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Animal Biodiversity and Conservation in Brazil's Northern Atlantic Forest





Ants (Hymenoptera: Formicidae) in the Pernambuco Endemism Center of the Brazilian Atlantic Forest

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Abstract

We revised the literature on ant records in the Pernambuco Endemism Center – the Biogeographical Sub-Region Pernambuco in the Atlantic Forest – to synthesize the information regarding the diversity and distribution of ants in this important endemism area of the biome. We gathered 3769 ant records, encompassing over 10 subfamilies, 71 genera, and 247 nominal species. We further provide up-to-date information regarding the state of knowledge, distribution gaps, and prospects for ant diversity in this key region for the maintenance of biodiversity of the Brazilian Atlantic Forest.

Keywords

Northern Atlantic Forest · Conservation · Endemism

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3.1 Introduction

Ants (Hymenoptera: Formicidae) are an ecologically successful and numerically dominant group of animals, playing key ecological roles as soil engineers, predators, nutrient recyclers, and regulators of plant growth and reproduction in most terrestrial ecosystems (Hölldobler and Wilson 1990; Lach et al. 2010; Parker and Kronauer 2021). Ants are also widely used as bioindicators of the ecological impact of land use (Andersen and Majer 2004), including several studies performed in the Atlantic Forest areas (reviewed in Ribas et al. 2012; Silva et al. 2022).

The Brazilian Atlantic Forest is a hotspot of biodiversity (Myers et al. 2000) and is recognized as one of the most diverse rain forests in the world (Marques and Grelle 2021), holding an impressive number of eusocial insect species, such as ants, bees, wasps (Hymenoptera), and termites (Blattodea, Isoptera) (Feitosa et al. 2021). Particularly for ants, a recent compilation of ant records across the entire Atlantic Forests of Brazil, Paraguay, and Argentina identified 1114 ant species representing 10 subfamilies and 99 genera (Feitosa et al. 2021; Silva et al. 2022).

In Atlantic Forest, the Pernambuco Endemism Center (PEC) – the biogeographical subregion (BSR) Pernambuco (Silva and Casteleti 2005; Peres et al. 2020) – is an important endemism center in South America. With a long history of habitat fragmentation, which began in 1500 with the economic cycle of brazilwood, PEC currently presents one of the highest deforestation rates among Brazilian biomes, at the same time it is one of the least studied regions in the Atlantic Forest, especially regarding invertebrates. This is of particular concern for ants, given that this region is seen as a global hotspot of discovery, with the potential to host at least 20 new records of ant genera (Guénard et al. 2012).

Despite the importance of ants as indicator of biodiversity (Leal et al. 2010) and of habitat quality (Leal et al. 2012) in the Pernambuco Endemism Center, there are very few checklists and distributional analyses for this biogeographical

subregion. Here, we organized a list of the ant species of this region aiming to describe its species richness and distribution in the PEC.

3.2 Methods

The complete data set comprises historical and current ant records (ranging from 1803 to 2021), most of them extracted from the Atlantic Ants data set (Silva et al. 2022). We updated this data set by incorporating published literature in 2021, especially by including data sets from recent taxonomic revisions of Neotropical ants, as those of the genera *Cephalotes* (Oliveira et al. 2021), *Dinoponera* (Dias and Lattke 2021), and *Hylomyrma* (Ulysséa and Brandão 2021). When coordinates were not available, we georeferenced the records using the GeoNames geographical database ([geonames.org](https://www.geonames.org)) and secondly Google Maps (www.google.com.br/maps/).

Regarding the source of the occurrence data available in the Atlantic Ants dataset, 3041 records were compiled from published literature, 212 from collections databases, and 516 come from unpublished data (i.e., ant surveys carried out by coauthors, including undergraduate and graduate studies; Silva et al. 2022). The data set includes occurrence data from the following Brazilian museums and institutions: Museu de Zoologia da Universidade de São Paulo (MZSP), São Paulo; Museu Paraense Emílio Goeldi (MPEG), Belém, Pará; Coleção Entomológica Padre Jesus Santiago Moure (DZUP), Universidade Federal do Paraná, Curitiba, Paraná. Further, ant records from online specimen repositories such as [AntWeb.org](https://www.antweb.org) as implemented by the California Academy of Sciences, San Francisco, California, United States, and GBIF (<https://www.gbif.org/>). Finally, 1481 ant records in the BRC Pernambuco were gathered from the Global Ant Biodiversity Informatics (GABI) Project (Guénard et al. 2017).

We prepared a map based on kernel density estimation (KDE) with a bandwidth of 15 km to describe the ant sampling distribution in the Pernambuco Endemism Center. Further, we extracted the relative sampling coverage by counting points (geographic coordinates) inside and outside of protected areas, Atlantic Forest remnants, and priority areas for conservation to describe sampling efforts inside the PEC. We considered ant records in the Pernambuco Endemism Center when they were within its boundaries as defined by the shapefile, including the so-called “brejos de altitude” (remnants of wet forest in a Caatinga landscape) in the states of Pernambuco and Paraíba. We defined the boundaries of the biogeographical Sub-Region Pernambuco using shapefiles from the Instituto Nacional de Pesquisas Espaciais (INPE) to the Brazilian States of Rio Grande do Norte, Paraíba, Pernambuco, and Alagoas, available online (<http://terrabrasilis.dpi.inpe.br/downloads/>). Shapefiles from both

protected and priority areas were provided by Ministério do Meio Ambiente (MMA; <https://www.mma.gov.br>).

