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Ants as Bioindicators of Habitat Conservation in a Conservation Area of the Atlantic Forest Biome

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Abstract

Ants are used as bioindicators because they play diverse ecological roles in terrestrial ecosystems. Their richness, abundance, and broad geographic distribution allow these insects to be used to predict the conditions of environmental conservation. This study aimed to evaluate the bioindicator potential of the ant fauna in Parque Estadual do Turvo, Rio Grande do Sul. Sampling was carried out in two events, in January and November of 2019, using soil and canopy pitfall traps, sardine baits, glucose baits, an entomological umbrella, and a sweeping net. We verified the association of ant species to the sampled strata (soil and leaf litter and vegetation) through an Indicator Species Analysis (ISA) and Principal Component Analysis (PCA). We identified 157 species belonging to 32 genera and eight subfamilies. The subfamily with the most outstanding richness was Myrmicinae, with 70 species, followed by Formicinae, with 40 species. The richest genera in the samples were *Camponotus* (S = 29), *Pheidole* (S = 23), and *Linepithema* (S = 11). Overall, 58 species occurred exclusively in the soil and leaf litter stratum and 23 in the arboreal stratum. Nine species had a significant indication value for the sampled strata, seven for soil and leaf litter, and two for the arboreal strata. The results show the potential of ant fauna as a basis for environmental impact studies and management and conservation plans in the southern Atlantic Forest biome.

Introduction

The advance of anthropic activities has increased and accelerated in recent decades (Magalhães et al., 2022), reflecting especially on the overexploitation of natural resources in environments for purposes related to agriculture, livestock, urbanization, and industrial plants that cause environmental impacts and lead to the loss and habitats fragmentation and increase threats to biodiversity conservation (Santos-Silva et al., 2016; García-Martínez et al., 2019). The invertebrate fauna is part of various ecological interactions, ranging from predation and competition to mutualistic relationships with plants and other arthropods (Hölldobler & Wilson, 1990). Despite their relevance for ecological processes, gaps in knowledge about invertebrate biodiversity in different ecosystems stand out.

Biodiversity is generally lost at an unprecedented rate in Earth's recent history. There are gaps in knowledge on the biodiversity in the remnants of the Atlantic Forest biome, limiting discussions and development of conservation plans for these environments (Carlucci et al. 2021). The emerging concern with environmental issues has encouraged researchers to search for indicator species capable of providing information on the conservation degree of the environments where bioindicator species live (Lutinski & Garcia, 2005). One way to identify and monitor patterns of changes in biodiversity is to have species that act as bioindicators and allow inferences about conservation conditions (Santos-Silva et al. 2016).

Bioindicators can be represented by organisms or biological processes used to assess environmental impacts or to monitor the recovery of degraded areas (Vicente et

al., 2014). The use of certain organisms or species, such as invertebrates, has been highlighted in this process (Zhang et al., 2020).

Ants are used as bioindicators because they play roles in many ecosystem dynamics (Majer, 1997; Sid-Ali et al., 2021) due to their species diversity, wide geographic distribution (Silva et al., 2022), and ecological importance (Conceição-Neto et al., 2021). Approximately 16,580 species belonging to 501 genera have been described (Bolton, 2023). The use of Formicidae as bioindicators because they play a role in the most varied trophic levels, are widely distributed and abundant in terrestrial environments (Hölldobler & Wilson, 1990; Santos-Silva et al., 2016), interact with other organisms (Vicente et al., 2014), including other ants (Powell et al., 2014), can be easily sampled and their taxonomy is relatively well established (Santos-Silva et al., 2016).

Ant diversity is associated with environmental complexity (Rocha et al., 2015). According to these authors, the species diversity is related to foraging and reproductive habits, the vegetation complexity, and the amount of leaf litter available. Thus, assemblages comprise generalist or specialist species according to environments under different management or conservation stages (Hu et al., 2021; Ladino & Feitosa, 2022). In this sense, the ant fauna has been used as a natural ecosystem bioindicator due to their structural complexity and fast response to environmental changes (Bagliano et al., 2012).

Turvo State Park is recognized as an essential area for biodiversity conservation and represents the largest remnant of semideciduous forest in the state of Rio Grande do Sul (Sema, 2023). The knowledge of the bioindicator potential of the ant assemblage in Turvo State Park, one of the main conserved forest remnants of the Atlantic Forest biome, can support studies on biodiversity conservation and management within the park.

Thus, considering the increasing pressure of human activities on natural ecosystems, the fragmentation and loss of habitats in the Atlantic Forest Biome, and the need for studies on bioindicator organisms, this study aimed a) to characterize the diversity of ants in different habitat strata in the Parque Estadual do Turvo and b) to analyze the bioindicator potential of ant species for the soil and leaf litter and arboreal strata. The Parque Estadual do Turvo represents one of the most significant remnants of the Atlantic Forest in southern Brazil, and there is no history of significant previous anthropogenic disturbance in the area occupied by the park. In this sense, our hypothesis in this study is that ant assemblages sampled on the ground and in the litter and vegetation of the park can bioindicate the conservation status of these habitats.

