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Original article

Diversity of the *Passiflora* L. in the Serra do Mar ecoregion and the relationships with environmental gradients, South and Southeast, Brazil

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ABSTRACT

The species of the *Passiflora* (Passifloraceae *s.s.*) are distributed in tropical and subtropical regions and are of great ecological importance. The Serra do Mar is formed of large escarpments along Brazil's east coast, between the States of Rio de Janeiro and Rio Grande do Sul. This study aims to point out occurrences of *Passiflora* species in herbaria along the Serra do Mar, in addition to evaluating the conditions of each specimen found. The richness and sample effort maps were prepared to establish the locations where the greatest numbers of species and records were encountered. We evaluated the relationship of species distribution through Canonical Correlation (CCA) and Quadratic Polynomial Analysis. We also evaluated the floristic composition using a cluster analysis. Calculations of the Extent of Occurrence (EOO) and Area of Occupancy (AOO) were performed for endemic species to the Atlantic Forest area occurring in the Serra do Mar. A total of 53 species, belonging to the *Passiflora* were found in the Serra do Mar. The States of Rio de Janeiro and São Paulo were the ones that recorded the greatest numbers of species and collection effort. The climatic variables Precipitation of the Driest Quarter and Annual Average Temperature are the most correlated to the distribution of *Passiflora* in the area. Twenty-two species are endemic to the Atlantic Forest area, and 21 are recorded as having some degree of threat on Official Lists. In this study, we present all the *Passiflora* species recorded for the Serra do Mar, the richness of species, including those endemics to the Atlantic Forest, demonstrates the importance of the area for conservation.

Keywords: Atlantic Forest, Conservation, Diversity, Mountainous Range, Passionflower, Serra do Mar.

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Introduction

The passionflower species known are part of the genus *Passiflora* L. (Passifloraceae *sensu stricto*) and are characterized by woody and herbaceous climbers with tendrils, alternate leave, axillar tendrils, and extrafloral nectaries in the petiole and/or leaf blades; flowers with androgynophore and filament corona, five stamens, three or four carpels, and a locule and berried or capsuled fruit (Milward-de-Azevedo *et al.* 2012).

Brazil records about 166 species belonging to the *Passiflora* L. (Bernacci *et al.* 2020), divided into four subgenera: *Astrophea* (DC.) Mast., *Decaloba* (DC.) Rchb., *Deidamioides* (Harms) Killip and *Passiflora*. Studies of this genus in the state of Rio de Janeiro: Pessoa (1994; 1996), Milward-de-Azevedo *et al.* (2004), Milward-de-Azevedo and Baumgratz (2004), Milward-de-Azevedo and Fernandes (2021), and Fernandes *et al.* (2022), and in the state of São Paulo: Cervi (1992), Bernacci and Vitta (1999) and Bernacci (2003), have collaborated so that both states have a larger number of recorded species and greater collection effort in the areas. In the Atlantic Forest Domain in South of Brazil, studies from Cervi (1981) for Paraná, Sacco (1962; 1980), for the Rio Grande do Sul and Santa Catarina, respectively, and only Rio Grande do Sul: Mäder *et al.* (2009) and Mondin *et al.* (2011). In general, for Brazil, we have: Cervi (1997; 2000), Nunes (2009), Milward-de-Azevedo *et al.* (2012), and Mezzonato-Pires *et al.* (2020). Regarding the ecology and conservation of the group, some studies covering the Serra do Mar ecoregion, namely Moraes *et al.* (2020), Milward-de-Azevedo and Fernandes (2021) and Fernandes *et al.* (2022). Thus, the existence of collection gaps regarding species distribution is a factor to be considered.

The original limits of the Serra do Mar coastal forests ecoregion are inserted entirely in the Atlantic domain, in the Rio de Janeiro, São Paulo, Paraná, Santa Catarina e Rio Grande do Sul states (WWF 2008). This ecoregion is defined as an extensive area, with heterogeneous environmental conditions that determine the occurrence of communities that share critical ecological processes (Dinerstein *et al.* 1995). Its forest fragments are interconnected by escarpment regions, where agricultural activities are not possible, contributing to it being one of the largest forest extensions of the Atlantic Forest (WWF 2008).

Passiflora species are directly linked to environmental filters and respond significantly to gradients. Studies such as Kessler (2002), Ocampo-Pérez *et al.* (2007) Ocampo *et al.* (2010), Moraes *et al.* (2018; 2020), and Fernandes *et al.* (2022) demonstrate the complex relationships between these taxa and the environment where they occur. Environmental filters that include total area considered, latitude, altitude, precipitation, and the interactions between them demonstrate the complexity of these relationships with *Passiflora* (Lomolino 2001; McCain 2009).

Therefore, this study aimed to evaluate the distribution patterns of *Passiflora* in the Serra do Mar and its relationship with environmental variables. Moreover, we assessed the of conservation status of the species found and identified possible collection gaps in the study area.

Material and methods

The original area of the Serra do Mar corresponds to 113,411 km², covering 364 municipalities (Table S1), inserted in the States of Rio de Janeiro, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul (Fig. 1), in Brazil's South and Southeast regions (WWF 2008). The vegetation classifications vary from *Restinga* to Highland Fields, passing through Ombrophilous Forest Low Montane, Montane, and Upper Montane Ombrophilous Forests, in addition to Deciduous and Semi-Deciduous Seasonal Forests (WWF 2008). The exact geomorphological delimitation of the Serra do Mar and its geographic limits is still not a consensus among authors. The revised limits of the Serra that include the state of Espírito Santo is a complex approach due to the considerable size of the area and for belonging to another ecoregion (RBMA 2008; WWF 2008). In addition, most studies for the Serra do Mar are carried out on a one-off basis (e.g., Barros *et al.* 2009; Cortines *et al.* 2011; Fernandes *et al.* 2022), which makes it difficult to effectively define the boundaries of the area. Thus, we chose to use the original limit of the Serra do Mar ecoregion, where the area is continuously delimited, and we excluded the disjoint part of the limits revised by WWF (2008) that includes the state of Espírito Santo. Therefore, we used 364 municipalities, and the area was divided into grids corresponding to the points of occurrence.

Data collection - Occurrence data for *Passiflora* inside the Serra do Mar were obtained from specimen samples deposited herbariums (license SISGEN A387E5D), available on systems of scientific collection management, such as *Species Link* (http://inct.florabrasil.net/), JABOT (http://jbrj.gov.br), and Reflora (http://reflora.jbrj.gov.br/). All municipalities in the Serra do Mar area were examined (Table S1), and the search for material was performed for each one of them separately. We used records of species defined by specialists of the group for materials without exsiccate images available. In addition, the specimens were checked using exsiccate images available on the website, to define unidentified material and to confirm species when necessary. Then we confirmed and reviewed the taxonomic nomenclature according to Tropicos.org (https://www.tropicos.org/home.aspx?langid=66), Flora do Brasil 2020 (http://floradobrasil.jbrj.gov.br/), and International Plant Names Index (https://www.ipni.org/).

Spatial analysis– Through the locations provided by the collectors, the geographical coordinates obtained were plotted superimposed on the shapefile of the Serra

do Mar (WWF 2008), in the QGIS software version 3.16 (QGIS DEVELOPMENT TEAM 2020), and occurrence was compared with the area boundaries. Within these aspects, we evaluated the distribution pattern of the species utilizing the same software with 0.50º × 0.50º squares, to analyze *Passiflora* richness and the collection effort in the Serra do Mar area.

