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Research Article

Distribution and Conservation of *Davilla* (Dilleniaceae) in Brazilian Atlantic Forest Using Ecological Niche Modeling

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We have modeled the ecological niche for 12 plant species belonging to the genus *Davilla* (Dilleniaceae) which occur in the Atlantic Forest of Brazil. This group includes endemic species lianas threatened by extinction and is therefore a useful indicator for forest areas requiring conservation. The aims are to compare the distribution and richness of species within the protected areas, assessing the degree of protection and gap analysis of reserves for this group. We used the Maxent algorithm with environmental and occurrence data, and produced geographic distribution maps. The results show that high species richness occurs in forest and coastal forest of Espírito Santo to Bahia states. The endemic species comprise *D. flexuosa, D. macrocarpa, D. flexuosa, D. grandifolia*, and *D. sessilifolia*. In the Atlantic Forest of southeastern Brazil, the following endemic species occur: *D. tintinnabulata* and *D. glaziovii*, with this latter species being included in the "red list" due habitat loss and predatory extractivism. The indicators of species richness in the coastal region of Bahia correspond with floristic inventories that point to this area having a high biodiversity. Although this region has several protected areas, there are gaps in reserves, which, combined with anthropogenic threats and fragmentation, have caused several problems for biodiversity.

1. Introduction

About two-thirds of all plant species occur in the tropics, largely in the tropical humid forests, representing the most diverse terrestrial biomes on the planet [1, 2]. Brazil alone has nearly 19% of the world's flora, with more than 56,000 species (excluding fungi) [3]. This enormous biodiversity lies in the biggest and most complex biomes such as the Amazonian, the Atlantic Rain Forest (ARF), and Cerrado. With the exception of the Amazon, the Atlantic Forest (AF) and Cerrado are world's biodiversity *hotspots* [4]. The question "how many species are there" persists; in fact, we do not know [5], since the estimate of the probable number of flowering plants should grow between 10 and 20 percent due to taxonomic effort over time [6]. Of the species found since 1990 that occur in only one region, almost 80 percent inhabit biodiversity hotspots [7].

The Atlantic Rain Forest (ARF) has one of highest biodiversity ratings on the planet. Inventories reveal that in just one hectare of ARF there may be up to 476 species of plants [8], and a density of 144 tree species has been observed in only 0.1 hectare in southern Bahia, with this being one of the greatest numbers of tree species in Brazil and in the world [9]. This forest is considered one of the world's most important sites for biodiversity conservation [2], since within this biome there are regions with differing levels of species richness, species composition, and endemism [9]. However, the future of this biodiversity is now threatened due to expected high extinction rates [5], mainly in tropical forests [10]. Factors such as high human population densities in *hotspots* lead to rapid environmental changes and consequently the extinction of species; this is therefore a crucial factor in the conservation of global biodiversity [11]. There were nine biodiversity *hotspots* with less than 30% forest cover, and of the total 5 million km^2 of forest cover the Atlantic Forest has only 353,000 km^2 of its original area, and approximately 96,000 km^2 of this is in protected reserves [12]. Thus, because of their endangered *status* and high number of endemic species, it becomes a major challenge to conserve their biodiversity [13].

The fascinating question of how plants and animals are distributed on Earth, in space and time, has a long history which has inspired many biogeographers and ecologists to seek explanations [14]. New answers to these questions are emerging with the use of species distribution models (SDMs). These have become an important tool for understanding the geographic distribution, addressing varied applicabilities [14, 15], including assessing biodiversity patterns aiming at developing conservation strategies [16, 17].

With the ability to predict species' distributions with statistical confidence, broader assessments of distributional patterns across entire biotas become feasible [15]. Thus, the advance in SDMs allows us to potentially forecast anthropogenic effects on patterns of biodiversity at different spatial scales [14]. In this case, the SDM incorporate as one of their cornerstones habitat modeling approaches to create and update species distributions data [16].

There are several ways to propose conservation measures. Among them we highlight the presence of endangered species, regions with high rates of endemism, areas with high biodiversity, distribution areas of rare species, remnants or conserved areas under threat, and so forth [16, 18]. Overall, we need a holistic approach to solve conservation problems [19]. For example, after generating the predicted ranges, the next step consists of overlaying these distributions with the geographical extent of the protected areas network, thus identifying existing "gaps"—species that are not represented in the network—and providing potential locations for the future expansion or creation of new protected areas [16, 20].

The aim of this paper is to produce results on the geographical distribution of *Davilla* species (Dilleniaceae), an important genus which has numerous lianas representatives in several areas of Brazilian Atlantic Forest, including endangered species. Due to the fact that the *Davilla* has centers of diversity in the Atlantic Forest, especially in areas of coastal forests (Restingas), beyond the Cerrado and Amazon Rainforest [21, 22], this group shows an interesting diversity in terms of geographical distribution of its species, including rare and vulnerable species, one of them is threatened with extinction [22, 23] and, therefore, useful in conservation process. Thus, such information may be valuable in order to generate new information that will add to other efforts to learn the patterns of distribution and species richness of the Atlantic Forest. The evidence shows that the use of SDMs has been enormously useful and that conservation would benefit from a more explicit and structured integration of these techniques into basic monitoring programmes of the governmental agencies, NGOs, academia, and the private sector.

2. Methodology

2.1. Study Area. This study is targeted at the Atlantic Forest biome which covers about 1.3 million km^2 in the east coast of Brazil and small portions of eastern Paraguay and the Misiones Province in Argentina [24]. This is formed by a set of forest formations (Dense ombrophilous, mixed ombrophilous, open ombrophilous, semideciduous, and deciduous) and associated ecosystems such as Restinga forest, mangroves, and high-altitude fields [24]. Even after intensive deforestation that reduced and fragmented the Atlantic Forest, estimates indicate that there are at least 20,000 plant species, representing about 35% of the total found in Brazil, and with a high rate of endemic and endangered species [24]. This richness is higher than some whole continents (17,000 species in North America and 12,500 in Europe) and therefore the Atlantic Forest region is a high priority to the conservation of global biodiversity [25].

