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Key Points about North and Northern Brazilian Restinga: a Review of Geomorphological Characterization, Phytophysiognomies Classification, and Studies' Tendencies

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Abstract

Brazil has a pronounced complexity in coastal region, which affects the restingas' diversity patterns. Therefore, we reviewed and systematized the knowledge about the attributes influencing the characterization and, eventually, the biases in the identification of restingas' diversity patterns, mainly focusing in the Brazilian North and Northeast regions. Coastal geomorphology is one of the key attributes contributing to this complexity, acting as an environmental filter for the colonization of plant species. According to the standard classification, the Brazilian coast can be divided into five regions (North, Northeast, East, Southeast, and South). Another relevant attribute is phytophysiognomies, characterized by the collective characteristics of vegetation in a region, and for which exists six different classifications. The one proposed by Silva and Britez (2005) presents the best trade-off between specificity and generality by allowing both adequate local characterization and systematization for regional comparisons. Despite the length of the North and Northeast coast of Brazil, only 44 studies were conducted in these regions. The sampled areas were typically close to the state capitals, showing that logistical factors interfere with the selection of study areas. Besides, almost half of the studies omitted essential information such as the total area and sampling time, making it challenging to assess sample sufficiency and reproducibility. Another observed bias was a higher species richness in studies that partially or entirely used herbarium data. These gaps and biases on information constrain the ecological synthesis of restinga' biodiversity patterns, mainly in larger spatial scales than those in which individual studies were conducted.

Keywords Costal zones · Herbarium · Geomorphology · Phytophysiognomy · Atlantic forest · Amazon

Introduction

The restinga consists in a transition zone (ecotone) characterized as the vegetation that borders the biomes (Scarano, 2002) and covers the coastal plains of Holocene sands of marine origin (Fernandes, 1998). It is geologically recent, so its vegetation originates from other ecosystems or biomes, but exhibit phenotypic variations when compared with the source habitat, guaranteeing adaptation to distinct environmental conditions (Freire, 1990; Assumpção & Nascimento, 2000; Cerqueira, 2000). This factor makes the diversity pattern of restinga widely heterogeneous along its geographic distribution.

Restingas occupy about 80% of the Brazilian coast, corresponding to approximately 7360 km in length, spanning all coastal states (de Medeiros et al., 2007). The Brazilian restinga permeates various geological formations, which leads to environmental heterogeneity and modification of the colonization success of species from adjacent environments (Araujo, 1992). The Brazilian restingas are under the influence of various biomes (Atlantic Forest, Amazon, Cerrado, and Caatinga), that acts as the source of the colonizer species (Rizzini, 1979; Cerqueira, 2000; Scarano, 2002; Araujo & Pereira, 2009).

Brazil is of unique importance in the study and characterization of the restinga ecosystem due to its heterogeneous and complex coast. Thus, we reviewed the key aspects of the Brazilian restinga, systematizing the definitions and characterizations of this vegetation found in the current scientific literature. For this, we firstly assessed the geomorphology classifications of the Brazilian coast, commonly based on physical aspects such as location, barriers, weather, and climate. We also reviewed the physiognomic classifications of the Brazilian restingas, discussing their adequacy, challenges, and knowledge gaps.

Finally, we evaluated the literature on the floristic studies carried out in restingas in the North and Northeast of Brazil, once it is to the most extensive Brazilian coastline, covering 4477 km (IBGE, 2004), and has substantial knowledge gap. Floristic studies were classified as those using exploratory walk-based sampling method throughout the study area and collected specimens with flower or fruit. We assessed the spatial gap of floristic studies in restinga, verifying representativeness of distinct biomes and states. Also, we evaluated general methodological trends and biases and their effects on the reported species richness.

Geomorphological Characterization of the Brazilian Coast and its Divisions

Several classifications have been proposed for the Brazilian coast, but the one of Silveira (1964) is widely accepted. According to this author, the coast can be divided into five regions, based on oceanographic, climatic and continental elements: (i) North - Cape Orange (AP) to Mangues Secos (MA); (ii) Northeast – Mangues Secos (MA) to Salvador (BA); (iii) Oriental - Salvador (BA) to Cabo Frio (RJ); (iv) Southeast - Cabo Frio (RJ) to Cabo de Santa Marta (SC); and (v) South – Cabo de Santa Marta (SC) to Barra do Chuí (RS).