The altitude values were extracted from the information contained in the descriptions of the exsiccates. When the values were not presented, the altitude data were extracted from the point of occurrence, with the help of the WorldClim (Fick & Hijmans 2017) elevation raster, together with QGIS software version 3.16 (QGIS DEVELOPMENT TEAM 2020). To standardize the classes and avoid data bias, presence/absence matrices were computed in 11 altitude classes spaced at 199 meters intervals, in an altitudinal gradient from 0 to 2,199 (i.e., 0-199, 200–399, 400–599, 600-799, 800-999, 1,000- 1,199, 1,200- 1,399, 1,400-1,599, 1,600-1,799, 1,800, 1,999–1,999, 2.000–2,199), then we used polynomial analysis to evaluate the relation of the altitude with the richness of *Passiflora*.

We obtained 19 bioclimatic variables from the WorldClim database (available at: https://www.worldclim.org/) (Fick & Hijmans 2017). The average values of the variables were extracted from each grid of the Serra do Mar (Fig. 1). For the election of the best bioclimatic variables, we used a Factorial Analysis like Sobral-Souza *et al*. (2015). We choose as final variables, based on the highest absolute values, Annual Mean Temperature (BIO1), Precipitation of Wettest Month (BIO 13), Precipitation Seasonality (Coefficient of Variation) (BIO15), Precipitation of Driest Quarter (BIO17) and Precipitation of Warmest Quarter (BIO18). We also added collected the number of records to test the possible effect of sample bias.

Thus, to evaluate the correlation of the *Passiflora* composition in the Serra do Mar with the environmental gradients, we used the Canonical Correspondence Analysis (CCA) (Braak 1987). The species abundance matrix consisted of the number of individuals per grid. The matrix of environmental variables included the mean values of the five selected bioclimatic and the collection effort per grid. All previous analyzes were performed in the R program version 4.0.3 (R Development Core Team 2020).

To graphically represent the result, we also performed a quadratic polynomial regression analysis to test the relationship of the richness (dependent variable) in the function of the bioclimatic variables of temperature and precipitation (independent variables), obtained from the CCA, using the Past 1.8.1 - Paleontological Statistics software (Hammer *et al*. 2008). In addition, we performed the overlap of species occurrence with the rasters layers of bioclimatic variables.

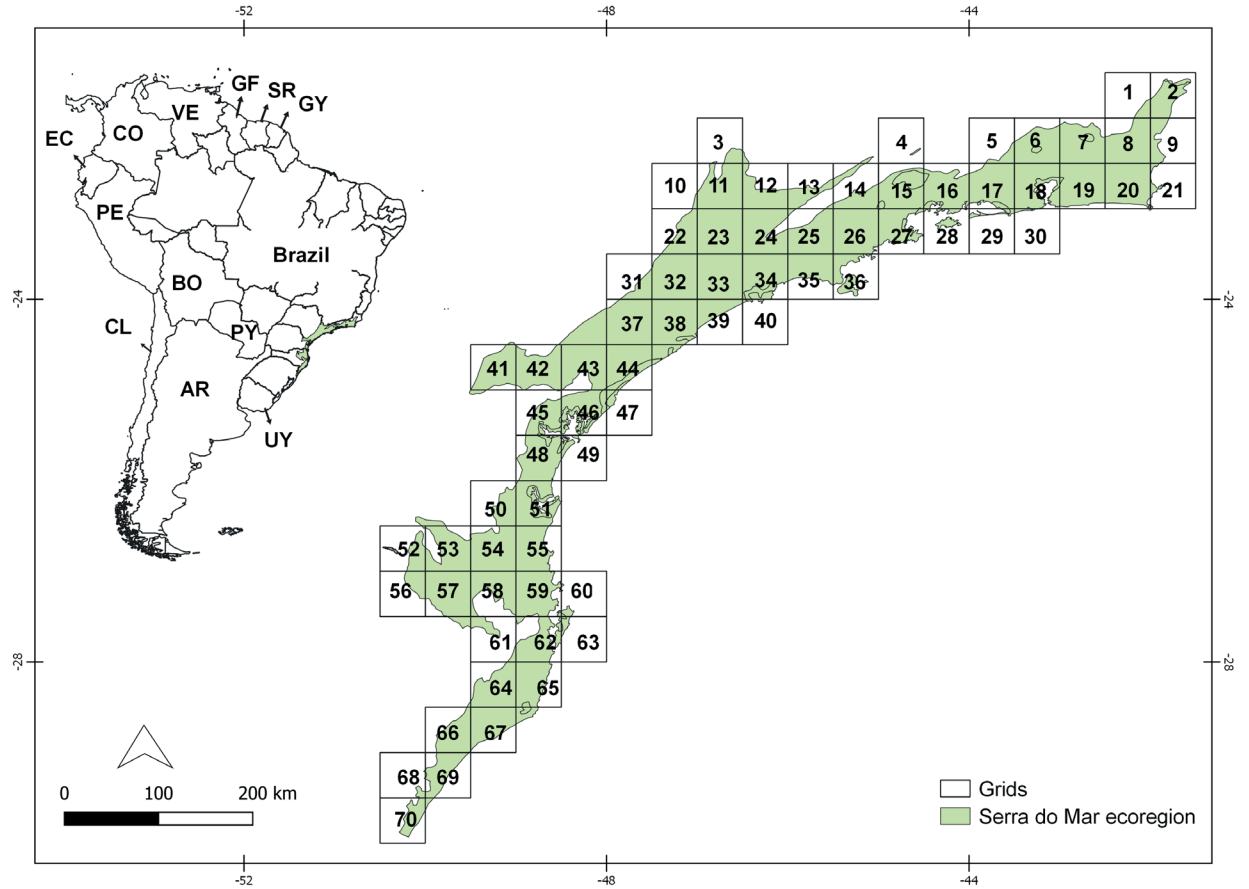

Figure 1. Original boundaries of the Serra do Mar ecoregion, South and Southeast Brazil, with 0.5° × 0.5° cells utilized in the analyses.

Conservation - Calculations of Extent of Occurrence (EOO) and Area of Occupancy (AOO) were performed to evaluate the status of conservation of endemic Atlantic Forest species found in the Serra do Mar and compared to national and state lists as well as other studies, to point out the category that species already evaluated were inserted (Cervi 1997; CONSEMA 2003; Bernacci 2003; SMA-SP 2004; 2016; Bernacci *et al*. 2005; Biodiversitas 2005; MMA 2008; 2022; Durigon *et al*. 2009; CNCFlora 2012a.; CONSEMA 2003; 2014; Milward-de-Azevedo & Fernandes 2021). The classification of the species as endemics of the Atlantic Forest and Tropical Rain Forest was based on the Flora do Brasil. The EOO and AOO calculations were performed using the GeoCAT tool (Bachman *et al*. 2011) (http://geocat.kew.org/editor), with a 2-km grid to calculate AOO, as recommended by the IUCN (2022). For species with populations restricted the Serra do Mar territory we suggest threat categories according to International Union Conservation of Nature (IUCN) Criteria B, based on the geographical distribution of the organisms (IUCN 2022). Concerning species with one or two points of occurrence, these parameters were not evaluated, because they do not form the polygon required to perform the calculations. These species were then classified as Data Deficient (DD).

Similarity – To evaluate the floristic composition of the *Passiflora* in the Serra do Mar, the UPGMA cluster analysis with the Jaccard index was used. The occurrence grids (0.50° × 0.50°) were compared using the Biodiverse 2.1 software, which allows cluster analysis of biogeographic data (Laffan *et al*. 2010).