Table 1: *Davilla* species list from Atlantic Forest.

Species	Habit	Range
(1) *D. angustifolia* A.St.-Hil.	Liana	MG and BA
(2) *D. cuspidulata* Mart. ex Eichler	Liana	MG and BA
(3) *D. flexuosa* A.St.-Hil.	Liana	ES and BA
(4) *D. glaziovii* Eichler	Subarbusto	End RJ
(5) *D. grandifolia* Moric. ex Eichl.	Liana	BA and ES
(6) *D. kunthii* A.St.-Hil.	Liana	Neotr.
(7) *D. latifolia* Casar.	Liana	SP, MG, ES, BA
(8) *D. nitida* (Valh.) Kub.	Liana	Neotr.
(9) *D. macrocarpa* Eichler	Liana	End BA and ES
(10) *D. rugosa* Poir.	Liana	BRA
(11) *D. sessilifolia* Fraga	Liana	End BA
(12) *D. tintinnabulata* Schlechtd.	Liana	SP and RJ

Legend: BA—Bahia; End—endemic; ES—Espírito Santo; MG—Minas Gerais; Neotr—Neotropical; SP—São Paulo; RJ—Rio de Janeiro.

2.2. Occurrence Data. In this study, we used 1520 occurrence records of 12 species belonging to the botanical genus *Davilla* (Dilleniaceae) (Table 1). The occurrence data were extracted from the database SpeciesLink and selected only data with reliable identification by experts. The species list for Atlantic Forest according to: *The Plant List* (2010), Version 1 published on the Internet; http://www.theplantlist.org/ (accessed 1st January). These data included ecological and geographical information. The coordinates of species were converted to decimal degrees and saved in csv format to 4 decimal places.

2.3. Environmental and Cartographic Data. We used climate and ecological data derived from the environmental database Ambidata, Division of Image Processing of INPE (DPI), available at (http://www.dpi.inpe.br/Ambdata/download.php), which produced the best AUC values (see below). Cartographic data as boundaries of political stats from Brazil were also obtained from the Brazilian Ministry of Environment (MMA—http://mapas.mma.gov.br/) and the Brazilian Institute of Geography and Statistics (IBGE—available at: http://www.ibge.gov.br/).

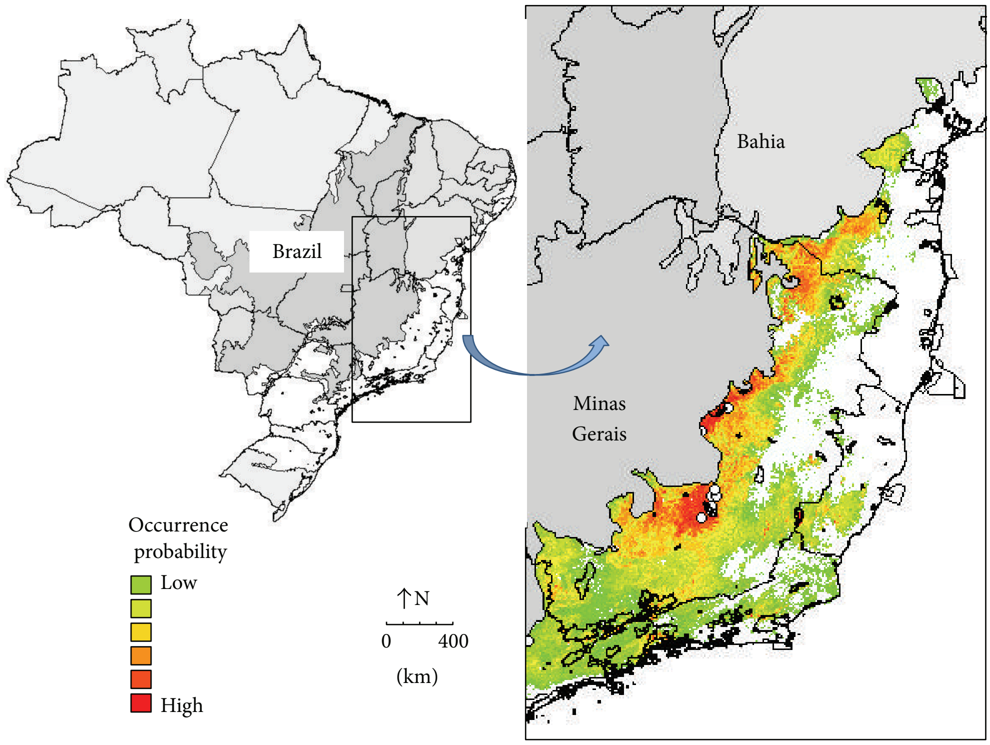

Figure 1: Distributional range of *Davilla angustifolia* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.971.

2.4. Procedure of Modeling. For the modeling procedure, we used the Maxent algorithm [26] that produces modeling of the geographical distribution based on maximum entropy. It used the option to output the results as logistic and included random testing of 25%, while all other functions were standards of the program. The results generated are images that represent the probability of occurrence in a different color scale, indicating that conditions are appropriate (close to 1), and gradually changing to inadequate (values close to 0). These images were subsequently processed into maps using the program DIVA GIS 7.1.7 for insertion of the limits of political and environmental drives in geographic space.

As a statistical measure that shows the efficiency of the model was generated area under the curve (AUC), which measures the ability of the models to correctly classify whether a species is present or absent [27]. The AUC value can be interpreted as a probability, where an area with the presence (closer to 1) and absence (closer to 0) is randomly evaluated.