Materials and methods

Study area

We conducted the study in the Parque Estadual do Turvo, located in Derrubadas, Rio Grande do Sul, Brazil (27° 8' 44" S; 53° 53' 10" W). The park comprises a total area of 174.9 km^2. In its western and southern borders, it is surrounded by cereals agricultural fields, while, to the east, it is limited by the province of Misiones (Argentina) and to the north, by the State of Santa Catarina border, delimited by the Uruguay River (Sema, 2023).

This conservation area was initially created as a State Forest Reserve in 1947. In 1954, it became a State Park. As the largest fragment of the Seasonal Deciduous Forest and Mixed Ombrophylous Forest in the state, it has the Yucumã Falls on the Uruguay River, representing a tourist attraction within the park (Cassenote et al., 2019). The average annual temperature in the park region is 19.1 ºC, and the average rainfall is 1,800 mm per year (Alvares et al., 2014).

The soil of Parque Estadual do Turvo is rich in iron and manganese with a shallow average depth, rapid drainage, and is very susceptible to erosion. It is characterized as loeutrophic and moderate dystrophic Cambisol, clayey texture, stony phase, basaltic substrate, and wavy relief. It is also composed of dystrophic purple Latosol (Sema, 2023).

The Park area is covered by the Floresta Subtropical Latifoliada or Floresta Latifoliada Decidual, also called "Mata Subtropical do Alto Uruguai". In addition to the Forest, other plant formations occur in environments such as wetlands and countryside. According to Brack et al. (1985), 772 plant species were cataloged. The upper arboreal stratum or cover is formed by trees with an average height of 20m, with emerging individuals reaching 30m, primarily deciduous species. The middle tree layer, between 10 m and 20 m high, is densely composed of evergreen species. The arboreal/shrub layer or under forest comprises trees and shrubs.

We sampled the ant assemblage at five sites distributed along the road that crosses the park to the Uruguay River.

Site 1 was closest to the forest edge (park entrance) and located approximately 500 m from the administrative area. Sites 2 and 3 were defined in the most central region of the park, while sites 4 and 5 were set closer to the park boundary with the Uruguay River. Despite the distance between one sampling site and another and their location in the park, they have relatively homogeneous soil and vegetation characteristics. In this way, the samples were pooled in the analyses.

Samples

The samplings were carried out in two events, in January and November of 2019, using sampling methods such as soil and canopy pitfall traps, sardine baits, glucose baits, entomological umbrellas, and a sweeping net. We selected five sites 2 km apart to ensure spatial independence in measuring the community diversity. In each site, we established a transect perpendicular to the road, located 50 meters from the road, to avoid the edge effect. In each transect, we installed 20 pitfall traps (10 on the ground and 10 on the canopy) and 20 baits (10 of each). Pitfall traps and baits were distributed 20 m apart. Each soil pitfall trap consisted of a 500 mL plastic cup (10 cm in diameter by 12 cm in height), buried so that its border was

at ground level. Inside each trap, we added 150 mL of water with a drop of neutral detergent to break the water's surface tension. The canopy pitfall traps comprised 500 mL plastic cups (10 cm in diameter by 12 cm in height). We added 150 mL of water with a drop of detergent and 1 g of sardines. The traps were fixed in trees with a diameter at breast height (DBH) of at least 30 cm, at a height between 1.5 and 2 meters from the ground. We arranged the sardine (~1 g) and glucose (~1 mL) baits in 20x30 cm paper rectangles on the soil and leaf litter stratum. The pitfalls remained in the environment for 72 hours, and the baits for one hour (Fernández, 2003; Baccaro et al., 2015).

The entomological umbrella consists of a fabric rectangle measuring 1 m^2, supported by an "X"-shaped wooden batten attached to the four corners. At each site, we used the umbrella under bushes (n = 10), chosen randomly and shaken ten times each. We used the sweep net on the vegetation in trails and clearings, with an effort of 30 minutes at each sample site in each sampling event.

The sampled specimens were placed in plastic vials containing 70% alcohol and were transported to the Entomology Laboratory for sorting and identification. We identified the ant species using the keys proposed by Gonçalves (1961), Kempf (1964), Watkins (1976), Della Lucia (1993), Lattke (1995), Taber (1998), Fernández (2003), Longino (2003), Longino & Fernández (2007), Wild (2007), and Baccaro et al. (2015). The classification followed Bolton (2023).

Data analysis

To characterize the ant assemblage in the soil and leaf litter stratum, we considered the ant fauna recorded in soil pitfalls traps and sardine and glucose baits. As for the arboreal stratum, we considered the species recorded in the arboreal pitfalls traps, sweeping net, and entomological umbrella.

