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Flora and Woody Vegetation Structure in an Insular Area of *Restinga* in Brazil

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ABSTRACT

The coast of Piauí State, Brazil, extends for 66 km and both continental and insular areas are completely contained within the Parnaíba Delta Environmental Protection Area. The coastline there is dominated by quartz sands of the Quaternary period and soils derived from the Barreiras Formation (Tertiary period). The municipality of Ilha Grande (02°50'84"S / 41°47'39"W), located just off the coast, is covered by mangrove vegetation and "*restinga*" (sandy substrate, near shore vegetation). The present work sought to demonstrate the floristic richness of the *restinga* vegetation on Ilha Grande and compare its woody vegetation structure to other such areas in northeastern Brazil through floristic and phytosociological studies, elaborating vegetation profiles and performing chemical and physical analyses of the soils. Sixty-seven species were encountered (belonging to 31 botanical families) growing on sandy soils with high aluminum concentrations. Clumped shrubby vegetation predominated, that demonstrated slightly more than 50% similarity with other coastal continental *restinga* vegetation areas of Piauí State – although its composition was more similar to *restinga* sites in the northeastern region of Brazil than to geographically adjacent environments.

Key Words: Coastal Vegetation; Diversity; Northeastern; Phytosociology; Plant Diversity; Richness.

INTRODUCTION

Although the convoluted coast of Brazil extends for more than 9000 km, relatively few studies have been undertaken examining restinga (sandy substrate, near-shore vegetation) ecosystems, especially in the northeastern region of the country which has the longest coastline (Araujo 1984, Araujo 2000, Zickel et al. 2004) with beaches facing both East and North (Santos-Filho et al. 2013).

Restinga is a vegetation type found along the Brazilian coast that experiences marine influences and grows on Quaternary period soils (Cerqueira 2000, Marques et al. 2004, Rizzini 1997), showing significant species richness (Almeida Jr. et al. 2009, Santos-Filho et al. 2011, Santos-Filho et al. 2015, Zickel et al. 2004) and many different physiognomies (Santos-Filho et al. 2010, Silva and Britez 2005). *Restinga* is considered an extension of adjacent ecosystems, such as Atlantic Coastal Forest (Araujo 2000, Rizzini 1997, Scarano 2002), cerrado (neotropical savanna), or caatinga (thorny deciduous vegetation) (Freire, 1990), although little is currently known about its dynamics, its inter-relationships with neighboring vegetation communities, or its ecological processes (Zickel et al. 2004).

While phytosociological studies are basic to our understanding of the structural organizations of communities, recruitment and regeneration processes, and site occupation, relatively very few projects of this nature have been undertaken along the Brazilian coastline in light of its vast extension. Studies have been reported for the states of Alagoas (Medeiros et al. 2010), Bahia (Menezes et al. 2009, Menezes et al. 2012), Pernambuco (Almeida Jr. et al. 2011, Cantarelli et al. 2013, Vicente et al. 2003), Piauí (Santos-Filho et al. 2013), and Rio Grande do Norte (Almeida Jr. and Zickel 2012, Trindade 1991), and floristic studies have analyzed and compared the species richness of various restinga areas (Almeida Jr. et al. 2006, Almeida Jr. et al. 2009, Cantarelli et al. 2012, Freire 1990, Sacramento et al. 2007, Santos-Filho et al. 2013, Silva et al. 2008).

The coastline of Piauí State is quite small (only 66 km) and is completely included within the Delta do Parnaíba Environmental Protection Area, comprising many small bays and four estuaries (formed by the Parnaíba, Portinho, Camurupim, and Ubatuba/Timonha rivers) with predominately mangrove vegetation (Baptista 1981). These coastal continental and insular areas are dominated by two geological formations: quartz sand deposits from the Quaternary period that extend west to Maranhão State; and the Barreiras Formation (of the Tertiary period) that extends eastward to Ceará State (Sousa and Rodrigues-Neta 1996). More inland from the *restinga* vegetation in Piauí are mangrove swamps and flat upland areas (of quartzitic neosols) also derived from the Barreiras Formation (Fernandes et al. 1996).

A number of phytophysiological differences can be observed between different *restinga* formations, with extensive areas being occupied by shrub or forest formations (Santos-Filho et al. 2013). These physiognomic differences are probably due to edaphic factors, as these sites share otherwise similar geological and climatic conditions (Santos-Filho et al. 2010, Santos-Filho et al. 2013). The present study sought to examine the floristic richness of a *restinga* site situated on Ilha Grande along the coast of Piauí State, and compare the structure of its woody vegetation with other *restinga* areas in northeastern Brazil.

STUDY AREA

The study area was located in the municipality of Ilha Grande (02°50'84"S, 41°47'39"W) (Figure 1), in Piauí State, Brazil. The geology of the area is dominated by quartzitic sand deposits (Ministério de Minas e Energia, 2006). It has a mega-thermic tropical climate, with summer rainfall (Peel et al. 2007), a mean annual temperature of 27.5 ºC, with a median precipitation of 1223 mm/year with April having the most rainfall (mean precipitation of 297.3 mm/month) and September the least (mean precipitation of 2.8 mm/month) (classified as Aw by the Köppen system 1948).

Restinga vegetation covers the largest fluvial-marine island in the Parnaíba Delta, although it shows varying physiognomies, such as open field and shrub formations (Santos-Filho et al. 2010). Insular areas tend to demonstrate lower richness and biodiversity than continental sites, due to their generally reduced sizes and isolation from the mainland; small islands generally have limited resources and habitats, factors that also reduce biodiversity (Brown and Lomolino 2006).

According to the classification proposed by Silva and Britez (2005), the phytophysiognomy of the study area included open and closed herbaceous fields, with flooded and non-flooded areas, and flooded and non-flooded shrub vegetation. Fields bordered by carnauba palms are also present, as described by Santos-Filho et al. (2010).