3. Results

The results showed that most species of *Davilla* occurs in coastline from the states of Espírito Santo to Bahia (see Figures 2–9). The endemic species of the region included *D. flexuosa* (Figure 3), *D. grandifolia* (Figure 4(a)), *D. macrocarpa* (Figure 7(a)), and *D. sessilifolia* (Figure 9(a)). Besides these species, *D. angustifolia* (Figure 1), *D. cuspidulata* (Figure 2), *D. kunthii* (Figure 5), and *D. nitida* (Figure 7(b)) also occur in this region but are also present in other biomes such the Amazon and Cerrado. Furthermore, *D. glaziovii* (Figure 4(b)), *D. latifolia* (Figure 6), *D. rugosa* (Figure 8), and *D. tintinnabulata* (Figure 9(b)) occur predominantly in the Atlantic Forest in the Southeastern region of Brazil (São Paulo, Minas Gerais, Rio de Janeiro, and Espirito Santo). Among those, *Davilla glaziovii* (Figure 4(b)) is endangered and occurs in a restricted area in Rio de Janeiro.

Regarding the distribution of individual species, these showed the following patterns: *Davilla cuspidulata* and *D. flexuosa, D. grandifolia* and *D. macrocarpa* are partially sympatric in AF (Figures 2, 3, 4(a), and 7(a)). These species were found from the north of the Espirito Santo extending in range to the coastal region just north of Reconcavo of Bahia, which corresponds to the region of the capital Salvador. The modeling indicated areas adjacent to collection points as potential areas for the occurrence of these species (see all Figures). *Davilla sessilifolia* (Figure 9(a)) is a restricted range area to north of the Bahia recôncavo, supported by the modeling results. *Davilla latifolia* occurs in Minas Gerais and Espírito Santo, although the modeling indicates the potential occurrence from Serra of Mar in Rio de Janeiro and Bahia (Figure 6). *Davilla rugosa* occurs in the AF in Minas Gerais and São Paulo, and ranges from the Serra do Mar in Rio de Janeiro and Espírito Santo to recôncavo baiano (Figure 8). *Davilla glaziovii* (Figure 4(b)) *D. tintinnabulata* (Figure 9(b)) are two of the rarest species in the group. The first of these is an endemic in the Serras of Mendanha and Couto in Rio de Janeiro (Figure 4(b)), whereas the second occurs only in Atlantic Forest in Serra of Mantiqueira on the border of the states of São Paulo and Rio de Janeiro (Figure 9(b)).

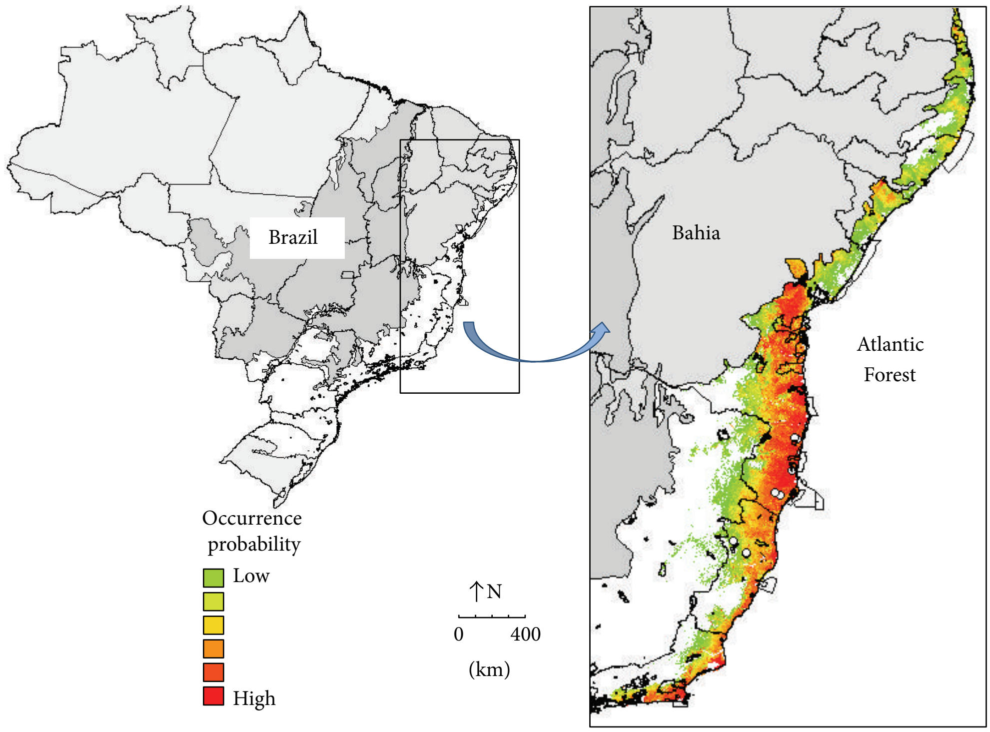

FIGURE 2: Distributional range of *Davilla cuspidulata* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.990.

