International Journal of Plant & Soil Science

20(4): 1-11, 2017; Article no.IJPSS.37998
ISSN: 2320-7035

Influence of Soil Fertility on Herbaceous Community Structure in Dunes and Swamps of the Coastal Plain of Laguna, South Brazil: An Ecological Approach

J. C. F. Melo-Júnior[1*], S. S. Dornelles[1], A. D. Viana[2], A. A. Ribeiro[2], A. M. Ruthes[2], A. Aviz[2], B. C. Fernandes[2], B. C. Reginato[2], B. L. Duarte[2], C. I. Telles[2], D. G. Mayer[2], G. Teixeira[2], G. H. D' Ambrósio[2], G. Lamin[2], G. M. Castilho[2], G. C. Mussoi[2], H. S. Devigili[2], J. B. Lopes[2], J. A. Falletti-Netto[2], J. M. Conrado[2], L. S. Bianchini[2], M. F. Goulart[2], M. C. Brand[2], T. S. Steffens[2] and V. F. Silveira[2]

[1]Joinville Regional University, Environmental Science Research Program, Laboratory of Morphology and Plant Ecology, Rua Paulo Maschitzki, n. 10, CEP 89219-710, Joinville, Santa Catarina, Brazil.
[2]Joinville Regional University, Marine Biological Science, Rodovia Duque de Caxias, Bairro Iperoba, CEP 89240-000 - São Francisco do Sul, Santa Catarina, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors JCFMJ and SSD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Others authors collected the data in the field, tabulated the data, and wrote the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/37998
Editor(s):
(1) Yong In Kuk, Department of Development in Oriental Medicine Resources, Sunchon National University, South Korea.
Reviewers:
(1) Ana Cano Ortiz And Eusebio Cano Carmona, University of Jaen, Spain.
(2) Gaebewe M. Ramolemana, University of Botswana, Botswana.
Complete Peer review History: http://www.sciencedomain.org/review-history/22141

Original Research Article

Received 6th November 2017
Accepted 28th November 2017
Published 4th December 2017

ABSTRACT

This study aims to evaluate the influence of soil nutrition on the organization of restinga communities on two different geoformations in the post-beach region. Studies were carried out at Laboratory of Morphology and Plant Ecology and Marine Biological Science Course, Joinville Regional University, in coastal plain of the municipality of Laguna, Santa Catarina, Brazil, during August 2017. A phytosociological survey was performed using 1 x 1m plots distributed along four

**Corresponding author: E-mail: joao.melo@univille.br;*

parallel transects spaced about 200m apart (50 plots were located on parabolic dunes and 50 plots were located on swamp of intercordion depressions). Chemical characterization of the soil of the parabolic dunes and the intercordion depressions adopted conventional soil protocols. The phytosociological survey recorded 28 species distributed among 25 genera and 12 families of angiosperms. Of these species, seven were found co-occurring in parabolic dunes and swamps of intercordion depressions, whereas the others were unique to one or the other geoformation. Swamp showed bigger diversity than dunes. The most diverse families were Asteraceae (9), Cyperaceae (5) and Poaceae (5), which accounted for 79.2% of the total number of species surveyed. The dune soil had higher salinity, while the swamps had greater availability of water and fertility. The results obtained in the present study corroborate the indissociable plant-soil relationship attributed to restinga environments, specifically that increases in both species richness and abundance are associated with higher fertility and water availability of soil, and whose edaphic climax is notorious in the most settled communities near the sea.

Keywords: Phytosociology; coastal vegetation; restinga; soil-plant relationship; edaphic climax; espodossol.

1. INTRODUCTION

Restingas comprise a mosaic of floristically and physiognomically distinct pioneer plant communities [1]. They occur along coastal plains on young sandy soils of quaternary origin [2], formed by the deposition of fluvial-sea sediments and secondarily modeled by wind action [3]. Restinga vegetation belongs to the Atlantic Forest domain [4], and is distributed in a discontinuous way along the almost 5000 km of the Brazilian coast [5], covering about 79% of its extent [6]. It plays an important role in the stabilization of sand dunes, in the control of coastal erosion processes and in the maintenance of local biodiversity [7].

Restinga communities are typically compartmentalized in a sea-to-continent direction by a soil nutrient gradient, and are characterized by herbaceous, shrub, shrub-tree and forest formations, the latter being in contact with transitional areas of Dense Ombrophilous Forest [8]. Throughout this spatial continuity, restinga communities exhibit increasing biological diversity, changing from their typically open physiognomy in the post-beach region to enclosed forests in the interior [9].

Restingas are influenced by severe environmental conditions such as high salinity, high temperatures, continuous winds, flood and drought events, and soil nutrient deficiency [10]. Thus, restingas are considered extremely fragile ecosystems, which is cause for great conservation and management concern [11].