Results

Spatial analysis - A total of 53 species were recorded for the Serra do Mar (Tab. 1), from a total of 3,246 obtained records. Of these, 107 were discarded due to the inability to identify the material. The state with the most significant number of records was Rio de Janeiro (1,138 collections), followed by São Paulo, (1,110 collections), Santa Catarina (464 collections), Paraná (400 collections) and Rio Grande do Sul (134 collections), which obtained the smallest number of records.

Regarding species richness, the largest number was found in grids 7 and 18, in the areas more to the northeast of the Serra do Mar (the municipalities of Rio de Janeiro, Petrópolis, Teresópolis and Nova Friburgo, in the State of Rio de Janeiro) (Fig. 2a). At the same time, grid 18 showed

Table 1. Occurrence of *Passiflora* L. (Passifloraceae *s.s.*) species in the Serra do Mar, in the South and Southeast Regions of Brazil. PR = Paraná; RJ = Rio de Janeiro; RS = Rio Grande do Sul; SC = Santa Catarina; SP = São Paulo.

Specie	Grids	Records	Occurence by state	Vegetation
Passiflora actinia Hook	18	131	RJ, SP, PR, RS, SC	Ombrophilous Forest and Seasonal Forest
Passiflora alata Curtis	37	169	RJ, SP, PR, RS, SC	Ombrophilous Forest, Seasonal Forest and Restinga
Passiflora amethystina Mikan	41	345	SP, RJ, PR, RS, SC	Ombrophilous Forest
Passiflora caerulea L.	7	14	RJ, SP, PR, RS, SC	Ombrophilous Forest and Seasonal Forest
Passiflora campanulata Mast.	10	47	RJ, SP, PR, SC	Highland Fields
Passiflora capsularis L.	46	193	SP, RJ, PR, RS, SC	Ombrophilous Forest, Seasonal Forest, and Restinga
Passiflora catharinensis Sacco	5	12	SP, PR, SC	Highland Fields and Ombrophilous Forest
Passiflora cervii M.A.Milward-de-Azevedo	5	6	SP, PR, RS, SC	Ombrophilous Forest, Seasonal Forest and Restinga
Passiflora cincinnata Mast.	3	3	SP	Seasonal Forest
Passiflora clathrata Mast.	3	8	SP	Seasonal Forest
Passiflora deidamioides Harms	10	26	RJ, SP	Ombrophilous Forest
Passiflora edulis Sims	48	333	RJ, SP, PR, RS, SC	Ombrophilous Forest, Seasonal Forest and Restinga
Passiflora eichleriana Mast.	17	27	SP, PR, RS, SC	Ombrophilous Forest
Passiflora elegans Mast.	3	8	SP, RS, SC	Ombrophilous Forest and Seasonal Forest
Passiflora elliptica Gardner	1	10	RJ	Ombrophilous Forest
Passiflora farneyi Pessoa & Cervi	3	15	RJ	Restinga
Passiflora filamentosa Cav.	3	3	RJ	Ombrophilous Forest
Passiflora foetida L.	11	21	RJ, SP, PR, RS, SC	Highland Fields and Ombrophilous Forest

Table 1. Cont.

Specie	Grids	Records	Occurence by state	Vegetation
Passiflora haematostigma Mart. ex Mast.	23	79	RJ, SP, PR, SC	Ombrophilous Forest
Passiflora imbeana Sacco	4	33	RJ	Ecotone: Highland Fields and Ombrophilous Forest
Passiflora ischnoclada Harms	3	21	SP	Ombrophilous Forest
Passiflora junqueirae Imig & Cervi	2	3	RJ	Ombrophilous Forest
Passiflora kermesina Link & Otto	4	22	RJ	Ombrophilous Forest and Restinga
Passiflora lepidota Mast.	1	1	SP, PR	Seasonal Forest
Passiflora loefgrenii Vitta	11	25	SP, PR, SC	Ombrophilous Forest
Passiflora malacophylla Mast.	3	6	RJ, SP, SC	Ombrophilous Forest and Seasonal Forest
Passiflora marginata Mast.	3	6	SP, RJ	Highland Fields
Passiflora mediterranea Vell.	29	160	RJ, SP, PR, SC	Ombrophilous Forest
Passiflora mendoncaei Harms	8	156	RJ, SP, PR, SC	Ombrophilous Forest
Passiflora miersii Mast.	17	165	RJ, SP, PR	Seasonal Forest
Passiflora misera Kunth	11	35	RJ, SP, PR, RS, SC	Ombrophilous Forest, Seasonal Forest and Restinga
Passiflora morifolia Mast.	8	11	SP, PR, RS, SC	Seasonal Forest
Passiflora mucronata Lam.	15	191	SP, RJ	Restinga
Passiflora odontophylla Harms ex Glaz.	2	2	RJ	Ombrophilous Forest
Passiflora ovalis Vell. ex M.Roem.	6	34	RJ, SP	Ombrophilous Forest
Passiflora pentagona Mast.	8	39	RJ	Restinga
Passiflora pohlii Mast	3	6	SP	Ombrophilous Forest and Seasonal Forest
Passiflora porophylla Vell.	40	256	RJ, SP, RS, SC	Ombrophilous Forest and Seasonal Forest
Passiflora racemosa Brot.	7	93	RJ, SP	Ombrophilous Forest
Passiflora reitzii Sacco	1	1	SC	Ombrophilous Forest
Passiflora rhamnifolia Mast.	11	32	RJ, SP	Ombrophilous Forest
Passiflora saxicola Gontsch.	2	3	RJ	Restinga
Passiflora setacea DC.	7	23	RJ	Restinga
Passiflora setulosa Killip	1	1	SP, PR	Seasonal Forest
Passiflora sidifolia M.Roem.	15	65	RJ, SP	Ombrophilous Forest
Passiflora silvestris Vell.	7	34	RJ	Restinga
Passiflora speciosa Gardner	4	31	RJ	Ombrophilous Forest
Passiflora suberosa subsp. *litoralis* (Kunth) Port.-Utl. ex M.A.M. Azevedo, Baumgratz & Gonç.-Estev.	32	150	RJ, SP, PR, RS, SC	Ombrophilous Forest, Seasonal Forest and Restinga
Passiflora tenuifila Killip	7	7	RJ, SP, PR, RS, SC	Ombrophilous Forest and Seasonal Forest
Passiflora transversalis M.A.Milward-de-Azevedo	2	2	SP, PR, RS, SC	Ombrophilous Forest
Passiflora truncata Regel	18	69	RJ, SP, PR, SC	Ombrophilous Forest
Passiflora vellozoii Gardner	13	88	RJ, MG, SP, PR, SC	Ombrophilous Forest
Passiflora villosa Vell.	6	25	RJ, SP, PR, SC	Ombrophilous Forest

the greatest number of efforts (in the municipalities of Rio de Janeiro, Petrópolis and Teresópolis, in the State of Rio de Janeiro), followed by grids 4 and 5, also to the northeast of the Serra do Mar (Fig. 2b). The most representative species in Serra do Mar considering the number of records, is *P. amethystina* Mikan with 345 occurrences, and *P. porophylla* Vell. with 256. Among the species recorded in the Serra do Mar, 22 are endemic to the Atlantic Forest and 12 are restricted to Tropical Rain Forest environments (Tab. 1).