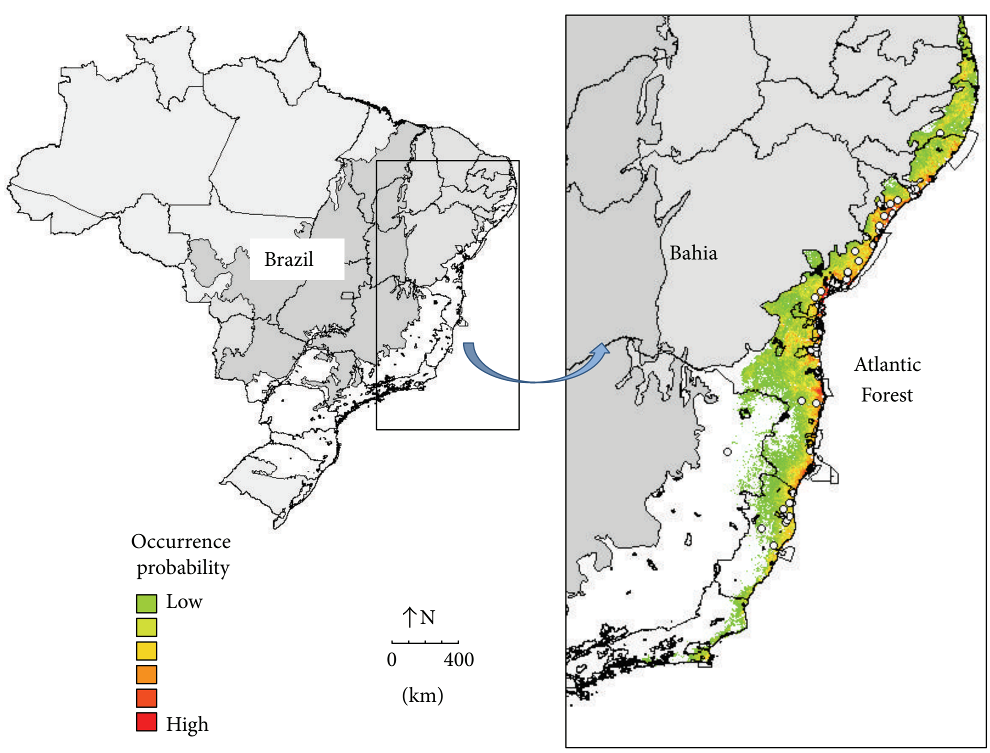

FIGURE 3: Distributional range of *Davilla flexuosa* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.990.

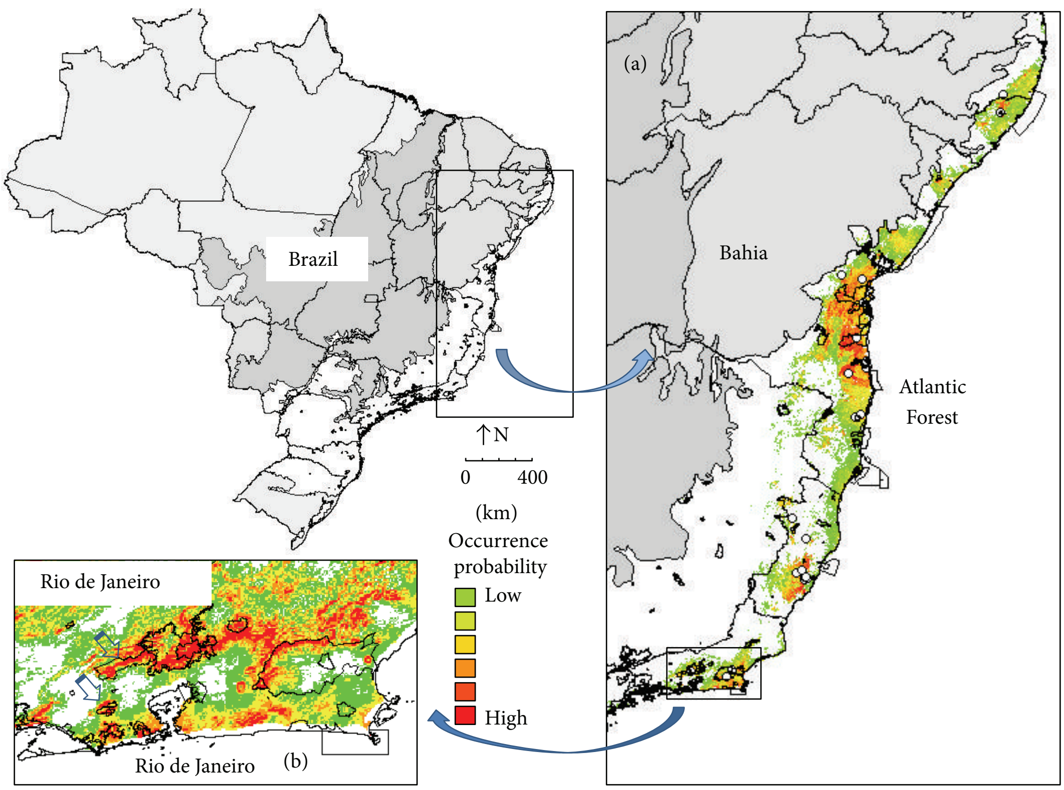

Figure 4: Distributional range of *Davilla grandifolia* (a) and *Davilla glaziovii* (b) in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.958 and 0.996, respectively.