In spite of their great ecological importance, restingas have historically been degraded by the disordered human occupation along the Brazilian coast [12]. This has led to habitat fragmentation and the loss of ecosystem functions, as well as the alteration of the coastal landscape [13]. In some regions of the country, such as in the state of Santa Catarina, restinga vegetation remains poorly studied, with only approximately 38% of its restinga flora having been mapped along the 490 km of its coastline [14].

Even more scarce in Santa Catarina are ecological studies of the relationship between restinga vegetation and the edaphic nutritional gradient [8]. Such research has been carried out in restingas of other Brazilian states, such as Espírito Santo [15,16], Paraná [17,18] and Pernambuco [19], Piauí [20], Rio Grande do Sul [21] and São Paulo [11,22], which identified structural differences in the plant communities of the restinga by virtue of edaphic variation. The few studies of this nature carried out in the restingas of Santa Catarina have also demonstrated a strong relationship between soil and vegetation in the assembly and organization of their floristic communities [8,23,24,25], which reinforces the need to broaden such studies in the coastal plain of this State. Such research will contribute to the generation of information applicable to environmental conservation actions along the northern coast of Santa Catarina.

Considering that only a few studies have investigated the role of soil variables in structuring restinga communities in southern Brazil, this study aims to evaluate the influence of soil nutrition on the organization of restinga communities on two different geoformations in the post-beach region of the coastal plain of the municipality of Laguna, Santa Catarina, Brazil.

2. MATERIALS AND METHODS

2.1 Study Area

The study took place in the restinga of Cardoso Beach, municipality of Laguna, in southern Santa Catarina State (SC), Brazil (S 28°36'14.4'', W 48°49'38.6'') (Fig. 1). It is located approximately 2 km from the main tourist point of the city, the Farol de Santa Marta. The region is influenced by moisture from the sea and is characterized as a mesothermic climate, without defined dry periods and with hot summers (Cfa, according to the Köppen classification) [26]. The region has an annual average rainfall of 1,874 mm [27], and an average annual temperature of 19.9°C, with January being the warmest month with an average temperature of 24.2°C, and July being coldest month with an average temperature of 15.9°C [28]. Other abiotic factors, such as wind action and tidal conditions, contribute to the movement of sandy sediment, which determine the shape and position of dunes.

2.2 Comparative Structural Characterization of Vegetation

The geoformations of parabolic dunes and swamps in intercordion depressions were chosen to characterize, in a comparative way, the influence of edaphic variables on the community structure of restinga vegetation in the post-beach region. A phytosociological survey was performed using 1 x 1m plots [29]. One hundred plots were distributed along four parallel transects spaced about 200m apart; 50 plots were located on parabolic dunes and 50 plots were located on swamp of intercordion depressions. The plots were spaced at regular 1-m intervals along each transect. The inclusion criterion was based on the vascular flora contained in the sample plots. For each species, coverage was estimated based on the Causton scale [30]. The phytosociological parameters of relative coverage, absolute and relative frequencies and importance value were also determined [31].

2.3 Species Collection and Identification

The collection and herborization of vegetal material followed standard protocols for botanical studies [3]. Species were identified based on specialized literature [8,32] and by comparative morphology. The validity of names and authors of species followed the List of Flora of Brazil [33], while the hierarchical classification used was that of APG IV [34]. Life forms were determined following the classification based in gem position and woodiness [35]. The red list of the National Center for Plant Conservation [36] was consulted to determine the level of conservation threat for each species.

2.4 Soil Variables

Chemical characterization of the soil of the parabolic dunes and the intercordion depressions adopted conventional soil protocols [37]. There were 40 sub-samples with 10 from each transect and two (2) samples from each transect. In all there were eight (8) soil samples from the study area. Soil samples were collected in 15-cm deep pits, that were combined to form a composite sample for each geoformation. The chemical analysis of the soil assessed pH, phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), potential acidity (H + Al, H + and Al^3 + ions), sum of bases (SB), cation exchange capacity (CEC), saturation by bases (V) and organic matter (OM), and was carried out by the Soil Laboratory of the Agricultural Research and Rural Extension Company of Santa Catarina. Soil water availability was determined for eight (8) soil samples of each geoformation by the gravimetric moisture method [37].

2.5 Statistical Analysis

Principal component analysis (PCA) was used to determine the largest variance among the selected soil variables, and was performed in R software [38].

3. RESULTS

The phytosociological survey recorded 28 species distributed among 25 genera and 12 families of angiosperms (Table 1). Of these species, seven were found co-occurring in parabolic dunes and swamps of intercordion depressions, whereas the others were unique to one or the other geoformation (Fig. 2). The most diverse families were Asteraceae (9), Cyperaceae (5) and Poaceae (5), which accounted for 67.86% of the total number of species surveyed; the remaining families were represented by only one species each. The genera with the greatest species richness were *Baccharis* (3) and *Eleocharis* (2). Two naturalized exotic species was recorded, which belonged to the family Apiaceae and Fabaceae. With regard to conservation status, 96.4% of the species are cited as of “less worrying” or “no conservation studies", while one species is considered "almost threatened". The predominant life forms were hemicryptophytic (46.43%) and camephytic (35.71%), while a minority were sub-shrub (10.71%) and geophytic (7.14%) (Table 1).