We defined the species richness as the number of species in each sample. We compared each stratum's richness using rarefaction analyses based on the number of occurrences. The abundance was defined based on frequency (the number of records of a given species in each trap or bait) and not on the number of individuals (Romero & Jaffe, 1989). We compared ant assemblages from strata (soil and leaf litter and arboreal) using Shannon-Weaver (H') diversity and Equitability (J') indices. We also obtained richness estimates (Chao 1). We used Principal Component Analysis (PCA) to evaluate species' association with strata. We excluded from the analysis species recorded with absolute frequency equal to or less than five. To perform the analysis, we used the statistical software Past (Hammer et al., 2001).

The ant species association with the strata (soil and leaf litter and arboreal) was also obtained through an Indicator Species Analysis (ISA) (Dufrêne & Legendre, 1997), obtaining the indication value for each species. We considered indicator species the ones obtaining an indication value ≥25%, adapted from Dufrêne & Legendre (1997) for ant assemblages with statistical probability $p < 0.05$ instead of $p < 0.01$. We used the software PC-Ord 5.31 (McCune & Mefford, 2006).

Ethical aspects

The samples were obtained with the authorization of the Environment and Infrastructure Bureau of the State of Rio Grande do Sul under number 619/2019 and SISBIO license n° 50736-1.

Results

We recorded a richness of 157 species belonging to 32 genera and eight subfamilies. The subfamilies registered were Dolichoderinae (S = 14), Dorylinae (S = 4), Ectatomminae (S = 5), Formicinae (S = 40), Heteroponerinae (S = 4), Myrmicinae (S = 70), Ponerinae (S = 15) and Pseudomyrmecinae (S = 6). The greatest richness was sampled in the soil and leaf litter stratum, with 123 species, followed by the arboreal stratum, with 87 species. The richest genera were *Camponotus* (S = 29), *Pheidole* (S = 23), *Linepithema* (S = 11), *Solenopsis* (S = 9), *Acromyrmex* (S = 8) and *Crematogaster* (S = 8). Overall, 58 species occurred exclusively in the soil and leaf litter stratum and 23 in the arboreal stratum (see the Appendix).

We recorded the highest abundance on soil and leaf litter samples (n = 820). On the other hand, we recorded the highest diversity (H' = 3.96) and the highest Equitability (J' = 0.89) in the arboreal stratum. The richness estimate (S_{Chao-1}) was 189.5, 20.7% higher than the observed richness (S_o) (Table 1). The ant assemblage richness was higher in the soil and leaf litter than in the arboreal stratum. The rarefaction curves indicated a trend toward increasing richness in the two evaluated strata (Figure 1).

Regarding the Principal Component Analysis, we excluded the data from 109 species because they had five or less occurrences in the samples. The analysis showed that 100.0% of the variation in the distribution of the 48 included species is explained by the first two axes of the PCA. The soil and leaf litter stratum were associated with the species *Dinoponera australis* Emery, 1901, *Odontomachus chelifer* (Latreille, 1802), *Pachycondyla striata* F. Smith, 1858, *Pheidole aberrans* Mayr, 1868, *Pheidole dyctiota* Kempf, 1972, *Pheidole lignicola* Mayr, 1887 and *Pheidole pubiventris* Mayr, 1887. *Camponotus*

Table 1. Ecological indicators of the myrmecofauna occuring in the Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019.

Ecological index	Soil and leaf litter	Arboreal	Total
Taxa S (Richness)	123	87	157
Abundance (n)	820	327	1248
Shannon (H')	3.82	3.96	4.22
Equitability (J')	0.79	0.89	0.83
Chao-1	160.8	108.1	189.5
Relationship between observed (S) and estimated richness (Chao 1)			20.7%

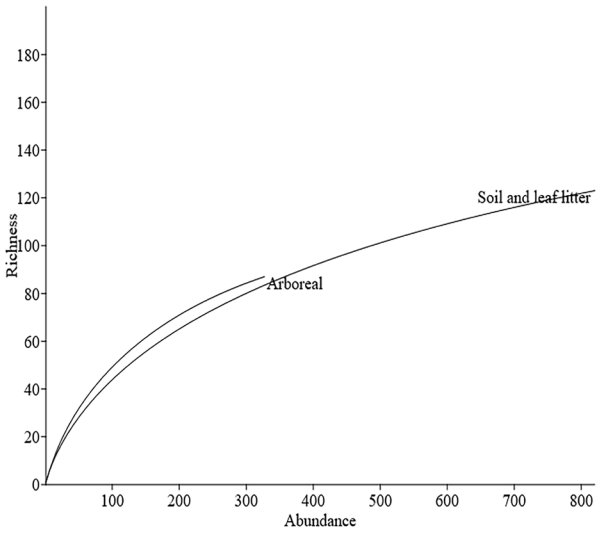

Fig 1. Comparison of observed richness, by rarefaction analysis, of the ant's assemblage sampled in the soil and vegetation in Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019.