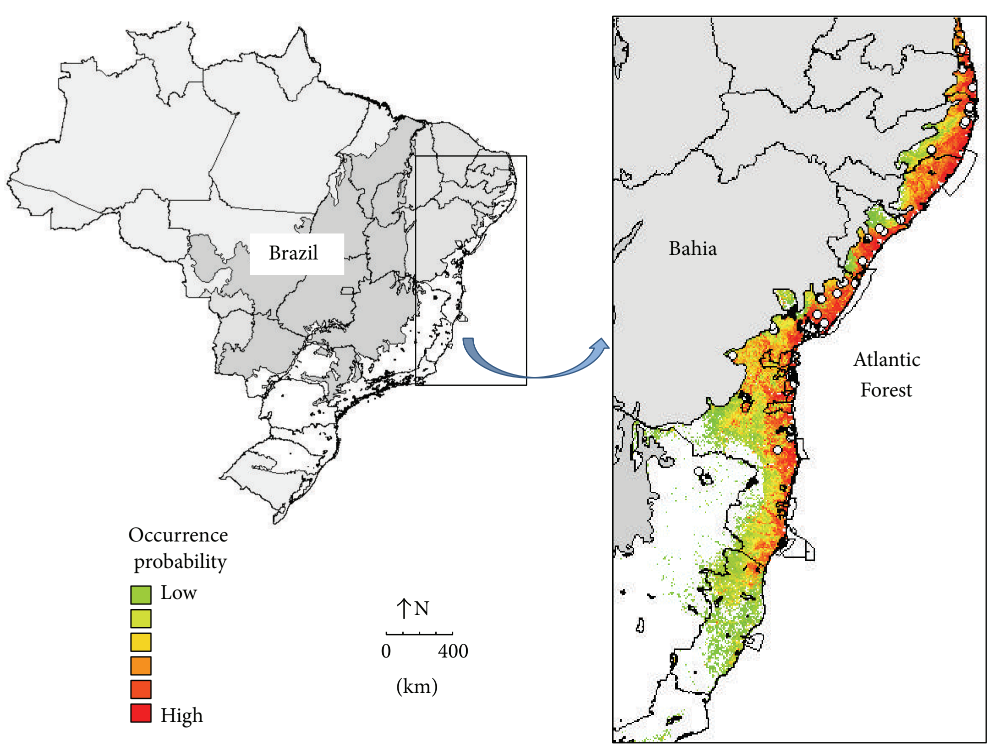

Figure 5: Distributional range of *Davilla kunthii* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.924.

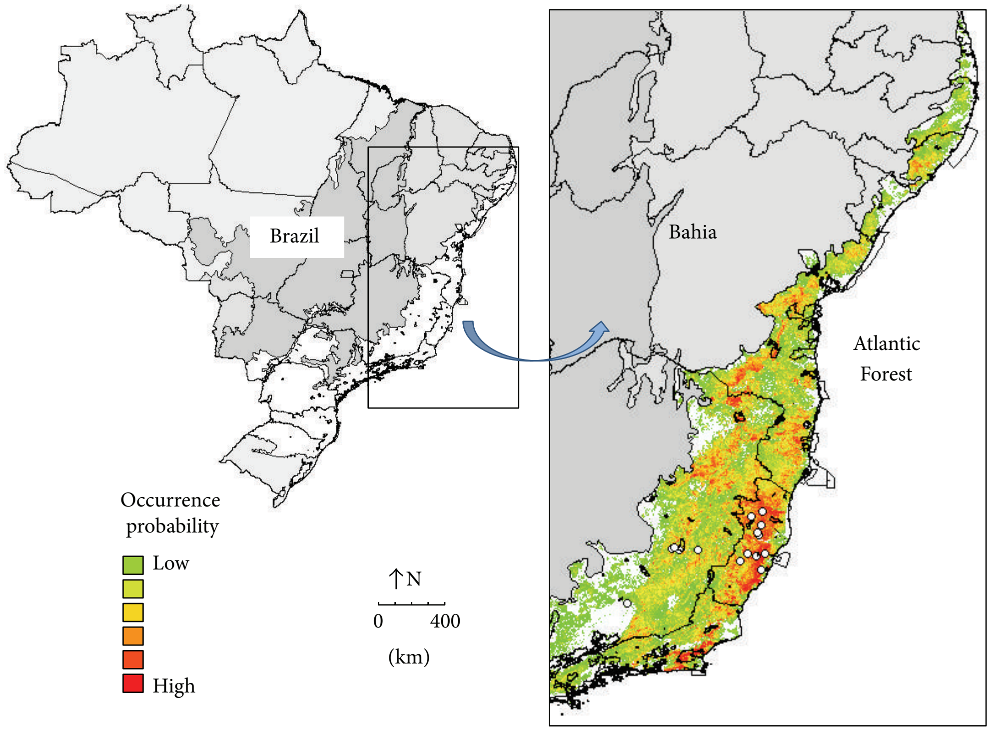

Figure 6: Distributional range of *Davilla latifolia* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.989.