Eleven species belonging to 11 genera and five families (Table 2) were recorded among the parabolic dunes, with Poaceae (4) and Asteraceae (3) having the greatest species richness in this geoformation. The species *Spartina ciliata*, *Andropogon arenarius* and *Androtrichum trigynum* represented about 54.6% of the importance value of all species sampled. The most frequent species were *Spartina ciliata* and *Hydrocotyle ranunculoides*, which were present in 80% and 24% of the sample plots, respectively. The species with the greatest coverage value was *Andropogon arenarius*, with 25.67%. The total community coverage in the parabolic dunes was approximately 35% of the sampled area.

Fig. 1. Spatial localization of study area, restinga environment of Laguna, Santa Catarina, Brazil

Table 1. Families and species found in the communities of parabolic dunes and swamps in intercordion depressions by means of phytosociological survey in the restinga of Laguna, Santa Catarina, Brazil

Family	Species	Author	PD	SID	Life form	Origin	Conservation
Apiaceae	*Centela asiatica*	L.	x		Ge	E	LW
Apocynaceae	*Oxypetalum tomentosum*	W. ex H.&Am.		x	Ca	N	NS
Araliaceae	*Hydrocolyte ranunculoides*	L.f.	x	x	Ge	N	LW
Asteraceae	*Ambrosia* sp.			x	Ca	N	NS
	Baccharis dracunculifolia	DC.	x		Ss	N	AT
	Baccharis gnaphalioides	Spreng.		x	Ss	N	NS
	Baccharis trimera	(Less.) DC.		x	Ca	N	LW
	Conyza bonariensis	(L.) Cronquist		x	Ca	N	NS
	Elephantopus mollis	Kunth	x	x	Ca	N	NS
	Pterocaulon lorentzii	Malme		x	Ca	N	NS
	Senecio crassiflorus	(Poir.) DC.	x	x	Ca	N	AT
	Symphyopappus reitzii	(Cabrera) R.M. K.& H. Rob.		x	Ss	N	NS
Cyperaceae	*Androtrichum trigynum*	(Spreng.) H. Pfeiff.	x	x	He	N	NS
	Eleocharis geniculata	(L.) Rowen. & Schult.	x	x	He	N	LW
	Eleocharis interstincta	(Vahl.) Rowen Schult.		x	He	N	NS
	Fimbristylis spadicea	(L.)Vahl.		x	He	N	NS
	Kyllinga vaginata	Lam.		x	He	N	NS
Droseraceae	*Drosera brevifolia*	Pursh.		x	He	N	NS
Fabaceae	*Desmodium adscendens*	(SW.) DC.		x	Ca	E	LW
Menyanthaceae	*Nymphoides humboldtiana*	(Kunh) Kuntze		x	He	N	NS
Plantaginaceae	*Bacopa monnieri*	Wettst.		x	Ca	N	LW
Poaceae	*Andropogon arenarius*	Hack	x	x	He	N	NS
	Chloris retusa	Lag.		x	He	N	NS
	Panicum racemosum	Spreng.	x		He	N	NS
	Paspalum vaginatum	Sw.	x	x	He	N	LW
	Spartina ciliata	Brong	x		He	N	NS
Verbenaceae	*Phyla* sp.			x	Ca	N	NS
Xyridaceae	*Xyris jupicai*	Rich.		x	He	N	NS

Notes: Geoformations: parabolic dunes (PD); swamps in intercordion depressions (SID). Life forms: camephytic grass (Ca); geophytic grass (Ge); hemicryptophytic grass (He); and sub-shrub (Ss). Origins: N = native; E = exotic naturalized. Conservation categories: LW = less worrying; NS = no conservation studies; and AT = almost threatened.

Table 2. Species sampled in parabolic dunes and swamps in intercordion depressions in herbaceous-sub-shrub restinga in the municipality of Laguna, Santa Catarina, Brazil