The quadratic polynomial analysis relating *Passiflora* species richness to altitude showed a decrease in the number of species as a function of the increase in altitude gradient (Figure 3 a-b) (R^2=80%, p=0.001). The greatest richness was found between an altitude range between 1-199 m.a.s.l. presenting 40 species, followed by the range between 600-899 m.a.s.l. with 39 species. Furthermore, the lowest richness was recorded above 2,000 m.a.s.l. with only one species.

The results of the canonical correlation analysis show the highest eigenvalues of the first axis, representing a strong gradient. Despite having a lower value, the second axis was also highly correlated (Table 2). Five corresponding variables were found, where two of them showed the highest correlation, the Annual Average Temperature (BIO 1) highly explained on axis 1 and the Precipitation of the Driest Quarter (BIO 17) highly explained on axis 2 (Fig. 4). The Monte Carlo permutation test indicated a relationship between species composition and environmental variables in the ordination axes (p=0.001).

Table 2. Results of the Canonical Correlation Analysis (CCA) with the five variables most correlated with the species richness of *Passiflora* L., in Serra do Mar, Brazil.

CCA	Axe I	Axe II
Eigenvalue	0.3960	0.2908
Proportion Explained	0.3842	0.2822
Cumulative Proportion	0.3842	0.6664
Variables		
Annual Mean Temperature (BIO 1)	**0.7935**	-0.2796
Precipitation of Wettest Month (BIO 13)	-0.5016	-0.0167
Precipitation Seasonality (Coefficient of Variation) (BIO 15)	0.0461	-0.7774
Precipitation of Driest Quarter (BIO 17)	-0.2834	**0.8766**
Precipitation of Warmest Quarter (BIO 18)	-0.2995	0.2697

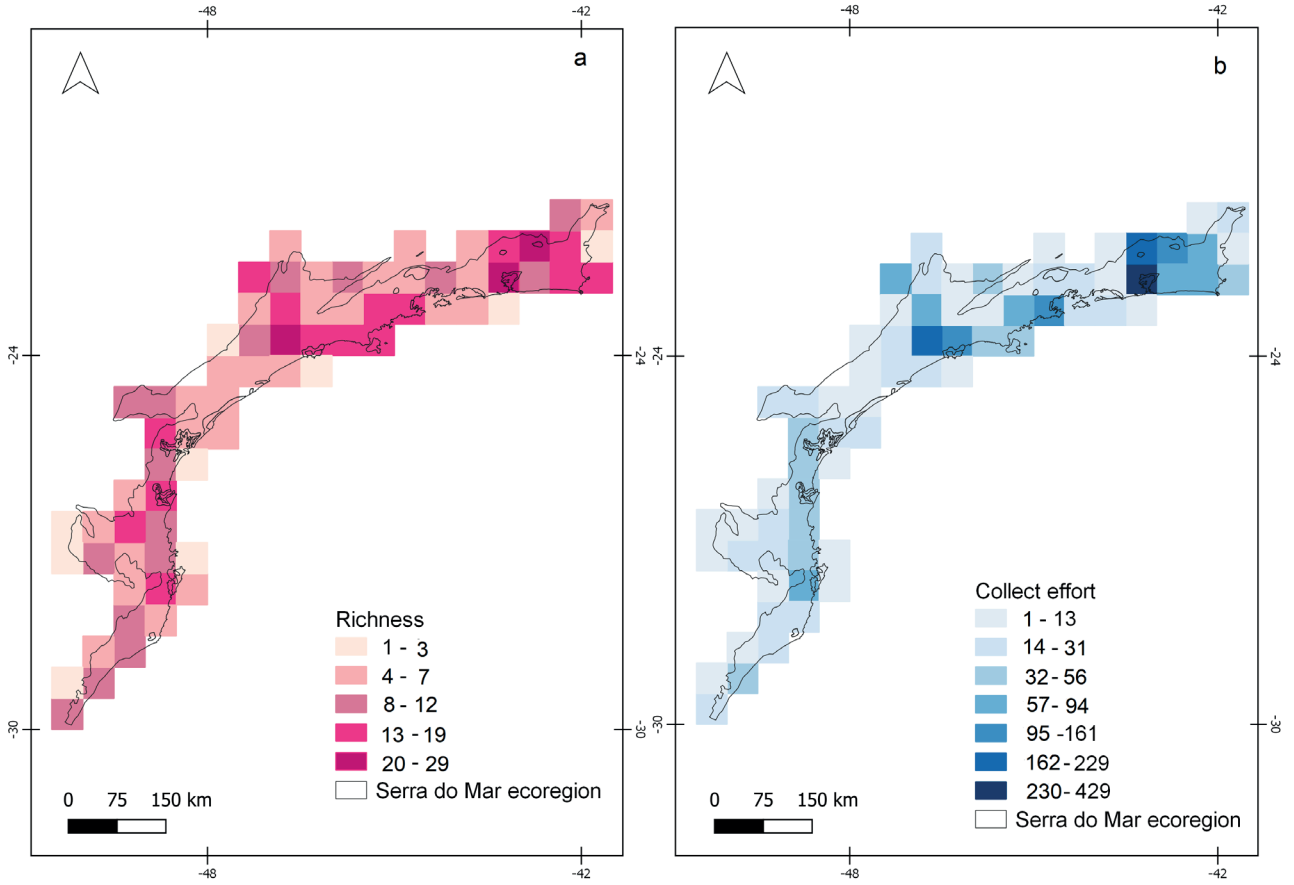

Figure 2. a. Richness of *Passiflora* L., in the Serra do Mar, in the South and Southeast Regions of Brazil; b. Collect effort of *Passiflora* L. species in the Serra do Mar, South and Southeast Brazil.

