Species recorded in high-altitude grasslands of southeast Brazil and implications to its conservation

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Keywords: Biodiversity; Atlantic Forest; protected areas; restoration.

ABSTRACT – The Atlantic Forest biome is a biodiversity hotspot with a large diversity of ecosystems, including high-altitude grasslands. These ecosystems exhibit high endemism rates, which are increasingly threatened by anthropogenic activities, even within protected areas. This study aimed to systematize information on the flora in four protected areas in southeast Brazil to identify common species suitable for restoration efforts and rare species requiring conservation actions. We conducted a survey of all digitized species occurring in the high-altitude grasslands of the protected areas from one of the most comprehensive digitized plant datasets, SpeciesLink. A total of 344 species were recorded, distributed among 178 genera and 70 families. The highest species richness was observed in Itatiaia National Park (171), followed by Serra do Papagaio State Park (167), Serra da Bocaina National Park (80), and Campos do Jordão State Park (34). Asteraceae was the family with the highest species richness and Baccharis was the genera with the most species. Endemism was observed in all protected areas, while threatened species were absent only in Campos do Jordão State Park. We identified 21 species common to at least three protected areas, exhibiting a lower risk of local extinction. Considering that some of these species may be at risk, our work highlights the importance of protecting and restoring areas of degraded high-altitude grasslands in the Vale do Paraíba and Mantiqueira regions.

Espécies registradas em campos de altitude do sudeste do Brasil e implicações para sua conservação

Palavras-chave: Biodiversidade; Mata Atlântica; unidades de conservação; restauração.

RESUMO – O bioma Mata Atlântica é um *hotspot* de biodiversidade com grande diversidade de ecossistemas, incluindo campos de altitude. Esses ecossistemas apresentam altas taxas de endemismo e estão sendo ameaçados por atividades antrópicas mesmo dentro de áreas protegidas. Este estudo teve como objetivo sistematizar informações sobre sua flora em quatro áreas protegidas no sudeste do Brasil, a fim de identificar espécies comuns que poderiam ser utilizadas em esforços de restauração e espécies raras que necessitam de ações de conservação. Realizamos um levantamento de todas as espécies digitalizadas ocorrentes nos campos de altitude dessas áreas protegidas a partir de um dos conjuntos de dados mais abrangentes do Brasil, o SpeciesLink. Foram registradas 344 espécies, distribuídas em 178 gêneros e 70 famílias. A maior riqueza de espécies foi observada no Parque Nacional do Itatiaia (171), seguido pelo Parque Estadual da Serra do Papagaio (167), Parque Nacional da Serra da Bocaina (80) e Parque Estadual de Campos do Jordão (34). Asteraceae foi a família com maior riqueza de espécies e Baccharis o gênero com mais espécies. A presença de endemismo foi observada em todas as áreas protegidas, enquanto espécies ameaçadas não foram observadas apenas no Parque Estadual de Campos do Jordão. Identificamos 21 espécies comuns em pelo menos três áreas protegidas, apresentando menor risco de extinção local. Considerando que algumas dessas espécies podem estar ameaçadas, nosso trabalho destaca a importância de proteger e restaurar áreas degradadas de campos de altitude no Vale do Paraíba e na região da Mantiqueira.

Especies registradas en pastizales de altura en el sureste de Brasil e implicaciones para su conservación

Palabras llave: Biodiversidad; Bosque Atlantico; áreas protegidas; restauración.

RESUMEN – El bioma del Bosque Atlántico es un punto crítico de biodiversidad con gran diversidad de ecosistemas, incluidos los pastizales de altura. Estos ecosistemas tienen altos índices de endemismo y están amenazados por las actividades antopogénicas, incluso dentro de áreas protegidas. Este estudio tuvo como objetivo sistematizar información sobre la flora de cuatro áreas protegidas en el sureste de Brasil para identificar especies comunes adecuadas para esfuerzos de restauración y especies raras que necesitan acciones de conservación. Evaluamos todas las especies digitalizadas presentes en los pastizales de altura de estas áreas protegidas utilizando uno de los conjuntos de dados más completos de Brasil, SpeciesLink. Registramos un total de 344 especies, distribuidas en 178 géneros y 70 familias. La mayor riqueza de especies se observó en el Parque Nacional Itatiaia (171), seguido por el Parque Estadual Serra do Papagaio (167), el Parque Nacional Serra da Bocaina (80) y el Parque Estadual Campos do Jordão (34). Asteraceae fue la familia con mayor riqueza de especies, y Baccharis fue el género más representado. O endemismo se observó en todas las áreas protegidas, mientras que las especies amenazadas estuvieron ausentes solo en el Parque Estadual Campos do Jordão. Identificamos 21 especies comunes en al menos tres áreas protegidas, con un menor riesgo de extinción local. Teniendo en cuenta que algunas de algunas de estas especies pueden estar en peligro, nuestro estudio destaca la importancia de proteger y restaurar áreas degradadas de pastizales de altura en las regiones de Vale do Paraíba y Mantiqueira.