Family	Species	N	AC	RC	AF	RF	IV
	Parabolic dunes						
Poaceae	*Spartina ciliata*	40	12.00	6.35	80.00	39.60	45.96
Poaceae	*Andropogon arenarius*	10	48.50	25.67	20.00	9.90	35.57
Cyperaceae	*Androtrichum trigynum*	11	32.50	17.20	22.00	10.89	28.09
Poaceae	*Paspalum vaginatum*	8	10.94	5.79	16.00	7.92	13.71
Araliaceae	*Hydrocotyle ranunculoides*	12	2.50	1.32	24.00	11.88	13.20
Apiaceae	*Centela asiatica*	4	15.63	8.27	8.00	3.96	12.23
Poaceae	*Panicum racemosum*	7	2.50	1.32	14.00	6.93	8.25
Cyperaceae	*Eleocharis geniculata*	1	10.00	5.29	2.00	0.99	6.28
Asteraceae	*Baccharis dracunculifolia*	4	2.50	1.32	8.00	3.96	5.28
Asteraceae	*Senecio crassiflorus*	3	2.50	1.32	6.00	2.97	4.29
Asteraceae	*Elephantopus mollis*	1	2.50	1.32	2.00	0.99	2.31
	swamps in intercordion depressions						
Verbenaceae	*Phyla* sp.	32	17.89	12.78	64.00	13.97	26.75
Apocynaceae	*Oxypetalum tomentosum*	17	19.26	13.76	34.00	7.42	21.18
Menyanthaceae	*Nymphoides humboldtiana*	29	11.81	8.43	58.00	12.66	21.10
Poaceae	*Andropogon arenarius*	15	17.33	12.38	30.00	6.55	18.93
Cyperaceae	*Fimbristylis spadicea*	14	9.11	6.50	28.00	6.11	12.62
Cyperaceae	*Kyllinga vaginata*	12	6.46	4.61	24.00	5.24	9.85
Araliaceae	*Hydrocotyle ranunculoides*	16	3.91	2.79	32.00	6.99	9.78
Droseraceae	*Drosera brevifolia*	15	4.50	3.21	30.00	6.55	9.76
Xyridaceae	*Xyris jupicai*	7	8.93	6.38	14.00	3.06	9.43
Asteraceae	*Pterocaulon lorentzii*	16	2.97	2.12	32.00	6.99	9.11
Asteraceae	*Senecio crassiflorus*	7	7.86	5.61	14.00	3.06	8.67
Plantaginaceae	*Bacopa monnieri*	14	2.50	1.79	28.00	6.11	7.90
Asteraceae	*Elephantopus mollis*	6	2.50	1.79	12.00	2.62	4.41
Asteraceae	*Symphyopappus reitzii*	6	2.50	1.79	12.00	2.62	4.41
Cyperaceae	*Eleocharis geniculata*	5	2.50	1.79	10.00	2.18	3.97
Asteraceae	*Baccharis gnaphaliodes*	4	2.50	1.79	8.00	1.75	3.53
Poaceae	*Chloris retusa*	4	2.50	1.79	8.00	1.75	3.53
Poaceae	*Paspalum vaginatum*	3	2.50	1.79	6.00	1.31	3.10
Cyperaceae	*Androtrichum trigynum*	2	2.50	1.79	4.00	0.87	2.66
Cyperaceae	*Eleocharis interstincta*	2	2.50	1.79	4.00	0.87	2.66
Asteraceae	*Ambrosia* sp.	1	2.50	1.79	2.00	0.44	2.22
Asteraceae	*Baccharis trimera*	1	2.50	1.79	2.00	0.44	2.22
Asteraceae	*Conyza bonariensis*	1	2.50	1.79	2.00	0.44	2.22
Fabaceae	*Desmodium adscendens*	1	2.50	1.79	2.00	0.44	2.22

Legend: number of occurrences of the species (N), absolute coverage (AC%), relative coverage (RC%), absolute frequency (AF%), relative frequency (RF%), and indicator value (IV).

Twenty-four species belonging to 22 genera and 11 families were recorded from the swamps in intercordion depressions (above Table 2). The families with the greatest species richness were Asteraceae (8), Cyperaceae (5) and Poaceae (3). The species *Phyla* sp., *Oxypetalum tomentosum*, *Nymphoides indica*, *Andropogon arenarius* and *Fimbristylis spadicea* represented 50.3% of the value of importance of the set of species sampled in this geoformation. The most frequent species were *Phyla* sp. and *Nymphoides indica*, which were present in 64% and 58% of the sample plots, respectively. The highest coverage was obtained by *Oxypetalum tomemtosum* (19.26%). The total community coverage of the swamps of intercordion depressions was approximately 59% of the area sampled.

Chemical analysis of the soil (Table 3) revealed that both restinga geoformations had slightly acidic soil. In the parabolic dunes, the soil content of the macronutrient potassium (K) was high. For the swamps in intercordion depressions, the soil content of phosphorus (P), calcium (Ca) and aluminum (Al) had the highest values. There was no significant difference between the geoformations with respect to magnesium (Mg) content of the soil. The dune soil had higher salinity, as indicated by sodium content (Na), while the swamps had greater availability of water. The sum of bases (SB), cation exchange capacity (CEC), real acidity (H + Al), as well as organic matter content (OM), were higher in the swamp soil. Principal component analysis (PCA) showed that the first two axes together explained 96.17% of the total variance (Table 3, Fig. 3). Organic matter and potassium content and CEC were the variables most related to axis 1, which explained 92.74% of the variance, while axis 2, for which calcium content was the most related variable, explained only 2.34% of the variance.