METHODS

Collections and Sampling of Woody Vegetation

The woody vegetation was surveyed between 10/2006 and 10/2011 during monthly visits. Fertile plant material was collected along existing trails, as well as on new trails that were opened to increase the collection efficiency.

Botanical material was collected and identified using traditional methodologies of plant taxonomy (Mori et al. 1989), by consulting bibliographic resources (identification keys, original descriptions, and specialized bibliographies), by comparisons with herbarium materials, and through consultations with specialists. The plants were listed following the classification system of the *Angiosperm Phylogeny Group* III (2009), and their life forms classified according to Raunkiaer (1934), as adapted by Mueller-Dombois and Ellenberg (1974). The herborized specimens were incorporated into both the Dárdano de Andrade Lima Herbarium of the Instituto Agronômico de Pernambuco (IPA) and the Afrânio Fernandes Herbarium of the Universidade Estadual do Piauí (HAF).

Figure 1. Map indicating the location of the municipality of Ilha Grande along the coast of Piauí State, Brazil.

Phytosociology

The point-quadrant method was used in the phytosociological survey (Cottam and Curtis 1956), establishing five parallel transects in the area, each separated by 10 m. Ten points were established along each transect at 10 m intervals, totaling 50 points. The inclusion criterion was plants have stem diameters at soil level (DSL) ≥ 3cm. The transects were installed in an area with a minimum level of anthropogenic disturbances.

Vegetation Profile Diagrams

Profiles of the woody vegetation were prepared to illustrate the vertical structure of the study area, using Corel Draw 5.0 software. The profile considered a strip 50 m long by 2 m wide of representative areas of the transects, indicating individuals whose total heights were measured, with their respective identifications (Richards 1996).

Soil Collections and Analyses

Twenty-five soil samples were collected at depths of 20 cm (five samples from each transect, which were chosen at random from among 10 equidistant points along their lengths). The samples from each transect were then mixed according to the recommendations of Rocha et al. (2004), so that each transect was represented by a single composite soil sample. Two basic types of analyses were conducted: analysis of the physical properties of the soil (performed at the Soil Physical laboratory at the Federal Rural University of Pernambuco - UFRPE) to determine its texture and granulometry; and chemical analyses (performed at the Soil Fertility Laboratory at UFRPE) to determine the concentrations of the principal soil nutrients. Both the granulometric and chemical analyses were performed following the methodology of Embrapa (1997).

Statistical Analyses

The phytosociological parameters of basal area (AB), relative density (DR), relative dominance (DoR), relative frequency (FR), importance value (VI), cover value (VC), and the Shannon diversity index and Pielou equitability for the species were calculated using FITOPAC 2.1 software (Shepherd 2009).

Statistical tests were performed to determine the normality of the data and the standard errors of the physical and chemical analyses of the soil (using the Kolmogorov-Smirnov nonparametric test) (Zar 1996), run on SPSS 10.0 software for Windows (SPSS 2000). To evaluate the floristic similarities between the areas, a presence/absence matrix was constructed for multivariate analysis (Unweighted Pair Group Method using Arithmetic averages – UPGMA) and the Jaccard similarity index was calculated, using SPSS 10.0 software for Windows (SPSS 2000). The maximum similarity values were determined using RANDMAT 1.0 software; one thousand replications were used (a=1%) with the data derived from the different ecosystems, and 2000 replications (a=1%) with the data from other *restinga* areas in Piauí State. The comparative studies were performed between this study and the lists of species from other *restinga* areas (Santos-Filho et al. 2013), from *restinga* areas in northeastern Brazil (Almeida Jr. et al. 2009-PE, Andrade-Lima 1951-PE, Andrade-Lima 1979-PE, Cabral-Freire and Monteiro 1993-MA, Cantarelli et al. 2012-PE, Esteves 1980-AL, Matias and Nunes 2001-CE, Oliveira-Filho and Carvalho 1993-PB, Sacramento et al. 2007-PE, Silva et al. 2008-PE, Trindade 1991-RN), and from adjacent ecosystems: cerrado (neotropical savanna) (Costa 2005, Farias and Castro 2004, Mesquita and Castro 2007, Oliveira 2004), caatinga (thorny dryland vegetation) (Emperaire 1989, Lemos and Rodal 2002, Mendes 2003), and carrasco (deciduous vegetation not thorny) (Araujo et al. 1998, Chaves 2005), areas of Atlantic Forest (Barbosa 1996, Siqueira et al. 2001), and areas of Amazon Forest (Espírito-Santo et al. 2005) (as the out group).

RESULTS

Floristics

A total of 67 species belonging to 31 families were identified. The most representative families in terms of the numbers of species (53.7% of the total richness of the area) were: Fabaceae (15 spp.), Cyperaceae, Myrtaceae, Rubiaceae (4 spp. each), Euphorbiaceae, Malpighiaceae and Poaceae (3 spp. each) (Table 1).

The most representative life forms in this restinga site were: phanerophytes (Micro and nanophanerophytes -totaling 35%), Therophytes (32%), and hemicryptophytes and (12%) (Figure 2). This composition corresponds to a closed vegetation form, with differences in stratification. In spite of the fact that the area had a general shrubby physiognomy, vegetation clumps were scattered through the area, with agglomerations of certain species, principally *Anacardium occidentale*, *Byrsonima gardneriana*, *Mouriri pusa*, and *Ouratea fieldingiana*.

Phytosociology

A total of 200 individuals from 12 species were examined (Table 2). The family Myrtaceae had the greatest number of species (22.2%). Shooting (ramifications at soil level) was observed in 42% of the individuals sampled, with up to 26 shoots per plant.

Anacardium occidentale was the most important species in terms of community structure, showing the greatest relative density and dominance as well as the greatest VI and VC (Table 2). The species *Cereus jamacaru*, *Ouratea fieldingiana*, *Caesalpinia pyramidalis,* and *Byrsonima gardneriana*, together with *Anacardium occidentale* were responsible for 72% of the total VI (Table 2).