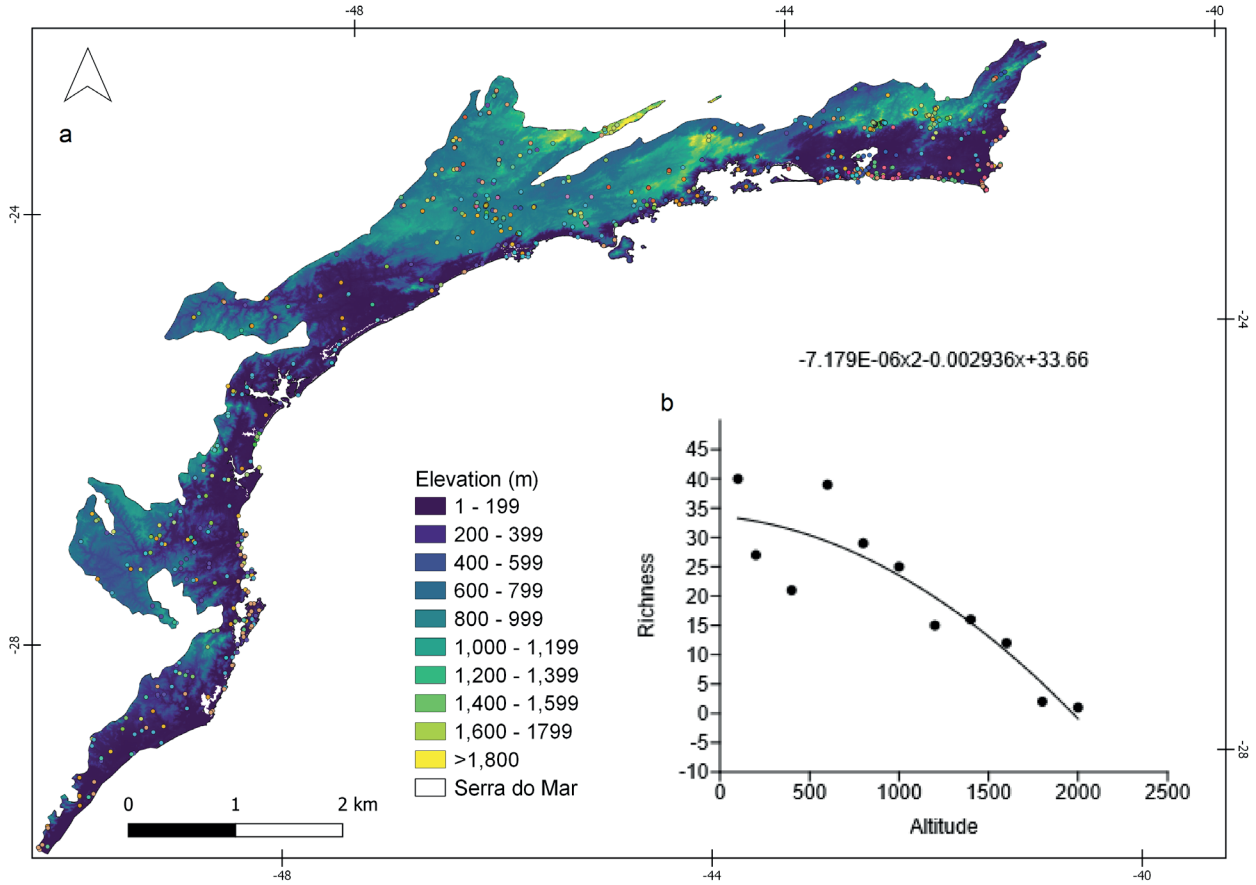

Figure 3. a. Elevation map of the Serra do Mar, Brazil; b. *Passiflora* L. species richness by altitude in the Serra do Mar, South and Southeast Brazil.

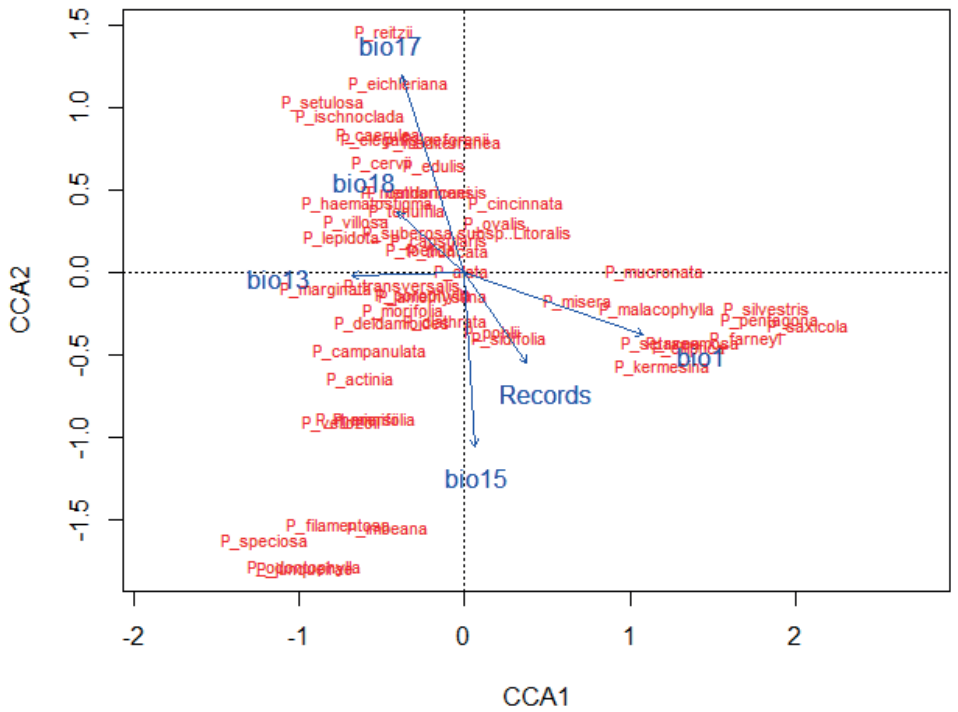

Figure 4. Results of Canonical Correspondence Analysis (CCA) with the records and five most correlated bioclimatic variables in the Serra do Mar, South and Southeast Brazil. BIO 1= Annual Mean Temperature; BIO 13= Precipitation of Wettest Month; BIO 15 = Precipitation Seasonality (Coefficient of Variation); BIO 17= Precipitation of Driest Quarter; BIO 18 = Precipitation of Warmest Quarter.

The polynomial analysis of the bioclimatic variables showed that Annual Mean Temperature had a close relationship with the number of *Passiflora* species (R^2= 80%, p=0.001) (Fig. 5 a-b), and the highest richness was recorded where the average is close to 20 °C; at low mean temperatures the richness was lower, in addition, it also tended to decrease when this average was above 23 °C. Another, of the Precipitation of the Driest Quarter, showed a negative correlation with the number of species (R^2= 66%, p=0.01), indicating a decline in richness as the average precipitation of this period increases (Fig 6 a-b).

Conservation – We found 17 threatened species among the endemic species that have already been evaluated (Table 3), *P. setulosa* Killip and *P. ischnoclada* Harms were the only ones found as "Extinct in the Wild" and "Critically Endangered" respectively. In addition, six species were presented in the "Endangered" categories and another six appeared as "Vulnerable", two species are listed as "Rare". We also suggest the categories of six species, two not yet evaluated, *P. cervii* as "Least Concern" for Extent of Occurrence and "Threatened" for Area of Occupancy, and *P. elliptica* Gardner as "Threatened" for both calculations.

Six species have their distribution restricted to the Serra do Mar territory (Tab. 3): *P. elliptica*, *P. farneyi* Pessoa & Cervi and *P. imbeana* Sacco in the State of Rio de Janeiro, *P. ischnoclada* in the State of São Paulo, *P. reitzii* Sacco in the State of Santa Catarina and *P. truncata* Regel with occurrences recorded along the entire Serra do Mar. Four of the species that showed the greatest range of distribution (AOO and EOO values) in the Serra do Mar area were the most representative: *P. actinia* Hook. had the greatest range of distribution, followed by *P. mediterranea* Vell., *P. truncata*, and *P. vellozoi* Gardner. Meanwhile, seven species showed the smallest distribution range: *P. junqueirae* Imig and Cervi (2014) with a small range of distribution, then *P. farneyi*, *P. filamentosa* Cav., *P. imbeana*, *P. ischnoclada*, *P. loefgrenii* Vitta, and *P. marginata* Mast.

