the

preservation of these environments is under threat due to the expansion of human activity. Fruit species play an important role in the permanence of the local fauna, especially insects, birds, and some mammals that have different patterns of habitat use.

Another significant anthropogenic impact identified in the dunes and surrounding areas is the accumulation of plastic, glass, and rubber waste, including packaging, bottles, and bags. This pollution poses a threat to the sediment dynamics of dune vegetation. During erosive events, dunes act as sediment reserves for beach areas (Amorim et al. 2023). Furthermore, Paiva & Almeida Jr. (2020) highlight the critical role of dunes as natural barriers that protect adjacent coastal zones.

In the study conducted by Guterres et al. (2019), signs of anthropogenic disturbance were identified related to the deposition of solid waste along the restinga vegetation near the urban perimeter of Caúra Beach, in São José de Ribamar. On the other hand, the dunes of Araoca Beach are located on the sandy ridge of Ponta dos Atins, a region parallel to the coast and far from urbanized areas. Although not close to urban centers, Ponta dos Atins is frequented by tourists and fishers, which contributes to the presence of debris across the open field. Most of the waste found on the slopes of the dunes is transported by tides, originating from areas affected by beach tourism and commercial activities.

Some areas of the original vegetation of the Araoca restinga have been devastated by the expansion of tourism-related urbanization, such as the construction of bars and chalets. Some areas of the original restinga vegetation in Araoca have been devastated to accommodate urban expansion related to tourism. The construction of bars and chalets serves as strong evidence of human interference in the Araoca Beach area. In the Atins region, fishing activities carried out by residents of the municipality of Guimarães, along with waste brought in by the tides, contribute to the accumulation of garbage in the area. The formation of trails indicates the removal of shrub species, while cattle grazing in the region leads to herbivory and trampling of key herbaceous-shrub species vital to the ecosystem. Additionally, the significant amount of litter left near the dunes highlights how tourism contributes to pollution, altering the dynamics and compromising the balance of this critical ecosystem (Figure 9).

Conclusion

Our floristic survey inventoried 122 herbaceous and shrub species in the restinga of Araoca Beach, enabling the characterization of the different phytophysiognomies present in the studied area, which were previously little known. Furthermore, the results highlight the need to conduct studies aimed at maintaining the plant diversity of the Reentrâncias Maranhenses EPA, directly contributing to its protection.

This is evident when considering that the Araoca Beach ecosystem is vulnerable to potential loss of plant biodiversity due to anthropogenic pressures, such as urbanization associated with tourism, improper waste disposal near the dunes, and the formation of trails and grazing areas for livestock. These activities compromise the dynamics and balance of the vegetation on Araoca Beach.

In light of this scenario, it is imperative to implement conservation measures and promote awareness to protect this unique ecosystem and its species. Actions such as waste control, proper tourism management, and the prevention of unplanned urban expansion are essential to ensure the survival and preservation of the rich biodiversity of Araoca Beach.

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Carmen Zickel

Author Contributions

José da Conceição Aguiar Penha: Conceptualization, Fieldwork, Specimen Identification; Manuscript Writing and Review.

Neuriane Pinheiro Ferreira Alves: Specimen Identification; Manuscript Writing and Review.

Mayara Silva Nunes: Fieldwork, Specimen Identification; Manuscript Writing and Review.

Maycon Jordan Costa da Silva: Manuscript Writing and Review.

Vitor Rafael Cardoso Neto: Manuscript Writing and Review.

Mateus César Araújo Pestana: Manuscript Writing and Review.

Alessandro Wagner Coelho Ferreira: Manuscript Writing and Review.

Raysa Valéria Carvalho Saraiva: Conceptualization, Fieldwork, Specimen Identification; Manuscript Writing and Review.

Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Ethics

This work was approved by the Biodiversity Authorization and Information System (SISBIO) of the Chico Mendes Institute for Biodiversity Conservation (ICMBio) under the number 84049-1.

Data Availability

The data collected and generated during this study are available in https://doi.org/10.48331/scielodata.WGB8VS.

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