Considering the stem diameter distributions of the individuals sampled, the Ilha Grande restinga appears to

Table 1. Species list and their respective life forms in restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil.

Family/ Species	Life forms	Voucher
Amaranthaceae		
Blutaparon portulacoides (A. St.-Hil.) Mears	Therophytes	F.S.Santos-Filho (426)
Anacardiaceae		
Anacardium occidentale L.	Microphanerophytes	F.S.Santos-Filho (556)
Anacardium sp.	Microphanerophytes	F.S.Santos-Filho (962)
Apocynaceae		
Matelea maritima (Jacq.) Woodson	Creeper	F.S.Santos-Filho (540)
Arecaceae		
Astrocaryum vulgare Mart.	Microphanerophytes	F.S.Santos-Filho (636)
Copernicia prunifera (Mill.) H.E. Moore	Microphanerophytes	F.S.Santos-Filho (634)
Boraginaceae		
Heliotropium polyphyllum Lehm.	Chamaephytes	F.S.Santos-Filho (367)
Cactaceae		
Cereus jamacaru DC.	Nanophanerophytes	F.S.Santos-Filho (637)
Pilosocereus catingicola subsp. *salvadorensis* (Werderm.) Zappi	Nanophanerophytes	F.S.Santos-Filho (963)
Celastraceae		
Maytenus distichophylla Mart.	Microphanerophytes	F.S.Santos-Filho (401)
Convolvulaceae		
Ipomoea asarifolia(Desr.) Roem. & Schult.	Chamaephytes reptant	F.S.Santos-Filho (471)
Ipomoeaprocumbens Mart. & Choisy	Chamaephytes reptant	F.S.Santos-Filho (926)
Cucurbitaceae		
Ceratosanthes trifoliata Cogn.	Hemicryptophytes	F.S.Santos-Filho (379A)
Cyperaceae		
Bulbostylis scabra (Presl) C.B. Clarke	Hemicryptophytes	F.S.Santos-Filho (635)
Cyperus articulatus L.	Hemicryptophytes	F.S.Santos-Filho (604)
Eleocharisinterstincta (Vahl.) Roem. & Schult.	Hemicryptophytes	F.S.Santos-Filho (612)
Rhynchospora riparia (Nees) Boeck.	Hemicryptophytes	F.S.Santos-Filho (613)
Dilleniaceae		
Davilla cearensis Huber	Creeper	F.S.Santos-Filho (354)
Eriocaulaceae		
Leiothrix rufula (A. St.-Hil.) Ruhland	Hemicryptophytes	F.S.Santos-Filho (964)
Euphorbiaceae		
Chamaesyce hyssopifolia (L.) Small	Therophytes	F.S.Santos-Filho (473)
Cnidoscolus urens (L.) Arthur	Nanophanerophytes	F.S.Santos-Filho (632)
Croton glandulosus L.	Therophytes	F.S.Santos-Filho (440)
Fabaceae		
Abrus precatorius L.	Creeper	F.S.Santos-Filho (373)
Aeschynomenehistrix Poir.	Chamaephytes	F.S.Santos-Filho (605)
Aeschynomene biflora Fawc. & Rendle	Chamaephytes	F.S.Santos-Filho (620)
Alysicarpus vaginalis (L.) DC.	Therophytes	F.S.Santos-Filho (603)
Caesalpinia pyramidalis var. *diversifolia* Benth.	Microphanerophytes	F.S.Santos-Filho (360)
Camptosema paraguariense (Chodat & Hassl.) Hassl.	Therophytes	F.S.Santos-Filho (618)
Chamaecristaracemosa (Vogel) H.S. Irwin & Barneby	Therophytes	F.S.Santos-Filho (371)
Chamaecrista ramosa (Vogel) H.S. Irwin & Barneby	Therophytes	F.S.Santos-Filho (392)
Copaiferamartii Hayne	Microphanerophytes	F.S.Santos-Filho (374)
Galactia striata (Jacq.) Urb	Creeper	F.S.Santos-Filho (534)
Indigofera microcarpa Desv.	Therophytes	F.S.Santos-Filho (610)
Senna gardneri (Benth.) H.S. Irwin & Barneby	Chamaephytes	F.S.Santos-Filho (592)
Tephrosia cinerea (L.) Pers.	Microphanerophytes	F.S.Santos-Filho (446)
Vignapeduncularis (Kunth) Fawc. & Rendle	Hemicryptophytes	F.S.Santos-Filho (553)
Zornia sericea Moric.	Therophytes	F.S.Santos-Filho (461)