In 1984, this classification and nomenclature were reclassified into five categories: (i) Amazonian or equatorial coast - mouth of Oiapoque to Oriental Maranhão; (ii)

Northeastern or Barreiras Coastline - from Maranhão to Recôncavo Baiano; (iii) Eastern Coastline - Recôncavo Baiano to the South of Espírito Santo; (iv) Southeast Coast or Crystal Escarpment- South of Espírito Santo to the Laguna region; and (v) Southern or Subtropical Coastal - Laguna region to the mouth of the Arroio Chuí (Suguio & Tessler, 1984).

However, a new classification was performed in 2005, based on the scheme proposed by Silveira (1964) (Villwock et al., 2005). This review changed geographical boundaries based on climatic and geographic factors, such as tides and sea currents. Again, five typologies were identified, but adopting subdivisions: (i) North Coast - extends from Cape Orange (AP) to São Marcos Bay (MA) and is subdivided into three coastal regions of distinct formations (Guyana Coast, Amazonian Gulf, and Eastern Amazon Coast); (ii) Northeast Coast - extending from São Marcos Bay (MA) to 'Todos os Santos' Bay (BA) and presenting two subdivisions (Semi-Arid Coast – comprising of the formation of Barreiras that originated the coastal tableland; Northeast East Coast or Coast of Barreiras - formed by tertiary sediments and marked by carved cliffs and beachrock fringes); (iii) East Coast - extends from 'Todos os Santos' Bay (BA) to Cabo Frio (RJ) and is characterized by the Barreiras Formation sediments, with the presence of rocky shores and cliffs; (iv) Southeast Coast - extends from Cabo Frio (RJ) to Cabo de Santa Marta (SC) and is characterized by the presence of Serra do Mar, a set of highlands composed of crystalline basement, whose escarpments reach the sea originating the rocky shores; and (v) South Coast - extends from Cabo de Santa Marta (SC) to Arroio Chuí (RS), notable for a coastal plain that can reach up to 120 km in length.

Another significant contribution was proposed by Ab'Sáber (2000) who characterized the coastal zone according to its geomorphology in 49 sectoral units from Amapá to the Rio Grande do Sul States. This classification is probably the most complete due to its level of detail when compared to other classification systems reviewed here.

In conclusion, and like noticed before, the geomorphological classifications of the Brazilian coast are mainly based on oceanographic, climatic, and continental components. The wide extension of Brazilian coast and the variables chosen to portray it rebound over the variety of classifications and categories existent. Despite differences among classification, all of them demonstrate the environmental complexity acting over restingas along the Brazilian coast.

Classifications of Brazilian Restinga Phytophysiognomies: Adaptations and Uses

The term restinga was first used by Ule (1901) to determine the various mosaics of vegetation formations found on the coast. Its classification was based on the general aspect of the site (e.g., swamp) or the most representative taxonomic group. For Rio de Janeiro, the region where their studies were conducted, the most representative groups comprised of the botanical families Clusiaceae, Ericaceae, and Myrtaceae. However, this classification is simplistic and somewhat unrealistic due to the heterogeneity found in these environments.

Consequently, new criteria were developed based on physiognomic, geographical, and compositional attributes to classify restinga phytophysiognomies. The first criteria were established by Rizzini (1979), which categorized the restinga based on

physiognomic and geographical attributes into swamp forest, sclerophyllous forest, thicket, and scrubs. Later, Eiten (1983) used vegetation cover attributes and classified the restinga into arboreous closed shrubby, open shrubby, savannah, prairie, and beach fields. On both classifications, the expressions thicket and scrubs are considered as closed shrubby vegetation and open shrubby vegetation (Thomazi et al., 2013).