We organized the entire data set in a single database, combining assemblage information and occurrence information. The data set can be accessed on GitHub Inc. repository (https://github.com/LEECLab/Atlantic_series) as a new release of the Atlantic Ants dataset. The literature used to compile the ant records (110 references in alphabetical order) can be consulted in a supplementary data (Supplementary Table 1).

3.3 Results

We identified 3769 records in the Pernambuco Endemism Center (Fig. 3.1a), encompassing over 10 subfamilies, 71 genera, and 247 species (Supplementary Table 1). The distribution of ant records by State is highly uneven (Alagoas = 1798; Paraíba = 968, Pernambuco = 812, and Rio Grande do Norte = 191). Over the 236 municipalities within the PEC (Alagoas = 71; Pernambuco = 99; Paraíba = 38; Rio Grande do Norte = 28), we recorded ant occurrences in 62 first-order administrative divisions (i.e., 25% of the municipalities). Further, sampling is strongly biased to the ten commonest municipalities that together include 82% of records ($N = 3103$; Figs. 3.1b and 3.2) and, in general, is represented by sampling sites close to the capitals or larger cities in the Pernambuco Endemism Center.

We characterized 1731 records (about 46% of records) inside protected areas, representing 18 conservation units in the PEC. The *Reserva Biológica Guaribas* ($n = 635$), *Área de Proteção Ambiental Aldeia Beberibe* ($n = 283$), *Área de Proteção Ambiental de Muricí* ($n = 276$), *Parque Estadual Dois Irmãos* ($n = 203$), and the *Refúgio de Vida Silvestre da Mata do Buraquinho* ($n = 184$) had the highest number of occurrences among the protected areas found in the PEC. In total, there were 150 nominal ant species recorded in protected areas (61% of species). According to the priority areas for conservation in the PEC, we determined 1187 ant occurrences (31% of the records), but site records are obviously aggregated (Fig. 3.1c).

Regarding Atlantic Forest remnants in the PEC, we found 1999 occurrences (53% of the records) representing 156 nominal ant species. However, remnants at north of Rio Grande do Norte, south of Paraíba, and north of Pernambuco, as well a large area at south of Alagoas, remain largely unsampled (Fig. 3.1d).

We gathered 20 records of a vulnerable species (*Lachnomyrmex nordestinus* Feitosa & Brandão, 2008) according to the Brazilian Red List of Threatened Species (ICMBio 2018) (Fig. 3.3). There were 27 records for exotic species throughout the Pernambuco Endemism Center – an unidenti-