Table 1. Continued

Family/ Species	Life forms	Voucher
Iridaceae		
Neomarica sp.	Geophytes	F.S.Santos-Filho (965)
Lauraceae		
Cassytha filiformis L.	Parasite	F.S.Santos-Filho (390)
Loranthaceae		
Psittacanthus robustus(Mart.) Mart.	Parasite	F.S.Santos-Filho (366)
Malpighiaceae		
Byrsonima gardneriana A.Juss.	Microphanerophytes	F.S.Santos-Filho (368)
Byrsonima intermedia A. Juss.	Microphanerophytes	F.S.Santos-Filho (364)
Byrsonima orbignyana A. Juss.	Microphanerophytes	F.S.Santos-Filho (445)
Melastomataceae		
*Mouriri pusa*Gardner ex Gardner	Microphanerophytes	F.S.Santos-Filho (369)
Pterolepis glomerata (Rottb.) Miq.	Therophytes	F.S.Santos-Filho (966)
Menyanthaceae		
Nymphoides indica (L.) Kuntze	Cryptophytes	F.S.Santos-Filho (933)
Myrtaceae		
Campomanesia aromatica (Aubl.) Griseb.	Nanophanerophytes	F.S.Santos-Filho (399)
Eugenia punicifolia (Kunth.) DC.	Nanophanerophytes	F.S.Santos-Filho (527)
Myrcia multiflora (Lam.) DC.	Nanophanerophytes	F.S.Santos-Filho (382)
Myrcia splendens (Sw.) DC.	Nanophanerophytes	F.S.Santos-Filho (595)
Ochnaceae		
Ourateafieldingiana (Gardner) Engl.	Microphanerophytes	F.S.Santos-Filho (365)
Onagraceae		
Ludwigia hyssopifolia (G. Don) Exell.	Therophytes	F.S.Santos-Filho (642)
Poaceae		
Aristidasetifolia Kunth	Therophytes	F.S.Santos-Filho (674)
Paspalum maritimum Trin.	Therophytes	F.S.Santos-Filho (938)
Urochloa fasciculata (Sw.) Webster	Therophytes	F.S.Santos-Filho (836)
Polygalaceae		
Polygala dusenii Norl.	Therophytes	F.S.Santos-Filho (623)
Polygala monticola Kunth	Therophytes	F.S.Santos-Filho (614)
Portulacaceae		
Portulaca umbraticola Kunth	Therophytes	F.S.Santos-Filho (429)
Rubiaceae		
Borreria verticillata (L.) G. Mey.	Therophytes	F.S.Santos-Filho (968)
Chiococca alba (L.) Hitchc	Nanophanerophytes	F.S.Santos-Filho (967)
Mitracarpus frigidus (Willd. ex Roem. & Schult.) K. Schum.)	Therophytes	F.S.Santos-Filho (621)
Richardia grandiflora (Cham. & Schltdl.) Steud.	Therophytes	F.S.Santos-Filho (358)
Sapotaceae		
Manilkara cavalcantei Pires & W.A. Rodrigues ex T.D. Penn.	Microphanerophytes	F.S.Santos-Filho (955)
Manilkara triflora (Allemão) Monach.	Microphanerophytes	F.S.Santos-Filho (645)
Solanaceae		
Solanum crinitum Lam.	Nanophanerophytes	F.S.Santos-Filho (601)
Turneraceae		
Turneraserrata Vell.	Therophytes	F.S.Santos-Filho (441)
Xyrydaceae		
Xyris sp.	Hemicryptophytes	F.S.Santos-Filho (969)

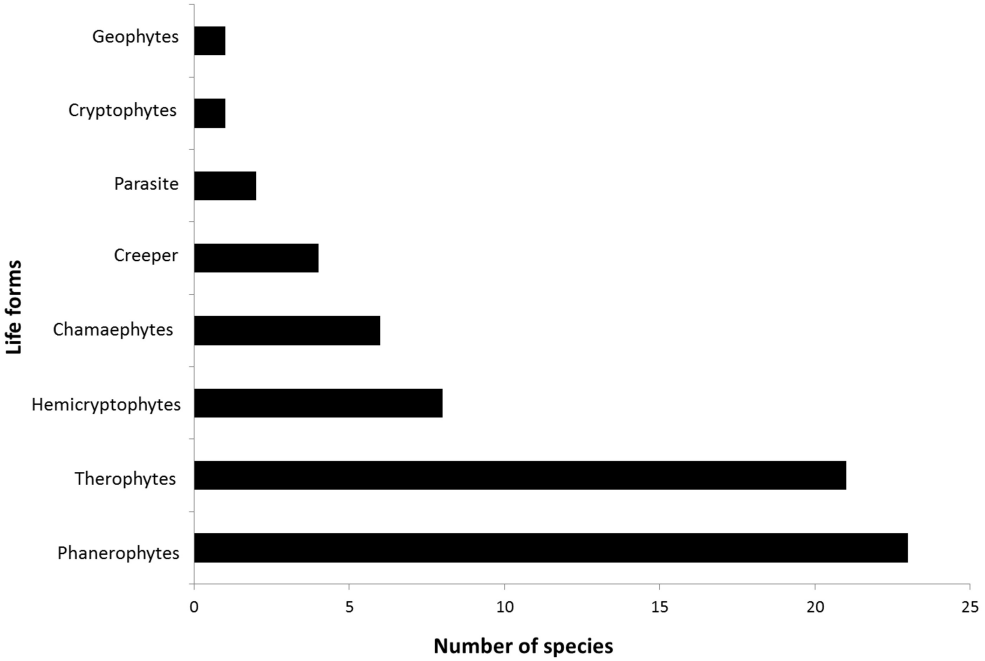

Figure 2. Species distributions according to their life forms in restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil.

Table 2. Phytosociological parameters of the species recorded in restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil. N- Number of individuals; RD- Relative Density; RDo- Relative Dominance; FR- Relative Frequency; IV- importance value; CV- coverage value; BA- basal area.

Species	N	RD	RDo	RF	IV	CV	BA
Anacardium occidentale L.	38	19.0	29.1	16.55	21.55	24.06	0.481
Astrocaryum vulgare Mart.	3	1.5	3.39	2.07	2.32	2.44	0.056
Byrsonima gardneriana A. Juss.	22	11.0	3.85	11.03	8.63	7.43	0.064
Caesalpinia pyramidalis Benth.	20	10.0	6.23	10.34	8.86	8.11	0.103
Campomanesia aromatica (Aubl.) Griseb.	7	3.5	1.67	3.45	2.87	2.58	0.028
Cereus jamacaru DC.	29	14.5	25.33	15.86	18.56	19.92	0.419
Copaifera martii Hayne	11	5.5	3.75	6.21	5.15	4.62	0.062
Eugenia punicifolia (Kunth) DC.	11	5.5	6.62	5.52	5.88	6.06	0.109
Maytenus distichophylla Mart.	10	5.0	1.88	4.14	3.67	3.44	0.031
Mouriripusa Gardner	1	0.5	0.07	0.69	0.42	0.28	0.001
Myrcia splendens (Sw.) DC.	13	6.50	9.31	6.90	7.57	7.90	0.154
Ouratea fieldingiana (Gardner) Engl.	35	17.5	8.82	17.24	14.52	13.16	0.146

be composed mainly of young individuals – as the diameter plot took on the form of an inverted “J”, with most of the individuals (85%) in the first diameter class (3-13 cm) (Figure 3). These individuals tend to group together, forming a woody plant community that can be characterized as "clumped".