Similarity - The similarity analysis considering overall composition of *Passiflora* species in the Serra do Mar (Fig. 7a), generated a dendrogram with four groups and two isolated grids (Fig. 7b). The main group (Group 3, red) concentrates a larger of grids extends all along the Serra do Mar area and groups broad-distribution species, such as *P. alata* Curtis, *P. amethystina* Mikan, *P. capsularis* L., *P. edulis* Sims, *P. haematostigma* Mart. ex Mast., *P. mediterranea* Vell., *P. porophylla* Vell. and *P. suberosa* subsp. *litoralis* (Kunth) Port.-Utl. ex M.A.M. Azevedo, Baumgratz & Gonç.-Estev. While Groups one, two and four are differentiated based on the composition in the northeast region of the Serra do Mar, harboring a variety of species with more

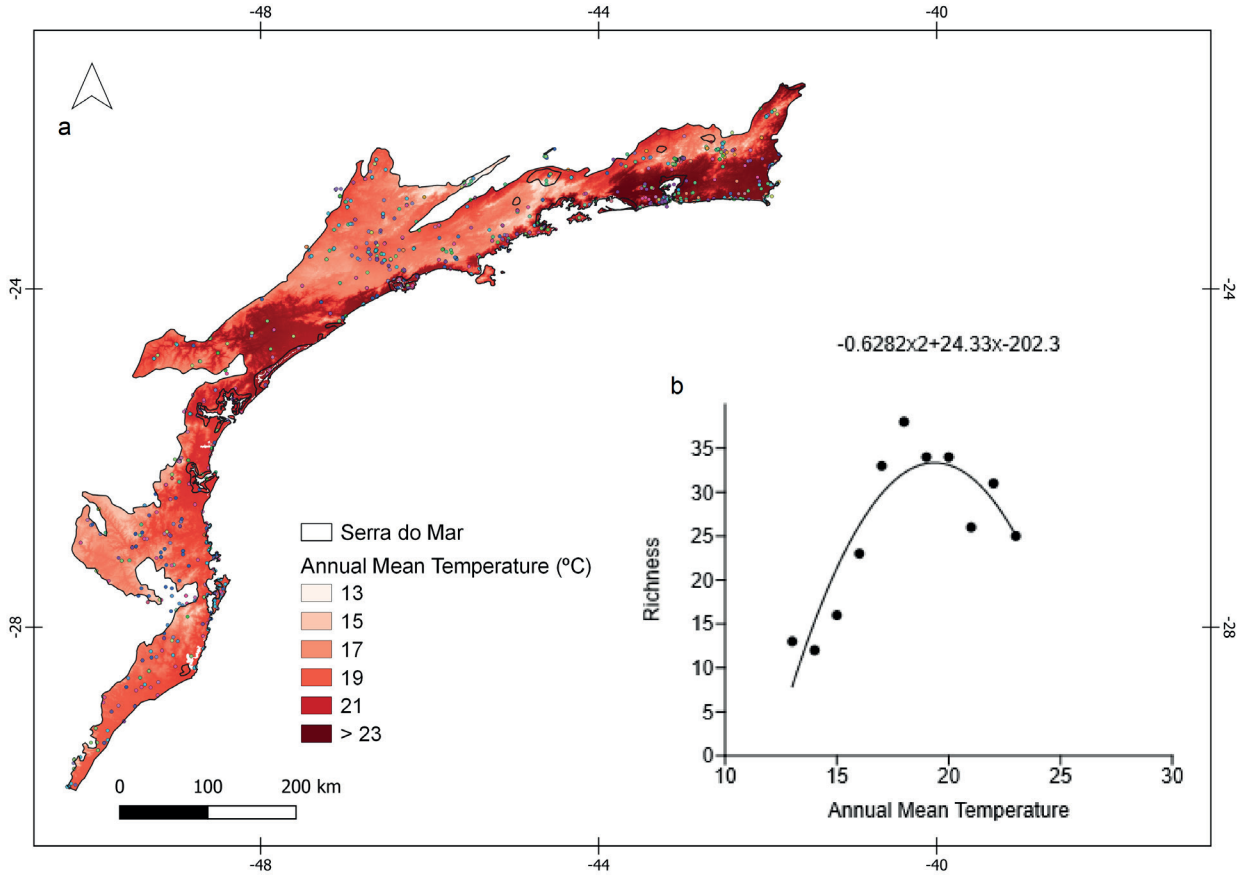

Figure 5. a. Annual Mean Temperature in the Serra do Mar, Brazil; b. *Passiflora* L. (Passifloraceae *s.s.*) species richness by annual mean temperature level in the Serra do Mar, South and Southeast Brazil.

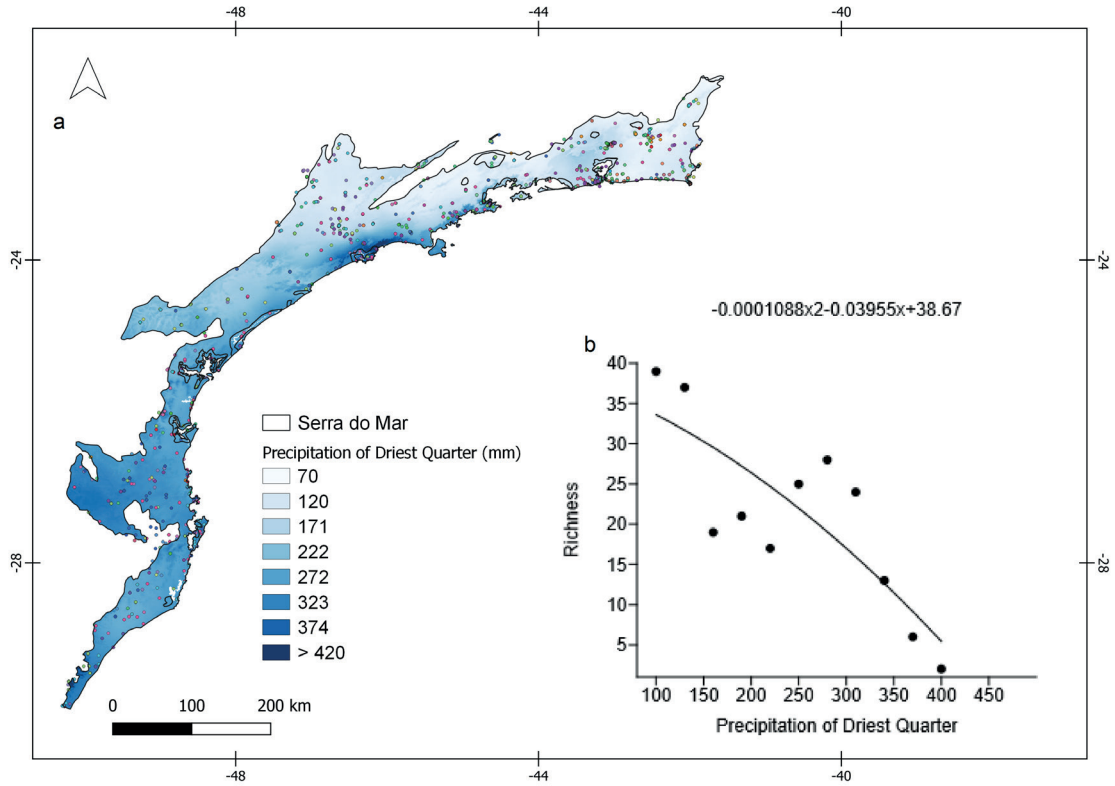

Figure 6. a. Precipitation of Driest Quarter in the Serra do Mar, Brazil; b. *Passiflora* L. (Passifloraceae *s.s.*) species richness by precipitation of driest quarter level in the Serra do Mar, South and Southeast Brazil.