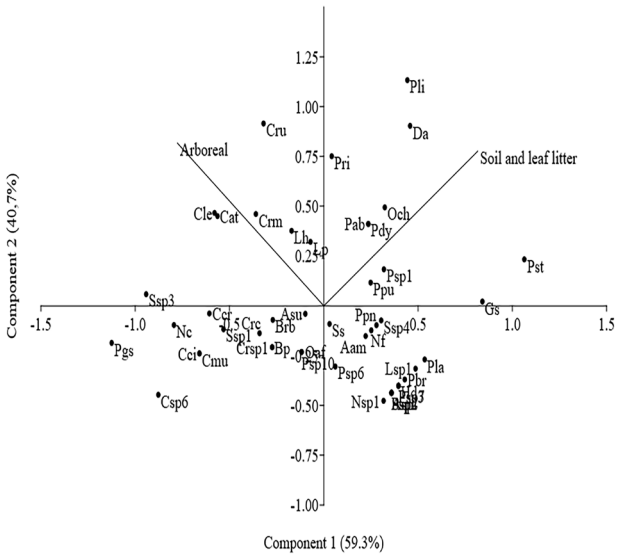

Fig 2. Principal Component Analysis (PCA) demonstrating the association of ant species that occur in two strata in Parque Estadual do Turvo, Derrubadas, RS, January and November 2019. Aam: *Acromyrmex ambiguus;* Asu: *Acromyrmex subterraneus;* Asp: *Apterostigma sp.;* Bp: *Brachymyrmex pilipes;* Cat: *Camponotus atriceps;* Cci: *Camponotus cingulatus;* Ccr: *Camponotus crassus;* Cle: *Camponotus lespesii;* Cmu: *Camponotus mus;* Cru: *Camponotus rufipes;* Csp6: *Camponotus sp. 6;* Brb: *Crematogaster bingo;* Crc: *Crematogaster corticícola;* Crm: *Crematogaster magnifica;* Crsp1: *Crematogaster sp. 1;* Da: *Dinoponera australis;* Gs: *Gnamptogenys striatula;* Hd: *Hypoponera distinguenda;* Lp: *Labidus praedator;* Lh: *Linepithema humile;* Lsp1: *Linepithema sp. 1;* Nc: *Neoponera crenata;* Nf: *Nylanderia fulva;* Nsp1: *Nylanderia sp. 1;* Oaf: *Odontomachus affinis;* Och: *Odontomachus chelifer;* Pst: *Pachycondyla striata;* Pab: *Pheidole aberrans;* Pbr: *Pheidole brevicona;* Pdy: *Pheidole dyctiota;* Pla: *Pheidole laevifrons;* Pli: *Pheidole lignicola;* Ppu: *Pheidole pubiventris;* Ppn: *Pheidole punctatissima;* Pri: *Pheidole risii;* Psp1: *Pheidole sp. 1;* Psp2: *Pheidole sp. 2;* Psp3: *Pheidole sp. 3;* Psp4: *Pheidole sp. 4;* Psp6: *Pheidole sp. 6;* Psp7: *Pheidole sp. 7;* Psp10: *Pheidole sp. 10;* Pgs: *Pseudomyrmex gracilis;* Ss: *Solenopsis stricta;* Ssp1: *Solenopsis sp. 1;* Ssp2: *Solenopsis sp. 2;* Ssp3: *Solenopsis sp. 3 e;* Ssp4: *Solenopsis sp. 4.*

atriceps (Smith, 1858), *Camponotus lespesii* Forel, 1886, *Camponotus rufipes* (Fabricius, 1775), *Crematogaster magnifica* Santschi, 1926 and *Linepithema humile* Mayr, 1868 were associated with the arboreal stratum. The other species showed no association with the strata (Figure 2).

We found seven species in the soil and leaf litter stratum with significant bioindication value: *Gnamptogenys striatula* (Mayr, 1884), Pheidole aberrans (Mayr, 1868), *Pheidole lignicola* (Mayr, 1887), Pheidole pubiventris (Mayr, 1887), *Dinoponera australis* (Emery, 1901), *Odontomachus chelifer* (Latreille, 1802) and *Pachycondyla striata* (F. Smith, 1858). For the arboreal stratum, two species showed significant indication value: *Neoponera crenata* (Roger, 1858) and *Pseudomyrmex gracilis* (Fabricius, 1804) (Table 2).

Table 2. Ant species with an Indication Value (IV) greater than 25% and statistical probability p<0.05 associated with two types of strata (soil and litter and vegetation) in Parque Estadual do Turvo, Derrubadas, RS, January and November, 2019.