With the need to adapt the classification of Brazilian vegetation to an international system and to recognize the soil as a conditioning factor of coastal vegetation, the Radam Brasil project, formerly called Radam, undertook several attempts to classify the Brazilian phytogeography (Veloso & Góes Filho, 1982; Veloso et al., 1991). This project created empirical classification criteria for coastal plains, including distinct phytoecological units such as the Lowland Dense Ombrophilous Forest and the Pioneering Formations with marine, fluvial-marine or fluvial-lacustrine influences. Despite the efforts, Radam Brasil was criticized for simplifying phytophysiognomy into a single category, sometimes called 'restinga', 'complex', or 'restinga mosaic'. Thus, they failed to capture the existing phytophysiognomic varieties and subtypes within the ecosystem, probably due to the scale of the work, that is generally superior to that of the restinga phytophysiognomies (Silva & Britez, 2005).

The main initiatives to refine restinga phytophysiognomies classification were done by studies conducted in the South and Southeast regions, especially in the states of Rio de Janeiro, Sao Paulo, Santa Catarina, and the Rio Grande do Sul (Silva & Britez, 2005). These attempts often led to region-specific classifications, making them limited to the study areas and of little value for comparative work, such as the classification of (Araujo, 1992) for the restingas in Rio de Janeiro.

Following the trend of refining the classification of phytophysiognomies, Silva and Britez (2005) proposed a detailed categorization in a study conducted in the Southern region of Ilha do Mel (PR). This classification showed usefulness for all coastal plains in Brazil, as it exhibits a flexible approach and unified nomenclature with previous classifications. Therefore, this classification seems, at least currently, the most efficient to studies in Brazilian restinga which, despite being proposed to Southern Brazil, were already efficiently used in studies conducted in the Northeast region (Santos-Filho et al., 2010; Cantarelli et al., 2012; Almeida Jr. et al., 2016; Lima et al., 2017).

A Systematic Review of Floristic Studies in Restinga in the North and Northeast

For the literature review, we conducted a bibliographic survey on Google Scholar and Web of Science, using the following keywords (in Portuguese and English): restinga, floristic, floristic survey, physiognomy, Northeast, North, Amapá, Pará, Alagoas, Bahia, Ceará, Maranhão, Paraiba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe (the latter comprise the North and Northeast coastal states from Brazil). We complemented the review by actively and non-systematically searching articles and book chapters cited in the sampled research papers. All papers were evaluated to get the following information: (i) year of publication, used to evaluate the publication growing over the time; (ii) geographic coordinates and (iii) biome in which the study area occurred, which enabled to assess spatial gaps in the studies; (iv) number of species found, informing about the diversity in such areas; (v) total area of study location, used

to weight comparison of diversity among different studies; (vi) data source, assessing whether the data came from herbariums or from field studies; (vii) complementary sampling methods, evaluating if species list is complemented with other methods like phytophysiognomy and phytosociology; and (viii) number of sampling units (ix) sampling time, which gave us some sampling design details and tendencies.

We found 44 studies, among research papers and book chapters (Supplementary Material), which did not show a growth trend of publications over the years (Fig. 1). The few studies and the lack of growth evidence demonstrate that few attention is given to floristic studies in this ecotone by the scientific community, despite the importance of the flora on maintaining key ecosystem functions for the restingas' environmental dynamics (Santos & Silva, 2012).

The existing knowledge gap is more substantial in some portions of the North and Northeast coast due to the concentration of studies in some states and localities (Fig. 2). Therefore, floristic studies in restinga are disproportionately distributed along the coast, with a more significant gap in the northern portion, especially in the states of Ceará and the Rio Grande do Norte (Fig. 2). We also observed that most studies were conducted near the state capitals, showing that logistical factors, such as access and proximity to research centers, probably interfere with the selection of study areas (Hortal et al., 2008, 2015).

Most studies were conducted in the Atlantic Forest ($N = 27$), but a portion of them were conducted in the Amazon ($N = 10$) or transition areas of these or other biomes ($N = 7$). The number of studies per biome are proportional to their range extension according to the area constrain of this review. However, it is essential to emphasize the importance of conducting surveys in all biomes, especially in transitional areas, which may reveal important biodiversity patterns and community structuring rules. The restingas are naturally transitional systems and possess a flora with unique characteristics (Freire, 1990; Rizzini, 1979; Assumpção & Nascimento, 2000; Cerqueira, 2000).