In terms of plant heights, approximately 56% of the individuals were represented in the second height class, between 1.1 and 2 m (Figure 4) – resulting in an overall low phytophysiognomy. Only three individuals (1.5%) had heights between 3.1 and 4 m.

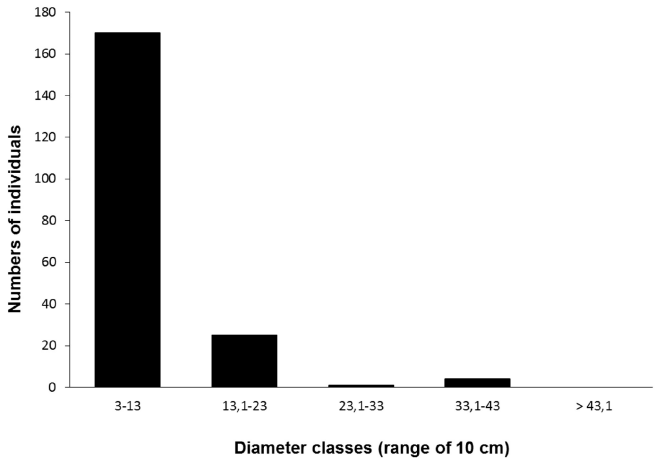

Figure 3. Distributions of individuals into diameter classes in restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil.

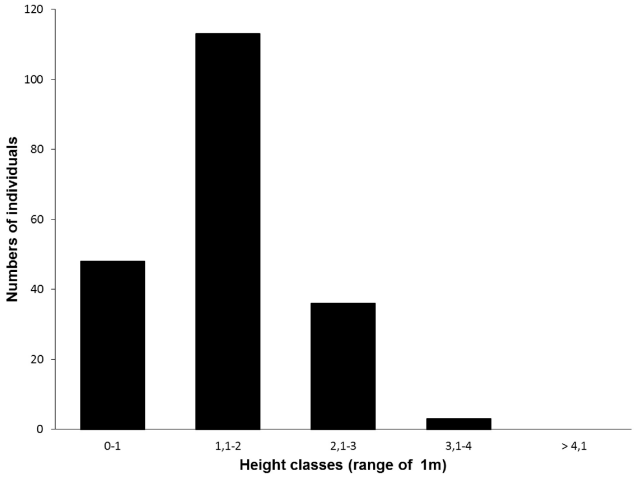

Figure 4 . Distributions of individuals into heights classes in restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil.

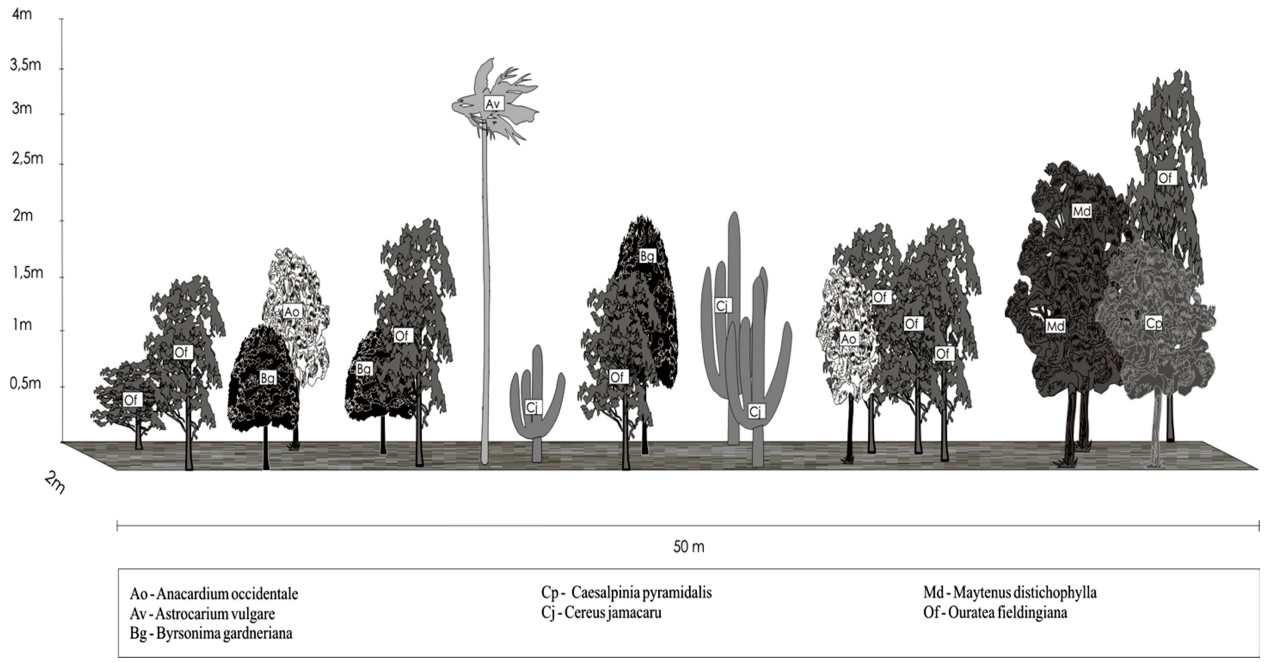

Figure 5. Profile of the shrub physiognomy of the restinga vegetation in the municipality of Ilha Grande along the coast of Piauí State, Brazil.