Introduction

The Atlantic Forest biome, recognized as a biodiversity hotspot [1], originally covered an area of approximately 1,315,460 km², spanning from northeastern to southern Brazil [2] and extending into parts of Paraguay and Argentina. However, due to intense deforestation and human disturbances, mostly occurred in the first half of the 19th century [3], only about 13% of its native vegetation remains in Brazil [4]. Of this remaining forest, only 9% is protected within nature reserves [5]. Despite these challenges, the Atlantic Forest is home to about 5% of the world´s flora, with 2% comprising of endemic vascular plants [6]. This remarkable biodiversity is distributed across a variety of ecosystems, including lowland and montane forests, cloud forests, deciduous and semideciduous forests, and high-altitude grasslands [2].

High-altitude grasslands, often considered ecological refugees, occur above 1200 meters in elevation and are characterized by rocky outcrops and a dominance of grasses, herbs and shrubs [2]. The lack of forest formation in these areas is attributed to specific climatic and pedological conditions [7]. This ecosystem shares significant floristic, physiognomic, climatic and edaphic ecological connections with the Andes and the mountains of Central America, being commonly named as "páramos brasileiros" [8].

In the Serra do Brigadeiro State Park in Minas Gerais, Caiafa and Silva [9] identified 81 vascular plant species, predominantly from the Orchidaceae and Asteraceae families, with many species exclusive to each family. In the Mantiqueira mountain range in southeastern Brazil, Meireles et al. [10] observed 96 species exclusive to this formation, of which 53 shrubby, 5 arboreal, and 71 herbaceous. These grasslands exhibit high levels of endemism [11]. For instance, Martinelli [12] estimated that 11% of the vascular species in the high-altitude grassland of Itatiaia are locally endemic, while 21% are endemic to high-altitude grasslands in southeastern Brazil. Alves and Kolbek [13] documented 100 plant species restricted to the high-altitude grasslands.

Although most of the high-altitude grasslands are located inside protected areas, they are being threatened by anthropic activities [14]. Degradation of these areas may have been intensified by mountain tourism and camping and trekking activities carried out by large groups of people, guides who are not trained and who are not part of associations of registered guides (reports from the Boletim Informativo das Cristas da Mantiqueira), as well as the recurring occurrence of fire caused by humans. They are pointed out as environments sensitive to human activities, especially to climate change and the removal of vegetation cover [15]. Silva et al. [16] observed an increase of 38,45% of invasive species over high-altitude grasslands areas in Poços de Caldas – Brazil, with predominance of grass species such as *Urochloa decumbens* (Stapf) R.D.Webster (capim brachiaria) and *Melinis minutiflora* P.Beauv. (capim gordura). According to Matos and Pivello [17], these exotic species (Poaceae) have grown invasive in Brazil, competing with native plants.

Ecological restoration can be defined as a process to help restore an ecosystem that has been degraded, damaged or destroyed [18]. Although most of previous restauration efforts have been focused on forests, the restoration of non-forest ecosystems such as grasslands and savannas remain a challenge [19], being much neglected in Brazil [20][21]. However, the need for grassland restoration has become evident in recent decades [22]. Regarding ecological restoration techniques, it has been observed that the storage of surface soil (topsoil) has shown good results and is widely promoted for revegetation activities after bauxite mining [23]. Also, aiming to maximize the chances of re-establishing some desired species or even to allow for rapid soil coverage, the use of seed mixtures has been adopted, with the inclusion of seeds from local species being important [24]. According to Moraes [25], regardless of the restoration practice adopted and the monitoring of the succession stage, it is essential to have knowledge of the species that occur in high-altitude grasslands and their potential use in restoration projects.

Protected areas in Brazil are divided in two categories: full protection ones, where natural resources may be only indirectly used, as in recreation and environmental education activities, and sustainable use ones, where direct use of resources are done, as extraction, low intensity agriculture and private rural lands are permitted [26]. Are examples of high-altitude grasslands located in full protection ones: Serra da Bocaina, Serra do Caparaó and Itatiaia national parks, Serra do Papagaio, Serra do Brigadeiro, Campos do Jordão and Serra do Mar state parks (nucleus Cunha and Curucutu), and are examples of high-altitude grasslands located in sustainable use ones: environmental protection area (APA) of Serra da Mantiqueira, the (MONA) Pedra do Baú and Mantiqueira natural monuments and

APA São Francisco Xavier. Parks are usually smaller but more protected, while APAs are larger but less protected, due to the activities permitted.