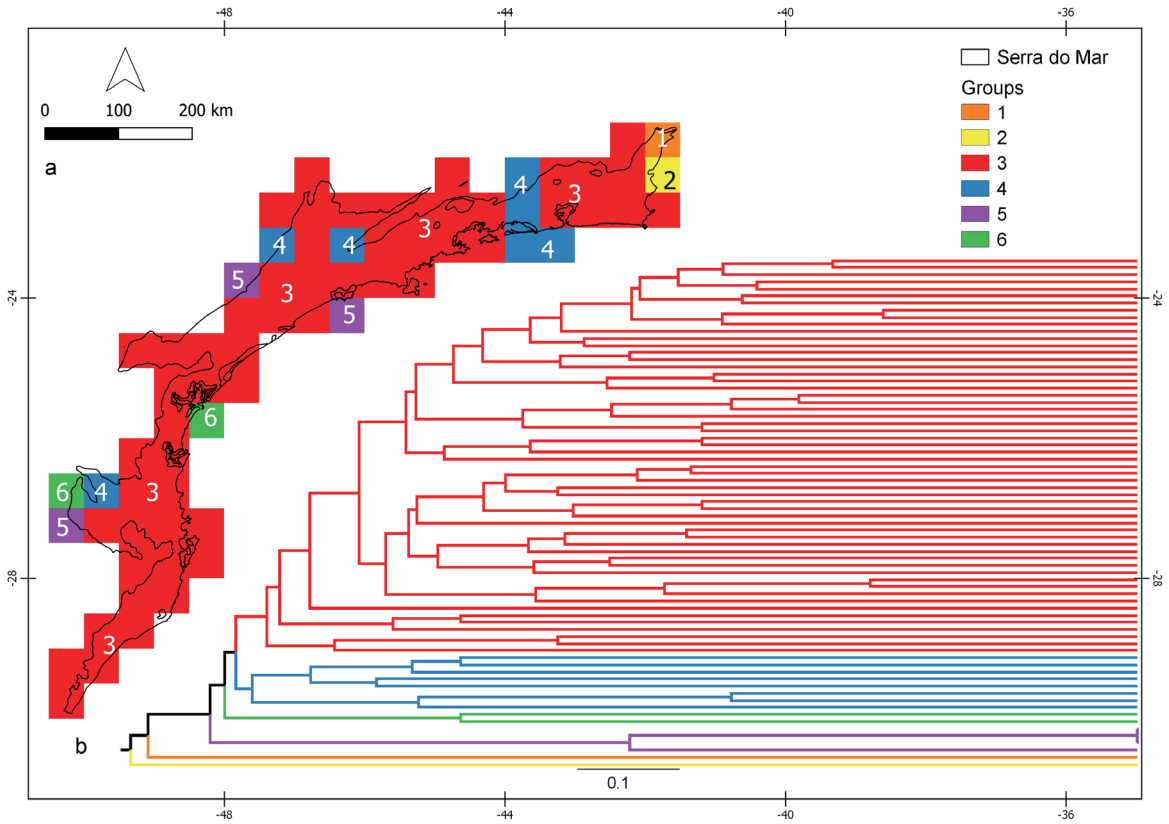

Figure 7. a. Similarity map in the composition of *Passiflora* L. (Passifloraceae *s.s.*) species obtained by the UPGMA method with grids (0.50° x 0.50°) of occurrence in the Serra do Mar, Brazil; b. Similarity dendrogram generated through the Jaccard index.

Table 3. Distribution and threat assessment of the endemic species of *Passiflora* L. from the Atlantic Rain Forest occurring in the Serra do Mar, Southeast and South, Brazil. Being: EOO = Extent of Occurrence; AOO = Area of Occupancy; CR = Critically Endangered; DD = Data Deficient; EN = Endangered; LC = Least Concern; NT = Nearly Threatened; VU = Vulnerable; EW = Extinct in the Wild; NE = Not Evaluated.

Species	Distribution range (km²)		Suggested Cartegories	Suggested Criteria	Official Categories	Reference
	EOO	AOO				
Passiflora actinia Hook	206,404	228	-	-	EN/VU	CONSEMA (2003; 2014), SEMA (2014) – EN/ Durigon *et al.* (2009) – VU
Passiflora catharinensis Sacco	119,424	40	-	-	VU	CONSEMA (2014)
Passiflora cervii M.A.Milward-de-Azevedo	119,902	36	LC/EN	B2ab (ii,iii)	NE	Present study
Passiflora deidamioides Harms	17,361	52	-	-	EN	Milward-de-Azevedo and Fernandes (2021)
Passiflora elliptica Gardner	20	12	EN	B1b (i,ii,iii) + 2ab (ii,iii)	NE	Present study
Passiflora farneyi Pessoa & Cervi	128	36	EN	B1b (ii,iii) + 2b (i,iii)	VU	Martinelli *et al.* (2018)/ Present study
Passiflora filamentosa Cav.	5,425	16	-	-	Rara	Bernacci *et al.* (2005)
Passiflora imbeana Sacco	7,234	28	VU/EN	B1b (ii, iii) + B2b (ii, iii)	EN	CNCFlora (2012b)/ Martinelli and Moraes (2013) Martinelli *et al.* (2018), Milward-de-Azevedo and Fernandes (2021), MMA (2022), Present study
Passiflora ischnoclada Harms	851	28	EN	B1ab(i, ii, iii) + B2b (i, ii, iii)	CR/VU	CNCFlora (2012c), MMA (2022), SMA-SP (2016), MMA (2008) – CR / Biodiversitas (2005) – VU/ Present study.
Passiflora junqueirae Imig & Cervi	< 1	8	-	-	EN	Milward-de-Azevedo and Fernandes (2021)
Passiflora lepidota Mast.	-	-	-	-	DD	
Passiflora loefgrenii Vitta	9,613	60	-	-	NE	
Passiflora marginata Mast.	9,525	24	-	-	EN	Bernacci (2003)
Passiflora mediterranea Vell.	189,061	356	-	-	NE	
Passiflora mendoncaei Harms	96,895	128	-	-	VU	Bernacci (2003)
Passiflora odontophylla Harms ex Glaz.	-	-		-	NE	
Passiflora ovalis Vell. ex M.Roem	10,137	64	-	-	VU	Bernacci (2003)
Passiflora pentagona Mast.	12,921	84	-	-	VU	Bernacci (2003)
Passiflora racemosa Brot.	41,641	144	-	-	VU	CNCFlora (2012d) - SMA-SP (2004)
Passiflora reitzii Sacco	-		DD	-	Rare/VU	Cervi (1997) – Rare/ CONSEMA (2014) – VU/ Present study – data deficient to make an assess of its risk of extinction
Passiflora rhamnifolia Mast.	34.905	68	-	-	NE	
Passiflora setulosa Killip	-	-	-	-	EW	Bernacci (2003), SMA-SP (2004)
Passiflora sidifolia M.Roem.	56.549	116	-	-	NE	
Passiflora truncata Regel	175.653	164	LC/EN	B2b(ii,iii)	EN	Milward-de-Azevedo and Fernandes (2021). Present study
Passiflora vellozoi Gardner	174.747	84	-		NE	

restricted distribution such as *P. catharinensis*, *P. farneyi*, *P. filamentosa*, *P. imbeana* and *P. ischnoclada*. It is possible to observe that the northeast portion of the Serra do Mar encompasses more heterogeneous areas regarding species composition. Meanwhile, the Center-West and Southwest areas of the range are characterized as presenting more homogeneity. Groups five and six presented a few species concerning other areas, which is why they turned into distinct groups.

Discussion

Spatial analysis - In this study, we found the greater richness of *Passiflora* in the areas comprised of the massifs inside the Serra do Mar and exactly where the main Conservation Units are (Tijuca National Park, Serra dos Órgãos National Park, Serra da Bocaina National Park, Serra do Mar State Park and Três Picos State Park). The so-called "mar de morros", in the Serra do Mar, shows that hillockes complexes represent the main landscapes in the Atlantic Forest (Graeff 2015). The distribution of species in an altitude gradient, defined by terrain characteristics, can show evident distinctions in diversity along a mountain (Grytnes 2003). Thus, the Serra do Mar terrain structure becomes a relevant factor in the distribution of climbing plants, since that *Passiflora* species significantly respond to altitude gradients (Ocampo *et al*. 2010; Moraes *et al*. 2018; 2020; Fernandes *et al*. 2022).