4. DISCUSSION

The nutritional and hydric characteristics of restinga soils exert a direct influence on species composition and, consequently, on the social organization of the communities on the sandy deposits. This is especially true for those that occupy the post-beach region because of the environmental factors that impede stabilization of sediments and the accumulation of organic matter [8]. Soil profiles of sandy substrates, such as those of restinga, often possess a surface horizon of accumulated organometallic complexes, through which the percolation of water leaches the surface deposited nutrients, making the soil poor and acidic [39]. The importance of organic matter in restinga environments is significant, mainly because it is responsible for the cation exchange capacity of the soil, thus influencing nutrient retention. It is also known that water availability facilitates cation exchange, besides being a very important variable in the structuring of communities [18].

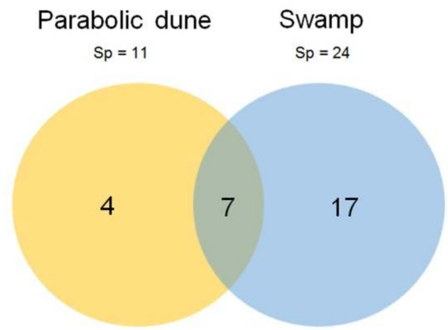

Fig. 2. Venn diagram showing the total number of species and the number of unique and co-occurring species recorded in each geoformation in the restinga of the municipality of Laguna, Santa Catarina, Brazil

The studied restinga geoformations show great edaphic variation, such that the greater availability of water and nutrients in the swamps of intercordion depressions favor the formation

Table 3. Chemical characterization and water availability of the soils of parabolic dunes and swamps in intercordion depressions in herbaceous-sub-shrub restinga in the municipality of Laguna, Santa Catarina, Brazil

Edaphic variable	Restinga		Engeinvalues	
	Parabolic dunes	Swamps in intercordion depressions	CP1	CP2
pH	5.0	5.1	-0.264	-0.488
Al (cmolc/dm^{-3})	0.9	1.2	-0.280	-0.363
Ca (mmolc.dm^{-3})	0.5	0.9	-0.267	0.650
Mg (mmolc.dm^{-3})	0.4	0.5	-0.269	-0.321
P (mg.dm^{-3})	7.5	4.3	0.298	-0.061
K (mmolc.dm^{-3})	14.0	24.0	-0.299	-0.157
H + Al (mmolc.dm^{-3})	1.4	2.2	-0.296	0.123
Na (mg.dm^{-3})	46.0	42.9	0.294	-0.197
SB (mmolc.dm^{-3})	0.95	1.42	-0.298	0.057
OM (g.dm^{-3})	0.1	0.5	-0.299	0.033
CEC (mmolc.dm^{-3})	2.35	3.62	-0.300	0.052
V (%)	40.60	39.21	-0.105	-0.200
Soil moisture (%)	0.62	12.89	-0.297	0.114

Legend: Ca - calcium, Mg - magnesium, CEC - Cation exchange capacity, OM - organic matter, H + Al - hydrogen + aluminum, P - Phosphorus, K - potassium, pH - hydrogenation potential, Na - Sodium, SB - Sum of bases, CP1 - Component principal 1, CP2 - Component principal 2.

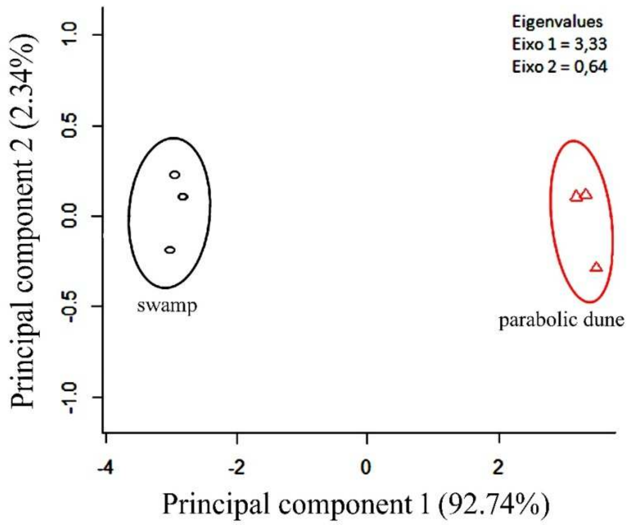

Fig. 3. Principal components analysis of nutritional variables and soil water availability of parabolic dunes and swamps in intercordion depressions in herbaceous-sub-shrub restinga in the municipality of Laguna, Santa Catarina, Brazil

a more fertile soil (greater CEC) than that found in the parabolic dunes, although both soils are classified as dystrophic [37]. This edaphic difference has resulted in the greater diversity of species and the highest degree of cover of the sandy sediment in the swamp geoformations, while the parabolic dunes were characterized by low diversity and high exposure of bare soil making it susceptible to wind action. The low coverage of restinga vegetation in parabolic dune environments has been documented in other areas of the coastal plain of Santa Catarina, and is probably the result of the great mobility of sand due to wind action [40]. In addition, the greater influence of water, nutritional restriction and high luminosity on the regional pool of species makes the post-beach environment more limiting to species colonization [8,13, 41].