Given the importance of protected areas for the conservation of the high-altitude grasslands, we aimed to compare information regarding its flora in four protected areas in southeast Brazil, in order to assess common species that could be used in restoration efforts.

Materials and Methods

Study area

This study was carried out in four protected areas (PAs) containing high-altitude grasslands, two national parks (PARNA) and two state parks (PE) (Table 1). These areas are located in southeastern Brazil (Figure 1), encompassing regions in the states of São Paulo, Rio de Janeiro, and Minas Gerais, within the Atlantic Forest biome.

Table 1 – Characteristics of the studied protected areas in Brazil, including size, date of creation, coordinates, soil, vegetation, climate, altitude, and location.

Protected area	Size (ha)	Creation	Coordinates	Soil	Vegetation	Climate	Altitude	Municipalities
PE Campos do Jordão	8,341	Lei Estadual nº 11.908 / 27 de março de 1941	22°41'26.55"S / 45°29`35.28"W	Argisols, Cambisols, Latosols, Neosols	Mixed Ombrophilous Forest; Dense Ombrophilous Forest; High-altitude grasslands; anthropized areas with reforestation of Pinus sp. and other exotic species	Temperate, with mild summer	1500-2000m	SP (Campos do Jordão)
PE Serra do Papagaio	22,917	Decreto Estadual nº 39.793 / 05 de agosto de 1998	22°08'31.85"S / 44°43'43.40"W	Espodosols, Cambisols, Neosols, Organosols	Nebular Forest; high altitude grasslands	Altitude subtropical, with dry winter and mild summer	1160-2340m	MG (Aiuruoca, Alagoa, Baependi, Itamonte, Pouso Alto)
PARNA do Itatiaia	28,084	Decreto Federal nº 1.713 / 14 de junho de 1937	22°22'22.03"S / 44°42'14.27"W	Argisols, Cambisols, Latosols	High Montane Dense Ombrophilous Forest; Montane Dense Ombrophilous Forest; Montane Semideciduous Forest; Campos Rupestres; high altitude grasslands	Altitude subtropical, with dry winter and mild summer	540-2791m	MG (Bocaina de Minas, Itamonte); RJ (Itatiaia, Resende)
PARNA da Serra da Bocaina	104,0	Decreto Federal nº 68.172 / 4 de fevereiro de 1971	22°44'14.34"S / 44° 36'56.59"W	Argisols, Cambisols, Espodosols, Latosols, Neosols	High altitude grassland, High Montane Dense Ombrophilous Forest, Montane Dense Ombrophilous Forest, Submontane Dense Ombrophilous Forest, Restinga	Temperate, with mild summer	0-2095m	SP (São José do Barreiro, Ubatuba, Cunha, Areias); RJ (Paraty, Angra dos Reis)