The physiognomic profile (Figure 5) presents the structure of the *restinga* area studied here, with low heights and limited diameters. The Shannon diversity index (H') and Pielou equitability (J) were 2.22 nat.ind^{-1} and 0.896 respectively.

Soil Analyses

Physical and chemical analyses (Table 3) indicated that the soils in the study area were typical of *restinga* sites, with a predominance of sand with low nutrient levels, including: the presence of aluminum, high acidity, and little organic matter. Analysis of variance demonstrated significant differences between all of the nutrient levels encountered in the research area and those in two other neighboring *restinga* sites – except in terms of K^+.

Table 3. Chemical and textural variables of surface soil samples (0 – 20 cm depth) collected randomly among the transects of three restinga areas within the Delta do Parnaíba Environmental Protection Area, along the coast of Piauí State, Brazil.

Variablesofsoil	ANOVAS F	(p)	Area I: Ilha Grande N=5	Area II: Parnaíba N=5	Area III: Luiz Correia N=5
pH in H_2O	170,022	0,0000	5,62 ± 0,228	6,18 ± 0,192	8,34 ± 0,305
P (mg/dm^3)	36,662	0,0000	4,00 ± 0,71	6,80 ± 2,59	15,2 ± 2,59
Na^+ ($cmol_c/dm^3$)	46, 71	0,0000	0,034± 0,005	0,058 ± 0,008	0,012 ± 0,008
K^+ ($cmol_c/dm^3$)	3,323	0,007^{ns}	0,03 ± 0,012	0,042 ± 0,018	0,054 ± 0,013
$Ca^{2+} + Mg^{2+}$ ($cmol_c/dm^3$)	47,31	0,0000	0,61 ± 0,096	3,01 ± 0,799	4,19 ± 0,639
Ca^{2+} ($cmol_c/dm^3$)	44,33	0,0000	0,14 ± 0,21	2,12 ± 0,688	3,05 ± 0,481
Al^{3-} ($cmol_c/dm^3$)	-	-	0,23 ± 0,067	0,00	0,00
H + Al (valor m) ($cmol_c/dm^3$)	69,34	0,0000	2,17 ± 0,062	2,062 ± 0,071	1,69 ± 0,067
C.T.C. ($cmol_c/dm^3$)	32,2	0,0001	2,84 ± 0,074	5,17 ± 0,853	5,95 ± 0,696
C (g/kg)	10,1	0,003	2,56 ± 0,492	5,73 ± 1,529	3,28 ± 1,24
M.O. (g/kg)	10,09	0,003	4,41 ± 0,85	9,88 ± 2,637	5,66 ± 2,13
Sand (%)	-	-	97,1	93,3 ± 0,91	95,7 ± 1,342
Clay (%)	-	-	2,9	4,6 ± 0,89	3,7 ± 0,837
Silt (%)	-	-	0,0	2,1 ± 0,22	0,40 ± 0,548
Textural classification	-	-	Sandy	Sandy	Sandy

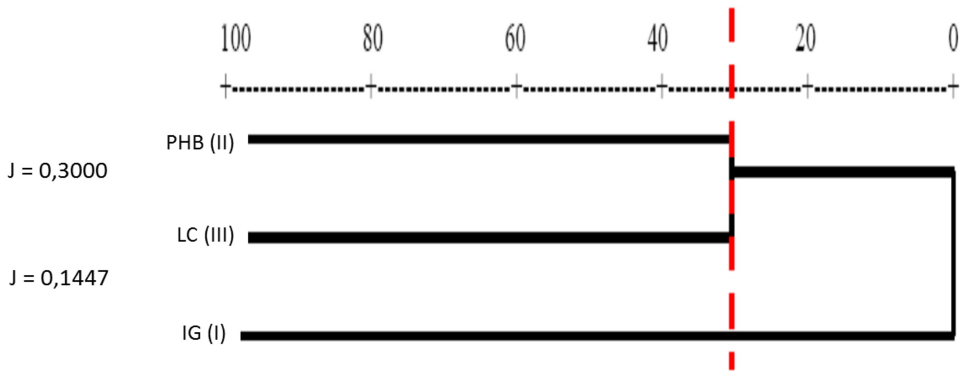

Figure 6. Dendrogram of the hierarchical analyses of the floral groups of the restinga of the Delta do Parnaíba Environmental Protection Area, Piauí State, Brazil. Jaccard similarity index = 0.30; a=1%; 2000 replications. Legend: IG (Ilha Grande), LC (Luiz Correia), PHB (Parnaíba); dotted vertical line – minimum similarity value. \

Floristic Similarity

The study area was located on a fluvial-marine island, but the floristic analysis demonstrated that its species assemblage was similar to neighboring mainland *restinga* areas along the coast of Piauí State (Figures 6 and 7 – Clade A).

Comparisons with adjacent ecosystems and other *restinga* areas in northeastern Brazil (Figure 7) indicated that the Ilha Grande *restinga* (clade A) had the greatest affinity with *restinga* areas in the states of Ceará and Maranhão (clade B); *restinga* sites in Piauí State likewise grouped with other *restinga* areas (clade C), but were separated from adjacent ecosystems - for example, caatinga (clade D). The adjacent ecosystems (caatinga, cerrado) grouped into clade D, reflecting their floristic similarities (although they were distinctly separate within this overall hierarchy).