Although the sandy sediments of the post-beach environment are typically occupied by a pioneer community of herbaceous-sub-shrub plants that are highly adapted to sediment mobility [10], the composition of plant species is determined by a combination of environmental factors of oceanic and continental origin at different scales [42]. In this sense, even considering the spatial microscale occupied by the coastal plain of the Santa Catarina, when compared to entire Brazilian coast, it is possible to observe significant changes in the floristic and structural composition of the communities established in the post-beach area of this plain. Although the families Asteraceae and Poaceae contribute to the species richness of the restingas of the Santa Catarina coastal plain, there is, for example, the phytosociological record of the occurrence of 33 species in a remnant of restinga in the municipality of São Francisco do Sul, SC [40] and 18 species in sandy spurs in the Capri peninsula, SC [43], in contrast to the 11 species recorded here. In general, restinga formations in the post-beach region are admittedly less diverse than those developed in the interior of continent [8,44-46], and whose coverage patterns reflect the local conditions of marine and wind action [43].

Despite the evident local differences, some species are quite common in these environments and can occupy a prominent social position in organization of the communities. In comparison to other restingas of the Santa Catarina coast, the species *Spartina ciliata* and *Oxypetalum tomentosum* also reach higher values of importance [8,40,43,47]. In association with other species, they play an important role in the establishment of sandy sediment and stabilization of dunes, by preventing erosive processes at the coastline [48]. This ability is closely linked to life form and other morphological attributes of these species, such as having stoloniferous, prostrate and subterranean rhizomatous stems that allow survival in psamophilic environments [49] and reach an extensive area of soil cover [3]. These attributes are easily observed in camephytic, hemicryptophytic and geophytic herbs, which allows them to develop under the stressful conditions in dune areas, such as substrate instability, water scarcity, high temperatures and high salinity [50,51].

In sandy plains subjected to seasonal or perennial flooding, herbaceous communities develop that have the ability to withstand submersion [52], as observed in the swamps of intercordion depressions of the restinga of Laguna. In this formation, typically hygrophytic taxa such as *Nymphoides humboldtiana*, *Phyla* sp. and *Xyris jupicai* become abundant, restricted to swamps and reflect the condition of soil flooding as aquatic macrophytes [53]. *Drosera brevifolia* is present in restinga swamps, but can tolerate wide physical-climatic variation, which has allowed it to extend its distribution into the altitudinal grasslands and pampas in southern Brazil [33].

Several studies have reported the occurrence of exotic species in the restingas of Santa Catarina, which reveals the impact of human activities on this ecosystem [13,41,46]. Most of the time these invasives are ruddy species that are dispersed by wind or by animals that find them as an extra nutritional source. On the other hand, this finding is cause for concern from the point of view of environmental conservation, since exotic species can, through competition for resources, interfere with the natural dynamics of restingas and cause native vegetation to die, thereby reducing local diversity [54]. This effect becomes more worrisome with the occurrence of species that are under a greater degree of threat, such as *Senecio crassiflorus* recorded in this study.

5. CONCLUSION

The results obtained in the present study corroborate the indissociable plant-soil relationship attributed to restinga environments, specifically that increases in both species richness and abundance are associated with higher fertility and water availability of soil, and whose edaphic climax is notorious in the most settled communities near the sea. Structural differences in vegetation between post-beach geoformations, such as parabolic dunes and swamps in intercordion depressions, are also influenced by the adaptability of species to the mobility of sandy sediment. In this environment, habit and plant architecture are strongly related to the geomorphological characteristics of sandy formations of restinga, with emphasis on herbaceous forms and subterranean or decumbent stems that, besides being more resistant to the strong winds, promote the fixation of the dunes against typical erosive processes at coastline. In addition, the flora species recognized in restinga of the Laguna municipality represent the biodiversity of coastal environments in Brazil and, due to the high degree of degradation of the Brazilian coast, special attention should be give to their conservation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Araujo DSD, Lacerda LD. The nature of the restingas. Science Today. 1987;6:42-48. English.
2. Bigarella JJ. Contribution to the study of the coastal plain of the state of Paraná. Braz Arc Biol Tech. 2001;65-110. English.
3. IBGE. Technic manual of Brazilian vegetation. Rio de Janeiro: IBGE; 2012.
4. Fernandes A. Brazilian phytogeography: Floristic provinces. Fortress: Enhance; 2006.
5. Holzer W, Crichyno J, Pires AC. Sustainability of urbanization in restinga areas: A post-occupation evaluation proposal. Country Amb. 2004;19:49-66. English.
6. Lacerda LD, Araújo DSD, Maciel NC. Dry coastal ecosystems of the tropical Brazilian coast. In: Van-Der-Maarel E, editor. Dry coastal ecosystems: Africa, America, Asia, Oceania. Amsterdam: Elsevier; 1993.
7. Kuki KN, Oliveira MA, Pereira EG, Costa AC, Cambraia J. Effects of simulated deposition of acid mist and iron ore particulate matter on photosynthesis and the generation of oxidative stress in *Schinus terebinthifolius* Raddi and *Sophora tomentosa* L. Sci Total Environ. 2008;403:207-214.
8. Melo-Júnior JCF, Boeger MRT. Wealth, structure and soil interactions in a restinga gradient of Acaraí State Park, State of Santa Catarina, Brazil. Hoehnea. 2015; 42(2):207-232. English.
9. Oliveira-Filho AT, Carvalho DA. Floristics and vegetation physiognomy at the northern end of the Paraíba coast. R Bras Bot. 1993;16(1):115-130. English.
10. Scarano FR. Structure, function and floristic relationships of plant communities