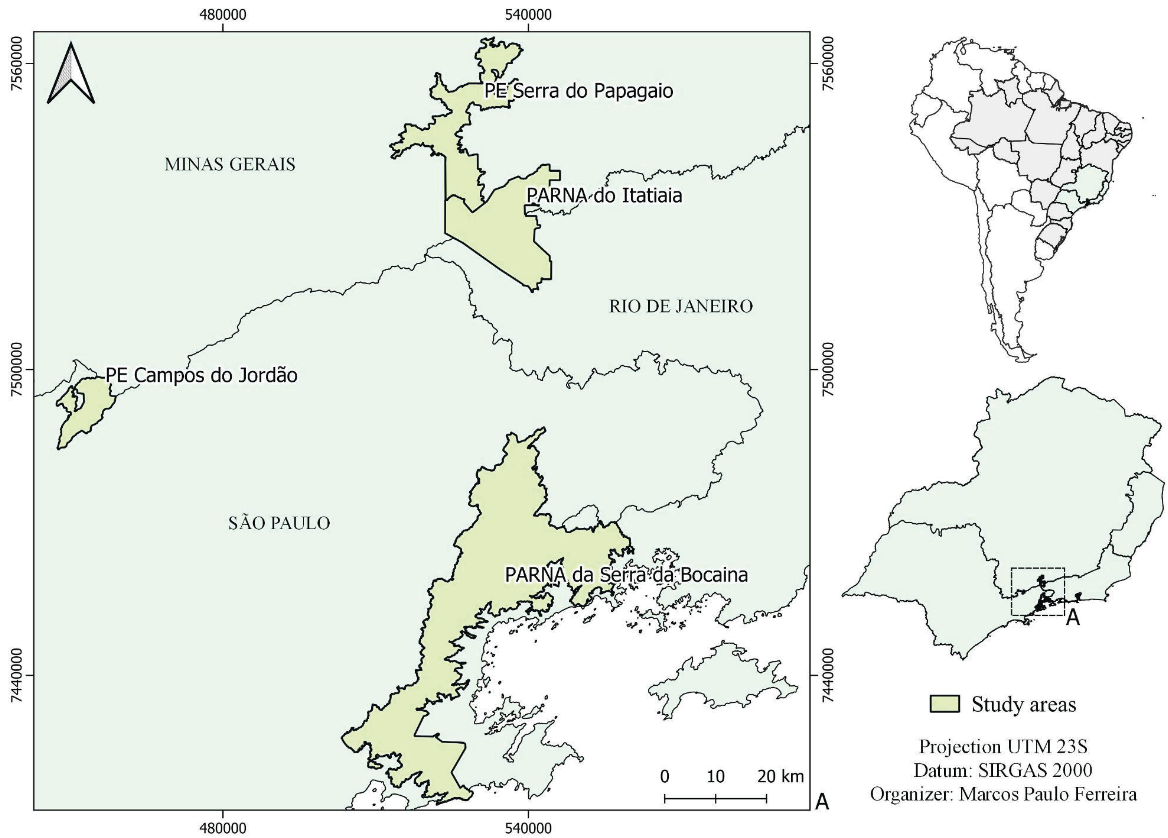


Figure 1 – Location of the study sites (PE – State Park; PARNA – National Park) in Minas Gerais, Rio de Janeiro, and São Paulo states, Brazil.

PE Campos do Jordão is a priority region for conservation [27] and host one of the first management plans created in Brazil [28]. PE da Serra do Papagaio is part of the Mantiqueira Ecological Corridor and the Serra da Mantiqueira Environmental Protection Area (APA) protecting, alongside PARNA do Itatiaia, one of the largest native vegetation fragment in the Mantiqueira region [29]. PARNA do Itatiaia, the first national park in Brazil, is part of the Atlantic Forest Biosphere Reserve and the Serra da Mantiqueira Mosaic of Protected Areas, an integrative and participative management tool established by the National System of Protected Areas (SNUC, in Portuguese) [30]. PARNA da Serra da Bocaina, an important fragment of the Atlantic Forest, harbors high biodiversity, multiple ecosystems, and several endemic, ecological refuge, and endangered species [31]. Among the studied areas, PARNA da Serra da Bocaina is the largest protected area, while PE Campos do Jordão is, the smallest (Table 1). All are characterized by temperate and subtropical climate [32][33], high-altitude grasslands, and altitudes reaching up to 2791 m (Table 1).

Database

Data on plant species in the high-altitude grasslands of the four protected areas until March, 5th 2023 were retrieved from the *speciesLink* database (http://specieslink.net), which consolidates digitized records from over 40 biological collections, comprising more than 16 million herbarium specimens from across Brazil. Although this platform may present gaps and limitations that may result in an under-representation of the studied areas, such as the need for herbaria to record their collections with all the correct information, it is a project supported by several institutions aiming to promote information for research.

Database search and filtering

In the *speciesLink* search tool, the terms "campo" (grassland) and "altitude" (altitude) were used, in order to have a list with all the species found in high-altitude grasslands. Records were filtered to include only those citing the four protected areas as collection sites. Subsequently, the data underwent a rigorous cleaning and validation process to eliminate duplicates, erroneous geographical coordinates, and spatial outliers. Species collected a long time ago were included in the analysis.

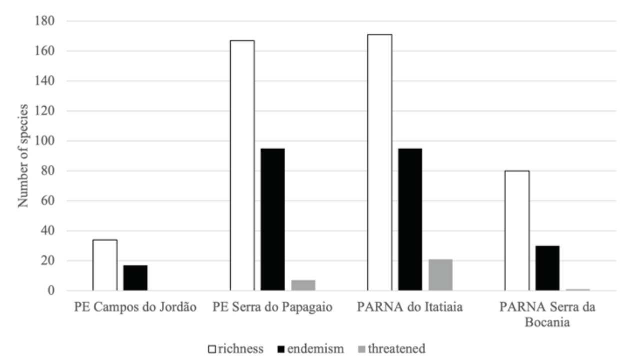
The data were then processed in the R software environment and programming language using the 'flora' package (version 0.3.4) to updated nomenclature, and gather information on vegetation type, domains, life forms (bamboo, cushion, foliose, herb, liana, shrub, subshrub, trama, tree, tuft), endemism, and conservation status from the Flora e Funga do Brasil [34].