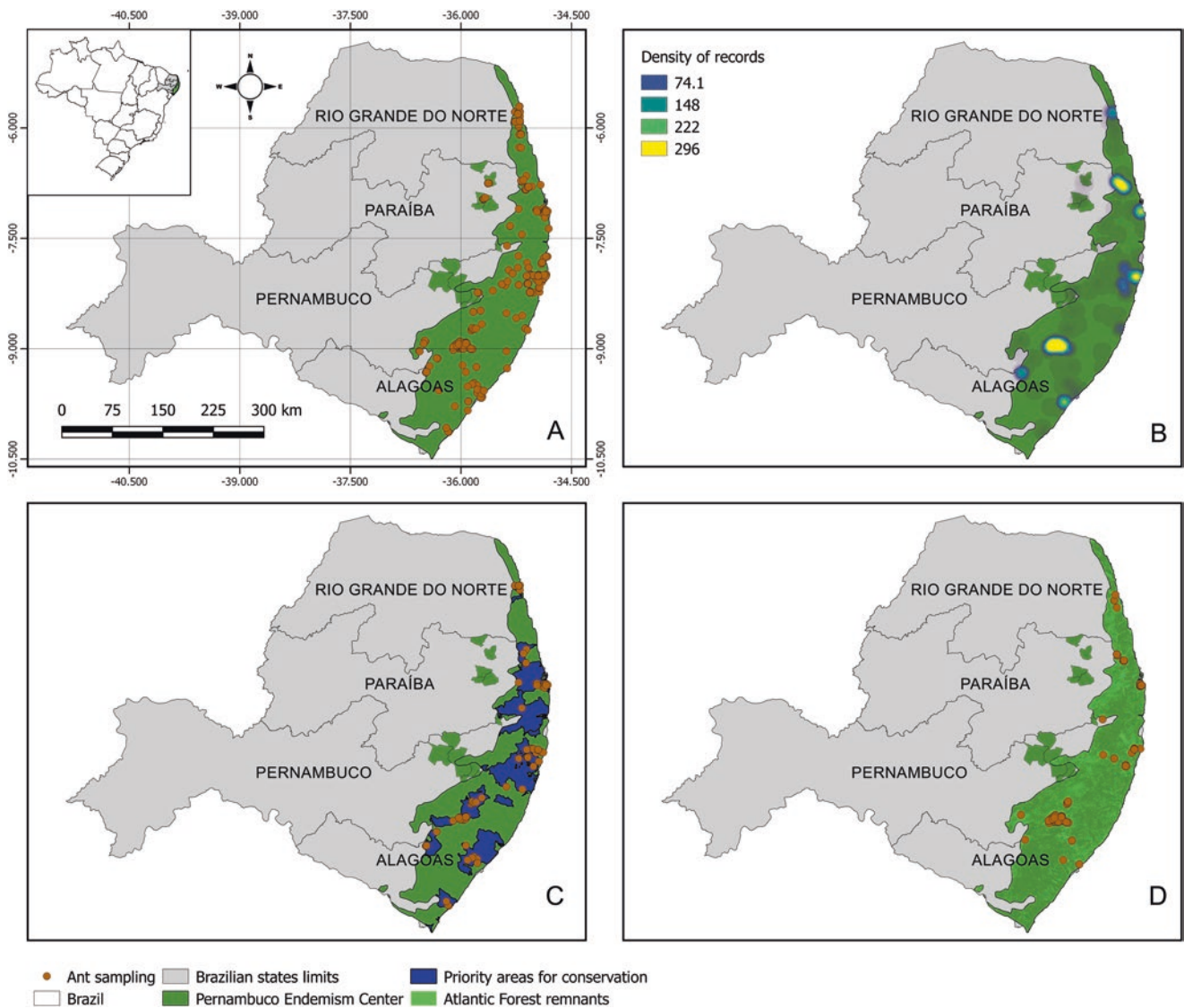


Fig. 3.1 Distribution of the 3769 ant records in the Pernambuco Endemism Center of the Atlantic Forest, compiled from 1803 to 2021 (a), density of records as estimated by KDE functions (b), ant sampling

distribution in priority areas for conservation (c), and distribution of ant records in remnants (d)

fied species of *Cardiocondyla* (1), *Monomorium floricola* (Jerdon, 1851) (5), *Paratrechina longicornis* (Latreille, 1802) (9), *Tapinoma melanocephalum* (Fabricius, 1793) (8) (Fig. 3.3), as well as *Tetramorium simillimum* (Smith, 1851) (4).

In terms of species richness (not including morphospecies), Myrmicinae was the richest subfamily (119 species), followed by Ponerinae (31), Formicinae (27), Dorylinae (22), Pseudomyrmecinae (20), Dolichoderinae (14), Ectatomminae (13), Proceratiinae (2 species), and Amblyoponinae (1 species). Among the genera recorded (morphospecies excluded), the richest genera in the PEC were *Pheidole* and *Pseudomyrmex* with 20 recorded species each, followed by *Camponotus* (19), *Strumigenys* (17), *Neivamyrmex* (12), *Cephalotes* (10), *Crematogaster* (9),

Solenopsis and *Dolichoderus* (8 species each), *Neoponera* (7), *Atta*, *Acromyrmex*, *Ectatomma*, *Gnamptogenys*, and *Odontomachus* (5 species each) (Fig. 3.4). There are 12 genera currently represented by one or two nominal species. The number of ant records represented by morphospecies (i.e., nonnominal species) is high (51% of the data set) (Fig. 3.5). Indeed, this scaled up to the genus level in the Biogeographical Sub-Region Pernambuco, ten genera were recorded only at morphospecies level, as *Acanthognathus*, *Acanthoponera*, *Cardiocondyla*, *Linepithema*, *Myrmicocrypta*, *Prionopelta*, *Typhlomyrmex*, *Probolomyrmex*, *Myrmelachista*, and *Mycetomoellerius/Paratrachymyrmex* (in this case, it is currently impossible to determine to which of these genera the species belongs without examined the specimens).