in stressful habitats to the Brazilian atlantic rainforest. Ann Bot. 2002;90:517-524.

11. Guedes D, Barbosa LM, Martins SE. Floristic composition and phytosociological structure of two fragments of restinga forest in the municipality of Bertioga, SP, Brazil. Acta Bot Bras. 2006;20:299-311. English.
12. Rocha CFD, Bergallo HG, Alves MAS, Van-Sluys M. Biodiversity in the large forest remnants of the state of Rio de Janeiro and in the restingas of the Atlantic Forest. São Carlos: RiMa; 2003.
13. Ribeiro PY, Melo-Júnior JCF. Richness and community structure of sand dunes (restinga) in Santa Catarina: Subsidies for ecological restoration. ABC. 2016;3(1):25-35. Portuguese.
14. Melo-Júnior JCF, Boeger MRT. Richness and structure of dune plants community in the coastal plain of Santa Catarina. Iheringia. 2018;73(1) *(In press)*.
15. Fabris LC. Floristic and phytosociological composition of a strip of sandy coastal forest of the State Park of Setiba, Municipality of Guarapari, State of. São Paulo: UNESP; 1995.
16. Magnago LFS, Martins SV, Schaefer CEGR, Neri AV. Phytophysiological-edaphic gradient in forest formations of restinga in southeastern Brazil. Acta Bot Bras. 2010;24:734-746. English.
17. Britez RM, Santos Filho A, Reissmann CB, Silva SM, Athayde SF, Lima RX et al. Nutrients in the soil of two forests of the coastal plain of Honey Island, Paranaguá, PR. Brazilian Journal of Soil Science. 1997; 21: 625-634. English.
18. Britez RM. Alone. In: Marques MCM, Britez RM, editors. Natural history and conservation of Ilha do Mel, Paraná. Curitiba: UFPR; 2005.
19. Almeida Jr. EB, Santos-Filho FS, Araújo EL, Zickel CS. Structural characterization of the woody plants in *restinga* of Brazil. J Ecol Nat Environ. 2011;3:95-103.
20. Santos-Filho FS, Almeida-Júnior EB, Zickel CS. Do edaphic aspects alter vegetation structures in the Brazilian *restinga*? Acta Bot Bras. 2013;27:613-623.
21. Costa CSB, Irgang BE, Peixoto AR, Marangoni JC. Floristic composition of plant formations on a topotrophic peat of the coastal plain of Rio Grande do Sul, Brazil. Acta Bot Bras. 2003;17:203-212. English.
22. Sztutman M, Rodrigues RR. The vegetative mosaic in a continuous forest area of the coastal plain, Campina do Encantado State Park, Pariquera-Açu, SP. R Bras Bot. 2002;25:161-176. English.
23. Melo-Júnior JCF, Boeger MRT. Leaf traits and plastic potential of plant species in a light-edaphic gradient from restinga in southern Brazil. Acta Biol Colomb. 2016;21(1):51-62.
24. Amorim MW, Melo-Júnior JCF. Functional diversity of restinga shrub species on the coastal plain of southern Brazil. Inter J Dev Res. 2017;7(6):13189-13202.
25. Melo-Júnior JCF, Boeger MRT. Functional traits of dominant plant species of the Brazilian sandy coastal plain. Int J Curr Res. 2017;9(1):45585-45593.
26. Alvares, CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteor Zeitschrift. 2013;22(6):711–728.
27. Knie JLW, editor. Environmental Atlas of the Joinville region: Babitonga Bay water complex. Florianópolis: FATMA / GTZ; 2002.
28. Climate-Data. Clima: Laguna. Available:https://pt.climate-data.org/location/25023 (Accessed 15 October 2017)
29. Felfili JM, Eisenlohr PV, Melo MMRF, Andrade LA, Neto JAAM, editors. Brazilian phytossociology. Viçosa: UFV; 2011.
30. Causton DR. Introduction to vegetation analysis. London: Unwin Hyman; 1998.
31. Mueller-Dombois D, Ellenberg H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974.
32. Binfaré RW, Falkenberg DB. Illustrated guide to the restinga flora of Santa Catarina. Available:https://www.crbio03.gov.br/single-post/2017/03/14/Guia-Ilustrado-da-Flora-da-Restinga-de-Santa-Catarina (Accessed October 20, 2017)
33. Brazilian Flora Group. Growing knowledge: an overview of Seed Plant diversity in Brazil. Rodriguésia. 2015;66(4):1085-1113.
34. Angiosperm Phylogeny Group. An update of the Angiosperm Phylogeny Group classification for the ordens and families of flowering plants: APG IV. Bio J Lin Soc. 2016;181:1-20.
35. Moore PD, Chapmann SB. Methods in plant ecology. Oxford: Blackwell Scientific Publications; 1986.