Results

Considering the four protected areas studied (Supplementary Material 1), 344 species were registered, distributed across 178 genera and 70 families (Supplementary Material 2)

Highest species richness was in PARNA do Itatiaia (171), followed by PE Serra do Papagaio (167), PARNA da Serra da Bocaina and PE Campos do Jordão (Figure 2a). Endemism was higher in PE Serra do Papagaio (57%) and PARNA do Itatiaia (56%: Figure 2a), while PARNA do Itatiaia had the highest number of threatened species (12%), followed by PE Serra do Papagaio (4%: Figure 2a).

a)



b)

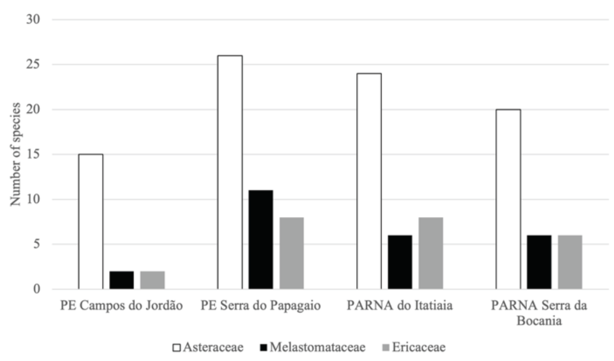


Figure 2 – Species richness, endemism and number of threatened species (a) and distribution of the most important families (b) among study sites (PE = state park; PARNA = national park) in Minas Gerais, Rio de Janeiro and São Paulo states, Brazil.

In terms of specific richness (Supplementary Material 3), Asteraceae was the most abundant family observed in all protected areas, followed by Melastomataceae and Ericaceae (Figure 2b).

Baccharis L. was the most abundant genera in the four studied areas (Table 2). *Xyris* Gronov. Ex L. was also well represented in PE Serra do Papagaio.

Table 2 – Genera distribution in the protected areas (PA). PE = state park and PARNA = national park. Bold is the most important Genera.

PA/Genera	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra da Bocaina
Achyrocline (Less.) DC.	1	1	1	
Actinocephalus (Körn.) Sano		1	1	
Aechmea Ruiz & Pav.				1
Agarista D.Don ex G.Don	1	2	2	3
Agrostis L.		1	1	
Alstroemeria L.	1	1	2	1
Anomobryum Schimp.			1	
Aongstroemia Bruch & Schimp.			1	
Asplenium L.			1	
Austroblechnum Gasper & V.A.O. Dittrich			1	
Austrolycopodium Holub			1	
Axonopus P.Beauv.		1		1
***Baccharis* L.**	**8**	**8**	**13**	**9**
Barbacenia Vand.		1	1	
Berberis L.		1	3	
Brunfelsia L.		1		1
Bryum Brid. ex Hedw.			1	
Buddleja L.		2	1	
Bulbostylis Kunth		1		
Calolisianthus Gilg		1	1	
Calydorea Herb.		1		
Campovassouria R.M.King & H.Rob.				1
Campylopus Brid.		1	2	
Cantinoa Harley & J.F.B.Pastore		1		
Carex L.				1
Castilleja Mutis ex L.f.				1
Centaurium Hill			1	
Cerastium L.			1	
Ceratodon Brid.			1	
Cestrum L.		1		
Chaetogastra DC.		2		
Chaetostoma DC.		1	1	
Chaptalia Vent.		1		1
Chascolytrum Desv.		2	3	
Chionolaena DC.			2	
Chromolaena DC.	1			
Chrysolaena H.Rob.		1		

PA/Genera	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra da Bocaina
Chusquea Kunth		2	4	
Cissus L.				1
Cleistes Rich. ex Lindl.		1		
Clethra L.			1	
Collaea DC.		1		
Conyza Less.		1		
Crotalaria L.		1		1
Croton L.	1	1	1	
Cunila Royen ex L.			1	
Cuphea P.Browne			1	
Cyanocephalus (Pohl ex Benth.) Harley & J.F.B.Pastore	1	1		
Danthonia DC.				1
Declieuxia Kunth	1	1		
Dendrophorbium (Cuatrec.) C.Jeffrey				1
Desmodium Desv.				1
Dicranopteris Bernh.		2	1	2
Dioscorea L.			2	
Diphasiastrum Holub		1	1	1
Elaphoglossum Schott ex J.Sm.		1	2	
Elionurus Humb. & Bonpl. ex Willd.	1			
Eremanthus Less.				1
Eriosema (DC.) Desv.		1		
Eryngium L.		1		
Escallonia Mutis ex L.f.			2	1
Esterhazya J.C.Mikan	2	2	1	3
Euphorbia L.			1	
Evolvulus L.	1			
Fernseea Baker			1	
Fuchsia L.		1	2	1
Gamochaeta Wedd.	1	1		1
Gaultheria L.		3	4	1
Gaylussacia Kunth	1	3	2	2
Gelasine Herb.			1	
Geranium L.			1	1
Glandularia J.F.Gmel.		2		
Glechon Spreng.		1		
Gomesa R.Br.		1	1	
Graphistylis B.Nord.		1	1	
Grazielia R.M.King & H.Rob.	1	1	3	1