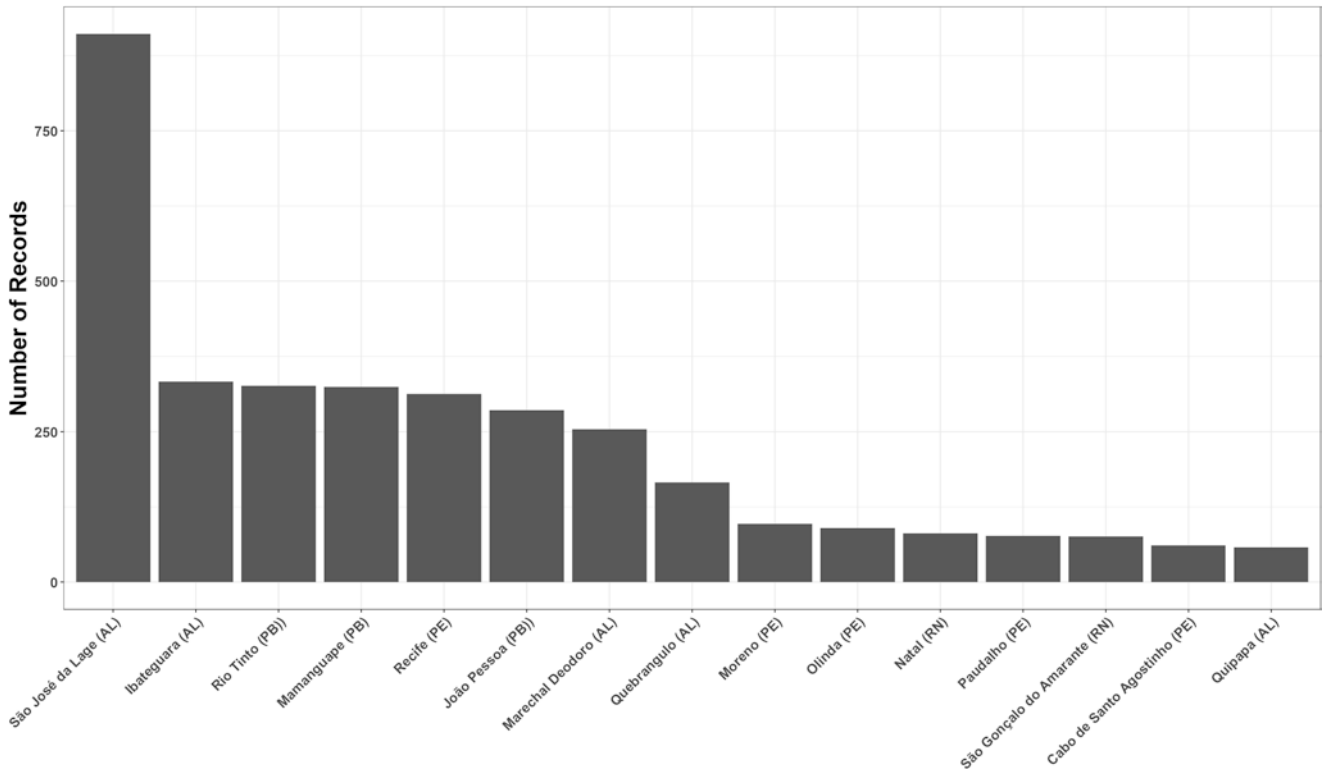
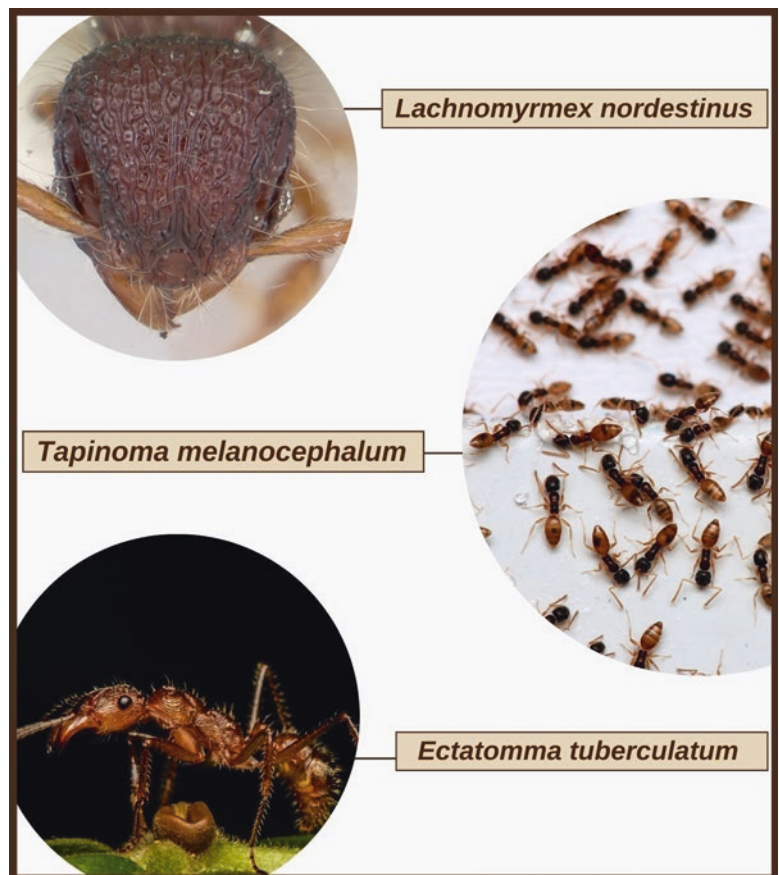


Fig. 3.2 Number of ant records per sampling site and municipality in the Pernambuco Endemism Center of the Atlantic Forest (only the 15 most frequently sampled municipalities are included, summing up 95% of total number of records). AL Alagoas, PE Pernambuco, PB Paraíba, RN Rio Grande do Norte