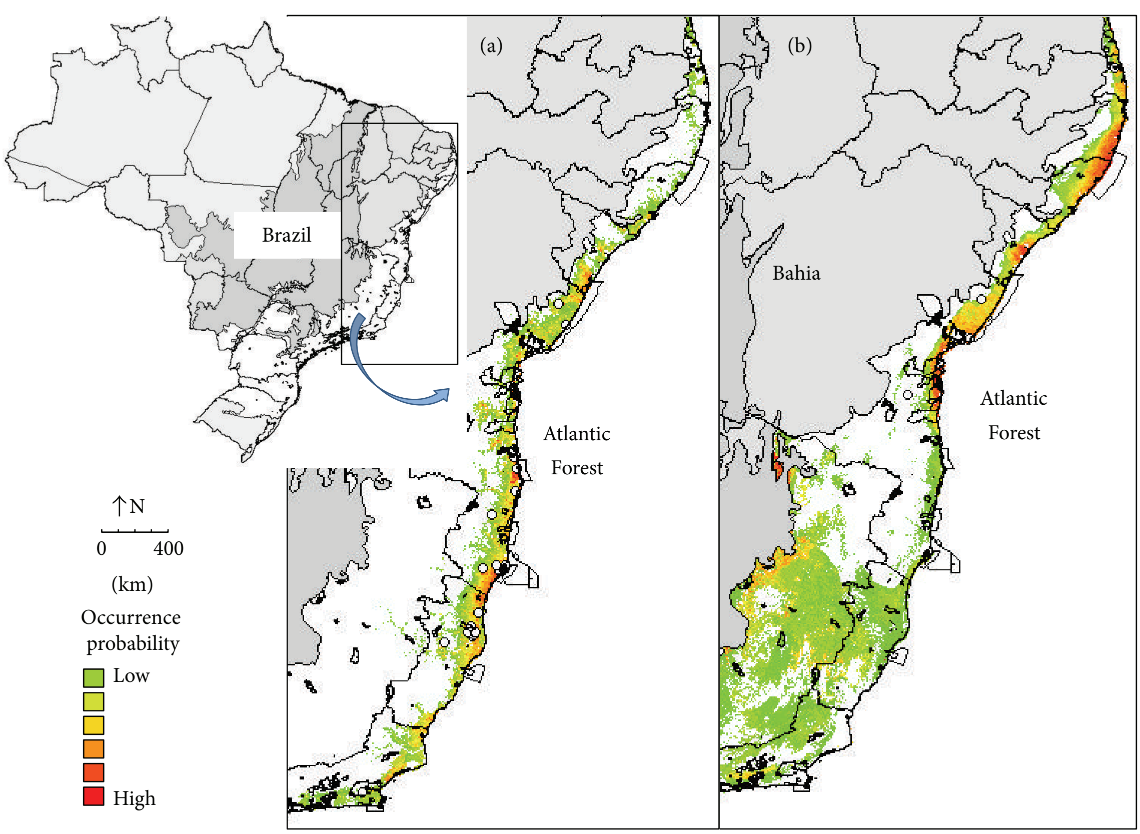

Figure 7: Distributional range of *Davilla macrocarpa* (a) and *D. nitida* (b) in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.997.

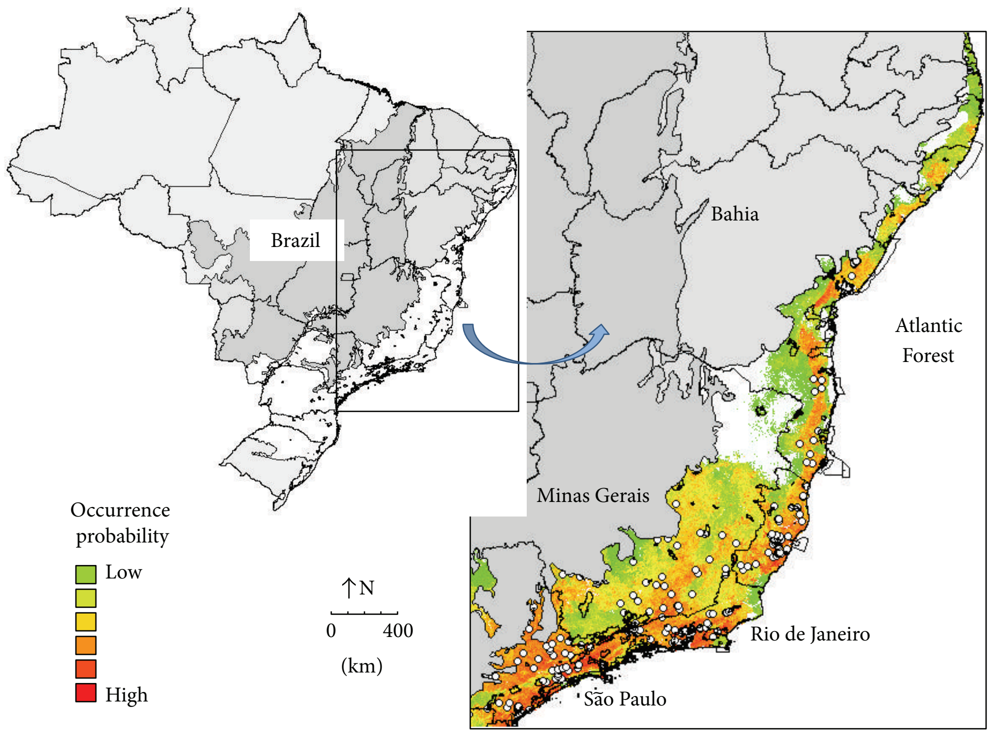

Figure 8: Distributional range of *Davilla rugosa* in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.934.