Taxa	IV(%) Soil and leaf litter	IV(%) Arboreal	*P*
Gnamptogenys striatula (Mayr, 1884)	40		0.0028
Pheidole aberrans (Mayr, 1868)	44.4		0.003
Pheidole lignicola (Mayr, 1887)	83.3		0.0002
Pheidole pubiventris (Mayr, 1887)	26.2		0.0388
Dinoponera australis (Emery, 1901)	46.2		0.0102
Odontomachus chelifer (Latreille, 1802)	30.2		0.0418
Neoponera crenata (Roger, 1858)		31.6	0.0128
Pachycondyla striata (F. Smith, 1858)	40.4		0.0104
Pseudomyrmex gracilis (Fabricius, 1804)		37.3	0.0088

Discussion

The richest ant fauna subfamilies in the Parque Estadual do Turvo, Myrmicinae, Formicinae, Ponerinae, and Dolichoderinae corroborate the study by Silva et al. (2022). The Myrmicinae subfamily, with a richness of 70 species in the samples, is constituted of ants having diversified foraging habits, high richness in surveys carried out in the Neotropical region, and representing approximately 55% of the Formicidae species in the world (Bolton, 2023). Such representativeness of Mymicinae over other subfamily richness is a pattern in the Atlantic Forest biome (Silva et al., 2022).

The richest Myrmicinae genera in the evaluated strata of Parque Estadual do Turvo were *Acromyrmex*, *Crematogaster*, *Pheidole*, and *Solenopsis*. According to Baccaro et al. (2015), these genera are rich and abundant in the Brazilian biomes. Ants belonging to *Pheidole*, *Solenopsis*, and *Crematogaster* genera are characterized as generalists and occur in several environments (Silvestre et al., 2003), including those under environmental impact, such as urban areas (Lutinski et al., 2014). The *Acromyrmex* and *Atta* genera present species with the potential to cause economic damage to crops by cutting leaves to cultivate a symbiotic fungus. These damages usually result from population imbalances of these ant species (Baccaro et al., 2015). They are polymorphic ants, endemic to the Neotropical region, and play an essential role in maintaining the soil where they nest. Their galleries play an important role in aeration, while their excrements and plant residues from fungal action enrich soil function (Silvestre et al., 2003).

Ants of *Apterostigma*, *Mycetophylax*, and *Mycocepurus* genera found in the soil and leaf litter stratum have their foraging habits, the cultivation of fungus on bark, feces, and organic matter in decomposition. These genera are characterized by medium and small-size individuals, and their colonies are found in conserved environments where the vegetation is in a more advanced stage of succession (Silvestre et al., 2003). Therefore, the conservation status of Turvo State Park can explain the occurrence of these ants.

Formicinae ants stand out for their richness and abundance in studies carried out in Rio Grande do Sul (Cantarelli et al., 2015) and in the Atlantic Forest biome (Silva et al., 2022). The diversity of ants of this subfamily allows the occupation of the most varied niches in the ecosystem, and, therefore, some species are conservation indicators. In contrast, others are associated with anthropized environments, such as urban areas (Lutinski et al., 2014). The genus *Camponotus* assembles polymorphic species with varied colors and habits nesting on the ground, trunks, and trees. Some species prefer sweeter substances, while others feed on protein sources (Silvestre et al., 2003). The conservation stage verified in the Parque Estadual do Turvo offers varied niches, both in the soil and leaf litter as well as in the vegetation, and, in this way, explains the *Camponotus* richness.

Myrmelachista ants have a small size and specialized activity associated and are typically arboreal (Baccaro et al., 2015). Species of the *Brachymyrmex* genus forage in the soil and on the vegetation. They are found under stones and trunks and respond to environmental changes (Marinho et al., 2002). The diversity of these ants indicates the diversity of the existing vegetation in the park and, consequently, the supply of food and nesting sites (Magalhães et al., 2022).

Dorymyrmex and *Linepithema* ants are rich and abundant in the Atlantic Forest biome (Silva et al., 2022). They are dominant and are commonly found in ecologically disturbed environments (Silvestre et al., 2003; Lutinski et al., 2017). *Linepithema* species were sampled both in the soil and litter and in the vegetation strata, which indicates the diversity of niches occupied by this ant fauna.

Ponerinae ants are associated with closed and humid environments, although some *Dinoponera*, *Pachycondyla*, and *Odontomachus* species can be found in open areas. *Dinoponera* is the genera that presents the most giant ants in the Americas and perhaps the world. The *Pachycondyla* genus encompasses predatory ants, abundant in soil and leaf litter samples. The *Odontomachus* genus has highly aggressive species that are effective as predators using well-developed jaws (Lattke, 2003). *Hypoponera* ants are specialized cryptic predators. Its colonies are small, and workers have low agility. The diversity of this genera positively correlates with the leaf litter accumulated on the ground (Silvestre et al., 2003). The Ponerinae diversity sampled indicates a high degree of conservation, reflected in a rich and abundant biodiversity of soil and leaf litter invertebrates, which constitute prey for these ants.

Ants belonging to the subfamily Pseudomyrmecinae, genus *Pseudomyrmex*, are frequent in inventories already carried out in southern Brazil (Ulysséa et al., 2011; Rizzotto et al., 2019). Although the genus is found in anthropized environments (Lutinski et al., 2017), they depend on the vegetation where they nest and forage. The subfamily Dorylinae includes ants known as legionnaires or army ants. These ants stand out for their ecological role as predators of other invertebrates and even small vertebrates and depend on conserved environments for their maintenance (Baccaro et al., 2015). The diversity of ants sampled from these subfamilies also highlights the conservation of the park, especially the vegetation and leaf litter where the prey is found.