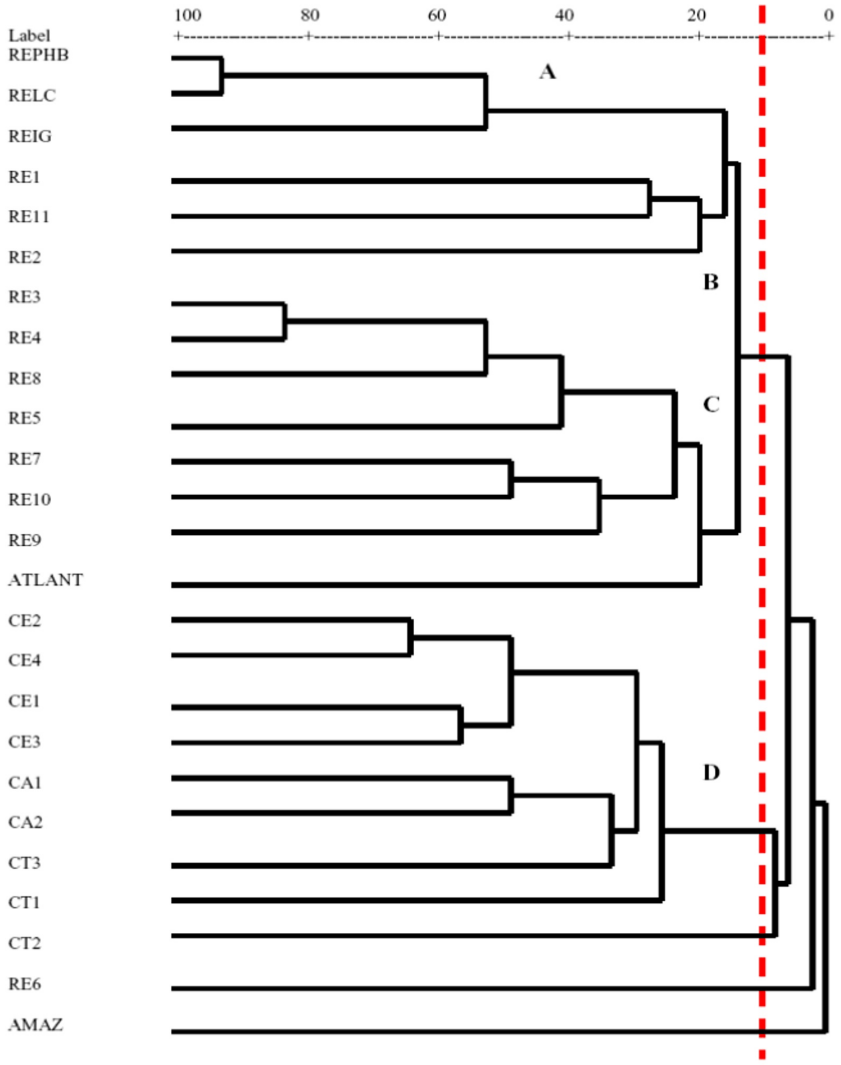

Figure 7. Dendrogram of the hierarchical analyses of groups, comparing areas of cerrado, caatinga, carrasco, Atlantic forest, Amazon forest, northeastern restinga areas, and the restinga of the Delta do Parnaíba Environmental Protection Area, Piauí State, Brazil. Jaccard similarity index = 0.10; a=1%; 1000 replications. Legend: CE1 (Cerrado - Complexo Campo Maior- PI), CE2 (Cerrado - Castelo do Piauí- PI), CE3 (Cerrado - Parque Nacional de Sete Cidades- PI), CE4 (Cerrado - Parque Nacional de Sete Cidades- PI), CA1 (Carrasco - Novo Oriente- CE), CA2 (Carrasco - Cocal- PI), CT1 (Caatinga - São José do Piauí- PI), CT2 (Caatinga - Serra da Capivara National Park- PI), CT3 (Caatinga - Serra da Capivara National Park- PI), ATLANT (Atlantic forest – Mata do Zumbi- PE; Mata do Buraquinho- PB), AMAZ (Amazon forest - Tapajós National Forest- PA), RE1 (Restinga - Jericoacoara- CE), RE2 (Restinga - São Luís- MA), RE3 (Restinga - Guadalupe- PE), RE4 (Restinga - Ariquindá- PE), RE5 (Restinga - Praia do Paiva- PE), RE6 (Restinga - Praia de Boa Viagem- PE), RE7 (Restinga - Janga-Maranguape- PE), RE8 (Restinga - Serrambi- PE), RE9 (Restinga - Parque das Dunas- RN), RE10 (Restinga - Mataraca- PB), RE11 (Restinga - Maceió-AL), REPHB (Restinga – Parnaíba- PI), RELC (Restinga - Luiz Correia- PI), REIG (Restinga - Ilha Grande- PI); dotted vertical stripe – minimum similarity value.

DISCUSSION

Floristics

The plant families found along the coast of Piauí State were also encountered in regional *restinga* areas (Almeida Jr. et al. 2009, Cantarelli et al. 2012, Silva et al. 2008) in environments with distinct characteristics, including a paucity of nutrients and available water, dune mobility (due to constant onshore winds), and high light intensities (Dillenburg et al. 1992).

In light of these varying environmental factors, the plants growing there demonstrate distinct physical characteristics, such as low heights (Waechter 1985) and

numerous stem shoots (Dunphy et al. 2000, Sá 1992), in addition to the intrinsic characteristics of their respective families, such as their life forms (Fabaceae), ecological preferences (Myrtaceae), and maintenance, defense, and reproductive structures (Cyperaceae and Poaceae) (Almeida Jr. et al. 2009).

The physiognomy of the *restinga* vegetation on Ilha Grande is worthy of note, with vegetation clumps intercalated with barren soils (sand), herbaceous vegetation, and/or subshrubs – a physiognomy which was also reported for northern Bahia State (Menezes et al. 2009, Santos 2013) or Espírito Santo and Rio de Janeiro (Araujo et al. 1998, Zaluar and Scarano 2000) demonstrating the importance of conserving this area due to its species richness and unique physiognomy in relation to other areas of *restinga* in northeastern Brazil.