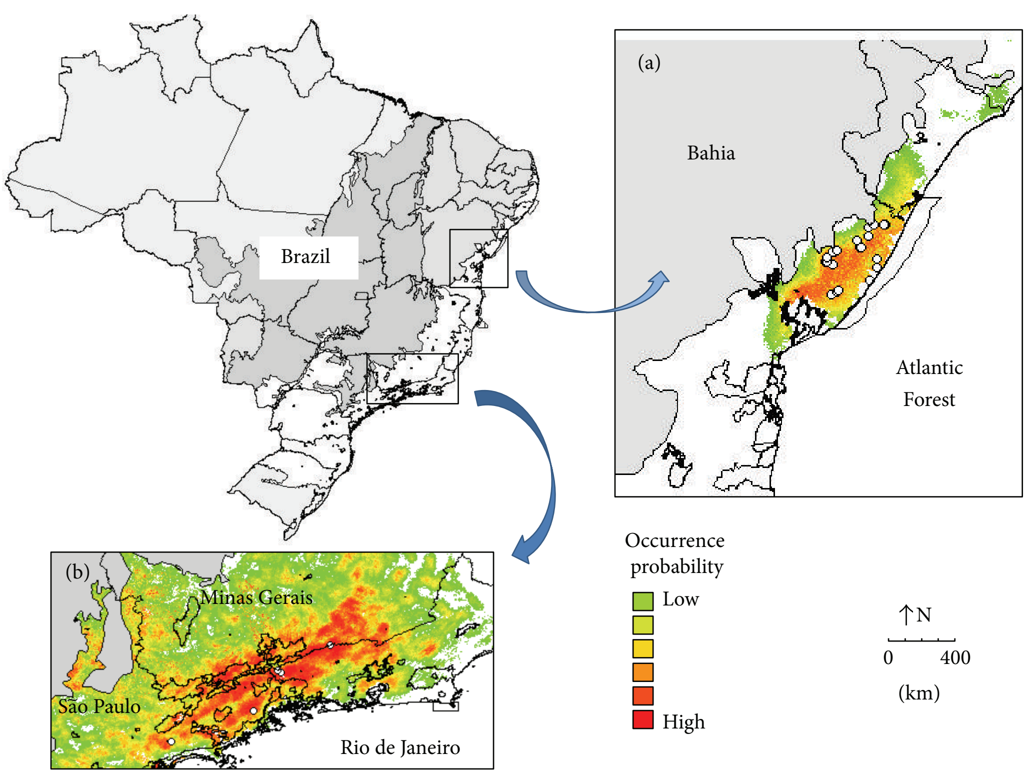

Figure 9: Distributional range of *Davilla sessilifolia* (a) and *Davilla tintinnabulata* (b) in Atlantic Forest. Legend: colors indicate high and low probability of occurrence. AUC = 0.999 and 0.998, respectively.

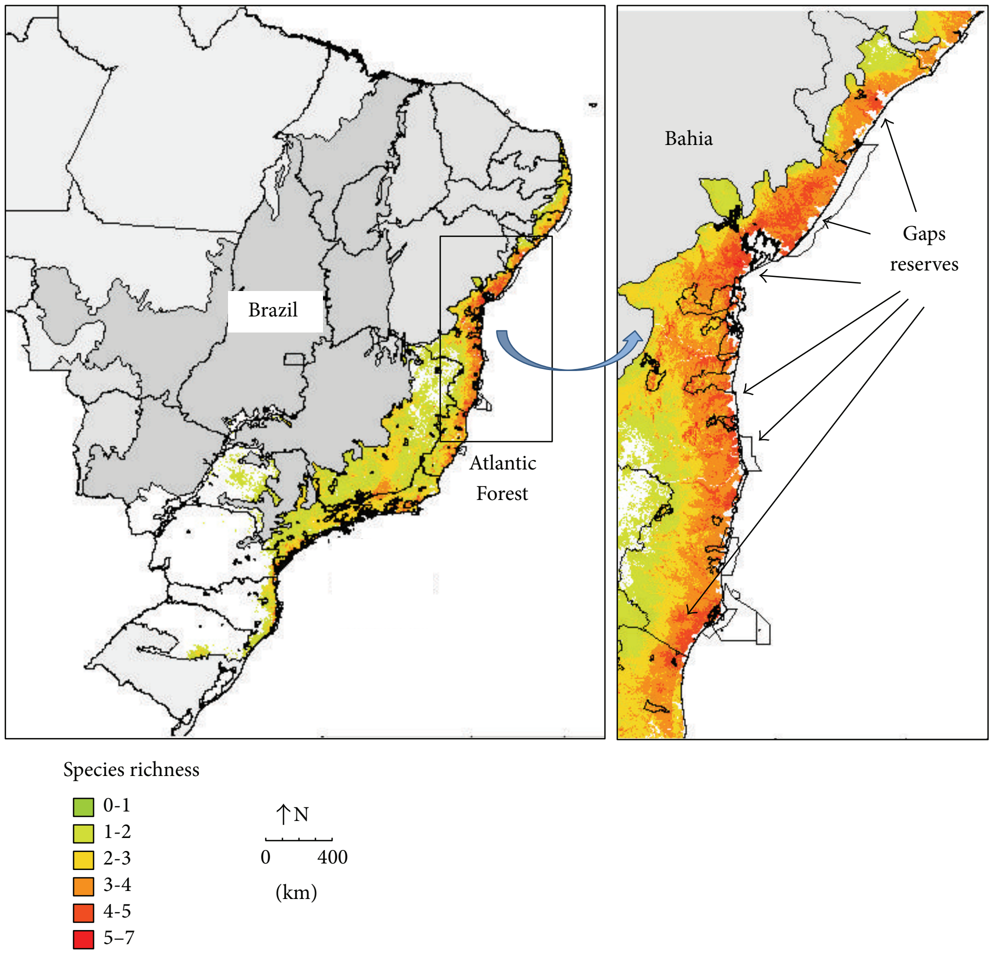

Figure 10: Species richness to *Davilla*, network of reserves and reserves gaps in the Atlantic Forest. Legend: dark colors (red) represent higher species richness, while light colors (yellow and green) represent smaller species richness.

Regarding the distribution of richness and endemic species, it was observed that the coastal region of Bahia, between the coastline of the states of Espírito Santo to Sergipe, contains 5–7 species, considering the richness species area. This region has the most protected areas but is also a highly populated and fragmented region (see Figure 10).

4. Discussion

The Atlantic Forest (AF) supports one of the highest species richness and rates of endemism on the planet, representing the world's richest repository of terrestrial biodiversity, but has also undergone a huge forest loss [28]. The forests also support the livelihoods of a substantial proportion of the world's population and are the source of many internationally traded commodities [29]. Due to these factors the AF has become one of the world's 25 biodiversity hotspots [4]. The conservation of these *hotspots* is critical because they harbor even greater amounts of evolutionary history than expected by species numbers alone [30]. The combination of all these factors and the conservation of AF are a major challenge [19].

First, it is important to understand the causes of these changes and the drivers of deforestation; for example, the economic agents that play a critical role in deforestation [31], the extent of overexploitation and fragmentation, and so forth. Second it is necessary to know the species range, as a holistic approach is needed to solve conservation problems.