The subfamilies Ectatomminae and Heteroponerinae occurred exclusively in the soil and leaf litter stratum. In both cases, specialized predatory ants colonize and forage the leaf litter (Silvestre et al., 2003). These characteristics highlight the park's conservation condition, which can shelter the sampled diversity of these ants.

The ecological indicators confirmed the expected differences in the richness, composition, and abundance of ants in the evaluated strata. The occurrence of unique species in each stratum points to the diversity and specializations of the niches of the ant fauna that occur in Parque Estadual do Turvo. Complementary sampling methods enable a more complete ant inventory (Fernández, 2003).

The bioindicator role of ants relies on the specializations and ecological relationships they are part of (Hölldobler & Wilson, 1990; Santos-Silva et al., 2016; Magalhães et al., 2022). The PCA demonstrated the association or dissociation of ant species with the different strata in the park. This result confirms what is expected, especially in the case of a conserved environment, where one of the highest richness of Formicidae was sampled in a recent study in the southern Atlantic Forest biome (Silva et al., 2022).

The ecological and biological knowledge of the species highlighted as bioindicators corroborates our hypothesis in the context of the strata evaluated. The conservation conditions (not disturbed) in the two strata are in accordance with the foraging and nesting habits of the ant species. Therefore, our hypothesis that ant species can bioindicate soil cover and the presence of leaf litter, vegetation diversity, and stage was confirmed.

The indicator species analysis also supported the association between the occurrences of ants with the two evaluated strata. The species *G. striatula*, *D. australis*, *O. chelifer*, and *P. striata* are soil and leaf litter predators (Baccaro et al., 2015) frequently sampled in fragments of the Atlantic Forest biome of southern Brazil (Silva et al., 2022). *Pheidole aberrans*, *P. lignicola*, and *P. pubiventris* have also been frequently sampled with pitfalls and baits on leaf litter (Lutinski et al., 2014), indicating association with this stratum. The species *N. crenata* and *P. gracilis* forage and nest in the vegetation (Silvestre et al., 2003), which explains the bioindicator potential of these species for the arboreal stratum of Parque Estadual do Turvo.

Conclusion

The bioindicator potential of the ant fauna in Parque Estadual do Turvo showed an important richness, composition, and abundance of ant assemblages. The association of species with the soil and leaf litter and arboreal strata corroborates the knowledge about what the literature already reports about the sampled ant species.

We observed that only nine species (5.7% of the sampled richness) had a significant Indication Value. However, the record of 86 species (52.7%) with exclusive occurrence in one or another of the evaluated strata allows inferring about the distinction between the sampled strata.

Considering the state of conservation of the Parque Estadual do Turvo, the results represent an information base for monitoring the ant fauna occurring in the park and allow inferences about the area's importance for the conservation of regional biodiversity. The indicator species have the potential to serve as a basis for environmental impact studies and management and conservation plans in the southern Atlantic Forest biome.

Authors' Contribution

JAL: Conceptualization; formal analysis; methodology; investigation; data curation; writing-original draft; writing-review and editing; resources.

CJL: Conceptualization; formal analysis; investigation; data curation; writing-original draft; writing-review & editing; resources.

ABS: Methodology; validation; data curation; writing-original draft.

MAB: Conceptualization; formal analysis; investigation; data curation; writing-original draft; writing-review & editing; resources.

FRMG: Conceptualization; formal analysis; investigation; data curation; writing-original draft; writing-review & editing.

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Appendix. Ant assemblage sampled in the soil and leaf litter and vegetation strata at Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019.