Phytosociology

The restinga of the Ilha Grande has a predominant shrubby structure, non-flooded, with the shrub vegetation growing in clumps. The specie *Anacardium occidentale*, which demonstrated the greatest VI, density and relative dominance, was also encountered by Vicente et al. (2003) in the restinga of Tamandaré on the southern coast of Pernambuco State. According to these authors, the high density of *Anacardium occidentale* in that area is associated with the economic value of their fruits. That which assures the survival of this species in relation to other plants deemed less important by local human inhabitants. The family Myrtaceae is consistently well represented in *restinga* areas in northeastern Brazil, as has been cited in many structural studies (Almeida Jr. et al. 2011, Almeida Jr. and Zickel 2012, Medeiros et al. 2010, Santos-Filho et al. 2013).

The biometric evaluations demonstrated the greatest concentration of individuals in the <13 cm diameter size class, indicating that the plants in this area are represented by individuals in their younger phases – suggesting a regular distribution of individuals and/or continual recruitment (Peixoto et al. 2005). In relation to plant size, the relatively low heights of the plants in the study area was similarly observed in areas of shrub vegetation analyzed by Cantarelli et al. (2013) and Silva et al. (2008), both in Pernambuco State, although the individuals in the latter sites grow up to 3 to 4 m. The combination of narrow stem diameters and low plant heights give the *restinga* vegetation of Ilha Grande a very distinct dwarf appearance, especially in light of the presence of numerous other naturally small species.

The Ilha Grande *restinga* demonstrated a diversity value (H' 2.22 nat.ind^{-1}) similar to values encountered in other *restinga* areas in northeastern Brazil (Ariquindá-PE with 2.85 nat.ind^{-1} - Vicente et al. 2003, Guadalupe-PE with 2.64 nat.ind^{-1} - Cantarelli et al. 2013, and Pipa-RN with 2.76 nat.ind^{-1} - Almeida Jr. and Zickel 2012). This value was, however, lower than in studies undertaken by Almeida Jr. et al. (2011) – 3.5 nat.ind^{-1} and Medeiros et al. (2010) – 3.33 nat.ind^{-1}, although their distinct environmental conditions (poor soils, high light intensities, strong winds, and other factors) and the historical use of *restinga* ecosystems by human populations must be taken into consideration to avoid underestimating the importance of these areas in terms of their conservation value.

Low biodiversity indices are seen in surveys of areas having many individuals of the same species and many species with widely varying numbers of species (Felfili and Rezende 2003, Kent and Coker 1994) – usually related to the poor nutrient levels of the soils, acidity, the presence of aluminum, and periodic flooded (Sugiyama 1998).

Edaphic Characteristics

The compositions of the soil samples collected on Ilha Grande did not vary greatly, consistently showing 97.1% sand, 2.9% clay, and 0% silt. Textural analyses confirmed that the soils were sandy and corroborated their geological classification (Ministério de Minas e Energia 2006). Analyses performed in other *restinga* areas likewise indicated the predominance of sandy soils. Gomes et al. (1998), for example, analyzed seven different *restinga* sites and collected soil samples at different depths. The mean percentage of sand reported by these authors at depths up to 20 cm was 96%. Sand contents for *restinga* areas in northeastern Brazil vary from 90.3% (in non-flooded forests) to 98% (in non-flooded grassland) (Sacramento et al. 2007).

The soils on Ilha Grande demonstrated higher levels of acidity and lesser concentrations of nutrients than samples collected from neighboring *restinga* areas (Santos-Filho et al. 2013). These samples had high aluminum contents and low levels of calcium, indicating that the plants growing there would encounter difficulty in absorbing water and nutrients, and would generate only superficial root systems (Casagrande 2003) – with expressive numbers of herbaceous species. Similar aluminum values were encountered in restingas at Carapebus - RJ, where herbaceous species predominated

(grasslands formations) (Henriques et al. 1986). Additionally, aluminum causes phosphorus to precipitate in the form of aluminum phosphates that are generally insoluble, generating phosphorus deficiencies in plants (Sutcliffe and Baker 1989) that will retard their growth.

Floristic Similarities

The floristic similarities between the *restinga* area studied here and other *restinga* sites along the coasts of the states of Piauí (Luiz Correia and Parnaíba), Ceará, and Maranhão, confirm the expected tendency of *restingas* along the northern coast of northeastern Brazil to be composed of dune- colonizing species in areas with similar edaphic/climatic conditions.

Similarities were noted between the restingas along the eastern coast of northeastern Brazil and areas of Atlantic Forest (links between Clades A and B and between the sister groups A-B and clade C), demonstrating a disjunction (Clade D) out of the level of similarity. This result contradicts the hypothesis that restingas receive greater floristic contributions from neighboring ecosystems (Scarano 2002). According to Araujo (2000), the restinga of southeastern Brazil have stronger similarity with geographically close áreas, when considering the effective dispersion of propagules.

According to the model proposed by MacArthur and Wilson (1967), island diversity is generally inferior to that of continental environments due to factors such as total area and the opposing tendencies of extinction and immigration. The environment on Ilha Grande is greatly influenced by the dynamics of shifting dunes that interfere with successional processes (Jimenez et al. 1999). This phenomenon likewise occurs along the coasts of the states of Maranhão, Piauí, and Ceará, due to the action of winds that dislocate enormous quantities of sand, create dunes, and modifying the coastal geomorphology (Marques et al. 2004). This of course establishes a disequilibrium (Drake et al. 2002, MacArthur and Wilson 1967), due to the actions of geological and climatological events within the same timescale as immigration and extinction events – thus modifying the floristic composition of island areas.

CONCLUSIONS

Based on these results, it can be concluded that the conservation of the floristic richness of *restinga* areas should be considered in light of the peculiarities of these coastal zones and the strong anthropogenic pressures that bear upon them. It should also be noted that the study area represents an important remnant of the original coastal vegetation of Piauí State, with the occurrence of species with restricted distributions (*Caesalpinia pyramidalis, Pilosocereus catingicola* subsp. *salvadorensis*) with great ecological values for areas of caatinga and the restinga vegetation the Piauí State.

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