PA/Genera	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra da Bocaina
Grimmia Hedw.			1	
Griselinia G.Forst.			1	1
Habenaria Willd.		6	1	
Hedwigidium Bruch & Schimp.			1	
Hesperozygis Epling		1	1	
Heterocondylus R.M.King		1		
Histiopteris J.Agardh			1	
Holomitrium Brid.			1	
Hypericum L.		2		1
Hypochaeris L.	1			
Hypolepis Bernh.			2	
Hyptis Jacq.		1		1
Inulopsis (DC.) O.Hoffm.	1	1		1
Isoetes L.			2	
Itatiella G.L.Sm.			1	
Jamesonia Hook. & Grev.			2	
Juncus L.			1	2
Lagenocarpus Nees		1		
Lamanonia Vell.				1
Lantana L.		1		
Lavoisiera DC.		1		
Leandra Raddi		2	4	3
Leiothrix (Körn.) Ruhland		1	1	
Lellingeria A.R.Sm. & R.C. Moran		1	1	
Lepechinia Willd.		1	1	
Leptostelma D.Don				1
Lippia L.		1		
Lobelia L.	1	1	1	1
Lomariocycas (J.Sm.) Gasper & A.R. Sm.		1	1	1
Lucilia Cass.		1		
Lupinus L.			1	
Luzula DC.			1	
Lycopodiella Holub		1	1	
Lycopodium L.		1	1	1
Lytoneuron (Klotzsch) Yesiyurt		3	3	
Machaerina Vahl			1	
Maytenus Molina			1	
Melpomene A.R.Sm. & R.C.Moran		2	3	
Meteorium (Brid.) Dozy & Molk.			1	

PA/Genera	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra da Bocaina
Miconia Ruiz & Pav.	1			1
Mikania Willd.	1	1		
Mimosa L.		3	3	
Myrceugenia O.Berg		1	1	
Myrcia DC.		4		
Nicotiana L.				1
Niphidium J.Sm.				1
Octomeria R.Br.		1		
Ophioglossum L.			1	
Oxalis L.		2	2	
Oxypetalum R.Br.	1	1	1	1
Paepalanthus Mart.		3	3	
Parablechnum C.Presl		1		1
Paspalum L.		2		
Passiflora L.				1
Peperomia Ruiz & Pav.		2	4	1
Peplonia Decne.		1		
Perezia Lag.				1
Phlegmariurus (Herter) Holub		2	3	
Phyllanthus L.		1		
Pimenta (L.) Merr.	1		1	
Plagiogyria (Benth.) H.Rob.			1	
Plantago L.		1		2
Pleopeltis Humb.	1	3	2	2
Pleroma D.Don		4	1	2
Pohlia Hedw.			1	
Polystichum Roth		1	1	
Polytrichum Hedw.			3	
Praxelis Cass.		1		
Prescottia Lindl.			1	
Pseudognaphalium Kirp.		1		
Pseudolycopodiella Holub		1		
Pteridium Gled. ex Scop.		1	1	
Rhabdocaulon (Benth.) Epling		1	1	
Rhynchospora Vahl.		1	1	
Rumex L.			1	
Rumohra Raddi		1		1
Salvia L.			1	
Schizachyrium Nees				1

PA/Genera	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra da Bocaina
Senecio L.		5	1	1
Senega Spach		4	2	
Serpocaulon A.R.Sm.		1	2	1
Siphocampylus Pohl		1	1	
Sisyrinchium L.		2	4	1
Skeptrostachys Garay		1		
Solanum L.		1	1	2
Sporobolus R.Br.	1			
Stenogrammitis Labiak		1	1	
Stevia Cav.			1	1
Sticherus C.Presl	1	2	1	
Symphyopappus Turcz.			1	
Symplocos Jacq.	1		2	
Trembleya DC.	1	1		1
Trifolium L.				1
Trilepis Nees		1		
Trixis P.Browne			1	
Valeriana L.			1	
Velloziella Baill.		1		
Verbena L.		1	2	2
Vriesea Lindl.		1		
Wahlenbergia Schrad. ex Roth		1	1	
Woodsia Spreng.			1	
Xyris Gronov. ex L.		8	3	1

According to life forms (Figure 3), herbs were more common in all protected areas, but they were predominantly found in PE Serra do Papagaio, shrubs in PARNA do Itatiaia and shrub/subshrub in PE Serra do Papagaio.