The AF continues to suffer under severe anthropogenic pressure, risking imminent extinction of some of the remaining species [32]. The author [33] notes that, of the threats to biological diversity in southeastern Brazil, habitat destruction and the overexploitation of species are perhaps the two most important. Whilst the growing human population puts considerable pressure on biological resources, a number of social and economic factors tend to augment overexploitation of these resources; for example, a study showed that the overexploitation of the tropical palm tree *Euterpe edulis* Mart. [24], as a consequence of social problems, has contributed significantly to its extinction in several forest fragments [33]. Similarly the species, *Davilla glaziovii* "Herb of Santa Luzia," endemic to the Atlantic Forest in the Serra of Mendanha and Couto, in Rio de Janeiro City, is listed as an endangered species [24] due to high level of anthropogenic threats, including habitat loss and irrational exploitation [34], thus requiring subsidies to maintain the conservation of these species. Other studies predict that, by 2050, human land-use practices will have reduced the habitat available, for example to Amazonian plant species, to such an extent that this will result in species becoming “committed to extinction,” and contrary to previous studies, showing that the primary determinant of habitat loss and extinction risk is not the size of a species’ range but rather its location [35].

The Atlantic Forest is one of the most threatened tropical biomes, with much of the standing forest in small, disturbed, and isolated patches [36]. Moreover, studies revealed a serious situation for AF: more than 80% of the fragments are <50 ha, almost half the remaining forest is <100 m from its edges, the average distance between fragments is large (1440 m), and nature reserves protect only 9% of the remaining forest and 1% of the original forest [28]. Evidence of negative effects suggests that specialist ants (especially cryptic species, specialist predators, and climate specialists) are particularly sensitive to forest fragmentation [37].

Overall, the FA has about 8,000 endemic species, of which vascular plants are 6,933 [24], and due to such anthropogenic threats at least 530 plants and animals are officially endangered, some at the biome level and nationally, others globally, since they are not found in protected areas, indicating the need to rationalize and expand the current system of protected areas [13]. Although conservation initiatives have grown in number and scale during the last two decades, they are in many cases insufficient to ensure the conservation of biodiversity of the Atlantic Forest [13]. In this case, as defined by the percentage of the species extent of occurrence that must overlap protected areas for the species, where this is not represented in any protected area, it is considered a gap species, while a species that meets only a portion of its representation target is considered a partial gap species [38]. Protection for these species is urgently necessary.

The AF is the center of diversity for Dilleniaceae with at least 36 species [22], with 12 of them belonging to the genus *Davilla*, which are liana plants and shrubs found in the forests and restingas. Although *Davillas* are few in number in the AF, some are among themost typical representatives into this biome, for example, *Davilla rugosa* [39]. However, any group of organisms used for conservation, such as *Davilla*, does not necessarily need criteria such as “threatened,” an economic value, and so forth [40] since these are valuable in themselves [41]. Moreover the overall goal of biodiversity management will usually be to maintain or restore biodiversity, not to maximize species richness [19]. Anyway most of its species are endemic, restricted in distribution to only a few localities, and in specific vegetation types. Among these, *D. sessilifolia* was recently described for the state of Bahia [23]. Owing to this rarity, combined with anthropogenic threats on species and their habitats, it therefore becomes an interesting group to study on their contribution to the knowledge of biodiversity and conservation.

The modeling results indicated that the center of diversity of the genus *Davilla* occurs in forest in the biogeographic region of Bahia [28], comprising the coastal area of the states of Espírito Santo and Bahia. These results agree with other studies addressing the flora which have shown high biodiversity and endemism [42], since in the Sierra Conduru, southeast of Bahia, one of the highest rates of floristic biodiversity on the planet was detected [28]. At this location there are several protected areas such as Serra Conduru State Park; National Parks of Discovery and Monte Pascoal, the Una Biological Reserve, the Environmental Protection Area (APA) of Trancoso, the Lagoa Encantada, the coast Itacari/Serra Grande, the Caminho Ecológico of Boa Esperança, and the Extractive Reserve of Cassurubá, among others, which belong to the conservation units located in the State of Bahia. In addition to these, we have the Rio Preto National Park in the Espírito Santo and APA Bacia do São João-Golden Lion Tamarin in Rio de Janeiro, which are the main conservation areas covering areas indicated as high biodiversity for *Davilla*. However, note that the reserves such as the National and State Parks are scarce and small, while the vast majority is Environmental Preservation Areas (APA), mainly located in the Bahia state. Thus, excepting this region, it is found that there are vast areas indicated with high biodiversity wealth and gaps reserves, which are indicated as priority for the creation of new protected areas. This consideration is also based on the fact that there is evidence that some types of vegetation, such as coastal forest restingas, are still poorly protected; for example, only 14,000 ha of restingas are protected as the single federal conservation unit in the country (Restinga de Jurubatiba National Park) [43].

Thus, the present conservation networks are insufficient to support the long-term survival of this rich and endangered tropical forest, and urgent conservation and restoration actions should be implemented to mitigate this situation, based on careful planning and with clear targets [28]. To the question of small and isolated remnants of AF, the author [36] indicates that dynamic regeneration in Atlantic Forest could be of great importance for biodiversity conservation due to the potential effects of young secondary forests in reducing forest isolation and maintaining a significant amount of the original biodiversity. In addition, there are some recent advances, such as the creation of National Parks Alto Cariri, Boa Nova e Serra of Lontras, of the Wildlife Refuge of Boa Nova, the addition to the expansion of the National Park Pau Brazil, totaling more than 65,000 hectares of new protected areas. For the Atlantic Forest of Bahia, this represents an increase of about 60% area in units of integral conservation and a 5% increase in total units of conservation, considering both the full protection and sustainable use. Values are significant, considering that the Atlantic Forest biome is the one with the smallest area of original coverage.

5. Conclusions

The indicators of species richness for *Davilla* in the coastal region of Bahia correspond with floristic inventories that point to this area having a high biodiversity. Moreover, although this region has several protected areas, there are gaps in reserves, which, combined with anthropogenic threats and fragmentation, have caused several problems for biodiversity. In this case, we emphasize the need to increase the coverage of protected areas and also management concerning the use of natural resources, thereby avoiding biodiversity loss.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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