Taxa	Soil and litter		Arboreal	
	n	%	n	%
SubfamilyDolichoderinae				
Dorymyrmex brunneus Forel, 1908	2	0.24		
Dorymyrmex pyramicus(Roger, 1863)	1	0.12		
Linepithema angulatum(Emery, 1894)	2	0.24	1	0.31
Linepithema gallardoi (Brèthes, 1914)	2	0.24		
Linepithema humile (Mayr, 1868)	11	1.34	8	2.45
Linepithema iniquum (Mayr, 1870)			3	0.92
Linepithema micans (Forel, 1908)	1	0.12	1	0.31
Linepithema sp. 1	11	1.34		
Linepithema sp. 2	2	0.24	2	0.61
Linepithema sp. 3	1	0.12	1	0.31
Linepithema sp. 4	2	0.24		
Linepithema sp. 5	3	0.37		
Linepithema sp. 6			2	0.61
Tapinoma melanocephalum (Fabricius, 1793)	1	0.12		
Subfamily Dorylinae				
Labidus coecus (Latreille, 1802)	4	0.49		
Labidus praedator (F. Smith, 1858)	12	1.46	6	1.83
Neocerapachys splendens Borgmeier, 1957	1	0.12		
Nomamyrmex hartigii (Westwood, 1842)			1	0.31
Subfamily Ectatomminae				
Gnamptogenys striatula Mayr, 1884	36	4.39		
Gnamptogenys striolata (Borgmeier, 1957)	1	0.12		
Gnamptogenys sp. 1	2	0.24		
Gnamptogenys sp. 2	3	0.37		
Ectatomma edentatus Roger, 1863	1	0.12		
Subfamily Formicinae				
Tribe Camponotini				
Camponotus atricep (Smith, 1858)	6	0.73	18	5.50
Camponotus blandus (Smith, 1858)			1	0.31
Camponotus cameranoi Emery, 1894	1	0.12	3	0.92
Camponotus cingulatus Mayr, 1862	1	0.12	6	1.83
Camponotus crassus Mayr, 1862	2	0.24	8	2.45
Camponotus fastigatus Roger, 1863	1	0.12		
Camponotus lespesii Forel, 1886	6	0.73	19	5.81
Camponotus melanoticus Emery, 1894			2	0.61
Camponotus mus Roger, 1863	1	0.12	6	1.83
Camponotus novogranadensis Mayr, 1870			2	0.61
Camponotus punctulatus Mayr, 1868			3	0.92
Camponotus rufipes (Fabricius, 1775)	21	2.56	27	8.26
Camponotus sericeiventris (Guérin-Méneville, 1848)	1	0.12	1	0.31
Camponotus sexguttatus (Fabricius, 1793)	1	0.12		
Camponotus sp. 1	1	0.12	3	0.92

Appendix. Ant assemblage sampled in the soil and leaf litter and vegetation strata at Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019. (Continued)

Camponotus sp. 2			2	0.61
Camponotus sp. 3			2	0.61
Camponotus sp. 4	1	0.12		
Camponotus sp. 5	2	0.24	3	0.92
Camponotus sp. 6			6	1.83
Camponotus sp. 7			1	0.31
Camponotus sp. 8			1	0.31
Camponotus sp. 9			3	0.92
Camponotus sp. 10			1	0.31
Camponotus sp. 11	2	0.24		
Camponotus sp. 12			1	0.31
Camponotus sp. 13	1	0.12	3	0.92
Camponotus sp. 14			4	1.22
Camponotus sp. 15			1	0.31
Tribe Myrmelachistini				
Brachymyrmex coactus Mayr, 1887	4	0.49		
Brachymyrmex cordemoyi Forel, 1895	1	0.12	1	0.31
Brachymyrmex pilipes Mayr, 1887	3	0.37	3	0.92
Brachymyrmex sp.			1	0.31
Myrmelachista catharinae Mayr, 1887			2	0.61
Myrmelachista kloetersi Forel, 1903	2	0.24	2	0.61
Myrmelachista nodigera Mayr, 1887	1	0.12	3	0.92
Myrmelachista sp.	1	0.12		
Tribe Lasiini				
Nylanderia fulva (Mayr, 1862)	10	1.22	1	0.31
Nylanderia sp. 1	6	0.73		
Paratrechina longicornis (Latreille, 1802)	2	0.24		
Subfamily Heteroponerinae				
Heteroponera dolo (Roger, 1860)	1	0.12		
Heteroponera flava Kempf, 1962	4	0.49		
Heteroponera inermis (Emery, 1894)	2	0.24		
Heteroponera microps Borgmeier, 1957	1	0.12		
Subfamily Myrmicinae				
Tribe Attini				
Acromyrmex ambiguus (Emery, 1888)	9	1.10	1	0.31
Acromyrmex aspersus (F. Smith, 1858)	3	0.37	1	0.31
Acromyrmex disciger (Mayr, 1887)	2	0.24		
Acromyrmex lundii (Guérin-Méneville, 1848)	2	0.24		
Acromyrmex niger (F. Smith, 1858)	2	0.24		
Acromyrmex subterraneus (Forel, 1893)	6	0.73	3	0.92
Acromyrmex sp. 1	2	0.24		
Acromyrmex sp. 2	1	0.12		
Apterostigma mayri Forel, 1893	3	0.37		
Apterostigma pilosum Mayr, 1865	3	0.37		
Apterostigma wasmannii Forel, 1891	2	0.24		

Appendix. Ant assemblage sampled in the soil and leaf litter and vegetation strata at Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019. (Continued)