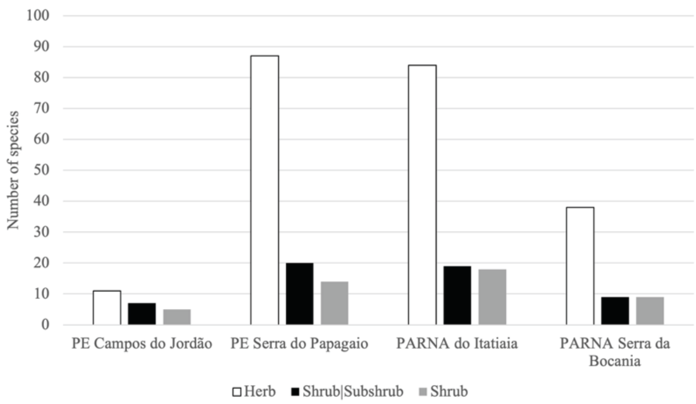


Figure 3 – Herbs, shrub/subshrub and shrub distribution among study sites (PE = state park; PARNA = national park) in Minas Gerais, Rio de Janeiro and São Paulo states, Brazil.

In total, 64 species were common to two protected areas studied, 19 to three and two to four sites (presented in Table 3), mostly herbaceous species.

Table 3 – Common species to at least three of the studied protected areas. PE = state park and PARNA = national park. Bold species are least concern (LC) and other species are non evaluated (NE).

Family	Specie	Life Form	Threat	PE Campos do Jordão	PE Serra do Papagaio	PARNA do Itatiaia	PARNA da Serra do Papagaio
Asteraceae	*Achyrocline satureioides* (Lam.) DC.	Herb	NE	x	x	x	
	Baccharis crispa Spreng.	Subshrub	NE	x		x	x
	Baccharis glaziovii Baker	Shrub	NE	x		x	x
	Baccharis tarchonanthoides DC.	Shrub	NE	x	x	x	x
	Grazielia intermedia (DC.) R.M.King & H.Rob.	Shrub/ Subshrub	NE		x	x	x
	***Inulopsis scaposa* (DC.) O.Hoffm.**	Herb	LC	x	x		x
Blechnaceae	*Lomariocycas schomburgkii* (Klotzsch) Gasper & A.R. Sm.	Herb	NE		x	x	x
Campanulaceae	*Lobelia camporum* Pohl	Herb	NE	x	x	x	
Ericaceae	*Agarista hispidula* (DC.) Hook. ex Nied.	Shrub/ Subshrub	NE	x	x	x	
	Gaultheria serrata (Vell.) Sleumer ex Kin.-Gouv.	Shrub/ Subshrub	NE		x	x	x
	Gaylussacia amoena Cham.	Shrub/ Subshrub	NE	x		x	x
Euphorbiaceae	*Croton dichrous* Müll.Arg.	Shrub/ Subshrub	NE	x	x	x	
Gleicheniaceae	*Dicranopteris nervosa* (Kaulf.) Maxon	Shrub	NE	x	x	x	
	Sticherus pruinosus (Mart.) Ching	Herb	NE	x	x	x	
Lycopodiaceae	*Diphasiastrum thyoides* (Willd.) Holub	Shrub	NE		x	x	x
	Lycopodium clavatum L.	Herb	NE		x	x	x
Onagraceae	***Fuchsia regia* (Vell.) Munz**	Schrub|Liana/ twining/climber	LC		x	x	x
Orobanchaceae	*Esterhazya macrodonta* (Cham.) Benth.	Scrub|Subshrub	NE	x	x		x
Piperaceae	*Peperomia galioides* Kunth	Herb	NE		x	x	x
Polypodiaceae	*Pleopeltis macrocarpa* (Bory ex Willd.) Kaulf.	Herb	NE	x	x	x	x
	Serpocaulon catharinae (Langsd. & Fisch.) A.R.Sm.	Herb	NE		x	x	x

Discussion

Our results are consistent with findings from other studies in high-altitude grasslands, where Asteraceae is the predominant family [35][36][13][37]. This family is dominant in grassland formations of tropical mountains in South America [38][39] and tropical savannas [40]; Additionally, it occurs widely in various ecosystems worldwide [41]. Melastomataceae was also frequent in the high-altitude grasslands. This family is widely distributed across Brazil, being particularly common in the Amazon, Cerrado, and Atlantic Forest biomes, including its grasslands [42]. Previous studies in nearby regions have also reported Melastomataceae as the second most species-rich family [36][43][13][44].