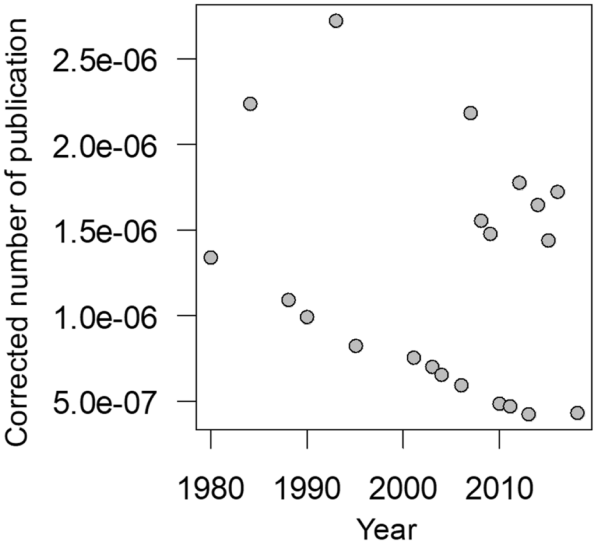

Fig. 1 Absence of relations between the number of floristic studies conducted in restingas in Northern and Northeastern Brazil and year of publication (Linear regression: $R^2 = 0.06$, $p = 0.30$)

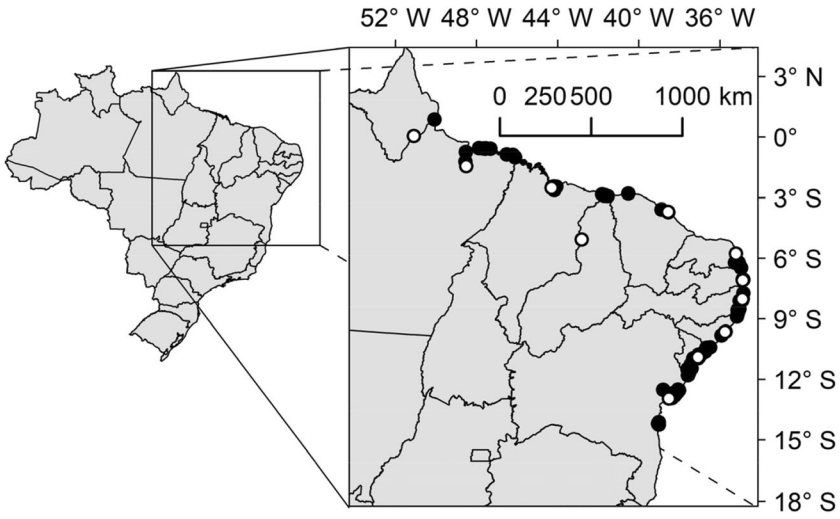

Fig. 2 Distribution of floristic studies conducted in restingas in Northern and Northeastern of Brazil. Left panel -The Brazilian states and a box representing the target area of study. Right panel - geographical location of the studies in the reviewed papers (black dots) and state capitals (white dots)

Consequently, the study of restinga in transitional areas between biomes may confer higher uniqueness to such regions and reveal a complex response system to heterogeneity.

The observed species richness ranged from 47 to 250 in study areas and from 37 to 194,000 ha. This richness is, in general, inferior to the core area of the Cerrado and Amazon biomes, which vary between 120 and 301 and 130–432, respectively, in a study areas with similar extensions (e.g. Weiser & Godoy, 2001; Costa et al., 2004; Oliveira & Amaral, 2004; Tannus & Assis, 2004; Ishara et al., 2008; Rossatto et al., 2008; Carvalho et al., 2010; Ishara & Maimoni-Rodella, 2012). However, it is noteworthy that, due to the limiting factors that influence the vegetation, comparisons with the flora of other ecosystems require caution regarding the particularities of the restinga environment.