Apterostigma sp.	7	0.85		
Atta sexdens (Linnaeus, 1758)	3	0.37		
Basiceros convexiceps (Mayr, 1887)			1	0.31
Cephalotes angustus (Mayr, 1862)			1	0.31
Cephalotes pusillus (Klug, 1824)			1	0.31
Cyphomyrmex rimosus (Spinola, 1851)	1	0.12		
Mycetophylax plaumanni (Kempf, 1962)	2	0.24		
Mycetophylax strigatus (Mayr, 1887)	1	0.12		
Mycocepurus goeldii (Forel, 1893)	1	0.12		
Mycocepurus sp.	1	0.12		
Octostruma rugifera (Mayr, 1887)	2	0.24		
Octostruma sp.	1	0.12		
Pheidole aberrans Mayr, 1868	24	2.93	4	1.22
Pheidole brevicona (Mayr, 1887)	9	1.10		
Pheidole dyctiota Kempf, 1972	24	2.93	4	1.22
Pheidole laevifrons Mayr, 1887	13	1.59		
Pheidole lignicola Mayr, 1887	110	13.41	11	3.36
Pheidole pubiventris Mayr, 1887	15	1.83	2	0.61
Pheidole punctatissima Mayr, 1870	11	1.34	1	0.31
Pheidole risii Forel, 1892	30	3.66	11	3.36
Pheidole sp. 1	19	2.32	2	0.61
Pheidole sp. 2	7	0.85		
Pheidole sp. 3	8	0.98		
Pheidole sp. 4	7	0.85		
Pheidole sp. 5	3	0.37		
Pheidole sp. 6	5	0.61	1	0.31
Pheidole sp. 7	8	0.98		
Pheidole sp. 8	3	0.37		
Pheidole sp. 9	4	0.49		
Pheidole sp. 10	4	0.49	2	0.61
Pheidole sp. 11	1	0.12		
Pheidole sp. 12			1	0.31
Pheidole sp. 13	1	0.12		
Pheidole sp. 14	1	0.12		
Pheidole sp. 15			3	0.92
Procryptocerus adlerzi (Mayr, 1887)	1	0.12	2	0.61
Procryptocerus convergens (Mayr, 1887)			1	0.31
Strumigenys sp. 1	1	0.12		
Strumigenys sp. 2	1	0.12		
Tribe Crematogastrini				
Crematogaster acuta (Fabricius, 1804)	1	0.12		
Crematogaster bingo Forel, 1908	4	0.49	4	1.22
Crematogaster corticicola (Mayr, 1887)	3	0.37	4	1.22
Crematogaster magnifica Santschi, 1926	9	1.10	13	3.98
Crematogaster sp. 1	3	0.37	3	0.92

Appendix. Ant assemblage sampled in the soil and leaf litter and vegetation strata at Parque Estadual do Turvo, Derrubadas, RS, from January to November, 2019. (Continued)

Crematogaster sp. 2			2	0.61
Crematogaster sp. 3	1	0.12	1	0.31
Crematogaster sp. 4			1	0.31
Tribe Pogonomyrmecini				
Pogonomyrmex naegelii Forel, 1878	1	0.12		
Patagonomyrmex angustus Mayr, 1870	3	0.37		
Tribe Solenopsidini				
Monomorium floricola (Jerdon, 1851)	1	0.12	1	0.31
Solenopsis helena Emery, 1895	3	0.37		
Solenopsis invicta Buren, 1972	1	0.12		
Solenopsis saevissima (F. Smith, 1855)			1	0.31
Solenopsis stricta Emery, 1896	7	0.85	2	0.61
Solenopsis sp. 1	2	0.24	6	1.83
Solenopsis sp. 2	7	0.85		
Solenopsis sp. 3	1	0.12	17	5.20
Solenopsis sp. 4	12	1.46	1	0.31
Solenopsis sp. 5	2	0.24		
Subfamily Ponerinae				
Tribe Ponerini				
Dinoponera australis Emery, 1901	78	9.51	7	2.14
Hypoponera distinguenda (Emery, 1890)	8	0.98		
Hypoponera trigona (Mayr, 1887)	2	0.24		
Hypoponera sp. 1	2	0.24	1	0.31
Hypoponera sp. 2	1	0.12		
Odontomachus chelifer (Latreille, 1802)	32	3.90	4	1.22
Odontomachus affinis Guérin-Méneville, 1844	4	0.49	2	0.61
Neoponera crenata (Roger, 1858)	1	0.12	10	3.06
Neoponera villosa (Fabricius, 1804)	2	0.24		
Pachycondyla harpax (Fabricius, 1804)	3	0.37		
Pachycondyla striata F. Smith, 1858	74	9.02		
Pachycondyla sp. 1	1	0.12		
Pachycondyla sp. 2	1	0.12	2	0.61
Pachycondyla sp. 3			1	0.31
Pachycondyla sp. 4	1	0.12	2	0.61
Subfamily Pseudomyrmecinae				
Tribe Pseudomyrmecini				
Pseudomyrmex gracilis (Fabricius, 1804)			15	4.59
Pseudomyrmex flavidulus (F. Smith, 1858)			2	0.61
Pseudomyrmex phyllophilus (F. Smith, 1858)			2	0.61
Pseudomyrmex sp. 1			2	0.61
Pseudomyrmex sp. 2			1	0.31
Pseudomyrmex sp. 3			2	0.61
Richness	**123**		**87**	
Abundance	**820**		**327**	