Fig. 3.3 *Lachnomyrmex nordestinus*, classified as a vulnerable species according to the Brazilian Red List of Threatened Species of the Instituto Chico Mendes de Conservação da Biodiversidade/ICMBio. (ICMBio 2018). *Tapinoma melanocephalum*, species classified as exotic and recorded at the Pernambuco Endemism Center. (Image: César Favacho). *Ectatomma tuberculatum*, considered one of the most frequently recorded species in the Pernambuco Endemism Center as well as in Brejos de altitude. (Image: César Favacho)



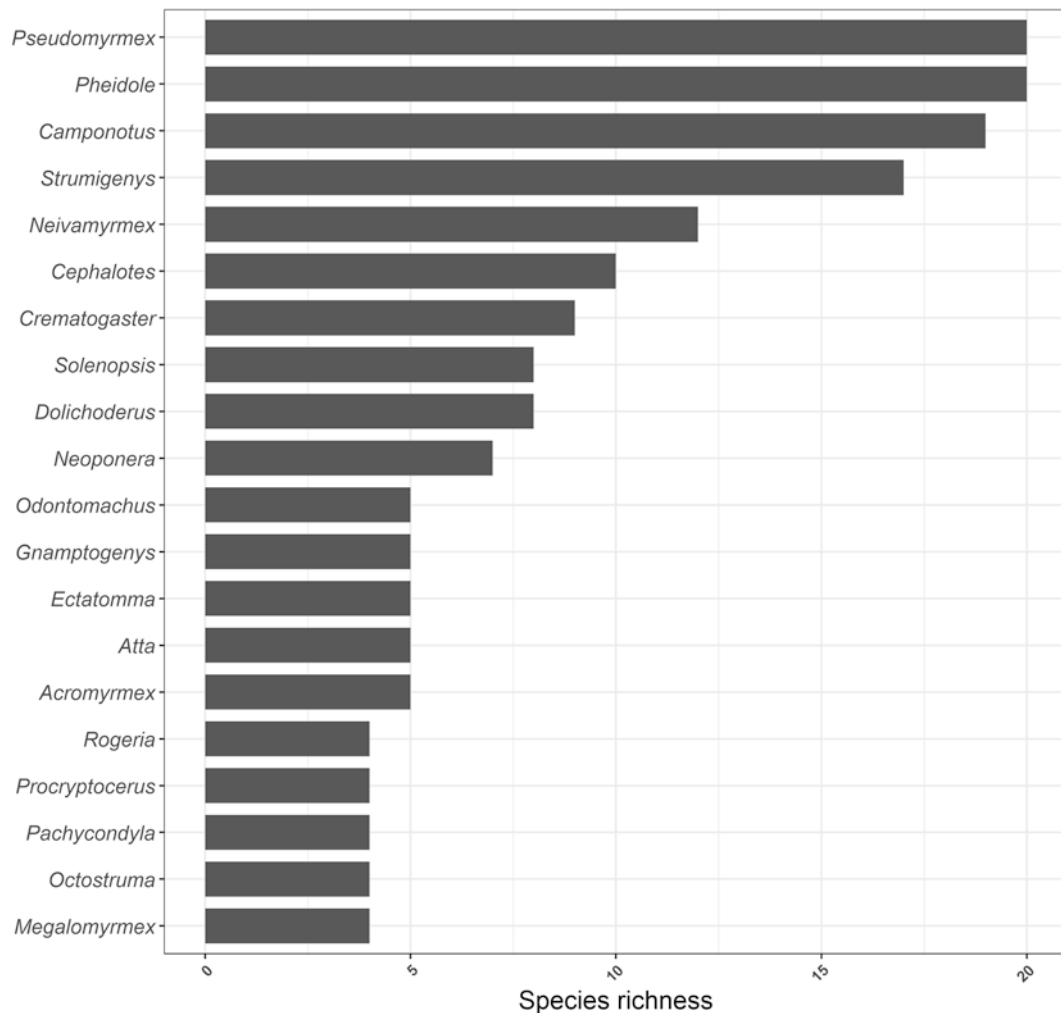


Fig. 3.4 The top 20 most species-rich ant genera in the Pernambuco Endemism Center of the Atlantic Forest

Regarding the nominal species, there were 1207 species occurrences (i.e., discarding duplicate records) (Fig. 3.6), where site locations were defined by coordinates (based on six decimal places). The ten most frequently recorded ant species in the PEC were *Dinoponera quadriceps* Kempf, 1971 ($n = 59$ localities), *Atta sexdens* (Linnaeus, 1758) (56), *Ectatomma tuberculatum* (Olivier, 1792) ($n = 33$) (Fig. 3.3), *Strumigenys denticulata* Mayr, 1887 (30), *Odontomachus meinerti* Forel, 1905 ($n = 27$), *Pachycondyla harpax* (Fabricius, 1804) ($n = 27$), *Mayaponera constricta* (Mayr, 1884) ($n = 24$), *Atta cephalotes* (Linnaeus, 1758) (20), *Odontomachus brunneus* (Patton, 1894) ($n = 20$), and *Cephalotes pusillus* (Klug, 1824) (19). On the other hand, there were 72 species recorded from a single locality (Supplementary Table 1).