36. National Center for Plant Conservation. Red list. Available:http://cncflora.jbrj.gov.br/portal/pt-br/listavermelha (Accessed 15 October 2017)
37. EMBRAPA. Brazilian system of soil classification. Brasília: EMBRAPA; 2013.
38. Borcard D, Gillet F, Legendre P. Numerical ecology with R. New York: Springer; 2011.
39. Gomes JBV, Resende M, Rezende SB, Mendonça ES. Soils from three restinga areas. I. Morphology, characterization and classification. Pesq Agropec Bras. 1998; 33:1907-1919. English.
40. Melo-Júnior JCF, Ferrari A, Gern AF, Daniel A, Maia AC, Hartelt BT, et al. Comparative phytosociology of the herbaceous-subarbustive community of restinga in two geological formations of dunes in the coastal plain of Santa Catarina. ABC. 2017;4(2):5-15. English.
41. Matilde-Silva M, Melo-Júnior JCF. Floristic and structural composition of an herbaceous-shrub community of restinga in Balneário Barra do Sul, Santa Catarina. R Bras Bioci. 2016;14(4):207-214. English.
42. Alves RJV, Cardin L, Kropf MS. Angiosperm disjunction "Cave fields - resting": A re-evaluation. Acta Bot Bras. 2007;21(3):675-685.
43. Cristofolini J, Vieira CV, Melo-Júnior JCF. Relationship between the sand spit geomorphology and Restinga vegetation in São Francisco do Sul Island, south region of Brazil. Inter. J. Dev. Res. 2017;7(7): 13314-13321.
44. Bresolin A. Restinga flora of the Island of Santa Catarina. Insula. 1979;10:1-55. English.
45. Cordazzo CV, Costa CSB. Vegetation associations of the frontal dunes of Garopaba (SC). Ciên Cult. 1989;41(9): 906-910. English.
46. Klein AS, Citadini-Zanette V, Santos R. Floristic and community structure of herbaceous restinga in the municipality of Araranguá, Santa Catarina. Biotemas. 2007;20(3):15-26. English.
47. Danilevicz E, Janke H, Pankowski LHS. Floristics and structure of the herbaceous and shrub community of Ferrugem Beach, Garopaba, SC. Acta Bot Bras. 1990;4(2): 21-34. English.
48. Cordazzo CV, Paiva JB, Seeliger U. Dune plants on the Atlantic Southeast coast. Balls: Useb; 2006.
49. Boeger MRT, Gluzezak RM. Structural adaptations of seven plant species for environmental conditions of the Santa Catarina dune area, Brazil. Iheringia. 2006; 61(1-2):73-82. English.
50. Seeliger U. Coastal dunes of southern Brazil: physiography, habitats and vegetation. In: Seeliger U, Odebrecht C, Castello JP, editors. Subtropical convergence environments: the coastal sea in the southwestern Atlantic. Berlin: Springer; 1992.
51. Spanou S, Verroios G, Dimitrellos G, Tiniakou A, Georgiadis T. Notes on flora and vegetation of the sand dunes of western Greece. Willdenowia. 2006; 36:235-246.
52. Amaral MCE, Bittrich V, Anderson LO, Aona LY. Field guide for aquatic plants and marshes in the state of São Paulo. Ribeirão Preto: Holos; 2008.
53. Valadares RT, Souza FBC, Castro NGD, Peres ALSS, Schneider SZ, Martins MLL. Floristic survey of a brejo-herbaceous located in the restinga of Morada do Sol, municipality of Vila Velha, Espírito Santo, Brazil. Rodriguésia. 2011;62(4):827-834. English.
54. Ziller SR. Invasive alien plants: the threat of biological contamination. Science Today. 2001;30(178):77-79. English.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/22141