Fernandes *et al*. (2022), in a study concerning the species richness of *Passiflora* as a function of altitude in an area within the Serra Mar, found higher species richness in the middle part of the gradient. Meanwhile, in this study, we found a negative correlation, where richness decreased with increasing altitude. However, our results corroborate with the demonstrated by Moraes *et al.* (2020), in which there is *Passiflora* richness reduction with increasing altitude, and other lianas studies also found similar patterns, such Malizia *et al*. (2004), Hernández *et al.* (2012), Carvalho and Melis (2013) and Sainge *et al*. (2019).

The temperature was a relevant factor in understanding the distribution of *Passiflora*, we found the highest species richness where the average annual temperature varies between 19 °C and 23 °C. Places with very low temperatures present a deficit in the water balance because they do not maintain the same humidity as warmer areas and cause lianas to establish themselves better in places with higher temperatures (Stephenson 1990; Barry 1992; Hu and & Riveros-Iregui 2016). An example of this is those very low temperatures can impede the water conductance of liana species, which explains the low richness found in this study (Ewers 1985).

In contrast to the result found for temperature, the Precipitation of Driest Quarter showed a negative correlation with *Passiflora* species richness. We observed a decrease in the number of species as we moved south of the Serra do Mar, where the highest rainfall was recorded in the driest period. Even so, the areas in this region suffer less influence from the variation in relief (Pandolfo *et al.* 2002), while the north portion of the Serra do Mar sustains the areas humidity in these periods through orographic rains and fogs.

Studies such as the one by Arcova *et al*. (2021) and Cortines *et al*. (2011) point to fog as a water source for vegetation during all months of the year, which maintains the area's humidity in drier periods. In addition, water droplets suspended in the air and intercepted by the canopy commonly occur in Ombrophilous Forests and are called hidden rain, contributing to the maintenance of the area's water resource (Pereira *et al*. 2016).

Conservation - According to studies and Official National and State Lists (SEMA/GTZ-PR 1995; Cervi 1997; CONSEMA 2003; Bernacci 2003; SMA-SP 2004; Bernacci *et al.* 2005; Durigon *et al*. 2009; CNCFlora 2012a; Martinelli & Moraes 2013; List of Endangered Flora in the States of Rio Grande do Sul (CONSEMA 2003; SEMA 2014) and Santa Catarina (CONSEMA 2014; Martinelli *et al.* 2018; Milward-de-Azevedo & Fernandes 2021), at least 21 species found in the Serra do Mar area are classified in some level of threat. An example is *P. farneyi,* restricted to *Restinga* vegetation. It is worth highlighting that this type of vegetation has been suffering significant losses of habitat due to urban expansion and real estate speculation in the *Restinga* areas, further threatening endemic and restricted species (Leme 2000; Guerra 2005; Ribeiro & Oliveira 2009).

Passiflora elliptica is solely restricted to the municipality of Rio de Janeiro, occurring in the areas of Tijuca National Park (Mezzonato-Pires *et al.* 2020) and no evaluation was made as to its status of endangerment. Thus, we indicate this species as "Endangered", due to the quantity of specimens found and the small number of locations where they were encountered following the IUCN category criteria (IUCN 2022). Of the species found which are endemic to the Atlantic Domain seven others, in addition to *P. elliptica* were not evaluated as being endangered nor were they mentioned on any national or state list or study.

Another species presented as rare, according to Cervi (1997), was *P. reitzii*, found in the forests on the slopes of the Serra do Mar and is represented in this study by only one record and no calculation was possible to determine its status of endangerment. However, the date of the last record is 1957, thus the species can be considered as CR*, a classification which indicated that, in addition to the species being "Critically Endangered", there is also the possibility of extinction, as there are no new records of collection over the last 30 years, ensuring its legal protection and conservation actions (IUCN 2022; Penedo *et al.* 2015; Martinelli & Moraes 2013).

Pointed out as "Endangered" for the State of Rio Grande do Sul, on the Official List of Native Flora Species in Danger

of Extinction (SEMA 2014), *P. actinia* was one of the species with the largest number of records along the Serra do Mar (11 grids). However, most of these records are in Brazil's Southeast Region, which explains the presence of this species in the endangered categories in the South of the country.

In this study, we suggested four endemics species for the Serra do Mar: *P. elliptica* and *P. ischnoclada* recorded in the Ombrophilous Forest, *P. farneyi* in Restinga vegetation, and *P. imbeana* Sacco in ecotones between Highland Fields and Upper Montane Ombrophilous Forest. The heterogeneity of vegetation in the Serra do Mar ecoregion contributes to the occurrence of several endemic taxons (Garcia & Pirani 2005). Characteristics of these phytophysiognomes are determined by terrain formation and may differ according to the altitude and latitude (Ivanauskas & Assis 2009; IBGE 2012).

Similarity - In a study performed by Moraes *et al.* (2020), for the Serra da Mantiqueira, a similarity analysis of floristic composition indicated two well-defined groups (Northern and Southern) and an isolated group, which corroborates with the geomorphological division of the range (Machado-Filho *et al.* 1983). The Northern portion presents greater richness and a more heterogeneous composition of *Passiflora* species, while the Southern portion points to less variation of richness and greater homogeneity in composition (Moraes *et al.* 2020). Compared with the Serra do Mar, the Northeast and North areas, adjacent to the Northern and Southern portions of the Serra da Mantiqueira, showed material heterogeneity, also related to the greater richness of *Passiflora* species. The homogeneity in the floristic composition of the Serra do Mar is observed only in the areas more to the Central-West and Southwest of the range.

In this study performed by Moraes *et al.* (2020) 42 species were found in common with this study, most of them belonging to the Ombrophilous Forest at altitudes above 500 m.a.s.l, which can be explained by the proximity between the two ranges. The change in vegetation composition and questions covered related to terrain explain the heterogeneity of the species clusters in the Northeastern part of the Serra do Mar and point to the fact that the Ombrophilous Forest regions are made up of more homogeneous groups. This can be observed by the number of species restricted to Brazil's Southeast Region, where terrain is rugged.

Considerations - We presented the analysis of all *Passiflora* species recorded thus far in data bases for the Serra do Mar. Rainfall levels and terrain conditions are factors that influence the distribution of these species. In this study, we point to the fact that the Southeast Region showed the greatest richness and collection effort in the area, precisely in the regions where there is the greatest rainfall and variation in altitude. The State of Rio de Janeiro recorded the largest number of endemic species in the Serra do Mar.

A considerable portion of the species found in this study were presented on lists indicating endangered flora taxons. We also suggest including *P. elliptica* and *P. reitzii*, which are found only in Rio de Janeiro and Santa Catarina, respectively, on the lists of endangered species. It is also important to consider the species with insufficient data to make AOO and EOO calculations and revise them regarding their degree of threat.

The richness of *Passiflora* species, including those which are endemic to the Atlantic Forest, reveals the importance of the Serra do Mar area for conservation. Filling collection gaps in the South Region is also necessary to express and understand the diversity of these species in the range areas.

Supplementary Material

Table S1 - List of municipalities that are part of the original boundary of Serra do Mar ecoregion, South and Southeast Brazil. Presence=1; Absence=0.

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