We found only 35 ant records in “brejos” or “brejos de altitude” or “brejos nordestinos” (Rizzini 1997, p. 381). These records represented 13 ant species – *Acromyrmex*

landolti (Forel, 1885), *A. rugosus* (Smith, 1858), *Acropyga goeldii* Forel, 1893, *Atta laevigata* (Smith, 1858), *Camponotus atriceps* (Smith, 1858), *C. crassus* Mayr, 1862, *Dinoponera quadriceps* Kempf, 1971, *Ectatomma brunneum* Smith, 1858, *E. edentatum* Roger, 1863, *E. tuberculatum* (Olivier, 1792), *Odontomachus haematodus* (Linnaeus, 1758), *Tetramorium simillimum* (Smith, 1851) (exotic), and *Wasmannia auropunctata* (Roger, 1863).

3.4 Discussion

It is well known that, although ants are among the best-studied taxa among invertebrates, the knowledge on their occurrence and diversity in the Atlantic Forest is uneven distributed across the biome and understanding fine-scale distribution of each species remains challenging (Feitosa et al. 2021; Silva et al. 2022). Our analysis of ant records in the

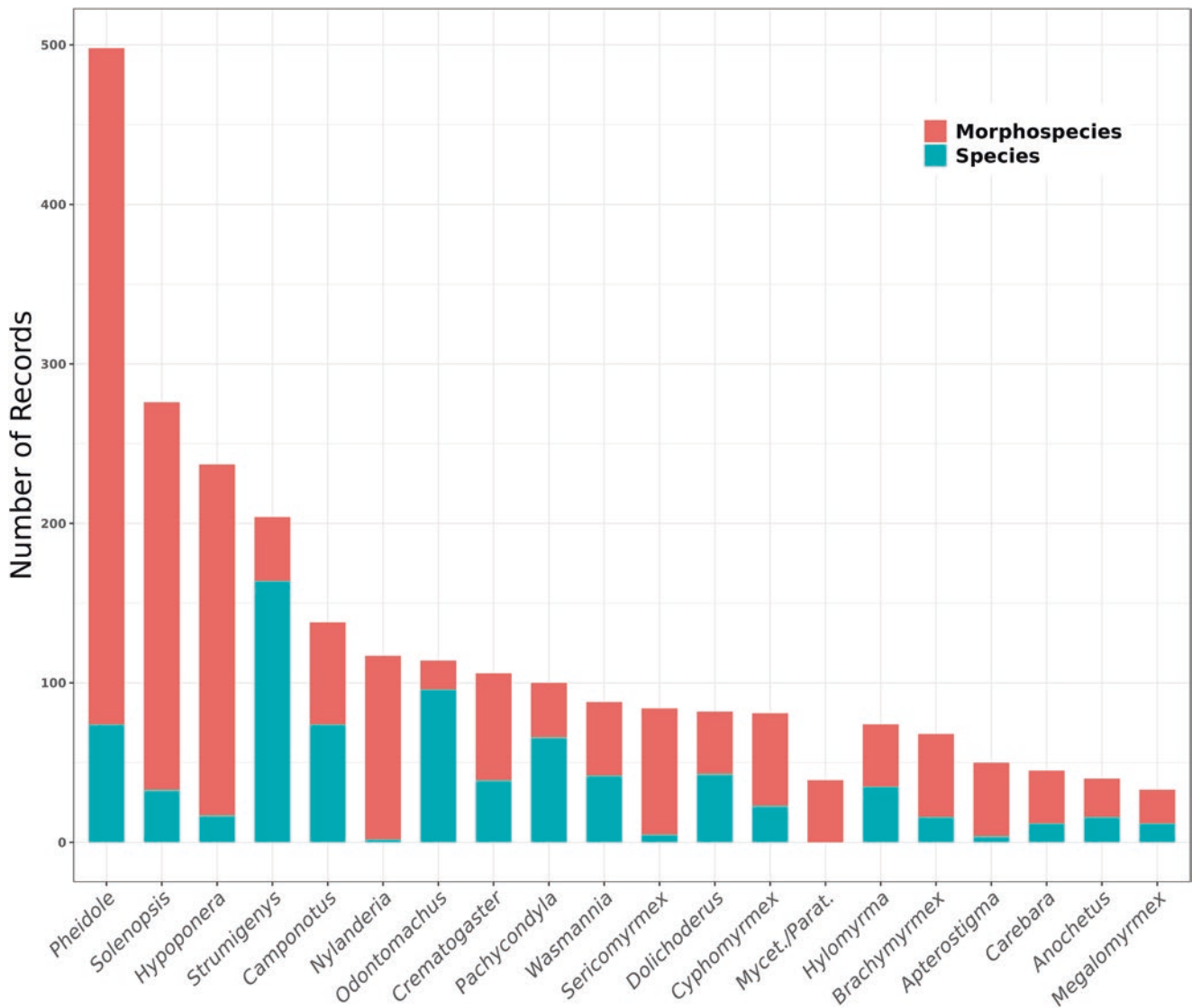


Fig. 3.5 The top 20 most recorded species and morphospecies per ant genus in the Pernambuco Endemism Center of the Atlantic Forest. *Mycet./Parat.* = *Mycetomoellerius/Paratrachymyrmex*

Pernambuco Endemism Center also suggests such drawbacks because large gaps in ant sampling are too much evident in this subregion of the Atlantic Forest, including fragment remnants and priority areas for conservation.