The genus *Baccharis* presented a high number of species across all four protected areas, corroborating findings by Campestrini [45] and Meireles et al. [13], which identified this genus as one of the most representative in mountainous regions. *Baccharis* is notably important in South America, with 90% of its species occurring in the region [46]. Herbs, shrubs, and subshrubs, were the most common life forms recorded, consistent with grassland characteristics [2].

Among the protected areas, both PARNA do Itatiaia and PE Serra do Papagaio exhibited the highest level of endemism and the greatest number of threatened species, followed by PARNA da Serra da Bocaina, and PE Campos do Jordão. PARNA do Itatiaia borders PE Serra do Papagaio, in a high-altitude region of Serra da Mantiqueira [47]. The climatic characteristics that confer uniqueness to its vegetation formations, such as the strongly marked climatic seasonality and the occurrence of lower temperatures in winter, which leads to high rates of endemism [9], is expressive in this region due to its geography, as well as higher isolation of some regions in the protected areas. According to Colwell et al. [48], the species occurring on mountain tops are more susceptible to extinction, a process known as "mountaintop extinctions". As these regions have disjoint distribution, short geographic extension and narrow longitudinal range, this vegetation could not migrate and would become locally extinct due to disturbances [49]. In fact, PE Campos do Jordão had the lowest plant species richness (and consequently lowest endemism level and threatened species), likely due to a history of continued disturbances since the protected area creation.

Special attention should be given to these areas concerning anthropogenic fire occurrences and fire management. Natural fires in these sites are expected to be ignited by lightning and spread over small areas, while the anthropogenic ones occur in large extensions and in the middle of the dry season, as it happens in the Brazilian savanna [50]. Fires occurring at regimes different from natural ones — e.g., with higher frequency and intensity — pose a significant threat to local biodiversity and may lead to species extinction. Species like *Baccharis reticularia* DC. (Asteraceae) are sensitive to fire events and possess limited recovery abilities, similar to *Eremanthus erythropappus* (DC.) MacLeish (Asteraceae) and *Myrsine gardneriana* A.DC. (Primulaceae) [51]. The perennial *Actinocephalus polyanthus* (Bong.) Sano (Eriocaulaceae) thrives significantly in the aftermath of fire, yet locally diminishes when the fire regime is excessively intense [52].

In the context of climate change, extreme events such as extreme temperature increases and prolonged droughts are becoming more likely [53][54]. Plus, the combination of high temperatures with the increase in precipitation deserves attention, since these would be the ideal conditions for the arrival of invasive species [55]. Although research regarding the effects of climate change on high-altitude ecosystems is limited [49], changes in climate conditions in mountain environments are a global concern, as the consequences of such changes extend beyond the mountains themselves [56]. Thus, conservation strategies should prioritize rare, endemic, and endangered species in the four protected areas.

These 21 species found in at least three of the studied protected areas may have a lower risk of local extinction and should be prioritized in restauration efforts of high-altitude grasslands in the Vale do Paraíba and Mantiqueira regions, either inside or outside protected areas. These resilient species might be generalist species that are better adapted to the environment, compete effectively for resources, have high reproductive rates, and benefit from a positive feedback loop where successful individuals increase their chances of colonizing and thriving in new locations, making them ideal for restoration efforts, as well. Although this list is a first step towards achieving this goal, there is a need for more studies to identify areas that have undergone or are undergoing a degradation process, identifying threats and outlining appropriate restoration strategies. Although there is no current program that involves the community in the conservation of this ecosystem, it could be applied in this context given the threats it poses. Community-based conservation strives to integrate culturally sensitive socioeconomic development with nature conservation to catalyze benefits for both people and nature [57].

Conclusions

The United Nations Decade on Ecosystem Restoration – a global initiative to restore ecosystems – seeks to protect biodiversity, secure ecosystem services, mitigate climate change, and enhance human livelihoods (https://www.decadeonrestoration.org/). This study was able to bring a list of 21 species that could be used as a valuable resource for the restoration of degraded high-altitude grasslands, addressing an urgent need for its conservation and recovery. Besides, there were other less common species, mostly Asteraceae and herbs found in the studied sites, that should be included in restoration efforts. Nonetheless, studies on methodologies to restore this ecosystem are still incipient and the use of integrated fire management strategies could be included in Prevfogo agenda as restoration efforts in high-altitude grassland protected areas. Given the unique biodiversity and conservation needs of high-altitude grasslands, there is a need to advocate for the importance of these grasslands and, through field surveys, to identify more common species not only in the study areas assessed but also in other nearby high-altitude grasslands.

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