The reviewed research exposes methodological trends and sometimes lack of information that interferes in comparative analysis. Most studies used new field data (70.4%), a minority merged field and herbarium data (15.9%) or exclusively used herbarium data (9.09%). Some studies (16.3%) complemented the floristic inventory with other sampling methods, such as phytophysiognomy and phytosociology. However, the key methodological issue was the lack of information to determine sufficiency of sampling effort, such as the total sampled area and the sampling time, whose gaps were of respectively 45.4% and 34.1%.

The variability of species richness and the lack of methodological information may be generating biases in the characterization of the biodiversity patterns in restingas. Species richness could be related to ecological aspects (e.g., areas within the boundaries of a single biome or in a transition between two or more biomes), or due to methodological differences (such as total time in the field and methodology used). Therefore, we verified whether the observed species richness (in logarithmic scale) is influenced by the biome in which the research was conducted (Amazon, Atlantic Forest or

Table 1 Predictive ability of the variables to describe species richness in floristic inventories in Northern and Northeastern Brazilian restingas, calculated using a Covariance Analysis

Variable	DF	F value
Sampling time	1	3.55
Sampled biome	2	0.02
Data source (field and/or herbarium)	2	11.30*
Residue	23	

$p < 0.001$

transition), sampling time (months), or the data source (field, herbarium or both). This evaluation was performed through a covariance analysis (ANCOVA), conducted in the program R version 3.5.1 by 'stats' package (R Core Team, 2017). Our results revealed that neither the biome nor the sampling time influenced the observed richness (Table 1). In contrast, the data source affected the total richness observed, as studies using partially or fully herbarium data have higher species richness (Table 1 and Fig. 3). Therefore, we found a methodological bias that interferes with the description of richness patterns in restingas. Our study demonstrates the need for standardization of studies in restingas on North and Northeast Brazil, allowing comparison with other studies or even generalization of the results found.

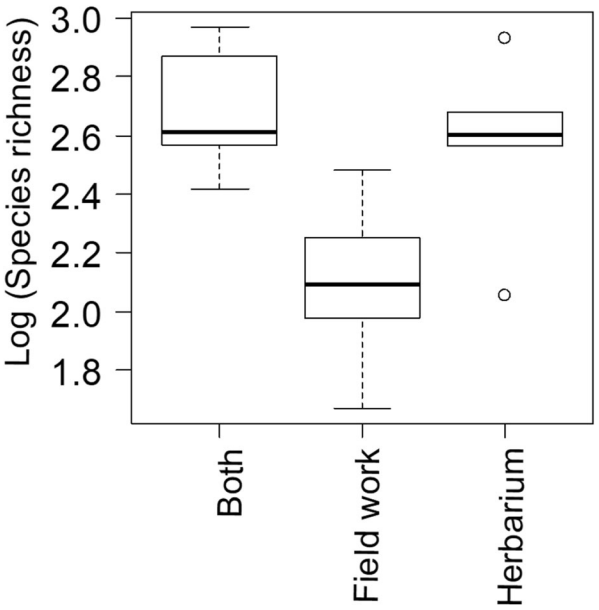

Fig. 3 The difference between the averages of species richness (in logarithmic scale) found on the reviewed literature according to the data source (field, herbarium, or both)

Conclusion

The restingas are distinct due to the full range of factors that modulate their biodiversity, creating complex gradients and intricate patterns (Fernandes, 1998; Scarano, 2002). Such complexity has made it difficult to standardize methodologies to make restinga studies comparable along the Brazilian coast.

Despite over 100 years of studies conducted in Brazilian restingas, systematization was slow until the beginning of the twenty-first century. Since then, significant advances occurred in the area, like the standardization of phytophysiognomies classification. However, more attention should be given to fundamental aspects of the studies being conducted in restingas of North and Northeast Brazil, especially detailing the methodological information that allows the comparison among studies.

The systematization of the studies ensures a good trade-off between specificity and generality, allowing both adequate local characterization and systematization for regional comparisons. Thus, the inclusion of some information would enable studies, such as this review, to identify and synthesize biodiversity patterns at spatial scales and organizational levels higher than those at which the studies were developed. This is a trend in science worldwide, but still scarce in many research areas, which can generate critical products for the topic under investigation.

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