Ant surveys have been concentrated around urban centers and a few conservation units or protection areas, such as the *Área de Proteção Ambiental de Murici* (Alagoas), *Reserva Biológica Guaribas* and *Mata do Buraquinho* (Paraíba), *APA Aldeia Beberibe*, and *Parque Estadual Dois Irmãos* (Pernambuco). The aggregated distribution of sampling density in Brazilian ecoregions is well known (Oliveira et al. 2016) and strategies that incorporate both sampling density and habitat loss are important for identifying the highest priority areas for new ant surveys (Divieso et al. 2020).

Most of the available ant records in the PEC only can be retrieved from examined material in taxonomic studies (e.g., Wheeler 1907–1925, Borgmeier 1923–1959, Santschi 1925–1930, Kempf 1951–1978; Supplementary Table 1 references) or taxonomic catalogues (Carvalho and Freitas 1960; Kempf 1972; Brandão 1991; Scott-Santos et al. 2008; Esteves et al. 2011). Biogeographical studies in the PEC are largely incipient and limited to fungus farming-ants (e.g., Barbosa 2018). Further, research on ant biology or population biology is focused on leaf-cutter ants of the genus *Atta* (e.g., Wirth et al. 2007; Meyer et al. 2009; Correa et al. 2016; Farias et al. 2018) or large-sized ants (e.g., *Dinoponera quadriceps*; Araújo and Rodrigues 2006).

In terms of species richness, we recorded 247 ant species in the PEC and this number strongly underestimates the true

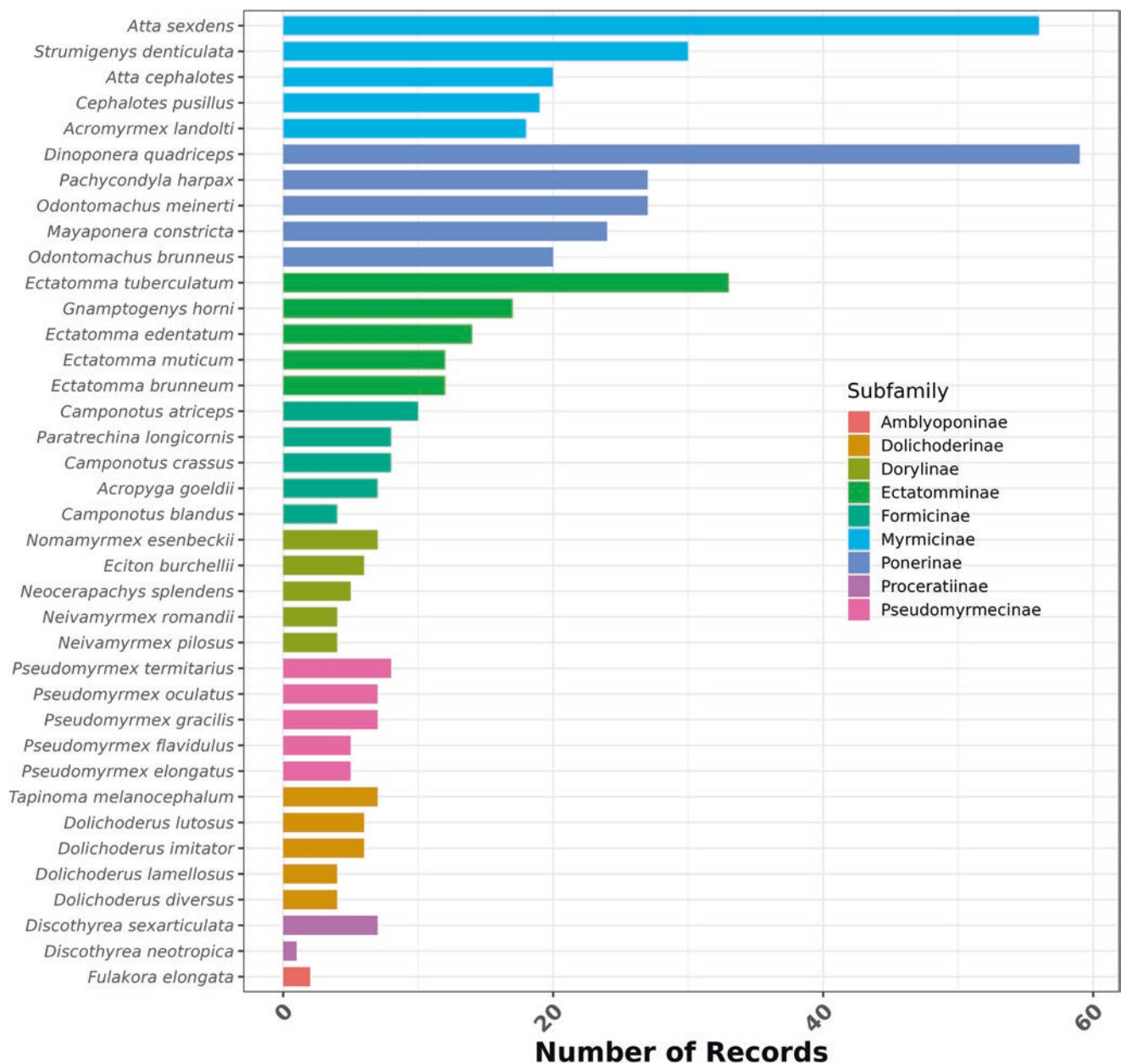


Fig. 3.6 Number of records per ant species in the Pernambuco Endemism Center of the Atlantic Forest (the top five most recorded species per subfamily are included)

number of species in this region of the Atlantic Forest. Considering the list of ant species recorded for the entire Atlantic Forest (Silva et al. 2022), the ant fauna of the Pernambuco Endemism Center seems to be a subset of the Atlantic Forest ant fauna. Indeed, for leaf-litter ants, northeastern sites showed higher similarity in species composition than intermediate latitude areas or low and high southeastern-south Atlantic Forest areas (Silva and Brandão 2014).

Interestingly, Dorylinae, the army ants and their relatives (Brady et al. 2014), is the third richest subfamily in number of species (22 species). Army ants are keystone species in

Neotropical forests because of their major role as top predators, as well as numerous vertebrate- and invertebrate-associated species that depend upon their colonies for survival (Pérez-Espona 2021). Such high species richness in the PEC is in part related to the occurrence of 12 species of *Neivamyrmex*. Those records of nominal species of *Neivamyrmex* date back from classical taxonomic studies by Borgmeier, Kempf and Watkins in the twentieth century (see Supplementary Table 1). However, eight recent records for this genus published in the ecological literature are based on unidentified specimens. Army ants and their relatives are

very sensitive to habitat loss and modification (Pérez-Espona 2021). Given the current conservation status of the Atlantic Forest of the PEC, with no single fragment larger than 10,000 ha, low functional connectivity, and only 1% protected in nature reserves (Ribeiro et al. 2009; Lins-e-Silva et al. 2021), studies on army ants distribution can be important to understand the consequences of habitat loss and fragmentation for biodiversity maintenance of invertebrates.

Among the ant genera exclusively found within the Atlantic Forest domain (*Anillidris*, *Phalacrotermes*, and *Diaphoromyrma*), there are no records for them in the PEC, probably because the leaf-litter and subterranean stratum remains largely undersampled in this region. Information on endemism or biogeography of Atlantic Forest ants is scant, and therefore, the extent to which endemism within the Atlantic Forest ant fauna is related to environments or regions is uncertain (Feitosa et al. 2021). Over the 1114 ant species recorded in the Atlantic Forest, we found that only three species are endemic of the PEC (*Hylomyrma lopesi* Ulysséa, 2021, *Pheidole deima* Wilson, 2003 and *Pheidole impressa* Mayr, 1870). On the other hand, there are currently 866 additional ant species occurring in the Atlantic Forest but not recorded in the PEC.

The pervasive presence of morphospecies in ant community studies of the Neotropical region (Delabie et al. 2012), representing 50% of the ant records in the PEC data set, is one of the main impediments to comparative analyses on assemblage structure in the Atlantic Forest (Silva et al. 2022). Particularly for the Pernambuco Endemism Center, we found ten ant genera currently known only at morphospecies level (*Acanthognathus*, *Acanthoponera*, *Cardiocondyla*, *Linepithema*, *Myrmicocrypta*, *Prionopelta*, *Typhlomyrmex*, *Probolomyrmex*, *Myrmelachista*, and *Mycetomoellerius* or *Paratrachymyrmex*). However, if the original samples cannot be tracked (Turney et al. 2015), the presence of these genera cannot be confirmed.

The recent synthesis of ants across the Atlantic Forests of South America, a collaborative database of species occurrences (Silva et al. 2022), indicated that one of the main knowledge gaps regarding ant distribution in the Atlantic Forest is the poor sampling along mountain sites, since most records in the biome are concentrated in low altitudes. We identified a very low sampling coverage in the “brejos” (altitude swamps) and an incipient list of ant species (12 native species, most of them very common and widely distributed in Brazil). Therefore, enclaves of dense forests in the semi-arid Northeast (in the Caatinga domain), in regions of high altitude and humidity (Marques et al. 2021), represent large gaps in sampling effort for ants and, although not inside the PEC, should be a priority for further inventories.

Our data provide a comprehensive analysis on the regional richness and distribution of an important insect group in the Atlantic Forest north of the São Francisco River, combining

available quantitative and qualitative data on ant species occurrences. We found large sampling gaps in the Pernambuco Endemism Center and thus, new guided sampling expeditions may provide additional useful data to estimate distributions of rare and endemic species as well as reveal new species (e.g., *Hylomyrma lopesi*; Ulysséa and Brandão 2021).

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